LT26
The 26th International Conference on Low Temperature Physics

August 10 - 17, 2011, Beijing International Convention Center, Beijing, China
LT26 Conference Venue

Beijing International Convention Center (BICC)
Address: No.8 Beichen East Road, Chaoyang District, Beijing, China.

Restaurants:
- **Japanese Cuisine**
- Yonghe Soya-1818 bean Milk Restaurant
  (open 24 hours)
- **Tea House**
- **Korean Restaurant**
- Chinese Fast Food (4th Floor of Shopping Center)
- UBC Coffee and Food
- McDonald’s
- Kenny Rojers Roasters

Hotels:
- **Beijing Continental Grand Hotel**
  (亚运村五洲大酒店)
- **Crowne Plaza Hotel Park View Wuzhou**
  (亚运村五洲皇冠大酒店)
- **Grand Skylight Catic Plaza Hotel**
  (亚运村凯蒂克兰云天大酒店)
- **Beijing Ao You Hotel**
  (亚运村奥友酒店)
- **Ya Yun Cun Hotel**
  (亚运村宾馆)
- **Celebrity International Grand Hotel**
  (亚运村名人大酒店)
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Layout of Beijing International Convention Center (BICC)
Layout of Beijing International Convention Center (BICC)

PLAN OF BICC LEVEL 2

Convention Hall 1
Convention Hall 2
Convention Hall 3

VIP Room B
VIP Room A

201A
201B
201C
202

2nd Floor
Exhibition Area

1st Floor
Business Area

North
Layout of Beijing International Convention Center (BICC)
Important Events

<table>
<thead>
<tr>
<th>Event</th>
<th>Location</th>
<th>Date/Time</th>
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<tr>
<td>Welcome Reception</td>
<td>Convention Hall 1</td>
<td>August 10 - 6:00 pm</td>
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<tr>
<td>Opening Ceremony &amp; Plenary Session</td>
<td>Convention Hall 1</td>
<td>August 11 - 9:00 am</td>
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<tr>
<td>Special Evening Session for the Celebration of the</td>
<td>Convention Hall 1</td>
<td>August 12 - 7:30 pm</td>
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<td>Centennial of Superconductivity</td>
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<tr>
<td>Conference Banquet</td>
<td>Convention Hall 1</td>
<td>August 13 - 6:30 pm</td>
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<tr>
<td>Plenary Session &amp; Closing Ceremony</td>
<td>Convention Hall 1</td>
<td>August 17 - 9:00 am</td>
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Welcome Reception
Convention Hall 1
   Wednesday, August 10  6:00 pm
LT26 will provide buffet for all conference participants.

Opening Ceremony & Plenary Session
Convention Hall 1
   Thursday, August 11  9:00 am
The Opening Ceremonies of the Conference will be dedicated to the presentation of the London Memorial Prize, the Simon Memorial Prize and IUPAP Young Scientist Prize in Low Temperature Physics. This arrangement carries on the tradition of presenting the London Prize, the Simon Prize (since LT24) and the Young Scientist Prize (since LT25) at the LT International Conference.

Special Evening Session for the Celebration of the
Centennial of Superconductivity
Convention Hall 1
   Friday, August 12  7:30 pm
Invited speakers:
   Peter Kes
   Georg Bednorz
   Frank Steglich
   Douglas Scalapino

Conference Banquet
Convention Hall 1
   Saturday, August 13  6:30 pm
Dress code is informal.
Participants will enjoy a show featured by traditional Chinese performances. Tickets for conference banquet cost CNY 350/person. Registration for the banquet is preferably made when you register for the Conference and the purchase of the tickets made at the Registration Desk. The seats are limited and available on a first-come, first served basis.

Plenary Session & Closing Ceremony
Convention Hall 1
   Wednesday, August 17  9:00 am
Information and Instructions

**Wireless Service**
BICC will provide free wireless in the public space, exhibition halls and convention halls. The network name is BICC-GJHY. It is an open network, so no password is needed.

**Audio Visual Equipment**
All rooms will be equipped with a projector, screen, laptop, microphone and pointer. If you are going to do a PowerPoint presentation, please bring your program on your USB flash disk and visit the Speaker-Ready Room in advance to run through your presentation. In case you would like to use your own laptop for the presentation, please do go to the Speaker-Ready Room to run it through.

**Speaker-Ready Room**
Level 2, Convention Hall 2 VIP Room A
The speaker-ready room will be open as follows:

- Wednesday, August 10…………………….. 2:00 pm – 6:00 pm
- Thursday, August 11…………………….. 8:00 am – 5:00 pm
- Friday, August 12…………………….... 8:00 am – 5:00 pm
- Saturday, August 13…………………….. 8:00 am – 5:00 pm
- Monday, August 15…………………….. 8:00 am – 5:00 pm
- Tuesday, August 16…………………….. 8:00 am – 5:00 pm

**LT26 Exhibit Show**
Exhibition Hall 1

- Thursday, August 11…………………….. 9:00 am – 7:00 pm
- Friday, August 12…………………….... 9:00 am – 7:00 pm
- Saturday, August 13…………………….. 9:00 am – 7:00 pm
- Monday, August 15…………………….. 9:00 am – 7:00 pm
- Tuesday, August 16…………………….. 9:00 am – 1:00 pm

Move-in Hours: Wednesday, August 10………. 9:00 am – 5:00 pm
Dismantle: Tuesday, August 16………………… 1:00 pm – 4:00 pm

**Poster Presentation**
Exhibition Hall 1

- Thursday, August 11…………………….. 4:00 pm – 6:00 pm
- Friday, August 12…………………….... 4:00 pm – 6:00 pm
- Saturday, August 13…………………….. 4:00 pm – 6:00 pm
- Monday, August 15…………………….. 4:00 pm – 6:00 pm
- Tuesday, August 16…………………….. 4:00 pm – 6:00 pm

- Posters setting up time: after 8:00 pm a day before the presentation.
- Posters need to be removed before 8:00 pm after the presentation.
Lunches
We will provide ordinary meals, vegetarian meals and Muslim meals for the lunches.

BICC, Convention Hall 1
Boxed lunch……August 11……………….. 12:30 am – 2:00 pm
Beijing Continental Grand Hotel, Level 2, Grand Ballroom
Buffet……………August 12, 13, 15, 16….. 12:30 am – 2:00 pm
BICC, Convention Hall 1
Boxed lunch…..August 17 ……………….. 12:30 am – 2:00 pm
Note: No lunch is provided on August 14

Tea Breaks
Entrances of the conference rooms
August 11............................ 10:50 am – 11:20 am
August 12, 13, 15, 16..................... 10:30 am – 10:50 am
August 17.................................. 11:00 am – 11:20 am
(Coffee, Tea, Snacks)
LT26 will provide coffee and tea throughout conference hours.

Beverage
Pickup site: Exhibition Hall 1
August 11, 12, 13, 15, 16............... 3:40 pm – 6:00 pm

Session Naming Rule - Samples
17P-1: the 1st oral presentation in the Plenary session of August 17th.
12H1-3: the 3rd oral presentation in the 1st Half plenary session of 12th.
12E-2: the 2nd oral presentation in the Evening session of 12th.
15m-A2: the 2nd oral presentation in direction A in the morning of 15th.
15a-C5: the 5th oral presentation in direction C in the afternoon of 15th.
12P-A006: the 6th Poster presentation in direction A on 12th.
Thursday, August 11

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<th>Event</th>
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<th>Chairs</th>
<th>Institution</th>
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<tr>
<td>09:00</td>
<td>Opening Ceremony</td>
<td>Convention Hall 1</td>
<td>Zhongxian Zhao, Robert B. Hallock, Moses Chan, John Saunders, Robert B. Hallock</td>
<td>Institute of Physics, CAS, University of Massachusetts, Pennsylvania State University, Royal Holloway University, University of Massachusetts</td>
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<tr>
<td>09:05</td>
<td>IUPAP C5</td>
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<tr>
<td>09:10</td>
<td>London Prize Ceremony</td>
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<tr>
<td>09:20</td>
<td>Simon Prize Ceremony</td>
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<td>09:30</td>
<td>Young Scientist Award Ceremonies</td>
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<tr>
<td>09:40</td>
<td>Plenary Session</td>
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<tr>
<td>09:40</td>
<td>London Prize Lectures:</td>
<td></td>
<td>Humphrey Maris, Gerd Schön, Hans Mooij, Nikolai B. Kopnin</td>
<td>Studies of Quantum Liquids in Metastable States, Quantum State Engineering with Josephson Junctions, Quantum Vortices, Quantum Phase Slip and Quantum Bits, Vortex Dynamics in Superconductors and Fermi Superfluids</td>
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<tr>
<td>10:15</td>
<td>London Prize Lectures:</td>
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<td>A1472</td>
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<td>10:50</td>
<td>Coffee Break</td>
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<td>D1439</td>
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<td>11:20</td>
<td>Simon Prize Lecture</td>
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<td>D1448</td>
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<td>11:55</td>
<td>Simon Prize Lecture</td>
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<td>D1467</td>
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<td>12:30</td>
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12:30 Lunch

14:00 Parallel Session

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<td>11a-A</td>
<td>11a-B Supersolid I</td>
<td>Room 5A</td>
<td>Sebastien Balibar, Shin-ichi Uchida</td>
<td>room 5A Supersolid I Chair: Unseong Kim 11a-B Supersolid I Chair: John Tranquada</td>
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<tr>
<td></td>
<td>Thermal Properties of Fe-based Superconductors</td>
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<tr>
<td>14:00</td>
<td>11a-C Low Dimension and Frustrated Magnetism I</td>
<td>Room 5B</td>
<td>Oleg Astafiev</td>
<td>Low Dimension and Frustrated Magnetism I Chair: Tao Xiang 11a-D Superconducting devices/qubits I Chair: Per Delsing</td>
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<td></td>
<td>Physical Anisotropy of Iron Pnicnites</td>
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<td>11a-D</td>
<td>11a-E Ground State Techniques</td>
<td>Room 305</td>
<td>Yuki Sato</td>
<td>Ground State Techniques Chair: Arttu Luukanen</td>
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<td></td>
<td>Superfluid Helium Quantum Interference Devices: Present Status and Future Prospects</td>
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<td>14:20</td>
<td>11a-A2 Keiya Shirahama</td>
<td>A1539</td>
<td>Pierre-François Cohadon</td>
<td>11a-A2 Keiya Shirahama Keio University Supersolid Behavior and Inertial Anomalies in Solid 4He Formed in Nanoporous Media</td>
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<tr>
<td>Time</td>
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<td>14:40</td>
<td>11a-A3</td>
<td>Anatoly Kuklov</td>
<td>City University of New York</td>
<td>Superclimbing dislocations in solid Helium-4</td>
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<tr>
<td>11a-B3</td>
<td></td>
<td>Hong Ding</td>
<td>Institute of Physics, CAS</td>
<td>ARPES studies on the pairing symmetry and mechanism of iron-based superconductors</td>
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<tr>
<td>11a-C3</td>
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<td>P. Mendels</td>
<td>University Paris Sud XI</td>
<td>Quantum Kagome Antiferromagnets : Local NMR and muSR Experiments</td>
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<td>11a-D3</td>
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<td>Xiaobo Zhu</td>
<td>NTT BRL</td>
<td>Coupling an ensemble to a superconducting qubit</td>
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<td>Weijun Yao</td>
<td>Oak Ridge National Laboratory</td>
<td>Search for the Neutron Electric Dipole Moment on SNS</td>
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<td>11a-A4</td>
<td>Jordi Boronat</td>
<td>Tokyo University</td>
<td>Vacancies and $^3$He atoms in solid $^4$He</td>
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<td>11a-B4</td>
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<td>N. C. Yeh</td>
<td>California Institute of Technology</td>
<td>Comparative studies of the field-dependent scanning tunneling spectroscopy in cuprate and iron-pnictide superconductors</td>
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<td>11a-C4</td>
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<td>T. Shiroka</td>
<td>ETH Zurich</td>
<td>Low-temperature features of random Heisenberg spin chains</td>
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<td>11a-D4</td>
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<td>Marco Aprili</td>
<td>CNRS</td>
<td>Microwave cooling of Josephson plasma oscillations</td>
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<tr>
<td>11a-E4</td>
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<td>D. Vasyukov</td>
<td>Weizmann Institute of Science</td>
<td>Nano-sized SQUID-on-tip for a scanning SQUID microscope</td>
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<td>11a-A5</td>
<td>John Reppy</td>
<td>Cornell University</td>
<td>Torsional Oscillator Studies of the Shear Modulus of Solid $^4$He</td>
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<td>11a-B5</td>
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<td>Peter Armitage</td>
<td>The Johns Hopkins University</td>
<td>Fast vortices in the Cuprates? A vortex plasma model analysis of the THz conductivity and diamagnetism in $La_{2-x}Sr_xCuO_4$</td>
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<td>11a-C5</td>
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<td>S. Maegawa</td>
<td>Kyoto University</td>
<td>Quantum Spin Liquid in an Organic Triangular Lattice Antiferromagnet $EtMe_3Sb[Pd(dmit)_2]^2$</td>
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<td>11a-D5</td>
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<td>Francesco Giazotto</td>
<td>NEST, Instituto Nanoscienze-CN and Scuola Normale Superiore</td>
<td>A quantum electron pump operating at the Josephson frequency</td>
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<td>Masamichi Saitoh</td>
<td>University of Tsukuba</td>
<td>Development of Tunnel Junction Micro-SQUID Magnetometer for Investigation of Single-Molecule Magnets</td>
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<td>Supersolidity</td>
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<td>New Superconducting Materials</td>
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<td>11P-D</td>
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<td>Superconducting Devices/Qubits</td>
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<td>11P-E</td>
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<td>Quantum Ground State Techniques</td>
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<tr>
<td>Time</td>
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<td>Speaker</td>
<td>Institution</td>
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<td>09:00</td>
<td>Half Plenary Sessions</td>
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<td>09:00</td>
<td>12H1-1</td>
<td>Eunseong Kim</td>
<td>KAIST</td>
<td>NCRI and shear modulus of solid helium at low temperatures</td>
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<td>12H1-2</td>
<td>Robert Hallock</td>
<td>University of Massachusetts</td>
<td>Mass Flux through Solid $^4$He Induced by Chemical Potential Differences</td>
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<td>09:30</td>
<td>12H1-3</td>
<td>Cheng Chin</td>
<td>University of Chicago</td>
<td>Scale Invariance and Quantum Criticality in Atomic Quantum Gases</td>
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<td>12H2-1</td>
<td>Naoto Nagaosa</td>
<td>U. Tokyo &amp; RIKEN</td>
<td>Emergent Electromagnetism in Solids - Spin-Orbit Interaction as a Gauge Field</td>
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<td>12H2-2</td>
<td>Leon Balents</td>
<td>KITP, UCSB</td>
<td>Quantum Spin Liquids in Quantum Spin Ices</td>
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<td>10:00</td>
<td>12H1-3</td>
<td>Steve Bramwell</td>
<td>London Centre for Nanotechnology</td>
<td>Monopoles and Magnetocrity in Spin Ice</td>
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<td>12H2-3</td>
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<td>10:30</td>
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<td>10:50</td>
<td>Parallel Sessions</td>
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<td>10:50</td>
<td>12m-B$_1$</td>
<td>Norman Birge</td>
<td>Michigan State U.</td>
<td>Spin-Triplet Supercurrent in Ferromagnetic Josephson Junctions</td>
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<td>12m-B$_2$</td>
<td>Yoshihiro Kubozono</td>
<td>Okayama University</td>
<td>Structures and physical properties of new types of organic superconductors, Apxicene, Axcoronene and Axphenanthrene</td>
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<td>12m-C</td>
<td>R. K. Kremer</td>
<td>MPI for Solid State Research</td>
<td>The spin-1/2 frustrated helicoidal afm multiferroic system LiCuV04: Recent Results</td>
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<td>12m-D</td>
<td>Mika Sillanpää</td>
<td>Aalto University, Low Temperature Laboratory</td>
<td>Micromechanical resonator cooled down close to the motional ground state, and electromechanically induced microwave amplification</td>
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<td>12m-A</td>
<td>Ruichao Ma</td>
<td>Harvard University</td>
<td>Quantum Magnetism with Ultracold Atoms - A Microscopic View on Artificial Quantum Matter</td>
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| 11:10 | 12m-B₁² | B1477 | Rafi Budakian  
University of Illinois at Urbana-Champaign  
Probing the Physics of the Fractional Vortex State in Mesoscopic Rings of Sr₂RuO₄ |
| 11:30 | 12m-B₃³ | B0674 | Xian-Hui Chen  
University of Science & Technology of China  
Phase diagram in high-Tc iron pnictide and chalcogenide superconductors |
| 11:50 | 12m-B₄⁴ | B0072 | A. Zheludev  
ETH Zurich  
Low Temperature Dynamics of Magnons in a Spin-1/2 Ladder Compound |
| 12:10 | 12m-B₅⁵ | B0173 | Valerii Vinokour  
Argonne National Laboratory  
Quantum Turbulence and Localization of Disordered Bosons |

| 11:10 | 12m-B₁² | B1477 | Xian-Hui Chen  
University of Science & Technology of China  
Phase diagram in high-Tc iron pnictide and chalcogenide superconductors |
| 11:30 | 12m-B₃³ | B0674 | C. W. Chu  
University of Houston  
A possible unusual superconducting state up to 49 K in single crystalline R-doped CaFe₂As₂ |
| 11:50 | 12m-B₄⁴ | B0072 | A. I. Smirnov  
P.L.Kapitza Institute for Physical Problems RAS  
Low Energy Dynamics of Spin-Liquid and Ordered Phases of S=1/2 Antiferromagnet Cs₂CuCl₄ |
| 12:10 | 12m-B₅⁵ | B0173 | S. Okubo  
Kobe University  
Spin Dynamics of Frustrated Honeycomb Lattice Antiferromagnet |

| 11:10 | 12m-B₁² | B1477 | Yosi Yeshurun  
Bar-Ilan University  
Large oscillations of the magnetoresistance in nano-patterned La₁₋₀₄Sr₀₋₁₆CuO₄ superconducting films |
| 11:30 | 12m-B₃³ | B0674 | C. W. Chu  
University of Houston  
A possible unusual superconducting state up to 49 K in single crystalline R-doped CaFe₂As₂ |
| 11:50 | 12m-B₄⁴ | B0072 | M. K. Wu  
Academia Sinica  
Correlation between the Anomalous Properties and the Low Temperature Structural Distortion in β-FeSe |
| 12:10 | 12m-B₅⁵ | B0173 | S. Okubo  
Kobe University  
Spin Dynamics of Frustrated Honeycomb Lattice Antiferromagnet |

| 11:10 | 12m-B₁² | B1477 | Xian-Hui Chen  
University of Science & Technology of China  
Phase diagram in high-Tc iron pnictide and chalcogenide superconductors |
| 11:30 | 12m-B₃³ | B0674 | C. W. Chu  
University of Houston  
A possible unusual superconducting state up to 49 K in single crystalline R-doped CaFe₂As₂ |
| 11:50 | 12m-B₄⁴ | B0072 | M. K. Wu  
Academia Sinica  
Correlation between the Anomalous Properties and the Low Temperature Structural Distortion in β-FeSe |
| 12:10 | 12m-B₅⁵ | B0173 | S. Okubo  
Kobe University  
Spin Dynamics of Frustrated Honeycomb Lattice Antiferromagnet |

12:30 Lunch
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<tr>
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<th>Speaker</th>
<th>Title</th>
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| 14:00 | Parallel Sessions| Room 5A| Minoru Kubota                | Institute of Tokyo, Japan, Co-Headed by: John Reppy  
Quantized Vortex Physics in the hcp 4He, Studied by Torsional Oscillator with Detailed AC  
Dependence and Under DC Rotation |
|       | 12a-A1           | Room 5B| Martin Greven                | University of Minnesota, Director: Pierre Richard  
Novel Magnetism and the Phase Diagram of the Cuprates                                             |
|       | 12a-B1           | Room 201| Gang Su                      | Graduate University of Chinese Academy of Sciences, Director: Alexei Tsvelik  
Emergence of novel states in low-dimensional quantum magnets                                      |
|       |                  |        | Konstantin Kechedzhi        | Rutgers University, Director: Nikolai Kopnin  
Origin of 1/f magnetic noise in superconducting circuits                                           |
| 12a-D1|                  |        | J. Tempere                  | Universiteit Antwerpen, Director: Andrew Truscott  
Preformed pairs and quasicondensation in imbalanced Fermi gases in 2D                           |
|       | 12a-A12          |        | Norbert Mulders              | University of Delaware, Director: Pierre Richard  
The Crystal Structure of Solid Helium-4 in Vycor                                                 |
|       | 12a-B2           |        | Hugo Keller                 | Physics Institute, University of Zurich, Director: Pierre Richard  
From cuprate to iron-based superconductors – some key elements of high-temperature superconductivity |
|       | 12a-C2           |        | Virginie Simonet            | Institut Neel, CNRS, Director: Pierre Richard  
Slow dynamics in ordered Fe-oxalates kagome antiferromagnets                                       |
|       | 12a-D2           |        | Alina Hriscu                | Delft University of Technology, Director: Andrew Truscott  
Quantum Phase-slip Devices                                                                        |
|       | 12a-A2           |        | Tian-Cai Zhang              | Shanxi University, Director: Andrew Truscott  
Temperature determination of cold atoms based on single atom detection                           |
| 14:20 |                  | Room 5B| Zhihang Cheng               | The Pennsylvania State University, Director: Pierre Richard  
Heat Capacity of Solid 4He in Aerogel                                                           |
|       | 12a-B3           |        | Alain Sacuto                | University Paris 7, Director: Pierre Richard  
Superconducting gap and pseudo gap in hole doped cuprates                                         |
|       | 12a-C3           |        | Satoru Nakatsuji            | Institute of Tokyo, Director: Pierre Richard  
Quantum criticality without tuning in the intermediate valence material $\beta$-YbAlB$_4$         |
|       | 12a-D3           |        | Pertti Hakonen              | Aalto University, Low Temperature Laboratory, Director: Andrew Truscott  
Dynamical Casimir effect in a Josephson metamaterial                                              |
| 12a-A2|                  |        | Shih-Chuan Gou              | National Chung Hua University, Director: Andrew Truscott  
Spontaneous Crystallization of Skyrmions and Fractional Vortices in the Fast-rotating and  
Rapidly-quenched Spin-1 Bose-Einstein Condensates                                               |
| 12a-B4|                  |        | Dukyoung Kim                | The Pennsylvania State University, Director: Pierre Richard  
Solid helium in long path length torsional oscillators                                             |
|       | 12a-B3           |        | Eun Kim                     | Cornell University, Director: Pierre Richard  
Electronic Liquid Crystal Correlations in the Pseudogap States of High T$_c$  
Superconductors                                                                                |
|       | 12a-C4           |        | Suguru Ueda                 | Department of Physics Kyoto University, Director: Pierre Richard  
Spin and charge ordering in heterostructures of strongly correlated electron systems           |
|       | 12a-D4           |        | Hu-Jong Lee                 | POSTECH, Director: Andrew Truscott  
Spin-relaxation in graphene: by covalently bonded adsorbates via EY mechanism                   |
|       |                  |        | Bao-Long Lu                 | Wuhan Institute of Physics and Mathematics, Director: Andrew Truscott  
Observation of universal behaviour of ultracold quantum critical gases                           |
Special Evening Session: Celebration of the Centennial of Superconductivity

19:30  Evening Session 12E  Chair: Zhongxian Zhao  Convention Hall 1

19:40  12E-1  Peter Kes  Kamerlingh Onnes Lab  B1446
        *Kamerlingh Onnes’s Notebooks and the Discovery of Superconductivity*

20:15  12E-2  Georg Bednorz  IBM Zurich Research  B1485
        *High Tc Superconductivity in Copper Oxides - From Retrospective to Outlook*

20:50  12E-3  Frank Steglich  Max Planck Institute for Chemical Physics of Solids  B1314
        *Heavy-Fermion Superconductivity Mediated by Antiferromagnetic Spin Fluctuations*

21:25  12E-4  Douglas Scalapino  UCSB  B1485
        *A Common Thread: the Pairing Mechanism in the Unconventional Superconductors*

22:00  Ending
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**13H1**
- Mechanical Resonators in the Quantum Regime
- Chair: Jukka Pekola

**13H2**
- Chair: Fuchun Zhang

**Coffee Break**

**Parallel Sessions**
- **13m-A**
  - Superfluid He-3 in Aerogel
  - Chair: Bill Happer
- **13m-B**
  - Recent Discovery and Properties of AFex Se2 (A=K, Rb, Cs, Tl)
  - Chair: Zhu-An Xu
- **13m-C**
  - Single Spin Devices / Qubits
  - Chair: Lieven Vandersypen
- **13m-D**
  - Heavy Fermion Superconductivity
  - Chair: Frank Steglich

**Closing: 10:30**
| 11:10 | 13m-A2 | A0908 | Vladimir Dmitriev  
Kapitza Institute  
Structure of A-like Phase of $^3$He in Anisotropic Aerogel |
| 13m-B2 | B0493 | Dong Lai Feng  
Fudan University  
Electronic structure of iron chalcogenides |
| 13m-C2 | C0324 | Guanming Zhang  
Tsinghua University  
Landau forbidden continuous quantum phase transition between two topologically valence bond solid states |
| 13m-D2 | D1189 | Katja Nowack  
Kavli Institute of Nanoscience, Delft University of Technology  
Single-shot correlations and two-qubit gate of electron spins in a double quantum dot |
| 13m-B2 | B0743 | Hui-Qiu Yuan  
Zhejiang University  
Nodal gap structure in weak-coupling non-centro-symmetric superconductors |

| 11:30 | 13m-A3 | A0434 | Pierre Hunger  
Institut Neel, CNRS, France  
New Types of Magnon BEC in Superfluid $^3$He in Aerogel |
| 13m-B3 | B1432 | Wei Bao  
Renmin University of China  
Neutron Scattering Study on the Newest 245 Family of Fe-based Superconductors |
| 13m-C3 | C1162 | Oliver Stockert  
Max-Planck-Institut CPfS  
Superconductivity and magnetism in CeCu$_2$Si$_2$ |
| 13m-D3 | D1224 | Christian Enss  
Heidelberg University  
Investigation of the dephasing of tunneling systems in glasses using two-pulse polarisation echo experiments |
| 13m-B3 | B1239 | Honda Fuminori  
Graduate School of Science, Osaka University  
Pressure-induced novel superconductivity and heavy electron state in rare earth compounds |

| 11:50 | 13m-A4 | A1474 | Jeevak Parpia  
Cornell University  
Phase diagram of superfluid $^3$He in 10% uniaxially compressed aerogel |
| 13m-B4 | B0931 | Zhong-Yi Lu  
Renmin University of China  
Electronic structures and magnetic orders of iron-pnictides or chalcogenides |
| 13m-C4 | C1345 | Andy Schmidt  
University of California  
Imaging Heavy Fermion Hybridization in URu$_2$Si$_2$ |
| 13m-D4 | | | |
| 13m-B4 | B1447 | Stefan Kirchner  
Max Planck Institute  
Tracing the Kondo Lattice in YbRh$_2$Si$_2$ |

| 12:10 | 13m-A5 | A0397 | Hiromitsu Takeuchi  
Hiroshima University  
Drag Force on a High Porosity Aerogel in Liquid $^3$He |
| 13m-B5 | B1451 | Qimiao Si  
Rice University  
Electron Correlations and Superconductivity in Iron Pnictides and Selenides |
| 13m-C5 | C0204 | Kazunari Yamaura  
National Institute for Materials Science  
Continuous metal-insulator transition at 410 K of the 5d oxide NaOsO$_3$ |
| 13m-D5 | D1358 | Natania Antler  
University of California, Berkeley  
Readout and Control of Spin Systems with Superconducting Circuits |
| 13m-B5 | B1456 | Milan P. Allan  
Cornell University  
Intra-band Quasiparticle Interference and Direct Determination of the Anisotropic Superconducting Energy-Gap Structure in LiFeAs |

| 12:30 | Ending | | |

12:30 Lunch
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| 15:00 | 13a-A4  | A1516    | Andrei Golov | University of Manchester  
**Turbulence in superfluid 4He in the T=0 limit, generated and probed by injected ions** |
|       | 13a-B4  | B0268    | Hiroshi Kontani | Nagoya University  
**Superconductivity and structure transition in iron based superconductors: analysis based on the orbital fluctuation theory** |
|       | 13a-C4  | C1170    | Georgios Varelogiannis | National Technical University of Athens  
**Patterns of Coexisting Condensates Forming Domes Preventing the Quantum Critical Point** |
|       | 13a-D4  | D0810    | Akihito Takeuchi | Tokyo Metropolitan University  
**Magnetic Monopole Generated by Spin Damping with Spin-Orbit Coupling** |
|       | 13a-E4  | E0114    | E. Collin | Institut Neel, CNRS  
**Low temperature nanomechanical probes: from linear to nonlinear regimes** |
| 15:20 | 13a-A5  | A1532    | Enrico Fonda | University of Maryland - University of Trieste  
**Visualization of Quantum Turbulence** |
|       | 13a-B5  | B1416    | Yunkyu Bang | Chonnam National University  
**Volovik Effects of the ±S-wave state in the iron-based Superconductors** |
|       | 13a-C5  | C1455    | Bruce Normand | Renmin University  
**Following elementary excitations to finite temperatures at the pressure-induced quantum phase transition in TlCuCl3** |
|       | 13a-D5  | D1386    | Michiyasu Mori | Japan Atomic Energy Agency  
**Dynamics of Josephson-phase coupled with spin waves** |
|       | 13a-E5  | E1025    | Francesco Massel | Low Temperature Laboratory Aalto University  
**Microwave amplification in nanomechanical systems** |
<p>| 15:40 | Ending  |          |            |       |
| 15:40 | Coffee Break |          |            |       |
| 16:00 | Poster Sessions | Exhibition Hall 1 |          |       |
| 16:00 | 13P-A4  | Others  |            |       |
| 13P-B | B6 Recent Discovery and Properties of K(Tl)Fe₂Se₂ | Others  |            |       |
| 13P-C | C3 Quantum Criticality and Novel Phases | Others  |            |       |
| 13P-D | D2 Single Spin Devices / Qubits | Others  |            |       |
| 13P-E | E3 Terahertz Techniques | Others  |            |       |
| 18:00 | Ending  |          |            |       |
| 18:30 | Conference Banquet |          |            |       |</p>
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<td>Surface Andreev Bound State of Superfluid $^3$He and Majorana Fermion</td>
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<td>Theory for Superconductivity (Mottness or mostly Cuprates)</td>
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<td>Department of Physics, The University of Tokyo</td>
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### 15:00 - 15:20

**Erkki Thuneberg**
**University of Oulu**

**Pendulum in a Fermi liquid**

**Guo-Qing Zheng**
**Okayama University**

**Spin-orbit coupling, anisotropic magnetic fluctuations and nodeless gap in iron-pnictides revealed by NMR**

**Premala Chandra**
**Rutgers University**

**Functional Heterostructures that Harness Frustration**

**Liang Fu**
**MIT**

(to be announced)

### 15:20 - 15:40

**Lev Levitin**
**Royal Holloway, University of London**

**Superfluid Phases of 3He Confined in a Single 0.6 Micron Slab**

**Takashi Imai**
**McMaster University**

**NMR investigation of iron-based high Tc superconductors**

**B. Lorenz**
**University of Houston**

**Giant Magnetoelectric Effect in HoAl₃(BO₃)₄ at Low Temperatures**

**Yang Fan**
**Institute of Physics, CAS**

**Superconducting Proximity Effect and Conductance Anomalies in Sm-Bi₂Se₃ Junctions**

**M. Rosticher**
**Laboratoire Pierre Aigrain**

**Detection of Single Electrons or Photons using a Superconducting Nanowire**

### 15:40 - 16:00

**Coffee Break**

### 16:00 - 18:00

**Poster Sessions**
**Exhibition Hall 1**

**A6 A1D & 2D Quantum Liquids**
**B8 Mechanisms of Superconductivity**
**D5 Nanowires / Nanotubes**

**C4 Topological Order**
**C6 Multiferroics / Ferroics**
**E5 Cryogenic Sensors and Cryogenic Standards**
**Tuesday Morning, August 16**

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<td>Vikram Tripathi Department of Theoretical Physics, Tata Institute of Fundamental Research An Unusual Kondo Effect with a Topological Transition in the Honeycomb Kitaev Model</td>
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<td>J. L. Yu, Institute of semiconductors, CAS</td>
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<td>16m-A3</td>
<td>A1071</td>
<td>P. Gumann University of Waterloo Simultaneous torsional oscillator and NMR study of solid $^3$He-$^4$He mixtures at low temperatures</td>
<td>P. Gumann, University of Waterloo</td>
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<td>B1504</td>
<td>Makoto Hashimoto SLAC National Accelerator Laboratory The pseudogap phase in Bi2201 studied by ARPES</td>
<td>Makoto Hashimoto, SLAC National Accelerator Laboratory</td>
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<td>Changqing Jin Institute of Physics, CAS Pressure induced superconductivity in Topological Compounds</td>
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<td>Tristan Meunier, CNRS</td>
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<td>Takeshi Mizushima Okayama University Majorana Fermions Bound at Vortices and Surface of Superfluid $^3$He</td>
<td>Takeshi Mizushima, Okayama University</td>
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<td>16m-B4</td>
<td>B0405</td>
<td>Manuel Nunez Regueiro Institute Neel The relationship between the normal state Fermi liquid scattering rate and the superconducting state</td>
<td>Manuel Nunez Regueiro, Institute Neel</td>
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<td>16m-C4</td>
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<td>Dai Aoki CEA-Grenoble Fermi Surface Properties in the Hidden Order State and in the Antiferromagnetic State on URu$_2$Si$_2$</td>
<td>Dai Aoki, CEA-Grenoble</td>
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<td>16m-D14</td>
<td>D0643</td>
<td>Tian Gang University of Twente Novel 2D spin system and its interaction with conduction electrons</td>
<td>Tian Gang, University of Twente</td>
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<td>11:50</td>
<td>16m-A5</td>
<td>A0787</td>
<td>H. Ikekami RIKEN Ultra-low Temperature Mobility of Electron Bubbles Formed below the Free Surface of Superfluid $^3$He-B</td>
<td>H. Ikekami, RIKEN</td>
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<td>16m-B5</td>
<td>B1520</td>
<td>Xiao-Li Dong Institute of Physics, CAS Unconventional Magnetic Phase Diagram of Cuprate Superconductor La$_{2-x}$Sr$_x$CuO$_4$ at Quantum Critical Point $x = 1/9$</td>
<td>Xiao-Li Dong, Institute of Physics, CAS</td>
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<td>16m-C5</td>
<td>C0907</td>
<td>E. Blackburn University of Birmingham Exploring the antiferromagnetic superconducting phase in CeCoIn$_5$</td>
<td>E. Blackburn, University of Birmingham</td>
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<td>16m-D15</td>
<td>C1178</td>
<td>Zhihuai Zhu University of British Columbia Spin-Polarization Control at the Surface of a Topological Insulator</td>
<td>Zhihuai Zhu, University of British Columbia</td>
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## Tuesday Afternoon, August 16

### 14:00 Parallel Sessions

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<td>Room 5B</td>
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<td>Magnetism &amp; Superconductivity</td>
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<td>Room 201</td>
<td>14a-D</td>
<td>Graphene / Dirac Electrons</td>
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<td>Room 305</td>
<td>14a-E</td>
<td>Novel Devices and Applications</td>
<td>Chair: Hu-Jong Lee</td>
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#### 16a-A1
D. M. Lee (Texas A & M University)
Spin Wave Resonances Excited by Moving Domain Walls in Polarized Dilute Liquid $^3$He-$^4$He Mixtures

#### 16a-B1
H. Z. Arham (University of Illinois)
Novel Ordered Region Preceding The Magnetic And Structural Transition In Underdoped BaFe$_{1-x}$Co$_x$As$_2$ And Fe$_{1+y}$Te

#### 16a-C1
Huihai Zhao (The Institute of Physics, CAS)
Quantum spin liquid phase in the spin-1 bilinear-biquadratic Heisenberg model on a honeycomb lattice

#### 16a-D1
Cory Dean (Columbia University)
(to be announced)

#### 16a-E1
Tetsushi Biwa (Tohoku University)
Thermoacoustic devices

### 14:20

| Room 5A | 16a-A2 | Frank Gasparini (University at Buffalo, SUNY)
Spin Confinement and Collective Behavior of $^4$He near the Superfluid Transition |
| --- | --- | --- |
| Room 5B | 16a-B2 | Hai-Hu Wen (Physics Department, Nanjing University)
Anisotropic Superconducting Gap Revealed by Angle Resolved Specific Heat, Point Contact Tunneling and Scanning Tunneling Microscope in Iron Pnictide Superconductors |
| Room 5B | 16a-C2 | Mikhail Eremets (Max Planck Institute for Chemistry)
Metallic dense hydrogen |
| Room 201 | 16a-D2 | Alberto Morpurgo (University of Geneva)
Gate tunable normal and superconducting transport through a 3D topological insulator |
| Room 305 | 16a-E2 | L. Skrbek (Charles University)
Quartz tuning fork as a multipurpose tool for low temperature research - recent development |

### 14:40

| Room 5A | 16a-A3 | J. Dupont-Roc (Ecole Normale Supérieure/CNRS)
Observation of metastable solid helium-4 below its melting pressure |
| --- | --- | --- |
| Room 5B | 16a-B3 | Teppi Yoshida (University of Tokyo)
An energy scale directly related to superconductivity in the high-Tc cuprate superconductors: Universality from the Fermi arc picture |
| Room 5B | 16a-C3 | A. Schilling (University of Zurich)
Josephson Effects in Insulating Quantum Spin Systems? |
| Room 201 | 16a-D3 | Jianhao Chen (University of Maryland)
Dissipative charge transport in graphene |
| Room 305 | 16a-E3 | H. Ohta (Kobe University, Molecular Photoscience Research Center)
Developments of Multi-Extreme Terahertz ESR System at Low Temperature |
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<td>Hydrodynamics of Superfluid Flow through a Nanohole: Towards the 1D Regime</td>
<td>G. Gervais, McGill University</td>
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<td>16a-B</td>
<td>B0708</td>
<td>Quantum Criticality and Superconductivity in $\text{Ba(Fe}_{1-x}\text{Co}_x\text{)}_2\text{As}_2$</td>
<td>Masahito Yoshizawa, Iwate University</td>
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<td>16a-C</td>
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<td>Quantum Ice</td>
<td>Nic Shannon, University of Bristol</td>
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<td>16a-D</td>
<td>D1219</td>
<td>Tunable Superconductor-Insulator transition in tin-doped Graphene</td>
<td>Adrien Allain, Institut Néel - CNRS – France</td>
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<td>16a-E</td>
<td>E0045</td>
<td>New Generation of Cryogen Free Superconducting Magnets for Neutron Scattering Experiments</td>
<td>Oleg Kirichek, ISIS Facility, STFC</td>
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<td>15:20</td>
<td>16a-A</td>
<td>A0683</td>
<td>Vortex Loops and the Superfluid Phase Transition in d Dimensions</td>
<td>Gary Williams, UCLA</td>
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<td>16a-B</td>
<td>B1321</td>
<td>Nodal s-wave superconductivity in $\text{BaFe}_2(\text{As,P})_2$</td>
<td>Takasada Shibauchi, Kyoto University</td>
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<td>16a-C</td>
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<td>Single Crystal NMR Study of Frustrated Spin-liquid $\text{ZnCu}_3(\text{OD})_6\text{Cl}_2$</td>
<td>Mingxuan Fu, McMaster University</td>
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<td>16a-D</td>
<td>D0127</td>
<td>Magnetoexciton Superfluidity in Graphene-Dielectric-Graphene Structures</td>
<td>Dmytro Fil, Institute for Single Crystals, National Academy of Sciences of Ukraine</td>
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<td>16a-E</td>
<td>B1257</td>
<td>A 630kVA/10.5kV superconductor substation</td>
<td>Liangzhen Lin, Institute of Electrical Engineering, CAS</td>
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<td>Christophe Salomon</td>
<td>Laboratoire Kastler Brossel</td>
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<td>17P-1</td>
<td><em>From Ultracold Fermi Gases to Neutron Stars</em></td>
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<td>17P-2</td>
<td>Peter Johnson</td>
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<td><em>High Resolution Photoemission Studies of High Tc Superconductivity</em></td>
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<td>12:30</td>
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Co-Director: Li Lu (Institute of Physics, Chinese Academy of Sciences)
Members: Lieven M.K. Vandersypen (Delft University of Technology)
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**Director:** Yu-Sheng He (Institute of Physics, Chinese Academy of Sciences)

**Co-Director:** Pertti Hakonen (Aalto University School of Science and Technology)

**Members:**
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<td>Yuichi</td>
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<td>Douglas D. Osheroff</td>
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<td>Hans R. Ott</td>
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<td>Richard Packard</td>
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<td>Thomas T.M. Palstra</td>
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<td>Ray Radebaugh</td>
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<td>S. Ramakrishnan</td>
<td>Tata Inst., Mumbai</td>
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<td>Alain Ravex</td>
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<td>Luciano Reatto</td>
<td>Università degli Studi di Milano</td>
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<td>R.C. (Bob) Richardson</td>
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<td>Eduard Rudavski</td>
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<td>Subir Sachdev</td>
<td>Harvard University, Cambridge</td>
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<td>Gary Williams</td>
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<td>Masahito Yoshizawa</td>
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Satellite Conferences

The International Conference on Novel Superconductivity
August 4 - 9, 2011, National Cheng Kung University, Tainan
Organizers: T. K. Lee, M. K. Wu

New Frontiers of Low Temperature Physics
International Conference on Ultra Low Temperature Physics – ULT 2011
August 19 - 22, 2011, KAIST, Daejeon
Organizers: Hu-Jong Lee, Eunseong Kim

APCTP Conference on Localisation 2011
August 4 - 7, 2011, POSCO International Center, POSTECH, Pohang

Topological insulators and superconductors
August 18 - 21, 2011, Tsinghua University, Beijing
Organizers: Carlo Beenakker, Xi Chen, Xi Dai, Aharon Kapitulnik, Qi-Kun Xue, Shou-Cheng Zhang

Fudan Summer School for Condensed Matter Physics
July 13 - August 7, Fudan University, Shanghai
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<td>Cryogenic leads the market in cryogen free technology and offers a large variety of measurement facilities in a helium free environment. This includes Vibrating Sample Magnetometer, Specific Heat, AC susceptibility, Resistivity Measurements and Thermal conductivity. Offered with a field of up to 20 Tesla and ultra low temperatures down to 300 mK with a He-3 insert or 25 mk with a DR. Cryogenic has now developed a CF SQUID Magnetometer with a sensitivity of 10-8.</td>
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<td>GWR Instruments, Inc. manufactures simple, reliable, and inexpensive systems for producing and storing liquid helium in any location. The Advanced Technology Liquefier (ATL) systems are energy efficient and will drastically reduce the cost per liter of liquid helium. Capacity sizes range from 40L to 160L.</td>
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<td>BlueFors Cryogenics Oy is a company that specializes in cryogen-free dilution refrigerator systems. Our aim is to deliver the highest quality, robust and easy to operate refrigerators that require no cryogenic experience of the user. All systems can be optimized and/or customized to meet the requirements of each individual customer.</td>
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<td>Quantum Design International (QDI) manufacturers and distributes scientific and industrial instrumentation through an international network of local direct offices in every major technological center around the world. At our booth during LT26, you will see the latest version of cryogen-free PPMS, SQUID-VSM, VersaLab and new IR image furnace (Floating zone furnace) from Quantum Design. Besides, a full line of research cryostats (including unique ADR type from High Precision Devices and Ultra-Low vibration cryogen free cryostat from Montana Instruments) and various superconductivity magnets (including vector rotate and split pairs magnets etc from American Magnetics Inc) will be exhibited.</td>
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<td>The American Institute of Physics is a federation of 10 physical science societies representing more than 135,000 scientists, engineers, and educators and is one of the world's largest publishers of scientific information in physics. AIP publishes 12 journals; two magazines, including its flagship publication Physics Today; and the AIP Conference Proceedings series.</td>
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World Scientific Publishing Company was established in 1981 with only five employees in a tiny office. Today, the company employs more than 200 staff at its headquarters in Singapore, and has offices in New Jersey, London, Hong Kong, Taipei, Chennai, Beijing and Shanghai. In less than three decades, it has established itself as one of the leading scientific publishers in the world, and the largest international scientific publisher in the Asia-Pacific region.

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Website: http://fullsharecryogenics.com

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Oxford Instruments is a market leader in Ultra-Low-Temperature instrumentation and superconducting magnets. The product range includes dilution refrigerators, 3He refrigerators, superconducting magnets and optical cryostats. Most products are now available as Cryo free products and the helium-free range includes our award winning Triton Cryogen-free dilution refrigerator, standard solenoids (up to 18 T), vector rotate and split pairs magnet systems. Oxford Instruments can also offer complete system integration of magnet and low or ultra-low temperature inserts even for cryogen-free and/or UHV compatible systems.

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Ulvac Cryogenics Inc.

For almost 30 years, ULVAC CRYOGENICS INC. has been manufacturing cryopump systems for the semiconductor, LCD and related high vacuum industries. Our wealth of vacuum and cryogenics technology experience in these competitive markets has taught us how to build highly reliable and powerful 2-stage Gifford-McMahon refrigerators and compressors. These refrigerators, referred to as “cold heads” are used in nearly all closed cycle cryopumping systems, single-stage and two-stage units, available in a wide range of sizes, from small to large for many different applications.

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Sumitomo Heavy Industries (Shanghai) Management, Ltd

Belonging to Sumitomo Heavy Industries, Ltd., is the leading manufacturer of cryogenic products in the world. With the headquarter in Tokyo, and a history of more than 50 years, SHI Cryogenics Group owns three factories, eight sales & service centers all over the world.

Website: http://www.shi.co.jp/cn
Booth No. 25, 26

**Leiden Cryogenics**

Leiden Cryogenics B.V. is a company specialized in building equipment for research at low and ultra low temperatures, particularly dilution refrigerators both of the wet as of the dry type, but also thermometry and other low temperature equipment. Leiden Cryogenics exists since 1992 and has built several hundred dilution refrigerators of the highest quality and performances.  
Website: http://www.leidencryogenics.com

Booth No. 27

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Lake Shore Cryotronics, Inc. is a corporation which supplies the needs of scientists and researchers studying the physical properties of metals and ceramics at very low temperatures. Main product are: temperatures sensor and instrument, probe stations, Hall effect systems, VSM systems, field control platform systems, magnetic instrument & sensor, power supply.  
Website: http://www.lakeshore.com

Booth No. 28

**Linkphysics Corporation**

Linkphysics Corporation supply low temperature, magnet and vacuum products and it is appointed by the following companies as its representative in the territory research of the People’s Republic of China: Lakeshore Cryotronics Inc., Leiden Cryogenics b.v., CRYO Industries of America Inc., Tristantech Technologies, MEDA Inc., Cryofab, GGB Industries Inc., CFIC Qdrive, CPC-Cryolab, CeramTec Group, CryoBIND  
Website: http://www.linkphysics.com

Booth No. 29

**Beijing Scientific applications Co., Ltd**

Beijing Scientific Applications Co., Ltd. was established under the environment of global carbon reduction and protection of ecological environment of the earth. With related researches of Chinese Academy of Sciences, it strives to achieve the energy saving transformation of high energy consumption enterprises.  
The company aims for application-oriented science and science-based application by promoting the transformation of scientific and technological achievements and establishing long-term mechanism energy conservation, making contribution to the energy saving transformation of high energy consumption enterprises, to china and to the world.  
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National Series in Physics of Peking University Press (PUP) is supported by National Publication Foundation of China. In the National Series in Physics, Peking University Press plans to publish about 200 high-level physics monographs before Dec 31st, 2012. Books in the series will cover all major areas of physics, such as particle physics, nuclear physics, condensed matter physics, astrophysics, optics, mathematical physics et al. The series provides original Chinese or English up-to-date monographs on Frontiers of physics, the photocopies of excellent English published monographs, translated foreign books, and reprinted classic Chinese monographs. Welcoming distinguished physicists to write and submit their manuscripts for the National Series in Physics.
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VTT is a globally networked multitechnological contract research organization. VTT provides high-end technology solutions, innovation services and production ramp-up. In the field of tunnel junction devices VTT has competence on Nb and Al tunnel junction multi-layer processes, SQUID design and process, and Quantum information devices based on Josephson tunnel junctions.

Website: http://www.vtt.fi

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Aivon Oy is a private Finnish company established in 2006. Aivon Oy is specialized in ultrasensitive measurements especially with superconducting sensors and low-noise readout electronics. Product range includes among other things Coulomb Blockade Thermometer and cryogenics related electronics.

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Scientific Magnetics manufactures standard and bespoke superconducting and cryogenic solutions. We design and manufacture magnet systems from low and high temperature superconductors, in liquid Helium cooled and cryogen free configurations. We also integrate cryogen free superconducting magnets with ultra low temperature inserts through our collaboration with BlueFors Cryogenics Oy Ltd.

Website: http://www.scientificmagnetics.co.uk

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Western Superconducting Technologies Co. LTD (WST)

WST is located in Xi’an, China. It is mainly engaged in R&D and manufacture of NbTi ingots, bars and NbTi/Cu, Nb3Sn/Cu super-conducting wires. WST is one of the important suppliers for ITER project. WST have yearly production capacity of 500 tons for NbTi superconducting wire. Our products have been widely applied in the field of high magnetic field, nuclear fusion, accelerator, MRI, NMR. The products have got a good reputation and approved by ITER Organization.

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The Physical Society of Japan (JPS) is an organization of some 20,000 physicists, researchers as well as educators, and engineers. The JPS was founded in 1877 as the first society in natural science in Japan. The JPS publishes the Journal of the Physical Society of Japan, which is devoted to the rapid dissemination of important research results pertaining to all fields of physics.

Website: http://jpsj.ipap.jp
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Nanomagnetics Instruments

Nanomagnetic Instruments is specialized on high resolution scanning probe microscopy production. Products for high as well as low temperature down to 20mK are available. Website: http://www.nanomagnetics-inst.com

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East Changing Technologies, Inc.

Founded in 1999, as a high-tech enterprise, ECT (East Changing Technologies, Inc.) specializes in developing and trading products used in cryogenics, magnetics, semiconductor, vacuum and other fields related. After years of hard working, we are so proud that we have become a company with sales of millions US dollars per year and all products we are selling have top quality and prestige all over the world. We are experts in marketing China market. We warmly welcome companies who are interested in China to collaborate with us. We also welcome people who can bring our products to international markets to contact us for collaboration. We trust that today’s collaboration is tomorrow’s success! Website: http://www.eastchanging.com/

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CamCool Research Limited

With over fifty years of research experience in low temperature and high pressure physics among our team, CamCool Research is a spin-off company from the Cavendish Laboratory, University of Cambridge. We specialize in realizing ultra-low noise measurements using magnetic refrigerators capable of smooth and continuous temperature sweeps from 20mK to 300K and hydrostatic high pressure systems up to 200kbar. Website: http://www.camcool.co.uk

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Session 11P: London Prize & Simon Prize Lectures

London Prize Lecture Chair: Moses Chan
Simon Prize Lecture Chair: John Saunders
Thursday August 11, 09:40 – 12:30
Convention Hall 1

11P-1 Studies of Quantum Liquids in Metastable States
H.J. Maris*, *Department of Physics, Brown University, Providence, Rhode Island 02912, USA
Helium can be prepared with a purity much higher than any other element. As a consequence, it is an ideal material in which to study nucleation processes. We describe work in which liquid helium has been studied at pressures below the pressure range in which the liquid is the thermodynamically stable phase. This has made possible the study of a wide range of interesting phenomena including the quantum nucleation of bubbles and the imaging of the motion of single electrons moving through the liquid.

11P-2 Quantum State Engineering with Josephson Junctions
Gerd Schönh*, *Institut für Theoretische Festkörperphysik, Karlsruhe Institute of Technology, 76128 Karlsruhe, Germany
Josephson junctions have been studied for decades because of their rich classical and quantum mechanical properties and their wide range of tunability, which allows entering otherwise inaccessible parameter regimes. In this talk I will shortly review some of their properties, selected according to my personal experiences. Starting in the 80s it became possible to fabricate sufficiently small, low-capacitance Josephson junctions such that quantum tunneling of the phase became observable. This raised the theoretically interesting question how dissipative effects influence the quantum dynamics. Later, in still smaller junctions the interplay of coherent Cooper pair tunneling and incoherent single-electron tunneling could be studied. This led in a natural way to Josephson qubits, based either on charge, flux, or phase degrees of freedom. Their quantum dynamics can be controlled by established electronics, and simple algorithms have been demonstrated by now. The control of dissipative effects, which limit the coherence time, remains one of the major challenges. By coupling Josephson qubits to superconducting resonators, concepts developed previously in cavity quantum electrodynamics could be demonstrated with, in part, unprecedented quality, and qualitatively new behavior, such as the properties of a single-atom laser could be observed.

11P-3 Quantum vortices, quantum phase slip and quantum bits
Hans Mooij*, *Kavli Institute of Nanoscience, Delft University of Technology, Delft, The Netherlands
Modern nanofabrication techniques allow access to new physical phenomena. Superconducting thin film structures at very low temperatures exhibit quantum effects that can be explored for their fundamental interest and for possible applications. Three examples will be discussed.
- In two-dimensional arrays of small Josephson tunnel junctions, vortices can be created that distinctly behave as quantum particles. Localization in artificial potentials and interference of vortices moving around a charge are manifestations of this quantum nature.
- In long, extremely thin and narrow nanowires the phase differences along the wire can locally jump by 2pi in a quantum process. When the strength of this quantum phase slip process is large enough, a quantum phase transition from superconducting to superinsulating occurs. The dynamics should be similar (dual) to the dynamics of Josephson junctions, but observation is difficult.
- Circuits of small junctions can be used to create quantum bits. The flux qubit, with quantum superpositions of macroscopic currents, is one of several practical realizations.

11P-4 Vortex Dynamics in Superconductors and Fermi Superfluids
N.B. Kopnin*, a, b, a Low Temperature Laboratory, Aalto University, 00076 AALTO, Finland  bK. Landau Institute for Theoretical Physics, Moscow, Russia
We discuss forces which act on vortices moving in Fermi superfluids such as superconductors, superfluid Helium 3, etc. Using the microscopic theory we derive the force balance equation and identify three various mechanisms of vortex interaction with the environment: (i) Interaction with the superfluid component which produces the Magnus (or Lorentz) force, (ii) Scattering of normal excitations from the vortex potential giving rise to the transverse Iordanskii force and to a small part of the friction force, and (iii) Scattering of normal excitations from quasiparticles localized in the vortex core. This mechanism produces the transverse spectral flow force and the main contribution to the viscous friction force. Both of these forces are highly sensitive to the quasiparticle mean free path that controls the crossover from dissipative to Hamiltonian vortex dynamics as a function of the sample purity and/or of temperature.

1 S.V. Iordanskii, Annals of Phys. 29, 335 (1964); Sov. Phys. JETP 22, 160 (1966)
11a-A1 Supersolidity vs Quantum Plasticity in solid helium

S. Balibar, X. Rojas, A. Haziot, A. Fefferman, H.J. Maris, J. West, M.H.W. Chan, "Laboratoire de Physique Statistique, Ecole Normale Supérieure, CNRS, Universités P.M. Curie and D. Diderot, 24 rue Lhomond, 75231 Paris Cedex 05, France. a Department of Physics, Brown University, Providence, RI 02912, USA b Department of Physics, The Pennsylvania State University, University Park, Pennsylvania 16802, USA College.

Seven years after Kim and Chan’s discovery of a rotation anomaly in solid helium, the interpretation of the observed phenomena in terms of supersolidity remains controversial. J. Beamish’s group has shown that the rotation anomaly is accompanied by an elastic anomaly: when the TO period increases, the shear modulus decreases, due to the unpinning of dislocations from 4He impurities. Could the observed phenomena be only due to this softening? In some experiments this is probably true but not in some others, especially the recent study by Kim’s group of oscillators under dc-rotation. I will shortly describe our elastic measurements in high quality crystals containing no impurity and our more recent comparison of TOs filled with either single crystals or polycrystals. The latter illustrate the difficulty we encounter when trying to attribute rotation anomalies in solid helium to supersolidity or to changes in elastic properties. This work is supported by ERC Grant AdG247258-SUPERSOLID.


11a-A2 Supersolid Behavior and Inertial Anomalies in Solid 4He Formed in Nanoporous Media

Keiya Shirahama, a Department of Physics, Keio University, Yokohama 223-8522, Japan

“Non-classical rotational inertia (NCRI)” observed in solid 4He formed in a porous Vycor glass [1] has been remaining as a puzzle in theoretical interpretations for possible supersolidity in solid 4He. To elucidate the mechanism of NCRI, we have made torsional oscillator studies for solid 4He in a nanoporous Gelsil glass, which has much narrower pores (2.5 nm) than Vycor has. Most of the supersolid properties found in bulk solid are also observed in the confined solid. Moreover, we observe an additional decrease in rotational inertia accompanied with a dissipation peak around 1 K. This “high – T inertial anomaly” has a slight, systematic dependence on pressure but no dependence on oscillation velocity, unlike the NCRI seen below 0.15 K. We attribute the high – T anomaly to a relaxation of microscopic excitations in amorphous solid 4He. Similar inertial anomaly is observed in thin solid 4He films adsorbed on the same porous glass sample. The onset temperature decreases to 0 K as the superfluid critical coverage approaches, suggesting that the inertial anomaly in solid films is related to a quantum phase transition between a gapped solid and a genuine superfluid [2].


11a-A3 Superclimbing dislocations in solid 4He

A.B. Kuklov, D. Aleinikava, “The College of Staten Island and The Graduate Center, City University of New York, USA

Superclimbing dislocations1 are shown to exhibit stress induced and temperature assisted roughening proceeding as a first-order phase transition at finite temperature2. The transition develops at a macroscopic scale $L_h$ growing with temperature $T$. For a dislocation size $L$ smaller than $L_h$, speed of first sound along the superfluid core experiences a drastic suppression in a narrow temperature interval. We suggest that this feature is behind the recently observed suppression of the superflow rate3. Such a suppression is a consequence of the resonant-type creation of the jog-antijog pairs by the imposed chemical potential $\mu$ which induces a mechanical stress on the core. We have also found that the suppression is characterized by the quasi-periodicity with respect to $\mu$ and suggest that it should be searched for in the Umann-Sandwich setup 3. For $L > L_h$, the hysteretic behavior with respect to the applied $\mu$ develops. We also argue that contributions of a network of superclimbing dislocations, stressed by mechanical and thermal forces, to specific heat of a 4He crystal are essentially independent of the dislocation density – in a full analogy to the dislocation contribution to elastic moduli4.

We present the recent activity of our group in the microscopic study of solid $^4$He using quantum Monte Carlo methods. In the limit of zero temperature, we have calculated the vacancy formation energy and enthalpy from the melting pressure up to $P \approx 160$ bar. The vacancy formation volume shows a maximum at $P \approx 60$ bar which is coincident with a minimum of the vacancy formation energy at fixed pressure. Close to this pressure, experimental data shows an enhancement of the superfluid fraction. At finite temperatures, we have studied the physics of solid $^4$He with vacancies. For different vacancy concentrations, we have estimated the onset temperature at which the vacancy becomes delocalized and off-diagonal long range order starts to appear. This onset temperature approaches the range of temperatures $\sim 100$ mK where a supersolid fraction has been experimentally observed. Finally, we report preliminary results of a microscopic description of the role of $^3$He impurities in hcp $^4$He with and without vacancies.

The observation by Kim and Chan, using a torsional oscillator containing solid $^4$He, of nonclassical rotational inertia (NCRI) or a supersolid state of the solid, along with the discovery by Day and Beamish, of an anomalous increase in the shear modulus of solid $^4$He, were two of the most significant developments in the study of solid $^4$He in the last decade. These two phenomena share many common features, including sensitivity to $^3$He impurities, mechanical stress, and the display of annealing and relaxation dynamics over the temperature region of the supersolid transition. The similarity of these two phenomena gives rise to a problem in interpreting the NCRI and dissipative signals seen in single frequency torsional oscillator experiments. In many cases, the fraction of the total moment of inertia that is decoupled from the torsional oscillator in the supersolid state may be as small as 0.01 to 0.1 percent of the solid moment of inertia. Depending on the design of the oscillator, the signal arising from the shear modulus anomaly may comparable or even larger. In the experiments discussed here, an attempt to separate these two phenomena is made by constructing oscillators operating at two or three different frequencies. In addition, oscillators have been designed to be especially sensitive to the shear modulus anomaly and provide an alternate to the peizo-electric technique employed by Day and Beamish for the determination of the shear modulus of the solid. This work has been supported by the National Science Foundation through Grant DMR-096569.
Session 11a-B: Physical Properties of Fe-based Superconductors I

Chair: John Tranquada
Thursday August 11, 14:00 – 15:40
Convention Hall 3

11a-B1 In-Plane Electronic Anisotropy in Iron Pnictides
S. Uchida, Department of Physics, University of Tokyo, Hongo, Tokyo 113-0033, Japan

The iron pnictides possess a competing and sometimes coexisting phase in their underdoped regime. This phase appears below the magneto-structural phase transition at $T_S$. We address the questions associated with a remarkable in-plane anisotropy in the charge transport of Co-underdoped $\text{BaFe}_2\text{As}_2$: (i) Why is the conductivity in the $a$-axis direction higher than that in the $b$-direction? (ii) Does the anisotropy persist up to temperatures well above $T_S$ (nematicity)? and (iii) Why is the anisotropy enhanced by the Co doping?

The measurements of resistivity and optical conductivity spectra on detwinned crystals reveals that the in-plane anisotropy arises primarily from an opening of anisotropic pseudogap with wider gap along the $b$-direction. As the sample quality is improved, the temperature range of nematicity shrinks, and the transition at $T_S$ becomes a first-order like, suggesting that the nematicity may be an extrinsic effect. It turns out that the dopant Co atom works as a strongly anisotropic scattering center which causes the enhanced anisotropy.

This work has been done in collaboration with M. Nakajima, S. Ishida, T. Liang, T. Kakeshita, Y. Tomioka, T. Ito, C.H. Lee, H. Kito, A. Iyo, and H. Eisaki.

11a-B2 Comparable energy scales of superconducting charges and spin fluctuations in unconventional superconductors: implications on condensation and pairing
Y.J. Uemura, Physics Department, Columbia University, New York, NY 10027, USA

An “effective Fermi energy” $\epsilon_F$ of superconducting carriers can be derived from measurements of the magnetic field penetration depth and the superfluid density $n_s/m^*$ (superconducting carrier density / effective mass). Accumulated results of $n_s/m^*$ in cuprate, FeAs, organic BEDT, $\text{A}_3\text{C}_6\text{O}$ and heavy fermion $\text{CeCoIn}_5$ systems exhibit a strong correlation between $T_c$ and the charge energy scale $\epsilon_F$ [1]. This feature has been discussed as a support for Bose-Einstein condensation of pre-formed pairs. On the other hand, another strong correlation exists between $T_c$ and the spin fluctuation energy scale $\hbar\omega_{SF}$ which represents the strength of the exchange coupling $J$, as was noticed by Moriya and Ueda [2]. This feature has been discussed as a support for BCS condensation mediated by antiferromagnetic magnons. Co-existence of these two different correlations indicates that the spin energy $J$ is comparable to the condensing charge energy $\epsilon_F$, and suggests a resonant behavior in condensation and pairing. This is a key to understanding highly unusual non-BCS like behaviors of the superfluid density in the overdoped / pressurized regions of these systems. We will discuss this energy-scale phenomenology by showing the most recent experimental data on the superfluid density in various FeAs and CeCo(In,Sn)$_5$ systems.


11a-B3 ARPES studies on the pairing symmetry and mechanism of iron-based superconductors
Hong Ding, Institute of Physics, Chinese Academy of Sciences, Beijing, China

Angle-resolved photoemission spectroscopy (ARPES) has been used extensively in studying electronic structure and superconducting gap of the iron-based high-temperature superconductors. In this talk, I will present our ARPES results on these new superconductors, mainly focus on high-resolution measurements of the superconducting gap of different iron-based superconductors, including 122, 111, and 11 systems. Our results observed Fermi surface dependent nodeless superconducting gap on all these materials, and suggest that the superconductivity of the iron-based superconductors is likely to be driven by short-range antiferromagnetic fluctuations.

11a-B4 Comparative studies of the field-dependent scanning tunneling spectroscopy in cuprate and iron-pnictide superconductors
N.-C. Yeh, M. L. Teague, A. D. Beyer, P. Chen, B. Shen, H.-H. Wen, Department of Physics, California Institute of Technology, Pasadena, CA, USA

Institute of Physics, Chinese Academy of Sciences, Beijing & Nanjing University, China

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We study the scanning tunneling spectroscopy of hole-type cuprate YBa$_2$Cu$_3$O$_{7-\delta}$ (Y-123, $T_c = 93$ K), electron-type cuprate Sr$_{0.4}$La$_{0.1}$CuO$_2$ (La-112, $T_c = 43$ K), and “122” iron pnictides Ba(Fe$_{1-x}$Co$_x$)$_2$As$_2$ ($x = 0.06, 0.08, 0.12$ for $T_c = 14, 24, 20$ K). In zero field ($H=0$), spatially homogeneous coherence peaks at energies $\omega = \pm \Delta_{SC} \sim \pm 21$ meV flanked by spectral “shoulders” at $\pm \Delta_{eff} \sim \pm 38$ meV are found in Y-123. In contrast, only a pair of spatially homogeneous peaks are seen in La-112 at $\pm \Delta_{eff} \sim \pm 13$ meV. For $H > 0$, vortices with a radius much larger than the coherence length $\xi_{SC}$ is found in Y-123, whereas the vortex radius is comparable to $\xi_{SC}$ in La-112. Moreover, pseudogap ($\Delta_{PG}$) features are revealed inside the vortices, with $\Delta_{PG} = \sqrt{\Delta_{eff}^2 - \Delta_{SC}^2} > \Delta_{SC}$ in Y-123 and $\Delta_{PG} < \Delta_{SC}$ in La-112. The Fourier transformation (FT) of the Y-123 spectra exhibits spectral peaks due to $\omega$-dependent quasiparticle interference (QPI) wave-vectors and $\omega$-independent wave-vectors associated with competing orders.\textsuperscript{1} In 122 iron pnictides, two-gap superconductivity is evident in the $H = 0$ spectra for all doping. The FT spectra for $H \geq 0$ exhibit $\omega$ and $x$-dependent QPI consistent with sign-changing $s$-wave pairing.\textsuperscript{2} 


11a-B5  
Fast vortices in the Cuprates? A vortex plasma model analysis of the THz conductivity and diamagnetism in La$_{2-x}$Sr$_x$CuO$_4$

L. S. Bilbro$^a$, R. V. Aguilar$^a$, G. Logvenov$^b$, O. Pelleg$^b$, I. Bozovic$^b$, N. P. Armitage$^a$. 
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The nature of the underdoped pseudogap regime of the high-temperature copper oxide superconductors has been a matter of long-term debate. On quite general grounds, we expect that, owing to their low superfluid densities and short correlation lengths, superconducting fluctuations will be significant for transport and thermodynamic properties in this part of the phase diagram. Although there is ample experimental evidence for such correlations, there has been disagreement about how high in temperature they may persist, their role in the phenomenology of the pseudogap and their significance for understanding high-temperature superconductivity. Here we use THz time-domain spectroscopy to probe the temporal fluctuations of superconductivity above the critical temperature (Tc) in La$_{2-x}$Sr$_x$CuO$_4$ (LSCO) thin films over a doping range that spans almost the entire superconducting dome ($x=0.09-0.25$). Signatures of the fluctuations persist in the conductivity in a comparatively narrow temperature range, at most 16 K above Tc. We compare our results with measurements of diamagnetism in a similarly doped crystals of LSCO and show through a vortex-plasma model that if the fluctuation diamagnetism solely originates in vortices, then they must necessarily exhibit an anomalously large vortex diffusion constant, which is more than two orders of magnitude larger than the Bardeen-Stephen estimate. This points to either the extremely unusual properties of vortices in the under-doped d-wave cuprates or a contribution to the diamagnetic response that is not superconducting in origin.
Session 11a-C: Low Dimensional and Frustrated Magnetism I

Chair: Tao Xiang
Thursday August 11, 14:00 – 15:40
Room 5B

11a-C1 Neutron scattering Studies of Spin-Ladders
B. Lake	extsuperscript{a}, S. Notbohm	extsuperscript{a}, D.A. Tennant	extsuperscript{a}, T.G. Perrin	extsuperscript{b}, P. Ribeiro	extsuperscript{e}, C. Sekar	extsuperscript{e}, G. Krabbes	extsuperscript{e}, \textsuperscript{a}Helmholtz-Zentrum Berlin GmbH, Hahn Meitner Platz 1, D-14109 Berlin, Germany. \textsuperscript{b}ISIS Facility, Rutherford Appleton Laboratory, Chilton, Didcot OX11 0QX, U.K. \textsuperscript{c}IFW Dresden Helmholtzstrasse 26, 01069 Dresden, Germany.

Spin-ladders consists of two parallel antiferromagnetic chains of magnetic spin-1/2 ions (legs of ladder) coupled together (rungs of ladder). In the limit of strong rung coupling, the magnetic spectrum is dominated by the excitations of an antiferromagnetic dimer i.e. a gapped magnon mode; introduction of leg coupling modulates this mode but the gap remains. In the limit of weak rung coupling the excitations are similar to the multi-spinon continuum of the one-dimensional, spin-1/2, Heisenberg antiferromagnet. The gap remains in the presence of finite rung coupling but can be suppressed by cyclic exchange interactions. Inelastic neutron scattering of some spin-ladder compounds will be presented. La$_4$Sr$_9$Cu$_{24}$O$_{41}$ has strong rung coupling and its excitations consist of a gapped one-magnon mode and a two-magnon continuum, a substantial cyclic exchange reduces the gap and destroys the bound two-magnon excitations. In contrast CaCu$_3$O$_4$ has a weak rung interaction and a large cyclic exchange which drives the system gapless and quantum critical. At high energies the excitations resemble the multi-spinon continuum of the antiferromagnetic, spin-1/2 chain. At low energies however the excitations are gapless and quantum critical. Comparison to theory suggests that the spinons are bound by the rung coupling and the ladder is close to the Wess-Zumino-Novikov-Witten quantum critical point.

11a-C2 MAGNETICALLY DRIVEN ANOMALOUS ELASTICITY IN ULTRATHIN FILM OF IRON ON Cu(001)
Xiaofeng Jin	extsuperscript{a}, \textsuperscript{a}Department of Physics, Fudan University, Shanghai 200433, China

Properties of matter depend sensitively on physical parameters that define them. Tailoring these parameters in a well controlled way often lead to new phenomena and new state of matter. Unfortunately our ability to tune and combinatorially manage these parameters is very limited, leaving a large universe for discovery untouched. Here we develop a novel technique with molecular beam epitaxy to tune continuously the surface lattice constant. Applying this to Cu(001) on which ultrathin Fe films are epitaxially grown, we are able to observe for the first time the abnormal elastic property in Fe which expands vertically along its [001] direction when stretched horizontally along the [100] and [010] directions - a phenomenon has long been predicted by Landau but never realized in experiment. It is further proved unambiguously that this unusual elasticity originates from the interesting magnetic properties of face-centered-cubic Fe.

11a-C3 Quantum Kagome Antiferromagnets : Local NMR and μSR Experiments
P. Mendels	extsuperscript{a}, F. Bert	extsuperscript{a}, E. Kermarrec	extsuperscript{c}, M. Jeong	extsuperscript{a}, J. Quilliam	extsuperscript{a}, R. Colman	extsuperscript{b}, A.S. Wills	extsuperscript{b}, P. Strobel	extsuperscript{c}, \textsuperscript{a}Laboratoire de Physique des Solides, Université Paris-Sud 11, UMR CNRS 8502, 91405 Orsay, France. \textsuperscript{b}University College London, Department of Chemistry, 20 Gordon Street, London WC1H 0AJ, UK. \textsuperscript{c}Institut Néel, bât. F, BP 166, 38042 Grenoble cedex 9, France.

The frustration of antiferromagnetic interactions on the loosely connected kagome lattice associated to the enhancement of quantum fluctuations for $S = 1/2$ spins was acknowledged long ago as a key combination to stabilize novel ground states of magnetic matter such as spin-liquids. Only in 2005, a model compound, the Herbertsmithite ZnCu$_3$(OH)$_6$Cl$_2$, could be synthesized and has triggered since then a remarkable activity [1]. There are now a few new candidate materials, among which Kapellasite and Haydeeite [2], Mg analogues of Herbertsmithite [3], and Vesignieite [4]. I will present a selection of the properties uncovered by our recent NMR and μSR experiments in these systems and will tentatively classify them with respect to the most studied case of Herbertsmithite. I will discuss the role played by Dzyaloshinskii-Moriya interactions. More generally, the question of the criticality and stability of the kagome Heisenberg model is addressed on the basis of recent results in Herbertsmithite.

11a-C4  Low-temperature features of random Heisenberg spin chains

T. Shiroka\textsuperscript{a}, F. Casola\textsuperscript{a}, V. Glazkov\textsuperscript{b}, A. Zheludev\textsuperscript{a}, K. Prša\textsuperscript{a}, H.-R. Ott\textsuperscript{a}, J. Mesot\textsuperscript{c}, \textsuperscript{a}Laboratorium für Festkörperphysik, ETH Hönggerberg, CH-8093 Zürich, Switzerland \textsuperscript{b}P.-L. Kapitza Institute for Physical Problems RAS, 119334 Moscow, Russia \textsuperscript{c}Paul Scherrer Institut, CH-5232 Villigen PSI, Switzerland

Low-dimensional spin systems, consisting of arrays of spins arranged in chains or ladders, have been intensively investigated in recent years using both exactly solvable theoretical models as well as a wide range of experimental techniques. In case of random variations of the exchange couplings the renormalization group theory predicts the existence of a random-singlet (RS) state, corresponding to spins coupled at all possible distances and energy scales. However, the scarce availability of suitable random systems has so far prevented the experimental identification of this peculiar magnetic ground state. In a joint effort using nuclear magnetic resonance (NMR), dc magnetometry and numerical simulations we found compelling evidence of the formation of a random-singlet state in this class of materials.\textsuperscript{1} Randomness seems to generate a distribution of local magnetic relaxations, in turn reflected in a stretched exponential NMR relaxation. This distribution exhibits a progressive broadening with decreasing temperature, caused by a growing inequivalence of magnetic sites, as expected from RS theory. Our work suggests that NMR is the tool of choice for probing the low-energy physics also in other disordered magnets, where extended-scale excitations are dominant.


11a-C5  Quantum Spin Liquid in an Organic Triangular Lattice Antiferromagnet EtMe\textsubscript{3}Sb[Pd(dmit)\textsubscript{2}]\textsubscript{2}

S. Maegawa\textsuperscript{a}, T. Itou\textsuperscript{b}, K. Yamashita\textsuperscript{a}, M. Nishiyama\textsuperscript{a}, A. Oyamada\textsuperscript{a}, K. Kubo\textsuperscript{b}, R. Kato\textsuperscript{b}, \textsuperscript{a}Graduate School of Human and Environmental Studies, Kyoto University, Kyoto 606-8501, Japan \textsuperscript{b}Condensed Molecular Materials Laboratory, RIKEN, Wako 351-0198, Japan

A quantum spin liquid state has been found in a quasi-two-dimensional organic spin 1/2 antiferromagnet on the triangular lattice, EtMe\textsubscript{3}Sb[Pd(dmit)\textsubscript{2}]\textsubscript{2}, by means of enriched $^{13}$C-NMR.\textsuperscript{1} Neither classical magnetic ordering nor a spin-glass state exists down to 19 mK due to the spin frustration and quantum fluctuation, although the magnetic exchange interaction is 220–250 K. The $^{13}$C nuclear spin-lattice relaxation rate $T_1^{-1}$ shows a clear kink at 1.0 K without broadening of the NMR spectrum. The result exhibits an exotic phase transition accompanied with symmetry breaking or topological ordering. The gradual temperature dependence of the relaxation rates above 1.0 K indicates that the excitations have no spin gap, while the dependence proportional to the square of the temperature below 1.0 K exhibits the appearance of an excitation gap that may imply a nodal gap rather than a full gap. Various attractive predictions have been proposed theoretically for the instability or transition in the quantum spin liquid. Our discovery of the transition is expected to give important information on a new instability of the quantum spin liquid.\textsuperscript{2}

Session 11a-D: Superconducting devices/qubits I

Chair: Per Delsing
Thursday August 11, 14:00 – 15:40
Room 201

11a-D1  Josephson-junction quantum systems in open 1D space
O. V. Astafiev\textsuperscript{a}, A. A. Abdumalikov\textsuperscript{a}, A. V. Zagoskin\textsuperscript{a}, Yu. A. Pashkin\textsuperscript{a}, Y. Nakamura\textsuperscript{a}, J.-S. Tsai\textsuperscript{a}, \textsuperscript{a}NEC Green Innovation Research Laboratories, Tsukuba, Ibaraki 305-8501, Japan and RIKEN Advanced Science Institute, Wako, Saitama 351-0198, Japan \textsuperscript{b}Department of Physics, Loughborough University, Loughborough, LE11 3TU Leicestershire, UK

A superconducting quantum system (artificial atom) coupled to a transmission line is a direct analog of a natural atom in the open space. An important feature of the system is strong coupling to the 1D open space, which is experimentally observed as nearly 100\% scattering of resonant radiation. This is theoretically possible but difficult to achieve for the natural atom. We use the artificial atom strongly coupled to the 1D space to demonstrate a series of basic quantum optical phenomena such as resonant fluorescence in elastic and inelastic scattering, anomalous dispersion, nonlinear properties of the two-level system. Using upper levels, we also demonstrate quantum optical effects on the three-level atom (textbook system of quantum optics), namely, electromagnetically induced transparency and quantum amplifier on a single atom. Having full coherent control of our atom by microwave pulse technique applied through the same transmission line, we demonstrate manipulation and dynamics of the atomic quantum states. We suggest an algorithm and perform derivation of two-time correlation function of fluctuations by measuring only coherent dynamics of the atomic emission.

11a-D2  A two-step transition description of underdamped phase diffusion
H. F. Yu\textsuperscript{a}, Ye Tian\textsuperscript{a}, G. H. Chen\textsuperscript{a}, D. N. Zheng\textsuperscript{a}, L. Lu\textsuperscript{a}, S. P. Zhao\textsuperscript{a}, Siyuan Han\textsuperscript{b}, \textsuperscript{a}Beijing National Laboratory for Condensed Matter Physics, Institute of Physics, Chinese Academy of Sciences, Beijing 100190, China \textsuperscript{b}Department of Physics and Astronomy, University of Kansas, Lawrence, Kansas 66045, USA

A two-step transition model to describe the phase diffusion and switching process in underdamped Josephson junctions is discussed. The model takes into account the phase particle’s escape rate out of the potential well and the transition rate from phase diffusion to the running state. Using as examples the experimental switching current distributions of two Nb/AlO\textsubscript{2}/Nb junctions of different sizes fabricated on the same chip, we directly extract the transition rate, which turns out to follow the predicted Arrhenius law in the thermal regime but is greatly enhanced when macroscopic quantum tunneling becomes the dominant escape mechanism. Our results show that the transition rate can be conveniently used for the description of underdamped phase diffusion in both the thermal and quantum regimes.

11a-D3  Coupling an ensemble to a superconducting qubit
Xiaobo Zhu\textsuperscript{a}, Shiro Saito\textsuperscript{a}, Alexander Kemp\textsuperscript{a}, Kosuke Kakuyanagi\textsuperscript{a}, Shin-ichi Karimoto\textsuperscript{a}, Hayato Nakano\textsuperscript{a}, William J. Munro\textsuperscript{a}, Yasuhiro Tokura\textsuperscript{a}, Mark S. Everitt\textsuperscript{b}, Kae Nemoto\textsuperscript{c}, Makoto Kasu\textsuperscript{c}, Norikazu Mizuochi\textsuperscript{c,d}, Kouichi Semb\textsuperscript{c,d}, \textsuperscript{a}NTT Basic Research Laboratories, NTT Corporation, 3-1 Morinosato-Wakamiya, Atsugi, Kanagawa 243-0198, Japan \textsuperscript{b}National Institute of Informatics, 2-1-2 Hitotsubashi, Chiyoda-ku, Tokyo-to 101-8430, Japan \textsuperscript{c}University of Osaka, Graduate school of Engineering Science, 1-3, Machikaneyama, Toyonaka, Osaka, 560-8531, Japan \textsuperscript{d}PRESTO JST, 4-1-8 Honcho, Kawaguchi, Saitama 332-0012, Japan

We report here the first demonstration of strong coupling and coherent exchange of a single quantum of energy between a superconducting qubit and an ensemble quantum system. This is the first step towards the realization of a long lived quantum memory for condensed matter systems with an additional potential future application as an interface between the microwave and optical domains.

11a-D4  Microwave cooling of Josephson plasma oscillations
M. Aprili\textsuperscript{a}, J. Hammer\textsuperscript{b}, I. Petkovi\textsuperscript{c}, \textsuperscript{a}Laboratoire de Physique des Solides, UMR8502-CNRS, University Paris-Sud, 91405 Orsay Cedex, France \textsuperscript{b}Institute for Experimental and Applied Physics, University of Regensburg, 93040 Regensburg, Germany, \textsuperscript{c}Institute of Informatics, 2-1-2 Hitotsubashi, Chiyoda-ku, Tokyo-to 101-8430, Japan

Macroscopic Josephson junctions allow strong coupling between the superconducting phase difference across the junction (the Josephson phase) and transverse microwave cavity modes in the junction itself. When the cavity bandwidth is much smaller than the Josephson plasma frequency the coupled phase and photon dynamics generate sideband resonances for each of the cavity modes. This makes it possible to use inelastic photon scattering to dampen or to enhance the Brownian motion of the Josephson phase. In particular, by measuring the histograms of the junction’s switching current, we have observed that Stokes (anti-Stokes) scattering effectively heats (cools) the Josephson phase \textsuperscript{1}. Both these effects increase with microwave power. These out-of-equilibrium phase dynamics results from a large phase relaxation time. We have measured this time directly using a pump-probe
like technique\textsuperscript{2}. Finally I shall discuss analogies and differences with similar experiments on the cooling of optomechanical devices.


11a-D5 A quantum electron pump operating at the Josephson frequency

F. Giazotto\textsuperscript{a}, P. Spathis\textsuperscript{a}, S. Roddaro\textsuperscript{a}, S. Biswas\textsuperscript{a}, F. Taddei\textsuperscript{a}, M. Governale\textsuperscript{b}, L. Sorba\textsuperscript{a}, \textsuperscript{a}NEST, Istituto Nanoscienze-CNR and Scuola Normale Superiore, Piazza S. Silvestro 12, I-56127 Pisa, Italy \textsuperscript{b}School of Chemical and Physical Sciences and MacDiarmid Institute for Advanced Materials and Nanotechnology, Victoria University of Wellington, P.O. Box 600, Wellington 6140, New Zealand

A macroscopic fluid pump works according to the law of Newtonian mechanics and transfers a large number of molecules per cycle (of the order of $10^{23}$). By contrast, a nano-scale charge pump can be thought as the ultimate miniaturization of a pump, with its operation being subject to quantum mechanics and with only few electrons or even fractions of electrons transferred per cycle. It generates a direct current in the absence of an applied voltage exploiting the time-dependence of some properties of a nano-scale conductor. So far, nano-scale pumps have been realised only in systems exhibiting strong Coulombic effects, whereas evidence for pumping in the absence of Coulomb-blockade has been elusive. Here we report the experimental detection of charge flow in an unbiased InAs nanowire embedded in a superconducting quantum interference device (SQUID). In this system, pumping may occur via the cyclic modulation of the phase of the order parameter of different superconducting electrodes. The symmetry of the current with respect to the enclosed magnetic flux and bias SQUID current is a discriminating signature of pumping. Currents exceeding 20 pA are measured at 250 mK, and exhibit symmetries compatible with a pumping mechanism in this setup which realizes a Josephson quantum electron pump.
Session 11a-E: Ground State Techniques

Chair: Arttu Luukanen
Thursday August 11, 14:00 – 15:40
Room 305

11a-E1 Superfluid Helium Quantum Interference Devices: Present Status and Future Prospects

Yuki Sato\textsuperscript{a}, Richard Packard\textsuperscript{b}, \textsuperscript{a}Rowland Institute at Harvard, Harvard University, Cambridge, MA 02142, USA \textsuperscript{b}Department of Physics, University of California at Berkeley, Berkeley, CA 94720, USA

Josephson weak links between samples of macroscopic systems such as superconductors, superfluids, and Bose-Einstein condensates provide a unique tool with which to explore quantum mechanics and an opportunity for applications based on macroscopic quantum physics. The development of superfluid weak links has led both to the discovery of new physical phenomena and also to the development of superfluid helium quantum interference devices (SHeQUIDs). This talk will describe the physics underlying the SHeQUID and the novel applications and utility of this promising technology.

11a-E2 The LT challenge in optomechanics

Pierre-Francois Cohadon\textsuperscript{a}, \textsuperscript{a}Laboratoire Kastler Brossel, ENS-UPMC-CNRS

Optomechanics, the coupling between laser light and a moving mirror, enforces quantum limits to position measurements of macroscopic mechanical resonators but also yields efficient laser-cooling mechanisms for such resonators, possibly down to their quantum ground state, with the ability to shed new light on the quantum/classical border. Reducing the environment temperature of the mechanical resonator is mandatory to enter deeply into the quantum regime, but optomechanical systems impose new rules to design suitable fridges. I will describe some recent optomechanics experiments and current effort to operate such systems in cryogenic environments.

11a-E3 Search for the Neutron Electric Dipole Moment on SNS

W. Yao\textsuperscript{a}, \textsuperscript{a}Oak Ridge National Laboratory, Tennessee, USA

This project invokes a new technique for searching for the electric dipole moment(EDM) of the neutron. It is based on the magnetic-resonance technique in which the magnetic dipole moment of a neutron is placed in a plane perpendicular to parallel magnetic and electric field. The impact of the electric field on the precession of the neutron is characterized by the first moment of the neutron charge distribution, \( d_n \), its EDM. In principle, this new type of EDM experiment can achieve more than two orders of magnitude improvement in the experimental limit for the neutron EDM in conjunction with the Spallation Neutron Source (SNS) at Oak Ridge National Laboratory. This factor results from the possibility of an increased electric field due to the excellent dielectric properties of superfluid \( ^4 \)He, an increase in total number of ultracold neutrons (UCNs) stored and an increased storage time due to the low temperature of the walls. The UCN needed for this experiment are produced via the superthermal method in superfluid \( ^4 \)He at a temperature below 0.5 K. The use of spin polarized \( ^3 \)He as a volume co-magnetometer is crucial to the elimination of the magnetic-field systematics. With the proposed experiment, an EDM limit of \( 10^{-28} \) e·cm is possible.

\textsuperscript{1} Submitted on behalf of nEDM collaboration.

11a-E4 Nano-sized SQUID-on-tip for a scanning SQUID microscope

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A novel SQUID design for a scanning SQUID microscope was reported recently by our group \textsuperscript{1}. This type of SQUID can be easily manufactured in a simple 3-step deposition process by evaporation of either Al, Pb or Nb without any need of lithography or wet processing. The shape of the SQUID allows approaching a sample’s surface within a few nanometers if the SQUID is attached to a standard AFM tuning fork. The resulting devices have the smallest tip diameter of 75 nm, the flux sensitivity of 1.8 \( \mu \Phi_0 / \text{Hz}^{1/2} \) and magnetic field sensitivity of \( 10^{-7} \text{T/Hz}^{1/2} \), which corresponds to spin sensitivity of 65 \( \mu_B / \text{Hz}^{1/2} \) for aluminium, and can operate at magnetic fields up to 0.6 T. These parameters make our SQUIDs the world’s smallest and also the most suitable for use as scanning SQUIDs to date. This work is supported by the Israel Science Foundation and the European Research Council.

\textsuperscript{1} A. Finkler et al., Nano. Lett. 10, 1046 (2010)
11a-E5 Development of Tunnel Junction Micro-SQUID Magnetometer for Investigation of Single-Molecule Magnets

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We have developed tunnel junction micro-SQUID magnetometer for the precise investigation of single-molecule magnets (SMMs). The magnetometer can be operated in magnetic field up to 1.3 T. The Joule heat associated with the measurement is extremely small (less than 2 fW). This value is $10^7$ times smaller than the conventional micro-SQUIDs with Dayem bridge Josephson junction.\(^1\) By using the tunnel junction micro-SQUID magnetometer, the quantum tunneling of magnetization of Fe\(_8\) SMM was reproduced as the stepwise magnetization curve.

Session 11P-A:

A3 Supersolidity

Thursday August 11, 16:00 – 18:00

Exhibition Hall 1

11P-A001 Bose-Einstein Condensation in Liquid Helium under Pressure

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We report neutron scattering measurements of the Bose-Einstein condensate fraction, $n_0$, the atomic momentum distribution and of Final State effects in liquid helium as a function of pressure, from $p = 0$ to 24 bar. Measurements in both the superfluid phase at low temperature and in the normal liquid phase have been made. The measurements were made on the MARI instrument at ISIS. We find that the condensate fraction decreases with increasing pressure, from 7.25 ± 0.75% at $p = 0$ (saturated pressure) to 3.2 ± 0.75% at 24 bar which extrapolates to 3.0% at the liquid-solid interface (25.3 bar). The atomic momentum distribution broadens with increasing pressure (i.e. the kinetic energy increases). The atomic momentum distribution differs significantly from a simple Gaussian function with high occupation of low momentum states (glassy) phase in solid helium. In the torsion oscillation experiments the drop in the period of oscillations with achievement of some small temperature has been observed. This effect was attributed to the appearance of the superfluid component. There are ideas that specific response of the oscillator appears due to existence of the vortex fluid (vortex tangle) in this system. In the present talk we submit the approach describing the vortex tangle non-linear relaxation model for large torsional oscillation of quantum systems, having in mind to apply it for the study of solid $^3$He. The study of this problem shows that there is a quasi-linear solution with the amplitude dependent relaxation time. Both the dissipation $\Delta Q^{-1}/Q$ and the shift of period $\Delta P/P$ are the functions of amplitude oscillations $V_n$ and temperature $T$. The maximum of the relative dissipation $\Delta Q^{-1}/Q$ over $\Delta P/P$ (taking at zero temperature) have various values on the $T - V_n$ plain, with the maximum differing essentially from the value 1/2, which is prescribed by the linear Debye model.

11P-A003 Effect of Crystal Growth on Liquid-like Droplets Formation in the hcp Solid Helium


The samples of hcp solid helium (1% $^3$He in $^4$He) are studied by NMR technique. Samples are grown by blocked capillary method under different growth rates (about 8, 2, and 0.08 mK/s). NMR technique is used for phase identification by measurements of diffusion coefficient $D$ and spin-spin relaxation time $T_2$ at temperatures of 1.3 – 2.0 K and pressures of 34 – 36 bar. Along with $D$ and $T_2$ for the hcp phase, we simultaneously observed the $D$ and $T_2$ typical for liquid for growth rates 8 and 2 mK/s. That means liquid-like inclusions quenched from melting curve during fast crystallization of the samples. It is also shown that the slower growth rate corresponds to smaller size of liquid-like droplets that results from lower spatially restricted values of $D$ and, finally, absence of these inclusions at the longest crystallization times. The diffusion coefficient measured for liquid-like droplets is also decreasing during the NMR experiment at constant temperature that indicates the size reducing of these droplets. Liquid-like droplets are shown to disappear after sample annealing nearby the melting curve.

11P-A004 Search for a disordered (glassy) phase in solid $^3$He


A disordered (glassy) state has been searched for in solid $^3$He deformed in the course of the experiment through precise measurements of pressure. The analysis of the temperature dependence of the crystal pressure measured at a constant volume shows that the main contribution to the pressure is made by the phonon subsystem, with the influence of the disordered phase being very weak. Annealing of the deformed crystal does not affect this state. The results obtained differ greatly from the corresponding data for solid $^4$He measured in the region of supersolid effects, where a pressure excessive in comparison with the phonon one was registered. The excess pressure had a quadratic dependence on temperature, which is typical of a disordered system. Absence of the distinct excess pressure in solid $^3$He is yet unclear; some speculative interpretations are suggested.
11P-A005 Supersolidity under AC and DC rotations
S. T. Chui, Bartol Research Institute and Dept. of Physics and Astronomy, University of Delaware, Newark, DE 19716

We have recently proposed an explanation of the supersolidity effect in terms of the Bose Einstein condensation of kinks of dislocations. In this talk we discuss our understanding of some current experimental results in our picture. Under an AC rotation field alone, a surprisingly low critical rotation velocity is observed experimentally. We estimate the critical velocity as one that can create a kink wave of wavevector of the order of $1/L$ where $L$ is the distance between nodes of the dislocation network. With no adjustable parameter, order of magnitude agreement with the experimental critical velocity is found. Recently several experimental groups have studied the supersolidity effect under both a steady and an oscillating rotation. We incorporate the effect of the DC rotation by calculating its effect on the phonon frequency and thus the kink wave. The effect of the DC rotation is found to be very different from the AC rotation.

11P-A006 Nuclear Spin Relaxation of Very Dilute $^3$He in Solid $^4$He
S. S. Kim, C. Huan, L. Yin, J. S. Xia, N. S. Sullivan, D. Candela, Department of Physics, University of Florida, USA

We report measurements of the nuclear spin-lattice and nuclear spin-spin relaxation times of very dilute $^3$He in solid $^4$He in the temperature range $0.01<T<0.5$ K, and for densities where anomalies have been observed in torsional oscillator and shear modulus measurements. We compare the results with the values of the relaxation times reported by other observers for higher concentrations and compare the results with the theory of Landesman that takes into account the elastic properties of the $^4$He lattice. For high concentrations, $x>50$ ppm, the $^3$He impurities are in a constant interaction regime because of the relatively long range of the elastic deformation surrounding each $^3$He impurity. For very dilute concentrations the $^3$He atoms are in a gas-like regime and the relaxation times are determined by the cross-section for their mutual scattering. A sharp increase in the magnitude of the nuclear spin-lattice relaxation times compared to the classical Landesman theory are observed close to the temperatures where the torsional and shear modulus anomalies are observed. The NMR results imply that an additional relaxation process occurs in series with the usual processes that is related to the observed change in the dissipation of the elastic modulus of the lattice.

11P-A007 Dislocation Model for the TO-Period Anomaly
I. Iwasa, Fuji Xerox Co., Ltd., Kanagawa, Japan

The anomaly of the torsional-oscillator (TO) period observed originally by Kim and Chan, i.e. the nonclassical rotational inertia (NCRI), has been ascribed to the supersolid transition of hcp $^4$He inside the TO. Day and Beamish has observed a similar anomaly in the shear modulus of solid helium, which can be well described by pinning of dislocations by $^3$He impurities. In order to explain both anomalies on the same basis, I have proposed a dislocation-vibration model for the NCRI. According to this model the period change is proportional to $\Lambda^2$, where $\Lambda$ is the dislocation density and $L$ is the temperature-dependent average pinning length. By modifying the model from a delta-function distribution function for the network pinning lengths to continuous distribution functions, such as an exponential one, the observed amplitude dependence and hysteresis of the TO period can be reproduced. Moreover, an actual distribution of the network pinning lengths is determined from the experimental data.

11P-A008 Two-dimensional hard-core bosons in the superfluid phase: Excitation spectra
K. A. Chishko, T. N. Antsygina, I. I. Poltavsky, M. I. Poltavskaya, Bartol Research Institute and Dept. of Physics, University of Delaware, Newark, DE 19716

The spectra of elementary excitations of the hard-core bosons on square and triangular lattices in the superfluid phase are investigated using the second order spin-wave theory. The nearest neighbor repulsion and next nearest neighbor interaction (repulsive or attractive) are taken into account. The behavior of the spectra along different directions in the Brillouin zone at fixed particle density is analyzed in detail at various relations between the parameters of the system. Particular attention is given to the spectrum minina with the aim to find out the conditions for instability of the superfluid phase. In the case of the triangular lattice with the next nearest neighbor repulsion and the known minima on the zone boundary, a true roton minimum inside the Brillouin zone is found. Expressions for the spin-wave velocity are obtained in an explicit form for both types of lattices. Account for the spin-wave interaction considerably improves the quantitative description of the excitation spectra. Our analytical results are in very good agreement with the corresponding data known from literature.

11P-A009 Quantized Vortex Physics in the hcp $^4$He, Studied by Torsional Oscillator with Detailed AC Velocity Dependence and Under DC Rotation
Minoru Kubota, Masahiko Yagi, Nobutaka Shimizu, Akira Kitamura, Institute for Solid State Physics, University of Tokyo, Kashiwa, Chiba277-8581, Japan

The anomaly of the torsional-oscillator (TO) period observed originally by Kim and Chan, i.e. the nonclassical rotational inertia (NCRI), has been ascribed to the supersolid transition of hcp $^4$He inside the TO. Day and Beamish has observed a similar anomaly in the shear modulus of solid helium, which can be well described by pinning of dislocations by $^3$He impurities. In order to explain both anomalies on the same basis, I have proposed a dislocation-vibration model for the NCRI. According to this model the period change is proportional to $\Lambda^2$, where $\Lambda$ is the dislocation density and $L$ is the temperature-dependent average pinning length. By modifying the model from a delta-function distribution function for the network pinning lengths to continuous distribution functions, such as an exponential one, the observed amplitude dependence and hysteresis of the TO period can be reproduced. Moreover, an actual distribution of the network pinning lengths is determined from the experimental data.

We describe the unique responses of the torsional oscillato(TO) containing hcp $^4$He starting below a unique onset temperature, $T_o$, by studying the AC velocity dependence below $T_o$[1], and discuss the appearance of the vortex fluid(VF) state[1, 2]. We found a unique $T_c$, well below $T_o$, below which hysteretic behavior appears when the AC drive level is changed below $T_c$[3]. In addition, we found an extra energy dissipation of the TO appears in proportion to the DC rotation speed only below the same $T_c$[4]. This is the evidence for quantized vortex lines penetration in the supersolid state under DC rotation which we have been searching for at $T << T_c$ [2, 5] as in an artificial 3D superfluid [6].


11P-A010 Formation of a Glassy Phase in Solid $^4$He: Comparison of Rapidly Quenched and Deformed Samples

A series of experiments has been performed to find out the conditions for the formation of a disordered (glassy) phase in quenched cooled crystals of solid helium and in crystals deformed in situ. In both cases there were found that aside from the usual phonon contribution there is an additional contribution $\sim T^2$ which is typical for a disordered (glassy) phase. It was found, that changing time of crystal growth from 1.5 min to 60 min does not influences significantly on the glassy contribution. In the deformed crystal a glassy phase appears if the deformation exceeds a critical value, above which the contribution of this phase enhances with increase of deformation degree. It has been shown that, in all crystals, disordered (glassy) phase practically disappears after annealing. For rapidly quenched crystals, during annealing, there was observed a huge drop of pressure turns into by a slow relaxation. However in deformed crystals, only a slow relaxation was observed.

11P-A011 Quantum Monte Carlo study of quantized vortices in two–dimensional solid Helium
L. Reatto*, D.E. Galli*, M. Rossi*, * Dipartimento di Fisica, Università degli Studi di Milano, Via Celoria 16, 20133 Milano, Italy

Quantum vortices have been invoked to explain some aspects of supersolidity in $^4$He but no microscopic study of such vortices has been published yet. A vortex state can be addressed by Quantum Monte Carlo using the fixed–phase approximation: for a given phase one is led to solve a ground state problem of a suitable inhomogeneous many–body system. We solve exactly this last problem by using the Shadow Path Integral Formal Supersolid State method. At the simplest level one can use the Onsager–Feynman (OF) phase and in this case the vortex acts as a static external potential. For solid $^4$He in two dimensions with the OF phase the vortex core is found to sit in an interstitial site and a very weak relaxation of the lattice positions away from the vortex core position has been observed. Also other properties like Bragg peaks in the static structure factor or the behavior of vacancies and dislocations are very little affected by the presence of the vortex. No evident spatial correlations among the vortex and the positions of the mobile defects has been observed. We have computed also the one-body density matrix in perfect and defected Helium crystals finding that the vortex has only a weak effect on the off–diagonal long range tail of the density matrix. These findings suggest that it is important to include backflow terms in the phase and work along these lines is under way.

11P-A012 Magnetic resonance study of H atoms in solid H$_2$ at temperatures below 1 K
J. Ahokas*, O. Vainio*, J. Järvinen*, V. V. Khmelenko*, D. M. Lee*, S. Vasiliev*, Dimitri Phys. Laboratory, Department of Physics and Astronomy, University of Turku, Turku, Finland, *B. Verkin Institute for Low Temperature Physics and Engineering of the National Academy of Sciences of Ukraine, Kharkov, Ukraine

We present our recent experiments with H atoms embedded in solid H$_2$ at temperatures below 1 K and discuss future experiments. Solid H$_2$ films were created by slow recombinaction of H atoms in the gas phase or by direct deposition from H$_2$ vapor. Atomic populations inside the H$_2$ films were created by running a pulsed low power r.f. discharge in the sample cell. We achieved record high H concentrations exceeding $3 \times 10^{19}$ cm$^{-3}$. The samples were characterized by means of magnetic resonance: electron spin resonance (ESR) and electron–nuclear double resonance (ENDOR) in a magnetic field of 4.6 T. We observed density dependent broadening and shifts of the ESR lines due to the dipolar interactions and found two narrow ENDOR transitions shifted to the red. The steady state hyperfine level populations of H were found to deviate substantially from Boltzmann statistics below 1 K. We plan to implement cold atom and molecule beam epitaxy to improve sample quality and to increase H density. Experiments with deuterium may reveal phenomena related to quantum statistics. We also plan to study quantum diffusion of the impurity atoms and to investigate possible supersolid–behaviour of the samples.


11P-A013 BCC vs. HCP - The Effect of Crystal Symmetry on the High Temperature Mobility of Solid $^4$He
A. Eyal*, E. Polturak*, *Physics Department, Technion, Haifa 32000, Israel
Torsional Oscillator (TO) experiments done on solid 4He show a partial mass decoupling. First reported by Kim and Chan\(^1\), and later confirmed by many others, these results are under a debate regarding their interpretation as a sign of supersolidity. We performed TO measurements on solid 4He at temperatures between 1.1K and 1.9K\(^2\), and observed large mass decoupling associated with the generation of disorder. If this decoupling is due to dislocation movement, then the mass decoupling would depend on the growth direction with respect to the plane of motion. This would give a mass decoupling which is different for the two crystal symmetries. Our results on the subject will be presented.


\(11P-A014\) Dynamics of one-dimensional supersolids

M. Kunimi\(^a\), M. Kobayashi\(^a\), Y. Kato\(^a\), \(\text{Department of Basic Science, The University of Tokyo, Japan}\)

Above the critical velocity, superfluidity breaks down and solitons or vortices are emitted periodically.\(^1,2\) The period of the solitons or vortices emission obeys a scaling law : \(T \propto |v - v_0|^{-0.5}\). Here, \(T\) is the period, \(v\) is the velocity, and \(v_0\) is the critical velocity. This scaling law is related to a saddle node bifurcation.\(^3,4\) In our previous work\(^5\), we showed that there exists the steady flow state of one-dimensional supersolids in the presence of an obstacle by using the Gross-Pitaevskii equation with a finite range two-body interaction. However, the dynamical properties of this system were not known well. We investigate the breakdown dynamics of one-dimensional supersolids above a critical velocity. We show that solitons are emitted periodically, as in the case of superfluids. Moreover, we find that the period of the solitons emission obeys a power law. We will discuss the difference between superfluids and supersolids from a viewpoint of the scaling properties.

\(11P-A015\) Migration of 3He Impurities along Dislocation Lines in 4He Single Crystals

X. Rojas\(^a\), A. Haziot\(^a\), S. Balibar\(^a\), \(\text{Laboratoire de Physique Statistique, Ecole Normale Supérieure, CNRS, Universités P.M. Curie and D. Diderot, 24 rue Lhomond, 75231 Paris Cedex 05, France}\)

We have studied acoustic resonances in 4He single crystals in the temperature region 20 < \(T\) < 300 mK where a large softening occurs due to the unbinding of dislocations from 3He impurities.\(^1\) Here we present an analysis of the dependence of resonance frequencies on the sound amplitude, that is on the acoustic stress in the crystal. Above a threshold of order 10\(^{-6}\) bar, this stress is able to unbind dislocations from impurities which may bind again after the stress is reduced below the threshold.

Our results indicate that, on a time scale of typically one hour, 3He impurities diffuse along dislocations at 60 mK but not at 25 mK. This work is supported by ERC Grant AdG247258-SUPERSOLID.

\(11P-A016\) Supersolidity in Solid 4He and the Shear Modulus Anomaly

Xiao Mi\(^a\), Erich Muller\(^a\), John Reppy\(^a\), \(\text{Laboratory of Atomic and Solid State Physics, Cornell University, Ithaca, NY 14853-2501, USA}\)

Recent years have seen the discovery of two new phenomena in the low temperature properties of solid 4He: first the discovery by Kim and Chan of evidence for supersolidity and second the observation by Day and Beamish of an unexpected anomaly in the shear modulus of the solid. A remarkable feature of these phenomena is the striking similarity in their temperature dependence as well as in a number of other properties such as sensitivity to 3He impurities and to the effects of disorder and annealing. In the work reported here, we attempt to separate and delineate the effect of these two phenomena on the low temperature behavior of torsional oscillators containing solid 4He samples. We have constructed double and triple compound torsional oscillators, operating at several different frequencies to take advantage of the fact that supersolidity phenomenon is believed to be relatively frequency independent, while the anomaly in the shear modulus should have to a well-defined frequency dependence. The key feature of our oscillator design has been to provide an internal moment of inertia that is primarily coupled by the shear modulus to the rest of the system and thus makes the oscillator modes sensitive to temperature variations in the shear modulus. The temperature dependence of the modes for our triple oscillator can be accounted for by the variation in the elastic properties of the solid, while supersolid mass decoupling makes a negligible contribution. The National Science Foundation through Grants DMR-096569 and Phy-0758104 has supported this work.

\(11P-A017\) Hysteresis Response of Torsional Oscillators Containing Solid 4He at Low Temperatures

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A characteristic but outstanding puzzling property of solid 4He contained in a torsional oscillators at very low temperatures is the history dependent response to changes in the oscillator drive level. Extensive measurements on hysteretic response of torsional oscillator containing solid 4He have been carried out by varying the oscillator drive level starting from high to low and then back up to the initial high value. Hysteresis in the oscillator response appeared only below an onset temperature (\(T_H\)) and disappeared above it. Studies by a compound oscillator showed that \(T_H\) did not depend on the oscillator frequency. Annealing of a sample surpris-
ingly increased its hysteresis response but did not alter its $T_H$. Dependence of $T_H$ was studied as $^3$He impurity concentration in the solid $^4$He samples was varied from $0.1\times10^{-9}$ to $25\times10^{-9}$. $T_H$ varied tantalizingly close to theoretical values for isotopic phase separation temperature of solid $^4$He-$^3$He mixtures.

11P-A018 Temperature Dependence of $^4$He Diffusion through Common Epoxies

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$^4$He gas at room temperature is known to leak through the epoxies commonly used in various low temperature apparatus, including sample cells, feed-throughs, etc. The helium flux typically decreases with decreasing temperature, but we are not aware of a previous study of the temperature dependence of this decrease. We have therefore measured the flux of $^4$He that passes through thin ($\approx 1$ mm thick) sections of as-cast clear Stycast 1266, black Stycast 2850FT and blue TRABOND epoxies as a function of temperature in the range $77K<T<300K$. We analyze the data to create normalized (to constant sample thickness) data for comparison. We will report these temperature dependencies, which show significant differences among the epoxies studied.

Partially supported by NSF DMR 08-55594

11P-A019 Quantum crystal induced by interparticle repulsive interaction

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Superfluid behavior in solid $^4$He has attracted the interest of both theoreticians and experimentalist. This counterintuitive behavior is observed only in solid $^4$He, which has the large quantum effect. Path Integral Monte Carlo (finite temperature method) and Diffusion Monte Carlo (zero temperature method) calculations have shown that the perfect commensurate $^4$He crystal has neither finite superfluid density nor condensation fraction. It may be premature to conclude that a perfect quantum crystal never exhibits superfluid behavior; the quantum fluctuations much stronger than those in $^4$He may favor superfluid behavior even in a solid phase. We study the quantum crystal phase with much stronger quantum fluctuations, using the DMC method. The strength of the quantum effect can be parametrized by the so-called quantum parameter, the ratio of the zero point energy to the interparticle attractive interaction energy. Here, we consider boson systems where only interparticle repulsive interaction works; the quantum parameter may be considered to be infinity. It has been known that quantum hard spheres$^1$ crystallize at much lower density than classical hard spheres$^2$. This result implies that the quantum effect can help crystalization of boson gas. In this work, we calculate the ground state energy of bosons interacting with hardcore-like potential and obtain the phase diagram describing the gas-solid phase transition.


11P-A020 Supersolid Measurements using a Two-Mode Torsional Oscillator

G. Nichols$, J. Saunders$, B. Cowan$, Milliken Laboratory, Royal Holloway University of London, Egham, Surrey, UK

The frequency-dependence of the response is vital for understanding the nature of the supersolidity observed in solid $^4$He. We have made measurements using an oscillator optimized for widely-spaced resonances, where the antisymmetric mode frequency is five times that of the symmetric mode. We report supersolid measurements using this oscillator. These are interpreted within the Nussinov-Balatsky formalism$^1$. We also compare and discuss other double-frequency measurements.


11P-A021 Extreme softness of crystallites in polycrystalline $^4$He.

A. Penzey$, E. Varoquaux$, Y. Mukharsky$, CEA-Saclay/DSM/IRAMIS/SPEC, 91191 Gif sur Yvette, Cedex, France.

We have measured the elastic moduli of solid $^4$He between $-40$mK and $\sim 1$K. The temperature dependence was traced both by measurements of the uniaxial modulus and of the acoustic resonance frequency. The measurements agree between themselves and demonstrate reduction of the shear modulus of a polycrystalline sample with increasing temperature down to $\sim 40$% of its value below $\sim 40$mK. When analyzed using recent results of numerical calculations by Maris and Balibar$^1$, this indicates that the shear modulus of individual crystallites decreases to $\sim 8$% lower than softening observed in an ultra-pure sample$^2$. 1. H. J. Maris, S. Balibar, J. of Low Temp. Phys. 160, 5 (2010). 2. X. Rojas, A. Haziot, V. Bapst, S. Balibar, H. J. Maris, Phys. Rev. Lett 105, 145302 (2010).

11P-A022 Absence of temperature dependence of the lattice constant of solid $^4$He.

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Classical explanation of supersolidity in solid helium is based on existence of vacancies, that are thought to persist down to the lowest temperatures. Most measurements indicate that vacancies should be frozen-out below $\sim 1$K and helium atoms should form a commensurate crystal. Following a preliminary experiment, we plan simultaneous high-precision measurements of the dielectric constant (easily translated into the density) and the lattice constant of helium crystal to test the commensurability of the solid. In the earlier measurements, however, we found that the temperature variation of the lattice constant, recorded from very low
temperatures up to 1.2 K, is much weaker than reported previously [1]. We plan to obtain new experimental data before the conference. 1. B. A. Fraass, P. R. Granfors and R. O. Simmons, Phys. Rev. B 39, 124 (1989).

11P-A023 Simultaneous Measurements of the Torsional Oscillator Anomaly and Thermal Conductivity in Solid 4He

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In these torsional oscillator experiments the samples of solid 4He were characterized by measuring their thermal conductivity. Polycrystalline samples of helium of either high isotopic purity or natural concentration of 4He were grown in an annular container by the blocked-capillary method and investigated before and after annealing. No correlation has been found between the magnitude of the low-temperature shift of the torsional oscillator frequency and the amount of crystalline defects as measured by the thermal conductivity. In samples with the natural 3He concentration a substantial excess thermal conductivity over the usual T^3 dependence was observed below 120 mK.

11P-A024 Boundary and Phonon-Dislocation Scattering in Thermal Conductivity of HCP 4He Crystals

A.A. Levcchenko*, L.P. Mezhov-Deglin*, aISSP RAS, Chernogolovka, Moscow region, 142432, Russia

Investigations of thermal conductivity of perfect hcp 4He crystals grown at different pressures from 25.5 to 185 atm (and different Debye temperatures Θ, accordingly) in long tubes with inner diameters D = 1-3 mm and subsequent computer simulations1 of the proper phonon mean free path L_M had demonstrated possibility of observation of the well pronounced Knudsen minimum on L_M(T) curves (with relative depth ∆L/L ≈ 0.15) placed at reduced temperatures T/Θ ≤ 0.02 in the region of transition from Poiseuille to Knudsen flow of phonon gas in crystal under the condition L_R ≫ L_N, L_R ≫ D, where L_R is the phonon path due to any resistive scattering in bulk, L_N – due to normal phonon phonon scattering, and D is the sample diameter. From further studies of thermal conductivity of weakly bent crystals and processes of recovery of the bent samples2 it followed that scattering of phonons on freshly introduced dislocations was up to 10^2 times higher than that predicted by the theory. It could be attributed either to the flutter effect or to scattering of phonons on high mobile kinks propagating along the dislocations as it was proposed recently3 for the inelastic electron-dislocation scattering in bent metal crystals.

3 L.P. Mezhov-Deglin, S.I. Mukhin, submitted to LTP.

11P-A026 Hysteresis of Non-Classic Rotational Inertia in 2D 4He Films on Graphite

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A 4He film on graphite is an interesting system in terms of a two-dimensional (2D) correlated Bose system. By torsional oscillator (TO) studies of the 4He bilayers, Crowell and Reppy observed novel mass decoupling in the vicinity of the second layer completion and disappearance of the decoupling just at the second layer completion1 They argued the decoupling was caused by non-classical rotational inertia (NCRI) of the bilayers, but the details have not yet been clarified. If 2D solid phase forms at the second layer completion, the NCRI is possibly due to a 2D solid doped with zero-point vacancies. This is interesting in the context of the supersolid state of solid 4He. In order to study the peculiar NCRI, we have studied 4He films on graphite by a TO

2 In this work, we report the hysteresis of the NCRI with TO velocity sweeps. A 18.39 atoms/nm^2 sample, which exhibited a finite NCRI below 300 mK, was kept at 65 mK after cooling down to 10 mK with no TO driving. And then the velocity sweeps were carried out up to 6000 μm/s. A finite hysteresis in the NCRI was observed below 1000 μm/s. The size was approximately 50% of the total NCRI. We will discuss the hysteresis and possible phase diagrams of the 4He films.


11P-A027 Onset Properties of Supersolid Helium

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Supersolid helium has a rather low transition temperature and a small critical velocity, compared with liquid helium. These properties could be explained in terms of helium’s spectrum structure and quantum jumps involving large momentum transfer. A grain in the solid helium possesses valleys (local minima) in its many-body dispersion curve (the lowest eigenenergies of the system as a function of given momenta), and an exchange of large momenta with the grain’s surroundings occurs in a jump between a level in one valley and another level in the neighboring valley. Such jump process also naturally causes dissipation accompanying the onset of supersolidity.

11P-A028 Rotation Measurement of Supersolid in Nanoporous Media

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After first discovery of supersolid1, a lot of efforts, both experimental and theoretical, have been devoted to uncover the nature of its ground state whether it is quantum nature or not. Recently, we have observed the suppression of the non-classical rotational inertia (NCRI) with increasing DC angular rotation velocity.2 One pos-
sible explanation of the result is that a new dissipation mechanism arises attributed to the quantized circulation under DC rotation. However, there might be some possible explanations for the result because of the motion of dislocation lines. The torsional oscillator measurement in nanoporous media under rotation allows us to elucidate this point further. Because the media is possible to pin the motion of the dislocation and affect the crystal defects and so on. In the present experiment, a torus-shaped Vycor glass with a pore size of \( \sim 6 \) nm is introduced into the torsional oscillator. We observe the suppression of the NCR with increasing DC rotation speed the same as the bulk case reported in ref.[2]. We will present and discuss the details of the experimental results.


11P-A029 Torsional oscillator studies of helium-4 single crystals

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We have studied the rotational inertia of \(^4\)He single crystals with the torsional oscillator (TO) method. The cell is a sapphire minibottle with a cylindrical shape, 20 mm tall and 11 mm on the inner diameter. Our results show that for single crystals grown at constant temperature and pressure from the superfluid liquid (natural purity), there is no measurable change in the TO resonance frequency between 10 and 600 mK that \( \sim \) 6 nm is introduced into the torsional oscillator. We observe the suppression of the NCR with increasing DC rotation speed the same as the bulk case reported in ref.[2]. We will present and discuss the details of the experimental results.


11P-A031 Interplay of Rotational, Relaxational, and Shear Dynamics of Solid \(^4\)He

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One explanation for the unusual rotational dynamics of solid \(^4\)He hypothesizes a classic supersolid, with the shift in torsional oscillator frequency \( \omega_0 \) upon increasing temperature and/or rim-velocity being due to the supersolid critical temperature \( T_c \) and velocity \( V_c \). A very different explanation postulates inertially-active crystal excitations whose smoothly diverging relaxation times \( \tau(T) \) generate the observed effects upon passing through the condition \( \omega_0 \tau = 1 \). To distinguish between them, we map solid \(^4\)He rotational and relaxation dynamics throughout the velocity-temperature plane and find them everywhere consistent with the \( \omega_0 \tau = 1 \) mechanism but with contributions from both thermally and mechanically stimulated excitations. Moreover we find that \( \tau \) diverges smoothly with no evidence for the sudden changes signifying the \( V_c \) or \( T_c \) of a supersolid phase transition. Finally, we show that the relative influence of \( T \) and \( V \) on the rotational inertia is identical to the relative influence of \( T \) and shear strain \( \varepsilon \) on the \(^4\)He shear modulus. This implies strongly that the rotational dynamics of solid \(^4\)He are due to the generation (presumably by inertial shear strain for which \( \varepsilon \propto V \)) of the same type of microscopic excitations that are generated by direct shear strain.

11P-B001 Voltage-current characteristic and transport current AC losses measured by the transformer method in high pressure synthesized MgB2 bulk cylinders

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The recently developed manufacturing technologies use high pressure and various doping additions to prepare bulk MgB2-based materials with high critical current density. To measure voltage-current characteristic and AC losses in these samples, a contactless method is applied which is based on the use of the transformer configuration. A MgB2 hollow cylinder forms the secondary coil of a transformer in which the primary coil is connected with an AC source. Using Hall-probe technique, the magnetic flux density along the cylinder axis was measured as a function of the instantaneous current in the primary coil with following calculation of the electric field and AC losses in the superconductor. The obtained dependence of the losses on the primary current (applied magnetic field) and frequency reveal the sufficient deviations from Bean’s model. The character of these deviations is discussed. The obtained results are compared with those revealed from magnetization experiments.

11P-B002 Interpretation of optical conductivity in normal state of Iron-Based Superconductors CeOFeAs

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Quantitative analysis of the optical conductivity (σ) for the normal state of Iron-Based superconductors CeOFeAs have been made within the two-component scheme: one is the coherent Drude free carrier excitations and other is incoherent motion of carriers leading to a polaron formation, originated from inter and intra layer transitions of charge carriers. The model successfully accounts for the anomalies reported in the optical measurements for metallic state of the superconductors. The frequency dependent relaxation rates are expressed in terms of memory functions and the coherent Drude carriers from the effective interaction potential leads to a sharp peak at zero frequency which is an indication of metallic conduction and a long tail at higher frequencies, i.e. in the infrared region. While to that the hopping of carriers from Fe to Fe in the FeAs layer and from FeAs layer to CeO layer (incoherent motion of carriers) yields two-peak value around 100 cm\(^{-1}\) and 425 cm\(^{-1}\) respectively in the optical conductivity centred at mid-infrared region. Both the Drude and hopping carriers contribute to the optical process of conduction in the iron-based superconductors and shows similar results on optical conductivity in the mid-infrared as well as infrared frequency regions as those revealed from experiments.

11P-B003 Analysis of heat transport in the of iron oxyarsenide TlFeAsO\(_{0.85}\)

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The electronic contribution to the thermal conductivity (\(\kappa_e\)) is estimated following Wiedemann-Franz law. The lattice contribution to the thermal conductivity (\(\kappa_p\)) is discussed within the Debye-type relaxation rate approximation in terms of the acoustic phonon frequency and relaxation time. The theory is formulated when heat transfer is limited by the scattering of phonons from defects, grain boundaries, charge carriers, and phonons. The lattice thermal conductivity dominates in TlFeAsO\(_{0.85}\) and is an artifact of strong phonon-impurity and -phonon scattering mechanism. Our result indicates that the maximum contribution comes from phonon-scatters and various thermal scattering mechanisms provide a reasonable explanation for maximum appeared in \(\kappa(T)\).

11P-B004 Superconductivity in a topological Insulator doped with Pd and H

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The topological Insulator Bi\(_2\)Te\(_3\) was doped with different amounts of high purity Pd. Superconductivity was observed with a transition temperature about 4 K. After injecting Hydrogen, we observed an addition increment of the amount of diamagnetic phase. In this presentation we will show our experimental findings and we will comment about the possible superconducting pairing mechanisms.

11P-B005 New Iron-based Perovskite-type Superconductors of (Ca\(_4\)Al\(_2\)O\(_{6−y}\))(Fe\(_2\)Pn\(_2\)) and (Ca\(_3\)Al\(_2\)O\(_{5−y}\))(Fe\(_2\)Pn\(_2\)) (\(Pn = As, P\))


Perovskite-type blocking layered iron based superconductors are one of the challenging candidates for new materials searching owing to two dimensionality in crystal structure, chemical and structural flexibility with maximum \(T_c\) reaching to 47 K. Here we demonstrate the discoveries of the (Ca\(_4\)Al\(_2\)O\(_{6−y}\))(Fe\(_2\)Pn\(_2\))(Al-42622(\(Pn\)) and (Ca\(_3\)Al\(_2\)O\(_{5−y}\))(Fe\(_2\)Pn\(_2\)) Al-32522(\(Pn\)) (\(Pn = As, P\)), synthesized by high pressure technique. Al-42622(\(Pn\)) exhibits superconductivity for both \(Pn = As, P\) with the transition temperatures of 28.3 K and 17.1K, respectively. The a-lattice constants of Al-42622(\(Pn\)) (\(a = 3.713\)Å and 3.692Å for \(Pn = As\) and \(P\)), respectively are smallest among the iron-pnictide superconductors, consequently has the smallest As-Fe-As bond angle (102.1°). Al-32522(\(Pn\)) is the first and the unique superconductors comprised of the perovskite-
based “32522” structure ever reported. Their transition temperatures ($T_c$) are 30.2 K ($Pn = As$) and 16.6 K ($Pn = P$), respectively. Emergence of the superconductivity is ascribed to their small tetragonal $a$-axis lattice constants. We demonstrate the valid existence of the strong correlation between the crystal structure and $T_c$, the more details on these discovering will be discussed in this conference.

11P-B006 Electrical transport properties of clean and pinning-improved Codoped Ba-122 thin films on single-crystal and technical substrates


High-quality thin films of Ba(Fe$_{0.3}$Co$_{0.2}$)$_2$As$_2$ (Ba-122) are deposited by pulsed laser deposition from stoichiometric targets under UHV conditions (base pressure $10^{-9}$ mbar). At the interface between oxide substrates and the film, a natural and highly coherent Fe interfacial layer of a few nm thickness is often observed. Introducing artificial thin Fe buffer layers, which improve the structural film quality dramatically, we gain more freedom in the type of substrate. Recently, we showed for the first time Ba-122 films on IBAD-MgO covered flexible metal tapes and on piezo-electric PMN-PT. Angular dependent electrical transport properties ($J_c(T, B, \theta), R(T, B, \theta)$) of Ba-122 films on a variety of substrates are shown and discussed within the framework of Anisotropic Ginzburg-Landau Scaling and Vortex Path Model. The $J_c$ scaling approach on clean films reveals the temperature dependence of the effective mass anisotropy $\gamma$. The contribution of $c$-axis correlated defects to the $J_c$ anisotropy is analysed with the Vortex Path Model. On IBAD-MgO tapes with an in-plane FWHM of 1.7$^\circ$, $J_c$ values comparable to films on single-crystal MgO were achieved ($J_c \geq 1$ MA/cm$^2$ at 4 K, 0 T). $J_c$ is limited by intra-grain pinning rather than the grain boundaries in these films.

11P-B007 Study of superconductivity in a single crystal of noncentrosymmetric $\alpha$-BiPd

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Ever since the discovery of the non-centrosymmetric heavy fermion superconductor CePt$_3$Si [E. Bauer et al, Phys. Rev. Lett. 92, 027003 (2004)], there is widespread research activity to understand the nature of superconductivity in such unconventional superconductors. The term "non-centrosymmetric" characterizes the symmetry of a crystal lattice without inversion center. Study of superconductivity in non-centrosymmetric materials which do not exhibit heavy fermion features is also important since it avoids additional complication that arises due strong $e$-electron correlations. We report the bulk superconductivity of a high quality sample of monoclinic BiPd ($\alpha$-BiPd, space group $P2_1$) below 3.8 K by studying its electrical resistance, magnetic susceptibility and heat capacity. We establish that it is a clean type-II superconductor with a moderate value of electron-phonon coupling constant and determine its superconducting and normal state parameters. Although $\alpha$-BiPd is a noncentrosymmetric superconductor with large electronic heat capacity (therefore, large $\gamma$), the effect of spin-orbit splitting of the electronic bands at the Fermi level is small. This makes a very small influence on the superconducting properties of $\alpha$-BiPd.

11P-B008 Quantum Criticality and Superconductivity in SmFe$_{(1-x)}$Co$_x$AsO

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One of the iron pnictide superconductors, SmFe$_{(1-x)}$Co$_x$AsO shows a domelike $T_C$ curve against Co concentration $x$. The parent compound SmFeAsO shows the crystal structure transition and an antiferromagnetic (AFM) ordering. With increasing $x$, the structural transition temperature $T_D$ and AFM $T_N$ decrease and reach 0 K at the critical concentration $x_C$. It is not so clear that the critical concentrations for $T_D$ and for $T_N$ coincide to each other or not. In our present report we investigated the structural transition by the low temperature x-ray diffraction and the AFM ordering and the superconductive transition by measuring magnetization using the SQUID magnetometer, MPMS. We determined the phase diagram of $T_D$, $T_N$ and the superconductive transition temperature $T_C$ against the Co concentration $x$ near the critical concentration $x_C$ precisely. We found that the maximum of $T_C$ in domelike shape locates near the critical concentration $x_C$, suggesting the QCP. We will also discuss the quantum fluctuation of the structure change.

11P-B009 Vortex Phase Diagram of PrFeAsO$_{0.60}$F$_{0.12}$ Superconductor

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We have measured the resistivity and magnetization of the PrFeAsO$_{0.60}$F$_{0.12}$ polycrystalline sample as functions of temperature and magnetic field ($H$) in the normal and superconducting state. The superconducting onset transition temperature $T_{on}$ is determined from resistivity shifts by $\sim 4$ K as $H$ is increased from 0 to 14 T. The zero-temperature upper critical field $H_{c2}(0)$ estimated by using the Ginzburg-Landau theory and the Werthamer-Helfand-Hohenberg equation exceeds 100 T. The resistivity below $T_{on}$ exhibits Arrhenius behavior due to thermally activated flux flow of vortices. The activation energy $U_0$, determined from the Arrhenius plot of the resistivity, shows a power-law decrease ($U_0 \propto H^\alpha$) with magnetic field. The observed total magnetization is the sum of a superconducting
irreversible magnetization and a paramagnetic magnetization. Analysis of dc susceptibility $\chi(T)$ in the normal state shows that the paramagnetic component of magnetization comes from the Pr$^{3+}$ magnetic moments. The intragrain critical current density ($J_c$) derived from the magnetization data is large. The $J_c(H)$ curve displays a second peak which shifts towards the high-field region with decreasing temperature. In the low-field region, a plateau up to a field $H^*$ followed by a power law $H^{5/8}$ behavior of $J_c(H)$ is the characteristic of the strong pinning. A vortex phase diagram for the present superconductor has been obtained from the magnetization and resistivity data.

**11P-B010** Characteristics of $T_c$ and $\rho(T)$ of polycrystalline (In$_2$O$_3$)-(ZnO) films with low carrier density

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For the polycrystalline (In$_2$O$_3$)$_{1-x}$(ZnO)$_x$ prepared by annealing in air, we have investigated the relation among superconductivity, $\rho(T)$ characteristics and preparation conditions. To study the distribution of elements, we have investigated the microstructure by scanning transmission electron microscopy (STEM) and electron energy-loss spectroscopy (EELS). It has been found that 1) the films annealed at restricted region of annealing temperature $T_a$ and for time $t_a$ show the superconductivity. Superconducting transition temperature $T_c$ and the carrier density $n$ are $T_c < 3.3$ K and $n \approx 10^{25}/m^3 \sim 10^{26}/m^3$, respectively. 2) Although data in the $T_c$-$T_a$ relation are scattered depending on $t_a$, the $T_c$ shows relatively good correlation with $n$ and $T_c$, taking a convex form. 3) The data on EELS spectra mapping of indium plasmon indicate that droplets of the pure indium phase exist on grain boundaries and near the interface between the film and the glass substrate. However, it seems that these droplets do not form an electrical conducting path from the dispersed distribution of droplets in STEM-EELS spectra mapping.

**11P-B011** Electronic properties across the first-order phase transition in Fe$_{1.05}$Te

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We present here resistivity, magnetization, specific heat, scanning tunneling microscopy, and spectroscopy (STM/S) studies on Fe$_{1.05}$Te single crystals grown by a horizontal Bridgman method. In this compound, the superconductivity appears upon Se substitution and the physical properties are found to be extremely sensitive to non-stoichiometry and disorder [1]. In our crystals, a first-order phase transition is observed around 57 K in the resistivity, magnetization and the specific heat measurements. This transition is associated with a structural change from the tetragonal P4/mmm to the monoclinic P 2$_1$/c space group. At this temperature, the compound becomes antiferromagnetic and the temperature dependence of the resistivity changes from log (-T) to T$^2$. This observation suggests that the material becomes a Fermi-liquid metal at low temperatures. Metallic behavior is also confirmed in the I-V characteristics of the STM measurements taken on an atomically resolved surface.


**11P-B012** Spin-wave excitations and Fermi surfaces of iron-pnictide superconductors from the local magnetic moment limit

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Reasonably good agreement with experimental results for the magnetic response and the spectral function are obtained considering that the iron pnictide parent compounds are hole-doped Mott insulators in the vicinity of a quantum critical point separating a hidden ferromagnet from a commensurate spin-density-wave phase. The Fermi surfaces, spectral function and magnetic response are obtained in the framework of a t-J model with 2 Fe orbitals per lattice site, where intra-orbital hopping of the holes, but no inter-orbital hopping, is allowed. Using Schwinger-boson-slave-fermion meanfield theory and Lanczos exact diagonalization to obtain the energy spectrum of one hole, hole-pockets near the Γ-point are found. The incoherent part of the spectral function is also shown to exhibit features with mixed hole and electron character near $k = (\pi, 0)$, in agreement with experimental results from ARPES. The spectral weight of the spin-waves is vanishingly small at small momenta, in agreement with experimental results for the magnetic response, as observed through inelastic neutron scattering.

**11P-B013** Superconducting and structural properties of pure FeTe$_{1-x}$Se$_x$ (0.3 < $x$ < 0.5) and Co, Ni, and Cu substituted Fe$_{1+\delta}$Te$_{0.65}$Se$_{0.35}$ single crystals

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The superconducting single crystals of FeTe$_{1-x}$Se$_x$ (0.3 < $x$ < 0.5) and Fe$_{1+\delta}$Te$_{0.65}$Se$_{0.35}$ ($\delta \approx 0$) doped with Co, Ni or Cu have been grown applying Bridgman’s method. Obtained crystals of the highest crystallographic quality exhibit cleavage plane (001) and

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11P-B016 (Eu$_4$Sc$_2$O$_{5-y}$)(Fe$_2$Pn$_2$) (Pn = As, P): new possible iron oxynitrides for superconductors
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Iron-based compounds including perovskite-type blocking layers are one of the challenging candidates for new superconductors owing to their rich structural and chemical variations. Here we report the synthesis and physical properties of (Eu$_4$Sc$_2$O$_{5-y}$)(Fe$_2$Pn$_2$) (Pn = As, P) abbreviated to Eu$_4$Sc$_2$O$_{5-y}$Fe$_2$Pn$_2$ as new possible iron oxynitrides for superconductors. Nearly single-phase samples were synthesized under a pressure of 2 GPa. Lattice parameters of the samples are $a = 4.059$ Å, $c = 26.39$ Å for Pn = As and $a = 4.019$ Å, $c = 25.77$ Å for Pn = P. Both samples do not show superconductivity probably due to their long $a$-axis lengths and/or magnetism caused by Eu$^{3+}$. Now we are controlling the lattice parameters and magnetism by changing chemical compositions in the samples to induce superconductivity.

11P-B017 Tunnel Spectroscopy and Microstructure on Bi$_2$Sr$_2$Ca$_{1-x}$Y$_x$Cu$_2$O$_{8+y}$ Crystals
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Although various subjects of the superconductor-insulator transition (SIT) have been studied more than 20 years old, there are many open questions. We reported that the relation between microscopic structure and transport properties for Bi$_2$Sr$_2$Ca$_{1-x}$Y$_x$Cu$_2$O$_{8+y}$ (Y-Bi2212) crystals. There is the theoretical estimate that the electrons form Cooper pairs even in the insulating state. In this study we report tunneling experiments on Y-Bi2212 crystals and experimental results are discussed with microscopic structures. Y-Bi2212 crystals were grown using a Bi$_2$O$_3$-excess self-flux method. Tunneling spectra were measured for Y-Bi2212 crystal-SiO$_2$-Ag planar junctions. The ratios $x$ of [Y]/[Y+Ca] of the nominal composition on Y-Bi2212 crystals used for measurements were 0, 0.01, 0.05, 0.1, 0.11 and 0.12. Note that the measured Y content is

larger than the nominal one. For superconducting samples the V-shaped gap structure and zero bias conductance peaks (ZBCP) were observed. While, neither superconducting gap nor ZBCP was observed for insulating samples. These results suggest that Cooper pairs break up on the insulating side of SIT. In our spectra there were also several characteristic behaviors. They may be related to inhomogeneous structures because the inhomogeneous distribution of Y was found by using a scanning transmission electron microscope in our previous work.\textsuperscript{2}

\textsuperscript{1} A.M. Goldman, Int. J. Mod. Phys. B 24, 4081 (2010).
\textsuperscript{2} S. Komaki et al., J. Phys.:Conferences Series 150, 052117 (2009).

11P-B018 \hspace{1cm} POINT-CONTACT CONDUCTANCE OF THE NS HYBRID SYSTEM MO(N)/MO-C(S)

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Studies of the physical phenomena underlying the process flow of the stream of charges through interfaces heterosystems, always relevant, since the uncertainty of characteristics of interfaces such as quality and geometry, suggests a large variety of scenarios of the electron scattering at the interfaces. This is especially as for interfaces at the contacts of normal metals (N), including magnetic, with superconductors (S), the study of scattering mechanisms which are currently stimulated, in particular, the advent of new superconductors based on multicomponent systems with complex mechanisms of electron correlation.

This report presents the results of a study of the conductance of normal-metal point contacts with unconventional superconductors - carbizided molybdenum Mo-C. Shown that the maximum in the curve of the normalized conductance vs. the bias that occurs with increasing the latter from zero value, indicates the presence of a mechanism for increasing the cross section of scattering by impurities in Andreev retroreflection, and a decrease of conductance with a further increase of the bias - the contribution of the charge imbalance in the increase of the boundary resistance terms of spatial dispersion of the order parameter on the side of the superconductor near the NS interface.

11P-B019 \hspace{1cm} \textsuperscript{23}Al- and \textsuperscript{95}Mo-NMR Study on Noncentrosymmetric Superconductor Mo\textsubscript{3}Al\textsubscript{2}C

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Superconductivity on a crystal without inversion center is of great interest as the absence of parity can induce a novel superconducting (SC) pairing state. The first discovered noncentrosymmetric superconductor (NCS) CePt\textsubscript{3}Si undergoes a magnetic transition at $T_N \approx 2.2$ K before the SC transition at $T_c \approx 0.75$ K. The strong electron-electron interactions complicate the electronic states where superconductivity appears.\textsuperscript{3} A weakly-correlated NCS, Li$_2$Pt$_3$B then has been investigated to extract a purely crystal-structure involved effect on superconducting pairs. In another weakly-correlated NCS Mo$_3$Al$_2$C with $T_c \approx 9$ K, a power law temperature dependence of specific heat was clearly observed in the SC state.\textsuperscript{2}\textsuperscript{3} Rather high $T_c$ of Mo$_3$Al$_2$C allows us to study the SC state using various experimental techniques. We have performed \textsuperscript{23}Al- and \textsuperscript{95}Mo-NMR experiments on Mo$_3$Al$_2$C to explore both the normal and SC state. Exotic SC properties of this compound will be discussed on the basis of the results at low temperatures.\textsuperscript{1}


11P-B020 \hspace{1cm} NMR Study of Layered Transition Metal Ditelluride (Ir,Pt)Te$_2$

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Layered transition metal dichalcogenide IrTe$_2$ shows the anomalous behavior with a hysteresis in temperature around 270 K in electrical and magnetic properties, originating from a structure deformation.\textsuperscript{1} The NMR measurement suggests that a simple metallic state realizes in both high- and low- temperature region and the density of states at Fermi surface $N(E_F)$ is reduced below the transition temperature.\textsuperscript{1} In contrast, PtTe$_2$ with the same CdI$_2$ structure type shows no anomaly. Quite recently, it is reported that the superconductivity exhibits in Ir$_{1-x}$Pt$_x$Te$_2$ with the maximum of $T_c = 3.1$ K for $x = 0.04$.\textsuperscript{3} Thus, further studies are necessary to clarify the microscopic electronic states related with the superconductivity. It is quite helpful to make use of the NMR method for a study of local electronic properties. In this presentation, we present the \textsuperscript{125}Te and \textsuperscript{195}Pt NMR results of (Ir,Pt)Te$_2$ and discuss about them at the conference.

\textsuperscript{1} N. Matsumoto et al., J. Low Temp. Phys. 117, 1129 (1999).
\textsuperscript{2} K. Mizuno et al., Physica B 312-313, 818 (2002).
\textsuperscript{3} S. Pyon et al., presented at International Workshop on Novel Superconductors and Super Materials 2011 (NS²2011).

11P-B021 \hspace{1cm} Angular Resolved Photoemission Spectroscopy Study on Layered Pnictide-oxide BaTi$_2$As$_2$O

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The electronic structure of a new layered pnictide-oxide, BaTi$_2$As$_2$O, has been studied by angular resolved photoemission spectroscopy. Clear band structure and kz dependence is revealed. Detailed temperature dependence measurements have been conducted around 200K, at which temperature the transport measurements show a SDW/structural like transition that
behaves similarly to those observed in parent compounds of high-Tc iron-based pnictide superconductors.

11P-B022 Angular Resolved Photoemission Spectroscopy Study on Layered Pnictide-oxide BaTi2As2O
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The electronic structure of a new layered pnictide-oxide, BaTi2As2O, has been studied by angular resolved photoemission spectroscopy. Clear band structure and kz dependence is revealed. Detailed temperature dependence measurements have been conducted around 200K, at which temperature the transport measurements show a SDW/structural like transition that behaves similarly to those observed in parent compounds of high-Tc iron-based pnictide superconductors.

11P-B023 Growth, structure and some superconducting properties of FeSe crystals
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Superconducting FeSe crystals were grown from KCl solution-melt. Phase and element composition was invigilated. X-ray diffraction analysis revealed that the obtained crystals always contain a hexagonal phase in addition to tetragonal one. It was observed via measurement of resistivity and magnetic susceptibility that the crystals have a high volume of superconducting region.

11P-B024 Fermi Surfaces of the Iron-Pnictides LaFe2P2 and CeFe2P2
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We report on a comprehensive study of the Fermi surfaces (FS) of the iron-pnictide compounds LaFe2P2 and CeFe2P2 by use of de Haas-van Alphen (dHvA) experiments and band-structure calculations. The dHvA data were gained using a capacitive torque cantilever in fields up to 18 T in Dresden and up to 32 T in Grenoble. The band-structure calculations were done fully relativistically in the framework of density-functional theory. For LaFe2P2 we find strongly corrugated quasi-two-dimensional (2D) FS sheets in addition to three-dimensional bands. The calculations can nicely explain most of the observed dHvA frequencies. For CeFe2P2 we find a much richer dHvA frequency spectrum with no 2D bands indicating that the Ce 4f electrons are of importance for the electronic band structure.

11P-B025 Critical currents anisotropy in REFeAsO1−xFx (RE = Sm, Nd) single crystals
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High values and relatively low anisotropy of the upper critical field of FeAs-based superconductors revived hopes for large scale applications. An important question arises if the pinning properties of these compounds provide satisfactory high and isotropic critical currents at high magnetic fields. We focus on the critical currents and their anisotropy for the REFeAsO1−xFx single crystals (RE111, RE = Sm, Nd) in high magnetic fields (up to 14 T). The highest magnetically measured jc > 10⁴ A/cm² (T ~ 5 K, B ~ 14 T) has been determined for a Sm111 crystal with Tc ≈ 46 K, which shows slightly lower Bc2(T) if compare to the Sm111 crystals with higher Tc and to the Nd111 crystal. The jc anisotropy, γ = jcb/jca ≈ 2, is surprisingly low and almost field independent at low temperatures. These results agree well with those obtained by transport measurements.1 The pinning force for B||c has been analyzed by a scaling procedure using Dew-Hughes’ approach, which clearly shows pinning centres of only one type to be dominant at higher fields and temperatures. Our detailed studies of the superconducting magnetic and transport properties of the RE111 single crystals reveal a promising combination of high and nearly isotropic intragrain critical current densities.  

11P-B026 Superconducting Properties of Boron-doped Eu-123 HTSs
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Nominally pure and B2O3-added Eu-123 HTSs with nominal composition EuBa2Cu3BOxy (x=0, 0.03 and 0.05) were prepared by the solid state reaction method. The influence of boron-doping was studied using X-ray diffraction (XRD), resistivity and AC susceptibility measurements. Only reflection peaks corresponding to orthorhombic structure of Eu-123 phase were observed in the XRD patterns for both pure and B-doped samples. For the undoped specimen zero resistivity is reached at Tc=91K. Critical temperature gradually decreases with increasing a doping level and drops to 85K at x=0.05. The measurements of the real and imaginary parts of AC susceptibility indicate that boron-doping leads to the decrease of critical temperature and marked deterioration of connectivity between the superconducting grains. Acknowledgement:
This work has been fulfilled by financial support of the Shota Rustaveli National Science Foundation (Grant GNSF/ST09-844-7-121).

11P-B027 Phase Evolution and Superconducting Properties of Boron-doped (Bi,Pb)-2223 HTSs

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Two series of the nominally pure (control) and boron-doped (Bi,Pb)-2223 HTSs with nominal composition Bi1.7Pb0.3Ca2Sr2Cu3BxOy (x=0, 0.05, 0.5, 1.5) were prepared under the different conditions: in an alumina crucibles and on an alumina plates. The influence of boron-doping as well as annealing conditions on the high-Tc 2223 phase evolution was studied using X-ray diffraction (XRD), resistivity and AC susceptibility measurements. Obtained results indicate that boron dopant drastically accelerates the formation of (Bi,Pb)-2223 HTS synthesized in alumina crucibles. The boron-doped sample with x=0.5 revealed significant improvement in the zero resistivity temperature compared to the control sample (from 72K up to 100K). On the other hand, the additives of boron (x=0.05 and 0.5) have shown to have a beneficial effect on the formation of (Bi,Pb)-2223 HTSs prepared by the heat treatment of Bi1.7Pb0.3Ca2Sr2Cu3BxOy precursors on alumina plates, although do not essentially affect the critical temperature $T_c$(zero)=102 K of nominally pure compound. Acknowledgement: This work has been fulfilled by financial support of the Shota Rustaveli National Science Foundation (Grant GNSF/ST09-844-7-121).

11P-B028 Doping and substitutions in LnFeAsO single crystals grown at high pressure: influence on superconducting properties and structure

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An overview of the basic superconducting properties measured on single crystals of LnFeAsO (Ln = La, Pr, Nd, Sm, Gd) will be presented. LnFeAsO single crystals were grown from NaCl/KCl and NaAs/KAs fluxes at high-pressure of 30 kbar. Application of NaAs flux let to mm size of LnFeAsO crystals. Superconductivity was induced by partial substitution of O by F, Sm by Th, Fe by Co, As by P and by oxygen vacancies. By comparing our experimental data for (Sm,Th)FeAsO, SmFeAs(O,F) and SmFeAs(P)O it was found that the pnictogene height is a key factor that determines the superconducting critical temperature. In all superconducting samples after doping the charge-reservoir SmO layer moves closer to the superconducting FeAs layer which facilitates electron transfer. In SmFe(As,P)O samples superconductivity appears only after high pressure treatment which generates oxygen deficiency and induces electron doping. SmFe(As,P)O samples without O deficiencies are non-superconducting however spin density wave is suppressed. The magnetic and transport properties studies of SmFeAs(O,F) single crystals reveals a promising combination of high and nearly isotropic critical current densities exceeding $10^6$ A/cm\textsuperscript{2}.\textsuperscript{1}


11P-B029 High-pressure studies for hydrogen substituted CaFeAsF_{1−x}H\textsubscript{x}

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High-pressure electrical resistivity measurements have been carried out for CaFeAs$_{1−x}$H$_x$, which has been successfully synthesized very recently.\textsuperscript{1} Hydrogen atoms are incorporated as H$^-$ ions at the F$^-$ sites. In case of CaFeAsF superconductivity appears with Co substitution into Fe, which is considered to be an electron doping. In CaFeAs$_{1−x}$H$_x$, superconductivity does not appear with H substitution, because the isovalent substitution does not affect largely the electronic state. On the other hand, pressure-induced superconductivity appears at 28 K at 5 GPa\textsuperscript{2} for CaFeAsF. In this study superconducting properties for H substituted materials were investigated from the high-pressure electrical resistivity measurements. For CaFeAsH the pressure-induced superconductivity was confirmed at 28 K at 3 GPa, which is a little smaller than the case of CaFeAsF. High-pressure x-ray diffraction is now in progress to decide the crystal structure under high pressure.\textsuperscript{1,2} T. Hanna et al., arXiv :1103.1177.\textsuperscript{2} H. Okada et al., Phys.Rev. B81, (2010) 054507.

11P-B030 High-pressure crystal growth of LnFeAsO (Ln=rare earth)

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Further progress in understanding the nature of superconductivity in the Fe-based compounds depends crucially on the availability sufficiently large single crystals of high-quality. Till now, crystal growth of LnFeAsO oxypnictides (Ln-1111 with Ln=rare earth) has proven to be a difficult task. We adopted the high pressure method and carried out a systematic investigation of the parameters controlling the growth of crystals, including the thermodynamic variables (T, P), reagent composition and kinetic factors, such as reaction time and cooling rate. NaCl/KCl, NaAs, and KAs fluxes were used to grow Ln-1111 crystals at a pressure of 30 kbar. From NaCl/KCl flux, crystals with linear sizes up to 300 $\mu$m were reproducibly obtained. The reaction time was one of the key parameter that influences the crystal size. Millimeter-sized superconducting Nd-1111
and Sm-1111 single crystals were successfully grown from NaAs and KAs fluxes. This crystal growth starts with a 2 h dwell at 1450 °C, followed by a slow cooling (4-5 °C/h) to 1150 °C, and a final to room temperature within 2 h. The size of Ln-1111 crystals suggests that liquid NaAs or KAAs are sufficiently effective solvents, and allow oxygen to diffuse at high temperatures. In addition to substituting F for O, superconductivity has also been induced by substituting Th for Sm, Co for Fe, and P for As. Studies of the crystal structure confirmed high structural quality, and show modifications due to substitutions, which are linked to superconducting properties. The magnetic and transport properties of Ln-1111 crystals are compared with other Fe-based pnictides.

11P-B031 Probing the local properties of superconducting silicon

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Heavily boron doped silicon epilayers prepared by gas immersion laser doping lead to a superconducting state at low temperature. With a milliKelvin scanning tunneling microscope, we have performed density of states spectroscopy showing locally the conventional (BCS) nature of the superconductivity in silicon. The observed variation on a nanometer scale of the superconducting energy gap value can be related to the distribution of boron atoms resolved by atom probe tomography. Since the latter technique gives an accurate three-dimensional spatial chemical composition of the superconducting silicon material, we also succeed to show that the boron atoms incorporated well above their solubility limit are still randomly distributed into the silicon lattice, without forming any cluster or precipitate.

11P-B033 STM/STS Observation on Layered Nitride Superconductor α-(H2N-((CH2)10-NH2)2)TiNCl

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Layered nitride MNC (M=Ti, Zr, Hf) becomes superconducting with its Tc’s up to as high as 25.5 K. This can be attained by electron doping to MN double layers through the intercalation of alkali-metals and/or inorganic molecules. Generally, the Tc of such a compound is known to proportional to the interlayer spacing, which is expanded by the intercalated molecules. However, very recently, the interesting properties were discovered, namely, linear-alkyldiamine intercalated compounds α-(H2N-((CH2)10-NH2)2)TiNCl show non-monotonic change of the Tc (i.e. higher Tc with even number of n) without any remarkable change of the interlayer spacing. Here, to investigate this interesting phenomenon, we present the scanning tunneling microscopy and spectroscopy (STM/STS) on one kind of these compounds α-(H2N-((CH2)10-NH2)2)TiNCl (n=10, Tc=16 K). The STM/STS measurements were carried out at T=5 K and P ~ 10^-8 Pa. STM topographies show simple rectangular shaped atomic lattice with the periods of [a]=0.38 nm and [b]=0.33 nm. In spite of the capturing the surface atomic arrangements, the location of the intercalated molecules is not yet identified by our STM observation. The STS results show the averaged gap value of Δ ≃ 10 meV, showing an unusually large gap ratio 2Δ/kBTc ≃ 15. Nevertheless, this value is a common to the one observed before in the α-KyTiNCl and β-HfNCl2 compounds.

11P-B034 Pressure tuning of superconductivity of A3Fe2-ySe2 (A=K and Rb) single crystals

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The recent discovery of superconductivity in K0.8Fe2Se2 with high transition temperature above 30 K has generated considerable interest not only since its Tc is almost ten times higher than that in the isostructure of KFe2As2 but it is more environment-
naturally friendly than the latter one as well. In this talk, we will report experimental finding of pressure tuning of the superconducting transition temperature *T*\textsubscript{c} and enhancement of the temperature of the resistance hump *T*\textsubscript{H} through charge transfer between two iron sites with different occupancies. The activation energy for the electric transport of the high-temperature resistance is observed to go to zero at a critical pressure of 8.7 GPa, at which superconductivity tends to disappear and the semiconductor-to-metal transition takes place. Beyond the critical point, the resistance exhibits a metallic behavior over the whole temperature range studied. The observation provides an opportunity to understand the underlying mechanism of superconductivity in new Fe\textsubscript{3}Se-based superconductors. Work done in collaboration with XJ Chen, J Guo, C Zhang, JG Guo, XL Chen, Q Wu, DC Gu, PW Gao, X Dai, LH Yang, and HK Mao.

11P-B035 Shear Viscosity of the Superconductor of *Sr*\textsubscript{2}Ru*O*\textsubscript{4} in the Normal State

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*Sr*\textsubscript{2}Ru*O*\textsubscript{4} is an unconventional superconductor of two dimensional layered perovskite structure with spin-triplet state and being probably *p*-wave. So energy gap in *Sr*\textsubscript{2}Ru*O*\textsubscript{4} is suggested on the two-dimensional cylindrical Fermi surface in isotropic form |Δ(\textbf{k})| = (\textit{k}_x\textsuperscript{2} + \textit{k}_y\textsuperscript{2})\textsuperscript{1/2}. The recent studies show that thermodynamic quantities in *Sr*\textsubscript{2}Ru*O*\textsubscript{4} such as specific heat represent different behaviors. The presence of nodes in Energy gap leads to the presence of power laws instead of exponential behavior for *T* ≪ *T*\textsubscript{c}. Therefore, gap structure in *Sr*\textsubscript{2}Ru*O*\textsubscript{4} may not be isotropic and it may have linear nodes. In our calculations for shear viscosity coefficients of *Sr*\textsubscript{2}Ru*O*\textsubscript{4} in normal state, energy gap is considered two dimensional and isotropic. The normal state of *Sr*\textsubscript{2}Ru*O*\textsubscript{4} is well characterized as a quasi-two-dimensional Fermi liquid. *Sr*\textsubscript{2}Ru*O*\textsubscript{4} is very similar to *A*\textsubscript{2}Ru*O*\textsubscript{4}, which is a phase of superfluid *3*\textit{He}. In this paper, shear viscosity coefficients in normal state of *Sr*\textsubscript{2}Ru*O*\textsubscript{4} has been calculated based on Boltzmann equation and Abrikosov-Khalatnikov method and its temperature dependence gained in *T*\textsuperscript{−2} , it is acceptably consistent with the prediction of Fermi liquid theory about the superfluidity of three dimensional *3*\textit{He} and their difference is only related to their coefficients. It is worth mentioning that calculation of shear viscosity coefficients in the superconductor phase of *Sr*\textsubscript{2}Ru*O*\textsubscript{4} is under study and the first calculations show exponential linear behavior for shear viscosity which is consistent with the experimental results.

11P-B036 Anisotropy in the magnetic state of undoped iron pnictides

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The high temperature superconductors iron pnictides present singular magnetism. The undoped compound is metallic with Q=(0,0) columnar ordering with low magnetic moment, lower than predicted in ab-initio calculations. A strong anisotropy is found in transport, optical and inelastic neutron experiments. This situation has put forward orbital ordering as a possible theoretical scenario. We calculate the mean field Q=(\textit{p},0) magnetic phase diagram using a five orbital tight-binding model. For intermediate values of the interaction, metallic regimes with low and high magnetic moments arise both with orbital ordering. The low moment state is characterized by on-site antiparallel orbital magnetic moments and it is consistent with the strong exchange anisotropy found in neutron experiments. The orbital ordering found reproduces a large \textit{zx} weight seen around Gamma in ARPES experiments. We also calculate the ratio of the Drude weight along the \textit{x} and \textit{y} directions for different interaction parameters. Large values of orbital ordering favor an anisotropy opposite to the one found experimentally. On the other hand D\textit{x}/D\textit{y} is strongly dependent on the topology and morphology of the reconstructed Fermi surface. This anisotropy extends to higher frequencies and changes direction as seen in optical experiments. Our results points against orbital ordering as the origin of the observed conductivity anisotropy, which may be ascribed to the anisotropy built by the magnetic state.\textsuperscript{1}

\textsuperscript{1} E. Bascones, M.J. Calderon, B. Valenzuela, PRL’10; B. Valenzuela, M.J. Calderon, E. Bascones, PRL’10.

11P-B037 Superconducting Critical Fields in K\textsubscript{0.8}Fe\textsubscript{2}Se\textsubscript{2} (LT26)

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We report the results of an experimental study of dc and low frequencies magnetic properties of K\textsubscript{0.8}Fe\textsubscript{2}Se\textsubscript{2} single crystal when the dc magnetic field is applied parallel to the \textit{ab} plane. From the data obtained, we deduce the full H-T phase diagram which consists of all three H\textsubscript{1}(T), H\textsubscript{2}(T) and H\textsubscript{3}(T) critical magnetic field plots. The two H\textsubscript{1}(T) and H\textsubscript{2}(T) curves were obtained from dc magnetic measurements, whereas the surface critical field H\textsubscript{3}(T) line was extracted by ac susceptibility studies. It appears that near T\textsubscript{c}, the H\textsubscript{3}(T)/H\textsubscript{2}(T) ratio is ≈ 4.4 which is much larger than expected 1.7 value.

11P-B038 Superconductivity induced by Fe doping in 1T-TaS\textsubscript{2} single crystals

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Charge-density wave (CDW) and superconductivity (SC) are collective states that coexist in layered transition-metal dichalcogenides (TMD). The nature of the relationship (competition or/and cooperation) between CDW and SC remains to be further elucidated. Here we report the SC that develops within the CDW state, and the electronic phase diagram in
the Fe-doped 1T-TaS\(_2\) single crystals. The single crystals of Fe\(_x\)Ta\(_{1-x}\)S\(_2\) \((x = 0 \sim 0.05)\) were successfully grown via the chemical vapor transport (CVT) method with iodine as a transport agent. Our experimental and density-functional theory (DFT) calculation results show a semimetal behavior in undoped 1T-TaS\(_2\) due to the pseudo-gap occurring in CDW phase. With Fe doping, the commensurate CDW state is suppressed and the reduced SC density occurs at low temperatures for samples with moderate doping levels \((x = 0.02\) and 0.03). The magnetic property measurements evidently indicate a type-II superconductor with low superconducting critical fields. We propose that the induced SC and CDW phases are separated in real space. For high Fe-doping concentration \((x \geq 0.04)\), the Anderson localization (AL) state is observed due to the disordered/random potential, which results in an insulating behavior. We think this is the first report of the induced SC by doping and the complete electronic phase diagram in Fe-doped 1T-TaS\(_2\) system.

11P-B039 Evolution of superconductivity and ferromagnetism in Eu(Fe\(_{1-x}\)Ru\(_x\))\(_2\)As\(_2\)

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EuFe\(_2\)As\(_2\) undergoes a collinear antiferromagnetic spin-density wave (SDW) transition at 190 K for the Fe sublattice and, an A-type antiferromagnet ordering at 19 K for the Eu sublattice. By the substitution of Fe with Ru in Eu(Fe\(_{1-x}\)Ru\(_x\))\(_2\)As\(_2\) crystals, we found that the SDW transition is gradually suppressed, at the same time, superconductivity emerges with \(T_c \sim 22\) K. The magnetic ordering in the Eu sublattice changes from antiferromagnetic to ferromagnetic at \(x \sim 0.2\), making the coexistence of superconductivity and ferromagnetism in a broad regime of \(0.2 < x < 0.6\).

11P-B040 Gate-Induced Superconductivity in Layered-Material-Based Electric Double Layer Transistors

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Ion-gated devices using a electrochemical concept of electric double layer are attracting increasing interests due to its unique abilities in accumulating high density carriers required even for inducing superconductivity\(^1\)\(^2\). With the introduction of new gate dielectrics: ionic liquid, the ability of ion gating was further improved by promoting the surface charge density to the order of \(\sim 10^{14}\) cm\(^{-2}\). Comparing with the carrier density required by conventional superconductors, this density is well within the range in which superconductivity could be hopefully induced in a broad range of materials. Using the graphene techniques, atomically flat surface can be fabricated from the layered materials easily providing ideal transistor channels. And a combination of the techniques above can be an important tool to investigate the gate-induced superconductivity.

11P-B041 “111” iron pnictide superconductors: pressure enhanced superconductivity

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The recent discovery of superconductivity at 26 K of LaO\(_{1-x}\)F\(_x\)FeAs opened a new door for research in the area of high-temperature superconductors\(^3\). In Fe-based superconductors, the correlation between the pressure-tuned superconductivity and the atomic structure under pressure plays a key role in the search for new materials as well as in the elucidation of the mechanism of superconductivity in iron arsenide superconductors. We reported recently the effect of pressure on the superconductivity of 111-type Na\(_{1-x}\)FeAs that crystallizes into the same structure as that of Li\(_x\)FeAs superconductor. It was found that the superconducting critical temperature of Na\(_{1-x}\)FeAs can reach a maximum of 31 K at approximately 3 GPa representing the record high for “111” system. To provide insights into the pressure behavior of the 111-type Na\(_{1-x}\)FeAs, we further performed studies on crystal structural evolution as a function of pressure based on in situ high-pressure synchrotron x-ray powder diffraction data with Rietveld refinements. The non-monotonic \(T_c(P)\) behavior of Na\(_{1-x}\)FeAs is found to correlate with the anomalies of the FeAs coordination. This behavior provides the key structural information in understanding the origin of the pressure dependence of \(T_c\) for 111-type NaFeAs iron pnictide superconductors.


11P-B042 Crystal growth and superconductivity of Fe-base materials

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A number of Fe-base superconducting materials have been discovered recently. The Fe-11 phase FeTe1-xSex and Fe-112 phase KFe2Se2 superconducting materials are very interesting new materials. We have grown a number of the FeTe1-xSex and KFe2Se2 single crystals by using a Bridgman growth technique and zone method. The effects of the growth condition and the compositions of a raw materials on the single crystal growth of FeTe1-xSex and KFe2Se2 have been studied by using a Bridgman growth technique. Various physical properties of these single crystals will be presented.

11P-B043 Fullerene Superconductivity 20 Years on

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A$_3$C$_60$ (A=alkali metal) superconductors were known to adopt fcc structures with their superconducting $T_c$ increasing monotonically with increasing interfullerene spacing, reaching a 33 K maximum for RbCs$_2$C$_{60}$; this physical picture had remained unaltered since 1992. Trace superconductivity ($<$0.1%) at 40 K under pressure was also reported in 1995 in multiphase samples with nominal composition Cs$_3$C$_{60}$. Despite numerous attempts by many groups worldwide, this remained unconfirmed and the structure and composition of the material responsible for superconductivity unidentified. Thus the possibility of enhancing fulleride superconductivity and understanding the structures and properties of these archetypal molecular solids had remained elusive. Here I will present our recent progress in accessing high-symmetry hyperexpanded alkali fullerenes in the vicinity of the Mott-Hubbard metal-insulator boundary and at previously inaccessible intermolecular separations. The physical picture that emerges for the alkali fullerenes is that, contrary to long-held beliefs, they are the simplest members of the high-$T_c$ superconductivity family. We demonstrated this by showing that in the two hyperexpanded Cs$_3$C$_{60}$ polymorphs (fcc- and A15-structured), 1 superconductivity emerges upon applied pressure out of an antiferromagnetic insulating state and displays an unconventional behaviour, a superconductivity dome, explicable by the prominent role of strong electron correlations.


11P-B044  Growth of Y-123 Thick Film with Modified Ultrasonic Spray Pyrolysis method and effects of post-annealing on the critical current density

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Y-123 material was fabricated by solid state reaction technique. After appropriate heat treatment, Y-123 powders were inserted in to the ball-milling system for 2 h to decrease grain size. The nano sized powders obtained were then mixed in ethanol to obtain colloidal system. Mixture was atomized with 2.4 MHz ultrasonic nebulizer system on to the polished MgO and SrTiO$3$ single crystal substrates at room temperature for fabrication of thick films. After nebulization a suitable heat treatment was applied to the films and ~1 μm thick films were obtained. Microstructural, Electrical and I-V properties were investigated by using XRD, SEM-EDX and PPMS analysis. The superconducting transition temperatures, $T_c$, was obtained to be 92 K and the $T_{zero}$ was obtained to be 85 K for MgO single crystal substrates. But the films produced on the SrTiO$3$ single crystal substrates showed slightly better result than the MgO substrates. The critical current density was obtained to be 3.2x10$^4$ A/cm$^2$ for the best sample. However after post annealing microstructural formation and critical current density increased largely. We also describe largely the modification on the ultrasonic spraying method and its effect on the film production and the properties. We also discussed the large scale fabrication using ultrasonic spraying method.

Session 11P-C:

C1 Low Dimensional and Frustrated Magnetism

Thursday August 11, 16:00 – 18:00

Exhibition Hall I

11P-C001  Static and Dynamic Low Temperature Magnetic Properties of the $(Nd_{0.9}Y_{0.1})_{2/3}Ca_{1/3}MnO_3$ Perovskite

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Colossal magnetoresistive perovskite $(Nd_{0.9}Y_{0.1})_{2/3}Ca_{1/3}MnO_3$ exhibits a sequence of magnetic phase transitions at low temperatures leading to its phase segregated state: nanoclusters of two antiferromagnetic phases and the ferromagnetic one coexist below 42 K. We have studied its static and dynamic magnetic properties in the 2 – 250 K temperature range in magnetic fields up to 6 T. The data obtained, such as strongly divergent ZFC and FC dc magnetization, frequency dependent ac magnetization, and the aging effect, are evident of a glassy magnetic state (GS) of the compound at low temperatures. The freezing temperature $T_f = 60$ K has been defined as a maximum on the ZFC curve in magnetic field $H = 100$ Oe. The effect of the applied magnetic field on the GS of the compound was estimated fitting the experimental data by the expression $\Delta M/M_{FC} = \exp (-H/H_0)$, where $\Delta M = M_{FC}(T), H) - M_{ZFC}(T), H)$ is a “glassy” parameter. At 2 K the magnetic field $H \sim 1$ T effectivly suppresses the GS, $H_0 = 0.38$ T. The obtained rate of the frequency shift $\partial \ln (T_f)/\partial \ln (\omega) \approx 0.017$ is in agreement with the results for related compounds. The obtained high value of the magnetic field which suppresses the GS of the compound implies that its cluster glass state is tightly connected with the phase separation.


11P-C002  Magnetic Excitation of Possible Spin-Peierls System TiOBr

Low Temperature Magnetic Properties of a Spin-Ice System CdEr2Se4


Electron Spin Resonance in Triangular Spin Tubes

H. Manaka, Y. Miura

Simple model of magnetization processes in rare-earth tetraborides

P. Farkašovský, H. Čenčaríková

Simple model of magnetization processes in rare-earth tetraborides

P. Farkašovský, H. Čenčaríková
magnetization $m^p_s$. The ground-states corresponding to magnetization plateaus have the same spin structure consisting of parallel antiferromagnetic bands separated by ferromagnetic stripes. In addition, the transitions from the low temperature ordered phase to the high-temperature disordered phase are analyzed by the canonical Monte-Carlo method.

11P-C007 Geometrically frustrated CuFeO$_2$

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Complex magnetic oxides exhibit a rich variety of intriguing phenomena arising from the interplay between multiple coupled degrees of freedom, with the latter eventually determining their macroscopic behaviour. A particularly interesting class of materials in this respect are the geometrically frustrated spin systems, with the multiferroic two dimensional delafossite system (CuFeO$_2$) as one of the more intriguing examples. This material exhibits a staircase of metamagnetic phase transitions, originating from competing spin-spin, spin-phonon, spin-orbit, and spin-field interactions. The physical origin of this fascinating behavior has been unraveled by a variety of experimental and theoretical approaches, including magnetization, nuclear forward scattering and x-ray absorption experiments, as well as band structure calculations and semiclassical magnetic modeling. Apart from obtaining a detailed insight in the nature of the various ground states and the observation of a reversed spin-Peierls transition at high magnetic fields, one of the eye-opening findings is the existence of a finite 3d spin density on the nominally 3d$^9$ Cu$^+$ site. This spin density is shown to play a pivotal role in the low temperature magnetism potentially also in the field induced multiferroic state of this material.

11P-C008 Magnetostriiction of Tb$_2$(MoO$_4$)$_3$ and MnF$_2$ in high magnetic field

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Magnetostriiction $\Delta L/L$ and magnetization $M$ along the principal axes of monocrystalline samples of the paramagnetic Tb$_2$(MoO$_4$)$_3$ and antiferromagnetic MnF$_2$ were measured in wide temperature range in magnetic fields $H$ up to 14 T. Observed in the experiment anisotropy of the magnetostriective deformation is absolutely different from that produced by a hydrostatic pressure. Thermodynamic description of the magnetostriiction based on the fact that magnetic field does not perform any work is proposed. Obtained equation $\Delta E = MH + T\Delta S$, where $\Delta E$ is the change of the lattice energy due to the magnetostriiction and $\Delta S$ is the change of the entropy, well describes the experimental results with a reasonable value of the Born term in the inter-ion interaction.


11P-C009 Ultrasonics in the two-dimensional dimer spin system YbAl$_3$C$_3$


We report results of sound velocity, $i.e.$, elastic constant measurements in the two-dimensional dimer spin system YbAl$_3$C$_3$. This system exhibits a clear phase transition at $T^* = 80$ K, evidenced by the specific heat and elastic constant measurements.$^1$ No significant anomaly, however, was observed in the magnetic susceptibility crossing $T^*$, suggesting a non-magnetic origin of the phase transition. Initially, a quadrupolar ordering scenario was proposed by our group. Since a reference system LuAl$_3$C$_3$ also exhibits the same phase transition confirmed by the specific heat measurement, it was commonly understood that a quadrupolar moment was not a primary order parameter below $T^*$. Instead, a dimer spin model was proposed then.$^2$ The longitudinal $C_L$ and transverse $C_T$ elastic constants of the poly crystal sample show a pronounced anomaly in sound velocity at low temperatures and in applied magnetic field. Below 1.5 K, these constants demonstrates a softening with increasing field close to the meta-magnetic transition field, $B_m \approx 7.5$ T. The ultrasonic results are analyzed with a theory based on magneto-elastic coupling. We can obtain good qualitative agreement between theoretical results and experimental ones.$^1$


11P-C010 Spin-Glass and Antiferromagnetic Transitions in Ru$_2$Fe$_2$CrSi

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Measurements of the magnetization $M(T)$ of the Heusler compound Ru$_{1.9}$Fe$_{0.1}$CrSi have revealed two anomalies: one is a peak in $M(T)$ at $T_g \sim 30$ K and the other is strong irreversibility in $M(T)$ below $T_N$, the onset of which is defined as $T_g$. This behavior suggests successive spin-glass transitions, which may be interpreted in terms of theoretically proposed AT (de Almeida-Thouless) and GT (Gabay-Toulouse) transitions.$^1$ On the other hand, the properties of Ru$_2$CrSi were not investigated, and thus in the present study the magnetization $M(T)$ and specific heat $C_p(T)$ are investigated. Clear peaks observed in $M(T)$ and $C_p(T)$ indicate that an antiferromagnetic transition occurs at $T_N = 13$ K. This is in marked contrast with the case for Ru$_{1.9}$Fe$_{0.1}$CrSi, where no anomaly in $C_p(T)$
was observed at $T_N^*$ or at any other temperatures.\(^2\) In $M(T)$ for $0 < x < 0.1$ the characteristic two anomalies are also observed, and $T_N^*$ ($\sim 15$ K) appears not to change with $x$ while $T_N$ appears to decrease with decreasing $x$. This result suggests the relation between the anomaly at $T_N^*$ and the antiferromagnetic transition at $T_N$ for $x = 0$.

11P-C011 Heat Transport of Quasi-One-Dimensional Ising-Like Antiferromagnet BaCo$_2$V$_2$O$_8$ in the Longitudinal and Transverse Fields

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We study the very-low-temperature thermal conductivity $\kappa$ of BaCo$_2$V$_2$O$_8$, a quasi-one-dimensional Ising-like antiferromagnetic spin chain material, to probe the magnetic phase transitions induced by transverse and longitudinal magnetic fields, respectively. $\kappa$ shows nearly isotropic behavior for heat current along or vertical to the spin-chain direction, indicating the magnetic excitation scattering on phonons. In the longitudinal field, $\kappa$ is always smaller than the zero-field conductivity, and there is a sharp decrease at $\sim 4$ T in $\kappa$/$H$ isotherms, which is related to the quantum phase transition from Néel order to incommensurate state. This is coincide with the $H = T$ phase diagram.\(^3\) Moreover, another dip below 4 T is found and is likely resulted from the spin-flop transition. The case in the transverse field is quite different, in which $\kappa$ presents a deep minimum at $\sim 10$ T and this “diplike” feature becomes broader with increasing temperature. This result strongly suggests a newly found field-induced magnetic phase transition.

11P-C013 Huge magnetothermal conductivity in a spin liquid material Tb$_2$Ti$_2$O$_7$

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Low-temperature magnetic states of the pyrochlore compound Tb$_2$Ti$_2$O$_7$ with geometrical frustration have attracted much interest because of a variety of exotic behaviors at low temperature, such as the Tb$^{3+}$ moments remaining in a collective paramagnetic or spin-liquid state down to 70 mK. In order to study the nature of spin liquid, we have measured the low-temperature thermal conductivity ($\kappa$) of the high-quality single crystal of Tb$_2$Ti$_2$O$_7$. It is found that the low-temperature thermal conductivity is extremely small, about $10^{-4}$ W/Km at 300 mK, which is comparable to the thermal conductivity of some amorphous solids. When applying the field along the [111] direction or perpendicular to it, $\kappa$ show very large enhancements, for example, up to 35 times at 9 T along [111] and 30 times at 14 T perpendicular [111], (at 0.36 K) respectively. This indicates that phonons are scattered by the magnetic fluctuations strongly in zero field, which can be strongly suppressed by magnetic field. A remarkable phenomenon is that $\kappa$($H$) for two field directions show striking differences, showing three peaks with $H \parallel [111]$ while monotonously increasing with $H \perp [111]$ till 14 T, which may be related to the low temperature anisotropic magnetic properties of Tb$^{3+}$ induced by crystal field effect. The result with field along [111] suggests that a polarized paramagnetic or a short-range magnetically ordered phase is induced.

11P-C014 Transport properties of $Y_{1-x}$Nd$_x$Co$_2$ compounds

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The electrical resistivity $\rho$ and thermopower $S$ of the light rare-earth pseudo-binary $\text{Y}_{1-x}\text{Nd}_x\text{Co}_2$ compounds have been measured at temperatures from 2 K to 300 K under pressures up to 3 GPa. For the compounds of $x > 0.3$, the anomalies in $\rho(T)$ and $S(T)$ curves, correspond to the magnetic phase transition at $T_C$, have been observed. The Curie temperature $T_C$, determined as the temperature where the temperature derivative of $\rho$ has a maximum, decreases with decreasing Nd concentration $x$ and apparently vanishes around $x_c=0.3$. The residual resistivity $\rho_0$ increases rapidly with decreasing $x$, having a maximum at $x = x_c$, and decreases with increasing $x$. On the other hand, the temperature coefficient of thermopower $S/T$ at low temperature limit shows a complex $x$ dependence: $S/T$ changes its sign from negative to plus at $x \approx 0.2$, having a maximum at $x = x_c$, and shows an almost constant value at $x > 0.5$. The pressure dependences of $T_C$ and $\rho_0$ of $\text{Y}_{0.6}\text{Nd}_{0.4}\text{Co}_2$ show almost the same behavior as that of the $\text{Y}_{1-x}\text{R}_x\text{Co}_2$ ($\text{R}=$ heavy rare-earthes) system, which imply that the magnetic state of the Co-3d electron subsystem is responsible for the transport properties at low temperatures in the $\text{Y}_{1-x}\text{Nd}_x\text{Co}_2$ system.

11P-C015 Dimensionality-Controlled Collective Charge and Spin Order in Nickel-Oxide Superlattices
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The competition between collective quantum phases in transition metal oxides depends very sensitively on the dimensionality, because the low-dimensioned correlated electron systems are known to be more susceptible to collective ordering phenomena. Such high susceptibility indicates an alternative route towards dimensionality control by means of the deposition sequence of electronically active and inactive TMO layers. Motivated by the desire to realize the potential of TMO heterostructures in controlling collective quantum phases, we have fabricated superlattices of the paramagnetic metal LaNiO\textsubscript{3} and the wide-gap insulator LaAlO\textsubscript{3} with atomically precise layer sequences. Using optical ellipsometry and low-energy muon spin rotation, superlattices with LaNiO\textsubscript{3} as thin as two unit cells are shown to undergo a sequence of two sharp, collective electronic phase transitions upon cooling. We have provided strong evidence that the two transitions correspond to the onset of charge and antiferromagnetic spin order. By showing that samples with thicker LaNiO\textsubscript{3} layers remain uniformly metallic and paramagnetic at all temperatures, we have demonstrated full dimensionality control of these collective instabilities [1].


11P-C016 Spin freezing in geometrically frustrated magnetic molecule Fe\textsubscript{30} revealed by NMR
Y. Furukawa\textsuperscript{a}, E. Micotti\textsuperscript{b}, A. Lascialfari\textsuperscript{b}, F. Boris\textsuperscript{b}, P. Kägerler\textsuperscript{c}, \textsuperscript{a}Ames Laboratory, and Department of Physics and Astronomy, Iowa State University, Iowa 50011, USA \textsuperscript{b}Dipartimento di Fisica “A Volta” e Unita’INFM di Pavia, Pavia, Italy \textsuperscript{c}Institute of Inorganic Chemistry, RWTH Aachen University, 52074 Aachen, Germany

Recently much attention has been paid to peculiar magnetic properties of spin frustrated magnetic molecules. The compound \[\text{M}_2\text{Fe}_{30}\text{O}_{252}(\text{Mo}_2\text{O}_7\text{H}_2\text{O})_2(\text{Mo}_2\text{O}_6\text{H}_2\text{O})(\text{CH}_3\text{COO})_2(\text{H}_2\text{O})_9\] (in short Fe\textsubscript{30}) has 30 Fe\textsuperscript{3+} ($S = 5/2$) ions occupying the 30 vertices of an icosidodecahedron, which makes a closed spherical structure consisting of 20 spin frustrated triangles with antiferromagnetic (AF) exchange coupling ($J = 1.57$ K) between Fe spins. In order to investigate magnetic properties of Fe\textsubscript{30}, we have carried out proton nuclear magnetic resonance (NMR) measurements at low temperatures down to $T = 0.05$ K using a $^3\text{He}-^4\text{He}$ dilution refrigerator. From a measurement of nuclear spin-lattice relaxation rates as a function of temperature and external field, fluctuation frequency of Fe\textsuperscript{3+} spins is found to become slower on lowering temperature. Broad proton NMR spectrum was observed at low temperatures below $\sim 0.6$ K. These results indicate spin freezing state at low temperatures in Fe\textsubscript{30}. We will compare our NMR results with those of a quantum spin system, $V_{30}$ ($V^+; S = 1/2$) with the same structure and discuss the similarities and differences in the magnetic properties of these two systems.

11P-C017 Studies of Crystal Structure and Spin State in Diluted Triangular Spin Tube KCr\textsubscript{1-x}Al\textsubscript{2}F\textsubscript{4}
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Non-magnetic impurity substitution in triangular spin tubes is expected to be competition between geometrical spin frustration in each triangular plane and impurity-induced antiferromagnetic long-range order. In equilateral triangle spin tubes composed of CsCr\textsubscript{1-x}Al\textsubscript{2}F\textsubscript{4} ($x = 0 - 0.06$), we found that no anomaly that indicates an antiferromagnetic long-range order appeared because geometrical spin frustration in the equilateral triangular plane is robust. In this study, we performed X-ray diffraction and magnetic susceptibility experiments on non-equilateral triangular spin tubes composed of $\alpha$-KCr\textsubscript{1-x}Al\textsubscript{2}F\textsubscript{4} ($x = 0 - 0.10$). In $\alpha$-KCrF\textsubscript{4}, successive antiferromagnetic long-range order occurred at $T_{N1} = 2.5(1)$ K and $T_{N2} = 4.0(1)$ K, because geometrical spin frustration collapsed in each non-equilateral triangle. As a result, the values of spin-flop transition field drastically decreases with increasing $x$. This is probably due to the close correlation between the spin structure in the antiferromagnetic ordered state and the crystal structure as theoretically predicted by Néhert and Palstra, i.e., a magnetoelectric linear effect in which a magnetic field in an antiferromagnetic ordered state induces electrical polarization.\textsuperscript{1} Thus we carefully verified the crystal structure for $x = 0\sim 0.10$.

\textsuperscript{1} G. Néhert and T. T. M. Palstra, J. Phys.: Condens. Matter 19, 406213 (2007).
11P-C018  Finite energy spectral function of an anisotropic 2D system of coupled Hubbard chains

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We study the crossover from the one-dimensional to the two-dimensional Hubbard model in the photoemission spectra of weakly coupled chains. The chains with on-site repulsion are treated using the spin-charge factorized wave function, that is known to provide an accurate description of the dynamics of the model in the strong coupling limit, while the hoppings between the chains are considered as a perturbation. We calculate the dynamical spectral function at all energies in the random-phase approximation, by resuming an infinite set of diagrams. Even though the hoppings drive the system from a fractionalized Luttinger-liquid-like system to a Fermi-liquid-like system at low energies, significant characteristics of the one-dimensional system remain in the two-dimensional system. Furthermore, we find that introducing (frustrating) hoppings beyond the nearest neighbor one, the interference effects increase the energy and momentum range of the one-dimensional character.

11P-C019  Thermal conductivity of pure and Zn-doped LiCu\textsubscript{2}O\textsubscript{2} single crystals

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LiCu\textsubscript{2}O\textsubscript{2} is the first example of Cu-based multiferroic material and is particularly attractive because of its one dimensional spin structure.\textsuperscript{1} The competition between the nearest-neighbor ferromagnetic (FM) interaction and the next-nearest-neighbor antiferromagnetic (AF) interaction of Cu\textsuperscript{2+} spins in the spin chain leads to magnetic frustration and a spiral (helicoidal) magnetic order below \( \sim 24 \) K. We study the low-temperature thermal conductivity (\( \kappa \)) of pure and Zn-doped LiCu\textsubscript{2}O\textsubscript{2} single crystals. The \( \kappa \) of pure LiCu\textsubscript{2}O\textsubscript{2} shows a double-peak behavior, with two peaks locating at 48 K and 14 K, respectively. The different dependences of the peaks on the Zn concentration indicate that the high-\( T \) peak is likely due to the phonon transport while the low-\( T \) one is attributed to the magnon transport in the spin spiral ordering state. In addition, the magnetic field can gradually suppress the low-\( T \) peak but does not affect the high-\( T \) one; this further confirms that the low-\( T \) peak is originated from the magnon heat transport.

11P-C020  Novel Phase of the Dzyaloshinsky-Moriya Spiral Magnet


11P-C018  Finite energy spectral function of an anisotropic 2D system of coupled Hubbard chains

P. Ribeiro\textsuperscript{a}, P. D. Sacramento\textsuperscript{a}, K. Penc\textsuperscript{c}, \textsuperscript{a} Max Planck Institute for the Physics of Complex Systems, Nöthnitzer Str. 38, 01187 Dresden, and CFIF, Instituto Superior Técnico, TU Lisbon, Av. Rovisco Pais, 1049-001 Lisbon, Portugal \textsuperscript{b}Max Planck Institute for the Physics of Complex Systems, Nöthnitzer Str. 38, 01187 Dresden, and CFIF, Instituto Superior Técnico, TU Lisbon, Av. Rovisco Pais, 1049-001 Lisbon, Portugal \textsuperscript{c}Research Institute for Solid State Physics and Optics, P.O. Box 49, H-1525 Budapest, Hungary

We use the crossover from the one-dimensional to the two-dimensional Hubbard model in the photoemission spectra of weakly coupled chains. The chains with on-site repulsion are treated using the spin-charge factorized wave function, that is known to provide an accurate description of the dynamics of the model in the strong coupling limit, while the hoppings between the chains are considered as a perturbation. We calculate the dynamical spectral function at all energies in the random-phase approximation, by resuming an infinite set of diagrams. Even though the hoppings drive the system from a fractionalized Luttinger-liquid-like system to a Fermi-liquid-like system at low energies, significant characteristics of the one-dimensional system remain in the two-dimensional system. Furthermore, we find that introducing (frustrating) hoppings beyond the nearest neighbor one, the interference effects increase the energy and momentum range of the one-dimensional character.

11P-C019  Thermal conductivity of pure and Zn-doped LiCu\textsubscript{2}O\textsubscript{2} single crystals

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LiCu\textsubscript{2}O\textsubscript{2} is the first example of Cu-based multiferroic material and is particularly attractive because of its one dimensional spin structure.\textsuperscript{1} The competition between the nearest-neighbor ferromagnetic (FM) interaction and the next-nearest-neighbor antiferromagnetic (AF) interaction of Cu\textsuperscript{2+} spins in the spin chain leads to magnetic frustration and a spiral (helicoidal) magnetic order below \( \sim 24 \) K. We study the low-temperature thermal conductivity (\( \kappa \)) of pure and Zn-doped LiCu\textsubscript{2}O\textsubscript{2} single crystals. The \( \kappa \) of pure LiCu\textsubscript{2}O\textsubscript{2} shows a double-peak behavior, with two peaks locating at 48 K and 14 K, respectively. The different dependences of the peaks on the Zn concentration indicate that the high-\( T \) peak is likely due to the phonon transport while the low-\( T \) one is attributed to the magnon transport in the spin spiral ordering state. In addition, the magnetic field can gradually suppress the low-\( T \) peak but does not affect the high-\( T \) one; this further confirms that the low-\( T \) peak is originated from the magnon heat transport.

11P-C020  Novel Phase of the Dzyaloshinsky-Moriya Spiral Magnet

11P-C022 Possible origin of dual character of the electrons in iron-pnictides
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Great effort has been devoted to understanding the origin of the magnetism in iron-based superconductors since its discovery. This is due to the fact that the superconducting phases appears mostly in the vicinity of magnetic phases and it is now believed that magnetic fluctuations play important roles in the pairing mechanism. While there exists two contradictory points of view on the mechanism of magnetism in iron-based superconductors, i.e., the nesting effect from itinerant picture versus the spin exchange effect from localized scenario, a combination of these two effects was also proposed, i.e., coexistence of localized and delocalized electrons in the iron-based superconductors. Here, based on the analysis of the band structures obtained from ab initio calculations, we propose a new mechanism for the coexistence of particle-like and wave-like electrons in iron-based superconductors by investigating a multi-orbital Hubbard model and further explain the origin of different magnetic pattern such as collinear and bicollinear antiferromagnetic ordering within such a model.

11P-C023 Analytical Approach for Investigation of Generalized Hubbard Model with Correlated Hopping and Low-Temperature Antiferromagnetism
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In this work the analysis of indirect interactions in narrow band materials connected both with charge transfer and the exchange between localized magnetic moments is done. Anion subsystem is described by the band theory Hamiltonian and Hubbard operators are used to describe the localized subsystem. The spectrum of conduction electrons of a narrow-band semiconductor in paramagnetic and antiferromagnetic phases for arbitrary value of electron concentration is investigated within the effective Hamiltonian approach. Forasmuch the effective integrals of the exchange interaction depend on the hybridization parameter, one obtains that in narrow band systems with high Neel temperature for antiferromagnets the conductivity is higher as well. At T=0 in absence of current carriers in both cation and anion subsystem the ferro- or antiferromagnetic ordering can be realized due to indirect (through anion subsystem) exchange interactions between localized magnetic moments. We argue that in systems with correlated hopping of electrons conditions for antiferromagnetic ordering onset are more favorable. Typical antiferromagnetic interaction is realized due to mechanism equivalent to delocalized indirect Anderson exchange. The region of electron concentrations in which antiferromagnetism is stable is substantially wider and Neel temperatures are much greater in presence of the correlated hopping which appear to be a decisive parameter in this case.

11P-C024 Anisotropic hysteretic Hall-effect and magnetic control of chiral domains in the chiral spin states of Pr2Ir2O7
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We uncover a strong anisotropy in both the anomalous Hall effect (AHE) and the magnetoresistance of the chiral spin states of Pr2Ir2O7. The AHE appearing below 1.5 K at zero magnetic field shows hysteresis which is most pronounced for fields cycled along the [111] direction. This hysteresis is compatible with the field-induced growth of domains composed by the 3-in 1-out spin states which remain coexisting with the 2-in 2-out spin ice manifold once the field is removed. Only for fields applied along the [111] direction, we observe a large positive magnetoresistance and Shubnikov de Haas oscillations above a metamagnetic critical field. These observations suggest the reconstruction of the electronic structure of the conduction electrons by the field-induced spin-texture.

11P-C025 Is superconductor magnetic characteristic associated with unpaired itinerant electrons?
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The Microscopic theories of ferromagnetic superconductors and antiferromagnetic superconductors have many unanswered questions concerning the properties. Otherwise, To explain these phenomenon the Cooper pair have to sign-changing state sometimes and another times is unconventional spin triply-state. This theories maybe are not gospel. In such a scenario, the electron system of materials are reinterpreted and discussed. The Heisenberg direct exchange model, spin-density-wave, Hartree-Fock and local magnetization theories are employed to calculate the electrons team effect the magnetic property. The results indicate that the Cooper pairs reduces the local magnetization and the unpaired itinerant electrons is likely to participating influence the magnetic characteristic.

11P-C026 Random Spin Freezing in Single Crystalline Ce2CuSi3
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Nonmagnetic atom disorder compounds Ce2CuSi3 crystallizing in a hexagonal AlB2-type structure is a very interesting example among the ternary intermetallic compounds with composition 2:1:3. We have reported the discovery of spin glass (SG) behavior with extended short-range magnetic order for a polycrystalline...
Ce₂CuSi₃. Considering the SG behavior is very sensitive to the levels of crystallographic disorder, in order to get an intrinsic and complete physical picture and to open up the possibility of studying magnetic anisotropy of Ce₂CuSi₃, systematic investigation on single crystalline sample is indispensable. In this paper, we present the results of ac and dc susceptibilities, magnetization, magnetic relaxation and specific heat measurements performed on single crystalline Ce₂CuSi₃ with magnetic field applied along two typical crystallographic directions, i.e. \( H \perp c \)-axis and \( H \parallel c \)-axis. For both the directions, SG state is confirmed to form at low temperature with the same spin freezing temperature \( T_f(=2.07 \text{ K}) \), initial frequency shift \( \delta T_f(=0.015) \) and activation energy \( E_a/k_B(=10.04 \text{ K}) \) in zero dc field. Strong anisotropy is also found to be a significant feature of this compound. The experimental results and the dynamical analyses suggest that the SG behavior is intrinsic to Ce₂CuSi₃ which could be qualitatively understood on the basis of a magnetic cluster model.

11P-C027 Temperature Dependence of Magnetization at Zero Applied Magnetic Field in Nearly Two Dimensional Ferromagnets
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NMR measurement have been made at low temperatures on the crystal structure of K₂CuF₄ and \((\text{C}_2\text{H}_2\text{NH}_3)_2\text{CuCl}_4\) at zero applied magnetic field. \( ^{63}\text{Cu}, ^{65}\text{Cu} \) and \( ^{35}\text{Cl} \) NMR have been used to measure spontaneous magnetization at the temperature range 2 K down to 30 mK. We have made the NMR experiments using a \(^3\text{He}⁻\text{He} \) dilution refrigerator by conventional pulsed NMR method without external magnetic field. The magnetization at zero applied magnetic field in the nearly two-dimensional ferromagnet K₂CuF₄ of the experimental data is in a good agreement with Yamaji-Kondo theory and \( \theta_e=0.3 \), which is applied the double-time Green’s function method incorporated with Tyablikov’s decoupling. For temperature 1.1 K down to 0.26 K, the spontaneous magnetization of \((\text{C}_2\text{H}_2\text{NH}_3)_2\text{CuCl}_4\) is support (\( t \log t' \))-formalism from the spin wave theory.

11P-C028 Heat transport study of Dy₂Ti₂O₇ single crystals in a [110] magnetic field
Dy₂Ti₂O₇ is considered to be a model of spin ice materials which display a variety of fascinating magnetic behaviors due to the geometrical frustration. Magnetic Dy³⁺ ions on the vertexes of each tetrahedra process a strong Ising anisotropy along the local \( <111> \) axis, and form the “2-in 2-out” ground state with six-fold degeneration at low temperature. Magnetic field can easily break the macroscopic degeneracy and the spin system will show up various types of magnetic order depending on the field directions. We report a particular study of the low temperature heat transport of a Dy₂Ti₂O₇ single crystals in the magnetic field applied along [110] crystallographic direction up to 14 T, in which case the spins along and perpendicular to the field will form long-range ferromagnetic \( \alpha \)-chains and short-range antiferromagnetic \( \beta \)-chains, respectively (\( Q=\pi \) state) or a simple long-range ferromagnetic order state (\( Q=0 \) state). The \( \kappa(T) \) curves show a small and broad phonon peak extraordinarily. It is because of the serious scattering of phonons by the spin fluctuation. Also, the thermal conductivities exhibit obvious field dependencies. The over all behavior of \( \kappa(H) \) is that the magnetic field strongly suppresses thermal conductivity, but with some drastic decreasing at some critical fields which are corresponded to the field induced magnetic order transitions from the spin ice state to \( Q=\pi \) and \( Q=0 \) states.

11P-C029 Thermodynamic and magnetic properties of triangular spin cluster system \( \text{Cu}_3(\text{C}_{12}\text{H}_9\text{N}_2\text{O}_3)(\text{OH})(\text{NO}_3)_2\cdot\text{CH}_3\text{CN} \)
E. Čičínek*, M. Orendač* A. Orendačová*, A. Feher*, S.-D. Jiang*, S. Gao*,  *Institute of Physics, P.J. Šafárik University, Park Angelium 9, 41154 Košice, Slovakia \( b \)Beijing National Laboratory of Molecular Science, State Key Laboratory of Rare Earth Materials Chemistry and Applications, College of Chemistry and Molecular Engineering, Peking University, Beijing 100871, China
The novel trinuclear spin-1/2 copper compound \( \text{Cu}_3(\text{C}_{12}\text{H}_9\text{N}_2\text{O}_3)(\text{OH})(\text{NO}_3)_2\cdot\text{CH}_3\text{CN} \) was synthesized and magnetization, specific heat and X-band ESR studies were performed. The effective magnetic moment of the compound shows a sharp decrease at low temperatures, suggesting the presence of the weak antiferromagnetic exchange coupling among the copper ions. The magnetization measured at 2 K reaches full saturation at magnetic field 5 T. With the aim to identify the magnetic ground state, the specific heat measurements were performed in the temperature range from 100 mK to 10 K. The temperature dependence of specific heat is characterized by the presence of a Schottky-like maximum at 0.31 K. No \( \lambda \)-like anomaly indicating the formation of long-range order in the system was observed down to 100 mK. The specific heat can be described by the model of general spin trimer with antiferromagnetic exchange couplings \( -0.8 \text{ K}, -0.65 \text{ K}, \) and \( -0.25 \text{ K} \). The entropy removed in the measurement range represents the full magnetic entropy for spin-1/2 magnetic system suggesting a low level of frustration in title compound. This work has been supported, in part, by VEGA 1/0078/09, SK-CN-0008-09, NSFC (90922033).

11P-C030 Low temperature magnetism of PrF₃ single crystal, micro- and nanopowders
The “PrF$_3$-liquid $^3$He” system is of interest because of the possibility for using the magnetic coupling between the nuclei of the two spin systems for the dynamic nuclear polarization of liquid $^3$He. The resonance magnetic coupling between liquid $^3$He nuclei and the $^{111}$Pr nuclei of microsized (45 mkm) Van Vleck paramagnet PrF$_3$ powder has been discovered by authors$^1$. The series of nanoscopic samples (size 10 - 50 nm) of Van Vleck paramagnet PrF$_3$ were synthesized. The X-ray and HRTEM experiments showed high crystallinity of synthesized samples$^2$. The simulations of $^{111}$Pr NMR spectra are in good agreement with experimental data. At the first time, NMR in zero magnetic field was carried out on PrF$_3$ samples (including nanosized powders) on a specially built pulsed NMR spectrometer. This work is partially supported by the Ministry of Education and Science of the Russian Federation (FTP “Scientific and scientific – pedagogical personnel of the innovative Russia” GK- P900).


11P-C034 Heat Transport in the Quasi-One-Dimensional Alternating Spin Chain Material (CH$_3$)$_2$NH$_2$CuCl$_3$

Erik Wulf$^a$, Sebastian Mühlbauer$^a$, Tatiana Yankova$^a$, Vasily Glazkov$^b$, Dan Hüvonen$^c$, Andrey Zheludev$^a$.

$^a$Neutron Scattering and Magnetism Group, ETH Zürich, Zürich, Switzerland

We study the effect of bond randomness on the magnetic and thermodynamic properties of a geometrically frustrated $S = 1/2$ quantum spin ladder Sul-Cu$_2$Cl$_4$. The pure system is a gapped quantum spin liquid that in a magnetic field $H_c$ = 3.75 T experiences a quantum phase transition to an ordered helimagnetic state $^1$. Bond disorder is implemented by substituting chlorine for bromine on the non-magnetic halogen site in Sul-Cu$_2$(Cl$_{1-x}$Br$_x$)$_4$. Materials with $x < 0.1$ retain the original crystal structure but show quite different properties in applied fields. The main result is that for $x$ as low as $x = 0.0025$, the field-induced long-range ordering is disrupted. Instead, at $H_c$ one observes a crossover to a short-range ordered state. A new regime or phase is detected at $T > 0$, just below $H_c$. The extreme sensitivity to disorder is linked to the incommensurate nature of field-induced magnetic order in the parent compound. A novel mechanism for disorder in weakly-coupled one dimensional incommensurate systems is proposed.


11P-C032 Bond randomness in the frustrated spin ladder Sul-Cu$_2$(Cl$_{1-x}$Br$_x$)$_4$

Erik Wulf$^a$, Sebastian Mühlbauer$^a$, Tatiana Yankova$^a$, Vasily Glazkov$^b$, Dan Hüvonen$^c$, Andrey Zheludev$^a$.

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We study the effect of bond randomness on the magnetic and thermodynamic properties of a geometrically frustrated $S = 1/2$ quantum spin ladder Sul-Cu$_2$Cl$_4$. The pure system is a gapped quantum spin liquid that in a magnetic field $H_c$ = 3.75 T experiences a quantum phase transition to an ordered helimagnetic state $^1$. Bond disorder is implemented by substituting chlorine for bromine on the non-magnetic halogen site in Sul-Cu$_2$(Cl$_{1-x}$Br$_x$)$_4$. Materials with $x < 0.1$ retain the original crystal structure but show quite different properties in applied fields. The main result is that for $x$ as low as $x = 0.0025$, the field-induced long-range ordering is disrupted. Instead, at $H_c$ one observes a crossover to a short-range ordered state. A new regime or phase is detected at $T > 0$, just below $H_c$. The extreme sensitivity to disorder is linked to the incommensurate nature of field-induced magnetic order in the parent compound. A novel mechanism for disorder in weakly-coupled one dimensional incommensurate systems is proposed.


11P-C031 Size effect on magnetic properties of (La,Ca)MnO$_3$ nanoparticles

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Magnetic properties of La$_{1-x}$Ca$_x$MnO$_3$ nanoparticles (NPs), with particle size ranging from 12 to 42 nm for $x = 2/3$ and from 15 to 37 nm for $x = 0.8$, were studied. Reduction in the particle size suppresses antiferromagnetism and decreases the Neel temperature. Comparison of the results obtained for both compounds reveals some common features as well as significant differences. In particular, NPs of both $x = 2/3$ and 0.8 composition, exhibit an enhancement of weak ferromagnetism at $T > 200$ K that is linked to the reduction in the particle size. Moreover, magnetic hysteresis loops indicate size dependent exchange-bias effect. The temperature dependencies of magnetization of $x = 0.8$ composition show size dependent peak at orbital ordering (OO) temperature $T_{OO} = 153$ K for smaller 15 nm particles and $T_{OO} = 201$ K for larger 37 nm particles and two peak structure of ac-susceptibility, where high temperature peak is associated with establishment of orbital ordered AFM state. Such features are absent for $x = 2/3$ composition and for all particles one wide peak, associated with transition to AFM state, shows up. We suggest that the C-type AFM structure observed in bulk $x = 0.8$ composition is much more stable than the 2/3-type one in $x = 2/3$, resulting in surviving of OO even in 15 nm of $x = 0.8$ composition NPs and leading to an disappearance of any charge ordered state for $x = 2/3$ at particle size $\leq 42$ nm.

11P-C034 Heat Transport in the Quasi-One-Dimensional Alternating Spin Chain Material (CH$_3$)$_2$NH$_2$CuCl$_3$

V. O. Garlea et al., JETP Lett. 86, 416 (2007).
11P-C035  Fermionic representation and mean field theory for large spin models
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We generalized the fermionic representation for $S = 1/2$ to large spin models. We find that integer spin and half-integer spin have different symmetry groups. This fermionic representation is helpful to study large-spin quantum magnetism. For instance, the Heisenberg model can be decoupled with fermion hopping and pairing terms such that one can apply mean theory to study its low energy physics. We studied a frustrated $S = 1$ antiferromagnet on triangular lattice and found a spin liquid phase. We also generalized the Gutzwiller projection to $S = 1$ mean field states, and the result is fairly good in 1-dimension.

Collaborators: Tai-Kai Ng, Yi Zhou

11P-C036  Absence of Magnetic Order in Ising Honeycomb-Lattice Ba$_3$Co$_2$O$_6$(CO$_3$)$_{0.7}$
K. Igarashi*, Y. Shimizu*, E. Satomi*, Y. Kobayashi*, T. Takami*, M. Itoh*, aDepartment of Physics, Nagoya University, Nagoya, Japan

Ba$_3$Co$_2$O$_6$(CO$_3$)$_{0.7}$ is a rare example of Ising spin chains on honeycomb lattice. We have found the quasi-one-dimensional electric conduction and its localization at low temperatures below 100 K. The magnetic susceptibility exhibits highly anisotropic Curie-Weiss behavior with the Weiss constant of 69 K for the magnetic field parallel to the chain and $-104$ K for perpendicular to the chain, which indicates the intrachain ferromagnetic interaction and the interchain antiferromagnetic one. The specific heat $C$ and NMR measurements revealed no indication of magnetic order down to 2 K. Based on these experimental results, we discuss possibilities of weak localization, spin glass, and spin liquid states. The spin liquid state on the honeycomb lattice is supported by recent theoretical calculations considering the next-nearest neighbor interactions. A large $C/T$ value at the lowest temperature suggests a gapless spin liquid state. The result is in contrast to the ferromagnetic state induced by magnetic field in the Ising antiferromagnet Ca$_3$Co$_2$O$_6$ with spin $S = 2$.\footnote{Y. Shimizu, M. Horibe, H. Namba, T. Takami, and M. Itoh, Phys. Rev. B 82, 094430 (2010).}

11P-C037  Heat transport study of a layered spin-dimer compound Ba$_3$Mn$_2$O$_8$

Ba$_3$Mn$_2$O$_8$ single crystal, a layered spin-dimer compound exhibiting the magnetic-field induced magnetic order or the magnon Bose-Einstein condensation (BEC). The thermal conductivities ($\kappa$) along both the $ab$ plane and the $c$ axis show nearly isotropic dependence of magnetic field, that is, $\kappa$ is strongly suppressed with increasing field, particularly at the critical fields of magnetic phase transitions. These results indicate that the magnetic excitations play a role of scattering phonons and the scattering effects enhanced when the magnetic field closes the gap in the spin spectrum. In addition, the magnons in the BEC state of this materials do not show notable ability of carrying heat.\footnote{X. F. Sun, W. Tao, X. M. Wang, and C. Fan, Phys. Rev. Let. 102, 167202 (2009).}

11P-C038  Spin glass state in Kagomé antiferromagnet Co(NO$_3$)$_2$·(bpg)DMF$_{4/3}$
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The results of static, alternating susceptibility and specific heat of Co(NO$_3$)$_2$·(bpg)DMF$_{4/3}$ are reported. The studied material consists of Kagomé layers created by Co(II) ions linked by azido ligands. The layers are connected by bridging meso-$\alpha$, $\beta$-$\beta$-$\beta$-$\beta$-$\beta$(4-pyridyl)glykol(bpg) ligands creating a 3D network of exchange paths. The analysis of static susceptibility using Curie-Weiss law yielded $\theta = -165.8$ K revealing strong antiferromagnetic coupling. Sharp increase of effective magnetic mo-
ment below 16 K suggests a weak-ferromagnet state [1]. The transition to magnetically ordered state was confirmed by a small spike in specific heat observed at 16.5 K, which is suppressed by magnetic field. The behavior supports ferromagnetic nature of the ordered state. Systematic study of alternating susceptibility revealed frequency-dependent hump located at nominally 8 K. Its presence suggests that spins continue to fluctuate even below ordering temperature until spin-glass state is established. The analysis in terms of Cole-Cole formalism yielding $\alpha \approx 0.9$ confirms a wide distribution of relaxation times. The temperature dependence of the median relaxation time analyzed using dynamic scaling approach and modified Arhenius formula yielded for both approaches the value of the dynamical exponent $\nu \approx 4$ found in spin-glass systems.


11P-C039 NMR Study of Geometrically Frustrated Compounds $\text{Mn}_2\text{Br}((\text{OH})_3$

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NMR studies of $\text{Mn}_2\text{Br}((\text{OH})_3$ are carried out at low temperature to clarify the spin state. This compound shows two antiferromagnetic transitions$^1$ at 3.3K and 2.4K. In the antiferromagnetic phase less than 2.4K six proton NMR lines are observed in the frequency range from 8 to 29MHz. The existence of the peaks shows the order of Mn moments. The Mn magnetic moments point the peculiar directions in the local crystal axis. The line width is much broader than usual antiferromagnet. The broad line width shows the spin fluctuation of this compound. These results are similar to those of $\text{Mn}_2\text{Cl}((\text{OH})_3$. But the spin arrangement is not the same as $\text{Mn}_2\text{Cl}((\text{OH})_3$. With increasing temperature NMR frequency decreases similary to usual antiferromagnet. The decrease is caused by the decrease of thermal average of the Mn moment. But at $T > 2.0K$ the change in NMR frequency is not observed (independent of temperature). The reason is unknown. With increasing temperature the NMR intensities sharply decrease and disappear at 2.15K. In the antiferromagnetic phase between 2.4K and 3.3K any NMR signals are not observed in zero applied field.


11P-C040 Novel Field-Induced Quantum Phase Transition of the Kagome-Lattice Antiferromagnet

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The magnetization process of the $S = 1/2$ kagome-lattice quantum antiferromagnet is investigated using the numerical exact diagonalization up to 39-site clusters, in comparison with the triangular-lattice one. The finite-size scaling analysis$^4$ indicates the “magnitization ramp” phenomenon$^2$, as a novel field-induced quantum phase transition, at 1/3 of the saturation magnetization in the kagome-lattice system, while the conventional 1/3 magnetization plateau in the triangular-lattice one. The magnetization ramp is characterized by the following properties; (i) there is a single critical field $H_c$ (no plateau), (ii) the field derivative $dm/dH$ is divergent at the lower-field side, and (iii) $dm/dH$ is vanishing at the higher-field side. The spin gap issue of the kagome-lattice antiferromagnet is also studied by the numerical diagonalization up to 42-spin clusters$^3$. The finite-size scaling analysis suggests that the system has no spin gap (gapless), as well as the triangular-lattice one. Our present estimation of the critical exponent in the magnetization curve also supports the conclusion.


11P-C041 Low-Temperature Magnetization Study of Spin Gap System $(\text{CH}_3)_2\text{NH}_2\text{CuCl}_3$ with Nanometer Particle Size

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$^b$Department of Physics, Kyushu University, Fukuoka, Japan

$(\text{CH}_3)_2\text{NH}_2\text{CuCl}_3$ system have revealed that the magnetic field vs. temperature phase diagram depended significantly on the system size. For instance, the single crystal showed the spontaneous magnetic ordered (SMO) phase in low fields and the field induced (FIMO) one in high fields separated by the magnetization plateau range between 2.0 T and 3.5 T, while the powder sample with typically nanometer particle size showed a quite different trend that FIMO phase extended to zero field even in the presence of SMO phase in low fields. In this study, we measured dc and ac magnetization of single crystal and nanometer-size powder samples. Measurements were performed down to the lowest temperature of 0.5 K using commercial Quantum Design MPMS equipped with handmade $^3$He refrigerator insert. Most remarkable feature is that the 1/2 plateau was not observed clearly in the magnetization process for the nanometer-sized powder sample indicating the disappearance of the spin gap. Detailed results will be presented.

11P-C042 Ground State Properties of the $S = 3/2$ Three-Leg Heisenberg Tube

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The ground state properties of the $S = 3/2$ three-leg Heisenberg tube are studied using the effective model derived by the strong-coupling expansion and the density-matrix renormalization group method. We find that the spin excitation gap associated with a spontaneous dimerization opens in the entire region of the
Magnets

S. Nishimoto, Y. Fuji, and Y. Ohta, preprint cond-mat/1102.4559.

of the valence-bond-solid states depending on the ratio of the legs, in particular in the weak-coupling and intermediate-coupling regions. We thus argue that, unless the coupling of the rungs is significantly stronger than that of the legs, the gap may be quite hard to be observed experimentally. We also calculate the quantized Berry phase to show that there exist three types depending on the ratio of the coupling strengths between the legs and rungs. See Ref. [1] for details.


11P-C043 Low-Temperature Heat Transport of Spin Gapped Quantum Magnets


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Low-dimensional or frustrated quantum magnets were revealed to exhibit exotic ground states, magnetic excitations, and quantum phase transitions (QPTs). For a particular case of the spin-gapped antiferromagnets, the external magnetic field can close the gap in the spectrum, which results in a QPT between a low-field disordered paramagnetic phase and a high-field long-range ordered one. An intriguing finding is that this ordered phase can be approximately described as a Bose-Einstein condensation (BEC) of magnons. In this work, we study the low-temperature and high-field thermal conductivity ($\kappa$) of several spin gapped quantum magnets, including the quasi-one-dimensional $S=1$ chain compound $\text{NiCl}_2$-$4\text{SC(NH}_2\text{CHNH}_2\text{Cl})$, the layered spin-dimer compound $\text{Ba}_3\text{Mn}_2\text{O}_8$, and the ferromagnetic-antiferromagnetic alternating chain compound $\text{Cu}_3\text{Cl}_2\text{CHNH}_2\text{CuCl}_3$, etc. It is found that the magnetic excitations are commonly scattering phonons rather strongly in these materials; in some particular cases they can also act as heat carriers and make a substantial contribution to the heat transport.$^1$


11P-C044 Magnetic properties of disordered quasi-two-dimensional Heisenberg antiferromagnets

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We study the effect of bond disorder on the quasi-two-dimensional frustrated quantum Heisenberg antiferromagnet piperazinium hexachlorodicuprate (C$_4$H$_{12}$N$_2$Cu$_2$Cl$_6$, PHCC)$^1$. In an external magnetic field of $H_c \sim 10$ T, the disorder-free material undergoes a quantum phase transition to a magnetically ordered state, by virtue of a Bose-Einstein condensation of magnons. Bond randomness is introduced by partially substituting Cl$^-$ ions by Br$^-$. This affects the Cu-Cl-Cu superexchange pathways and therefore the spin interaction strengths. Concentrations of up to 10% Br are realized in well-characterized single crystal samples. With increasing bond randomization, the field-induced transition is replaced by a broad crossover to a short-range ordered state. This behavior is manifested in magnetic, calorimetric and neutron scattering experiments performed in magnetic fields up to 15 T. We interpret the results in terms of the formation of magnon Bose glass phase. It remains unclear whether a truly long-range ordered BEC phase survives in disorder PHCC at any field values.


11P-C045 Anomalous electronic states of hollandite-type transition-metal oxides

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We make the electronic structure calculations of transition-metal oxides with the hollandite-type crystal structure $A_xM_yO_{16}$ using the generalized gradient approximation (GGA) in the density functional theory, where the Hubbard-type repulsive interaction is taken into account (GGA+$U$). We examine the 3d series ($M=Ti, V, Cr, Mn$) as well as the 4d series ($M=Mo, Ru, Rh$) to discuss generic aspects in the electronic structure of hollandites first. Then, we in particular study the origins of the metal-insulator transition observed in K$_2\text{Ru}_x\text{O}_{16}$ and quasi-one-dimensional electron conduction observed in K$_2\text{Ru}_x\text{O}_{16}$ by focusing on singularities in their calculated band structures and Fermi surfaces [1,2]. We also study the electronic structure of K$_2\text{V}_x\text{O}_{16}$ to consider the origins of the observed anomalous electronic states and metal-insulator transition and find that the effect of electron correlations plays an essential role in the metal-insulator transition of this material [3,4].


11P-C046 Spin dynamics in a low-dimensional dipolar magnet CsGd(MoO$_4$)$_2$

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We study the effect of bond disorder on the quasi-two-dimensional frustrated quantum Heisenberg antiferromagnet piperazinium hexachlorodicuprate (C$_4$H$_{12}$N$_2$Cu$_2$Cl$_6$, PHCC)$^1$. In an external magnetic field of $H_c \sim 10$ T, the disorder-free material undergoes a quantum phase transition to a magnetically ordered state, by virtue of a Bose-Einstein condensation of magnons. Bond randomness is introduced by partially substituting Cl$^-$ ions by Br$^-$. This affects the Cu-Cl-Cu superexchange pathways and therefore the spin interaction strengths. Concentrations of up to 10% Br are realized in well-characterized single crystal samples. With increasing bond randomization, the field-induced transition is replaced by a broad crossover to a short-range ordered state. This behavior is manifested in magnetic, calorimetric and neutron scattering experiments performed in magnetic fields up to 15 T. We interpret the results in terms of the formation of magnon Bose glass phase. It remains unclear whether a truly long-range ordered BEC phase survives in disorder PHCC at any field values.

Magnetization, ac susceptibility and dc susceptibility of CsGd(MO$_3$)$_2$ single crystal have been investigated in the temperature range from 2 to 30 K, magnetic fields B|a from 0 to 5 T and frequencies from 0.5 Hz up to nominally 1 kHz. Previous specific heat studies in B=0 [1] revealed a phase transition to the magnetically ordered state at $T_c$=0.45 K and confirmed a spatial anisotropy of magnetic correlations expected from the crystal structure. The strength of intrachain and interchain dipolar coupling was estimated, $J$ the crystal structure. The strength of intrachain and interchain dipolar coupling was estimated, $J_1$/$K_B$ $\approx$ 0.6 K and $J_2$/$J_1$ $\approx$ 0.01, respectively. The temperature dependence of dc susceptibility obeys Curie-Weiss law with Curie temperature $\theta$=-0.8 K, reflecting the combined effect of dipolar coupling and crystal field. While ac susceptibility measured in B=0 implies only real part, in the field 100 mT, imaginary susceptibility, $\chi''$, appears, indicating a thermally activated relaxation process. The behaviour of $\chi''$ is nontrivial and potentially reflects two relaxation regimes separated by the frequency region of the order 10 Hz. The origin of the observed behavior is discussed.


The quantum magnet Cs$_2$CuCl$_4$ represents the spatially anisotropic version of a quasi-twodimensional triangular spin-1/2 Heisenberg antiferromagnet with moderate magnetic coupling constants. Of particular interest here are the anomalous physical properties which result from the interplay of strong quantum fluctuations and geometric frustration. Due to a weak interlayer coupling, long-range antiferromagnetic order occurs at $T_N$ = 0.62 K and $B$ = 0. The antiferromagnetic order can be suppressed to $T_N$ = 0 in a magnetic field $B_c$ $\sim$ 8.5 T (B||a), which constitutes a quantum-critical point (QCP). Anomalous physical properties at finite temperatures are expected to be observed at $B_c$ due to quantum-critical fluctuations. Here we present a detailed investigation of the longitudinal elastic constants $c_{11}$, $c_{22}$ and $c_{33}$ together with the ultrasonic attenuation near the $B$-induced QCP. Distinct anomalies were found at $B_c$, which are particularly strongly pronounced in the ultrasonic attenuation. In isothermal field sweeps performed at low temperatures 0.3 K $\geq$ $T$ $\geq$ 0.032 K and around $B_c$, the ultrasonic attenuation of the all three modes exhibits a pronounced double structure, indicating two anomalies of different origin. While one of them is very sharp, strongly temperature dependent and coinciding with $T_N(B)$, the other one is distinctly broader and located at slightly higher fields. Upon cooling both features merge and extrapolate to $B_c$ for $T$ = 0.

11P-C047 Ultrasonic investigations near the $B$-induced quantum critical point of the triangular antiferromagnet Cs$_2$CuCl$_4$


The quantum magnet Cs$_2$CuCl$_4$ represents the spatially anisotropic version of a quasi-twodimensional triangular spin-1/2 Heisenberg antiferromagnet with moderate magnetic coupling constants. Of particular interest here are the anomalous physical properties which result from the interplay of strong quantum fluctuations and geometric frustration. Due to a weak interlayer coupling, long-range antiferromagnetic order occurs at $T_N$ = 0.62 K and $B$ = 0. The antiferromagnetic order can be suppressed to $T_N$ = 0 in a magnetic field $B_c$ $\sim$ 8.5 T (B||a), which constitutes a quantum-critical point (QCP). Anomalous physical properties at finite temperatures are expected to be observed at $B_c$ due to quantum-critical fluctuations. Here we present a detailed investigation of the longitudinal elastic constants $c_{11}$, $c_{22}$ and $c_{33}$ together with the ultrasonic attenuation near the $B$-induced QCP. Distinct anomalies were found at $B_c$, which are particularly strongly pronounced in the ultrasonic attenuation. In isothermal field sweeps performed at low temperatures 0.3 K $\geq$ $T$ $\geq$ 0.032 K and around $B_c$, the ultrasonic attenuation of the all three modes exhibits a pronounced double structure, indicating two anomalies of different origin. While one of them is very sharp, strongly temperature dependent and coinciding with $T_N(B)$, the other one is distinctly broader and located at slightly higher fields. Upon cooling both features merge and extrapolate to $B_c$ for $T$ = 0.

11P-C048 Experimental Study of Magnetocaloric Effect in the Two-Dimensional Quantum System Cu(en)(H$_2$O)$_2$SO$_4$


Magnetocaloric study have been performed on a two-dimensional (2D)quantum system Cu(en)(H$_2$O)$_2$SO$_4$ (en=ethylendiamine=C$_2$H$_4$N$_2$) in the temperature range from 0.4 K to 4 K in magnetic fields up to 2 T by adiabatic magnetization and adiabatic demagnetization measurements. The title compound has been previously identified as a potential realization of the quasi-two dimensional spatially anisotropic triangular Heisenberg antiferromagnet with spin 1/2 and effective intralayer exchange coupling, $J/K_B$ = -1.4 K. A phase transition to magnetically ordered state has been observed in zero magnetic field at $T_N$ = 0.91 K. The normal magnetocaloric effect (MCE) was observed in the temperature range from 0.62 K to 0.98 K. In contrast, at temperatures near the phase transition the character of MCE changes to inverse. Above temperature 2 K the normal MCE was observed again. This change can be ascribed to the onset of short-range magnetic correlations previously observed in specific heat and susceptibility studies.

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11P-C049 Thermal Properties of Quasi-2D Cobaltites


Two classes of cobaltites with a quasi-2D magnetic structure, i.e. R BaCo$_2$O$_{2.5}$ perovskites and a LiCoPO$_4$ olivine, will be considered. In the first class, Co ions in different spin state and a metal-insulator phase transition not related to a double exchange mechanism occur. Thermal properties of its three representatives, with R being: Y (nonmagnetic), Gd (magnetic but not influenced by crystalline field, CEF) and Tb (magnetic and strongly influenced by CEF), will be compared. Different contributions to specific heat and specific heat anomalies accompanying phase transitions will be analyzed. The other class exhibits a large magnetoelectric effect, quasi-2D behavior and a large uniaxial magnetic anisotropy. Specific heat, magnetization, and magnetic torque studies of LiCoPO$_4$ will be presented. Near the Néel temperature, the specific heat shows logarithmic divergence, expected for quasi-2D antiferromagnetic Ising system. A not known first-order phase transition induced by a magnetic field of 9 T at 9 K,
discovered and proved to be related to steep change in magnetic anisotropy, will be presented. Work was partly supported by MNiSW 2047/B/H03/2008/34 and POIG.01.02-00-108/09 contracts.

11P-C050 Magnetization Process of S=1/2 Antiferromagnetic Trimer System

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The complex spin system produced by ferromagnetic/antiferromagnetic coupled cluster (dimer, trimer, tetramer, ...) has demonstrated attractive magnetic properties depending on various magnetic interactions between the clusters. We have studied magnetization process in two kinds of S=1/2 antiferromagnetic trimer with or without three-dimensional magnetic interaction between the trimers, Cs\textsubscript{2}Cu\textsubscript{3}P\textsubscript{4}O\textsubscript{14} and (Cs\textsubscript{2}N\textsubscript{2}H\textsubscript{4})\textsubscript{3}Cu\textsubscript{3}Cl\textsubscript{4}H\textsubscript{2}O. The magnetization processes using a pulse magnetic field up to 56 T at 4.2 K exhibit a common one-third plateau that of saturation magnetization caused by antiferromagnetic trimer system. The all magnetization process of (Cs\textsubscript{2}N\textsubscript{2}H\textsubscript{4})\textsubscript{3}Cu\textsubscript{3}Cl\textsubscript{4}H\textsubscript{2}O without the three-dimensional magnetic interaction between trimers can be explained using a simple S=1/2 trimer system with antiferromagnetic interaction (J/k\textsubscript{B}≈20 K). However, the unexpected magnetization process of Cs\textsubscript{2}Cu\textsubscript{3}P\textsubscript{4}O\textsubscript{14} with T\textsubscript{N} = 10 K cannot be described by the localized trimer model. The anomaly of specific heat at 10 K in a zero field shifts to lower temperature with increasing applied magnetic field and cannot be observed in the plateau region. We present the magnetic phase diagram of Cs\textsubscript{2}Cu\textsubscript{3}P\textsubscript{4}O\textsubscript{14} and the possibility of field-induced magnetic ordering under high magnetic field.

11P-C051 Orbital Ordering and Spin-Singlet Clusters in Triangular-Based Vanadates

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Orbital ordering on geometrically frustrated lattices has attracted great interests in strongly correlated electron system. However, the microscopic observation of the orbital ordering remains to be an intriguing issue. We report rare examples of the orbital order and spin-singlet formation in the triangular based vanadates, AV\textsubscript{10}O\textsubscript{15}, AV\textsubscript{13}O\textsubscript{18}, and AV\textsubscript{13}O\textsubscript{22} (A = Ba, Sr), probed by \textsuperscript{51}V NMR. These compounds have orbital degrees of freedom and itinerant electrons due to the partially occupied 3d \textit{t}\textsubscript{2g} orbitals. In BaV\textsubscript{10}O\textsubscript{15}, the single-crystal \textsuperscript{51}V NMR revealed the spin-singlet trimer and the antiferromagnetic tertramter formation accompanied by the orbital order. The result suggests the competition between charge ordering and Peierls instability to relieve completely the geometrical frustration. The spin-singlet cluster and paramagnetic sites were also found via the local spin susceptibility measurements in BaV\textsubscript{13}O\textsubscript{22},\textsuperscript{1} while only the spin-singlet V site was observed in AV\textsubscript{13}O\textsubscript{18} (A = Ba, Sr). These result highlight the orbital physics of the metal-insulator transition on the frustrated lattice.

11P-C052 Thermodynamic Properties of Heusler Compounds Ru\textsubscript{2−x}Fe\textsubscript{x}CrSi

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Full-Heusler compounds with a generic chemical formula X\textsubscript{2}YZ (X and Y are transition elements, Z is an sp element) attract much interests because this system shows a number of physical properties and some of them have a potential for the technological applications. We have measured specific heat C\textsubscript{p}(T) of Full-Heusler compounds Ru\textsubscript{2−x}Fe\textsubscript{x}CrSi with x = 0.1, 0.3, 0.5 which show spin-glass behavior in its magnetic properties\textsuperscript{1}

In C\textsubscript{p}(T) for each sample, a discontinuity indicating magnetic long range order is not observed at around temperature appearing a cusp-like peak anomaly in temperature dependence of magnetization M(T). As is well known, C\textsubscript{p}(T) of a spin-glass system does not have discontinuity.

For all x samples, C\textsubscript{p}(T) show quadratic-temperature dependence in low temperature range. This is in contrast to simple linear-T dependence for conventional a spin-glass material. The quadratic-temperature dependence of C\textsubscript{p}(T) may be associated with Almeida-Thouless (AT) transition.


11P-C053 Spin lattice relaxation of proton NMR in Mn formate di-urea single crystal at low temperatures

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We have performed pulsed NMR experiments on the nuclear spins of proton in Mn formate urea of a single crystal, Mn(HCOO)\textsubscript{2}·2(NH\textsubscript{2})\textsubscript{2}CO in the temperature range between 1.4 K and 4.2 K. Below the Neel temperature (T\textsubscript{N}=3.78 K), the temperature dependence of spin lattice relaxation time (T\textsubscript{1}) of proton NMR has been studied\textsuperscript{1}. The T\textsubscript{1} increases slightly as the temperature decreases from 2.1 K and it becomes a minimum value of 6.5 ms at 1.95 K. After that, it decreases as the temperature decreases. At around 1.68 K, it reaches a minimum and again increases with decreasing temperature. The intensity of spin echo signal shows also a minimum at the temperature where T\textsubscript{1} becomes the smallest value. Because half of moments of Mn\textsuperscript{2+} electronic spins are paramagnetic below T\textsubscript{N}, these results
suggest that the re-entrant phase transition may occur at around 1.68 K [2].


11P-C054 Magnetic and Thermodynamic Properties of Fe₂Cr₂Se₄
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Transport and magnetic properties of a seleno compound Fe₂Cr₂Se₄ have been investigated. Electric resistivity $\rho(T)$ shows insulator-type temperature dependence defined as $\partial \rho(T)/\partial T < 0$ in the range 2.5 $< T < 300$ K. At $T_N = 200$ K, $\rho(T)$ has an inflection point associated with antiferromagnetic order. A cusp-like anomaly appears at $T_N$ in temperature dependence of magnetization $M(T)$. $M(T)$ above $T_N$ can be reproduced by Mean field approximation of ferrimagnet, and an effective Bohr magneton $\mu_{eff} = 7.19$ is obtained from Curie constant $C$. This value is close to the calculated one ($\mu_{eff} = 7.35$ ) from Fe²⁺ (spin quantum value $S = 2$ ) and Cr³⁺ ( $S = 3/2$ ). In $T < 125$ K, $M(T)$ increases with decreasing $T$. This behaviour makes us expecting that other magnetic phase transition occurs at low temperature. Below 20 K, between the values of zero-field-cooled magnetization $M_{ZFC}(T)$ and field-cooled magnetization $M_{FC}(T)$ show differences. This might come from spin-glass freezing. A discontinuity which indicates magnetic phase transition is not observed in the temperature dependence of specific heat $C_P(T)$ in the range 1.5K $< T < T_N$, although $\lambda$-type anomaly appears at $T_N$.

11P-C055 Electronic States of Half-Metallic Chromium Oxides Proved by $^{53}$Cr NMR
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Half-metallic chromium oxides with high-valence chromium ions attract new interests from the aspect of unusual electronic states, which lead to fascinating physical properties, in 3d transition metal oxides with the negative charge transfer. Recently, K₂Cr₃O₁₆ was reported to undergo an unusual transition from a half metal to an insulator at 95 K in the ferromagnetic phase below 180 K. The ferromagnetic half-metallic state may be closely related to the electronic state as theoretically discussed on the half metal CrO₂. However, the electronic state of these chromium oxides remains an open issue. In this study, we have performed $^{53}$Cr NMR measurements to clarify the local electronic state of K₂Cr₃O₁₆ and CrO₂. In the ferromagnetic metal phase of both chromium oxides, we observed $^{53}$Cr NMR spectra coming from several chromium sites which are inconsistent with one chromium site on tetragonal lattice, the hollandite structure (symmetry I4/m) of K₂Cr₃O₁₆ and the rutile structure (P4₂/mnm) of CrO₂. This anomalous electronic state is discussed with the metal-insulator transition in K₂Cr₃O₁₆.

11P-C056 Effect of pressure on thermopower of EuNi₂Ge₂

EuNi₂Ge₂ is antiferromagnetic below $T_N \approx 30$ K with an effective moment $\mu_{eff} \sim 7.7$ $\mu_B$, indicating the 4f electron configuration (Eu²⁺) in the ground state. On the other hand, EuNi₂Si₂, where Eu is trivalent with the 4f⁰ electron configuration, indicates a temperature independent magnetic susceptibility. It is well known that the application of pressure and replacement Ge by Si have equivalent effects on the valence transition of EuNi₂Ge₂. In order to investigate the electronic state of EuNi₂Ge₂, we have simultaneously measured thermopower $S$ and electrical resistivity $\rho$ at the temperature range between 1.5 K and 300 K and under pressures up to 3 GPa. In the pressure region of $P \lesssim 2.3$ GPa, $\rho$ increases with increasing temperature, and shows an anomaly in the form of a kink at the Neel temperature $T_N$. $S(T)$ also reveals a kink at $T_N$. Both $\rho(T)$ and $S(T)$ curves indicate a small pressure dependence at the low pressure range. However, $\rho(T)$ and $S(T)$ curves in the low temperature region suddenly changes its feature at $P > 2.3$ GPa, where the magnetic ordering disappears. $\rho$ linearly decreases with decreasing temperature, and shows a sudden drop at the valence transition temperature $T_v \approx 30$ K. $S(T)$ also reveals a drastic increase at $T_v$, changing its sign from negative to positive around 35 K, and takes maximum at $T \approx 7$ K. The thermal hysteresis was clearly observed in both $\rho(T)$ and $S(T)$ curves around $T_v$.

11P-C057 Anisotropic Behavior of Thermal Conductivity in the Bose-Einstein Condensed State of the Bond-Alternating Spin-Chain System Pb₂V₃O₉
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We have measured the thermal conductivity along the [101], [101] and b* directions, $\kappa_{[101]}$, $\kappa_{[101]}$ and $\kappa_{b*}$, respectively, of Pb₂V₃O₉ single crystals in magnetic fields parallel and perpendicular to the heat current, to investigate the origin of the enhancement of the thermal conductivity in the state of Bose-Einstein condensation (BEC) of magnetic excitations, namely, triplyons. By the application of magnetic field along to the [101] direction, $\kappa_{[101]}$ parallel to the spin-chains, it has been found that $\kappa_{[101]}$ is markedly enhanced but neither $\kappa_{[101]}$ nor $\kappa_{b*}$ in the BEC state with increasing field at 3 K. It is concluded that the enhancement of $\kappa_{[101]}$...
11P-C059 Dimensional Crossover in Spin-1 Heisenberg Antiferromagnets: a Quantum Monte Carlo Study

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We present a quantum Monte Carlo study of the spin-1 Heisenberg antiferromagnet on a cubic lattice. The stochastic series expansion method is used to calculate equilibrium thermodynamic variables in the presence of an external magnetic field. In particular, the low temperature magnetization curve is investigated in the quasi-one-dimensional (Q1D), quasi-two-dimensional (Q2D), and three-dimensional (3D) limits. Starting from the 3D limit, the Q1D (Q2D) limit is achieved by reducing the in-plane (out-of-plane) spin coupling strength towards zero. In the Q1D limit, a Haldane gap appears in the magnetization curve at low magnetic field. Additionally, near the saturation field the slope of the magnetization curve increases substantially, approaching the infinite-slope behavior of a one-dimensional spin-1 chain. A similar (though less pronounced) effect is seen in the Q2D limit. We also study the effect of uniaxial single-ion anisotropy on the magnetization curve for Q1D and Q2D systems. Our results will be important in understanding the field-induced behavior of a class of low-dimensional Ni-based quantum magnets.

11P-C060 Magnetic and Electric Properties in the Distorted Tetrahedral Spin Chain System Cu_3Mo_2O_9

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We study the multiiferroic properties in the distorted tetrahedral quasi-one dimensional spin system Cu_3Mo_2O_9 and clarify that the antiferromagnetic order is formed together with ferroelectric properties at T_S = 7.9 K under zero magnetic field. In this system, the effects of the low dimensionality and the magnetic frustration are expected to appear simultaneously. We find that there are three different ferroelectric phases in the antiferroelectric phase and obtain the magnetic-field-temperature phase diagram in Cu_3Mo_2O_9 by measuring dielectric constant and spontaneous electric polarization when the magnetic field is applied parallel to the c axis. Around the tricritical point at 10 T and 8 K, the change of the direction in the electric polarization causes a colossal magnetocapacitance effect. We calculate the charge redistribution in the small spin cluster made from two magnetic tetrahedra to demonstrate the electric polarization induced by the antiferromagnetism.
The other model is a Kondo lattice model with Ising spins on a pyrochlore lattice. By large-scale Monte Carlo simulation using the truncated polynomial expansion technique, we find a series of distinct magnetic phases and their competition while changing the electron density and coupling constant.


11P-C062 Metal-insulator transition in Hollandite-type $K_2V_4O_{16}$ and $K_2Cr_3O_{16}$

Masahiko Ito,

The synthesis, structure and electromagnetic properties of Hollandite-type $K_2Cr_3O_{16}$ and $K_2V_4O_{16}$ are reported. In the crystal structures, the double chains of edge sharing $MO_6(M=V, Cr)$ octahedra share corners with neighboring chains to form a $M_8O_{16}$ stoichiometry framework that encloses large four-sided tunnels. The K$^+$ cation is located in the tunnels. These are mixed-valence compounds. Since the crystallographic site of vanadium and chromium atom is unique, the formal oxidation is $V^{4+}(M=V, Cr)$. We successfully obtained $K_2V_4O_{16}$ and $K_2Cr_3O_{16}$ by a high pressure synthesis. Combining electrical resistivity, magnetic susceptibility, and x-ray diffraction, we found that $K_2V_4O_{16}$ exhibits a first order metal-insulator transition at 170 K, accompanied by charge order of $V^{4+}$ and $V^{3+}$ and the formation of $V^{4+}-V^{4+}$ singlet pairs and $V^{4+}-V^{4+}$ pairs in the low temperature insulator phase. On the other hand, $K_2Cr_3O_{16}$ is a ferromagnetic metal with $T_C = 180$ K and shows a transition to an insulator at 95 K without an apparent structural change but retaining ferromagnetism.


11P-C063 Low-Temperature Multi-frequency ESR Study of Spin 1/2 Kagome lattice Antiferromagnetic Materials

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S=1/2 kagome lattice antiferromagnet has attracted much attention as a spin liquid system. And several new model substances, such as Herbertsmithite or Vollborthite, have been found recently. It is also an interesting system because it is considered to have stronger geometrical frustration than the well-studied triangular lattice antiferromagnet. Moreover, there are still theoretical discussions about the ground state of S=1/2 kagome lattice antiferromagnet whether it is a gapped or gapless spin liquid state. Therefore, ESR studies about the low temperature ground state in the model substance of S=1/2 kagome lattice antiferromagnet are very important. Results of multi-frequency ESR measurements of S=1/2 Kagome lattice antiferromagnetic materials material down to 1.8 K will be discussed.

11P-C064 Dzyaloshinsky-Moriya Interaction Estimated by AFMR of Kagome Like Substance $Cu_2O(SO_4)$ Observed at 1.8K

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Dolerophanite $Cu_2O(SO_4)$, is one of candidate substances for $S = 1/2$ Kagome like antiferromagnetic spin system. The magnetic susceptibility of powder shows weak ferromagnetic behavior below 15K, and different behavior with zero field cool and field cool. Estimated Weiss temperature $\theta = 187$K suggests existence of strong antiferromagnetic interaction between spins. From these results, it is anticipated that $Cu_2O(SO_4)$ has long range ordering below 15K. Existence of Dzyaloshinsky-Moriya (DM) interaction is expected from the crystal structure. To estimate the D term of DM, the multi-frequency ESR measurements have been performed using pulsed magnetic fields up to 16 T in the frequency range from 50 GHz to 315 GHz. Obtained frequency-field diagram at 1.8K shows typical AFMR model with DM interaction. It suggests that the weak ferromagnetism derives from DM interaction. We will report detailed results of ESR measurements and estimated D term of $Cu_2O(SO_4)$

11P-C065 Inelastic Neutron Scattering Study of Mg and Al Doped Two-Dimensional Triangular-Lattice Antiferromagnet CuCrO$_2$


CuCrO$_2$ has triangular-lattice layers of magnetic Cr$^{3+}$ ions separated from each other by non-magnetic layers of Cu$^+$ ions, which makes this compound a quasi two-dimensional (2D) triangular-lattice antiferromagnet with $S = 3/2$. Recently, it was found that small amount of element substitution strongly affects magnetic and transport properties. In the present study, we have studied magnetic excitations in Mg and Al doped CuCrO$_2$ by inelastic neutron scattering using
the chopper spectrometer AMATERAS at J-PARC. We will discuss the substitution effect on the spin dynamics in comparison with non-doped compound as well as Ag doped compound.\footnote{1\ Describe address: Research Center for Neutron Science and Technology, CROSS, Tohoku, Japan}


11P-C066 Spin-glass Transition in Bond-disordered Heisenberg Antiferromagnets Coupled with Local Lattice Distortions on a Pyrochlore Lattice

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Motivated by puzzling characteristics of spin-glass transitions widely observed in pyrochlore-based frustrated materials, we investigate effects of coupling to local lattice distortions in a bond-disordered antiferromagnet on the pyrochlore lattice\footnote{1\ For example, by using a recently developed classical Monte Carlo algorithm.} by using a recently developed classical Monte Carlo algorithm.\footnote{2\ We show that the spin-glass transition temperature $T_g$ is largely enhanced by the spin-lattice coupling $b$. As a consequence, $T_g$ becomes almost independent of $\Delta$ and is set by $b$ in a wide range of the disorder strength $\Delta$. The critical property of the spin glass transition is indistinguishable from that of the canonical Heisenberg spin glass in the entire range of $\Delta$. These peculiar behaviors are ascribed to a modification of the degenerate manifold from continuous to semidefinite one by the spin-lattice coupling. The results reproduce qualitatively many aspects of the spin-glass transition observed in the pyrochlore-based geometrically frustrated magnets such as (La$_{3}$Y$_{-2}$)$_{2}$Mo$_{2}$O$_{7}$ and (Zn$_{11}$)$_{2}$Cd$_{7}$Cr$_{2}$O$_{4}$.} 1, 2, 3. We show that the spin-glass transition temperature $T_g$ is largely enhanced by the spin-lattice coupling $b$. As a consequence, $T_g$ becomes almost independent of $\Delta$ and is set by $b$ in a wide range of the disorder strength $\Delta$. The critical property of the spin glass transition is indistinguishable from that of the canonical Heisenberg spin glass in the entire range of $\Delta$. These peculiar behaviors are ascribed to a modification of the degenerate manifold from continuous to semidefinite one by the spin-lattice coupling. The results reproduce qualitatively many aspects of the spin-glass transition observed in the pyrochlore-based geometrically frustrated magnets such as (La$_{3}$Y$_{-2}$)$_{2}$Mo$_{2}$O$_{7}$ and (Zn$_{11}$)$_{2}$Cd$_{7}$Cr$_{2}$O$_{4}$. 1, 2, 3.

11P-C067 Magnetic Ordering of Antiferromagnetic Trimer System 2b-3CuCl$_{2}$·2H$_{2}$O

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2b-3CuCl$_{2}$·2H$_{2}$O ($b$=betaine, C$_{2}$H$_{11}$NO$_{2}$) is a first candidate for two-dimensional $S=1/2$ orthogonal antiferromagnetic trimer system; Cu$^{2+}$ ions form trinuclear complexes which are normal each other. Removic-Langer et al.\ studied magnetic properties by means of magnetic susceptibility measurement and estimated intra- and inter-trimer magnetic interactions, $J_{\text{intra}}/k_{B} = -15$ K and $J_{\text{inter}}/k_{B} = -4$ K, respectively. We have performed specific heat and magnetization measurements under extreme conditions, low temperature and high magnetic field. The specific heat in a zero field shows a sharp peak at 1.38 K corresponding to a long-range magnetic ordering, $T_{N}$. The $T_{N}$ shifts remarkably to lower temperature and suppresses as the magnetic field increases. Above 5 T, the specific heat has no anomaly down to 0.15 K. Magnetizations at 1.3 K ($< T_{N}$) using pulse magnetic field increase linearly up to one-third that of saturation value ($M_{S} = g\mu_{B}/f.u.$), and then clearly exhibit a plateau behavior with increasing magnetic field between 5 and 14 T. In this plateau region with some energy gap, the magnetic ordering seems to be disappeared. As the magnetic field exceeds the plateau region, the magnetization is once linear up to the saturation value above 22 T. We present and discuss the magnetic phase diagram of 2b-3CuCl$_{2}$·2H$_{2}$O.

11P-C068 X-ray Photon Correlation Spectroscopy as a Probe for Magnetisation Dynamics in the Spin Ice, Holmium Titanate

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Probing spin dynamics using x-ray photon correlation spectroscopy (XPCS) is a field still in its infancy. To date, only a handful of studies of this kind have been carried out. However, there are many processes that occur in the dynamical range of XPCS that cannot be accessed by other techniques. One particularly interesting problem is the spin ice, holmium titanate. This compound exhibits residual magnetic entropy and has been found not to order at finite temperatures. Bulk susceptibility measurements give evidence for long-lived magnetic fluctuations which are also hinted at in neutron spin echo measurements, although they fall outside the measurement window. These correlations are believed to occur on timescales accessible to XPCS. Developing XPCS to probe these correlations gives an unprecedented microscopic view of these systems and sets out to elucidate the nature of the magnetic fluctuations. This presentation outlines the work carried out so far, focusing on the static magnetic scattering, and the roadmap for further XPCS investigation.


11P-C069 Theory of quantum spin ice for realistic magnetic pyrochlore oxides

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Recent experimental observations of quantum effects in variants of classical spin ice have urged intensive and extensive theoretical studies. Here, we derive a realistic quantum pseudospin-1/2 model for magnetic pyrochlore oxides characterized by Kramers/non-Kramers magnetic doulets of rare-earth ions, including Pr$_{2}$TiO$_{7}$ ($TM = Zr, Sn, Hf, Ir$) and Yb$_{2}$TiO$_{7}$ ($TM = Ti, Sn$). It contains three/two quantum-mechanical...
nearest-neighbor coupling constants of the superexchange origin, which appreciably reduce the symmetry of the model from U(1). Then, the model is investigated both analytically and numerically in comparison with experimental findings on the neutron-scattering profile and the magnetization curve. Various non-trivial quantum phases are found within a realistic range of the coupling constants, including an emergent U(1) spin liquid and dipole/quadrupolar orders. Role of quantum effects on magnetic monopoles are also discussed.

11P-C070  Vector spin chirality order and dynamical magnetoelectric effects in frustrated spin-1/2 chain systems

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We show by unbiased numerical calculations that in a frustrated spin-1/2 chain relevant to multiferroic cuprates including LiCu$_2$O$_2$ and LiCuVO$_4$, the ferromagnetic nearest-neighbor exchange interaction, which has been established by neutron-scattering experiments, stabilizes a vector spin chirality order and a quasi-long-range helimagnetic order against the quantum fluctuation. This explains why these multiferroic materials do not show a dimer ordering, which is expected in the case of the antiferromagnetic nearest-neighbor coupling. We also perform realistic semiclassical analyses for LiCu$_2$O$_2$ by taking into account interchain/Dzyaloshinskii-Moriya interactions. A reasonably nice agreement with overall experimental findings including neutron-scattering, NMR, and THz spectroscopy data has been found for a reasonable choice of coupling parameters. This resolves controversies on the helical magnetic structure of the material and unveils the pseudo-Nambu-Goldstone modes as the origin of experimentally observed electromagnons. [S. Furukawa, M. Sato, and S. Onoda, Phys. Rev. Lett. 105, 257205 (2010).]


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FeGa$_2$S$_4$ (A=Ni and Fe) shows a strongly two-dimensional layered triangular antiferromagnet with spin $S=1$ and $S=2$, respectively.\textsuperscript{1} So, the materials show no feature indicating a long-range order for the geometrical frustration of antiferromagnetic interaction. Instead, a freezing phenomenon below $T_f=16$ K is observed in case of FeGa$_2$S$_4$. Especially, transport techniques are useful for studying FeGa$_2$S$_4$ since it has smaller resistivity value than that of NiGa$_2$S$_4$. It is also reported that the energy gap estimated by resistivities of FeGa$_2$S$_4$ is linearly reduced by pressure ($P \leq 8$ GPa) and predicted to become zero around 15 GPa.\textsuperscript{2} Then, we applied the further pressure in FeGa$_2$S$_4$ in order to find novel phenomena of metallic state arose by disappearance of energy gap. As a result of the transport measurements of FeGa$_2$S$_4$ under pressure up to 30 GPa using diamond anvil cell, we could not observed metallic state but observed a large energy gap drop around 10 GPa. This may indicate development of 3D antiferromagnetic interaction under pressure. In our lecture, we will also present magnetization results and these crystal structures given by X-ray measurement under pressure to investigate interactions between layers.

11P-C072  Possible new temperature phase observed in GeCo$_2$O$_4$ spinel by high field ESR

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Magnetic ions Co$^{2+}$ in spinel compound GeCo$_2$O$_4$ from pyrochlore structure. As a result, three dimensional frustration is expected in GeCo$_2$O$_4$. Temperature dependence of specific heat and the magnetic susceptibility show anomalies at 20.6K due to AF transition. To investigate spin dynamics, high frequency ESR measurements of GeCo$_2$O$_4$ for $B||[100]$ is performed using the pulsed magnetic field. ESR spectra drastically change at $T_N=20.6$K and 3K. It strongly suggests that new temperature phase exists below 3K. Possible new temperature phase will be discussed in connection with this resonance. References J. C. Lashley et al., Phys. Rev. B. 78 (2008) 104406

11P-C073  Anisotropic magneto-transport properties of layered perovskite Sr$_3$Fe$_{2-x}$Co$_x$O$_7$-$\delta$ crystals

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The parent compound of this study, Sr$_3$Fe$_2$O$_7$-$\delta$ with layered structure, undergoes a metal-semiconductor transition at 350 K and then an antiferromagnetic one at 120 K. By substituting Co for Fe-site, the system has been reported to be a ferromagnetic (FM) metallic phase and show a negative magnetoresistance (MR). In this work, we have systematically investigated the magnetic and electronic properties of single-crystalline solid solution Sr$_3$Fe$_{2-x}$Co$_x$O$_7$-$\delta$ ($x = 0.2, 0.5$) by measurements of magnetization and resistivity as a function of temperature and magnetic field. By applying magnetic fields parallel to the $c$ axis, the magnetization of
Sr$_2$Fe$_{2-x}$Co$_x$O$_{7-\delta}$ ($x = 0.5$) shows a steep increase at 150 K. In contrast, it is not steep in the case of perpendicular to the $c$ axis. These results suggest that the $x = 0.5$ sample has a large magnetic anisotropy, and that an FM moment is easily aligned along the $c$ axis. On the other hand, the resistivity perpendicular to the $c$ axis is smaller than that parallel to the $c$ axis, as simply expected from the crystal structure. The resistivity perpendicular to the $c$ axis drastically decreases with increasing magnetic fields parallel to the $c$ axis. In contrast, that parallel to the $c$ axis hardly changes against magnetic fields along the same direction. Therefore, the negative MR perpendicular to the $c$ axis is much larger than that parallel to the $c$ axis.

11P-C074 Spin dynamics of a quantum-spin-liquid ZnCu$_3$(OH)$_6$Cl$_2$ probed by NMR

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In quantum spin-liquids, the interacting spins remain fluctuating down to absolute zero due to strong quantum fluctuations. High geometrical frustration combined with strong quantum fluctuations can help to stabilize such spin-liquid phases in dimensions larger than one. Mineral Herbertsmithite ZnCu$_3$(OH)$_6$Cl$_2$, a quantum ($S=1/2$) Heisenberg antiferromagnet on the kagomé lattice, is one of a few materials which host a two-dimensional spin-liquid. Various experimental techniques have identified its ground-state as a gapless (critical) spin-liquid with the power-law temperature dependence of spin-correlations. Now the focus lies on uncovering the origin and nature of this spin-liquid ground-state. We investigate the spin dynamics of Herbertsmithite in various magnetic fields up to 13 T using $^{17}$O NMR. Since oxygen locates on the superexchange path bridging Cu$^{2+}$ magnetic ions, $^{17}$O is an excellent probe to the spin-lattice dynamics intrinsic to the kagomé planes. We also present the $^{35}$Cl NMR results on oriented powder which elucidate the defect physics of Herbertsmithite. Clearly, these two nuclei probe provide complementary information essential to understand Herbertsmithite. We discuss the implications of our work in the context of theoretical proposals.

11P-C075 Collective spin states in lightly doped LaCoO$_3$

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We present results of electron spin- (ESR), nuclear magnetic resonance (NMR) and inelastic neutron scattering (INS) studies of single crystals of the lightly doped LaCoO$_3$. In contrast to undoped system, which is nonmagnetic at $T \lesssim 30$ K, a very small Sr$^{2+}$ doping ($x \approx 0.002$) yields a strong magnetization already at low $T$. $^{59}$Co NMR measurements indicate the formation of extended magnetic clusters in this temperature regime. ESR spectroscopy reveals multiple gapped resonance excitations with different g-factor values suggesting that magnetic clusters have a large spin multiplicity and substantial spin-orbital coupling. These results and INS data [see, A. Podlesnyak, et al., Phys. Rev. Lett. 101, 247603 (2008)], gives evidence that the cluster comprises 7 magnetic Co ions. We argue that the doped hole couples these ions ferromagnetically yielding a spin-state polaron with a huge local magnetic moment. Influence of different sorts of dopants on the polaron formation was studied.

11P-C076 The magnetic properties of Ce$_3$Pt$_4$ nanoparticles

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The Ce$_3$Pt$_4$ bulk with a Neel temperature near 2.8 K was fabricated by arc-method. The Ce$_3$Pt$_4$ nanoparticles were fabricated by plus-laser deposition method to research the size effect on the magnetic behavior of Ce$_3$Pt$_4$. The sizes of nanoparticles were estimated about 2.5 nm by HR-TEM. No antiferromagnetic order could be observed for nanoparticles between 2K and 300K by SQUID measurement. The Curie-constant of nanoparticles was about 0.04 (emu K) very smaller than the value of bulk (0.807 emu K). This result indicates the most Ce$^{3+}$ weretransformed to the Ce$^{4+}$. The similar behavior was also observed in the CeAl$_2$ and the CePt$_2$ nanoparticles. The specific-heat was measured to research the competition between RKKY interaction and Kondo effect in nanoparticles.

11P-C077 Antiferromagnetic Ordering in Genuine Organic Anion-Radical Salt (N-Me-2,6-di-Me-Pz)(TCNQ)$_2$ at Very Low Temperatures

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The (N-Me-2,6-di-Me-Pz)(TCNQ)$_2$ is a genuine organic anion-radical salt with layered structure consisting of [N-Me-2,6-di-Me-Pz]$^+$ cations and TCNQ$^-$ anions. Cation layers alternate along the $c$ axis with layers consisting of TCNQ$^-$ anion-radicals. It was shown that magnetic and thermodynamic properties of the sample can be described in terms of a spin-ladder model. We performed the measurements of heat capacity and dielectric properties from 2 K down to 50 mK in magnetic fields up to 9 T. We separated the lattice contribution to the total heat capacity and calculated the Debye temperature $\Theta_D \approx 61$ K. The specific heat data of (N-Me-2,6-di-Me-Pz)(TCNQ)$_2$ showed a sharp phase transition at $T_N \approx 90$ mK, indicating the possible onset of long-range order. Both specific heat and dielectric measurements under magnetic field also revealed that this phase transition is not due to charge ordering or structured phase transition but to magnetic ordering.
11P-C: C1 Low Dimensional and Frustrated Magnetism

11P-C078 One-Dimensional Short-Range Ordering of Bond-Alternating Antiferromagnetic Chains in F$_5$PNN

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Pentafluorophenyl nitronyl nitroxide (F$_5$PNN) is a pure organic magnet with $S=1/2$ bond-alternating Heisenberg antiferromagnetic chains. The field-induced 3D magnetic ordering between 3 and 6.5 Tesla intermediated by small interchain interaction has been confirmed by heat capacity studies. In this study, we have measured the ac magnetic susceptibility increasing field until by heat capacity studies. The heights of $\chi AC$ of F$_5$PNN single crystals in magnetic fields, in order to examine the short-range ordering in 1D chains, which should occur at higher temperatures prior to the 3D long-range order about 0.2 K. Below $H_{c1}=3$ T, exponential decreases of $\chi AC$ are observed, which indicate spin gaps due to dimer formation. The gap energy decreases with increasing field until $H_{c1}$. Between $H_{c1}$ and $H_{c2}$, a maximum of $\chi AC$ is observed at higher temperatures than the 3D ordering temperatures $T_D^{3D}$. The heights of $\chi AC$ maxima diverge in the vicinity of the critical fields with the critical index of 1/2, which agrees with short-range ordering expected for the 1D XY model. At $T_D^{3D}$, $\chi AC$ has no clear anomaly, which suggests that the 3D ordering occurs in spin components transverse to the field. Around critical fields, the boundary of 1D short-range ordered region defined by the maxima of $\chi AC$ depends almost linearly on applied fields, which agrees with Tomonaga-Luttinger liquid picture.


11P-C079 Finite size effects in the honeycomb lattice compound InCu$_2/3$V$_{1/3}$O$_3$

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We report the results of high field electron spin resonance, nuclear magnetic resonance and magnetization studies addressing the ground state of the quasi two-dimensional spin-1/2 honeycomb lattice compound InCu$_2/3$V$_{1/3}$O$_3$. Uncorrelated finite size structural domains occurring in the honeycomb planes are expected to inhibit long range magnetic order. Surprisingly, magnetic resonance data show the development of two collinear antiferromagnetic (AFM) sublattices below 20K and the presence of the staggered internal field. Magnetization data evidence a spin reorientation transition at 5.7T. Quantum Monte-Carlo calculations show that switching on the coupling between the honeycomb spin planes in a finite size cluster yields a Néel-like AFM spin structure with a substantial staggered magnetization at finite temperatures. [see, A. Yehia, et al., Phys. Rev. B 81, 060414 (2010)].

11P-C080 High-Field Magnetic Phase of the S=1/2 Frustrated Chain Antiferromagnet LiCuVO$_4$

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A new high magnetic field phase transition was found in magnetization measurements of the frustrated S=1/2 chain compound LiCuVO$_4$ just below the saturation field, which is about 45 T. This magnetic phase could be a spin nematic, resulting from a condensation of two magnon bound states. The spin-nematic phase was predicted theoretically in the S=1/2 linear chain model with the nearest neighbor ferromagnetic and the next nearest neighbor antiferromagnetic exchange interactions. From theoretical considerations, the nematic phase should be realized in a magnetic field range below saturation field. The slope of magnetization in the high field phase is in good agreement with a calculated in a realistic quasi 2-dimensional model of the spin-nematic phase. We compare the observed phase diagram with theoretical predictions and discuss the possibility of the spin nematic phase.


11P-C081 Micromagnetism and Spin Dynamics in Geometry Frustrated Magnets CuCrO$_2$ and CaBaCo$_4$O$_7$

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Transition metal oxides with geometry frustration have attracted considerable interest over decades. They commonly exhibit the persistence of strong spin fluctuations at low temperatures, which is critical to understand their physics. Here we report the investigation on the micromagnetism and spin dynamics of two typical geometry frustrated magnets, CuCrO$_2$ and CaBaCo$_4$O$_7$ by using electron spin resonance, magnetization as well as thermodynamic technique. The doping effect will also be discussed.

11P-C082 Dynamic Minor and Major Hysteresis Loops of New Ferromagnetic Oxi-halide System Co$_7$(TeO$_3$)$_4$Br$_6$

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New oxi-halide Co$_7$(TeO$_3$)$_4$Br$_6$ reveals sequence of magnetic orderings below $T_N$=34 K. Magnetism of this system is characterized by competing magnetic interactions dominated by strong single ion anisotropy energy of variously coordinated Co$^{2+}$ ions. We report
on interesting magnetic dynamics in the compound’s ferrimagnetic phase, \(T \leq T_C = 27\) K marked, at \(T_C\), by unusually big imaginary part of ac susceptibility. Effective parameters of the compound’s magnetism, notably a very large Arrenhius activation energy of 17.2 meV involved with domain wall dynamics, enable detailed studies of dissipative relaxations within experimentally favorable frequency window 0.05 Hz - 1 kHz. Cole-Cole plots are almost semi-circular, consistent with the validity of the Debye-relaxations model. Induction type hysteresis, in their transformation from minor to major loops, will be presented and interpreted within a simple model of thermally activated collective spin reversals. Associated dissipations is studied by imaginary susceptibility scanned by dc magnetic field ramping up and down.\(^1\)


11P-C083 Low temperature Raman study of the spin ladder compound BiCu\(_2\)PO\(_6\)

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Recently, quantum antiferromagnets with an intrinsically disordered (‘spin liquid’) ground state have attracted great interest. BiCu\(_2\)PO\(_6\) shows such a structure where the Cu spins form two-leg zigzag ladders providing a valuable model of quantum magnets. From a recent study details on the growth of undoped and Zn-doped single crystals, the structure, and the magnetic properties were published Bi(Cu\(_{1-x}\)Zn\(_x\))\(_2\)PO\(_6\). It was shown that the magnetic susceptibility \(\chi(T)\) passes through a broad maximum around 60K confirming the formation of a spin singlet ground state. In this study, we investigate the low temperature micro-Raman spectra of the BiCu\(_2\)PO\(_6\) single crystals. A detailed assignment of the observed bands is suggested based on the selection rules, the spectral evolution with temperature, and lattice dynamic calculations. Phonon modifications at low temperatures indicate a coupling of the lattice with the antiferromagnetic state. The Raman results are compared with the findings from other experimental methods and theoretical calculations.

\(^1\) E. Dagotto and T.M. Rice, Science 271, 618 (1996)

11P-C084 Influence of pressure on magnetization and magnetostriction jumps in the manganite (Eu,Gd)\(_{0.58}\)Sr\(_{0.42}\)MnO\(_3\)

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We have demonstrated the influence of external pressure on magnetization jump in Gd substituted Eu\(_{0.58}\)Sr\(_{0.42}\)MnO\(_3\). The collapse of magnetization jump of the Eu based manganite caused by the applied pressure up to 1.2 GPa is explained by a suppression of the metastable blocked state, which is inherent to the phase separated manganite system exhibiting the magnetic avalanche. On the other hand, the magnetization jump of the Gd substituted sample is enhanced under the same pressure. To further examine the nature of the magnetization jump, the influence of pressure on the isothermal magnetostriction of the Gd substituted manganite is carried out. These findings indicate the crucial role on the abrupt transition played by the frozen phase separated phase.

11P-C085 The effect of interchain coupling on multipolar phases in quasi-1D quantum helimagnets

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Coupled frustrated spin-1/2 chains in high magnetic fields described within the ferro-antiferromagnetic J\(_1\)-J\(_2\) Heisenberg model are studied by density-matrix renormalization group, hard-core boson, and spin wave theory approaches. Multimagnon and magnon bound states are destroyed (supported) by weak antiferromagnetic (ferromagnetic) interchain couplings J\(_{ic}\). We show that quantum spin nematics might be found for LiVCuO\(_4\) whereas for Li(Na)Cu\(_2\)O\(_2\) it is prevented by a sizeable antiferromagnetic J\(_{ic}\). Also for Li\(_2\)ZrCuO\(_4\) with a small antiferromagnetic J\(_{ic}\) expected triatic or quartic phases are unlikely, too. The saturation field is found to be strongly affected even by a relatively small J\(_{ic}\).


11P-C086 Ground State and Magnetic Excitations of S = 1/2 Kagome Antiferromagnets

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Kagome lattice antiferromagnet (KAFM) is well known as one of the geometrically frustrated system. For \(S = 1/2\) system, when we approach the ground state of KAFM using the dimer model, we can expect two kinds of quantum state. One is the resonating valence bond (RVB) state and the other is the valence-bond solid (VBS) state. Since both ground states are non-magnetic, we need to distinguish between the two by measuring the magnetic excitation using the inelas-
tic neutron scattering method. $A_2Cu_3SnF_{12}$ ($A = Cs$ and Rb) is the first experimental realization of $S=1/2$ KAFM whose single crystals are available. For $A=Rb$, the ground state is non-magnetic with finite excitation gap. For $A=Cs$, the system undergoes antiferromagnetic phase transition at $T_N = 20 K$. In order to investigate their ground states and magnetic excitations, we have performed inelastic neutron scattering experiments. For $A=Rb$, two singlet-to-triplet gaps are clearly observed at Brillouin zone center experiments. For $A=Rb$, two singlet-to-triplet gaps are

tions, we have performed inelastic neutron scattering
investigate their ground states and magnetic excitation

Spin glasses are frustrated many-body systems where
ferromagnetic and antiferromagnetic spin interactions

in zero-temperature mean-field spin-glass models

Spin glasses are frustrated many-body systems where
ferromagnetic and antiferromagnetic spin interactions

compete. There is a low-temperature ordering in spin-
glass models that seems difficult to be described by
standard tools of statistical mechanics. The order pa-
rameters of the glassy phase are not directly measur-
able and we succeeded in analyzing the susceptibility
data by the four spin cluster model with

11P-C089 The crystal structure and
magnetic properties of an organic verdazyl biradical.

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A verdazyl radical is known as one of the stable organic radicals but few examples are reported crystal structures. We will report the crystal structure and the magnetic properties of metaphenylenedisverdazyl biradical ($m$-Ph$_2$V$_2$). This compound was first synthesized by R. Kuhn et al. and preliminary magnetic susceptibility measurements were reported by N. Azuma et al. We succeeded in solving the crystal structure for the first time. We also examined the magnetic properties. The temperature dependence of the product of the magnetic susceptibility and temperature ($\chi(T)$), which is proportional to the square of effective magnetic moment, shows a round maximum at about 40 K and a stationary behavior at half the value of the room temperature in the temperature range of 4 - 7 K. In the crystal structure, the dimeric structure of molecules is noticeable and we succeeded in analyzing the susceptibility data by the four spin cluster model with $S = 1/2$.

We have estimated the intramolecular ferromagnetic interactions $J_1/k_B = -23 K$ and intermolecular antiferromagnetic interactions with $J_2/k_B = 31.5 K$ by using the Hamiltonian, $H = J_1(S_1 \cdot S_2 + S_3 \cdot S_4) + J_2(S_2 \cdot S_3)$. 

R. Kuhn, F. A. Neugebauer and H. Trischmann, Angew. Chem., 76, 691 (1964)

unknown apart from the asymptotic region below the transition temperature to the glassy phase. Even more, arguments have been raised recently about the relevance of the Parisi solution in the zero-temperature limit.\(^1\) We use an explicit representation of the Parisi free energy functional\(^2\) and perform an appropriate low-temperature scaling of its dynamical variables so that we end up with a zero-temperature total-energy functional with full continuous replica-symmetry breaking describing the ground state of mean-field spin-glass models.


11P-C091 Negative magnetization of Li\(_2\)Ni\(_2\)Mo\(_3\)O\(_{12}\) including two spin subsystems, distorted honeycomb lattice and linear chain

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Magnetization is usually positive because of the Zeeman energy. However, in some cases, magnetization can be negative. The negative magnetization has been studied extensively since Néel proposed a theoretical model possessing the negative magnetization.\(^1\) Several materials showing the negative magnetization have been discovered and several models explaining the negative magnetization have been proposed. We also found the negative magnetization in the spin-1 substance Li\(_2\)Ni\(_2\)Mo\(_3\)O\(_{12}\). The spin system consists of distorted honeycomb lattices and linear chains. Both spin subsystems have disorder (partial substitution by Li\(^+\) ions). A magnetic phase transition occurs at \(Tc = 8.0\) K. In low magnetic fields, the magnetization increases rapidly just below \(Tc\), decreases below 7 K, and finally becomes negative at low temperatures. To investigate the origin of the negative magnetization, it is important to determine the magnetic structure. We performed neutron powder diffraction experiments at HRPT and DMC diffractometers in PSI. The honeycomb lattices and linear chains show antiferromagnetic and ferromagnetic long-range order, respectively. We discuss the origin of the negative magnetization.


11P-C092 \(^{11}\)B-NMR study on Shastry-Sutherland system TtB\(_{4}\)

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The network of magnetic R ions in Rare-earth tetaborides RB\(_4\) (R = La-Lu) is characterized by orthogonal dimers equivalent to the Shastry-Sutherland lattice (SSL) with magnetic frustration.\(^1\) In RB\(_4\) systems, the coexistence of magnetic frustration, the quadrupole interactions and the RKKY interactions may result in an novel magnetic states. TbB\(_4\) shows a large magnetization jump at \(H_c = 15.9\) T for \(H // [100].\(^2\) To investigate the change of the magnetic structure with this jump, we measured the field dependence of \(^{11}\)B-NMR spectra under a wide field region around \(H_c\). Observed \(^{11}\)B-NMR spectra showed a drastic change at \(H_c = 15.9\) T, suggesting that the magnetic structure changes on the metamagnetic transition. We estimated the hyperfine field at each \(^{11}\)B-site by the classical dipole-dipole interaction to reproduce the observed NMR spectra. With an assumption of a spin model in accordance with the magnetization jump, the calculated spectra showed a qualitative agreement with an observation.

\(^{1}\) B.S.Shastry et al., Physica B 208, 1069 (1981).


11P-C093 \(^{11}\)B-NMR study on dimer-chain complex quantum spin system Cu\(_2\)Mo\(_3\)O\(_9\)

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The low dimensional quantum spin system Cu\(_2\)Mo\(_3\)O\(_9\) possesses two spin degrees of freedom, the antiferromagnetic chain denoted as Cu(1), and dimer-like site denoted as Cu(2) and Cu(3), which are crystallographically slightly inequivalent. These two spin degrees of freedom are interacting with one another, and are expected to bring a novel spin state at low temperatures. So far, it has been reported by T. H. that this system shows a Néel order at \(T_N = 7.9\) K, with a slightly canted spin structure.\(^1\) We have performed Cu-NMR study on a single crystal under a wide range of the magnetic field up to 16T. In the ordered state, the signal peak of the dimer-like site shows an anomalous splitting at high fields above \(H_c(4.2K) \simeq 8\) T, where a slight magnetization jump of 0.01\% was observed, indicating an existence of the field-induced phase transition. A prominent hysteresis in spectra depending on the field-sweeping direction was observed at the vicinity of \(H_c\), suggesting that the phase transition is of the first order and is involved in a spin-charge or spin-lattice coupling.


11P-C094 Novel Magnetic Order and Quantum Spin Fluctuations in d-Electron Magnetic Compounds of Hydroxyhalogenides M\(_2\)(OH)\(_3\)X Series

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In recent years, we identified unconventional magnetic transitions in a transition-metal hydroxyhalogenide series of deformed pyrochlore compounds M\(_2\)(OH)\(_3\)X,
where $M$ represents a d-electron magnetic ion such as Cu$^{2+}$, Ni$^{2+}$, Co$^{2+}$, Fe$^{2+}$, and Mn$^{2+}$ and $X$ represents the halogen ions. Many of them show unusual magnetic behaviours as we reported in related papers published in PRL and PRB. The hydroxyhalogenide compounds have many merits. First, dipolar interaction is negligible and the exchange interaction dominates, providing excellent reference systems for the rare-earth oxides. Secondly, this material category presents a complete series for spins $S = 1/2$ to $S = 5/2$. Thirdly, the lattice distortion can be controlled and adjusted using different halogen ions. Fourthly, the magnetic ions can be selectively replaced with a non magnetic ion to result in polymorphous triangular lattice compounds. Fifthly, many of them have polymorphous triangular lattice compounds. Here we will report recent development in investigating the diversal magnetic states exhibited by this materials series.

11P-C095  Inelastic neutron scattering study of S=1/2 kagome lattice single crystals

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Recent success in the single crystal growth of mineral Herbertsmithite paves the way in the search for quantum spin liquid in a 2D magnet. Single crystal Herbertsmithite displays a magnetic susceptibility that is anisotropic at high temperatures, indicating the presence of spin Hamiltonian terms in addition to the isotropic Heisenberg exchange. Synchrotron x-ray scattering puts restrictions on the proposed valence bond solid state and rules out the long debated Zn-Cu antitise disorder. Inelastic neutron scattering has been performed and the observed dynamic structure factor is consistent with a spin liquid ground state. Application of a magnetic field induces a spectral weight shift which provides additional information on the long debated role played by the interlayer non-magnetic impurities.

11P-C096  Magnetic Properties of the S=2 Heisenberg Antiferromagnetic Chain Compound MnCl$_3$(bpy)

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We report the experimental results of magnetic susceptibilities at temperatures between 2 and 300 K, and high-field magnetization in magnetic fields of up to 52 T on a powder sample of MnCl$_3$(bpy) (bpy=2, 2'-bipyridine). This compound is one of the rare examples of the spin 2 quasi-one-dimensional Heisenberg antiferromagnet, and the magnetic properties on tiny single crystal samples were reported previously. The temperature dependence of magnetic susceptibility and the magnetization curve after subtracting the contribution of magnetic impurity are well fitted to those calculated by a quantum Monte Carlo method (up to 96 and 97% with periodic and open boundary conditions, respectively) with $J/k_B$=31.2 K and $g$=2.02 which are comparable to reported values ($J/k_B$=34.8±1.6 K and $g$=2.04±0.04).


11P-C097  Field-Induced Gap in Quantum Spin-1/2 Chains in Strong Magnetic Fields

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The low-temperature excitation spectrum in copper pyrimidine dinitrate, a spin-1/2 antiferromagnetic chain with alternating g-tensor and Dzyaloshinskii-Moriya interactions that exhibits a field-induced spin gap, is probed by means of ESR spectroscopy in magnetic fields up to 63 T. In particular, we report on a minimum of the gap in the vicinity of the saturation field $H_{sat} = 48.5$ T associated with a transition from the sine-Gordon region (with soliton-breather elementary excitations) to a spin-polarized state (with magnon excitations). This interpretation is fully confirmed by the quantitative agreement over the entire field range of the experimental data with the DMRG calculations for spin-1/2 Heisenberg chain with a staggered transverse field. This work was partly supported by the DFG and EuroMagNET II.


11P-C098  Orbital fluctuations and orbital order below the Jahn-Teller transition in Sr$_3$Cr$_2$O$_8$


We report on the magnetic and phononic excitation spectrum of Sr$_3$Cr$_2$O$_8$ determined by THz and infrared (IR) spectroscopy, and electron spin resonance (ESR) measurements across the Jahn-Teller (JT) transition,
which is detected by specific-heat measurements to occur at \( T_{JT} = 285 \) K. We identify the singlet-triplet excitations in the dimerized ground state and estimate the exchange couplings in the system. ESR absorptions were observed up to \( T^* = 120 \) K with a linewidth orbital state of the Cr e doublet in the orbitally ordered state. Upon entering the low-symmetry JT distorted phase below \( T_{JT} \), we find an extended regime \( T^* < T < T_{JT} \) where the IR active phonons change only gradually with decreasing temperature. This regime is associated with strong fluctuations in the orbital and lattice degrees of freedom in agreement with the loss of the ESR signal above \( T^* \). Using the measured magnetic and phononic excitation spectrum we model the orbital contribution to the specific heat and find the persistence of strong fluctuations far below \( T_{JT} \).

11P-C099 Competing Interactions and Continuum Excitations in the Spin-1 Triangular Lattice Antiferromagnet NiGa\(_3\)S\(_4\)

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Quasi-2D NiGa\(_3\)S\(_4\) is the only known S=1 antiferromagnet with an exact triangular lattice. Recent neutron scattering experiment on high quality NiGa\(_3\)S\(_4\) single crystals revealed short range quasi-2D incommensurate spin correlation with a critical wavevector close to \((1/6, 1/6, 0)\). Here we report a measurement of the dynamic spin correlation function through a volume of Q-E space for \( T < \xi \). A gapless spectrum was observed at the incommensurate critical wavevector while a softened but still gapped response was found at \((1/3, 1/3, 0)\). This indicates dominant third neighbor interaction and competing weaker near neighbor interactions. The excitation spectrum takes the form of a bounded continuum throughout the 2D Brillouin zone, which is quite different from conventional resonant spin waves. This work is supported by the DoE, BES, Division of Material Science and Engineering through DE-FG02-08ER46544.

11P-C100 Majorana Fermion Representation of Gapless Spin Edge

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In an fermionic representation and the bond-operator mean-field theory associated with it, we study the spin edge state of the spin 1 system with open boundaries. The gapless spin edge state is re-expressed as the Majorana fermion state in the auxiliary representation. We first verify the picture in the well-known one-dimensional spin 1 bilinear-biquadratic chain. Then we generalize it to the two-dimensional system with open boundaries in one direction. The zero energy nature of the excited fractional spin edge is well captured in our theory.

11P-C101 Two-Dimensional Antiferromagnetic Fractons in Rb\(_2\)Mn\(_{8}\)Mg\(_{1-\epsilon}\)F\(_4\) with \( \epsilon \) close to the percolation concentration

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An inelastic neutron scattering experiment on the two-dimensional Heisenberg antiferromagnet Rb\(_2\)Mn\(_{8}\)Mg\(_{1-\epsilon}\)F\(_4\) with \( \epsilon \) close to the percolation concentration was performed at \( 1.5K \) well below \( T_N = 19.5K \) using the IRIS spectrometer at ISIS with the energy resolution of \( \Delta E = 17.5\mu eV \). The dispersion relation of observed magnetic fractons was well fitted to \( E(q) = q^2z \) with \( z = 1.8 \pm 0.1 \). The dynamical exponent \( (z = Df/d) \) was in very good agreement with the fractal dimension \( Df \) for this system, and therefore the spectral dimension was concluded to be \( d = 1 \), as predicted by the numerical study. Also, the peak intensity of observed magnetic fractons was well fitted to \( A(q)q^{-y} \) with \( y = 2.9 \pm 0.1 \). In the single-length-scaling postulate (SLSP), the dynamical structure factor can be scaled as \( S(q,\omega) = q^{-y\beta}F[q\Lambda(\omega)] \) with an energy dependent length scale, \( \Lambda(\omega) \). Assuming \( \Lambda(\omega) \omega^{-1/2} \) and using the determined values of \( y \) and \( z \), this scaling was confirmed.

11P-C102 Decay of helical magnons and spectral weight transfer in ferrates

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A theoretical description of the helical magnetic order and spin dynamics in 3D is discussed. Inelastic neutron scattering intensity as a function of wave vector and energy is calculated and compared with the experimental data in SrFeO\(_3\) and CaFeO\(_3\). Spectral weight transfer due to coupling of single magnon excitations to two magnon continuum is found.

11P-C103 Field-anisotropy phase diagrams of some frustrated magnets

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We study the zero temperature phase diagram of some frustrated spin-1/2 Heisenberg spin models as a function of spatial anisotropy and magnetic field. Using a combination of techniques, including a semiclassical expansion, a dilute spin flip approximation, and a renormalization group method based on coupled chains, different scenarios for ordered states and quantum phase transitions are discussed. Our results are compared with experimental and numerical results.

11P-C104 Monte Carlo Study of Spin-Peierls Transition in Quasi-One-Dimensional Heisenberg Model with
11P-D: D1 Superconducting Devices/Qubits
Thursday August 11, 16:00 – 18:00
Exhibition Hall 1

11P-D001 Quantum oscillations of the surface impedance of a layered conductor
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We have analyzed the propagation of electromagnetic waves in layered conductors placed in a quantizing magnetic field, orthogonal to the layers, in a wide range of frequencies at low temperature. By means of the Kubo method we have derived the surface impedance of a layered conductor with the Q2D electron energy spectrum under the condition when the elastic scattering by short-range impurity centers is a main relaxation mechanism in the electron system. In the whole frequency range the Q2D character of the electron energy spectrum results in occurrence of different types of oscillations of the impedance as a function of the inverse mag-

11P-C105 Magnetic properties in the doped spin-1/2 honeycomb-lattice compound In$_3$Cu$_2$VO$_9$
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We report the magnetic properties in the Co- and Zn-doped spin-1/2 honeycomb-lattice compound In$_3$Cu$_2$VO$_9$. The magnetic susceptibility and specific heat experiments of In$_3$Cu$_2$VO$_9$ show no magnetic ordering down to 2 K. Approximately $T^2$-dependent magnetic specific heat and linearly $T$-dependence spin susceptibility at low temperature range were observed in In$_3$Cu$_2$VO$_9$, suggesting a spin liquid candidate with a $S = 1/2$ honeycomb lattice. When Cu$^{2+}$ ions are partially substituted by Co$^{2+}$ ions, both impurity potential scattering and magnetic impurity scattering induced by magnetic Co$^{2+}$ ions break the homogenous spin-singlet spin liquid state, releasing the AFM long-range correlation. While replacing Cu$^{2+}$ ions with nonmagnetic Zn$^{2+}$ ions, the antiferromagnetic correlation between Cu$^{2+}$ ions is destroyed, leading to suppression of low-dimensional magnetic properties.

11P-C106 Disorder in quantum magnets: from Random Singlet to Bose Glass.
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Traditionally, Hamiltonian disorder in spin systems was studied in the context of its effect on magnetic long-range ordering. Hence the interest in spin glasses, percolation and random-field effects. However, in a vast class of “quantum” magnets, ordering is destroyed by zero-point quantum spin fluctuations even in the unperturbed case. In these materials all spin correlations are dynamic. Therefore, the effect of Hamiltonian disorder is to be discussed in terms of its influence on excitations. Theory predicts a range of phenomena, from reduced quasiparticle lifetimes, to Anderson localization of magnons, to universal scaling of the dynamic spin correlation and transport functions. Particularly dramatic is the effect on spin systems that are either at a quantum critical point or can be brought to one by the application of an external magnetic field or pressure. In these “hypersensitive” cases, qualitatively new quantum phases are expected to emerge. Realizations of disordered quantum magnets suitable for experimental investigation are recent and still few, but steady progress is being made. The elusive “Random Singlet” phase has been identified in the random-bond $S = 1/2$ chain system BaCu$_2$SiGeO$_5$. Evidence of the “magnon Bose Glass” was found in several metallic materials based on Cu-halogen networks with bond disorders. I shall review some of these studies, including thermodynamic, NMR, $\mu$-SR and neutron scattering experiments, setting the stage for several contributed presentations and the Conference.
magnetic field value: fundamental harmonics possessing a form of beatings, and low-frequency oscillations which have smaller amplitude but decay weakly with temperature. The low-frequency fraction of the quantum oscillations might be observed at such temperatures when the basic harmonics are utterly small. The dependencies on the wave frequency of the amplitude and phase of both types of the oscillations are found, which allows to mark out various regimes of the electromagnetic wave absorption. Besides that, the specificity of the electron spectrum of layered conductors gives rise to the quantum oscillations of the transparency of thin specimens whose thickness does not exceed the electron free path length. These oscillations are related to the weakly attenuating Reuter-Sondheimer waves which propagate with the extreme velocity of electrons motion along the normal to the layers.

11P-D004 Direct characterization of noise processes in superconducting microresonators
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NTT Basic Research Laboratories, Japan
We have studied the frequency noise of superconducting on-chip microresonators using techniques borrowed from precision frequency metrology. By using a so-called Pound locking technique we are able to track the shift in the centre frequency of the resonator which is caused by interaction with the environment. We analyze the data in the time and frequency domain. We demonstrate how the Allen deviation (ADEV) provides valuable additional information about the noise processes present in the resonator, as well as the timescales over which they act. We have used this technique to study lumped element resonators made from Niobium, with and without an extra dielectric layer deposited over the capacitor, in the temperature range 30-800 mK and at low powers. We show that flicker frequency noise dominates at short and long timescales, but that random walk noise is important over intermediate timescales. Our results provide insights into the processes that for example affect the noise level in kinetic inductance detectors, as well as limiting the coherence time in solid state quantum information processing.

11P-D002 Development of Ultra-low Noise nanoSQUIDs using FIB for Quantum Measurement
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The demands of quantum metrology and nanoscience are driving the requirements for single particle detection capability across a wide variety of physics, including QIP, single photon detection, NEMS, nanomagnetism and spintronics. NanoSQUIDs represent a new manifestation of an old but exciting superconducting technology which addresses some of these requirements. We have fabricated different types of Nb nanoscale SQUIDs with loop size down to 100nm using nanobridge weak-links (~50nm) as Josephson junctions, utilising a relatively simple FIB-based approach. These devices show non-hysteretic IVCs and very low noise even at operating temperatures at 4.2K and above (white noise at 1kHz ~ 0.2 μV/√Hz1/2 at 7K). A single nanomagnetic particle e.g. PtFe bead and NEMS resonator have been incorporated into the nanoSQUID system using micro/nano manipulation and FIB techniques. The performance of prototype devices will be described for applications such as energy resolving single photon detection, nanoparticle spin detection1 and NEMS resonator readout2.

11P-D003 Strong Interaction Between a Single Artificial Atom and Propagating Microwave Photons
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We have experimentally investigated a single superconducting three-level artificial atom strongly coupled to a superconducting one dimensional open transmission line. We have observed strong coupling between the artificial atom and propagating microwave photons, revealed by the high degree of scattering of an incident microwave field. By exploiting the phenomenon of electromagnetically induced transparency (EIT), we can route a single photon signal from an input port to either of two output ports with an on-off ratio of approximately 90%. The switching time of the router is shown to be a few nanoseconds, consistent with theoretical expectations and the device parameters. Besides the router, we also observed some fundamental phenomena of the single atom, such as strong nonlinearity, anomalous dispersion and the Mollow triplet.

11P-D005 Temperature Dependence of Driven Duffing Oscillators
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We investigate the temperature dependence of the stationary distribution for the Driven Duffing Oscillator (DDO). We focus on the fragility of the zero temperature solution. This unusual phenomenon means that the probabilities over the two stable vibrational states will endure an abrupt change in the presence of a small temperature. In this work, we first numerically demonstrate the fragility of the zero temperature solution. Realizing that this is due to the violation of the de-
11P-D006  Effects of dissipative electromagnetic environment on transport properties of hybrid single-electron transistor in Coulomb blockade regime

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We study low temperature transport properties of a hybrid single-electron transistor, consisting of a superconducting island and normal-metal electrodes, in the Coulomb blockade regime. We derive analytic expressions for the elastic and inelastic cotunneling currents, which exhibit power law suppression induced by the dissipative electromagnetic environment. The results can be used to improve the accuracy of hybrid devices employed in electrical metrology and for noise measurements in quantum information processing.


11P-D007 Observation of Andreev Tunneling Effects in Current Pumping with SINIS turnstiles

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A top priority in metrology is to develop measurement standards that are based on fundamental physical constants. Although such standards exist for resistance and voltage (the quantum Hall effect and the Josephson constants), although such standards exist for current, they are not as widespread and are not as well accounted for by numerical simulations. We can control this Andreev process by tuning the charging energy of the normal island. Raising the charging energy effectively suppresses the tunneling. Understanding and eliminating error processes in these turnstiles is vital for the achievement of a quantum metrological triangle (QMT) measurement, a key goal in metrology. In closing the QMT, the three standards of voltage, resistance and current would be compared against each other via Ohm’s law.

11P-D008 Breakdown of Adiabaticity and Role of the Environment in a Cooper-Pair Pump

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The Cooper-pair sluice is an all-superconducting charge pump consisting of a single-electron transistor with tunable Josephson junctions. Past theoretical and experimental investigation mainly focused on its operation in the adiabatic regime. The geometrical nature of the charge pumped in a closed-loop configuration was recently exploited for a measurement of the Berry phase. Starting from the adiabatic picture, we have moved forward and carried out our measurements at the onset of adiabaticity breakdown. Our results demonstrate that coupling to the environment effectively extends the adiabatic behavior to higher-frequency regimes, in agreement with recently developed theory.

11P-D009 Superconductor-normal metal single-electron trap in a combined on-chip RC-environment

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Growing interest is observed to single-electron pumping with the help of an rf-driven single electron transistor built on two superconductor-insulator-normal metal (SIN) hybrid tunnel junctions. It was shown that the attainable accuracy of such a pump is exposed to a nonequilibrium quasiparticles problem, arising due to the quantum noise of the electromagnetic environment. It was also found that the microwave photons emitted by environment could be efficiently filtered out by either resistive (R) or capacitive (C) passive on-chip elements. In the present work, we will focus on combined effect of different on-chip RC-topologies on the retention time of a two-junction hybrid single-electron SINIS trap, which we adopt as a figure of merit for various experimental environments. Local and global environment is assessed for its significance for quasiparticle generation.


11P-D010 Enhanced Josephson coupling in PbIn-based graphene proximity junction

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A superconductor-graphene (SG) hybrid system pro-
vides a unique platform to study the relativistic electrodynamics of Dirac fermions in graphene, combined with the superconductivity. Successful realization of a superconductor-graphene-superconductor (SGS) junction is the first step toward the observation of the relativistic quasiparticle behavior. However, the often-adopted superconducting electrode material, Al, provides low superconducting transition temperature and energy gap. To overcome the shortcomings, we fabricate proximity-coupled superconducting junctions consisting of a graphene sheet in contact with Pb₁₋ₓInₓ (x=0.07) electrodes. A much higher superconducting transition temperature (Tc ≈ 7.0 K) and a larger superconducting energy gap (ΔPbIn ≈ 1.1 meV) of Pb₁₋ₓInₓ alloy allow the observation of the Josephson supercurrent for temperatures as high as 4.8 K with a large value of the IcRn product of ∼255 μV, an order of magnitude higher than that for Al-based SGS junctions. Magnetic-field and microwave responses of the junction yield direct evidences for genuine Josephson coupling through graphene. Multiple Andreev reflection is also observed in the subgap structure of the differential conductance (dI/dV).

11P-D011 Electron co-tunneling transport in gold nanocrystals arrays


Arrays of metallic, semiconducting, or magnetic nanoparticles with radii of 2 – 7 nm can now be synthesized. Owing to their small self-capacitance, the charging energy for electron hopping between nanoparticles is large, of the order of 0.1 eV. Thus, these systems are ideally suited for the study of correlated electronic diffusion in presence of both disorder and strong Coulomb interactions. We describe low temperature current-voltage characteristics measurements of alkyl-ligated ~ 5 nm gold nanoparticles arrays in long screening length limit. Tailoring the length of the alkyl ligands surrounding the nanoparticles allows to tune the electronic tunnel coupling between the nanoparticles. For long ligands, i.e. weak tunnel coupling between the nanoparticles, the conductance follows an activated behavior with temperature ∝ exp(−T0/T) and electrical field ∝ exp(−E/F). For short ligands, i.e. large tunnel coupling, the dependence on temperature and electric field of the conductance crossover to Efros-Shklovskii type formulas ∝ exp(−T0/T)^1/2 and ∝ exp(−E/F)^1/2. This shows that, at low temperature and for large enough tunnel coupling, the electronic transport in metallic nanoparticles arrays occurs through electron cotunnelling.

11P-D012 Phase measurement in strong Kondo regime in a self assembled InAs dot superconducting quantum interference device

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11P-D013 Proposal for an optical laser producing light at half the Josephson frequency


We study the emission of visible laser light by a superconducting device at half the Josephson generation frequency. The device consists of a single mode optical cavity containing a p-n semiconductor nanowire that is attached to superconducting leads. Two quantum dots are embedded in the nanowire via which emission of photons by electron-hole recombination can occur. The cavity induces a phase locking between optical phase and superconducting phase difference. Spontaneous switchings within the device are studied as a source of decoherence. These switchings guarantee stationary lasing states for suitable parameter regimes.

11P-D014 Statistics of temperature fluctuations in superconductor-normal metal tunnel structures

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Recently, temperature fluctuation statistics has been studied in non-interacting islands, and overheated single-electron transistors. Here we present a detailed study of the fluctuating temperature on a normal metal
island coupled by tunnel junctions to two superconducting leads, forming a so called SINIS structure. We also study the effect of these temperature fluctuations on the noise of the electric current through the structure. We find that near the threshold voltage, $V = 2\Delta$, fluctuations of temperature are large compared to the temperature of the normal metal island. These fluctuations give rise to large fluctuations in the electric current, with a noise power that can exceed the intrinsic current fluctuations by a factor of $10^2$. We also find that due to the cooling effect in SINIS structures the island temperature is low enough that the effect of the electron–phonon coupling to these results is negligible in practical devices.

11P-D015 Statistics of voltage fluctuations in resistively shunted Josephson junctions

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The intrinsic nonlinearity of Josephson junctions converts Gaussian current noise in the input into non-Gaussian voltage noise in the output. For a resistively shunted Josephson junction with white input noise we determine numerically exactly the properties of the few lowest cumulants of the voltage fluctuations, and we derive analytical expressions for these cumulants in several important limits. The statistics of the voltage fluctuations is found to be Gaussian at bias currents well above the Josephson critical current, but Poissonian at currents below the critical value. In the transition region close to the critical current the higher-order cumulants oscillate and the voltage noise is strongly non-Gaussian. For coloured input noise we determine the effect of “lasing without inversion”. It arises since the coupling to the dissipative environment enhances photon emission as compared to absorption, similar to the recoil effect which was predicted for atomic systems. While the recoil effect is very weak, and so far elusive, the effect described here should be observable with present circuits. We analyze the requirements for the system parameters and environment.

11P-D017 Terahertz Wave Emission from Intrinsic Josephson Junctions in Bi$_2$Sr$_2$CaCu$_2$O$_{8+\delta}$

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The discovery of strong, coherent, continuous and monochromatic electromagnetic wave emission at a terahertz region from high $T_c$ superconductor Bi$_2$Sr$_2$CaCu$_2$O$_{8+\delta}$ intrinsic Josephson junctions (IJJs) has attracted much attention to the researchers working in fundamental physics as well as many applied scientists and engineers, since they are stimulated to envision the useful applications for the next generation human society. The basic mechanism of the emission by now can be attributed to the ac-Josephson effect, which drives an ac-oscillating current through whole IJJ’s connected in series and the additional resonance mechanism, which enhances the self-oscillating ac-Josephson current by the cavity amplification effect. This understanding is brought by the detailed studies of emission patterns of many mesas in relation with the geometrical shape of them in comparison with the theoretical model calculations$^3$. It is not entirely trivial why such a coherent coupling is established in only a certain arbitrary fixed number of junctions, what controls the frequency of the emission, etc.$^2$ We argue the importance of nonlinearity and nonequilibrium conditions, and the role of cavity resonance to the coherent coupling between IJJs.$^2$

11P-D018 Electrically Tunable Quantum States in Graphene-based Josephson Junctions

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Graphene-based Josephson junctions (GJJ’s), consisting of a graphene layer in contact with two superconducting electrodes, provide a unique system to investigate superconducting proximity effect with in-situ tunable Josephson coupling energy. We investigated the stochastic switching behavior of the supercurrent in this system, which has not been seriously studied yet although the phase-coherent behaviors of GJJ’s under the
external magnetic field and microwave irradiation have been reported previously. Here, we present the three different escaping regimes for a phase particle from a washboard potential of GJJ’s, including macroscopic quantum tunneling (MQT), thermal activation (TA), and phase diffusion (PD). The crossover temperature \( T_{\text{MQT}} \) between the classical to quantum regime can be controlled by the electrostatic gating, implying that the discrete energy level of a phase particle in the potential well is also gate-tunable. Moreover, direct observation of energy level quantization (ELQ) by microwave spectroscopy shows the consistent gate dependence of \( T_{\text{MQT}} \).

A new class of quantum devices such as a gate-tunable phase qubit is potentially realized by utilizing quantum tunneling (MQT), thermal activation (TA), and phase diffusion (PD). The crossover temperature \( T_{\text{MQT}} \) between the classical to quantum regime can be controlled by the electrostatic gating, implying that the discrete energy level of a phase particle in the potential well is also gate-tunable. Moreover, direct observation of energy level quantization (ELQ) by microwave spectroscopy shows the consistent gate dependence of \( T_{\text{MQT}} \).


11P-D019 Andreev reflection and Josephson current through a Kondo Y-junction

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We study low-temperature transport through a single quantum dot (QD) connected to three terminals, consisting of two superconducting (SC) leads and one additional normal lead. This system shows interesting behavior caused by an interplay between Josephson, Andreev and Kondo physics. The low-energy excitations of this system can be described by a local Fermi liquid theory for the renormalized Bogoliubov particles. We calculate the renormalized parameters using the Wilson numerical renormalization group approach. The Kondo temperature and the residual interaction between the renormalized Bogoliubov particles depend sensitively on the Josephson phase \( \phi \) at the crossover region between the local Cooper-pairing singlet and the Kondo singlet states. This crossover reflects the quantum phase transition between a non-magnetic singlet and magnetic double states, which takes place in the case where the addition normal lead is disconnected.

We will also discuss the results for the Josephson current and the DC conductance due to the Andreev reflection.

11P-D020 Interstitial vortex in superconducting film with honeycomb array

Shi-kun He\(^a\), Wei-jun zhang\(^b\), Xiang-gang Qiu\(^c\), \(^a\)National Laboratory for Superconductivity, Institute of Physics, Chinese Academy of Sciences, Beijing 100190, China \(^b\)Superconducting Nb film with honeycomb array of holes are studied using magnetotransport measurement. Two types of resistance minima with different field spacing indicating the reconfiguration of vortex lattice from honeycomb to triangular arrangement. We find hysteretic effects presented in a large field region from \( H = 2H_1 \) to \( H = 8.5H_1 \). We also show the transition field of the two regimes in magnetoresistance curves is temperature dependent. These findings confirm the existence of interstitial vortex. In addition, a comparison study show the depth of fractional matching minima at 1/2, 1/4, and 3/4 depend on the direction of drive while the integer matching minima show no difference under different current directions.

11P-D021 Superadiabatic Approximations for Cooper Pair Pumping

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Cooper pair pumping is a process of transferring charge via external manipulation of the system parameters providing a way to study the geometrically and dynamically accumulated quantum phases. Depicting the dynamics of such steered systems coupled to a dissipative environment has remained an unsolved problem until recently. Based on a recently derived master equation, we introduce a numerical method where successive coordinate transformations are applied to decrease the error resulting from truncation in the local adiabatic parameter. We then show that our method applied to a well-known pumping problem reduces the non-physical behaviour observed previously and that the environment-induced relaxation leads to adiabatic ground-state pumping only in the lowest-order approximation. We illustrate the robustness of the frequency where the adiabaticity breaks down using the higher-order theory and show the emergence of an optimal environmental coupling strength where ideal pumping is preserved for the highest frequency. Finally, we give an estimate for the relaxation rate of an experimentally measured system.


11P-D022 From thermal to quantum: A detailed look at escape rates in Josephson junctions

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The switching in underdamped Josephson junctions from zero voltage to the dissipative state is known to be driven by either thermal fluctuations or quantum tunneling depending on temperature. We have measured escape rates of junctions with systematically varying size as a function of temperature with high precision. All junctions show the crossover from the thermal to the quantum regime at the expected temperature. The thermal regime is described with high accuracy by the low damping limit of transition state theory. The observed quantum rate, however, is by orders of magnitude smaller than what can be expected from existing
11P-D023 Local and nonlocal conductance enhancement due to Cooper pair splitting

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Enhanced local conductance due to Andreev reflection is well known for high transparency Normal-metal–Superconductor (NS) interface. For low transparency NS junctions, observation of two-electron tunneling (enhanced Andreev reflection) to current was also reported previously. In our recent work,\textsuperscript{1} for a three-terminal Cooper pair splitter geometry, i.e., with two closely placed NS junctions sharing the same S terminal, we were able to do a 2D scan of both local and nonlocal differential resistance, since for our ideal tunneling junctions there is little current redistribution (flow from one normal-metal lead to the other via the superconducting lead). In contrast to previous 1D nonlocal resistance measurements, 2D scans clearly show regime with pronounced contribution of the nonlocal processes to both local and nonlocal conductance enhancement. The enhanced local conductance and negative nonlocal resistance are consistent with enhanced Cooper pair splitting, and dynamical Coulomb blockade could be the origin of this enhancement.

\textsuperscript{1} J. Wei and V. Chandrasekhar, Nat. Phys. \textbf{6}, 494 (2010).

11P-D024 Microwave scattering on single one-dimensional array of Josephson junctions as a point defect in standing wave regime

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In this work, microwave scattering experiment was performed on one-dimensional(1D) arrays of Josephson junctions, which exhibited magnetic field-tuned superconductor-insulator transition as a point defect in a rf/microwave waveguide. The waveguide presented a standing wave nature of a period in frequency of 240 MHz, similar to a Fabry-Perot interferometer with a low coefficient of finesse. Because the 1D array is oriented in parallel to the polarization of rf/microwave, a larger coupling between rf/microwave photons and the 1D array was obtained. As such the 1D array gave rise to stronger rf/microwave absorption when the array is in superconducting state, resulted in an oscillatory modulation of rf/microwave transmission amplitude in magnetic field dipped at zero magnetic field. For the phase shift, the oscillation evolved from in-phase to out-of-phase when the rf/microwave frequency was swept from one transmission maximum to the adjacent one.

11P-D025 Josephson quantum interference in anisotropic superconducting antidot lattices

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We study quantum interference effects for the onset of full superconductivity in anisotropic antidot lattices as a function of temperature, magnetic field and current. We identify a new regime which differs from both the regime of classical matching of vortex structure with the underlying lattice geometry and the regime of ‘Hofstadter’ physics for the onset of superconductivity. In this nonlinear regime, where the parts have already established superconducting order parameter, the system is well described by the Frenkel-Kontorova model for Josephson coupling through multiple weak links. Above a certain field strength, the system crosses over into the usual classical regime of pinning-depinning of Abrikosov vortices.

11P-D026 Thermal Conductance by the Inverse Proximity Effect in a Superconductor

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We study heat transport in hybrid lateral normal metal – superconductor – normal metal (NSN) structures, consisting of a short S wire between two N reservoirs.\textsuperscript{3} For local electronic thermometry and temperature control, we utilize normal metal – insulator – superconductor tunnel junctions connected to the N reservoirs of the NSN structure. We find the quasiparticle thermal conductance of S wires of length comparable to the superconducting coherence length to be strongly enhanced beyond the BCS value due to inverse proximity effect, resulting from contributions of elastic cotunneling and crossed Andreev reflection of quasiparticles. Our measurements agree with a model based on the quasiclassical theory of inhomogeneous superconductivity in the diffusive limit.


11P-D027 Temporal dynamics within linear arrays of Josephson junctions in the Coulomb blockade regime

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Recent experiments have studied the transport of individual change carriers through a one-dimensional array of small Josephson junctions, in the limit of small Josephson coupling. Modern time resolved charge detection techniques allow the direct measurement of temporal correlations between these carriers. We study such a system theoretical with the aim of understanding the transport properties within the array, in both the normal and superconducting regimes. Of particular interest are the effects of Coulomb repulsion between the carriers and the resulting correlations between charges as they are transported through the array. In study-
ing such systems, a number of interesting mathematical and computational issues appear, as we require a theoretical model of a multi-particle system in which both coherent and incoherent dynamics play a role.

11P-D028 Cooling and Thermometric Performance of Non-ideal SINIS Tunnel Junction Devices
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We have investigated two distinct aspects associated with electronic conduction, cooling and thermometry of superconductor-insulator-normal metal-insulator-superconductor (SINIS) based tunnel junction devices. First, we address the effect of asymmetry of tunneling resistances of the individual junctions. By solving the electrical and heat flow equations numerically, we find that asymmetry gives rise to many new interesting features like appearance of an excess sub-gap current, negative differential resistance and temperature sensitivity differences of the individual junctions. Moreover, the total cooling power of a SINIS can be enhanced by asymmetry. Second, we discuss how finite resistivity of the normal metal electrode modifies the performance characteristics. In this case, as well, the individual junctions can exhibit negative differential resistance if normal metal resistivity is high enough.

11P-D029 Setup of laser-based angular resolved photoemission spectroscopy
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The laser angular resolved photoemission spectroscopy (ARPES) could achieve ultrahigh resolution, which is crucial in ARPES measurement. In addition, the dynamical and non-equilibrium processes in the condensed matter systems play a key role in their physical and chemical properties. Both ultraviolet laser ARPES and time resolved two-photon emission (TR2PPE) are established in our lab. The ultraviolet laser ARPES exhibits superior performance, including ultrahigh resolution and enhanced bulk sensitivity. Meanwhile, the TR2PPE could investigate the ultra-fast electronic dynamics of the non-equilibrium charge carriers in the time domain directly. Here we show the setup of laser-based ARPES and some preliminary results.

11P-D030 Comparing Charge Offset and Charge Noise for a Single Electron Transistor
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We report measurements of the temperature dependence of both offset charge and charge noise measured by Single Electron Transistors. We describe these quantities in terms of a complex susceptibility $\chi = \chi_1 + i\chi_2$, where $\chi_1$ is related to the offset charge $Q_\text{offset}$, and $\chi_2$ is related to the charge noise $S_Q(f)$ via the fluctuation-dissipation theorem. Furthermore, $\chi_1$ and $\chi_2$ are Kramers-Kronig related at all temperatures and should therefore have the same temperature dependence. This implies that the ratio of the charge offset and the charge noise should vary as $1/T$. Our preliminary results show a temperature independent offset charge and linearly increasing noise power which agrees with these general arguments.

11P-D031 Quantum Phase-Slip Devices
We theoretically propose two types of novel devices to illustrate the coherent quantum phase-slips (QPS): 1. the QPS oscillator and 2. devices that exhibit Coulomb blockade due to QPS. The QPS oscillator can be realized on the basis of a thin superconducting wire or a chain of Josephson junctions. It proves that the experimental detection of quantum phase slips is achievable for small phase slip amplitudes, contrary to what is usually assumed. The responses of this damped-driven oscillator exhibit a cosine dependence on the charge induced by a gate electrode and very unusual oscillatory dependence on the drive/frequency. The second type of devices are derived from the Cooper-pair box and Cooper-pair transistor. They exhibit sensitivity to a charge induced by a gate electrode, this being the main signature of Coulomb blockade. Experimental realization of such devices will prove the Coulomb blockade as an effect of coherence of QPS processes.

11P-D032 Wafer-scale Fabrication of High Quality Josephson Tunnel Junction Phase Qubits.
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It is well-known that the choice of materials and processes is essential for achieving long decoherence times in superconducting qubits and that one of the main loss mechanisms comes from surrounding dielectrics. We have investigated a way how to reduce this loss by utilizing a wafer-scale fabrication technology to fabricate Al/Al$_2$O$_3$/Al Josephson tunnel junction circuitry, i.e. phase qubits with SQUID read-out. The tunnel junctions are defined by a plasma-etched via through a dielectric layer covering the bottom Al electrode. The ex situ tunnel barrier is formed by oxidation of the bottom electrode in the junction area. As the dielectric layer, Si$_3$N$_4$ has been used and in addition to the tunnel junction stack, an Al layer for low-ohmic interlayer connections was added. As a final step we used the top Al layers as a hard mask for removing residual Si$_3$N$_4$ by plasma etching, and hence reducing the amount of dielectric surrounding the qubit. From decay time measurements of the phase qubits, we can show a four times
increase of the relaxation time, $T_1$, after the dielectric removal, and measure a $T_1 = 130$ ns.


11P-D035 Theoretical Description of Motional Averaging in a Superconducting Qubit

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In a superconducting qubit, the energy splitting of the two quantum states can be controlled accurately with e.g. magnetic flux or voltage. In addition, the energy splitting can be measured with a weak excitation field i.e. by using spectroscopy. Motivated by these we study the absorption spectrum of a superconducting qubit, whose energy splitting is randomly jumping between the discrete values $h(\omega \pm \delta)$. We derive the absorption spectrum by solving the master equation and averaging over the Markovian stochastic fluctuations of the energy splitting. The spectrum is studied as a function of the average jumping rate $\Omega$, which, together with the amplitude $\delta$, characterizes the jumping process. When the jumping rate is small with respect to the amplitude $\Omega \ll \delta$, the qubit absorbs energy at frequencies $\omega \pm \delta$. In the opposite limit ($\Omega \gg \delta$), the absorption occurs only at the average frequency $\omega_0$. This phenomenon is observed in motional averaging in NMR, but, to our knowledge, it has not been studied before in a single artificial atom. We have studied the effect by making numerical simulations based on quantum trajectories. We show that the motional averaging phenomenon can be observed in a parameter range that is experimentally realizable in a circuit QED system consisting of a superconducting transmon qubit and a superconducting quarter-wave length coplanar waveguide.

11P-D036 Dynamic Autler-Townes effect, decoherence, and dark states in a phase qubit

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When a three-level quantum system is irradiated by an intense coupling field resonant with one of the two possible transitions, the absorption peak of an additional probe field with frequency close to the remaining transition is split (Autler-Townes effect). This phenomenon has been experimentally demonstrated by us in a phase qubit. We present a theoretical modeling of this effect, including decoherence, cross-couplings, and leaking to higher excited states (up to the fifth level). Numerical simulations and analytical results for the stationary state based on this model allow us to extract the decoherence parameters and they provide excellent agreement with the Autler-Townes experiment. We then demonstrate experimentally by pulsing the coupling field that the system can be operated dynamically, as a quantum switch that produces on-demand dark states with high fidelity. Time-dependent numerical simulations of the model described above are in good agreement with the experiment.

2. J. Li et. al., arXiv:1103.2223.

11P-D037 Microwave induced effects in diffusive SNS junctions

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The observation of very large microwave-enhanced critical currents in superconductor-normal metal-superconductor (SNS) junctions at temperatures well below the critical temperature of the electrodes has remained without a satisfactory theoretical explanation for more than three decades. In this talk I present our theory of the supercurrent in diffusive SNS junctions under microwave irradiation, based on the quasiclassical Green’s function formalism. We show that the enhancement of the critical current is due to the energy redistribution of the quasiparticles in the normal wire induced by the electromagnetic field. Our theory provides predictions across a wide range of temperatures, frequencies, and radiation powers, both for the critical current and the current-phase relationship. At linear response, the microwave absorption can be described via the ac susceptibility (admittance) of the SNS junc-
Decay and generation of entanglement in coupled, driven systems with bipartite decoherence

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In a bipartite system subject to decoherence from two separate reservoirs, entanglement is typically destroyed faster than decoherence of each single qubit. This effect is known as entanglement sudden death (ESD).\textsuperscript{1} We analyze a system of two coupled qubits with classical on-resonance driving embedded in two different environments. In the secular limit, we obtain exact analytical results for the evolution of the system for several classes of two-qubit mixed initial states.\textsuperscript{2} In non-secular limit, surprisingly however, in a certain region of the parameter space the existence of separate reservoirs can also have a beneficial entangling effect: the system can end up in a stationary state characterized by a finite degree of entanglement.\textsuperscript{3}


Experimental demonstration of motional averaging in a transmon

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When the transition frequency of a two-level quantum system is randomly jumping between two values ±δ, the shape of this system’s spectrum is dependent on the average jumping frequency Ω. For δ² ≪ Ω², there are two spectrum lines with the same linewidth 4δ and a separation 2δ; for δ² ≫ Ω², there is only one spectrum line with a linewidth δ²/Ω. This phenomenon is known as motional averaging in NMR.\textsuperscript{1} We observe this phenomenon (see also\textsuperscript{2}) experimentally in a circuit QED\textsuperscript{3} system which consists of a transmon qubit and a superconducting coplanar waveguide (CPW) resonator. With nonrandom (square and sinusoidal) modulations of transmon’s transition frequency, we also observe Landau-Zener-like interference patterns. The experimental data is in good agreement with numerical simulations.

11P-D042 Coulomb Drag in Double Layer Graphene Systems

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Coulomb drag effect in semiconductor electron-electron and electron-hole double layer systems has been a useful tool to study the many-body properties of such systems. In these systems, current is allowed to flow in one of the layers and the potential difference in the other layer is measured. Their ratio which is related to the transresistivity or the drag resistivity is a measure of the momentum transfer from one-layer to the other.\textsuperscript{1} Recently, experimental results on the drag resistivity of two parallel layers of graphene sheets have been reported.\textsuperscript{2} In this work, we use the Kubo formalism and the mode-decoupling approximation to express the drag resistivity in terms of the intra- and inter-layer density-density response functions of a double layer graphene system to compare our results with those found in the experiment and other theoretical works. We also explore the drag effect in the electron-hole graphene layers and the possibility of excitonic condensation in these systems.\textsuperscript{3}

\textsuperscript{2} S. Kim et al. cond-mat/arXive 1010.2113

11P-D043 Switching Current of a Superconducting Single Electron Transistor in a Tunable Dissipative Environment

Shuchao Meng\textsuperscript{a,}\textsuperscript{b}, Luke Yaraskavitch\textsuperscript{a,}\textsuperscript{b}, Andrew Sachrajda\textsuperscript{a}, Jan Kycia\textsuperscript{a,}\textsuperscript{b}, \textsuperscript{a}Department of Physics and Astronomy, University of Waterloo, 200 University Avenue W, Waterloo, ON, N2L 3G1, Canada
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The switching current ($I_{SW}$) of a superconducting single electron transistor (sSET) is investigated under the influence of a tunable dissipation as a function of gate charge and temperature. A two-dimensional electron gas (2DEG) located 100 nm below the surface of a GaAs/AlGaAs heterostructure substrate is capacitively coupled to the sSET and provides a frequency dependent dissipative environment. The sSET has a SQUID configuration allowing a fully controllable Josephson coupling energy ($E_J$) via a small magnetic field. This device has a well-defined Hamiltonian with competing $E_J$ and charging energy ($E_C$). The measured $I_{SW}$ exhibits a 1e periodicity with the charge number on the central island, showing its charging nature. By increasing the dissipation, the quantum fluctuations of the phase across the sSET is compressed, resulting in an enhanced $I_{SW}$ and effective $E_J$. The effect of thermal fluctuations on the quantum phase fluctuation and phase diffusion in the sSET will also be presented.

11P-D044 Novel Non-Contact Measurement of the Specific Heat of Insulating Glasses at Low Temperatures

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Parasitic heat inputs through wires are a general problem in measurements at low and ultra-low temperatures. To avoid such unwanted effects new contact-free techniques for investigating the thermal properties of glasses have been developed in recent years. Particularly challenging in this respect is the measurement of the specific heat of dielectric glasses at temperatures below about 25 mK. With a new technique based on the amplitude of coherent polarisation echoes as an intrinsic temperature information and an optical heating method we hope to extend the temperature range, in which the specific heat of glasses can be measured reliably, to well below 10 mK. In this experiment the glass sample is located in a microwave cavity attached to the mixing chamber of a dilution refrigerator and is heated via an optical fibre by a pulsed LED mounted at the 1K pot. The properties of glasses at such temperatures are governed by atomic tunnelling systems. These degrees of freedom allow for the generation of polarisation echoes whose temperature dependent amplitude is used as a thermometer in the specific heat experiments. First heating sequences have been recorded using a BK7 glass as sample. We discuss this new technique and preliminary results obtained with it.

11P-D045 Energy gap evolution of the $\nu_{tot} = 1$ quantum Hall state in an electron-electron bilayer system measured by single electron transistors

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\textsuperscript{b}Department of Physics, Harvard University, Cambridge, USA

One intriguing property of the $\nu_{tot} = 1$ quantum Hall state hosted in a bilayer two-dimensional electron system (2DES) is its tolerance to electron density imbalance between the layers. Previous activation experiments in a small range of density imbalance have revealed a counter-intuitive asymmetric behavior of the energy gap at $\nu_{tot} = 1$ depending on the layer index. Here we extend the imbalance study to the extreme case by tuning the system from a single 2DES to a bilayer 2DES with a back gate. We observed a continuous evolution of the $\nu_{tot} = 1$ quantum Hall state in the transition region from $\nu = 1$ to $\nu_{tot} = 1$. Transport studies are complemented with measurements of the local compressibility using a single electron transistor (SET). It allows addressing compressibility issues, but also analyzing the evolution of the energy gap.

11P-D046 Temperature dependence of the electrical resistivity and the magnetization in RuSr$_{2−x}$Ca$_x$GdCu$_2$O$_8$ ($x = 0, 0.1, 0.3, 2$).


In RuSr$_{2−x}$Ca$_x$GdCu$_2$O$_8$, it was found that the magnetization (= $M$) decrease with the increase of $x$ from 0 to 0.3 viceversa the electrical resistivity(= $\rho$) and then $M$ drastically and perpendicularly arise from the transverse (as referred to temperature(= $T$)) for $x = 2$ as well as $\rho$, however the arising positions of $M$ and $\rho$ in terms of $T$ are different. These matters are very intriguing, so the author inferred from the pattern of $M$, $\rho$, $T$, etc. that these occurred due to the impurity originated, the distortion of the crystal structure with the substitution of Ca for Sr and the double exchange interaction with the ferromagnetic transition of Ru ion.

11P-D048 A strategy for development of superconducting qubits with large decoherence time

V.L. Gurtovoi*, V.A. Tulin**, *Institute of Microelectronics Technology, Russian Academy of Sciences, 142432 Chernogolovka, Moscow District, Russia

Recently it has been successfully developed several types of superconducting qubits which allowed operation with quantum information. Nevertheless, the best decoherence time achieved for all types of qubits is not larger than several microseconds. It is clear, that any electric capacitance connected in parallel to a qubit results in decoherence due to nonideal dielectric with low loss tangent. The main idea for development of quiet qubits is the usage of high quality crystalline dielectrics in Josephson junctions and quality dielectrics in shunting capacitances, insulating layers and noise filtration systems.¹

Realization. We suggest to use tantalum ($T_c = 4.4\, K$) for the qubits with large decoherence time. It is well known that epitaxial 3-layer structures Ta-MgO-Ta are realized on c-cut sapphire. Moreover, in contrast to niobium, tantalum has the only oxide (Ta$_2$O$_5$), which could be used as low-noise crossover dielectric. We will present measurements of critical current, rectified voltage and resistance vs. magnetic field for asymmetric 1 $\mu$m diameter rings fabricated from monocrystalline Ta films with R(300K)/R(4.2K)=30 and measurements of epitaxial Ta-MgO-Ta single JJs and SQUID structures.


11P-D049 Single-photon heat conduction in electrical circuits

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We report our results on the photonic heat conduction between two resistors which are weakly coupled to a single superconducting microwave cavity. For temperatures $T \ll 1\, K$ the heat transport in this system is, in practice, entirely photonic and quantization of the thermal conductance can be observed. We show that by altering the temperature of one of the resistors, it is possible to control the temperature of the other as a direct result of the quantum mechanical coupling between the resistors and the photonic modes of the cavity. This is a signature of single-photon heat conduction and suggests a simple method for the remote cooling and heating of electrical components at an extremely narrow bandwidth, thus having a minimal perturbation to the usual operation of the component.

11P-D050 All YBCO Transmon for Low Energy Quasiparticle Spectroscopy

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Recent findings of macroscopic quantum properties in high critical temperature superconductor (HTS) Josephson junctions (JJs) point toward the need to revise the role of zero energy quasi-particles in this novel superconductor.¹ A deeper insight into the low energy spectrum of quasi particles is thought to be fundamental for understanding the mechanism leading to high critical temperature superconductivity. We have engineered high quality YBa$_2$Cu$_3$O$_{7−\delta}$ (YBCO) grain boundary JJs on low dielectric constant substrates.

By fabricating submicron junctions, we extract values of capacitance and Josephson critical current densities that satisfy the main transmon design requirements, i.e. an artificial two level system strongly coupled to the quantized electromagnetic field in a resonator. Measurements of the microwave reflection coefficient at 20 mK of a YBCO transmon embedded in a YBCO resonator clearly demonstrate that we reach the strong coupling limit. Moreover we present first relaxation time measurements of our YBCO artificial two level system enabling us to extract information about the low energy quasiparticle spectrum.


11P-D051 Readout and Control of Spin Systems with Superconducting Circuits

N. Antler*, K. W. Murch**, R. Vijay***, S. Weber**, E. M. Levenson-Falk**, *Quantum Nanoelectronics Laboratory, Department of Physics, University of California Berkeley, Berkeley, California 94720, USA

All electrical readout and control of spin systems with superconducting circuitry is an attractive route for implementing hybrid quantum information processing. Isolated spins, in general, have much longer coherence times than present day superconducting qubits, and thus could be utilized as memory elements. Species with a zero-field splitting (ZFS), such as bismuth doped silicon or NV centers in diamond, are particularly attractive as the absence of a strong magnetic bias field facilitates compatibility with low-loss superconducting circuitry. We present progress towards observation of
strong coupling between such spin systems and a superconducting resonator. Information swapping between the spin ensemble and a qubit via the resonator will also be discussed. Furthermore, we will present data on a dispersive nanoSQUID magnetometer with a flux sensitivity of $26 nV/Hz^{1/2}$, capable of detecting a small number of spins.

11P-D052 Dynamics of Josephson-phase coupled with spin waves

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Coupling of Josephson-phase and spin-waves is theoretically studied in a ferromagnetic Josephson junction, in which two superconductors (S’s) are separated by a ferromagnet (F). Electromagnetic (EM) field inside the junction and the Josephson current coupled with spin-waves in F are calculated by combining Maxwell and Landau-Lifshitz-Gilbert equations. In the SIFS junction, it is found that the current-voltage ($I-V$) characteristic shows two resonant peaks. Voltages at the resonant peaks are obtained as a function of the normal modes of EM field, which indicates a composite excitation of the EM field and spin-waves in the ferromagnetic Josephson junction. We examine a ferromagnetic Josephson junction, in which an insulator (I) is inserted in one of interfaces between S and F. In such an SIFS junction, three resonant peaks appear in the $I-V$ curve, since the Josephson-phase couples to the EM field in the insulating layer.

11P-D053 Critical current noise in Josephson junction from interacting trap states

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We analyze the impact of trap states in the oxide layer of superconducting tunnel junctions on the fluctuation of the Josephson current and thus on coherence in superconducting qubits. Two mechanisms are usually considered: the current blockade due to repulsion at the occupied trap states, and the noise from electrons hopping across a trap. We extend previous studies of noninteracting traps to the case where the traps have on-site electron repulsion. We use second order perturbation theory which allows to obtain analytical results limited to small and intermediate repulsions. Remarkably, it still reproduces the main features of the model as identified from the Numerical Renormalization Group. We present analytical formulations for the subgap bound state energies, the singlet-doublet phase boundary, and the spectral weights. We show that interactions can reverse the supercurrent across the trap. We finally work out the spectrum of junction resonators for qubits in the presence of on-site repulsive electrons and analyze its dependence on microscopic parameters that may be controlled by fabrication.

11P-D054 Coupling an ensemble to a superconducting qubit

Xiaobo Zhu$^{a}$, Shiro Saito$^{b}$, Alexander Kemp$^{c}$, Kosuke Kakuyanagi$^{d}$, Shin-ichi Karimoto$^{e}$, Hayato Nakano$^{f}$, William J. Munro$^{g}$, Yasuhiro Tokura$^{h}$, Mark S. Everitt$^{i}$, Kae Nemoto$^{j}$, Makoto Kasai$^{k}$, Norikazu Mizuochi$^{l}$, Kouichi Semba$^{m}$
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We report here the first demonstration of strong coupling and coherent exchange of a single quantum of energy between a superconducting qubit and an ensemble quantum system. This is the first step towards the realization of a long lived quantum memory for condensed matter systems with an additional potential future application as an interface between the microwave and optical domains.

11P-D055 Generating and Detecting Propagating Photons in Superconducting Circuits

Andreas Wallraff$^{a}$
$^{a}$ETH Zurich, Zurich, Switzerland

Using modern micro and nano-fabrication techniques combined with superconducting materials we realize quantum electronic circuits to create, store, and manipulate individual microwave photons on a chip. The strong interaction of photons with superconducting quantum two-level systems allows us to probe the fundamental quantum properties of light. In particular, I will discuss experiments in which we realize an on-demand microwave frequency single photon source which we characterize by correlation function measurements. In the absence of efficient single photon counters, we use on-chip 50/50 beam splitters with off-chip linear amplifiers and quadrature amplitude detectors for which we have developed efficient methods to separate the detected single photon signal from the added noise. We verify the operation of the single photon source by demonstrating single photon coherence and photon antibunching in first and second-order correlation measurements. I will also present measurements in which we reconstruct the Wigner function of itinerant single photon Fock states and their superposition with the vacuum. The techniques and methods demonstrated in this work may find broad application in the analysis of microwave radiation emitted from mesoscopic devices, in future linear optics and quantum information processing experiments.


11P-D056 Fast generation of multi-particle entanglement state with flux qubits in tunable coupled cavities

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Session 11P-E:

E1 Quantum Ground State Techniques
Thursday August 11, 11:00 – 18:00
Exhibition Hall 1

11P-E001 Strong Gate Coupling of High-Q Nanomechanical Resonators
J. Sulkko, M.A. Sillanpää, P. Häkkinen, M. Helle, A. Fefferman, J. Parpia, P.J. Hakonen, Low Temperature Laboratory, Aalto University, Finland

The detection of mechanical vibrations near the quantum limit is a formidable challenge since the displacement becomes vanishingly small when the number of phonon quanta tends towards zero. An interesting setup for on-chip nanomechanical resonators is that of coupling them to electrical microwave cavities for detection and manipulation. We have developed a fabrication method for achieving a large cavity coupling energy of up to \( (2\pi) 1 \text{ MHz/mm} \) for metallic beam resonators at tens of MHz. We used focused ion beam (FIB) cutting to produce uniform slits down to 10 nm, separating patterned resonators from their gate electrodes, in suspended aluminum films. We measured the thermo-mechanical vibrations down to a temperature of 25 mK, and we obtained a low number of about twenty phonons at the equilibrium bath temperature. The mechanical properties of Al were excellent after FIB cutting and we recorded a quality factor of \( Q \sim 3 \times 10^5 \) for a 67 MHz resonator at a temperature of 25 mK. Between 0.2K and 2K we find that the dissipation is linearly proportional to the temperature.


11P-E002 Approaching the quantum limit of thermal motion on a graphene mechanical resonator
X. Song, M.A. Sillanpää, P.J. Hakonen, Low Temperature Laboratory, Aalto University, Finland

Graphene is a perfect two-dimensional crystal with high Young’s modulus and extremely low mass (7.6 \( \times \) \( 10^{-19} \) kg/\( \mu \text{m}^2 \)), which makes it ideal for high frequency mechanical resonators. With a mechanical resonance frequency approaching 1 GHz, the crossover from thermal motion to zero-point vibrations becomes detectable at \( \sim 50 \) mK. Comparing with other mechanical resonators like metallic beams, graphene provides a much higher vibration amplitude. As for carbon nanotubes, graphene offers a much bigger area, which makes capacitive determination of vibration amplitudes feasible down to the quantum limit. We have developed a new method to integrate graphene mechanical resonators with superconducting high-Q RF cavities. High quality exfoliated graphene is transferred with a micron sized PMMA stamp and assembled onto a pre-cut Al superconducting circuit with 1 \( \mu \text{m} \) precision using a micro-manipulator. A fully electric readout scheme was used where the graphene vibration is observed from the sideband of the RF carrier. Using realistic parameters for our graphene resonators and for the phase-modulated sideband detection scheme, we obtain a displacement sensitivity of \( \sim 10^{-15} \text{m}/\sqrt{\text{Hz}} \) for one-micron-wide resonators. This sensitivity is sufficient for observing zero-point vibrations up to a frequency of 1 GHz. So far our highest resonant frequency has been \( f \sim 200 \) MHz where we are bound to be limited to a few quanta, unless additional sideband cooling is employed.

11P-E003 Development of a Zero Boiloff Helium Cryostat for superconducting magnets
Meifen Wang, Huan Yang, Feipeng Ning, Zian Zhu, State Key Laboratory of Particle Detection and Electronics, Institute of High Energy Physics, Chinese Academy of Sciences, Beijing, China

This paper describes a horizontal type cryostat of a superconducting magnet with a 300mm room temperature bore. The magnet, with the diameter of 400mm and length of 815mm, is immersed in 30 liter liquid helium. Design consideration, including thermal staging of the silver/Bisco current leads, low thermal condensation mechanical support structure, and the theoretical calculation of heat load to the cryostat are discussed. And only a helium recondensing G-M cooler (40W at 50K, 1.5W at 4.2K) is used to achieve zero boil off.
12H1-1  NCRI and shear modulus of solid helium at low temperatures
Eunseong Kim*, a Korea Advanced Institute of Science and Technology

Supersolidity, the appearance of viscousless flow in solids, was first indicated in 4He torsional oscillator (TO) experiments. Despite many efforts to uncover the mechanism of supersolidity since the first observation of non-classical rotational inertia (NCRI), the microscopic origin and physical interpretation of the observed phenomena has been under considerable debate. Recently, shear modulus measurements of solid helium showed unusual increase with striking resemblance to those of TO anomaly. The similarities invigorate alternative non-superfluid explanations for the TO response. In this talk, we will present simultaneous measurement of shear modulus and NCRI in solid helium to examine the fundamental connection between two phenomena. TO response is found to be independent of the stiffening or softening of elastic modulus. In addition, the rotational response of NCRI is also contradicting with that of shear modulus; the NCRI shows strong suppression but the shear modulus remains unchanged. These results indicate that microscopic origin of TO anomaly is different from shear modulus change.

12H1-2  Mass Flux through Solid 4He Induced by Chemical Potential Differences
R.B. Hallock*, a Laboratory for Low Temperature Physics, Department of Physics, University of Massachusetts, Amherst, MA, 01003, USA

We the thermo-mechanical effect (and also direct mass injection) to create chemical potential differences between two superfluid-filled reservoirs connected to each other through Vycor rods in series with solid hcp 4He. We determine that an increasing DC flux of atoms takes place through the solid-filled cell with decreasing temperature below ≈ 600 mK. That flux falls abruptly in the vicinity of 80 mK, but increases again at lower temperatures 1. These experiments will be reviewed as will our studies of the growth of solid 4He where it is seen that it is impossible to add density to a solid freshly made at 60 mK and samples freshly made near 60 mK do not allow mass flux, even when raised in temperature to 200 mK. Solids created above ≈ 300 mK and cooled to 60 mK accept added density and demonstrate finite mass flux. Relationships to theoretical work and other solid helium work will be discussed.

1 Phys. Rev. Letters 100, 235301 (2008); 105, 145301 (2010). All work done in collaboration with Michael Ray who is now at UC Berkeley. Supported by NSF DMR 08-55594.

12H1-3  Scale Invariance and Quantum Criticality in Atomic Quantum Gases
Cheng Chin*, a James Franck institute and Department of Physics, University of Chicago, IL 60637, USA

The collective behavior of a many-body system near a continuous phase transition is insensitive to the details of its microscopic physics. Characteristic features near the phase transition, called critical phenomena, are that the thermodynamic observables follow generalized scaling laws. We will discuss the observation of the quantum critical behavior in strongly correlated 2D Bose based on direct in situ optical imaging. Our observation points toward a growing density-density correlations in the critical regime and raises new perspectives to explore quantum critical dynamics.
Session 12H2: Half Plenary Lectures

Chair: Duncan Haldane
Friday August 12, 09:00 – 10:30
Convention Hall 2

12H2-1  Emergent electromagnetism in solids - Spin-orbit interaction as a gauge field

N. Nagaosa*, a Department of Applied Physics, University of Tokyo, 7-3-1, Hongo, Bunkyo-ku, Tokyo 113-8656, Japan  b Cross-Correlated Materials Research Group (CMRG), and Correlated Electron Research Group (CERG), RIKEN-ASI, Wako, Saitama 351-0198, Japan

Electromagnetic field and the electronic interactions induced by it is the most fundamental to condensed matter physics. In addition to this, it often happens that the electronic system itself produces the effective internal electromagnetic field due to the various interactions as an emergent phenomenon. This is related to the quantum Berry phase associated with the constraint imposed on the Hilbert space in the low energy sector. Many nontrivial phenomena such as the anomalous Hall effect, spin Hall effect, and ferroelectric polarization originate from this Berry phase. In this talk, I will focus on the relativistic spin-orbit interaction. In the non-relativistic approximation, the electron-positron pair creations can be neglected leading to the projection of the Hilbert space to the positive energy solutions to the Dirac equation. Therefore, the spin-orbit interaction can be regarded as a non-Abelian Berry gauge field. As two representative examples of the applications of this idea, Skyrmion dynamics in magnets and the spin current conservation law will be discussed.

12H2-2  Quantum Spin Liquids In Quantum Spin ices

L. Balents*, L. Savaryb, K. A. Rossa, B. D. Gaulinan.e, Department of Physics and Astronomy, McMaster University, Hamilton, Ontario, L8S 4M1, Canada  b Ecole Normale Supérieure de Lyon, 46, allée d’Italie, 69364 Lyon Cedex 07, France  c Canadian Institute for Advanced Research, 180 Dundas St. W., Toronto, Ontario, M5G 1Z8, Canada  d Brockhouse Institute for Materials Research, McMaster University, Hamilton, Ontario, L8S 4M1, Canada  e Kavli Institute for Theoretical Physics, University of California, Santa Barbara, CA, 93106-4030, U.S.A.

A flurry of recent theory and experiments has highlighted exotic physics in the spin ice materials, Ho$_2$Ti$_2$O$_7$ and Dy$_2$Ti$_2$O$_7$, which comprise classical Ising spins on a pyrochlore lattice. There are a few related materials in which quantum fluctuations of spins are significant on the same lattice. I will discuss a general microscopic model for these materials, and specifically the case of Yb$_2$Ti$_2$O$_7$, where experiments have revealed a puzzling low temperature state in low field, and present a case that this indeed is an example of quantum spin ice. The ground state of this material may well be a quantum spin liquid, with even more exotic physics than in the classical spin ices. I will describe this quantum spin liquid state, its properties, and how this proposal may be further pursued.

12H2-3  Monopoles and Magnetricity in Spin Ice

Steven T. Bramwell*, a London Centre for Nanotechnology and Department of Physics and Astronomy, University College London, London WC1H 0AJ, U. K.

The analogy between spin configurations in spin ice materials like Ho$_2$Ti$_2$O$_7$ and Dy$_2$Ti$_2$O$_7$ and proton configurations in water ice, H$_2$O, has been appreciated for many years\(^1\). However it is only in the last few years that this equivalence has been extended into the realm of electrodynamics\(^2\). A particularly interesting aspect of the problem is the magnetic field induced transport of magnetic charges or ‘monopoles’ in spin ice to give so-called ‘magnetricity’\(^3\). In this talk I shall describe our recent experimental work that identifies these transient magnetic currents and demonstrates the role of universal Coulombic correlations. It is found that the latter lead to systematic deviations from Ohm’s law in the form of a magnetic equivalent of the Onsager-Wien effect, well known in electrochemistry.

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1 Bramwell and Gingras, Science, 294, 1495, 2001
Session 12m-A: Quantum Gases I

Chair: Cheng Chin
Friday August 12, 10:50 – 12:30
Room 305

12m-A1 Quantum Magnetism with Ultracold Atoms - A Microscopic View on Artificial Quantum Matter
Ruichao Ma*, Harvard University

Understanding the behaviors of strongly-interacting spin systems is one of the central objectives of modern many-body quantum physics. In recent experiments, we have realized quantum magnetism with ultracold atoms in an optical lattice. We carry out a quantum simulation of an Ising spin chain and demonstrate a quantum phase-transition from a paramagnetic phase to an anti-ferromagnetic phase. The magnetic phases are detected in situ through our quantum gas microscope. This work opens a wide range of new possibilities for studying quantum magnetism. Exotic states of matter and frustrated spin physics in optical lattices are now within experimental reach.

12m-A2 Quantum Simulation Using Two-electron Atoms
Y. Takahashi*, S. Sugawa*, S. Taie*, R. Yamazaki*, K. Inaba*, M. Yamashita**, aGraduate School of Science, Kyoto University, Kyoto, Japan bNTT Basic Research Laboratories, NTT Corporation, Atsugi, Japan

The two-electron atom of ytterbium (Yb) is very attractive for the study of a quantum gas because it offers many unique possibilities. The two valence electrons result in singlet and long-lived triplet states connected by extremely narrow intercombination transitions which are useful for probing and manipulating the gas. The existence of rich varieties of isotopes of five bosons and two fermions will allow us to study various interesting quantum gases. In particular, a fermionic isotope of 173Yb offers unique possibility of SU(6) enlarged spin symmetry. In this talk, I report our recent experiments on quantum degenerate Yb atoms loaded in an optical lattice. We describe our recent study on the interaction and filling induced quantum phases of dual Mott insulator of bosons and fermions by measuring various site occupancies both in attractively- and repulsively-interacting mixtures. A Bose-Einstein condensate in optical lattices is also studied in detail by high-resolution laser spectroscopy.

12m-A3 Hidden symmetries and exotic quantum magnetism of large-spin alkali and alkaline-earth fermions (LT26)
Congjun Wu*, aDepartment of Physics, University of California, San Diego

The recent experimental progress on the large-spin ultracold Fermi gases provides an exciting opportunity to investigate exotic many-body physics which does appear in usual solid state systems. Conventionally, large values of spin suppresses quantum spin fluctuations in solid state systems. On the contrary, spin fluctuations in large-spin cold fermion systems are enhanced and become even stronger than those in spin-1/2 electron systems. Under certain conditions, the large-spin cold fermion systems possess large symmetries of SU(2N) and Sp(2N). In the simplest case with hyperfine spin F = 3/2, a generic hidden symmetry of Sp(4), or isomorphically, SO(5) is proved without fine-tuning, which may be realized with alkali and alkaline-earth atoms of $^{132}$Cs, $^{9}$Be, $^{135}$Ba, $^{137}$Ba, and $^{201}$Hg. This high symmetry has important effects on the competitions among antiferro-spin-quadruple ordering, charge-density-wave ordering, and singlet Cooper pairing, which can be unified under even larger exact symmetries of SO(7) and Sp(4) ⊗ SU(2). Exotic quantum magnetism includes dominant multiple-site spin correlations in analogy to the baryon-type color-singlet states in quantum chromodynamics. Furthermore, the existence of the quartetting phase, a four-fermion counterpart of the Cooper pairing phase, and its competition with other orders are also studied.

12m-A4 Pattern Formation Dynamics in a Spinor Dipolar Bose-Einstein Condensate
Y. Kawaguchi*, aDepartment of Physics, University of Tokyo

We study the spin dynamics of a ferromagnetic Bose-Einstein condensate with magnetic dipole-dipole interaction (MDDI). Using the Gross-Pitaevskii and Bogoliubov theories, we find that various magnetic structures such as checkerboards and stripes emerge in the course of the dynamics due to the combined effects of spin-exchange interaction, MDDI, quadratic Zeeman and finite-size effects, and nonstationary initial conditions. We also introduce the hydrodynamic equations of motion for the spin and superfluid current for the above system. The equation of motion for the spin has the same form as an extended Landau-Lifshitz-Gilbert equation, which describes the
magnetization dynamics of solid-state ferromagnets, except for the term including the superfluid current. We discuss the effect of the superfluid current on the spin dynamics. 


12m-A5 Higher Order Correlations in Quantum Gases
A.G. Truscott*, S. Hodgman*, A. Manning*, R. Dall*, Wu Rugway*, K. Baldwin*, Research School of Physical Sciences and Engineering, Australian National University, Canberra, ACT 0200, Australia.

One of the seminal advances in quantum optics was the understanding that a quantised description of ensembles of photons is best characterised by correlation functions. Correlations are also a fundamental property of matter waves, and the single wavefunction that describes a Bose-Einstein condensate (BEC) is in principle characterised by long range coherence to all orders (i.e. a universal correlation value of unity). Here we use higher order correlations to probe the coherence, and long range order, of quantum gases.
12m-B1: Novel Phenomena in Superconductivity

Session 12m-B1: Novel Phenomena in Superconductivity

Chair: Yoshiteru Maeno
Friday August 12, 10:50 – 12:30
Room 5A

12m-B11 Spin-Triplet Supercurrent in Ferromagnetic Josephson Junctions

N.O. Birge*, T.S. Khaire*, M.A. Khasawneh*, C. Klose*, W.P. Pratt, Jr.*, Michigan State University, East Lansing, MI 48824-2320, USA

The proximity effect between a conventional superconductor (S) and a ferromagnet (F) decays and oscillates over an extremely short length scale in F due to the large exchange splitting between the spin-up and spin-down electron bands. If spin-triplet pair correlations were present, they would persist over much longer distances in F. Such spin-triplet correlations have been predicted to occur in S/F systems in the presence of certain forms of magnetic inhomogeneity near the S/F interface. We have observed strong evidence for spin-triplet pair correlations in S/F/S Josephson junctions containing strongly-ferromagnetic cobalt. The experimental signature of the triplet correlations is a Josephson critical current that decays very slowly for Co thicknesses up to several tens of nm. This long-range supercurrent appears only in samples with additional ferromagnetic F' layers inserted between the central Co and outer superconducting electrodes, and is caused by non-collinear magnetizations of the F' and Co layers. After application of a large in-plane magnetic field, the magnitude of the long-range supercurrent is further enhanced, contrary to expectation. I will discuss possible reasons for this additional critical current enhancement, and provide an update on our current experiments. Support by the US DOE is acknowledged, under grant DE-FG02-06ER46341.


12m-B12 Probing the Physics of the Fractional Vortex State in Mesoscopic Rings of Sr₂RuO₄

Raffi Budakian*, University of Illinois at Urbana-Champaign, IL 61801, USA

In the past decade, there has emerged strong evidence to support spin-triplet superconductivity in the layered-perovskite Sr₂RuO₄ (SRO), whose ground state is thought to be analogous to the A-phase of superfluid ³He. It is believed that the spin and orbital degrees of freedom of the superconducting order parameter can give rise to states with remarkable properties, such as chiral domains, and half-quantum vortices (HQV) that may obey non-Abelian statistics. With regards to the latter, recent theoretical work suggests that the HQV state could be made energetically favorable in mesoscopic SRO samples. In this talk, I will present a new method for ultrasensitive cantilever magnetometry that allows us to probe the magnetic response of mesoscopic samples of SRO. Our most intriguing observation is the appearance of fractional fluxoid states having half the magnetic moment of the full, or integer, fluxoid. In this talk, I will discuss the conditions required to stabilize the half-integer fluxoid states, and also present some ideas as to their origin.


12m-B13 Large oscillations of the magnetoresistance in nano-patterned La₁₃₄Sr₀₁₆CuO₄ superconducting films

Y. Yeshurun*, I. Sochnikov*, A. Shaulov*, G. Logvenov*, I. Bozovic*, Department of Physics, Institute of Superconductivity and Institute of Nanotechnology, Bar-Ilan University, Ramat-Gan 52900, Israel. Brookhaven National Laboratory, Upton, New York 11973-5000, USA

We report the results of magnetoresistance measurements in a unique network of non-interacting LSCO nanoloops. The network magnetoresistance exhibits oscillations with field periodicity \( \phi_0/A \), where \( \phi_0 = \hbar/2e \) is the flux quantum and \( A \) is the area of a single loop. Remarkably, the oscillation amplitude is larger by two orders of magnitude than that expected from the Little-Parks effect. We argue that unlike the Little-Parks oscillations, which originate from periodic changes in the superconducting transition temperature, the oscillations we observe are caused by periodic changes in the interaction between thermally-excited moving vortices and the oscillating persistent current induced in the loops. Despite the enhanced amplitude of these oscillations, we have not detected oscillations with a period of \( \hbar/e \), as recently predicted for nanoscale loops of superconductors with \( d \)-wave symmetry, or with a period of \( \hbar/4e \), as predicted for superconductors that exhibit stripes.

1 I. Sochnikov et al., Nature Nano. 5, 516 (2010); I. Sochnikov et al., PRB 82, 094513 (2010)
Consequences of broken time-reversal symmetry in triplet Josephson junctions

Dirk Manske*, a Max Planck Institute for Solid State Physics, Stuttgart, Germany b Work done together with P.M.R. Brydon (TU Dresden, Germany) and M. Sigrist (ETHZ, Switzerland)

There has been recently great theoretical interest in the behavior of Josephson junctions involving triplet superconductors.1,2 In this contribution, we study the novel Josephson effect between two triplet superconductors that are separated by a thin ferromagnetic layer (so-called TFT junction); in such a case the time reversal-symmetry can be broken due to the misalignment of the two d-vectors. We find that this allows the appearance of an additional spontaneous magnetization of the tunneling barrier, which radically alters the behavior of the junction.3 In particular, we find that the junction can be stabilized in a fractional state, i.e. the free energy lies at a phase difference intermediate between zero and π (so-called $\phi$-junction). Due to the increased transparency through one spin channel, there occurs also a pronounced enhancement of the critical current that should be observable in experiment.4 Furthermore, we also demonstrate that the d-vector misalignment results in the appearance of a Josephson spin current, even when the equilibrium (conventional Josephson) charge current is vanishing.

2 Y. Krockenberger et al., APL 97, 082502 (2010).

Direct imaging of coexistence of ferromagnetism and superconductivity in LaAlO$_3$/SrTiO$_3$ heterostructures

J. A. Bert*, C. Bellb, M. Kina, H. Y. Hwangc, K. A. Molera, a Geballe Laboratory for Advanced Materials, Stanford University, Stanford, CA, USA b Department of Advanced Materials Science, University of Tokyo, Tokyo, Japan

We report direct magnetic imaging by scanning SQUID microscopy and susceptometry of LAO/STO heterostructures, which have been shown to support high mobility conductivity at the interface with superconductivity at low temperatures and indications of magnetism from bulk measurements in some samples. Our measurement shows ferromagnetic ordering coexisting with the diamagnetic susceptibility of the superconducting state. The superfluid density is inhomogeneous, showing regions of susceptibility which vary over a large fraction of the total response. The ferromagnetic state appears as a substantial number of dipoles and remains unchanged from 20 mK to our maximum measurement temperature of 60 K. We compare results on LAO/STO and doped SrTiO$_3$ to confirm that the ferromagnetic order is related to the interface.
Session 12m-B2: New Superconducting Materials

Chair: Laura Greene
Friday August 12, 10:50 – 12:30
Convention Hall 3

12m-B21 Structures and physical properties of new types of organic superconductors, A_x picene, A_x coronene and A_x phenanthrene

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New types of organic superconductors are produced by intercalating alkali or alkali earth metal atoms into the solids of three different hydrocarbons, picene, coronene and phenanthrene. The superconducting transition temperatures, $T_c$s, are 5 – 18 K for these compounds\textsuperscript{1}. The K\textsubscript{3}picene has two different superconducting phases of $T_c$ = 7 and 18 K, while Rb\textsubscript{3}picene has one superconducting phase with $T_c$ of 7 K. It has been suggested from the lattice constants that the K and Rb atoms are intercalated into the herringbone stacking layer of picene molecules (intralayer). Very recently, more precise structural determination has been achieved for K\textsubscript{3}picene\textsuperscript{2}. The lower and upper critical fields for K\textsubscript{3}picene and Rb\textsubscript{3}picene gave physical parameters such as Ginzburg–Landau coherence length and magnetic penetration depth. The K\textsubscript{3}picene ($T_c$ = 7 K) showed the moderate negative pressure effect by applying pressure up to 10 kbar, in contrast to the positive pressure effect for K\textsubscript{3}phenanthrene\textsuperscript{3}. In this talk we will fully show the structures and physical properties of K\textsubscript{x}picene, Rb\textsubscript{x}picene, K\textsubscript{x}coronene and K\textsubscript{x}phenanthrene.

\textsuperscript{1} R. Mitsuhashi et al. Nature \textbf{464}, 76 (2010).
\textsuperscript{2} H. Sawa et al. private communication.
\textsuperscript{3} X. F. Chen et al. arXiv:1102.4075v1 in cond-mat.

12m-B22 Phase diagram in high-Tc iron pnictide and chalcogenide superconductors

X. H. Chen\textsuperscript{a, a} \textsuperscript{a}National Laboratory for physical sciences at Microscale and Department of Physics, University of Science and Technology of China, Hefei, Anhui 230026, China

We will talk about crystal, magnetism and superconductivity in R1-xFe2-ySe2 (R=K, Rb, Cs, Tl/K and Tl/Rb). We present the resistivity and magnetization as a function of temperature up to 600 K, and the strucure from room temperature to 20 K. We established a detailed electronic and magnetic phase diagram of KxFe2-ySe2 system as a function of Fe valence. We find two AFM insulating phases and reveal that the superconducting phase is sandwiched between them, and give direct evidence that the superconductivity in AxFe2-ySe2 originates from the AFM insulating parent compounds. The two insulating phases are characterized by two distinct superstructures caused by Fe vacancy orders with modulation wave vectors of q1=\((1/5, 3/5, 0)\) and q2=\((1/4, 3/4, 0)\), respectively. These experimental results strongly indicate that iron-based superconductors and cuprates share a common origin and mechanism of superconductivity. We will argue whether the superconductivity and antiferromagnetism coexist in in R1-xFe2-ySe2 system. For comparison, we also talk about the electronic phase diagram in Sm-1111 and Ba-122 system. The coexistence of superconductivity and spin-density-wave is observed in Sm-1111 and Ba-122 system. We show you the contrasting behavior between the region with coexistence of superconductivity and spin-density-wave and the region without the spin-density-wave ordering by high pressure, structure, high-magnetic field and muSR measurements.

12m-B23 A possible unusual superconducting state up to 49 K in single crystalline $R$-doped CaFe$_2$As$_2$ (Ca122) at ambient with $R =$ rare earth

C. W. Chu\textsuperscript{a, b} \textsuperscript{a}Department of Physics and Texas Center for Superconductivity, University of Houston, Houston, Texas \textsuperscript{b}Lawrence Berkeley National Laboratory, Berkeley, California

The discovery in 2008 of the Fe-pnictide and Fe-chalcogenide superconductors have generated immense interest. The highest $T_c$ of these compounds is 57 K in the 1111 structure class with electron-doping at ambient or under pressure. Until now, no effort has been successful to raise the maximum $T_c$ of Fe-pnictides or -chalcogenides to above the 60s K as predicted. We have detected superconductivity up to 49 K in single crystalline CaFe$_2$As$_2$ via electron-doping by partial replacement of Ca by rare-earth. The superconducting transition observed suggests the possible existence of two phases: one starts at ~ 49 K and the other at ~ 21 K, with drastically different responses to field. Our observations are in strong contrast to previous reports of hole-doping or pressurizing layered compounds AcFe$_2$As$_2$ (or Ac122), where Ac = Ca, Sr or Ba with a maximum $T_c$ of 38 K. The unusual 49 K phase observed appears to be filamentary or interfacial in nature. The associated superconducting transition at 49 K...
behaves as Josephson-Junction-coupled-like, suggesting the existence of a superconducting phase above 49 K in the $R$-Ca-Fe-As compound system. The results will be presented and the implications discussed.

1 Work supported in part by AFOSR, DoE, TCSUH, T. L. L. Temple Foundation and J & R Moores Foundation

12m-B24 Correlation between the Anomalous Properties and the Low Temperature Structural Distortion in $\beta$-FeSe

M.K. Wu*, a Institute of Physics, Academia Sinica, Nankang, Taipei, Taiwan

The discovery of Superconductivity in the tetragonal phase $\beta$-FeSe provides a unique platform for the detailed investigation of the correlation between the physical properties and crystal structure to better understand the possible origin of superconductivity in the new iron-based superconductors. We have carried out a series of properties characterizations by measuring resistivity, magnetic susceptibility, Raman, NMR and femtosecond spectroscopy on $\beta$-FeSe single crystals grown by flux-melt or high-pressure synthesis. Our results show clearly the presence of anomalies in all the characterized properties at the temperature where a structural distortion from tetragonal to orthorhombic (or monoclinic) appears for all superconducting samples, but not in the non-superconducting ones. This structural distortion was observed not accompanied by a magnetic ordering as commonly occurs in the parent compounds of FeAs-based superconductors. All the observations suggest that the low temperature structural distortion is essential for the occurrence of superconductivity in $\beta$-FeSe. Details of the experimental results will be presented and discussed.

12m-B25 Vortex Matter in Type-1.5 Superconductors


The existence of the novel superconducting state has been demonstrated in two-component high quality MgB$_2$ single crystalline superconductors where a unique combination of both type-1 and type-2 conditions is realized in a single material: $\lambda_1/\xi_1<1/\sqrt{2}$ for the first component of the order parameter and $\lambda_2/\xi_2>1/\sqrt{2}$ for the second one. Such materials are, in fact, neither type-1 nor type-2 superconductors (PRB 72, 180502 (2005)) and can be introduced as "type – 1.5 superconductors" (PRL 102, 117001 (2009); PRB 81, 020506(R) (2010)), since they combine simultaneously characteristic features of both type-1 and type-2 regimes. This leads to a drastic change in the vortex-vortex interaction, which results in the appearance of stable vortex stripes, clusters and gossamer-like vortex patterns. We have directly visualized these novel patterns by using scanning Hall probe microscopy, Bitter decoration and scanning SQUID microscopy. The observed patterns are in a good agreement with the molecular dynamics simulations based on the vortex-vortex interaction corresponding to the type-1.5 superconductivity. These data are also compared with the exotic vortex-vortex interactions in the so called “intermediate/mixed state” observed earlier in single gap superconductors in the vicinity of the special point $\lambda/\xi=1/\sqrt{2}$.
12m-C1  The spin-1/2 frustrated helicoidal afm multiferroic system
LiCuVO4: Recent Results*
R. K. Kremer∗, ‡Max Planck Institute for Solid State Research, Stuttgart, Germany
Lately much attention has been focused on the magnetic and especially the multiferroic properties of the helicoidal
quantum afm LiCuVO4. The spin-1/2 Cu2+ ions of LiCuVO4 form 1D chains. Spin frustration in LiCuVO4
brought about by competing nearest-neighbor (nn) ferromagnetic exchange J1 and the next-nearest-neighbor
(nnn) afm exchange J2 in these chains leads to helicoidal afm ordering and multiferroic behavior below about 2.5
K. I report and discuss new inelastic and elastic neutron scattering results in which we have studied the two-spinon
and the four-spinon continuum and the magnetic structure with and without an electric field by polarized neutron
diffraction. I also review a recent controversy on the magnitude of the nn and nnn spin exchange interaction which
we resolved by a careful re-investigation of the low-temperature crystal structure, the high-temperature magnetic
susceptibilities and new DFT calculations.
* work done in close collaboration with M. Enderle, B. Fák, M. Mourigal, H.-J. Mikeska, H.-J. Koo, C. Lee, G. J.
McIntyre, M-H. Whangbo, J. M. Law

12m-C2  Low Temperature Dynamics of Magnons in a Spin-1/2 Ladder
Compound
B. Náfrádi*, T. Keller†, H. Manaka*, A. Zheludev†, B. Keimer*, ‡Max-Planck-Institut für Festkörperforschung, Heisen-
bergstraße 1, D-70569 Stuttgart, Germany †ZWE FRM II, TU München, Germany §Graduate School of Science and Engi-
ing, Kagoshima University, Kagoshima 890-0065,Japan ‡Neutron Scattering and Magnetism Group, Laboratorium für Festkörper-physik,
ETH Zürich, CH-8093, Switzerland
We have used a combination of neutron resonant spin-echo and triple-axis spectroscopies (NRSE-TAS) to deter-
mine the intrinsic fine structure, linewidth, and energy of the magnon resonance in the model spin-1/2 ladder
antiferromagnet IPA-CuCl3 at temperatures T < ∆0/kB, where ∆0 is the spin gap at T = 0. Calculations based
on the non-linear sigma model with isotropic 1D exchange interactions yield a surprisingly good description of
the data at high temperatures. At temperatures T < ∆0/kB, however, where magnons are expected to be good
quasiparticles, we have found that spin-space and real-space anisotropies in the spin Hamiltonian as well as scat-
tering of magnons from a dilute density of impurities induce substantial deviations from the predictions of this
model. These effects are generic to all experimental realizations of 1D model Hamiltonians and should therefore
be taken into account in order to obtain quantitative descriptions of experimental data. We have shown that the
spectroscopic information derived from NRSE-TAS experiments can provide a solid basis for such a fully realistic
theory of quasi-1D quantum magnets.

12m-C3  Low Energy Dynamics of Spin-Liquid and Ordered Phases
of S = 1/2 Antiferromagnet Cs2CuCl4
RAS, Moscow, Russia †University of Utah, Salt Lake City, USA
Spin-1/2 antiferromagnet Cs2CuCl4 consists of weakly coupled 2D layers realizing distorted triangular lattice. In
the temperature interval between the Curie-Weiss (4 K) and the ordering Néel (TN = 0.6 K) temperatures, the
spins form a correlated spin-liquid state. We report electron spin resonance (ESR) measurements of Cs2CuCl4
in the frequency interval 9<f<140 GHz and down to the temperature of 0.05 K. We observed an unexpected energy
gap of about 14 GHz and a splitting of the ESR in the paramagnetic spin-liquid phase. Both the shift and the
splitting of the ESR signal, as well the pronounced sensitivity to the polarization of microwave radiation, can be
explained by considering the one-dimensional spinon excitations in presence of a uniform Dzyaloshinskii-Moriya
(DM) interaction. This DM interaction provides an effective magnetic field, the sign of which is different for the
right- and left-moving spinons. This causes the shift and splitting of the ESR. On cooling below TN the described
spinon-ESR response is found to survive deep in the ordered phase for f>50 GHz , while at lower frequencies the
ESR response is strongly modified. We observe a gradual crossover from the low-energy spectrum of a spiral-
ordered antiferromagnet to the spinon-type spectrum of a quasi-1D spin liquid at higher energies. Our experiments
demonstrate a novel way to probe fractionalized spinon excitations.
Spin Dynamics of Frustrated Honeycomb Lattice Antiferromagnet

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Low dimensional spin systems have attracted much interest because the quantum fluctuation is strong due to the less coordination number than that of three dimensional system. The fluctuation of honeycomb lattice spin system is expected to be stronger than the square lattice because its coordination number 3 is smaller than 4 of the square lattice. In the case of $S=1/2$, InCu$_2$/3V$_1$/3O$_3$, we found that the anomalous spin dynamics below $T_N$ is the peculiar feature of the honeycomb lattice antiferromagnet (HLAF) that is not observed in the square lattice antiferromagnet.\(^1\) On the other hand, Bi$_3$Mn$_4$O$_{12}$(NO$_3$), which is the model substance of $S=3/2$ HLAF, shows no long range order down to 0.4 K. Moreover, the field-induced magnetic ordering phase of Bi$_3$Mn$_4$O$_{12}$(NO$_3$) is reported by the neutron measurements. The peculiar spin dynamics of honeycomb lattice antiferromagnets will be reported and discussed from results of the high-field ESR measurements in the temperature range from 1.8 K to 300 K.\(^1\)


Graphene Nanoribbon Turns Magnetic

Hsiu-Hau Lin\(^a\), Toshiya Hikihara\(^b\), Horng-Tay Jeng\(^c\), Bor-Luen Huang\(^a\), Chung-Yu Mou\(^a\), Xiao Hu\(^d\), \(^a\)Department of Physics, National Tsing Hua University, Hsinchu 30013, Taiwan

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We study the electronic correlation effects in armchair graphene nanoribbon by the complimentary methods of the analytic effective field theory, non-Abelian density-matrix renormalization group and the first-principles local spin density approximation. We show that the ground state becomes ferromagnetic in the flat band regime, which arises from quantum interferences at nanoscale and the electronic correlations. It is rather remarkable that, starting from the single $\pi$-band in the nanoribbon, it generates both the flat band with intrinsic magnetic moments and the dispersive bands with itinerant carriers that mediate the exchange coupling among the magnetic moments. All three approaches we adopted here predict the same ferromagnetic ground state with quantitative agreement. The resultant ferromagnetic state with metallic conductivity is not only surprising for academic investigations, but also has potential applications in spintronics at nanoscale.
12m-D1  Micromechanical resonator cooled down close to the motional ground state, and electromechanically induced microwave amplification

M. Sillanpää*, F. Massel*, T. Heikkilä*, P. Hakonen*, J. Pirkkalainen*, S. U. Cho*, 1 Low Temperature Laboratory, Aalto University, Finland

The preparation and detection of mechanical vibrations near the quantum limit is a formidable challenge posed by several issues. A promising setup for the purpose is that of an on-chip microwave cavity, capacitively coupled to a nanomechanical resonator. A high electromechanical coupling energy, achieved in our setup by coupling from a flexural beam resonator via an ultranarrow 10 nm vacuum gap, facilitates operation near the quantum regime. We have prepared and observed such a 30 MHz micromechanical resonator very close to the ground state of its motion. By applying microwave irradiation to the cavity at the red mechanical sideband, we cooled the fundamental flexural mode to thermal occupancy of only 1.5 quanta. Under blue sideband irradiation associated to heating, we observe mechanical amplification of another, probe, signal applied at the cavity frequency by up to 30 dB. To our knowledge, this constitutes the first implementation of a mechanical microwave amplifier with true power gain. The changes in the absorption at the cavity frequency can be thought of as an analog of the electromagnetically induced transparency in quantum optics. A full quantum theory for the mechanical amplification is found to be in a good agreement to the experiment. The noise added by the mechanism is measured to be lower than that of a typical cryogenic microwave amplifier.

12m-D2  Quantum Turbulence and Localization of Disordered Bosons

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We present a theory of quantum transport in the strongly disordered insulating phase of the one-dimensional charged bosons, which provides an insight into the interplay of strong correlations and disorder in Cooper-pair insulators. The transport is ensured by the energy exchange of tunneling Cooper pairs with the self-generated environment of the dipole charge excitations comprised of the same charged particles that mediate the transport. In an ideal system the low-temperature current would have been suppressed completely except for resonance voltages determined by the energy of a single junction. The mechanism that unblocks the charge transfer is the development of the Landau-Hopf turbulence in the spectral flow of the energy levels of the dipole excitations of the environment. At moderate temperatures the conductivity exhibits conventional insulating thermally activated behavior with the activation energy corresponding to the macroscopic Coulomb blockade effect. At low temperatures the current is dramatically suppressed. However, due to interaction of disorder with an infinite number of environmental degrees of freedom, even an infinitesimal broadening of environmental excitations energy levels results in a still finite conductivity.

12m-D3  Quasiparticle transport measurements in attoampere scale in metallic devices

O.-P. Saira*, A. Kemppinen*, V. F. Maisi*, J. P. Pekola*, 1 Low Temperature Laboratory, Aalto University, P.O. Box 15100, FI-00076 AALTO, Finland, 2 Department of Applied Physics/COMP, Aalto University School of Science and Technology, P.O. Box 15100, FI-00076 AALTO, Finland, 3 Centre for Metrology and Accreditation (MIKES), P.O. Box 9, 02151 Espoo, Finland

Virtually in all devices based on superconducting tunnel junctions, the practical performance is degraded to some degree by excess quasiparticle processes. More precisely, the processes in question are those that do not follow from an application of the orthodox theory of single-electron tunneling assuming full thermal equilibrium, zero-impedance environment, and Bardeen-Cooper-Schrieffer form for the quasiparticle density of states in the superconducting electrodes. Reflecting on the extensive body of previous work on single-electron transport, we reach the conclusion that shielding against microwave noise originating from both on and off-chip sources is a crucial factor in suppressing the observed quasiparticle processes. In my presentation, I will describe transport measurements performed on Al/AlOx/Cu single-electron transistors where we obtained quasiparticle tunneling rates well below 10 Hz over a 1 MΩ tunneling resistance in the absence of bias. The results allow us to infer upper bounds $n_{qp} < 0.6 \, \mu m^{-3}$ for the density of non-equilibrium quasiparticles and $\gamma < 10^{-7}$ for the Dynes parameter $\gamma$ characterizing density of quasiparticle states in the gap of the aluminum electrode. Both figures are at least an
Demonstration of a single-photon router in the microwave regime

Io-Chun Hoi, C. M. Wilson, G. Johansson, T. Palomaki, B. Peropadre, P. Delsing, P. Delsing

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We have embedded an artificial atom, a superconducting “transmon” qubit, in an open transmission line and investigated the strong scattering of incident microwave photons (∼6 GHz). When an input coherent state, with an average photon number \( N ≪ 1 \) is on resonance with the artificial atom, we observe extinction of up to 99.6% in the forward propagating field. We use two-tone spectroscopy to study scattering from excited states and we observe electromagnetically induced transparency (EIT). We then use EIT to make a single-photon router, where we can control to what output port an incoming signal is delivered. The maximum on-off ratio is around 99% with a rise and fall time on the order of nanoseconds, consistent with theoretical expectations. The router can easily be extended to have multiple output ports and it can be viewed as a rudimentary quantum node, an important step towards building quantum information networks.

Vibrating Suspended Carbon Nanotube Josephson Junctions


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We study a Josephson junction with an embedded high-frequency and high-quality mechanical resonator, made from a suspended carbon nanotube. Good transparency of the superconductor-nanotube interface allows for the observation of supercurrent through the suspended nanotube, owing to the Josephson effect. The magnitude of the supercurrent is dependent on the charge on the nanotube and can be periodically modulated by a gate electrode, similar to previously reported experiments in unsuspended carbon nanotube Josephson junctions.\(^1,2\) In such a device we have observed a mechanical resonance frequency which is considerably larger than previously reported\(^3\), and still has a high quality factor. Frequencies of 2.8GHz were achieved. Such type of resonator can in principle be cooled to its ground state at dilution fridge temperatures. The Josephson junction with embedded a mechanical resonator, allows for the study of the Josephson effect in previously unexplored regimes. Currently we are experimentally and theoretically investigating the interaction of mechanical vibrations with the Josephson effect.

\(^3\) G.A.Steele et al., Science, Vol. 325 (2009)
Session 12a-A\textsubscript{1}: Supersolid II

Chair: John Reppy
Friday August 12, 14:00 – 15:40
Room 5A

12a-A\textsubscript{1}1  Quantized Vortex Physics in the hcp $^4$He, Studied by Torsional Oscillator with Detailed AC Velocity Dependence and Under DC Rotation

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We describe the unique responses of the torsional oscillator(TO) containing hcp $^4$He starting below a unique onset temperature, $T_o$, by studying the AC velocity dependence below $T_o$\cite{1}, and discuss the appearance of the vortex fluid(VF) state\cite{1, 2}. We found a unique $T_c$, well below $T_o$\cite{1}, below which hysteretic behavior appears when the AC drive level is changed below $T_c$\cite{3}. In addition, we found an extra energy dissipation of the TO appears in proportion to the DC rotation speed only below the same $T_c$\cite{4}. This is the evidence for quantized vortex lines penetration in the supersolid state under DC rotation which we have been searching for at $T << T_o$\cite{2, 5} as in an artificial 3D superfluid\cite{6}.

\begin{thebibliography}{9}
\bibitem{1} A. Penzev, Y. Yasuta, and M. Kubota, Phys Rev Lett 101, 065301 (2008).
\bibitem{3} N. Shimizu, Y. Yasuta, and M. Kubota, arXiv:0903.1326.v3.
\end{thebibliography}

12a-A\textsubscript{1}2  The Crystal Structure of Solid Helium-4 in Vycor

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In 2004, Kim and Chan found evidence that solid helium could exhibit superfluid like behavior, a phenomena dubbed supersolidity. Subsequent experiments have shown that the supersolid behavior is strongly modified by the quality of the helium crystals. In particular, crystals of very poor quality show the strongest supersolid effects. One way to create a very poor crystal is to grow it inside of a porous medium such as vycor glass, and, indeed, the first detection of supersolidity by Kim and Chan was inside vycor. However, the exact nature of solid helium in vycor is not known, even to the extent of the crystal symmetry. We present transmission x-ray diffraction experiments from solid helium in porous vycor glass in order to identify the structure of the crystal. At pressures up to 114 bar a single peak is observed in the diffraction pattern, which splits into three peaks above 114 bar. We tentatively identify the low pressure phase as BCC and the high pressure phase as HCP. Higher order peaks, could not, however, be observed, preventing definitive confirmation of these symmetries.

12a-A\textsubscript{1}3  Heat Capacity of Solid $^4$He in Aerogel

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Non-classical rotational inertia (NCRI) for solid $^4$He has been observed both in bulk samples and samples confined in porous media like Vycor, porous gold and silica aerogel. Meanwhile, heat capacity measurements of bulk solid helium show a peak in addition to the $T^3$ term at similar temperatures as the NCRI onset. Our current understanding of the origin of NCRI involves the interconnection of dislocation network. However, it is not easy to understand that this model is applicable to NCRI observed inside $^4$He confined in porous media where the pore size is as small as 7nm. Therefore, solid helium confined in porous media plays a very important role for further investigation. We have carried out heat capacity measurements of $^4$He inside aerogel and Vycor. Our experiments show the existence of a heat capacity peak of $^4$He in aerogel. Experiments of heat capacity as well as thermal conductivity measurements of solid $^4$He in Vycor are in process. This work is supported by NSF under grant DMR-0706339.
Solid helium in long path length torsional oscillators

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For macroscopic quantum phenomena, it is natural to wonder about the spatial extent of phase coherence. The non-classical rotational inertia of solid helium have been studied heretofore only in samples with physical dimension on the order of few centimeters. We have investigated solid helium in longer path length torsional oscillators. The solid samples were grown inside long narrow capillaries wound as a helical slinky. Solid helium samples in length scale from 1 m to 6 cm were studied. The inner diameter of the capillary ranges from 0.4 mm to 2.7 mm. NCRIs were found to be less than 0.01% in all samples. These results suggest that a network of defects, presumably dislocations, in solid helium may play an important role in the appearance of NCRI and the connectivity of the dislocation is severely weakened in these long and narrow capillaries. More investigations in different aspect ratio and geometry may clarify the relation between supersolidity and the network of defects. Support of this experiment was provided by NSF Grants No. DMR 0706339.
Preformed pairs and quasicondensation in imbalanced Fermi gases in 2D

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In a two-dimensional Bose gas, superfluidity is suppressed through the Kosterlitz-Thouless mechanism, whereby vortex-antivortex pairs appear and break up above a critical temperature. The proliferation of free vortices and antivortices, destroying phase coherence, has been observed experimentally in a tightly confined atomic Bose gas.

In this contribution, we focus on two-dimensional Fermi gases, where the formation of pairs is necessary to achieve superfluidity. Also for fermionic superfluids in two dimensions, superfluidity is suppressed by the Kosterlitz-Thouless mechanism. Additionally, when a population imbalance between the two pairing partners is present, pairing is frustrated. Also the binding energy of vortex-antivortex pairs is affected by population imbalance.

We investigate the effect of imbalance on the superfluid phase diagram using path-integral techniques, where we include fluctuations beyond mean-field. This allows us to describe not only the temperature zero superfluid\textsuperscript{1}, but also provides a description for the non-superfluid phase with preformed pairs. This phase is distinct from the normal, unpaired Fermi gas, and relevant to the understanding of high-temperature superconductivity. We derive the properties of this phase through a calculation of the spectral function and the response properties, and show that collective modes can be used to probe this phase.


Temperature determination of cold atoms based on single atom detection

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The temperature of the cold atoms in the magneto-optical trap (MOT) has been determined by either detecting the arrivals of the atoms or the speed distribution of the atoms directly. Using an optical micro-cavity which strongly couples to the single neutral atoms as a single atom detector, we can count the atoms individually and the temperature of the atom in the MOT can thus be determined. Compare to the conventional TOF method, this method provides an independent way to measure the temperature and it has some advantages.

Spontaneous Crystallization of Skyrmions and Fractional Vortices in the Fast-rotating and Rapidly-quenched Spin-1 Bose-Einstein Condensates

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Topological defects are a manifestation of spontaneously broken symmetries. Formation and observation of topological defects is one of the most fundamental and fascinating topics in various aspects of physics, ranging from condensed matter physics to cosmology. However, owing to the limitation of energy scales in the earth-bound physics experiments, topological defects are mostly created and observed in the condensed matter systems. Recently, owing to the realization of spinor Bose-Einstein condensate (BEC) of alkali atoms in optical trap, the creation of topological defects in ultracold atomic systems has become possible. In this presentation, we report the spontaneous generation of crystallized topological defects via the combining effects of fast rotation and rapid thermal quench on the spin-1 BECs. By solving the stochastic projected Gross-Pitaevskii equation, we show that, when the system reaches equilibrium, a hexagonal lattice of skyrmions, and a square lattice of half-quantized vortices can be spontaneously formed in a ferromagnetic and antiferromagnetic spinor BEC, respectively.

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Observation of universal behaviour of ultracold quantum critical gases

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The nature of quantum criticality driven by quantum fluctuations is still a great puzzle, despite of the remarkable advances in heavy-fermion metals and rare-earth-based intermetallic compounds, etc. New understanding of quantum criticality is widely believed to be a key to resolving open questions in metal-insulator transitions, high temperature superconductivity and novel material design, etc. Cold atoms in optical lattices provide a unique chance to not only simulate other strongly correlated systems, but also test some physical models unaccessible in solid state systems, particularly for the Bose-Hubbard model. Despite of its complexity, a strongly correlated system in quantum critical regime is expected to exhibit a universal behaviour described by a certain physical quantity.

We present here the observation of universal behaviour for ultracold quantum critical Bose gases in a one-dimensional optical lattice. Density probability distributions of the released gases are measured for different depths of the lattice potential. It was found that the density probability follows a simple exponential law when the Bose gases reach the quantum critical region above the Berezinskii-Kosterlitz-Thouless (BKT) transition. This universal behaviour can be well understood in terms of our theoretical model considering both the relative phase fluctuations of quasi-2D subcondensates and spatial phase fluctuations of individual subcondensates above the BKT transition. The method of density probability distribution should provide a unique tool for identifying certain quantum phases of optical lattice systems.


12a-A2 Manipulation of Quantum Bose Gas in One Dimensional Optical Lattice


It is reported in this paper that we controlled the super-radiant scattering in one dimensional optical lattice, plenty interested phenomena were observed. A Bose-Einstein condensate of $2 \times 10^5$ $^{87}$Rb atoms is loaded adiabatically along its long axis into an optical lattice formed with a retro-reflected laser beam ($\lambda_S = 852$nm), focused on the BEC to a waist of 110 μm. After holding a duration of 50 ms, we suddenly release the combined optical and magnetic traps. Following a delay $\Delta_t$, a light pulse, red or blue detuned from the $D_2$ transition ($\lambda_S = 780$ nm) by 1.3 GHz, is shined on the released matter waves. The suppression of superradiance and matter wave amplification (MWA) is observed (c), the phase transition appeared while the optical potential is increased to 34Er. Furthermore, we demonstrated the possibility of using matter wave amplification for characterizing spatial correlations of a Bose gas loaded in an optical lattice.

Session 12a-B: Pseudogap Phase in Cuprates

Chair: Pierre Richard
Friday August 12, 14:00 – 15:40
Convention Hall 3

12a-B1 Novel Magnetism and the Phase Diagram of the Cuprates
M. Greven*, 1 University of Minnesota, USA

Magnetic correlations might cause the superconductivity in the cuprates and are generally believed to be antiferromagnetic. Following our success in growing sizable crystals of the single-layer model compound $\text{HgBa}_2\text{CuO}_4$,$^{1}$ we used polarized neutron diffraction to demonstrate the universal existence of a novel type of magnetic order in superconducting samples.$^2$ Unlike antiferromagnetism, this order does not break the lattice translational symmetry. Our subsequent inelastic neutron scattering measurements confirmed the existence of the well-known magnetic resonance at the antiferromagnetic point$^3$ and led to the discovery of several excitations branches that appear to be fundamental collective modes associated with the novel magnetic order.$^4$ The observed magnetism is consistent with a particular type of order involving circulating charge currents and with the notion that the phase diagram of the cuprates is controlled by an underlying quantum critical point.$^5$

4 Y. Li et al., Nature 468, 283 (2010); and unpublished results.
5 C. Varma, Nature 468, 184 (2010).

12a-B2 From cuprate to iron-based superconductors - some key elements of high-temperature superconductivity
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Cuprate and the recently discovered iron-based high-temperature superconductors (HTSs) appear to have some features in common: 1) they have unusually high transition temperatures $T_c$, 2) they have layered structures with strongly anisotropic normal state and superconducting properties, 3) they exhibit a rich doping dependent phase diagram with coexisting or non-coexisting magnetic and superconducting phases (with the exception that for cuprates the undoped mother compound is an isolator, whereas in the iron-based systems the mother compound is metallic), 4) there exist hole doped and electron doped variants of these HTSs, 5) they show a pronounced isotope effect on $T_c$ (for the cuprates isotope effects on various quantities, including the in-plane penetration depth and the pseudogap temperature, were observed, whereas in iron-based compounds at present controversial results have been reported for the isotope effect on $T_c$), and 6) they are multi-band superconductors with (eventually) mixed order parameters. In this talk some common and unlike properties of cuprate and iron-based HTSs will be discussed and also compared to those of the non-magnetic layered two-band superconductor magnesium diboride. Furthermore, it is shown that pronounced lattice and multi-band effects are essential to achieve the high transition temperatures in the cuprate and iron-based HTSs.

12a-B3 Superconducting gap and pseudo gap in hole doped copper oxides
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Electronic Raman scattering measurements have been performed on hole doped cuprates as a function of temperature and doping level. In the superconducting state coherent quasiparticles develop preferentially over the nodal region in the underdoped regime. We then define the fraction of coherent Fermi surface, $f_c$ around the nodes for which superconductivity sets in. We find that $f_c$ is doping dependent and leads to the emergence of two energy scales. We then establish that the critical temperature $T_c \propto f_c \Delta_{\text{max}}$, where $\Delta_{\text{max}}$ is the maximum amplitude of the d-wave superconducting gap. In the normal state, the loss of antinodal quasiparticles spectral weight detected in the superconducting state persists and the spectral weight is only restored above the pseudogap temperature $T^*$. Such a dichotomy in the quasiparticles dynamics of underdoped cuprates is responsible for the emergence of the two energy scales in the superconducting state and the appearance of the pseudogap in the normal state. This advocates in favor of a low temperature phase transition inside the superconducting dome.$^1$

12a-B4  Electronic Liquid Crystal Correlations in the Pseudogap States of High T\textsubscript{c} Superconductors

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The nature of pseudogap phase of cuprate oxides has been one of the most debated topic in condensed matter physics. Recently, the peculiarities of the pseudogap states were beautifully captured by STM data on Bi\textsubscript{2}Sr\textsubscript{2}CaCu\textsubscript{2}O\textsubscript{8+x} in the form of an inhomogenous spatial pattern of density of states. From these pseudogap patterns, we constructed liquid crystalline order parameter fields to quantify the symmetry breaking features\textsuperscript{1}. These fields reveal two properties of the pseudogap phase: it has a net anisotropy (nematic order) over at least 100 nm length scales; the stripe-like smectic order in the patterns impacts the nematic order locally at dislocations in the tripe pattern. Further, we could construct a Ginzburg-Landau free energy of nematic and smectic order parameter fields that is minimally allowed by symmetry and capture these two properties\textsuperscript{2}. Our results point towards important role of oxygen sites for microscopic models and open up opportunities to investigate the role these properties of pseudogap states play in superconductivity of high T\textsubscript{c} cuprates.

\textsuperscript{1} Lawler, Fujita et. al., Nature 466, 347 (2010).
\textsuperscript{2} Mesaros, Fujita et. al., to appear in Science (2011)

12a-B5  Magnetic-field-induced stripe order in YBa\textsubscript{2}Cu\textsubscript{3}O\textsubscript{y}

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In the search of the broken-symmetry state inferred from quantum oscillation and other transport measurements, we undertook high magnetic field NMR experiments in ultra clean, oxygen-ordered, untwined single crystals of YBa\textsubscript{2}Cu\textsubscript{3}O\textsubscript{y}. We find that the translational symmetry breaking does not arise from the magnetic order anticipated by most of us, but from a unidirectional charge-ordered state. Because it occurs only in strong magnetic fields oriented along the crystalline c-axis, this charge order appears to compete with superconductivity. While two (orthogonal) ordered patterns are compatible with the NMR spectra, we argue that the charge ordered state is most likely the 4\textsuperscript{a}-periodic stripe phase ‘a la Tranquada’. Nevertheless, we provide evidence that the stripe order remains partly fluctuating down to low temperatures. While the charge order is visibly pinned here by CuO chains, its occurrence at doping levels near 1/8 hole/Cu in a noticeably cleaner cuprate than e.g. La\textsubscript{2−x}Ba\textsubscript{x}CuO\textsubscript{4}, strengthens the idea that stripe correlations are a generic propensity of charges in the CuO\textsubscript{2} planes of hole-doped cuprates.
12a-C1 Emergence of novel states in low-dimensional quantum magnets

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Low-dimensional quantum magnets always reveal quite interesting and complex behaviors owing to strong quantum fluctuations and competing interactions involved in the systems, making that they not only play important roles in fundamental advances of condensed matter physics and molecular magnetism, but also may have potential applications in the field of quantum information and computation, thereby attracting much attention both theoretically and experimentally recently. In this talk, I will give a brief review on our recent results of novel emergent states in several low-dimensional quantum magnetic systems, including trimeric, tetrameric, diamond-type, decorated, and trigonal prism quantum Heisenberg spin chains, and the distorted honeycomb Heisenberg and kagome Ising magnets as well. A newly proposed algorithm-linearized tensor renormalization group-for calculating the thermodynamics of quantum lattice systems and implications are also discussed.

12a-C2 Slow Dynamics in Ordered Fe-Oxalates Kagome Antiferromagnets

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When induced by the topology of the lattice, magnetic frustration is expected to produce new ground states, characterized for instance by a 120° spin arrangements on each triangle of a classical kagome lattice with antiferromagnetic interactions. These ground states are associated to remarkable excitations, such as deconfined magnetic monopoles in dipolar spin-ices yielding slow dynamics. We have studied a new quaternary oxalate family Na2Ba3[Fe3(C2O4)6]X with X=[AIV(C2O4)3] where AIV = SnIV, ZrIV or X = [FeIII(C2O4)2(H2O)2]0.5 in which the FeII ions, which are the only in-plane magnetic moment carriers, form a lattice with the kagome connectivity. Neutron diffraction measurements provide evidence for the onset of a 120° type of magnetic ordering below 3 K. The magnetic behavior, in particular a field-induced magnetization plateau, is well described by a strong multiaxial single-ion anisotropy, larger than the nearest-neighbor exchange interactions, and by weaker dipolar interactions. This new hierarchy of interactions on a kagome lattice produces in the ordered phase a remarkable slow dynamics as observed by AC susceptibility measurements. It is associated with strings of spins along the magnetic domain walls, with a first regime of single spin-flips enabled by the low lattice connectivity, evolving towards a cooperative behavior at lower temperature proposed to be due to the onset of dipolar interactions.

12a-C3 Quantum criticality without tuning in the intermediate valence material β-YbAlB4

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A number of nontrivial phenomena have been found in itinerant magnets in the vicinity of a quantum critical point, such as unconventional superconductivity and non-Fermi liquid. Spin liquid is another emergent quantum state, which has recently attracted much attention. In the family of heavy-fermion intermetallics, all the quantum critical materials reported so far are known to have an almost integral valence which stabilizes the local moments. By contrast, departures from integral valence associated with valence fluctuations have been regarded to promote screening of local moments, suppressing the critical phenomena. In this talk, we present our recent discovery of quantum criticality without tuning in the ultrapure intermediate valence material β-YbAlB4. This compound superconducts below $T_c = 80$ mK, which is highly sensitive to impurity. Above $T_c$, it exhibits pronounced non-Fermi liquid phenomena at zero field and local-moment behavior despite its strongly mixed valency. We discuss the possible mechanisms of localization process of moments and associated zero field quantum criticality, including valence instability and formation of spin liquid phase on the distorted honeycomb lattice of Yb 4f moments. This is the work performed in collaboration with Y. Karaki (Ryukyu), T. Sakakibara, Y. Shimura, Y. Uwatoko (ISSP), A.H. Nevidomskyy (Rice), and P. Coleman (Rutgers).
**12a-C4** Spin and charge ordering in heterostructures of strongly correlated electron systems

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In strongly correlated heterostructures, a non-uniform potential together with correlation effects can lead to novel electronic properties which are not realized in ordinary bulk systems. For example, it was reported experimentally [1] and theoretically [2] that the interface between the band insulator (BI) SrTiO\(_3\) and the Mott insulator (MI) LaTiO\(_3\) shows a metallic behavior. In this study, we consider a strongly correlated interface of BI and MI, like SrTiO\(_3\)/LaTiO\(_3\) [1], with particular emphasis on magnetic properties at the interface. To this end, we investigate the Hubbard model with long-range Coulomb interaction in the Hartree-Fock approximation [2]. We find intriguing magnetic/charge phase transitions at the interface, which are closely related with the non-uniform potential. We elucidate that these transitions are caused by the strong coupling between charge and spin degrees of freedom near the interface. When the MI region has an antiferromagnetic (AF) order, a canted AF order can emerge around the interface, which shows a first-order metamagnetic transition under an external magnetic field. We also find that the strong spin-charge coupling stabilizes a charge order with a checkerboard pattern at the interface.


**12a-C5** Stripe-type order of spin, orbitals and charges in single-layered manganites

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Stripe-type or checkerboard ordering of charges and orbitals in metal-oxide compounds is linked to exotic behavior such as high-temperature superconductivity and colossal magnetoresistivity. We studied two single-layer manganites with a doping level slightly above half-doping, \(\mathbf{x}>0.5\), \(\text{La}_{0.42}\text{Sr}_{1.58}\text{MnO}_4\) (LSMnO) and \(\text{Pr}_{0.33}\text{Ca}_{1.67}\text{MnO}_4\) (PCMnO). For this doping range there are essential controversies about the nature of the charge orbital and spin order. The neutron-scattering experiments on LSMnO yield clear evidence for ferromagnetic zigzag chains being disrupted by stripes of excess of Mn\(^{4+}\) ions\(^1\). In this material three incommensurate and one commensurate order parameter are tightly coupled. Elastic neutron scattering on PCMnO reveals incommensurate magnetic scattering of Mn\(^{4+}\) spins and commensurate scattering of Mn\(^{3+}\) spins which is opposite to our finding for LSMnO4. The spin-wave dispersion in PCMnO starting at the incommensurate magnetic zone-centers point to a dispersion resembling the hour-glass dispersion in cuprates and \(\text{La}_{1.67}\text{Sr}_{0.33}\text{CoO}_4\).

12a-D1 Origin of 1/f magnetic noise in superconducting circuits
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We analyze theoretically a possible origin of the recently observed 1/f noise in the complex inductance of SQUIDs. The experimental data indicate a large cross-correlation of the inductance noise with the usual flux noise which is the dominant cause of decoherence in flux and phase qubits. Understanding of this phenomena sheds a new light on the long standing problem of 1/f flux noise in superconducting circuits. Our analysis shows that in SQUIDs with relatively small loops (under 1 micron) the inductance noise is dominated by the kinetic inductance fluctuations due to the dynamics of charged impurities; whereas in SQUIDs with large loops (much larger 1 micron) the inductance noise is dominated by magnetic coupling of the loop to a system of unpaired spins localized on the surface of the superconducting wires. Moreover, we argue that the cross-correlations in the magnetic noise observed in large SQUIDs (perimeter of order of 100 micron) imply a formation of long range order in fractal spin structures on the surface of the superconducting wiring. We show that such structures appear naturally in a random system of spins with wide distribution of spin-spin interactions; and that the fractal nature of this ferromagnetic state manifests in $1/f^{1+\zeta}$ spectra of magnetization noise, with small exponent \(\zeta\), and large cross-correlations in the magnetic noise which reproduce inductance-flux cross-correlations observed in SQUIDs.

12a-D2 Quantum Phase-Slip Devices
A.M. Hriscu\textsuperscript{a}, Yu.V. Nazarov\textsuperscript{a}, \textsuperscript{a}Kavli Institute of Nanoscience, Delft University of Technology, The Netherlands.

We theoretically propose novel devices to illustrate the coherent quantum phase-slips (QPS): the QPS oscillator, the QPS-box and QPS-transistor. The QPS oscillator can be realized on the basis of a thin superconducting wire or a chain of Josephson junctions\textsuperscript{1}. It proves that the experimental detection of quantum phase slips is achievable for small phase slip amplitudes, contrary to what is usually assumed. The responses of this damped-driven oscillator exhibit a cosine dependence on the charge induced by a gate electrode and very unusual oscillatory dependence on the drive/frequency. The QPS-box and the QPS-transistor are derived from the Cooper-pair box and Cooper-pair transistor\textsuperscript{2}. They exhibit sensitivity to a charge induced by a gate electrode, this being the main signature of Coulomb blockade. Experimental realization of such devices will prove the Coulomb blockade as an effect of coherence of QPS processes.


12a-D3 Dynamical Casimir effect in a Josephson metamaterial
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A feat of the quantum theory of fields is that vacuum fluctuations have experimentally testable consequences. To calculate the ground-state wave function of a system one needs to specify the boundary conditions, and the theoretical prediction is that a mere, rapid change of boundary conditions in time can result in a measurable amount of energy being created (Dynamic Casimir effect, DCE). Indeed, the boundary conditions are responsible for the well-known static Casimir effect, in which vacuum fluctuations between two plates result in an attractive force. While there exists convincing experimental evidence for the static Casimir effect, the DCE has remained elusive so far. Recently, it was recognized that modulation speeds approaching effectively the velocity of light can be obtained in a circuit quantum electrodynamics setup in which the boundary condition is realized using a flux-tunable SQUID loop at the end of a superconducting coplanar waveguide. Instead of a single SQUID, we use a metamaterial consisting of an array of 250 SQUIDs, which allows us to change the boundary conditions at frequencies around 10 GHz at a modulation strength corresponding to a distance variation on the order of 0.1 mm. As expected by theory, we find creation of large amounts of noise, i.e. photon creation, even at temperatures where the field modes are essentially thermally unoccupied. Moreover, we have investigated correlations at frequencies about half of the pump frequency, and find characteristic behavior predicted for the DCE.

12a-D4 Spin-relaxation in graphene: by covalently bonded adsorbates via EY mechanism
We report spin-injection measurements in a direct-contact cobalt−single-layer-graphene nonlocal spin-valve system, overlaid with a top gate. The spin signal was controlled precisely in conformation with the top-gate-induced conductivity variation. No additional spin relaxation was observed as the carriers traversed the interface, particularly for the bipolar configuration of graphene. The spin relaxation for a homogeneous graphene configuration with neutral top gate was also studied via measurements of the Hanle spin-precession effect. Hanle analysis demonstrated that the ratio between spin and momentum relaxation times is proportional to the square of the density of states, which varies with the carrier density due to the unique linear dispersion relation of graphene. From the proportionality ratio, we determined spin-orbit coupling strength of $\sim 9-10$ meV. These findings lead to the conclusion that the spin state is most likely relaxed by covalently bonded adsorbates on the graphene via the EY mechanism. We emphasize that taking into account the carrier-density dependence of the density of states is crucial to correctly identifying the spin-relaxation mechanism in graphene.

**12a-D5 Coupling Propagating Acoustic Waves to Quantum Circuits**

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We present a method for coupling propagating Surface Acoustic Waves (SAW) to charge sensitive quantum circuits, by direct piezoelectric charge induction. Using an RF-Single Electron Transistor\textsuperscript{1} as a high-performance electrometer, and employing an on-chip mixing technique\textsuperscript{2}, we demonstrate ultra-high displacement sensitivity in the gigahertz frequency range, and an averaged detection sensitivity below the single-phonon level. Based on these experimental results, we discuss how the method can be enhanced and extended to superconducting qubits, and what roles Surface Acoustic Waves could potentially play in novel hybrid quantum devices.

Session 12P-A:

A1 Ultra-cold Quantum Gases in Optical Lattices
A2 Novel Quantum Phases in Ultra-cold Gases

Friday August 12, 16:00 – 18:00
Exhibition Hall 1

12P-A001 Possible Effects of $^3$He Impurities and Shearing on the Formation of Locally Amorphous Supersolid $^4$He driven by a Pressure Gradient

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Possible anomalous states of $^4$He crystal relevant to the possible onset of supersolidity in $^4$He crystal were reported recently. Here, by treating the $^4$He crystal locally as an amorphous matter and using the transition-state model together with the specific activation volume as well as activation energy, we observe a series of sudden change of the shearing stresses (which directly relates to the local transport resistance) at corresponding onset temperatures of $^4$He crystal for different activation volumes considering the role of $^3$He concentration. We found that once the pressure forcing increases for fixed concentration of $^3$He the transition temperature decreases which qualitatively agrees with previous results. We also investigate the possible effects of different shear strain rates as well as the pressure gradient upon the nearly frictionless transport of locally amorphous solid $^4$He within a confined cylindrical domain for a fixed $^4$He concentration. The tuning of different shear strain rates was found to play a crucial role in the formation of possible supersolidity in $^4$He crystal. The only author is partially supported by the 2011-IMUST Starting Funds for Scientific Research.


12P-A002 Resonant Enhancement of the FFLO State in 3D by an Optical Potential

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In a spin-imbalanced Fermi gas, a competition exists between Cooper-pairing with zero momentum and with finite momentum. The former is the well-known BCS superfluid, while the latter gives rise to the Fulde-Ferrell-Larkin-Ovchinnikov state (FFLO state). This exotic state has hitherto eluded all experimental observation. In this contribution, we propose a new way to stabilize the FFLO state in a three-dimensional (3D) Fermi gas. Our description is based on the Feynman path-integral framework in which we start from the partition sum of an imbalanced Fermi gas. To allow for the formation of the FFLO state, a suitable form for the saddle point is chosen, in which the pairs have a finite center-of-mass momentum. Subsequently, we investigate the effect of imposing an optical potential, applied along one direction, on the 3D Fermi gas. By constructing the phase diagrams of the system, we show that the presence of the optical potential greatly enhances the stability region of the FFLO state, relative to the case of the 3D Fermi gas without optical potential. It is shown that the FFLO state can exist up to a higher level of spin imbalance if the wavelength of the optical potential becomes smaller. We propose that this concept can be used experimentally to resonantly enhance the stability region of the FFLO state.


12P-A003 Strongly-correlated lattice bosons in the superfluid phase: a selfenergy-functional cluster approach

Enrico Autigoni*, Michael Knap*, Wolfgang von der Linden*, a Institute of Theoretical and Computational Physics, Graz University of Technology, 8010 Graz, Austria

We extend the variational cluster approach to deal with strongly-correlated lattice bosons in the superfluid phase. To this end, we reformulate the method within a pseudoparticle formalism, whereby cluster excited states are described in terms of particle-like excitations. The approximation amounts to solving a multi-component noninteracting bosonic system by means of a multi-mode Bogoliubov approximation. A criterion for the stability of the solution is discussed. In order to provide a rigorous background for this approach we provide an extension of the selfenergy functional approach to include the bosonic superfluid phase, and show that the two approaches are equivalent. We provide expressions for the single-particle normal and anomalous Green’s functions, the condensate density, the grandcanonical potential, and other static quantities. We apply the method to the two-dimensional Bose-Hubbard model and evaluate results in both Mott and superfluid phase. Our approach yields excellent agreement with Quantum Monte-Carlo calculations. The extension to other problems of interest, such as correlated light-matter systems, Fermi-Bose mixtures, as well as systems out of equilibrium is discussed.

12P-A004 Fermi gas with attractive potential and arbitrary spin in highly elongated trap

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A gas of ultracold $^6$Li atoms confined to an elongated trap with one-dimensional properties is a candidate to display three different phases: (i) fermions bound in Cooper-pair-like states, (ii) unbound spin-polarized particles, and (iii) a mixed phase with some resemblance to the FFLO pairing [1,2]. So far theoretical studies are restricted to spin-1/2 atoms, but it is pos-
sible to extend these to fermionic atoms with higher spin, e.g. for $^{43}$Ca, $^{87}$Sr or $^{173}$Yb. We investigated the $\mu$ vs. $H$ phase diagram for $S = 3/2$ ($\mu$ is the chemical potential and $H$ the external magnetic field) for the ground state using the exact Bethe Ansatz solution of the one-dimensional Fermi gas interacting with an attractive $\delta$-function potential [3]. The subtle differences between open and periodic boundary conditions on the next nested Bethe Ansätze are discussed. There are four fundamental states: The particles can be either unpaired or clustered in bound states of two, three and four fermions. The rich phase diagram consists of these four states and various mixed phases in which combinations of the fundamental states coexist. Bound states of four fermions are not favorable in high magnetic fields, but always present if the field is low. This calculation extends the FFLO picture in one-dimension to $S = 3/2$-particles.

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12P-A005 Effects of restricted geometry on Bose-Einstein condensation in optical lattices

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We study the influence of the restricted geometry of a cubic lattice confined within finite slab of $L$ layers (i.e. of the form $\infty \times \infty \times L$) on the ground state properties of interacting bosons in the optical lattice. Using the quantum rotor approach for the Bose-Hubbard model, we quantify how the restricted slab geometry affects the superfluid to Mott-insulator transition. For increasing values of $L$ both analytical approach for large $L$ as well as direct calculation using lattice density of states for any arbitrary $L$ shows that the behavior of the system becomes indistinguishable from the cubic bulk case ($L = \infty$) even for relatively small values of $L$ ($L \approx 10$). This may appear as an important justification of treating bosons in optical lattices using methods of statistical physics pertinent for infinite systems.

12P-A006 Coherent dynamics of quantum superfluid gases in optical lattices

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The localized-delocalized and the coherent-decoherent transition in superfluid Fermi gas, spinor condensate, dipolar condensate and impurity induced two-component condensate are studied in detail. We predict the existence of coherent matter waves, i.e., stable Bloch oscillating and moving solitons/breathers, and self-trapped state of the superfluid wave packets in higher dimensional optical lattices. The phase diagrams for localized-delocalized and the coherent-decoherent transition are obtained analytically and verified numerically. We find that Fermi-Fermi, spin-spin, dipole-dipole and impurity interactions can play crucial role in causing important coherence-decoherence and localization-delocalization phase transitions. Some interesting results are obtained: (1) The phase diagrams vary greatly along the BEC-BCS crossover in superfluid Fermi gas and the dynamics of Fermi wave packet (such as the coherent duration) are very different from that of Bose wave packet. Stable coherent 3D moving soliton/breather states exist in superfluid Fermi gas. (2) The spin-mixing dynamics are coupled with wave packets dynamics: when the wave packets are self-trapped, the spin-mixing oscillations are also arrested to the stationary configuration; during diffusion of the wave packets, however, the spin-mixing dynamics are inhibited; a robust quasi-periodic spin-mixing oscillation maintains in moving soliton and breather states. (3) By properly designing the sign and the magnitude of the contact and dipolar interactions (when the dipolar interaction, the contact interaction and the lattice dimension satisfy an analytical condition), it is possible to perfectly control the decoherence of Bloch oscillations. Stable coherent 2D moving soliton/breather states exist in dipolar condensate. (4) The dynamics of the condensates can be modified significantly by a minor admixture of an impurity in the system. The diffusion state of the single-component BEC will transit to the self-trapped state due to the minor admixture of an impurity, even if the two condensates are only with marginal spatial overlap. In some certain conditions, stable moving soliton can exist in high-dimensional lattices for the two-component BECs.

12P-A007 Gutzwiller study for phase diagram of extended Hubbard models with fixed boson densities

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We studied the phase diagram of extended Bose–Hubbard models with nearest-neighbor interaction on bipartite lattices in a canonical ensemble by using the Gutzwiller variational wave function and the linear programming method under the condition of fixed boson densities. Contrary to the hard-core model, the soft-core model at half filling has a possible SS phase between the solid and SF phases and all phase transitions are continuous. We also found that the phase diagram of the soft-core model strongly depends on its transfer integral $t$. For small $t$, the shape of the SF region is similar to that of the hard-core model with particle-hole symmetry and the SS phase does not appear because of the phase separation above half filling. In contrast, for large $t$, the SS phase appears even above half filling. The phase diagram becomes simplified for large $t$, where there is only a continuous SF–SS phase transition and the critical value of $t$ at the phase boundary is
a smooth decreasing function of boson density $N$. Finally, we also found that the density difference between nearest-neighbor sites $\delta n$, which shows the density wave order of the SS phase, strongly depends on the boson density $N$. In particular, for small $t$, the difference $\delta n$ is a discontinuous function of the nearest-neighbor interaction $V$ and is larger for smaller (larger) $N$ for small (large) $V$.

12P-A008 Color Superfluid of Three-Component Fermionic Atoms with Repulsive Interaction in Optical Lattices

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Motivated by recent intensive studies on cold fermionic atoms with multiple internal degrees of freedom such as $^6$Li and $^{173}$Yb, we have investigated the repulsively interacting three-component (color) fermionic atoms in optical lattices.\textsuperscript{1,2,3} We have shown that the system undergoes a Mott transition even in the incommensurate half filling. At the transition point, two atoms with the weakest repulsion form pairs so as to avoid stronger two repulsions, which leads to the paired Mott insulator (PMI). This result suggests that pair fluctuations are strongly enhanced and the color superfluid (CSF) may appear close to the transition point. In this study, we investigate the CSF of this system. Using the dynamical mean-field theory combined with an iterative perturbation theory and the self-energy functional approach, we calculate the CSF order parameter, the quasiparticle weight, and the double occupancy as functions of the interaction and temperature for several fillings. We discuss the zero- and finite-temperature phase diagrams for the characteristic states: the CSF, the PMI, and the color-selective Mott state.


12P-A009 Dynamical properties of bosons in an optical lattice with a synthetic magnetic field

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We study the dynamical properties of bosons in an optical lattice subject to a synthetic magnetic field at zero temperature. A synthetic magnetic field can be created through rotation of an optical lattice or Raman transition induced by a spatially-varying laser beam. First, we consider a regime where a large number of bosons are occupied in each site of the optical lattice. Then, the dynamics is well described by the Gross-Pitaevskii equation. We describe the nonlinear dynamics of vortex nucleation in a Bose-Einstein condensate in a deep optical lattice. The detailed comparison with the recent experimental observation of the vortex nucleation will be reported. Second, we study the effect of synthetic magnetic fields on quantum dynamics of bosons in an optical lattice under the hard-core limit. By solving the Heisenberg equation of motion for the annihilation operator, we find the periodic motion with the typical spatial period determined by the strength of the magnetic field. We also discuss the dynamics of usual bosons for comparison, revealing the effect of the hard core nature on the dynamics.

12P-A010 Mesoscopic Transport of Ultra-cold Atoms in Optical Lattices

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Ultra-cold atoms in optical lattices have been shown to be perfectly suitable for implementing physical models of fundamental interest to the field of atomic and condensed matter physics.\textsuperscript{1} In particular, ultracold systems have the advantage that they exhibit slow coherent dynamics (with kilohertz tunneling rates) and, more importantly, that single atoms are detectable on microscopic scales. We show how these features can be exploited to study mesoscopic transport of ultracold atoms in a specific setup, namely two atomic reservoirs connected by a short optical lattice.\textsuperscript{2} For our analysis in the tight-binding regime we use the non-equilibrium Green’s functions formalism extended to include the time dependence of the reservoirs. This allows us not only to determine the mean atomic current between the reservoirs but also the full counting statistics (FCS) of the atomic transport, i.e., shot noise and higher order cumulants. We argue that these quantities can be readily determined in experiments by counting the atoms in the reservoirs. Furthermore, we show that time-dependent modulations of the short optical lattice result in mesoscopic phenomena such as coherent suppression of tunneling and non-adiabatic quantum pumping.


12P-A011 Anomalous Hysteretic Behavior in a System of Dipolar Bose Gases

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We study quantum phase transitions of dipolar bosons loaded into triangular optical lattices. We analyze hysteresis properties of the system by applying a large-size cluster mean-field approximation to the corresponding hardcore Bose-Hubbard model. The long-range nature of dipole-dipole interaction gives rise to a rich ground-state phase diagram, containing superfluid (SF) phase, solid (Sol) phase, and the coexistence of them, the so-called supersolid (SS) phase. We find that the transition between the SF phase and the other phases is always first-order (discontinuous) except for the particle-hole symmetry point. In conventional first-order transitions, the transition between the two phases occurs
bidirectionally along a hysteresis loop. In contrast, we find that in the present case the quantum melting transition from the Sol (or SS) to SF phase occurs unidirectionally along a hysteresis curve, which does not form a standard loop structure.\(^1\)


12P-A012 Dynamics of ultracold fermions in optical lattices: negative absolute temperatures and constant forces

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We investigate the dynamics of ultracold fermionic atoms captured in optical lattice which can be described by the Hubbard model. Using a simple protocol, we show how and on what time scales negative absolute temperature can be realized by reversing the confining potential\(^1\). For bosonic atoms such negative temperatures can be detected by observing Bose condensation at the maxima of the kinetic energy. Furthermore, we study an atomic cloud in an optical lattice in the presence of a constant force\(^a\) arising, for example, from gravity. Energy conservation implies that the cloud expands symmetrically such that gains of potential energy at the top are compensated by losses at the bottom. Interactions stabilize the necessary heat currents by inducing gradients of the inverse temperature 1/T, with \(T < 0\) at the bottom of the cloud. Hydrodynamic equations allow for a precise quantitative analytic description of the expansion which we compare to numerical results from Boltzmann simulations.


12P-A013 large Stability of topological excitations under the phase transition in spinor BECs

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We study collective frequencies due to the dimensional effects in elongated quasi-two-dimensional (2D) optically trapped Bose gases. With the hydrodynamic theory of superfluids, the key ingredient accounting for the dimensional effects is the equations of state \(\rho_{Q2D}\) for quasi-2D Bose gases, which is obtained via the path integral method. The resulting frequency shift, proportional to the ratio \(a_{1D}/a_{2D}\) between the 3D and effective 2D scattering coupling constant, is compared with other corrections due to the finite size, nonlinearity, thermal effect and the presence of quantum vortex. We show that for reasonable choices of the relevant parameters of the system, such dimensionality correction is the leading contribution, well in reach for the ongoing experimental techniques.\(^1\)

of the \( p \)-wave interaction. Such non-monotonic interaction dependence of the pseudogap structure is quite different from the case with a \( s \)-wave interaction, where the pseudogap in DOS and SW simply becomes large in the BCS-BEC crossover. Thus, our results clarify how the symmetry of the pairing interaction affects the pseudogap phenomena in strongly correlated Fermi systems. We also show how the pseudogap structure in DOS and SW disappears, as one increases the temperature above \( T_c \). This work was supported by Global COE Program “High-Level Global Cooperation for Leading-Edge Platform on Access Spaces (C12)”.

12P-A016 Collective excitations in correlated two-dimensional fermion systems

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Godfrin et al. performed a neutron scattering experiment on two-dimensional (2D) \(^3\)He.\(^1\) They found the zero sound mode at small wave-vectors; the mode was found to lie very close to the particle-hole (PH) continuum band. At intermediate wave-vectors, the mode entered the PH band and was broadened by the Landau damping. Interestingly, they found that the mode reappeared below the PH band at large wave-vectors. To understand these findings, it is necessary to consider the correlation effect beyond the RPA theory as was emphasized, e.g. in Ref. 2. In this paper, we study the dynamical responses of 2D fermion systems taking account of the correlation effect. We use a model on a 2D lattice as an effective model for liquid \(^3\)He. To suppress the lattice discretization effect, we consider the dilute limit, \( n \approx 0.1 \), where \( n \) is the fermion number density. In addition to the on-site repulsion, we consider the interaction between particles at different sites. We study the dynamical responses of a dilute 2D extended Hubbard model. The correlation effect is considered with the second-order perturbation theory; the self-energy and the vertex corrections are consistently considered. In addition to the density correlation function, we calculate the spin correlation function.


12P-A017 Partially coherent matter wave soliton solutions_Multimode theory

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In a realistic system, the ultra cold Bose gases can be considered as partially coherent matter wave (PCMW). To analyze the dynamics of PCMW, many theoretic models have been presented. Most of them rely on the assumption that the zero momentum state is macroscopically populated and atoms in all other states are small perturbations. These models work well when the temperature is well below the critical temperature \( T_c \), but if the temperature increases to around or slightly above \( T_c \), it is not such appropriate to use the above assumption since the influences from other states can not be regarded as small perturbations. Inspired by the similarity between the physics of the interacting Bose gas and that of light in nonlinear medium, we present a multimode theory to deal with the nonlinear evolution of PCMW. We find that in some condition analytic soliton solutions of PCMW exist. We also analyze the coherence properties of them.

12P-A018 Controlled Split-Recombination of 2D Matter-Wave Solitons in Time-Dependent Trap

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We propose a novel approach to manipulate two-dimensional bright matter-wave solitons by tuning the frequency of the trap which is different from Feshbach resonance technique. The exact bright soliton solutions for two-dimensional Gross-Pitaevskii (GP) equation with attractive interaction strength in a time-dependent trap are constructed analytically and its dynamics show no collapse while modulating the trap frequency. The two-soliton dynamics exhibits an interesting splitting and recombination phenomenon which generates interference pattern in the process. This type of behaviour in two-dimensional BECs has wider ramifications and our approach opens new avenues in stabilizing bright solitons in higher dimensional regime. We have also explored the experimental realization of this novel phenomenon.

12P-A019 Localization of Bose-Fermi Mixtures in One-Dimensional Incommensurate Lattices

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Disordered Bose systems with strong correlation, described by Bose Hubbard models with disorder, have been one of the targets of theoretical and experimental investigation. Current interest is also directed towards disordered systems of ultracold atoms generated by using laser speckle patterns or additional incommensurate optical lattice potentials. Fallani et al.\(^1\) observed a localization transition of strongly interacting \(^{87}\)Rb bosons in incommensurate lattices, which suggested the formation of a Bose glass.

We will present the results of quantum Monte Carlo simulations of Bose-Fermi mixtures in one-dimensional incommensurate lattices. We observed localization as the strength of the incommensurate potential increases. We also found a characteristic behavior of the superfluid density when changing the Bose-Fermi interactions over a wide range. The superfluidity is enhanced by itinerant fermions when the strength of repulsive Bose-Fermi interactions becomes comparable to that of repulsive Bose-Bose interactions. On the other hand the superfluidity is enhanced in some cases and not in other cases with attractive Bose-Fermi interactions. The occurrence of the enhancement strongly depends on the particle densities and the Bose-Bose interactions. We propose a mechanism of these phenomena, showing snap-
shots of the imaginary-time evolutions of the particles and the dynamical structure factors.


12P-A020 Effects of particle-hole channel and BCS-BEC crossover on an optical lattice†
Qi Jin Chen*, ‡Department of Physics and Zhejiang Institute of Modern Physics, Zhejiang University, Hangzhou, Zhejiang 310027, China

BCS-BEC crossover is effected by increasing pairing strength between fermions from weak to strong. Such pairing is associated primarily with the particle-particle channel. Effects of the particle-hole channel is often dropped. On the other hand, Gor’kov et al argued that the particle-hole channel can cause a substantial reduction in both $T_c$ and the pairing gap. However, this result has largely been neglected until recent years when BCS-BEC crossover has been realized experimentally in ultracold Fermi gases. On the other hand, a periodic lattice potential has also dramatic effects on the behavior of BCS-BEC crossover. In this talk, we study both types of effects on BCS-BEC crossover in a $GaG$ scheme. While in the BCS limit, the particle-hole channel effects may be approximated by a shift in the pairing strength, the situation becomes more complex as the interaction becomes stronger where the gap is no longer small. At low densities, lattice effects make the transition temperature decrease with increasing pairing strength due to virtual ionization. In particular, at high density, the superfluid phase may disappear on an optical lattice when the pairing strength is high enough.


12P-A021 The quantum simulation setup of $^87$Rb Bose-Einstein condensates and numerical analysis of disorder induced dynamic-equilibrium localization
Yafan Duan*, Jianfang Sun*, Bonan Jiang*, Xu Zhen*, Tao Hong*, Yuzhu Wang**
Grand No. 2011CB921504),

We report on a rapid production of $^87$Rb Bose-Einstein condensates(9) in a tight confinement hybrid trap based on single-beam optical dipole trap(ODT) and magnetic quadrupole trap(MQT). By the help of preliminary evaporation cooling in MQT, more atoms can be transferred to ODT. Then the BEC phase transition will be achieved by forced evaporation in ODT. This setup has good optical access for loading multiple optical lattices and laser speckle to quantum simulation. In theory, we numerically analyze the dynamic behavior of Bose-Einstein condensates in one-dimensional disordered potential before its completely losing spatial quantum coherence. We find that localization length can be remarkably affected by both the disorder statistics and the atom interaction. We also find the phase of the condensates is broken into many small pieces while the system approaching localization, showing a counter-intuitive step-wise phase but not a thoroughly randomized phase. Although the condensates as a whole showing less flow and expansion, large currents occur where the phase changes abruptly. Thus we show explicitly that the localization of a finite size BEC is dynamic-equilibrium.

12P-A022 The quantum simulation setup of $^87$Rb Bose-Einstein condensates and numerical analysis of disorder induced dynamic-equilibrium localization
Yafan Duan*, Jianfang Sun*, Bonan Jiang*, Xu Zhen*, Tao Hong*, Yuzhu Wang**

We report on a rapid production of $^87$Rb Bose-Einstein condensates (BECs) in a tight confinement hybrid trap based on single-beam optical dipole trap(ODT) and magnetic quadrupole trap(MQT) by the help of preliminary evaporation cooling in MQT, more atoms can be transferred to ODT. Then the BEC phase transition will be achieved by forced evaporation in ODT. This setup has good optical access for loading multiple optical lattices and laser speckle to quantum simulation. In theory, we numerically analyze the dynamic behavior of Bose-Einstein condensates in one-dimensional disordered potential before its completely losing spatial quantum coherence. We find that localization length can be remarkably affected by both the disorder statistics and the atom interaction. We also find the phase of the condensates is broken into many small pieces while the system approaching localization, showing a counter-intuitive step-wise phase but not a thoroughly randomized phase. Although the condensates as a whole showing less flow and expansion, large currents occur where the phase changes abruptly. Thus we show explicitly that the localization of a finite size BEC is dynamic-equilibrium.

12P-A023 The quantum simulation setup of $^87$Rb Bose-Einstein condensates and numerical analysis of disorder induced dynamic-equilibrium localization
Yafan Duan*, Jianfang Sun*, Bonan Jiang*, Xu Zhen*, Tao Hong*, Yuzhu Wang**

We report on a rapid production of $^87$Rb Bose-Einstein condensates (BECs) in a tight confinement hybrid trap based on single-beam optical dipole trap(ODT) and magnetic quadrupole trap(MQT) by the help of preliminary evaporation cooling in MQT, more atoms can be transferred to ODT. Then the BEC phase transition will be achieved by forced evaporation in ODT. This setup has good optical access for loading multiple optical lattices and laser speckle to quantum simulation. In theory, we numerically analyze the dynamic behavior of Bose-Einstein condensates in one-dimensional disordered potential before its completely losing spatial quantum coherence. We find that localization length can be remarkably affected by both the disorder statistics and the atom interaction. We also find the phase of the condensates is broken into many small pieces while the system approaching localization, showing a counter-intuitive step-wise phase but not a thoroughly randomized phase. Although the condensates as a whole showing less flow and expansion, large currents occur where the phase changes abruptly. Thus we show explicitly that the localization of a finite size BEC is dynamic-equilibrium.
12P-A024 Experimental image transfer and frequency conversion based on an atom ensemble

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In this talk, we will show the experimental research about the image transfer between different lights with the aid of the atomic ensemble. We report on two different image transfer experiments: one is based on electromagnetically induced transparency effect. Another is based on four wave-mixing in an atomic ensemble. In the first experiment, we realize not only an image transfer from a control light to a probe light, but also an image transfer from a control light to two different probes, which can be definitely extended to more probes. This process can be regarded as image cloning. Besides, we consider a case in which a single photon detector instead of CCD camera is used to detect the probes, and find that the transferred images still exist. In the second experiment, we demonstrate an image transfer with large frequency conversion using four-wave mixing process in ladder-type configuration in an atomic ensemble. We realize experimentally that an image with telecom-band frequency that is suitable for fiber transmission over long distance is transferred to a short wavelength signal that matches the D2 line of Rb atom transition, to a light at 1530 nm in the window of the fiber through four wave-mixing in an atom ensemble. After that, the light at 1530 nm obtained previously is converted back to the light at 780 nm again through another FWM in another atom ensemble. Besides we experimentally prove that the coherence of the input light can be kept through this cascade FWM process by observing the interference between the light obtained finally and a reference light. Our research makes a preliminary step toward to realize the quantum repeater.

12P-A025 One-dimensional collision dynamics of fermion clusters

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Recent experiments with cold atomic gases have conducted from interest of the non-equilibrium dynamics of correlated quantum system. Of these experiments, the dynamics of the mixing of fermion clusters\textsuperscript{1} is important as a simple system in which classical dynamics and quantum dynamics can be compared. Our motivation is to understand the difference between classical dynamics and quantum dynamics.

We use the time-dependent density matrix renormalization group method\textsuperscript{2} and one-dimensional Fermi-Hubbard model. We simulate the collision dynamics of two fermion clusters. One of the clusters consists of spin-up fermions, and the other spin-down. Initially each cluster is separately trapped by a harmonic potential. Next we suddenly change the trapping potential into a shared symmetric harmonic potential. Then the clusters move towards each other, and collide at the bottom of the shared potential, and finally inter-penetrate or get reflected depending on the interaction. Reflection rate of the clusters $R$ is calculated changing particle number in one cluster and interaction between the two fermions. We have also evaluated the quasi-classical (independent collision) reflection rates $R^{qc}$ to compare it with $R$. The quasi-classical picture is quantitatively valid in the limit of no interaction, but it is not valid when interaction is strong.

\textsuperscript{1}A. Sommer, M. Ku, and M. W. Zwierlein, arXiv:1103.2337.

12P-A026 Bosons in Hofstadter Model: mesoscopic phenomenon and effective theory for superfluid

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A synthetic magnetic field for neutral atoms has been successfully realized through engineering an atom-light interaction. This technique can be applied to cold atom system in optical lattice straightforwardly. Here in this talk, I will present our study on boson systems in optical lattices with a uniform magnetic field (Hofstadter Model). First, I shall present a theorem that shows the degeneracy of many-body states in this model de-
depends on the total particle number and the flux filling ratio. Second, I will talk about the behavior of the ground state of mesoscopic boson system with flux filling ratio 1/3. Numerical simulation of the quantum ground states and theoretical understanding will be given. Also, I shall present an effective theory for superfluid in thermodynamic limit of this model, together with the mean-field study and analysis of low-energy excitation.

12P-A027 The quantum simulation setup of $^{87}$Rb Bose-Einstein condensates and numerical analysis of disorder induced dynamic-equilibrium localization

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We report on a rapid production of $^{87}$Rb Bose-Einstein condensates (BECs) in a tight confinement hybrid trap based on single-beam optical dipole trap (ODT) and magnetic quadrupole trap (MQT). The help of preliminary evaporation cooling in MQT, more atoms can be transferred to ODT. Then the BEC phase transition will be achieved by forced evaporation in ODT. This setup has good optical access for loading multiple optical lattices and laser speckle to quantum simulation. In theory, we numerically analyze the dynamic behavior of Bose-Einstein condensates in one-dimensional disordered potential before its completely losing spatial quantum coherence. We find that localization length can be remarkably affected by both the disorder statistics and the atom interaction. We also find the phase of the condensates is broken into many small pieces while the system approaching localization, showing a counter-intuitive step-wise phase but not a thoroughly randomized phase. Although the condensates as a whole showing less flow and expansion, large currents occur where the phase changes abruptly. Thus we show explicitly that the localization of a finite size BEC is dynamic-equilibrium.

12P-A028 Expansion dynamics in the one-dimensional Fermi-Hubbard model

J. Kajala*, F. Massel*, P. Törmä*. 

Expansion dynamics of interacting fermions in a lattice are simulated within the one-dimensional (1D) Hubbard model, using the essentially exact time-evolving block decimation (TEBD) method. In particular, the expansion of an initial band-insulator state is considered. We analyze the simulation results based on the dynamics of a two-site two-particle system, so-called Hubbard dimer. Our findings describe essential features of a recent experiment on the expansion of a Fermi gas in a two-dimensional lattice. We show that the Hubbard-dimer dynamics, combined with a two-fluid model for the paired and non-paired components of the gas, gives an efficient description of the full dynamics. This should be useful for describing dynamical phenomena of strongly interacting Fermions in a lattice in general.

12P-A029 Progress of making the MOT for neutral mercury atoms

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Due to less blackbody radiation shifts, mercury atoms are regarded as one of the best candidates for realizing the neutral atomic clock approaching the highest accuracy of $1 \times 10^{-18}$. Here we report our recent progress toward making a magneto-optical trap for mercury atoms, as a cold atom source for our future optical lattice clock of mercury. We designed and installed the ultra-high vacuum system. The mercury source and the cold pump can be cooled down to $-80^\circ C$ and $-100^\circ C$ by TEC, corresponding the saturated vapor pressure of mercury with $2.5 \times 10^{-9}$ Torr and $3 \times 10^{-11}$ Torr, to enhance the background vacuum pressure. To improve the power of the cooling laser, we are developing a new kind of Yb-doped fiber amplifier operating at 1014.8nm, which could be used as the fundamental frequency laser of the frequency quadrupling to 253.7 nm. We numerically simulated several spectroscopy of 6 naturally abundant isotopes of mercury atoms including: the saturated absorption spectroscopy (SAS), DAVLL spectroscopy and polarization spectroscopy (PS), and proposed the sub-doppler DAVLL and PS for frequency stabilization, which has advantage of simple, compactable and good signal to noise ratio. We would like to thanks Professor Yuzhu Wang for great supports. This work is supported by Research Project of Shanghai Science and Technology Commission (Grant. No. 09D1400700), National Natural Science Foundation of China (Grant No. 10974211) and National 973 Project (Grant No.2011CB921504).

12P-A030 Ultra low cost single chamber BEC apparatus with good optical access.

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We built an Ultra low cost Rb BEC apparatus at the Institute of Physics. The system is a single chamber design with good optical access. I will discuss several technical innovations to achieve extreme low cost, and show how to do 3D optical lattice, Feschbach resonance and In situ imaging with such a system.

12P-A031 Manipulation of a Bose-Einstein condensate by a time-averaged orbiting potential using phase jumps of the rotating field

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We report on the manipulation of the center-of-mass motion ("sloshing") of a Bose Einstein condensate in a time-averaged orbiting potential (TOP) trap. We
start with a condensate at rest in the center of a static trapping potential. When suddenly replacing the static trap with a TOP trap centered about the same position, the condensate starts to slosh with an amplitude much larger than the TOP micromotion. We show, both theoretically and experimentally, that the direction of sloshing is related to the initial phase of the rotating magnetic field of the TOP. We show further that the sloshing can be quenched by applying a carefully timed and sized jump in the phase of the rotating field.

12P-A032 Manipulating the external states of a condensate for rapid loading
Wei Xiong, Xuguang Yue, Zhongkai Wang, Yueyang Zhai, Xinxing Liu, Xiaoji Zhou, Xuzong Chen, School of Electronics Engineering & Computer Science, Peking University, Beijing 100871, China

We analyze the effect of sequences of standing wave pulses on a Bose-Einstein condensate (BEC). Experimental observations are in good agreement with a numerical simulation based on the band structure theory in the optical lattice. We also demonstrate that a coherent control method based on such sequences of pulses is very efficient for experimentally designing specific momentum states. With this method, we manage to load a condensate into an optical lattice with little heating.

12P-A033 Manipulating the momentum state of a condensate by sequences of standing wave pulses
Xuguang Yue*, Wei Xiong*, Zhongkai Wang*, Xiaoji Zhou*, Xuzong Chen*, School of Electronics Engineering & Computer Science, Peking University, Beijing 100871, China

Coherent momentum manipulation is very important for splitting and recombining ultra-cold atoms in atomic interferometry, and the diffraction of atoms from standing wave light is an usual and effective method to achieve this goal. Here we show a method for flexible manipulation of the atomic momentum states, where the standing wave pulses are less limited in pulse intensities and durations than in cases of Bragg or Kapitza-Dirac diffraction. The diffraction of a Bose-Einstein condensate from one, two, three and four standing wave pulses are demonstrated in our experiments and systematically analyzed by the band structure theory of one-dimensional optical lattice. With this method, we are able to design and realize specific momentum states, which may be applied in atomic interferometry. In principle, this method could be used for designing a wide range of possible target states.

12P-A034 Exploring multi-band excitations of interacting Bose gases in a 1D optical lattice by coherent scattering
X. Liu*, X. Zhou*, T. Vogt*, X. Yue*, B. Lu*, X. Chen*, *Institute of Quantum Electronics, School of Electronics Engineering and Computer Science, Peking University, Beijing 100871, China

We adiabatically load our Bose-Einstein condensate of about $2 \times 10^5$ $^{87}$Rb atoms into a one-dimensional optical lattice and give the atoms one momentum along the lattice direction within a short time (typically 5ms), using a Bragg beam sent from a special angle $\theta$, which satisfies the phase coherent condition of $\cos \theta = \lambda_u/\lambda_r$, where $\lambda_u = 780nm$ and $\lambda_r = 852nm$ are wavelength of Bragg beam and lattice light, respectively. After that we keep the lattice on for a duration of $\tau$, and then turn off the lattice suddenly and observe the time of flight image 30ms later. Oscillation of momentum distribution due to lattice potential is clearly observed. Compared with previous work which moved the lattice instead of the atoms to get such kind of oscillation, our experiment result is correspondent with the theory much better. By measuring the oscillating frequencies, we extract multi-band energy structures of single-particle excitations with zero pseudo-momentum transfer for a wide range of lattice depths. The excitation energy structures reveal the interaction effect through the whole range of lattice depth.

12P-A035 Properties of super-Tonks-Girardeau gases
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I shall give an introduction to our recent theoretical works on the super-Tonks-Girardeau gases, which are related to the recently experimentally observed super-Tonks-Girardeau state of bosonic Cesium atoms [Science 325, 1224 (2009)]. By solving exact dynamics of the integrable Lieb-Liniger Bose gas, we demonstrate that such an excited gas state can be a very stable dynamic state. Furthermore we calculate the breathing mode of the super Tonks-Girardeau gas which is found to be in good agreement with experimental observation. Our results show that the highly excited super Tonks-Girardeau gas phase can be well understood from the fundamental theory of the solvable Bose gas [1]. More general, we demonstrate that a stable excited state with no pairing between attractive fermionic atoms can be also realized by a sudden switch of interaction from strongly repulsive regime to the strongly attractive regime. Such a state is an exact fermionic analog of the experimentally observed bosonic super-Tonks-Girardeau state and should be possible to be observed by the experiment [2]. Alternatively, we also show that the strongly attractive Fermi gas can be effectively described by the super-Tonks-Girardeau gas composed of bosonic bound Fermi pairs with attractive interaction, instead of the Tonks-Girardeau gas composed of unbreakable Fermi pairs with strongly repulsive interaction [3]. We also show that the super-Tonks-Girardeau state can be realized in the multi-component Fermi gas [4]. The similar phenomena in the optical lattice is also studied [5].

12P-A036  Finite temperature effect in phase transition to superfluidity for Bose-Einstein condensates in a 1-D optical lattice (LT26)
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We experimentally study the Phase transition of $^{87}$Rb Bose-Einstein condensates adiabatically loaded to a combined trap of a 1D optical lattice and a magnetic trap. The phase coherence property of this system is probed by recording the interference pattern of the expanded atomic cloud suddenly released from the combined trap. We show that as the temperature is sufficiently low (below the critical temperature $T_C$), an interference pattern has a “peak on a peak” feature which is a true signature of macroscopic superfluid states. The normal gas only contributes to the broad background and three wide peaks in an interference pattern. These observations qualitatively agree with the recent theoretical predictions [Phys.Rev.Lett.98,180404 (2007); Nature Physics 4,617 (2008)]. We also computed both the critical temperature and the interference pattern for a practical combined trap as ours in the tight-binding limit, and the numerical results are consistent with our experimental observations.

12P-A037  Feshbach resonances in ultracold mixture of $^{87}$Rb and $^{40}$K (LT26)
Xiaorui Wang a,b, Xi Zhou a, Tan a,b, Lu Yang a,b, Hongwei Xiong a, Baolong Li a, a State Key Laboratory of Magnetic Resonance and Atomic and Molecular Physics, Wuhan Institute of Physics and Mathematics, Chinese Academy of Science, b Graduate school, Chinese Academy of Science, Beijing, China

We observe the magnetic Feshbach resonances in an ultracold mixture of fermionic $^{40}$K and bosonic $^{87}$Rb atoms between 0 and 600 G, including 6 homonuclear and 4 heteronuclear Feshbach resonances. The resonances are identified by the abrupt trap loss of atoms and microwave adiabatic rapid passages in an optical lattice and laser speckle to quantum simulation. We find that localization length can be remarkably affected by both the disorder statistics and the atom interaction. We also find the phase of the condensates is broken into many small pieces while the system approaching localization, showing a counter-intuitive step-wise phase but not a thoroughly randomized phase. Although the condensates as a whole showing less flow and expansion, large currents occur where the phase changes abruptly. Thus we show explicitly that the localization of a finite size BEC is dynamic-equilibrium.

12P-A039  FFLO physics in spin-polarized Fermi gases in one dimension
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I will discuss pairing correlations in a 1D Fermi gas with attractive interactions, loaded into an optical lattice. Using the density matrix renormalization group method I’ll show that the ground state of the negative-U Hubbard model is of the Fulde-Ferrell-Larkin-Ovchinnikov (FFLO) type, i.e., pairing correlations oscillate in real space, with the wave-length set by the difference of the Fermi wave vectors of the majority and minority species. Second, I’ll discuss the density profiles of such a system in a harmonic trap, which have been measured in a recent experiment at Rice University. Third, an extension to a two-channel model description of a spin-polarized Fermi gas will be studied that incorporates the closed channel molecules, relevant close to a Feshbach resonance. Within this so-called Bose-Fermi resonance model, as a result, we find that the FFLO state is stable on the BCS side yet competes with a Bose-Fermi mixture, stable on the BEC side yet competes with a Bose-Fermi one.

12P-A038  The quantum simulation setup of $^{87}$Rb Bose-Einstein condensates and numerical analysis of disorder induced dynamic-equilibrium localization
Yafan Duan a, Jianfeng Sun a, Bonan Jiang a, Xu Zhen a, Tao Hong a, Xuzhu Wang a, a Key Laboratory for Quantum Optics, Shanghai Institute of Optics and Fine Mechanics, Chinese Academy of Sciences, Shanghai 201800, China, b Center for Macroscopic Quantum Phenomena, Shanghai Advanced Research Institute, Chinese Academy of Sciences, Shanghai, China

We report on a rapid production of $^{87}$Rb Bose-Einstein condensates (BECs) in a tight confinement hybrid trap based on single-beam optical dipole trap (ODT) and magnetic quadrupole trap (MQT). By the help of preliminary evacuation cooling in MQT, more atoms can be transferred to ODT. Then the BEC phase transition will be achieved by forced evacuation in ODT. This setup has good optical access for loading multiple optical lattices and laser speckle to quantum simulation. In theory, we numerically analyze the dynamic behavior of Bose-Einstein condensates in one-dimensional disordered potential before its completely losing spatial quantum coherence. We find that localization length can be remarkably affected by both the disorder statistics and the atom interaction. We also find the phase of the condensates is broken into many small pieces while the system approaching localization, showing a counter-intuitive step-wise phase but not a thoroughly randomized phase. Although the condensates as a whole showing less flow and expansion, large currents occur where the phase changes abruptly. Thus we show explicitly that the localization of a finite size BEC is dynamic-equilibrium.

12P-A040  Mode competition in superradiant scattering of matter waves
T. Vogt a, B. Lu a,b, X. Liu a, X. Xu a, X. Zhou a, X. Chen a, a Institute of Quantum Electronics, Peking University, Beijing, China

Matter-wave amplification was for the first time analyzed in the phenomenon of superradiance scattering
from a Bose-Einstein condensate. In this experiment, the formation of a matter grating due to initial Rayleigh scattering of a pumping beam by an elongated Bose-Einstein condensate was self-amplified by resonant light diffraction. The geometry of the condensate favored absorption by each atom of a pumping photon and subsequent scattering into so-called end-fire modes along the BEC long axis. The purpose of our research has been to go further in the study of mode competition between superradiant modes that naturally leads to prefential scattering along the long axis. For this purpose, we have characterized superradiance after previously loading and release of our BEC into an optical lattice. Pumping at the Bragg angle for diffraction by the matter grating resulting from the optical lattice modulation can lead to superradiant scattering into the Bragg mode in parallel to usual superradiant scattering into end-fire modes. In our work, mode competition has been simply analyzed by modifying the optical lattice depth for controlling the initial diffraction efficiency of the grating.

12P-A042 Drag Forces at mK Temperatures of Multiple Resonating Wires, Including Frequency Dependency (LT26)
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We have used various wire resonators and “floppy” devices to investigate the drag forces in Superfluid He-4 at milli-kelvin temperatures. We compare the force-velocity relationships for the different devices, showing the onset of the quantum turbulent regime. A “floppy grid” device was driven at various frequencies over the range of 3Hz to 100Hz; it was found that the drag force was not frequency dependant. We aslo present measurements showing how quantum turbulence produced by one device will directly affect another.

12P-A043 Single-particle excitation spectrum in 1D ultracold fermionic optical lattices
A. Yamamoto*, S. Yamada*, M. Machida*, a Japan Atomic Energy Agency, Chiba, Japan b JST-CREST, Tokyo, Japan

We clarify the single-particle excitation spectrum of ultracold fermions in one dimensional (1D) optical lattices by using dynamical density-matrix renormalization group (DDMRG) method. Systems are described by 1D Hubbard model with a harmonic-trap potential. In 1D systems, owing to the trap potential and on-site interaction, the obtained spectrum shows quite rich structure. In an analysis of weakly repulsive interaction, we find that the spectrum structure changes to band branching and discrete bound-state states as increasing the trap strength. On the other hand, we consider the case of strongly repulsive interacting regimes which local density profile is described by central Mott-plateau phase with surrounded by metallic regions. We confirm the multiple flat bound-state levels lying above 1D Tomonaga-Luttinger (TL) liquid spectrum. Moreover, as increasing the trap strength, we find the break-down of TL spectrum which is alternative to an effective doping into the Mott phase. We also show the results in case of attractive interaction. We will present the various kinds of striking spectra, reveal the properties of growth of a dispersive band structure, and show the comparison of repulsive interaction case with attractive interaction one.

12P-A044 Quantum computer and quantum gases
Yuzhen Yuan, School of Science, Shandong University of Technology, China 250649

I study the mechanism of quantum computers and the properties of quantum gases and found that the biggest advantage of quantum computers is parallel computing, but there would be de-coherence when error-correcting codes are added to quantum system. One of the approaches to solve the problem would be using quantum gases as the quantum storages.

12P-A045 Unconventional Bose-Einstein condensations and exotic orbital physics in high bands of optical lattices (LT26)
Congjun Wu*, a Department of Physics, University of California, San Diego

Orbital is a degree of freedom independent of charge and spin, which plays an important role in transition metal oxides. Orbital physics is characterized by orbital degeneracy and spatial anisotropy. The recent progress of cold atom physics has provided another exciting opportunity to investigate orbital physics with both cold bosons and fermions in optical lattices. In this talk, we will present new features of orbital physics in the high orbital bands, which are not usually realized in solid state orbital systems. For bosons, the ferro-orbital interactions lead to a class of novel superfluid states with complex-valued wavefunctions breaking time reversal symmetry. These states are beyond Feynman’s celebrated argument of the positive-definitiveness of many-body ground state wavefunctions for bosons. For fermions, the honeycomb lattice with the pz-orbitals exhibits the flat band structure and the consequential non-perturbative strong correlation effects (e.g. Wigner crystallization) which is distinct from the graphene physics characterized by the px-orbital. The orbital exchange physics in the Mott-insulating states exhibits strong frustrations and provides a promising direction to realize the orbital liquid state. In the square and cubic lattice, the anisotropic band structure can stabilize the FFLO pairing phases in high dimensions. The current experimental efforts in realizing such novel states of matter will also been introduced.

12P-A046 Strong thermalization of a mesoscopic two-component Bose-Hubbard model
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We study the mechanism of quantum computers and the properties of quantum gases and found that the biggest advantage of quantum computers is parallel computing, but there would be de-coherence when error-correcting codes are added to quantum system. One of the approaches to solve the problem would be using quantum gases as the quantum storages.
We study thermalization of a two-component Bose-Hubbard model by exact diagonalization. Initially the two components do not interact and are each at equilibrium but with different temperatures. As the on-site inter-component interaction is turned on, perfect thermalization occurs. Remarkably, not merely those simple “realistic” physical observables thermalize but even the density matrix of the whole system—the time-averaged density matrix of the system can be well approximated by that of a canonical ensemble. A conjecture about this fact is put forward.

We investigate the optomechanical coupling between 1D interacting bosons and the electromagnetic field in a high-finesse optical cavity. We show that by tuning the interatomic interactions, one can realize the effective optomechanics with the mechanical resonators ranging from the side-mode excitations of a Bose-Einstein condensate (BEC) to particle-hole excitations of Tonks-Girardeau (TG) gas. We propose that, this unique feature can be formulated to detect the BEC-TG gas crossover and measure the sine-Gordon transition continuously and nondestructively, which are achievable immediately in current experiments.

We present the origin of the Abraham-Minkowski controversy of light-matter wave interacting system, which is a special case of the century-old Abraham-Minkowski controversy. We solve the controversy of laser-atom interacting case and find that for systems with perfect atomic spatial coherence, the systems prefer to show Minkowski momentum and canonical momentum for the atoms and light, respectively; while for the systems where the atoms are spatially incoherent, the momenta of light and atoms would choose the Abraham and kinetic forms. The provement of our solution can be realized with current techniques, using three-dimensional optical lattices and electromagnetically-induced absorption (EIA) to distinguish the kinetic and canonical recoil momentum of ultra-cold atoms.
12P-A052  
**Effect of Dominant Three-body Interaction in Two-dimensional Square Lattice**

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The effect of dominant three-body interaction to hardcore boson Hubbard model$^1$ is studied on a two-dimensional square lattice. In terms of quantum Monte Carlo method$^2$, it is shown explicitly a $\rho = 2/3$ solid phase with coexistence of charge-density-wave and bond orders appears due to the presence of the dominant three-body interaction. For strong three-body interaction, the $\rho = 2/3$ solid phase appears between superfluid phases and shrinks as decreasing the strength of the three-body interaction, forming a lobe structure in the phase diagram. For weak three-body interactions, superfluid phase exists for the whole range of hard-core densities except the full filled case, where the system is a Mott insulator.


12P-A053  
**Textures of Spin-Orbit Coupled $F = 2$ Spinor Bose Einstein Condensates**

T. Kawakami$, T. Mizushima$, K. Machida$, $^a$Department of Physics, Okayama University

Motivated by recent studies of Bose Einstein condensates (BECs) under synthetic gauge fields, we study the textures of BECs with Rashba like spin-orbit coupling (SOC). Nontrivial textures due to the Rashba type SOC in pseudospin $F = 1/2$ and $F = 1$ BECs have been studied in the recent work. However, it still remains an open question how textural structures can emerge in $F = 2$ spinor BECs, where the cyclic phase can be the magnetic ground state. Here, we analytically demonstrate that the Rashba like SOC favors helical modulations of the order parameters, where the rotation in the pseudospin space propagates along its rotation axis in the real space. We also find the stable textures obtained by numerical minimization of the Gross-Pitaevskii energy functional, where the rotationally symmetric spin-spin interaction has four magnetic ground states including the cyclic phase. In the parameter region which favors the cyclic phase, we find the energetically competitive textures, which are the hexagonal lattice with the uniaxial polar core and the $1/3$ vortex square lattice with the ferromagnetic core, and calculate the phase diagram of them. Finally, we show that these textures result from the two-dimensional networks of the helical modulations of the cyclic order parameters.


12P-A054  
**$\pi$-phase and Spontaneous Supercurrent induced by Pseudo-ferromagnetic Junction in a Spin-polarized Superfluid Fermi Gas**

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We theoretically propose a novel superfluid state with spontaneous current in a superfluid Fermi gas. When a weak non-magnetic potential barrier is embedded in a superfluid Fermi gas with population imbalance ($N_{\uparrow} > N_{\downarrow}$, where $N_\sigma$ is the number of atoms with pseudospin $\sigma = \uparrow, \downarrow$), the barrier is known to be “magnetized” in the sense that some excess $\uparrow$-spin atoms are localized around it.$^{1,2}$ This “ferromagnetic” junction naturally leads to the so-called $\pi$-phase, where the superfluid order parameter changes its sign across the junction. Using this phenomenon, we show that, when a non-magnetic potential barrier is set in a ring-shaped torus trap, the induced ferromagnetic junction twists the phase of the superfluid order parameter by $\pi$ along the ring, leading to finite circulating Josephson current. In contrast to the ordinary metastable supercurrent state, this phase-twisted state with spontaneous current is shown to appear as the stable ground state at $T = 0$.

2. This work is supported by the Global COE Program “High-Level Global Cooperation for Leading-Edge Platform on Access Space (C12).”

12P-A055  
**Crossover from Fulde-Ferrell State to Larkin-Ovchinnikov State in Cold Fermion Gases**

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A two component fermion gases with population imbalance attracts much attention from both theoretical and experimental point of view. In this system, one expect that the Fulde-Ferrell-Larkin-Ovchinnikov (FFLO) state which has a spatially modulated order parameter is stable. Roughly speaking, FFLO state is classified into the two phases. One has the order parameter $\Delta(x) = \Delta_0 \cos(q \cdot x)$ (LO state) and others has $\Delta(x) = \Delta_0 \cos(q \cdot x)$ (FF state). In the condensed-matter physics, it is understood that the LO state is stable. In contrast to the condensed-matter physics, various FFLO states may manifest itself in cold atomic gas, for example, angular FFLO (A-FFLO) state in which the order parameter changes its sign along the angular direction. In this research, we investigate a novel FFLO state realized in toroidal trap with rotation. When the system is at rest, the A-FFLO is stable. When a gas is rotated, the Cooper pairs flowing to the right and that flowing to the left are not equivalent. Then, the LO state changes to the “intermediate state” between FF and LO state. We also find the FFLO state with half-quantum vortex. We will report our studies on the physical properties of these FFLO states.

12P-A056  Inhomogeneous Pseudogap Phenomenon in the BCS-BEC Crossover Regime of a Trapped Superfluid Fermi Gas
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We study single-particle properties of a trapped superfluid Fermi gas in the BCS-BEC crossover region. Including pairing fluctuations within a T-matrix theory, as well as effects of a trap potential within the local density approximation, we self-consistently determine the superfluid order parameter and chemical potential below the superfluid transition temperature $T_c$. Using these, we calculate the local density of states (LDOS), local spectral weight, and photoemission spectra. In the crossover region above $T_c$, the trap potential leads to inhomogeneous pseudogap phenomena, where the pseudo-gapped LDOS in the trap center and free-fermion-like LDOS around the edge of the gas coexist in the system. At $T = 0$, the single-particle excitations are dominated by inhomogeneous superfluid order parameter. We clarify how the former changes into the latter below $T_c$. In the intermediate temperature region, the coexistence of pseudogap and superfluid gap is realized in the sense that, while the pseudogap in the trap center is replaced by the superfluid gap, pairing fluctuations enhance the pseudogap around the edge of the gap. We also determine the pseudogap region in the 3-D phase diagram of a superfluid Fermi gas in terms of temperature, pairing interaction, and spatial position. Our results would be useful for understanding strong-coupling effects in the BCS-BEC crossover regime of a trapped superfluid Fermi gas.

12P-A057  Mott-insulator and superfluid phases of correlated bosons in the bosonic dynamical mean-field theory with the strong coupling impurity solver
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We investigate the phase diagram of correlated lattice bosons using the bosonic dynamical mean field theory (BDMFT). The BDMFT, formulated by Byczuk and Vollhardt (Phys. Rev. B 77, 235106 (2008)), is a comprehensive and thermodynamically consistent approximation in which the normal and condensed bosons are treated on equal footing. Within BDMFT the lattice bosonic problem is replaced by a single impurity coupled to two bosonic baths (corresponding to normal and condensed bosons, respectively). The resulting set of equations, the so-called “impurity problem”, has to be solved self-consistently. Our approach is the strong coupling expansion within which the phase transition between Mott-insulating and superfluid phases can be described. Different thermodynamical quantities (particle density, compressibility, order parameter) as well as the bosonic density of states are investigated across the transition lines.

12P-A058  Monopoles and Dipoles in Spinor Bose–Einstein Condensates
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Spinor–Bose–Einstein condensates with spin degree of freedom may host many topologically interesting structures, absent in scalar condensates. For ferromagnetic order parameter manifold the triviality of the second homotopy group implies that isolated monopole defects are not allowed. Monopole defects may, however, appear as endpoints of vortex lines. It has been recently shown that, using a nontrivial magnetic field configuration, one can create a monopole defect into the spin texture of the condensate. The vorticity of this defect is equivalent to the magnetic field of a Dirac monopole. In this work, we show that such a monopole defect may exist as the ground state of the condensate. We also investigate a dipole defect associated with a vortex filament extending throughout the condensate.

12P-A059  Ferromagnetism of spinor atomic condensates in the double well
Chengjun Tao*a, Qiang Gu*b, *Department of Physics, University of Science and Technology Beijing, Beijing 100083, China.
The $^{87}$Rb gas comes as the first example of the ferromagnetic (FM) Bose system, thus it provides an opportunity to study the itinerant-boson ferromagnetism. It is already suggested that the spinor Bose gas with FM couplings undergoes a FM transition with the critical temperature never below the Bose-Einstein condensation temperature, regardless of the magnitude of the coupling. Nevertheless, the FM transition can not occur in the Fermi gas unless the FM coupling exceeds the Stoner point. We explore the manifestation of distinct magnetic phenomena of spin-1 Bose condensates in a symmetric double-well. We show that the condensate may not exhibit ferromagnetic behaviors unless the effective FM coupling is stronger than a critical value which is determined by the tunneling coupling. This feature is analogous to the Fermi gas. The ferromagnetic condensate displays strong symmetry-breaking dynamics, with the amplitude evolving exponentially from an almost negligible distortion of the original symmetric spin configuration. On the contrary, the distortion just results in a mild oscillation in the antiferromagnetic condensate. This phenomenon is relevant to the domain formation inside a single-well FM condensate.

12P-A060  Efimov and Non-Efimov Three-Body Bound States for 2+1 Particles
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For a three-body system interacting via resonant two-body interaction, there exist three-body bound states called Efimov states. Efimov states have attracted a lot of interest since their recent experimental realizations with ultracold atoms. One of the intriguing features of the Efimov states is their universal property: they can be characterized completely by two parameters, the $s$-wave scattering length and a short-range three-body parameter, and are unaffected by all other details of the potential. Recently, however, novel three-body bound states have been predicted theoretically, which depend only on the $s$-wave scattering length. Although the origin of these trimers is closely related to the Efimov effect, they have a distinct nature. We will discuss on the relationship between these two kinds of three-body bound states.


12P-A061 Magnons in Spin-Polarized Atomic Hydrogen Gas

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We report on experimental study of electron spin waves (magnons) in the gas of spin-polarized hydrogen. The gas is in the quantum regime, when the thermal de-Broglie wavelength is much larger than the characteristic scale of atomic interactions. We compress the H gas to densities $\approx 10^{18}$ cm$^{-3}$ and temperatures 200-500 mK in a strong magnetic field of 4.6 T. Spin waves are generated and studied by means of CW and pulsed electron spin resonance (ESR) at 128 GHz. We observed several narrow peaks superimposed on the main ESR peak, with strength and position depending on the gas density and static magnetic field profile. The behavior of magnons, spin 1 quasiparticles, is described by the wave equation similar to the Schrödinger equation with the static magnetic field playing a role of potential energy. For H gas density exceeding some critical value we found a strong and narrow magnon line corresponding to the maximum of magnetic field. In the free induction decays of pulsed ESR this is seen as a long coherent precession of electron spins, similar to the homogeneously precessing domain in superfluid $^3$He. Accumulation of magnons in the lowest energy state may be also explained in terms of their BEC, as it was recently performed for magnons in ferromagnets and $^3$He. We discuss a second type of magnons possible in H gas: due to the dipolar interactions, similar to the magnetostatic (Walker) modes in ferromagnets.

12P-A062 Fragmentation and Stillbirth of Condensation in the Rapid Evaporative Cooling of a Dual Species Bose Mixture

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Recently, the realization of dual-species Bose-Einstein condensate (BEC) with tunable miscibility has been reported. It has been pointed out that the dual-species Bose-Einstein condensate (BEC) may fail to form if the particle number of one component is too large at the start of evaporation. As a consequence, the other component cannot be cooled to condensation and thus remains a dilute thermal gas. In this investigation, we employ the stochastic projected Gross-Pitaevskii equation (SPGPE) to simulate the growth of dual-species condensate during the rapid temperature quench. The numerical results based on the SPGPE method are consistent with the experiment. We have found that the formation of dual-species BEC is very sensitive to the geometry of confining traps, and the interaction between atoms. Fragmentation, i.e., the reduced one-particle density of the system of $N$ identical bosons is having more than one macroscopic (with respect to $N$) eigenvalues, may occur and play a crucial role during the growth of condensates. We demonstrate three scenarios for the growth of phase-separated condensates by numerical simulations: First, the successful formation of two BECs without fragmentation. Second, the formation of two BECs, yet one of them is fragmented. Third, one species is condensed without fragmentation, while the other is stillborn.


12P-A063 Spin-asymmetric Josephson effect in ultracold Fermi gases

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In solid-state physics, the Josephson effect is of fundamental significance and has many practical applications. This effect can be realized as well with ultracold Fermi gases. Here we predict a new many-body effect, namely that in the case of a spin-asymmetric driving (in which the two spin components of a Cooper pair are driven with fields of different detunings), the spin up and down components oscillate at the same frequency but with different amplitudes. We propose two experimental implementations, by using four internal states of the atoms or two internal states and a two-well external potential. This effect cannot be realized in a straightforward way in solid-state systems, since it corresponds to biasing a Josephson junction of two superconductors with different voltages for spin up and down electrons, respectively. Furthermore, our results reveal that the standard interpretation of the Josephson supercurrent in terms of coherent bosonic pair tunneling is insufficient. We provide an intuitive interpretation of the Josephson supercurrent as interference in Rabi oscillations of pairs and single particles, the latter causing the asymmetry.
12P-A064 Resonances Induced by Dipolar Scattering

Zheyu Shi.


We investigate the scattering properties of aligned dipolar molecules in ultracold gases. The phase shifts and scattering lengths are calculated numerically in an adiabatic approximation, which shows several sequences of resonant states. In the high temperature limit, we use quantum virial expansion to derive the second virial coefficient of a dipolar system. It is found that the two-body scattering problem can be equivalently described by a single-channel model, and a local field theory can be applied to study the many-body problem.

12P-A065 Two-dimensional dipolar Bose gas with tilted polarization


We present results of diffusion Monte Carlo (DMC) simulations and of hyper-netted chain Euler-Lagrange (HNC-EL) calculations of a dipolar Bose gas in two dimensions, with the polarization axis tilted with respect to the plane. We study the behavior of this homogeneous, but anisotropic Bose gas at low densities, in particular the approach of the ground state energy to the universal limit, and the effect of the tilt angle on the condensate fraction. We find excellent agreement between the DMC and the HNC-EL low-density results. While the effect of anisotropy on the pair distribution function $g(x, y)$ is small for low densities, it becomes pronounced for high densities. Long-range fluctuation in $g$ show that the range of structural order increases in the direction perpendicular to the plane of the tilt angle as the tilt angle approaches the critical angle where the system becomes unstable. We perform a stability analysis in the HNC/0 approximation.

12P-A066 Microscopic Dynamics of $^3$He in Two and Three Dimensions

R. Holler, H. M. Böhm, E. Krotscheck, and M. Panholzer.

We have developed a systematic and manifestly microscopic theory of the dynamics in $^3$He. Our description builds upon the concept of dynamic multi-particle fluctuations which has provided a quantitative picture of the phonon/maxon/roton spectrum of $^4$He far beyond the roton wave-number. The theory includes both, energy-dependent effective interactions and a self-consistent single particle spectrum. A crucial neutron scattering experiment measuring the dynamic structure function of two-dimensional $^3$He shows that an equivalent of the roton minimum can indeed appear below the particle-hole continuum. This effect is correctly reproduced by our theory, whereas the textbook concept of assuming that the location of the collective mode is determined by the quasiparticle effective mass is inconsistent with experiments. Our calculations also clarify a controversy that was raised in recent X-Ray experiments on 3D $^3$He whether or not the zero sound mode at intermediate wave-vectors is Landau damped.

12P-A067 Efimov trimers in ultracold Lithium 6

P. Naidon, M. Ueda, Riken, Wako, Saitama, Japan.

Three particles can form unusual three-body bound states called Efimov trimers due to a universal attraction arising whenever the scattering lengths between the particles are much larger than the range of their interactions. Various indirect signatures and first-time direct spectroscopy of such Efimov trimers have been demonstrated in recent experiments using ultracold lithium 6 in three different spin states, where the scattering lengths are enhanced by magnetic Feshbach resonances. We found that all these measurements are indeed consistent with the universal Efimov effect, but non-universal deviations at negative energy remain to be understood and have been quantified by a variation of a short-range 3-body parameter.

12P-A068 Spin-orbit Coupled Boson Superfluid

H. Zhai, C. M. Jian, C. J. Wang, C. Gao.

Recently, spin-orbit coupled boson condensate has been realized in NIST experiment, and there are many proposals to generate various types of spin-orbit coupling in cold atom setup. I will present our theoretical results about ground state and finite temperature properties of spin-orbit coupled interacting bosons. At zero temperature this system exhibits two different phases, the plane wave phase and the stripe phase. At finite temperature, melting of stripe order gives rise to a novel phase, i.e. boson paired superfluid which supports fractionalized vortices. I shall present the phase diagram of this system in terms of temperature, interaction and anisotropy of spin-orbit coupling. Moreover, I will discuss collective modes, vortices and the response to optical lattices.
of spin-orbit coupled superfluids; 1 2
2 Chao-Ming Jian and Hui Zhai, to be published

12P-A069 A mixture of two species of spin-1 Bose gases with interspecies spin exchange
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We study ground states and physical properties of a mixture of two species of pseudospin-$\frac{1}{2}$ atoms, as well as a mixture of two species of spin-1 atoms, with both interspecies and intraspecies spin exchanges. Interplay among interspecies and two intraspecies spin exchanges significantly enriches quantum phases of spinor atomic gases.

12P-A070 Ultra-cold Polar Fermionic Molecules in Bilayers
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Ultra-cold polar fermionic molecules in a bilayer geometry constitute a novel system with interesting physical properties. The long-range dipole-dipole interaction between molecules of different layers leads to the emergence of interlayer superfluids, even in the absence of tunneling between the layers. The superfluid regimes range from a BCS-like fermionic superfluidity to a BEC of interlayer dimers, exhibiting a BCS-BEC crossover. The peculiar inter-layer two-dimensional scattering results in interesting novel effects. In particular, we consider the case where molecules in each layer are initially prepared in different rotational states. It is shown that inter-layer interactions can lead in a two-body collision to a swap of rotational state of molecules in different layers, resembling spin-changing collisions in spinor gases. The rate of these state-changing collisions shows a non-trivial dependence with density, temperature and inter-layer separation. For optically trapped highly reactive molecules, like KRb, such state-changing collisions are accompanied by immediate losses, and hence the swapping collisions may be easily observed by monitoring the molecule number.

12P-A071 Superfluidity of flexible chains of dipolar molecules in layered optical lattices
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We study properties of quantum chains in a gas of polar bosonic molecules formed in a stack of $N$ identical one- and two-dimensional optical lattices, with molecular dipole moments aligned perpendicularly to the layers. Quantum Monte Carlo simulations of a single chain (formed by a single molecule on each layer) reveal its quantum roughening transition. The case of in-layer finite density of the molecules is studied within the framework of the J-current model approximation, and it is found that $N$-layered molecular superfluid can undergo a quantum phase transition to a rough chain superfluid. A theorem is proven that no superfluidity of chains with length shorter than $N$ is possible. The scheme for detecting chain formation is proposed. In the case of 1d “cigar-type” layers at $T=0$, the transition is a multi-layered version of the Berezinskii-Kosterlitz-Thouless transition. The bosonization-type approach similar to Refs. captures its main features. In the case of 2d layers the transition becomes of strongly first-order which agrees well with the mean-field description.


12P-A072 Quantized vortices in a rotating Bose-Einstein condensate with spatiotemporally modulated interaction
Deng-Shan Wang, Shu-Wei Song, Bo Xiong, W. M. Liu, Beijing National Laboratory for Condensed Matter Physics, Institute of Physics, Chinese Academy of Sciences, Beijing 100190, China.
We present theoretical analysis and numerical studies of the quantized vortices in a rotating Bose-Einstein condensate with spatiotemporally modulated interaction in harmonic and anharmonic potentials, respectively. The exact solutions of quantized vortex and giant vortex are constructed explicitly by similarity transformation. Their stability behavior has been examined by numerical simulation, which shows that a new series of stable vortex states (defined by radial and angular quantum numbers) can be supported by the spatiotemporally modulated interaction in this system. We find that there exist stable quantized vortices with large topological charges in repulsive condensates with spatiotemporally modulated interaction. We also give an experimental protocol to observe these vortex states in future experiments.

12P-A073 From ultracold Fermi Gases to Neutron Stars
Ultracold dilute atomic gases can be considered as model systems to address some pending problem in Many-Body physics that occur in condensed matter systems, nuclear physics, and astrophysics. We have developed a general method to probe with high precision the thermodynamics of locally homogeneous ultracold Bose and Fermi gases. This method allows stringent tests of recent many-body theories. For attractive spin $1/2$ fermions with tunable interaction (6Li), we will show that the gas thermodynamic properties can continuously change from those of weakly interacting Cooper pairs described by Bardeen-Cooper-Schrieffer theory to those of strongly bound molecules undergo-
ing Bose-Einstein condensation. First, we focus on the finite-temperature Equation of State (EoS) of the unpolarized unitary gas. Surprisingly, the low-temperature properties of the strongly interacting normal phase are well described by Fermi liquid theory and we localize the superfluid phase transition. A detailed comparison with theories including Monte-Carlo calculations has revealed some surprises and the Lee-Huang-Yang corrections for low-density bosonic and fermionic superfluids are quantitatively measured for the first time. Despite orders of magnitude difference in density and temperature, our equation of state can be used to describe low density neutron matter such as the outer shell of neutron stars.

Session 12P-B:
B2 Novel Phenomena in Superconductivity
B3 Pseudogap Phase in Cuprates
Friday August 12, 16:00 – 18:00
Exhibition Hall 1

12P-B001 Observation of two Andreev-like energy scales in La_{2-x}Sr_xCuO_4 superconductor/normal-metal/superconductor junctions (LT26)
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Conductance spectra measurements of highly transparent ramp-type junctions made of superconducting La_{2-x}Sr_xCuO_4 electrodes and non superconducting La_{1.65}Sr_{0.35}CuO_4 barrier are reported. At low temperatures below Tc, these junctions have two prominent Andreev-like conductance peaks with clear steps at energies ∆_1 and ∆_2 with ∆_2 > 2∆_1. No such peaks appear above Tc. The doping dependence at 2 K shows that both ∆_1 and ∆_2 scale roughly as Tc. ∆_1 is identified as the superconducting energy gap, while a few scenarios are proposed as for the origin of ∆_2. Among these scenarios, the pre formed pairs one is quite appealing due to the similarity of the present phase diagram of ∆_2 to the T_onset results of the Nernst measurements.

12P-B002 Designing heterostructures with higher temperature superconductivity

12P-B003 Designing heterostructures

12P-B004 Acoustic analog of Hall effect in superconductive films
E.D. Gutiiansky*, The Research Institute of Physics of Southern Federal University, Rostov-on-Don, 344090, Russian Federation
Longitudinal electric field of a surface acoustic wave (SAW) drags vortex structure of a superconductive film, deposited on a piezoelectric substrate, and generates longitudinal DC component of an acoustoelectric field, which does not depend on direction of an external magnetic field. The contra-directional vortices are dragged by SAW in opposite directions. This phenomenon represents an acoustic analog of Hall effect, where vortices are an analog of current carriers, and the SAW Pointing vector acts as an impressed electric field. The calculation of the acoustoelectric field for a YBCO film with niobate lithium substrate coincides well with experimental data.

12P-B005 A Different Perspective on the AC Magnetic Susceptibility of Bi_{1.7}(Pb_{0.3})Sr_2Ca_2Cu_3O_{10+x} Superconductor Modelled Using a Mechanism of Eddy Currents
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Complex magnetic susceptibility of polycrystalline Bi_{1.7}(Pb_{0.3})Sr_2Ca_2Cu_3O_{10+x} at various AC magnetic field and frequencies was investigated. Experimental data indicated that for the magnitude of applied AC
magnetic fields used, the magnetization remains proportional to the applied field. Without the assumption of flux penetration, the behaviour of the loss manifested in the imaginary component of the AC magnetic susceptibility was explained using a mechanism of eddy currents induced in the superconducting grains. The loss peak occurs due to a competition of two mechanisms, the eddy current induced due to the AC magnetic field and the shielding current appearing at the onset of superconductivity. A model based on the behaviour of the eddy current and the shielding current from the intragranular to the intergranular transition is discussed. The model is found to agree well with the experimental data and may be universally applicable to all granular superconductors at low AC field.

12P-B006 Coexistence of Superconductivity and Magnetism in Intermetallic NiBi$_3$

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NiBi$_3$ polycrystals were synthesized via a solid state method. X-ray diffraction analysis shows that the main phase present in the sample corresponds to NiBi$_3$ in a weight fraction of 96.82 % according to the refinement of the crystalline structure. SEM - EDS and XPS analysis reveal a homogeneous composition of NiBi$_3$, without Ni traces. The powder superconducting samples were studied by performing magnetic measurements. The superconducting transition temperature and critical magnetic fields were determined as $T_C = 4.05$ K, $H_C1 = 110$ Oe and $H_C2 = 3.620$ Oe. The superconducting parameters were $\xi_{GL} = 301.5$ Å, $\lambda_{GL} = 1549$ Å, and $\kappa = 5.136$. Isothermal measurements below the transition temperature show an anomalous behavior. Above the superconducting transition the compound presents ferromagnetic characteristics up to 750 K, well above the Ni Curie temperature.

12P-B007 On the Oxygen and its Vacancies Diffusion in Proximity to Abrikosov Magnetic Vortices Cores in YBCO Thin Films

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The superconducting properties of YBCO thin films under exposure to electron radiation with energy 2x10$^4$ eV in magnetic field of 3x10$^2$ G at temperature of 77 K are researched. The nonequilibrium distribution of atoms of oxygen, originating at electron radiation, reduces in a change of dependence of the complex magnetic susceptibility of YBCO thin films on the temperature. The diffusion relaxation of a nonequilibrium distribution of oxygen and its vacancies in YBCO thin film at electron radiation, results in an appearance of new pinning centers in proximity to normal phase of Abrikosov magnetic vortices cores. The process is accompanied by an increase of both the Abrikosov magnetic vortices pinning forces and the density of critical current in YBCO thin films, influencing the magnetic susceptibility of YBCO thin films. The proposed theoretical mechanism of experimentally observed oxygen and its vacancies diffusion at gradient of a superconducting electron pair potential in proximity to Abrikosov magnetic vortices cores, may explain the observed physical properties of YBCO thin films.

12P-B008 Current carrying vortex crystals

B. Rosenstein, I. Shapiro, B. Ya. Shapiro

Abrikosov vortices in a type-II superconducting film subjected to strong magnetic field $B$ with hexagonal array of nanoholes of the density $n_{pin}$ form a vortex crystal. We considered instability, melting and dynamics of such vortex crystal carrying the transport current. The critical current for the case of the matching field ($f = 1, f = B/(\Phi_0 n_{pin})$) was studied analytically using a variational method in the framework of Ginzburg-Landau equations. The critical current in this case and the spring elastic constant were analytically calculated. It was shown numerically that the crystal melting and transition to the resistive state occurs as a coherent depinning of the single vortex lines-dislocations. For a system with interstitial vortices, $f > 1$, the mechanism of depinning depends on the current direction with respect to the pinning array. It was found that slightly above the critical current the trajectories of the moving vortices are not straight, but rather acquire a snake-like shape enveloping the system of pins. In contrast to $f = 1$, the transition to a resistive state is not coherent and is going through formation of “snake-like” vortex trajectories. The vortex depinning is closely associated with the appearance of a strongly varying electric field. We calculated the electric fields accompanying vortex crystal melting and found the voltage-current characteristics.

12P-B009 On the scaling of pinning force in ceramic MgB$_2$

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We present an investigation of the field dependence of the pinning force of MgB$_2$-based superconducting composites as obtained by spark plasma sintering with different ingredients which are designated to enhance the pinning force $F$. Generally, the latter quantity, scaled to the maximum pinning force $F_{\text{max}}$, obeys a scaling law as a function of the scaled field $h$ when the irreversibility field $H_{\text{irr}}$ is considered as scaling field. The scaled function is described in terms of a generalized scaled function $h^\alpha(1 - h)^\beta$. However, in our samples the scaling is absent. In addition, the peak of the
scaled function shifts to higher reduced fields $h$ when the temperature increases. Depending on the level of doping and the nature of the nanosized particles used to built the superconducting composites, we found that the scaled force can be depicted either with a combination of generalized scaled functions with different exponents or with a single function but multiplied with an envelope, usually an exponential factor. The former dependence is present in the samples with high amount of nanoparticles and mirrors two types of pinning of close weights. The presence of the exponential factor in the latter dependence is attributed to the combined effect of the intrinsic anisotropy of MgB$_2$ and the random orientation of the grains relative to the magnetic field.

12P-B010 Topological Matter, Flat Bands and Room Temperature Superconductivity

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Topological media are fermionic systems whose properties are protected by topology and thus are robust to different perturbations of the system including the interaction. In topological insulators, and in the nodeless topological superconductors and superfluids such as superfluid $^3$He-B, the bulk-surface and bulk-vortex correspondence gives rise to the gapless Dirac or Majorana fermions on the surface of the system or inside the vortex core. In gapless topological media, the bulk-surface and bulk-vortex correspondence is even more interesting: it produces topologically protected gapless fermions without dispersion – the flat band. Fermion zero modes forming the flat band are localized on the surface of topological media with protected nodal lines, such as cuprate superconductors and graphite-like layered systems, and in the vortex core in systems with topologically protected 3-dimensional Dirac points, such as superfluid $^3$He-A. Flat band has an extremely singular density of states. This property may give rise in particular to surface superconductivity with an unusually high transition temperature thus opening a possible route for room temperature superconductivity. 


12P-B011 Evolution of Kosterlitz-Thouless-Berezinskii (KTB) Transition in Ultra-Thin NbN Films

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The Kosterlitz-Thouless-Berezinskii (KTB) transition play very important role to determine the superconducting properties of 2D superconductor including high-Tc layered superconductor. In many cases it has been observed that the nature of KTB transition is different from known universal behavior. The non universal nature of KTB transition and the recent discovery of interface superconductivity have renewed our interest to study the KTB transition in conventional 2D superconductor. Here, we will present detailed experimental study on KTB transition in ultra-thin NbN films.

We have measured the superfluid density, normal carrier density and resistivity of a set of NbN films. Major advantage of our model system is that we can measure the superfluid density, normal carrier density and resistivity on same sample. Our results show that while the ground state is well described by BCS theory, at elevated temperatures, ultra-thin films show sudden drop in superfluid density associated with the KTB transition close to $T_c$. Although the sudden drop started at higher superfluid density expected from 2-D XY model, the nature of transition is well describe by considering the low vortex core energy and slight inhomogeneity in the system. Resistivity data is beautifully explained using effective medium theory (EMT) by considering both Aslamozov-Larkin and KT fluctuation.

12P-B012 The critical state of a superconducting ring caused by a current

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Distribution of a current in a ring from niobium consisting asymmetric on critical current and inductance branches when the transport current through one of branches reaches critical value is experimentally investigated. At achievement of a critical state of one of branches the distribution has view of low-frequency self-oscillations of a current into branches at a constant transport current through the ring or the distribution is characterized by occurrence in other branch the current in steps changing in process of increase of transport current through a ring, since its value equal to a critical current of a branch with its smaller value. Conditions of the first type current state of a ring are macroscopical value of length of its both branches and presence in one of branches local “weak” region with the lowered critical current. A condition of a state of the second type is presence in a ring a branch with microscopic length (the order of coherence length of the superconductor) and with smaller a critical current, than for other macroscopical branch with critical current. The “weak” branch region has been received by local etching Nb microwire. Microscopic branch represented clamping contact Nb - Nb, formed by imposing of ends Nb microwire against each other and their compression. The reasons of two types of current distribution are discussed.


12P-B013 Novel Facets of Crossover from Surface Superconductivity to Vortext State
The observation of positive magnetization between $H_{c2}(T)$ and $H_{c1}(T)$ was reported in a spherical crystal of Nb by P Das et al. (Phys. Rev. B 78, 214504 (2008)). Our motivated search for ‘paramagnetic magnetization’ on field cooling in a large variety of weakly pinned single crystals have now not only confirmed its presence in almost all systems, but also revealed many new facets, like, the sign of this ‘positive magnetization’ is independent of the sign of the applied field. The diamagnetic contribution that emerges on reducing the applied field below $H_{c2}$ however respects the sign of the field in the sense that the sign of this contribution is phase reversed to that of the field. Thus, the crossover from compressed flux regime, existing between $H_{c3}$ and $H_{c2}$ to fields below $H_{c2}$ in positive fields leads to a feature usually discussed as an anomalous Paramagnetic Meissner Effect, whereas on cooling in negative fields, the said crossover would pass off as precursor response to superconductivity in an inhomogeneous sample. Highlights of new findings in crystals of (Ca/Yb)$_3$Rh$_4$Sn$_{13}$ and Nb shall be presented.

12P-B014 The Superconducting Transition in Highly Resistive NbTiN Nanowires.

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Superconducting thin-film materials with a high normal-state resistivity are of interest as building blocks for quantum devices and radiation detectors. However, the very disordered nature of these materials gives rise to a strong competition between electron localization and superconductivity, leading to a superconductor-insulator transition with increasing disorder. Prior to this transition the electronic properties are expected to become inhomogeneous even for uniform structural disorder. This leads to the question how superconductivity manifests itself in these resistive materials. We present measurements of the normal-to-superconducting transition of NbTiN nanowires, with a thickness of 8 nm, widths varying from 50 nm to 400 nm, and a normal-state resistivity of $\sim 160 \mu\Omega cm$. Each width shows a smooth superconductive transition at $T_C = 10.5 \text{ K}$, consistent with the Aslamazov-Larkin theory for two-dimensional wires. Close to $T_C$ however, measurements of the critical current and the critical magnetic field of the nanowires reveal that the resistive state is reached in a series of steps, each adding a typical resistance of $5 - 10 \text{ k}\Omega$ to the wire. Moreover, from the critical currents we obtain a higher critical temperature than observed in the zero-bias resistive transition. From this, we conclude that in a certain temperature regime the wire is resistive while localized superconductivity is still present.

1 On leave from Massachusetts Institute of Technology, Cambridge MA 02139, U.S.A.

2 For example Sacépé et al, Nature Physics 7, 239 (2011)

12P-B015 Enhancement of Superconductivity by a Parallel Magnetic Field in Two Dimensional Superconductors

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We report the observation of enhancement of superconductivity by a parallel magnetic field in two-dimensional superconducting systems: ultrathin amorphous Pb films (a-Pb) and the 2D electron gas at the interface of LaAlO$_3$ and SrTiO$_3$. The experiments were performed in a dilution refrigerator capable of in situ film growth, magnetic impurity deposition and sample rotation. The mean-field $T_C$ in both a-Pb films and the LaAlO$_3$/SrTiO$_3$ heterostructures is increased by a parallel field as high as $8 \text{ T}$, while a perpendicular field of 20 Gauss causes a suppression of $T_C$. In the Pb films, the $T_C$ enhancement exhibits a non-monotonic dependence on film thickness, and reaches 13.5% in ST parallel field for certain film thickness. As paramagnetic Cr impurities were incrementally deposited onto a pure a-Pb film showing field-enhancement of $T_C$, the magnitude of the $T_C$ enhancement is progressively suppressed and eventually eliminated. Our results are contradictory to the mechanism based on the polarization of paramagnetic impurities. Systematic dependencies of this effect on film thickness, magnetic impurity density, and spin-orbit interaction will be presented. The results suggest that the effect is due to an intrinsic enhancement of superconductivity by a parallel magnetic field, rather than alleviation of a destructive effect.

12P-B016 Universal critical slowing down of the electron dynamics near the Mott transition in the organic superconductors $\kappa$-(BEDT-TTF)$_2X$

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As model systems for studying the physics of correlated electrons and the Mott metal-insulator transition (MIT) in reduced dimensions, the quasi-2D organic charge-transfer salts $\kappa$-(BEDT-TTF)$_2X$, where X denotes polymeric anions, become increasingly important. In this work, we focus on the anomalous metallic state in the vicinity of the critical endpoint of the Mott transition. Systematic studies of low-frequency fluctuation spectroscopy of materials located at different positions in the temperature-pressure phase diagram reveal a correlation-induced enhancement of the resistance noise power spectral density $S_R$ in the critical region of the phase diagram. We employ a theoretical model that quantitatively describes the temperature and frequency dependence of the normalized noise power $S_R/R^2$. We
find that very near the Mott critical endpoint the resistance fluctuations are strongly enhanced, accompanied by a substantial shift of spectral weight to low frequencies. We interpret this as a sudden slowing down of the electrons’ dynamics when approaching the critical point, and onset of non-Gaussian behavior at the MIT. A comparison with MIT’s in other systems suggests that correlated electron dynamics might be a universal feature, irrespective of the system’s dimensionality.


12P-B017 Temperature dependence of power-law index in \((\text{Nd}_x\text{Sm}_2\text{Gd}_{1-x})\text{Ba}_2\text{Cu}_3\text{O}_7-\delta\) films

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Superconducting \((\text{Nd}_x\text{Sm}_2\text{Gd}_{1-x})\text{Ba}_2\text{Cu}_3\text{O}_7-\delta\) films with \(x=0, 0.1, 0.25, 0.33\) were grown by PLD on STO single crystal substrates. Films are made at 760°C and 790°C under different oxygen partial pressures. Pure Gd films have high power-law index \(n\) around 31 at temperatures very close to the critical temperature \((T_c)\). With addition of Nd and Sm, \(n\) is low at about 1K below \(T_c\) and increases slowly with decreasing temperature, even for the films with \(x=0.1\), who have higher critical current density than the pure Gd ones. \(T_c\) was lowered by addition of Nd and Sm. The mixed rare earth films also tend to have a longer penetration depth near \(T_c\). These properties might be related to the distortion of the superconductor lattice due to different ion sizes.

12P-B018 Vortex molecules in thin films of layered superconductors

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Both the equilibrium and transport properties of the vortex matter are essentially affected by the intervortex interaction potential. In isotropic bulk superconductors this potential is well known to be repulsive and screened at distances larger than the London penetration depth \(\lambda\). As a result, in perfect crystals quantized Abrikosov vortices form a triangular lattice. In thin films of anisotropic superconductors this standard interaction potential behavior appears to be strongly modified because of the interplay between the long-ranged repulsion predicted in the pioneering work by J. Pearl and the attraction caused by the tilt of the vortex lines with respect to the anisotropy axes. This interplay results in a new type of vortex arrangement formed by finite-size vortex chains, i.e., vortex molecules. Tilted vortices with such unusual interaction potential form clusters with the size depending on the field tilting angle and film thickness or/and can arrange into multiquanta flux lattice. The magnetic flux through the unit cells of the corresponding flux line lattices equals to an integer number \(N\) of flux quanta. Thus, the increase in the field tilting (or varying temperature) should be accompanied by the series of the phase transitions between the vortex lattices with different \(N\). The similar scenario should be realized in strongly anisotropic BSCCO high \(T_c\) superconductors where in tilted field a crossing lattice of Abrikosov vortices and Josephson vortices appears.

12P-B019 Order-disorder transition and quantum magnetic oscillations in the vortex state of strong type-II superconductors

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Magnetic quantum oscillations, usually exploited for mapping the Fermi surface of metals, appear in the mixed state with reduced intensity as compared to the normal state signal. Understanding of this phenomenon should help to reveal the nature of superconductivity in high magnetic fields, which is yet to be clarified even for conventional superconductors. Here, we present results of \(\mu\)SR, dHvA, and SQUID magnetization measurements on boro-carbide superconductors, which show remarkable correlation between an order-disorder transition of the vortex lattice, observed in the \(\mu\)SR measurements, and enhanced additional damping of dHvA oscillations in the peak-effect region. It is, therefore, concluded that an important mechanism of additional damping of dHvA oscillations in the superconducting state should be associated with enhanced scattering of quasi-particles by the pair-potential in disordered vortex lattices.

12P-B020 Measurement of Substructure in the Dual Energy Gap of Magnesium Diboride below 1 Kelvin

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Among conventional, phonon-mediated (BCS) superconductors, magnesium diboride \((\text{MgB}_2)\) stands out as the only material demonstrated to have two distinct superconducting energy gap values. This has been widely reported in both theoretical and experimental studies. However, some theoretical analyses and experimental results suggest substructure within both gaps - a result which remains controversial. We present results of our tunneling spectroscopy experiments on \(\text{MgB}_2/\text{insulator}/\text{Pb}\) Josephson junctions, at temperatures as low as 20 mK, which are in clear agreement with theoretical predictions for this substructure.

12P-B021  
In-plane magnetic field anisotropy in FFLO state in layered superconductors

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During the last 40 years a lot of theoretical and experimental studies have been devoted to layered superconductors. In particular in some organic layered superconductors the in-plane critical field is mainly determined by the paramagnetic limit. This feature favors the formation of the Fulde-Ferrell-Larkin-Ovchinnikov state (FFLO state). There have been observed several hints indicating the experimental realization of the FFLO state in organic superconductors. In this work we provide the quasi-classical description of the anisotropy of the in-plane critical field in uniform and non-uniform (FFLO) phases of layered superconductors, taking into account the interlayer Josephson coupling. Near $T_c$ we generalize the Lawrence-Donahue model for the case of high magnetic fields. We show that the anisotropy of the onset of superconductivity may change dramatically in the FFLO state as compared with the uniform superconducting phase. The study of the character of this anisotropy gives an important information on the orientations of theFFLO modulation vector. Our results can qualitatively describe the recent experimental data by S. Yonezawa et. al.\textsuperscript{1}


12P-B022  
Li$_2$(Pd$_{1-x}$Pt$_x$)$_3$B Magnetic Phase Diagram and Superconducting Parameters

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The $H$–$T$ phase diagram and several superconducting parameters for the noncentrosymmetric superconductor Li$_2$(Pd$_{1-x}$Pt$_x$)$_3$B have been determined as a function of cation substitution $x$ by measurements of AC susceptibility and specific heat. The zero-temperature coherence length appears to be linear in platinum concentration. Despite the superconducting gap developing nodes and the pairing state appearing to change from singlet to triplet as Pd is replaced by Pt, and in spite of significant changes to the band structure with substitution, the $H$–$T$ phase diagram shows no systematic evolution. Unusual aspects of the $H$–$T$ phase diagram’s shape will be discussed, along with comparisons to theoretical expectations. The upper critical field $H_{c2}(0)$ is not anomalously high for any Pt content, likely due to low carrier masses. In the absence of heavy Fermions, Pauli depairing may be masked by orbital limiting behaviour, and the value of $H_{c2}(0)$ would not necessarily serve as a probe for novel physics.

12P-B023  
Proximity effect in crystalline nanowires and topological insulators

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On a single crystal individual Au nanowire contacted by superconducting electrodes, the proximity effect induced superconductivity was found to appear in two distinct steps. Furthermore, we observed clear periodic differential magnetoresistance oscillations in the superconducting to normal transition region [1]. In crystalline Co nanowires contacted by superconducting electrodes, unexpected long-range proximity effect was observed. Additionally, we observed a large and sharp resistance peak around $T_c$ [2]. We studied transport properties in single crystal topological insulators (TIs) nanowires and nanoribbons. Proximity effect and periodic quantum magnetoresistance oscillations were observed. We also found interesting phenomena in TI films [3] contacted by different superconducting/normal electrodes.

[1]. Jian Wang et al., Physical Review Letters 102, 247003 (2009);
[2]. Jian Wang et al., Nature Physics 6, 389 (2010);

12P-B024  
Spatial Modulation Patterns in Two-Dimensional Fulde-Ferrell-Larkin- Ovchinnikov Superconductivity

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FFLO superconductivity is an interesting class of superconductivity, which breaks the intrinsic symmetry and has spatially modulated order parameters. Determining its spatial modulation patterns is one of the fundamental problems concerning FFLO superconductivity. Preceding studies based on the Ginzburg-Landau expansion showed that, in isotropic two-dimensional systems, patterns such as stripe, triangle, square, hexagonal, are realized depending on the temperature and the applied magnetic field. However, the Ginzburg-Landau expansion is not necessarily applicable especially at the low temperature, and another approach is necessary. In this research, based on the Bogoliubov-de Gennes equations we investigate the patterns at absolute zero temperature.

12P-B025  
Vortex penetration into type-II superconductors with pinning centers

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The FFLO state in organic superconductors. In particular in some organic layered superconductors the in-plane critical field is mainly determined by the paramagnetic limit. This feature favors the formation of the Fulde-Ferrell-Larkin-Ovchinnikov state (FFLO state). There have been observed several hints indicating the experimental realization of the FFLO state in organic superconductors. In this work we provide the quasi-classical description of the anisotropy of the in-plane critical field in uniform and non-uniform (FFLO) phases of layered superconductors, taking into account the interlayer Josephson coupling. Near $T_c$ we generalize the Lawrence-Donahue model for the case of high magnetic fields. We show that the anisotropy of the onset of superconductivity may change dramatically in the FFLO state as compared with the uniform superconducting phase. The study of the character of this anisotropy gives an important information on the orientations of theFFLO modulation vector. Our results can qualitatively describe the recent experimental data by S. Yonezawa et. al.\textsuperscript{1}

In the vortex-glass regime at the temperature $T$ close to the melting curve $T_m(B)$, the superconductor response becomes substantially nonlinear because the parameter $\alpha \sim U(j)/T \rightarrow \infty$ as $j \rightarrow 0$. In this case, we have the continuity equation

$$\frac{\partial b}{\partial t} = -[\nabla \cdot (\nabla b)]_x.$$  

The activation barrier $b$ has the form $U(j) = U_0 \ln(j/j_c)$ and the vortex velocity can be represented as

$$v = v_0 \exp(-(U(j)/T) = v_0/j^{\theta}, \ (j = j/j_c).$$  

Then the equation can be reduced to

$$\frac{\partial b}{\partial t} = \nabla \cdot (\nabla b)_{\text{eff}}.$$  

Here, $U = U_0/T, x \rightarrow x/d_p, t \rightarrow tv/v_d, d_p = cB_0/4\pi j_c,$ and $j_c$ is the critical current density. Let us solve this equation with the boundary conditions $b(0,t) = b_0(1-t)^m, 0 < t < 1, m < 0$. In the case $m = -1/\sigma$, the problem has the solution

$$b_A(x,t) = b_0(1-t)^{-1/\sigma}(1-x/x_0)^{(\sigma+2)/\sigma} \text{ where } x_0 = \frac{(\sigma+2)/\sigma}{2\sigma(\sigma+1)/\sigma+2} b_0^\sigma.$$  

The solution is a magnetic wave with an immobile front at the front localization within $0 < x < x_0$. An analysis of the structure of the self-similar solutions shows that the blow-up regime is not localized for $m < -1/\sigma^2$, that is $x_f \sim (1-t)^{(1+m)(\sigma+2)/\sigma} \rightarrow \infty$ for $t \rightarrow 1^-$, where $x_f$ is the coordinate of the magnetic wave front.


12P-B026 Ni-site Doping Effect of New Antiperovskite Superconductor ZnNNi$_3$

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A new superconductor ZnNNi$_3$ with $T_c$ of about 3 K has the same anti-perovskite-type such as MgNi$_3$ and CdNi$_3$. The Ni-based anti-perovskite compound has attracted much attention in the context of the relation between superconductivity and ferromagnetism. As far as we know, ZnNNi$_3$ is the third superconducting material in Ni-based anti-perovskite series and the first superconducting material in anti-perovskite nitride. For this new superconductor, we have studied the Ni-site doping effect. The dopant elements are chosen to be Cu, Co, Fe, Mn, Cr, and V. In Fe and Mn doping, the superconductivity rapidly disappears but survives in V, Cr, Co and Cu cases up to 3, 10, 17 and 2 %-doping, respectively. Interestingly, in Co-doping case, the superconductivity and ferromagnetism coexist at low temperature. It has been revealed that form EPMA analysis the coexistence of superconductivity and ferromagnetism is originated from spatial phase separation of superconducting ZnNNi$_3$ and ferromagnetic ZnNNi$_{8}Co$_{2}O$_{6}$. suggesting the existence of miscibility gap of ZnNi$_3$Co$_3$ solid solution.


12P-B027 The Universal behavior of Superconducting Quantum Critical Points

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Quantum critical points (QCP) accompanied by superconductivity are common in condensed matter physics. In general, the transition temperature $T^*$ of an ordered state, e.g. antiferromagnetic, goes to zero under the influence of an external parameter, e.g. pressure. Superconductivity appears before the disappearance of the ordered state, but reaches its maximum $T_c$ when $T^* = 0$. Presently, the implications of the QCP’s on superconductivity are a subject of debate, e.g. it is speculated that the superconducting state is a reaction of the system towards quantum fluctuations. It is shown here for nine systems with ordered states of different nature, under different external parameters, that both transition temperatures satisfy the relation $T^2 + T_c^2 = 1$, where the tilde indicates normalization to the maximum values. In order words, both states are related, as they are the consequence of the same interaction. Superconductivity is just another facet of the ordered state, and the dependence of its transition temperature with the external parameter can be retrieved from the dependence of transition temperature of the ordered phase. Although proposed here on intuitive grounds, this approach can be viewed as a phenomenological application of $SO(N)$ theories of superconductors, strongly supporting their relevance.

12P-B028 THz-Wave Emission from Inner I-V Branches of Intrinsic Josephson Junctions in Bi$_2$Sr$_2$CaCu$_2$O$_{8+\delta}$

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Intense and coherent terahertz electromagnetic wave (THz-wave) emission from intrinsic Josephson junctions (IJJ’s) in single crystalline high-$T_c$ superconductor Bi$_2$Sr$_2$CaCu$_2$O$_{8+\delta}$ was reported in 2007$^7$, where we have studied only the outermost I-V curve in multiple branching I-V structures. In order to further investigate the phenomenon, we traced the whole I-V branches by sweeping the source voltage and got into the inner I-V branch by increasing the current in the return branching region. By examining inner branches, the observed frequencies spread more widely than expected from the geometrical resonance condition. Although the widely spreading emission frequency may indicate the violation of the cavity resonance condition for the strong emission, the ac-Josephson effect is found to be still satisfied, in which the voltage $v$ applied to an individual IJJ is proportional to the Josephson frequency $f_J$: $f_J = 2|e|v/h$, where $e$ is the electron charge and $h$ is Planck’s constant. This emphasizes that the ac-Josephson effect plays a dominant role for the THz-wave emission.


12P-B029 Physical properties of the
bulk-superconducting $\text{Cu}_2\text{Bi}_2\text{Se}_3$

Kouji Segawa, M. Kriener, Zhi Ren, S. Sasaki, Yoichi Ando.

The search for a topological superconductor has recently been an intriguing issue. To date, the most well-known candidate for the topological superconductor is $\text{Cu}_2\text{Bi}_2\text{Se}_3$. However, due to an instability of the samples in the air, it was difficult to reveal intrinsic physical properties in the system. In the present work, we improved the sample preparation process and succeeded in obtaining high-quality $\text{Cu}_2\text{Bi}_2\text{Se}_3$ crystals. The zero resistivity is robustly observed in our samples, and the temperature dependence of the specific heat shows a jump at the superconducting transition. The fully-opened superconducting gap is suggested from the temperature dependence of the specific heat, and thus the result qualifies this system as a strong candidate for a topological superconductor.


12P-B030 Longitudinal Collective Excitations in Intrinsic Josephson Junction Stacks with Two Tunneling Channels

Y. Ota, M. Machida, T. Koyama.

Like high-$T_c$ cuprates, highly-anisotropic layered iron-based superconductors can exhibit Josephson effects even as the single crystal. In this paper, we construct a theory to describe transport phenomena along the $c$-axis in layered iron-based superconductors, motivated by recent experiments. One of the intriguing properties of the iron-based superconductors is that there are multiple superconducting gaps. This means that multiple tunneling paths for the Cooper pairs can open up. We propose that this systems are described as intrinsic Josephson junction stacks with multiple tunneling channels. We focus on a two-channel case. The theory predicts the presence of longitudinal Leggett collective excitations in addition to the conventional longitudinal Josephson plasma mode. Inter-layer couplings and inter-band Josephson energy bring about a peculiar dispersion relation of the longitudinal Leggett mode. Specifically, this mode favors synchronous oscillations, in contrast to the Josephson plasma. This theoretical model and its results could contribute to the development of future applications.


12P-B031 High Pressure Studies of $(\text{Sr},\text{Ca})_4\text{Ir}_4\text{Sn}_{13}$ Single Crystals


The $(\text{Sr},\text{Ca})_4\text{Ir}_4\text{Sn}_{13}$ system exhibits a rich phase diagram which was reported to display non Fermi-liquid physics and to host a coexistence of superconductivity and ferromagnetic spin-fluctuations. We have conducted magnetic susceptibility and electrical resistivity measurements on $(\text{Sr},\text{Ca})_4\text{Ir}_4\text{Sn}_{13}$ single crystals up to 60 kbar. These measurements allow us to follow the evolution of the superconducting critical temperature $T_c$, the resistivity anomaly temperature $T^*$, the superconducting coherence length and the Fermi velocity under pressure. The pressure phase diagram constructed for $(\text{Sr},\text{Ca})_4\text{Ir}_4\text{Sn}_{13}$ shows a dome-shaped dependence of $T_c$. The initial rise in $T_c$, which is accompanied by a decrease in $T^*$, is consistent with the pressure dependence of material parameters extracted from the resistivity data.


12P-B032 Observation of enhanced nuclear spin-lattice relaxation by superconducting fluctuations in thin films by depth resolved $\beta$-NMR


Superconducting fluctuations close to the critical transition temperature, $T_c$, manifest themselves in various electronic properties such as paraconductivity, diamagnetism and tunnel conductance. However, no unambiguous signature has been observed by a sensitive probe of the electronic state such as NMR. We report $\beta$-NMR investigations of polarized $^6$Li nuclei implanted in a thin Pb film ($d=300$ nm) and in the Ag overlayer ($d=40-120$nm) of Ag/Nb bilayers, which by proximity effect display bulk superconductivity below 9.1 K. In both systems, at $T_c$, we observe an anomalous singular enhancement in the $T_1$ relaxation, which we ascribe to fluctuations of the order parameter. The peak is suppressed by a small ($\sim 3$ mT) magnetic field. The magnitude of the peak is much more pronounced than theoretical predictions based on the enhancement of the dynamic electron spin susceptibility by superconducting fluctuations in the Gaussian regime (Maki-Thomson contribution). Possible explanations for the enhancement are discussed.

12P-B033 Optical Studies of Weak-Ferromagnetic Superconductors $\text{RuSr}_2\text{RuCu}_2\text{O}_8$ ($R = \text{Eu, Sm, and Nd}$)


The weak-ferromagnetic superconductors $\text{RuSr}_2\text{RuCu}_2\text{O}_8$ ($R = \text{Eu, Sm, and Nd}$) polycrystalline samples were...
prepared. Their Curie temperature increases from 133 K for smaller rare earth Eu$^{3+}$ (ionic radius $r = 0.107$ nm), to 142 K for larger Sm$^{3+}$ ($r = 0.108$ nm), but decreases to 120 K for even larger Nd$^{3+}$ ($r = 0.112$ nm). Furthermore, superconducting transition temperature occurs at $T_c = 36$ K for Eu$^{3+}$, but Sm$^{3+}$ and Nd$^{3+}$ show non-superconducting behavior. The room-temperature Raman spectrum of Eu$^{3+}$ sample exhibits four phonon peaks at about 263, 300, 435, and 648 cm$^{-1}$. With increasing the ion radius $r_T$, these Raman lines shift toward lower frequencies and their linewidths broaden, indicative of strong distortions of lattice structure. Infrared and optical reflectance spectra of these samples have also been measured over a wide frequency range (50 - 52000 cm$^{-1}$) and at temperatures between 10 and 340 K. The room-temperature far-infrared conductivity of Nd$^{3+}$ sample shows the lines at 347, 587, and 648 cm$^{-1}$, which all shift toward lower frequencies with decreasing temperature, suggesting a strong spin-phonon coupling in this material. In the superconducting state, a partial sum-rule evaluation of the effective number of carriers from the optical conductivity indicates that the value of London penetration depth of RuSr$_2$EuCu$_2$O$_8$ is about 2380 nm.

12P-B034 Fabrication of the SQUID with Nb/Ru/Sr$_2$RuO$_4$ junction
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We have fabricated Nb-Sr$_2$RuO$_4$ hybrid dc superconducting quantum interference devices (SQUIDs) using a Nb/Ru/Sr$_2$RuO$_4$ junction. The superconducting loop is composed of Nb, Sr$_2$RuO$_4$ and two Nb/Ru/Sr$_2$RuO$_4$ junction, and made by building a Nb bridge between two individual Ru microinclusions at the ab-plane surface of the Ru-Sr$_2$RuO$_4$ eutectic system. We measure the supercurrent between Nb and Sr$_2$RuO$_4$ part of the SQUID, which oscillates with every flux quantum through the SQUID loop.

12P-B035 Superconducting vortex imaging through scanning tunneling microscopy and spectroscopy at very low temperatures
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Scanning Tunneling Microscopy and Spectroscopy (STM/S) down to 100mK is an efficient tool to make real space images of individual vortices. When increasing temperature, thermal smearing of the tunneling conductance makes it more difficult to resolve individual vortices. Nevertheless, it has been possible to follow the vortex lattice until $T_c$, observing phenomena such as vortex lattice melting. However, the simple real space visualization of the vortex lattice at very low temperatures and in the whole magnetic field range remains a challenge. Here, we show how superconducting vortices enter the sample when increasing the magnetic field, we study the relationship of the vortex lattice with pinning centers, and provide for real space visualization of vortex arrangements at fields very close to $H_c2$, including the appearance of pairs of dislocations, its un-binding leading to a hexatic phase, and the crossover to a fully disordered phase.

12P-B036 Properties of Heterostructures involving Superconducting and Semiconducting Elements with Strong Spin-Orbit Coupling
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Recently there has been a general excitement in the condensed matter community following the predictions that hetero-structures composed of relatively conventional materials, i.e. conventional superconductors and semiconductors with strong spin-orbit coupling, could exhibit so called Majorana Fermions and associated non-Abelian statistics properties which were initially predicted in far more exotic states of matter such as the $p+ip$ superconductors and the fractional quantum Hall state. While the initial proposals were based on a phenomenological low energy theory of the heterostructure region, several microscopic approaches including tunnel model and tight binding calculations have been used to confirm some features of the low energy theory. Here we present a more complete description of the system using a wave-matching technique for the generalized BdG equation which clarifies the role of the microscopic processes (Andreev Reflections) and interface bound states (Andreev Bound States) in defining the low energy theory.


12P-B037 Quantum Phase Slip Phenomena in Superconducting Nanostructures
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The topic of quantum fluctuations in quasi-1D superconductors, also called quantum phase slips (QPS), has attracted a significant attention [1]. The phenomenon is capable to suppress the zero resistivity of ultra-narrow superconducting nanowires at low temperatures $T_{ii}/T_c$
[2, 3] and quench persistent currents in tiny nanorings [4]. A superconducting nanowire in the regime of QPS is dual to a Josephson junction [5]. Here we experimentally demonstrate that, being embedded in a high-impedance environment, the I-V characteristic of such a wire demonstrates Coulomb blockade and Bloch oscillations. The latter phenomenon is dual to the well-known Shapiro effect: the voltage steps for a Josephson junction are substituted by the current steps for a QPS wire. The position of the n-th step follows the relation \( I_n = n \times (2e) \times f \), where \( f \) is the frequency of external RF radiation and 2e is the charge of a Cooper pair. The effect leads to the important metrological application - the quantum standard of electric current.


### 12P-B038 Experimental Study of Spatially Resolved Charge and Energy Imbalance in a Superconductor

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Spatially resolved relaxation of non-equilibrium quasi-particles in a superconductor at ultra-low temperatures was experimentally studied [1]. It was found that the quasiparticle injection through a tunnel junction results in modification of the shape of I-V characteristic of a remote ‘detector’ junction. The effect depends on temperature, injection current and proximity to the injector. The phenomena can be understood in terms of creation of quasiparticle charge and energy disequilibrium characterized by different length scales \( \lambda_Q \approx 5 \mu m \) and \( \lambda_R \approx 40 \mu m \). The findings are in good agreement with existing phenomenological models, while more elaborated microscopic theory is mandatory for detailed quantitative comparison with experiment. The results are of fundamental importance for understanding electron transport phenomena in various nanoelectronic circuits. In particular, the mechanism of relaxation of hot electrons is of crucial importance for operation of various devices such as solid state coolers and hot/cold electron bolometers.


### 12P-B039 Majorana-Weyl fermions in (2+1)-dimensional superconductors

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The topic of Majorana fermions is interesting in relation to both condensed-matter physics and high-energy physics. To study Majorana fermions in superconductors, we performed electric transport measurements at an edge of a chiral single domain of \( \text{Sr}_2\text{RuO}_4 \). Surprisingly, we found anomalous current-voltage \((I-V)\) curves. The induced voltage shows an even function of the bias current in four terminal measurements. The parity-violating \( I-V \) curves are dependent on the direction of the applied magnetic field parallel to \( e \) axis. In the vicinity of 450 \( \Omega \), the induced voltage changes from a positive voltage of \( V(+) = V(-) \) to a negative voltage of \( V(-) = -V(I) \). The result revealed spontaneous magnetization and a change in the chirality of the single domain \( \text{Sr}_2\text{RuO}_4 \). In addition, the zero-bias conductance peak through the tunnel junction at an edge of a microscale \( \text{Sr}_2\text{RuO}_4 \) crystal shows the existence of the gapless chiral Majorana state. Thus, we discuss excitation of Majorana-Weyl fermions along the edge of the single domain under bias current in order to understand the parity-violating \( I-V \) curves.\(^1\)


### 12P-B040 The bifurcation phenomena in the resistive state of the narrow superconducting channels

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The current-voltage characteristics (CVCs) of the narrow superconducting channels are investigated by direct numerical integration of the time-dependent Ginzburg-Landau equations (TDGLEs)\(^4\) for different lengths of the wire. We have demonstrated that singularities of the CVC correspond to a number of different bifurcation points of the TDGLEs. We have discovered some universal features of the CVC. The voltage appearance in the system corresponds to the saddle-node homoclinic bifurcation leading to the formation of the limit cycle with a diverging period when \( j \rightarrow j_c \). It also leads to the formation of the phase slip center (PSC) in the middle of the wire in agreement with experimental results\(^2\). The voltage \( V \propto (j - j_c)^{1/2} \) in this region. We have also analytically estimated the period of oscillations in the vicinity of this bifurcation. The second singularity corresponds to the period-doubling bifurcation. In that case two adjacent PSCs are shifted in opposite directions with respect to the center of the wire in striking similarity with the experimental results\(^2\). As a result of this bifurcation, a new frequency \( \omega_2 = \omega_1/2 \) appears in the spectrum. The next bifurcation is the destruction of the limit cycle. It doesn’t generate any clear singularity on the CVC. Further increase of the current leads to a nonuniversal CVC’s behavior.

\(^1\) L.P. Gor’kov, N.B. Kopnin, Sov. Phys. Usp. 18, 496 (1975)


### 12P-B041 Direct Observation of Superconducting Vortices under an Applied
Supercurrent

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We report on STM/S experiments to study at an atomic scale the response of a superconducting condensate to an applied current. Our setup is mounted in a dilution refrigerator, which can be operated down to 7 mK, under magnetic fields up to 9 T. Here we describe the technique, and we present our first experiments on aluminum and NbSe$_2$. Perspectives and applications of this new local imaging method include local vortex motion experiments or Doppler shift local density of states studies.

12P-B042 Phase-Sensitive Quasiparticle Scattering inside a Vortex Core in Unconventional Superconductors

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The elucidation of the superconducting pair potential structure is of great importance for obtaining the clue to the pairing mechanism in unconventional superconductors. The field-angle resolved thermal conductivity and specific heat measurements are powerful techniques which can detect the anisotropy of pair potential amplitude, but they cannot probe the phase in the pair potential. However, it is crucial to probe the phase of the pair potential in order to discriminate unconventional superconductivity from conventional one. Therefore, we theoretically propose that the field-angle dependence of the quasiparticle (QP) scattering rate $\Gamma$ inside a vortex core can be a phase-sensitive probe. We consider the following pair potential models: a line-node $s$-wave and a $d$-wave pair potential with the same anisotropy of the pair potential amplitude, but with a sign change only for the $d$-wave one. Our results reveal contrasting field-angle dependence of $\Gamma$ between these two pair potential models. To clarify its mechanism, we investigate the dependence of $\Gamma$ on the Fermi wave vector $k_F$. We also discuss the QP scattering process on a spherical Fermi surface.

12P-B043 Superconductor—Insulator Transitions in Pure Polycrystalline Nb Thin Films

F. Couedo, O. Crauste, L. Bergé, Y. Dolgorouky, C. Marrache-Kikuchi, L. Dumoulin, Univ Paris-Sud, CNRS, UMR8609, Orsay, F-91405; CNRS-IN2P3, Orsay, F-91405

We report on a study of the transport properties of Nb thin films. By varying the thickness of the films from 250 Å to 25 Å, we observed a depression of the superconductivity. Magnetic field was also applied up to 6 T, inducing the disappearance of the superconductivity and the onset of an insulating behavior. We have compared the analysis of these superconductor-to-insulator transitions (SIT) according to two models. The first, based on Finkelstein’s explanation of the destruction of superconductivity, implies the weakening of the amplitude of the superconducting order parameter. The second, based on the universality of the system’s behavior near continuous quantum critical points, implies the destruction of the superconducting phase order. The results were compared to those we have already obtained on a highly disordered system, a-NbSi, to understand whether the same mechanisms for the disappearance of the superconductivity could be at play in pure metallic thin films and in highly disordered systems. Finally we have inferred the phase diagram for Nb thin films in the thickness-magnetic field plane.

12P-B044 Superconductor-Insulator Transition in Amorphous Nb$_2$Si$_{1-x}$ Thin Films. Comparison between Thickness, Density of States and Microscopic Disorder effects.

O. Crauste, F. Couedo, L. Bergé, C. Marrache-Kikuchi, L. Dumoulin, Univ Paris-Sud, CNRS, UMR8609, Orsay, F-91405; CNRS-IN2P3, Orsay, F-91405

We report on the study of the Disordered-induced Superconductor-Insulator Transition (DSIT) in Nb$_2$Si$_{1-x}$ thin films. These films, synthesized by electron-beam co-deposition, are continuous, amorphous, homogeneously disordered and structurally stable for a wide range of compositions, thicknesses and annealing temperatures and thus particularly well suited for the study of DSIT. We present an analysis of the DSIT induced by three different parameters: the thickness, the Nb composition that changes the electronic density of states and the annealing temperature that changes the microscopic disorder. The annealing changes quantum interference patterns that decreases the local conductance. Our results show that the effect of the thickness on the destruction of superconductivity is very distinct from those of the composition or the annealing. We point out this material is particularly interesting to disentangle the effect of the parameters driving this quantum phase transition.

12P-B045 Appearance of Quantum Fluctuations in Submicron Intrinsic Josephson Junctions of Bi$_2$Sr$_2$CaCu$_2$O$_{8+\delta}$ Single Crystal Whiskers

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The tunneling of cooper pairs is more precise when the normal resistance of a submicron junction belongs in the range of quantum resistance and the characteristics of junctions are changed with quantum effect. To observe this quantum effect we have fabricated various in-plane area intrinsic Josephson junction (IJJ) stacks from 4 $\mu$m$^2$ down to 0.16 $\mu$m$^2$ in Bi$_2$Sr$_2$CaCu$_2$O$_{8+\delta}$ single crystal whisker through three-dimensional focused ion beam etching technique. A strong suppression in
critical current density \( (J_c) \) is noticed in current-voltage characteristics for stacks of in-plane area \( S < 1 \mu m^2 \) at 30 K. This suppression in \( J_c \) is archived for the first time ever at 30 K and is attributed due to quantum fluctuations of phase. The conditions for quantum region (charging energy > Josephson energy, thermal energy, and damping rate) are obeyed by submicron junctions at 30 K. The estimated ratio of Josephson energy and charging energy is less than 1 for submicron stacks which induced these quantum fluctuations. The array of LJJ's stack is following the Ambegaokar-Baratoff relation and reflects a good quality junction in submicron range as well.

**12P-B046** Pressure Dependent Anomalous Phase Transition in Ternary Superconductor Bi\(_2\)Rh\(_3\)Se\(_2\)

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We report temperature dependent resistivity measurements (2-350 K) under pressure as well as low temperature specific heat study (0.4-2 K) on the ternary superconductor Bi\(_2\)Rh\(_3\)Se\(_2\) to study the possible coexistence of charge-density-wave (CDW) and superconductivity. Interestingly, resistivity study under hydrostatic pressures, the anomaly near 250 K is shifted to high temperature. These experimental findings are not consistent with the traditional CDW phase. To make sure whether the anomaly is really a CDW transition or just a structural distortion, the temperature dependent electron diffraction measurements are in progress and the results will be discussed.

**12P-B047** Pressure Dependence of Superconductivity in FeSe Studied by DC Magnetic Measurements

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Pressure dependence of superconductivity in FeSe (\( T_c \sim 8 \) K) has been investigated by DC magnetic measurements under high pressure using miniature diamond anvil cell combined with commercial SQUID magnetometer. High quality specimens with nominal composition FeSe\(_x\) (\( x=0.80-1.00 \)) were prepared from iron pieces and selenium shot as described in the literature.\(^1\) In the specimens, no impurity phase of hexagonal FeSe was identified. It has been found that \( T_c \) increases in two steps for the composition range of 0.80\( \leq x \leq 0.98 \) by the application of pressure, showing a local maximum of \( T_c \sim 11 \) K at \( P \sim 1 \) GPa and a saturation at \( T_c^{\text{max}} \sim 20 \) K above \( P \sim 3 \) GPa. The \( T_c - P \) curve is qualitatively similar to those previously determined using specimens prepared from Fe and Se powders\(^2,3\) but \( T_c^{\text{max}} \) in the specimens is 25-30 K, fairly higher than that in the present specimens. It has been also found that the \( T_c - P \) curve for 0.99\( \leq x \leq 1.00 \) also becomes nearly constant of \( T_c^{\text{max}} \sim 15-20 \) K above 3 GPa but does not show a local maximum at \( P \sim 1 \) GPa, contrasting to the specimens for 0.80\( \leq x \leq 0.98 \). The origin of the sample dependence in the \( T_c - P \) curve will be discussed.


**12P-B048** DC Magnetization Measurements of LiFeAs under High Pressure

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The pressure effect of \( T_c \) in layered superconductor LiFeAs has been investigated by DC magnetic measurements using diamond anvil cell combined with a sample rod of commercial SQUID magnetometer. It has been found that \( T_c \) decreases monotonously for \( P \leq 5 \) GPa with a pressure coefficient \( dT_c/dP \sim -1.5 \) K/GPa. We have also observed that the \( T_c - P \) curve tends to be constant for \( P \geq 5 \) GPa. Recently, it has been reported that the pressure dependence of \( T_c \) and Se height \( h_{Se} \) from the nearest iron layer in FeSe superconductor is qualitatively similar to each other, suggesting the strong correlation between them.\(^1\) A strong correlation between \( T_c \) and As height \( h_{As} \) may be generally found in iron arsenide superconductors. The origin of the characteristic pressure dependence of \( T_c \) in LiFeAs will be discussed considering the pressure dependence of \( h_{As} \) extracted from the recently reported structural data.\(^2\)


**12P-B049** Vortex-core structure in d-wave superconductors with a subdominant triplet pairing

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The quasiparticle states found in the vortex core of a high-\( T_c \) cuprate superconductor may be probed by scanning tunneling spectroscopy. Results of such experiments have revealed typical spectra that are quite different from what is seen in conventional low-\( T_c \) superconductors. In particular the Caroli-deGennes-Matricon state at \( E \sim 0 \) in the core center is not seen. Instead, in a high-\( T_c \) vortex core, quasiparticle states are found at energies that are at a sizable fraction of the gap energy. One explanation for this could be that a finite amplitude of a competing order parameter stabilizes in the vortex-core center. Here I will explore the possibility of nucleating a vortex-core state that locally breaks inversion symmetry. The vortex-core order parameter is of mixed parity, with p-wave order parameter established in the core of the d-wave vortex. The resulting quasiparticle spectra lacks the zero-energy states in the core center. They are found at a finite energy set by the amplitude of the core order parameter.

**12P-B050** Quantum Nucleation of Josephson Vortices in Superconducting
Grain Boundary Junctions

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We report on new developments in the theory of time-correlated soliton tunneling, applying the model to quantum nucleation of Josephson vortex-antivortex pairs in high-temperature superconducting (HTS) grain boundary junctions. A magnetic dual of the Coulomb blockade mechanism leads to a sharply defined critical current for vortex pair nucleation. The model shows excellent agreement with a wide range of measured voltage-current characteristics of grain boundary junctions in HTS thin films. Moreover, by hypothesizing that the critical current of HTS coated conductors is limited by natural low-angle grain boundaries, the observed unusual critical current vs. thickness dependence and the mechanism for its improvement via multiple layers emerges naturally. Finally, when applied to charge density wave (CDW) systems, simulations of the time-correlated soliton tunneling model show excellent agreement with experimentally measured CDW current-voltage characteristics and coherent voltage oscillations.


12P-B051 Percolation transition in Josephson-junction arrays

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The percolation transition, dominated by the correlation length which is characterized by $\xi = \xi(p)$ in the vicinity of percolation threshold $p_c$, is investigated in the Josephson-junction arrays. Using the similar modeling strategy as in Refs. [1,2], we measure the current-voltage (IV) characteristics close to $p_c$ by resistivity-shunted-junction dynamics. We find that the transition belongs to the true superconducting transition. Further, we analyze the IV curves by two scaling schemes, which provide clear evidence to the critical behavior of the percolation-driven superconducting transition in the Josephson-junction arrays.3


12P-B052 Vortex Structure in Chiral p-wave Superconductors Studied by Eilenberger Theory

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In chiral $p_{\pm}$-wave superconductors, there is a possibility that double-winding vortex is stabilized instead of conventional single-winding vortex,1 because the opposite chiral ($p_{\mp}$-wave) component is induced around vortices. By the induced component, double-winding vortex becomes core-less vortex. The vortex structures for both winding cases are studied by Eilenberger theory in the vortex lattice state. We selfconsistently calculate the spatial structure of pair potential, internal magnetic fields and local electronic states, and discuss which winding vortex is stabilized depending on magnetic fields. We find that double-winding vortex has lower free energy than that of single-winding vortex at higher fields. On the other hand, in $\text{Sr}_2\text{RuO}_4$ which is considered as a chiral $p$-wave superconductor, square vortex lattice of single-winding vortices is observed by small angle neutron scattering experiments, where nearest neighbor vortex is located along (1,1)-direction. 2 In order to discuss the condition to reproduce this vortex lattice configuration and orientation, we study the vortex lattice state considering detailed form of possible gap functions and Fermi surface structure of $\text{Sr}_2\text{RuO}_4$.


12P-B053 Ru Doping Effect on the Dirac Cone State and the Possible Coexistence of the Dirac Cone state and the Superconductivity in $\text{Ba(Fe}_2\text{−}_x\text{Ru}_x\text{As)}_2$


Recently discovery of the Dirac cone state in the antiferromagnetic (AF) phase of Ba(FeAs)$_2$ provides a new insight in the study of iron pnictide superconductors. Because of the dominant contribution of the massless fermion on the electronic property in Ba(FeAs)$_2$, the influence of the Dirac cone state on the superconductivity is a curious subject in iron pnictide superconductors. We investigated the Ru doping evolution of the Dirac cone state in Ba(Fe$_{1−x}$Ru$_x$As)$_2$ from the transverse magnetoresistance measurements. The development of the linear MR for the magnetic field $B$ has been observed in $x = 0 - 0.244$. $B$-linear MR has theoretically been predicted in the quantum limit of the Dirac cone state and it agrees with the present observations. Therefore, it has been concluded that the Dirac cone state persists on the electronic phase diagram where the AF ordering state and the superconductivity coexist.


12P-B054 Magnetic field effects and dynamical control of terahertz electromagnetic wave emission from high-$T_c$ superconducting $\text{Bi}_2\text{Sr}_2\text{CaCu}_2\text{O}_{8+\delta}$ mesa structures

K. Yamaki*, a M. Tsujimoto*, b T. Yamamoto*, c

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Takashi electromagnetic waves are very useful for a number of security and medical applications. Recently, intense and coherent THz emission from high-\(T_c\) superconducting \(\text{Bi}_2\text{Sr}_2\text{CaCu}_2\text{O}_{8+\delta}\) intrinsic Josephson junctions (JJJs) has been intensively investigated.\(^1\) In this paper, we report magnetic field effects and dynamic control of THz EM wave emission generated by the rectangular mesa structure of \(\text{Bi}2212\). Magnetic field affects anisotropically the emission intensity at \(T = 25\) K. THz emission is strongly suppressed by applying magnetic field (less than 200 Oe) parallel to the \(c\)-axis. On the other hand, 20% enhancement of radiated power is observed when appropriate magnetic field (\(H = \Phi_0/2\)) was applied parallel to the \(ab\)-plane. This anisotropy seems to be reflected from its anisotropic vortex formation inside \(\text{Bi}2212\). We also demonstrate the intensity of THz emission can be controlled dynamically by applying a weak magnetic field, suggesting that we are able to modulate the continuous power of THz emission by applying weak pulses of magnetic field.


\textbf{12P-B055} \quad \textbf{Vortex-Lattice Orientation in the Flux-Flow State of Amorphous Superconducting Films in Oblique Fields}

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The vortex-lattice orientation in the flux-flow state of amorphous superconducting films is studied for arbitrary magnetic fields by means of mode-locking experiments. In oblique fields, we find that the lattice orientation depends on the tilt direction and the direction of motion. Defining an angle \(\phi\) between the tilt direction and the flow direction, we find that for \(\phi = 0^\circ\) the lattice orientation is parallel to the flow direction, whereas for \(\phi = 90^\circ\) it is perpendicular. The former orientation also appears for \(\phi = 60^\circ\) and the latter for \(\phi = 30^\circ\) due to hexagonal symmetry in the moving lattice. We also study how the moving lattice is deformed as the field direction is rotated away from normal to the films. Different from a naive expectation,\(^1\) the moving lattice is stretched in directions parallel and/or perpendicular to the flow direction, not to the tilt direction when \(0^\circ < \phi < 90^\circ\). A striking example observed is that for \(\phi = 45^\circ\) the moving lattice is uniformly stretched and it forms like a regular hexagon in oblique fields.


\textbf{12P-B056} \quad \textbf{Reorientation of a Moving Vortex Lattice in Amorphous Mo\(_{1-x}\)Ge\(_x\) Superconducting Films}

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The orientation of a vortex lattice in the flux-flow state of amorphous Mo\(_{1-x}\)Ge\(_x\) superconducting films is studied by mode-locking experiments. We observe the formation of a hexagonal vortex lattice in the flux-flow state for almost three decades of the velocity range up to \(20\) m/s, which is about 1/10 of the critical velocity (\(\sim 100\) m/s) at which the flux-flow instability occurs.\(^1\) The orientation of the hexagonal lattice is observed to be either parallel or perpendicular to the direction of motion, and the reorientation occurs at a characteristic velocity (\(\sim 1\) m/s), separating the perpendicular orientation at small velocity from the parallel orientation at high velocity.

Superconductor thin films with square pinning arrays were fabricated using electron beam lithography and reaction dry etching techniques to explore the vortex pinning behavior. Periodic critical current matching peaks are observed in magnetotransport measurements. At certain temperatures, it is found that the height of the third matching peak is about the same as that of the fourth matching peak for film with pinning size of 200 nm, and it appears that the third matching peak is missing. Similar phenomena are observed for films with larger pinning sizes, but the missing peaks are at the fourth or fifth matching fields. Molecular dynamic simulations were made to obtain the ground state vortex distributions at different parameters such as the pinning strength, pinning size and magnetic field. Phase diagrams are produced from these results. These simulation results reveal a systematic vortex reentrance phenomenon at certain magnetic fields, which could offer good explanations to the features we found in the experiments.

12P-B059 Upper Critical Fields of Electric-Field-Induced Superconductivity in SrTiO$_3$

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Recently we succeeded in converting an insulating surface of SrTiO$_3$ to a superconducting one with the critical temperature $T_c$ = 0.4 K purely by electric field effect.\(^1\) This conversion was made possible by high-density electrostatic carrier doping using an electric double layer transistor structure. In this work, the upper critical magnetic fields parallel ($H_{c2\parallel}$) and perpendicular ($H_{c2\perp}$) to the conducting surface were examined by the measurements of the transport properties at temperatures $T$ down to 0.1 K. A vector superconducting magnet allowing precise and accurate alignment of the magnetic field direction with respect to the sample surface was used. The observed $H_{c2}$ data were strongly anisotropic: At $T$ = 0.1 K, $H_{c2\parallel}$ is about fifteen times larger than $H_{c2\perp}$. We also found that $H_{c2\parallel}(T)$ obeys a $(1-T/T_c)^{1/2}$ law near $T_c$. These results are consistent with the fact that the electric-field-induced superconductivity occurs at the two-dimensional surface.


12P-B059 Single Vortex Flow in a Mesoscopic Superconducting Al Disk

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It is known that the collective motion of a vortex lattice in large superconducting films can be controlled by an RF current superimposed on a DC current, evidence of which is provided by voltage steps in current-voltage ($I$-$V$) characteristics, analogous to Shapiro step in weak-linked superconductors. However, the dynamical control of a single vortex has not been achieved so far. We report the first evidence of a single-vortex flow in a mesoscopic superconducting disk, which is controlled by RF current with an order of 100 GHz. Clear periodic voltage steps in the $I$-$V$ characteristics show that when a single vortex inside the disk is driven out of the disk, another vortex enters the disk similarly to two balls colliding in billiards: only one vortex passes through the Al disk at the same time. This single vortex billiard takes place irrespective of the number of vortices confined to the disk. In a large RF power region, the voltage steps become larger than that corresponding to the normal state resistance. The fact shows that the single vortex flow causes a large energy dissipation, which is not explained by conventional theories. The RF power and frequency dependences of the voltage steps are also discussed in terms of the single vortex billiard.

12P-B061 Simulations for Superconducting Thin Films with Honeycomb Pinning Arrays

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Superconductor thin films with honey pinning arrays have shown interesting pinning phenomena which are very different from those of films with square or triangular pinning arrays. Molecular dynamic simulations were made to obtain the ground state vortex distributions at different parameters such as the penetration depth, pinning strength, pinning size and magnetic field. For small pinning site cases, the interstitial positions capture vortices at low magnetic field and the ground distribution tend to be irregular at high magnetic fields. Interesting vortex distributions at large penetration depth and large pinning sites are found which may explain the pinning phenomena found in experiments for the films with honeycomb blind hole array.

12P-B062 Overdoping effect on the in-plane charge dynamics in (Y,Ca)Ba$_2$Cu$_3$O$_{7−δ}$

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In order to clarify the carrier overdoping effect on the in-plane charge dynamics, we have carried out a systematic study on the optical spectra of detwinned (Y,Ca)Ba$_2$Cu$_3$O$_{7−δ}$ crystals for various Ca- and oxygen contents. Ca-substitution introduces not only carriers but also disorders into the CuO$_2$ planes. The previous studies with the same interest were on the $c$-axis spectra\(^1\) without paying attention to the Ca-disorder effect\(^2\). In the present study, it was clearly demonstrated that the carrier overdoping induces a
huge amount of residual conductivity below the gap energy, which can be distinguished from the disorder-induced pair-breaking effect by Ca-substitution. The latter effect was also confirmed by comparison of the spectra for Ca-free and Ca-doped samples with a fixed doping level. As a result of increase of unpaired carriers, the superfluid density rapidly decreases with doping, compared to the moderate change in $T_c$. The present results suggest that there exists some intrinsic mechanism to create inhomogeneous electronic state in the overdoped regime.


12P-B063 Strain detwining of NaFeAs single crystals: Resistivity and magnetic susceptibility study
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Transport properties like resistivity and magnetic susceptibility have been studied on the mechanically detwinned single crystals of NaFeAs. The anisotropy of resistivity has been found obviously along the lattice parameter a (direction of the antiferromagnetic chains) and b (direction of the ferromagnetic chains) as direction a shows a smaller resistivity compared to direction b. The anisotropy occurs above the structural temperature ($T_X$). This behavior is the same as BaFe$_2$As$_2$ [1], Ba(Fe$_{1-x}$Co$_x$)$_2$As$_2$ and Eu(Fe$_{1-x}$Co$_x$)$_2$As$_2$[2] while different from CaFe$_2$As$_2$[1] in which the anisotropy vanishes immediately at TN. Moreover, we observed an enhancement of $T_X$ for about 10K. The magnetic susceptibility also shows very interesting behaviors from twinned to detwinned samples, which we are now focusing on.


12P-B064 Phase diagram of the SmFe$_{1-x}$Co$_x$AsO ($0 \leq x \leq 1$) system
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A series of the SmFe$_{1-x}$Co$_x$AsO ($0 \leq x \leq 1$) samples are synthesized and the evolution of electronic state with Co content is investigated. As well known, the parent compound (x = 0) undergoes a SDW transition of Fe 3d electrons around 140 K and an antiferromagnetic (AFM) ordering of Sm 4f electrons at 5.6 K. Even 5% Co doping severely suppresses the SDW transition to a very lower temperature, and meanwhile, superconductivity appears with $T_c$ of 8 K. With increasing Co content, $T_c$ (midpoint in resistivity) reaches a maximum value of 17.2 K at $x = 0.1$, and a narrow superconducting (SC) regime with ($0.05 \leq x \leq 0.2$) is identified.

On the other hand, the AFM order of Sm 4f electrons is robust in the whole Co doping range, and its Neel temperature $T_N$ slightly decreases in the intermediate doping range ($0 \leq x \leq 0.7$), and then it increases to 5.6 K at $x = 1$. Around $x = 0.7$, there is a transition from paramagnetic to ferromagnetic (FM) order of Co/Fe 3d electrons. Furthermore, an antiferromagnetic transition of Co/Fe electrons occurs at a lower temperature probably due to the interaction between Co 3d electrons and Sm 4f electrons. For the other end compound ($x = 1$), SmCoAsO shows a FM transition around 80 K, and an AFM transition around 45 K, and finally an AFM order of Sm 4f electrons at 5.6 K. Based on those results, an electronic phase diagram of the SmFe$_{1-x}$Co$_x$AsO ($0 \leq x \leq 1$) systems is established.

12P-B065 THz Emission from a Tringular Mesa Structure of Bi-2212 IJJs
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Applying dc-voltage along the c-axis of Bi$_2$Sr$_2$CaCu$_2$O$_{8+\delta}$ (Bi2212) single crystal, which is sculptured by a focus ion beam (FIB) milling technique into a mesa structure, intense, continuous, and monochromatic terahertz (THz) electromagnetic waves are generated as previously reported.1,2 It has been established that there are two conditions to be fulfilled in order to have THz radiation from the mesa: one is the ac-Josephson effect while another is the cavity resonance condition in order to form a standing wave inside the mesa. We fabricated the triangular mesas with various sizes and shapes; equilateral and isosceles triangular mesa structures with the various length of the sides, and observed THz emission from one of the isosceles triangles. In this THz emission, we see that the ac-Josephson relation is well obeyed and the resonance condition seems to agree with the calculated modes. We analyzed the data by simulating the mode, which will be discussed.


12P-B066 Coupling to External Structures: Boundary Conditions for the Bi2212-based Superconducting THz Emitter
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Monochromatic and continuous terahertz (THz) emission with a power of $\mu$W level can be generated by coherent enhancement of the ac-Josephson current in the intrinsic Josephson junction system.
of Bi$_2$Sr$_2$CaCu$_2$O$_{8+\delta}$ (Bi2212) fabricated into mesa structure.\textsuperscript{1} For single and simple mesa devices, the emission frequency fulfills the general resonance conditions determined by the geometrical shape and dimensions of the biased mesa. When the mesa device has some external structures outside the mesa, the resonance is still observed, indicating energy transfer to the external structure through the superconducting substrate. This suggests the necessity of careful treatment of the boundary conditions at mesa edges in order to understand the emission mechanism further, and also gives us a hint to enhance the emission power.\textsuperscript{1}


12P-B067  Frontiers Problems of the Josephson Effect in High Tc: From unconventional superconductivity to Mesoscopics and Macroscopic Quantum Phenomena

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The recent experiments on macroscopic quantum effects in high critical temperature superconductors (HTS) junctions represent another relevant step towards a Josephson platform, where important device functionalities are not anymore precluded to HTS unconventional junctions. Possible strategies towards more uniform and reproducible devices pass through progress in material science and a systematic use of nanotechnology. We will report on different nanotechnology approaches, employed to achieve high quality YBaCuO nano-junctions. Macroscopic and mesoscopic quantum phenomena have been observed. The possibility to have reproducible and reliable HTS nanostructures with quality factors above 10 meV, is also a major contribution towards nanoscale experiments. Results encourage the integration of HTS nanostructures in quantum circuits and hybrid systems, and pave the way to similar fundamental studies on novel superconducting materials. Comparative studies on macroscopic quantum phenomena in various unconventional systems might be inspiring for novel insights on coherence and dissipation.

12P-B068  Magnetic field effect in a topological superconducting junction Pb/Ru/Sr$_2$RuO$_4$

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Sr$_2$RuO$_4$ is a most promising candidate of a spin-triplet superconductor.\textsuperscript{1} In addition to its novel spin pairing, a number of experiments and theories suggest the chiral $p$-wave state. Recently, such a state has been attracting great interest as a topological superconducting state. We study Pb/Ru/Sr$_2$RuO$_4$ junctions, in which Ru normal metal is surrounded by Sr$_2$RuO$_4$, and find unusual temperature dependence of the critical currents.\textsuperscript{2,3} We attribute the behavior to a topological phase mismatch between the $p$-wave superconductivity and the $s$-wave superconductivity in Ru proximity-induced by Pb. In such junctions, spontaneous magnetic flux is expected at the Ru/Sr$_2$RuO$_4$ interface.\textsuperscript{4} To clarify the effect of the spontaneous magnetic flux, we focus on the behavior in small magnetic fields.


12P-B069  Novel superconductivity of the noncentrosymmetric compounds LaTC$_2$ (T=Ni, Pd and Pt)

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The superconductivity of the T=Ni, Pd and Pt based ternary carbides LaTC$_2$ has been studied with electrical resistivity, magnetization and specific heat measurements. The results for the Ni based compound show that the superconductivity of this material is well defined bulky one with the transition temperature of 2.8 K. The specific heat exhibits the $T^2$ temperature dependence below $T_c$, indicating that the energy gap has line nodes. Furthermore, the data of specific heat are not contradict with those of the materials with the $p$-wave superconducting symmetry that was previously claimed from the $\mu$SR experiment. The physical properties concerning to superconductivity of T=Pd and Pt based compounds have also been investigated carefully. The results are presented and compared with those of the Ni based sample.

12P-B070  New Fermi Surface Sheets Revealed in Sr$_2$RuO$_4$ Revealed by High Resolution Angle-Resolved Photoemission Spectroscopy

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We will present our detailed Fermi surface measurements on Sr$_2$RuO$_4$ by high resolution angle-resolved photoemission spectroscopy (ARPES) including vacuum ultra-violet (VUV) laser-based ARPES. In addi-
tion to the three sets of Fermi surface sheets originating from the bulk bands, the surface bands and the shadow bands of the surface bands, we have revealed two new Fermi surface sheets. The origin of these new Fermi surface sheets will be discussed.

12P-B071 Relativistic dynamics of domain wall in one-dimensional SQUID array
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A superconducting quantum interference device (SQUID) composed of three Josephson junctions has two lowest energy states, \(|0\rangle\) and \(|1\rangle\), which correspond to a persistent current circulating in opposite directions, when the total phase across the three junctions becomes \(\pi\) by applying half a flux quantum or by inserting a \(\pi\) junction. In a one-dimensional array of such SQUIDs, domain walls are formed between \(|0\rangle\) and \(|1\rangle\) domains. Since the SQUIDs in this array can be approximately described by a double sine-Gordon (DSG) model which obeys Einstein’s special theory of relativity, it is expected that relativistic motion of the domain wall will be observed. We investigate the classical dynamics of a domain wall in a one-dimensional SQUID array. We conduct numerical simulations of a discrete DSG equation, and show that the domain wall propagates solitonically through the SQUID array and exhibits quasi-relativistic behavior which agrees reasonably well with the predictions from a relativistic equation of motion of a particle, whose rest mass is extremely small compared to that of a single electron. We also study the relativistic quantum mechanics of the domain wall, and discuss the possibility of the observation of relativistic quantum effects, such as Klein tunneling.

12P-B073 Alcoholic beverages induce superconductivity in FeTe_{1−x}S_x
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Discovery of Fe-based superconductor was received with considerable surprise, since the Fe-based superconductor is expected to be a new series of high-Tc superconductors. The FeSe with \(T_c \approx 10\) K has the simplest crystal structure among the iron-based superconductors. On the other hand, analogous compound FeTe shows structural and magnetic transition around 70 K, and superconductivity was not observed. Recently, we found that hot alcoholic beverages were effective in inducing superconductivity in S doped FeTe. Heating the FeTe_{0.8}S_{0.2} compound in various alcoholic beverages enhances the superconducting properties compared to a pure water-ethanol mixture as a control. Heating with red wine for 24 h leads to the largest shielding volume fraction of 62.4 % and the highest zero resistivity temperature of 7.8 K. Some components present in alcoholic beverages, other than water and ethanol, have the ability to induce superconductivity in the FeTe_{0.8}S_{0.2} compound. Reference: K. Deguchi et al., Supercond. Sci. Technol. 24 (2011) 055008.

12P-B074 Observation of a Fractured Vortex Lattice Phase in Sr_2RuO_4 with \(H \parallel a\)
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The vortex lattice (VL) in Sr_2RuO_4 with \(H \parallel a\) was studied by small-angle neutron scattering. Bragg reflections indicative of a highly distorted hexagonal VL were observed, and an analysis of the magnitude of the scattering vector yield a VL anisotropy \(\sim 30\), comparable with reports of the \(H_{c2}\) anisotropy. A conventional field dependence of the VL form factor, related to the magnitude of the magnetic field modulation in the mixed state, was observed, and does not support theoretical predictions of Pauli paramagnetic effects in Sr_2RuO_4 with \(H \parallel a\) [K. Machida and M. Ichikawa, Phys. Rev. B 77, 184515 (2008)]. In contrast to the the anisotropy and form factor, the observed VL structure was highly unusual. For each VL Bragg reflection, rocking curves obtained by rotating around an axis perpendicular to
the scattering vector, show two clearly separated peaks instead of one. The separation of the two maxima is found to increase with increasing field. While the exact VL structure is not yet resolved, these results suggest a fracturing of the VL and the introduction of an additional periodicity along the applied field direction.

12P-B075 Scanning tunneling spectroscopy in ultra thin TiN films.


We have studied ultra thin films (thickness = 5-7 nm) of titanium nitride (TiN) with scanning tunneling microscopy and spectroscopy at 100 mK and under magnetic fields. We obtain atomic resolution and resolve nanocrystallites with different orientations and sizes between 5 nm and 7 nm. We compare interplanar spacings measured from the atomic images with those reported for face centered cubic TiN structure. We have measured different homogeneously disordered samples, and present a comparative study of the tunneling spectroscopy results in these films down to 100 mK and at high magnetic fields up to 7 T.

12P-B076 Macroscopic Quantum Tunneling and Thermal Activation Switchings in Nanometer-Thickness PbBi2212 Intrinsic Josephson Junctions.

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The switching dynamics of Pb1−xBixSr2CaCu2O8+x+δ (PbBi2212) stacked intrinsic Josephson junctions (IJJs) are studied up to 0.4 K. Utilizing e-beam lithography and Ar ion milling techniques, we prepare mesa structures with dimensions of 1 x 1 mm² in the ab-plane and a few unit cells along the c-axis on PbBi2212 single crystals grown by the self-flux method. The substitution of Pb for Bi in BiSCCO superconductors makes anisotropy parameter γ lower, which results in larger c-axis critical current density Jc. Sample A shows heavily under-damped IV characteristics with five branches equally separated in voltage with almost identical Jc, indicating that the mesa contains five IJJs consist of CuO2 double layers and (Pb, Bi)O2 block layers. The width of the switching probability distribution (SPD) from the superconducting (R ≈ 0) to the first resistive branch does not depend on temperature below 4 K while the SPD between 5 and 30 K fairly agrees with the thermal activation (TA) model. It is considered that the macroscopic quantum tunneling (MQT) is observed below 4 K. According to the single junction model, the fluctuation-free critical current Ic = 65 μA gives the crossover temperature as 1.3 K, which considerably lower than the experimental result. In sample B with inhomogeneous Jc, SPD results show large deviation from the TA model in the temperature dependent region. The difference among two mesas can be understood by applying the long junction model to the sample B.

12P-B077 Stripe order and superconductivity in the mechanical milled La1.6−xNd0.4Sr2CuO4.

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Mechanical milling introduces atomic disorders in the crystal lattice. In the present study, we performed mechanical milling for La1.6−xNd0.4Sr2CuO4 with various doping levels including x = 1/8, at which static stripe order appears and superconductivity is strongly suppressed. The X-ray diffraction patterns for the samples examined in the present study show that the crystallite size rapidly decreases and the lattice strain increases as the milling time increases. The superconducting transition temperature Tc for x = 0.13 is enhanced by the mechanical milling, while Tc for x = 0.17 is almost unchanged, although the magnitude of the diamagnetic signal for both doping levels are largely suppressed. These results suggest that the static stripe order can be suppressed by mechanical milling.

12P-B078 Long-Range Superconducting Proximity Effect in Template-Fabricated Single-Crystal Nanowires (LT26).

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We study a superconducting proximity effect observed in single-crystal nanowires of Zn, Sn, and Pb of length up to 60 μm. These nanowires are electrochemically deposited into the pores of anodic aluminum oxide membranes and polycarbonate membranes. Using an in situ self-contacting method, single nanowires are electrically contacted on both ends to a pair of macroscopic film electrodes of Au, Sn, or Pb pre-fabricated on both surfaces of the membranes. Superconductivity in the nanowires is strongly suppressed when Au electrodes are used. When electrodes having higher superconducting transition temperatures are used, the nanowires become superconducting at the transition temperatures of the electrodes. Microscopy analyses of the structure and chemical composition of the nanowires will be presented. Measurements of sample resistance and I - V characteristics at various temperatures and magnetic fields will also be presented. Furthermore, the effects of the length, the diameter, and the residual resistance ratio of the nanowires on the proximity induced superconductivity will be analyzed and discussed.

12P-B079 Ba0.8K0.8BiO3 single crystal as a multiple Josephson system: new co-
The existence of space inhomogeneous superconductor insulator state (SISIS) found out earlier in polycrystalline samples of high-$T_c$ system Ba$_{0.6}$K$_{0.4}$BiO$_3$ ($T_c \approx 30$ K) is confirmed on Ba$_{0.6}$K$_{0.4}$BiO$_3$ single crystal. At $T^* (T^* < T_c, T^* \approx 17$ K) the transition from the homogeneous superconducting state into the SISIS occurs. SISIS is characterized by the appearance of two gaps on the Fermi surface: semi- and superconducting, that are modulated in space in antiphase, the electric transport between superconducting regions being carried out due to Josephson tunneling. Thus the whole sample becomes a multiple Josephson system. Nonlinear I-V curves, depended on temperature and magnetic field, that are typical to a Josephson system, are observed on Ba$_{0.6}$K$_{0.4}$BiO$_3$ single crystal at temperatures below $T^*$. Besides a step like peculiarities at the values of voltage of the order of one and two superconducting gaps show up. These peculiarities are suppressed by magnetic field much earlier then critical current. Perhaps the last phenomenon is the consequence of “coherent” state of several successive Josephson junctions, appeared in exfoliation state.

12P-B080 Evidence for long-lived quasiparticles trapped in superconducting point contacts

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We use micro-fabricated mechanically controllable break junctions to obtain aluminum point contacts. The current-voltage characteristic of the contact allows to determine precisely the transmissions of its conduction channels, and its current-phase relation.$^{1,2}$ We have observed that the supercurrent across phase-biased, highly transmitting contacts is strongly reduced within a broad phase interval around $\pi$. We attribute this effect to quasiparticle trapping in one of the discrete sub-gap Andreev bound states formed at the contact.$^3$ Trapping occurs essentially when the Andreev energy is smaller than half the superconducting gap $\Delta$, a situation in which the lifetime of trapped quasiparticles is found to exceed 100\,$\mu$s. The origin of this sharp energy threshold is presently not understood.


12P-B081 Anomalous Skin Effect in a Drude-type Model Incorporating the Spatial Dispersion for Systems with Conductivity of Metal

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The existence of space inhomogeneous superconductor insulator state (SISIS) found out earlier in polycrystalline samples of high-$T_c$ system Ba$_{0.6}$K$_{0.4}$BiO$_3$ ($T_c \approx 30$ K) is confirmed on Ba$_{0.6}$K$_{0.4}$BiO$_3$ single crystal. At $T^* (T^* < T_c, T^* \approx 17$ K) the transition from the homogeneous superconducting state into the SISIS occurs. SISIS is characterized by the appearance of two gaps on the Fermi surface: semi- and superconducting, that are modulated in space in antiphase, the electric transport between superconducting regions being carried out due to Josephson tunneling. Thus the whole sample becomes a multiple Josephson system. Nonlinear I-V curves, depended on temperature and magnetic field, that are typical to a Josephson system, are observed on Ba$_{0.6}$K$_{0.4}$BiO$_3$ single crystal at temperatures below $T^*$. Besides a step like peculiarities at the values of voltage of the order of one and two superconducting gaps show up. These peculiarities are suppressed by magnetic field much earlier then critical current. Perhaps the last phenomenon is the consequence of “coherent” state of several successive Josephson junctions, appeared in exfoliation state.


12P-B082 Anomalous Normal State Properties of the Pressure-Induced Superconductor EuFe$_2$As$_2$

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Since the discovery of superconductivity in LaFeAs(O,F),$^1$ iron-pnictide superconductors have attracted much attention. Among the various iron-pnictide compounds, EuFe$_2$As$_2$ exhibits unique pressure-induced superconductivity due to the Eu$^{2+}$ magnetic moments.$^2$ Thus far, we have carried out comprehensive high-pressure studies on EuFe$_2$As$_2$, in order to elucidate the interplay between the superconductivity and two types of antiferromagnetism. In the conference, we will present recent results of the transport and quantum oscillation measurements of EuFe$_2$As$_2$ focusing on the anomalous normal state properties.

12P-B083  Zeeman Limited Superconductivity and Incoherent Cooper Pairing
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I will present low temperature tunneling density of states measurements on thin superconducting Al films that are in high parallel magnetic fields. The films undergo a first-order transition to the normal state at a parallel field that is near the predicted Clogston-Chandrasekhar critical field. I will present evidence for the existence of a disorderd FFLO phase that emerges as one approaches the critical field from below transition. Although this phase has no long-range order, it produces local order parameter oscillations that are manifest as an anomalous large subgap density of states 1. On the normal-state side of the transition a resonance feature appears in the tunneling spectra that is associated with incoherent Cooper pairing 2. I will show how this resonance can be used to determine the microscopic parameters of the superconductor, including the gap, spin-orbit scattering rate, and the antisymmetric Fermi-liquid parameter. In addition, we have exploited the resonance to probe the exchange field in Al-FM bilayers and to determine the high-field spin polarization in magnetic films 3.


12P-B084  Doping Evolution of Mass Renormalization Effects in Bi2201 Superconductors Revealed by VUV Laser-Based ARPES
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We have carried out VUV laser-based angle-resolved photoemission (ARPES) on Bi2(2−x)CuO3+y (abbreviated as La-Bi2201) and (Pb2Bi2−y)2Sr2CuO4 (abbreviated as Pb-Bi2201) samples with different dopings. We find that the mass renormalization effect along the (0,0) − (π, π) nodal direction is strongly dependent on the hole doping level. Possible implications of the observation will be discussed.

12P-B085  Upper Critical Field, Second Magnetization Peak and Irreversibility Line in BaFe2(As1−xP2x)2 Single Crystals
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The upper critical field $H_{c2}$ of optimal ($x = 0.31$, $T_c \sim 29$ K) and slightly overdoped ($x = 0.38$, $T_c \sim 26$ K) BaFe2(As1−xP2x)2 single crystals were extracted from the temperature dependences of in-plane resistivity $\rho_{ab}$ and magnetization with varying magnetic fields under both $H \parallel c$ and $H \perp c$ configurations. A nearly linear temperature dependence of $H_{c2}$ is observed, and the anisotropic ratio defined as $\gamma = H_{c2}^{||}/H_{c2}^{\perp}$ turns out to be $\sim 2.3$. In the case of $H \parallel c$, the second magnetization peak $H_{sp}$ is observed in the magnetic hysteresis loops (MHLs). The irreversibility line $H_{irr}(T)$ was determined by measuring temperature dependence of magnetization at different magnetic fields and MHLs at different temperatures. The vortex phase diagram of BaFe2(As1−xP2x)2 single crystals was subsequently established. The $H_{c2}$, $H_{sp}$ and $H_{irr}(T)$ of BaFe2(As1−xP2x)2 single crystals were analysed by comparing with those observed in optically doped Ba1−xKxFe2As2 and BaFe2−xCo2As2 single crystals. The origin of the second magnetization peak and mechanism of vortex pinning in BaFe2(As1−xP2x)2 single crystals are further discussed.

12P-B086  Overdoped YBaCuO thin films in THz frequency range
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Y1−xCa2/BaCu2O7−δ thin films were investigated using frequency domain THz spectroscopy by a submillimeter spectrometer in the Mach-Zehnder arrangement. For this purpose, 5% and 10% Ca concentration and films thickness of 500 − 600 Å were used. The films were deposited by off-axis DC sputtering on LaAlO3 substrates. The films reveal a clear c-axis orientation, $T_c = 85$ K and 77 K for 5% Ca and 10% Ca respectively. Both thin film batches show a decrease of plasma frequency as temperature increases and superconducting transition is approached. The quasiparticles scattering rate decreases in the normal state and undergo an abrupt decrease as $T_c$ is approached. The imaginary part of the conductivity was obtained to be proportional to $\omega^{-1}$. The real part of conductivity showed a well known frequency and temperature dependence, where it increases below $T_c$ and obtains a maxima at about 50 K. However, a sharp decrease of the real part of the conductivity was observed at about 10 cm−1. This decrease happens below $T_c$ and gets dominant as temperature decreases. Moreover, this sharp decrease in $\sigma(\omega)$ at 10 cm−1 was not observed in optimally doped YBCO samples. At these frequencies the gap values are much smaller than those obtained by Microwave and Tunneling measurements, arguing for a change in the superconducting order parameter in the overdoped regime. The difference between these mentioned observations will be discussed.

12P-B088  Detection of Novel Electronic Order Above the Structural Transition in Underdoped Ba(Fe1−xCox)2As2 and Fe1−yTe with Point Contact Spectroscopy
12P-B090 Correlations between critical current density profiles and microstructures in various superconducting coated conductors

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The magnetic flux profiles near surfaces of various superconducting coated conductors (CC) under applied magnetic fields were measured using scanning Hall probe (SHP) method and magneto-optical image (MOI) method. These CC samples are classified by two categories: granular structure and pinning structure. The CC samples fabricated by using IBAD texturing and RABiTS texturing have the granular sizes of several tens of nano-meters and several tens of micro-meters, respectively. The CC samples fabricated with and without additional ZrBaO3 have rod-type pinning centers (RPC) and no RPC, respectively. The magnetic flux profiles in these samples showed considerably different features. The current profiles, which were numerically calculated from the magnetic flux profiles using inversion method, also show clear differences correspondingly. The magnetic field dependences of critical current densities of these CC samples were measured by using I-V measurements while the magnetic fields were applied in various orientations with respect to the sample surfaces. The correlations between the anisotropic field dependence of critical currents and the magnetic flux profiles measured using SHP and MOI were observed. We found that the main factors to determine the features of flux profile are the field intensity dependence and the field angle dependence of the critical current densities. We found that these properties are due to the fact that the distributions of vortex densities, vortex orientations, and vortex structures in these superconducting films basically depend on microstructure of these various CC samples.

12P-B089 Testing odd-frequency Cooper pairing by microwave surface impedance

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In superconducting hybrid structures, where translational symmetry or spin-rotation symmetry is broken, superconducting order parameter acquires a component which is odd function of energy. Such odd-frequency pairing state may exist in Ferromagnet/Superconductor (FS) hybrids and in proximity structures involving diffusive normal metal attached to an odd-parity spin-triplet superconductor. Although it is currently assumed that long-range supercurrents observed in recent experiments in SFS junctions are carried by odd-frequency triplet Cooper pairs, there is no direct experimental evidence of odd-frequency pairing so far. In this work we suggest the robust test of odd-frequency pairing. Using the quasiclassical Keldysh-Usadel formalism, we study microwave surface impedance of a hybrid structure composed from a normal metal film covering a superconductor. In the case when a superconductor has p-wave order parameter symmetry, we predict anomalous features of the impedance which originate from negative superfluid density induced into a normal film. Sign change of the response function is specific to the odd-frequency pairing state. On the basis of obtained results, we propose the method to analyze the spin-symmetry of Cooper pairs in a superconductor and to detect odd-frequency superconductivity.

12P-B091 Pressure Effects on the Crystal Structure and Electronic Properties of the 1111 Iron Superconductors

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The study of the pressure effects on the crystal and electronic structure is a powerful tool that helps to find clues to analyze the superconducting state. The new iron based superconductors is an excellent example, where there are still plenty of opened questions to be answered. In this presentation, we will discuss the effect of structural parameters under pressure on the superconducting properties on compounds belonging to 1111 Fe based family. In particular, we have
observed a strong correlation of the crystal structure parameters on the TC in (La,Sm)FeAsO1-xFx, LiFeAs compounds. We have analyzed in detail the pressure dependence of the inter(intra)layer distance, the angle Fe-As-Fe and its effect on the TC. These results are of great importance for band structure calculations based on realistic atomic positions that permit to obtain a detailed microscopic interpretation of the subtle effects on the electronic properties, explaining the effects on the superconducting transition. We also studied the pressure evolution of the structural and spin density wave transition in the SmFeAsO compound and we will correlate it with the superconducting properties.

12P-B092 Electron Transport and Anisotropy of the Upper Critical Magnetic Field in Ba$_{0.68}$K$_{0.32}$Fe$_2$As$_2$ and Ba(Fe$_{0.92}$Co$_{0.08}$)$_2$As$_2$ Single Crystals

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We report measurements of the temperature dependence of the electrical resistivity, $\rho(T, H)$. Hall resistivity, $R_{xy}(T)$, magnetic penetration depth, $\lambda(T, H)$ in hole-doped Ba$_{0.68}$K$_{0.32}$Fe$_2$As$_2$ and electron-doped Ba(Fe$_{0.92}$Co$_{0.08}$)$_2$As$_2$ single crystals in zero, static, and pulsed magnetic fields up to 60 T, and $\rho(T, P)$ and thermopower $S(T, P)$ under hydrostatic pressures up to 15 kbar as well. We find that $\rho(T)$ and $S(T)$ of Ba$_{0.68}$K$_{0.32}$Fe$_2$As$_2$ are well described by an exponential term due to inter-sheet umklapp electron-phonon scattering between light electrons to heavy hole sheets. Taking into account Pauli spin paramagnetism we can describe $H_{c2}(T)$. In contrast, we find that Pauli paramagnetic pair breaking is not essential for Ba(Fe$_{0.93}$Co$_{0.07}$)$_2$As$_2$, where the data support a $H_{c2}(T)$ dependence that can be described by the Werthamer–Helfand–Hohenberg model for $H \parallel ab$ and a two-gap behavior for $H \parallel c$.

12P-B093 Fluctuation Current in Superconducting Loops

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A superconducting loop that encloses noninteger flux holds a permanent current. On the average, this current is also present above $T_c$, and has been measured in recent years. We are able to evaluate the permanent current within the TDGL or the Kramer–Watts-Tobin models for loops of general configuration, i.e., we don’t require uniform cross section, material or temperature. Our results agree with experiments. The situations with which we deal at present include fluctuation superconductivity in two-band superconductors, metastable fluxoid states generated by quenching through $T_c$, and ratchet effects.

1 Science 318, 1440 (2007)

12P-B094 Superfluid Density Study of Two-dimensional NbN Films near Superconductor Insulator Transition

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The superfluid densities of two-dimensional (2D) amorphous NbN films with sheet resistances up to 2 kΩ have been measured, with the goal of obtaining new insights into quantum and thermal fluctuations near the quantum critical point. Evidence for strong thermal phase fluctuations is found in a Kosterlitz-Thouless-Berezinskii-like downturn in superfluid density near $T_c$, although the downturn occurs at a lower temperature than anticipated by KTB theory for the highest sheet resistance films. Evidence for strong quantum fluctuations is found in a suppression of zero-temperature superfluid density below the BCS value, and a large difference between the $T_c$ determined resistively and the $T_c$ where superfluid appears.

12P-B095 Peculiar metallic properties of LaSb: a combined study of optical spectroscopy and band structure calculations


We present an optical spectroscopy study and first-principle band structure calculations on single crystal sample of LaSb. Density function calculations indicate that the compound is a semimetal with very low carrier density. Consistent with the band structural calculations, the optical reflectance measurement revealed a sharp plasma edge at low frequency, near 2800 cm$^{-1}$ at room temperature. Surprisingly, this plasma edge displays a substantial shift towards higher frequency with decreasing temperature. This phenomenon is rarely seen in metals. We attribute the anomalous behavior to a reduction of the effective mass, which is likely caused cooperatively by an upward shift of the chemical potential and non-parabolic band dispersions.

12P-B096 Optical Spectroscopy Study on SrPt2As2 Single Crystal


The recent discovery of high-temperature superconductivity in iron-pnictide compounds has attracted a considerable interest in the condensed matter community. Many efforts have been made for the exploration of new superconductors in intermetallic compounds. Superconductivity at 5.2K in SrPt2As2 crystallizing in the CaBe2Ge2-type structure was reported recently [1].
There is an indication that SrPt2As2 experiences a charge-density-wave transition well above room temperature (but below 470 K) [2]. It would be very interesting to probe the physical properties in SrPt2As2 single crystals. We have succeeded in synthesizing single crystals of SrPt2As2 by self-melting technique. Magnetization and electrical resistivity measurements confirmed Tc at 5 K. The optical spectroscopy study revealed a very high plasma frequency, which is completely different from other iron-based pnictide compounds. We will discuss the electronic properties of SrPt2As2 single crystals in detail.


12P-B097 Demonstration of Microwave Resonant Activation in large MgB2-based thin film Josephson Junctions

Roberto Ramos, Joseph Lambert, Jerome Mlack, Steven Carabello

The current-biased Josephson junction has been used as a testbed for studying resonant activation, or the escape of a Brownian motion particle from a potential well. As bias current is increased, the voltage across the junction switches from zero to a finite voltage. This is analogous to the escape of a phase particle originally oscillating with a plasma frequency ω in a washboard potential well, to the running state. Resonant activation has been observed in Al, Nb and high-Tc junctions. We report the first resonant activation data results using large MgB2/I/Pb thin film junctions, where we demonstrate good control over the escape of the phase particle using microwave frequency and power. Our results exhibit features in the escape rate suggestive of substructure within the π gap of MgB2, which is consistent with our recent work demonstrating substructure within the π and σ energy gaps of MgB2.


12P-B098 Sign reversal of the Hall resistance in the mixed-state of electron doped superconducting thin films (LT26)


We have studied the transport properties of La1.89Sr0.11CuO4 (LCCO) and La1.89Sr0.11(Cu0.99Co0.01) (LCCO-Co) superconducting thin films. When the external field H is applied perpendicular to the thin films, an abnormal double sign reversal of the Hall voltage in the mixed state of LCCO:Co thin films is observed whereas a single sign reversal is detected in LCCO. If the magnetic field is tilted away from the plane of the film, the double sign reversal of the Hall resistance in LCCO can also be observed. We find that the transition from one to two of the Hall sign reversal can be attributed to the change in the pinning strength from strong to weak. We explain the temperature or field dependent Hall sign reversal by either the magnetic impurities in LCCO:Co or the coupling between the pancake vortices and the in-plane Josephson vortices in LCCO.

12P-B099 Distinct electronic nematicities between electron and hole underdoped iron pnictides

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We systematically investigated the in-plane resistivity anisotropy of electron-underdoped EuFe2−xCoxAs2 and BaFe2−xCoxAs2, and hole-underdoped Ba1−xKxFe2As2. Large in-plane resistivity anisotropy was found in the former samples, while tiny in-plane resistivity anisotropy was detected in the latter ones. When it is detected, the anisotropy starts above the structural transition temperature and increases smoothly through it. As the temperature is lowered further, the anisotropy takes a dramatic enhancement through the magnetic transition temperature. We found that the anisotropy is universally tied to the presence of non-Fermi liquid T-linear behavior of resistivity. Our results demonstrate that the nematic state is caused by electronic degrees of freedom, and the microscopic orbital involvement in magnetically ordered state must be fundamentally different between the hole and electron doped materials.

12P-B100 Reentrant effect in a mesoscopic cylindrical structure of a superconductor coated with a normal metal layer

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The coherent phenomena in mesoscopic cylindrical normal metal (N-) superconductor(S) structures have been investigated theoretically. The magnetic moment (persistent current) of such a structure has been calculated numerically and (approximately) analytically. It is shown that the current in the N layer corresponding to the free-energy minimum is always diamagnetic. As the field increases, the magnetic moment (current) exhibits jumps at certain value of the trapped magnetic flux and the NS structure changes to a state with smaller absolute value of the diamagnetic moment. This occurs when the persistent current is unable to screen the ex-
ternal field. The magnetic moment increase stepwise and the system changes into a new stable state. The magnetic field penetrates into a larger volume of the N layer. The state has smaller absolute value of the diamagnetic moment. Experimentally, this is interpreted as the presence of a paramagnetic addition in the system (paramagnetic reentrant effect). The results obtained are in qualitative agreement with the experiments conducted by P. Visani, A.C. Mota and A. Pollini.

12P-B101 Entropy driven formation of a half-quantum vortex lattice
Suk Bum Chung*, Steven A. Kivelson*

Half-quantum vortices (HQVs) can exist in a superconductor or superfluid with an exact or approximate U(1) × U(1) symmetry, for instance in spinor condensates, 3He-A, Sr$_2$RuO$_4$, and possibly cuprate superconductors with stripe order. In this paper, we show that a lattice of HQVs can be stabilized at finite temperature even when it does not have lower energy than the lattice of full vortices at $T = 0$ since there is a gain in configurational entropy when a full vortex fractionalizes into a pair of HQVs. Specifically, the lattice of HQVs has an optical branch of phonon modes absent in the lattice of full vortices. Moreover, the HQV lattice at $T > 0$ can have a different structure than the HQV lattice at $T = 0$.

12P-B102 Electric Field Induced Interface Superconductivity
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Electric double layer (EDL), a nano-gapped capacitor self-organized at the solid-liquid interfaces, is an electrochemical concept proposed by Helmholtz 150 years ago. Because of its large capacitance and high density charge accumulation, EDL has been used in market as capacitor devices, called Supercapacitor or EDLC. We used EDL as a gate dielectric of a transistor device, which is named as EDL transistor (EDLT), and have demonstrated that EDLT can be a powerful tool for controlling interface quantum phases. An amazing example is the realization of electric field induced superconductivity in several insulators without any help of chemical doping, which has been anticipated for the last 50 years without success. In this paper, we describe a basic concept of EDLT and variety of electric field induced phenomena including superconductivity. This work has been carried out in collaboration with H. T. Yuan, J. T. Ye, Y. Kasahara, M. Kawasaki, K. Ueno, T. Fukumura (University of Tokyo), H. Shimotoani, T. Nojima, S. Nakamura (Tohoku University), and T. Hatano, M Nakano, S. Ono (RIKEN).

12P-B103 Superconductivity in Rh-doped CaFeAsF
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Superconductivity is induced during the doping of 4d transition metal element Rhodium into the parent compound of polycrystalline CaFeAsF with the highest achieved onset $T_c$ at about 25 K. We systematically studied the evolution of the resistivity with $x$ ranging from 0 to 0.15 in CaFe$_1$-xRhxAsF. The phase diagram is constructed based on the resistivity measurement and a region where antiferromagnetic and superconducting transitions coexist is observed. Annealing effect on the transition width is also studied while no obvious enhancement is found.

12P-B104 Superconducting Transitions and Crystal Structure for FeSe$_{1-x}$S$_x$ ($x=0.1$, 0.2, and 0.3) under Pressure.
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Fe-based superconductor FeSe has the simplest structure in all categories of Fe-based superconductors and has a record of maximum $T_c$ in ‘11’-type structure since the $T_c$ has been raised from 8 K to 37 K under pressure around 6 GPa. This shows the change of $T_c$ is very sensitive to pressure. Then, we studied the external pressure effect of nearly optimal S doping of FeSe, FeSe$_{1-x}$S$_x$ ($x=0.1$~0.3), where the substitution of Se by smaller S into FeSe introduces chemical pressure and gives the maximum $T_c = 11$ K at $x=0.2$. These $T_c$ are checked by the resistivity measurements under pressure up to 8 GPa using both the piston cylinder and cubic anvil cell. As a result of these pressure experiments of FeSe$_{1-x}$S$_x$, the phase diagrams are determined. In the phase diagrams of $x=0.2$ and 0.3, it is observed that $T_c$ slightly decreases with application of pressure up to 0.6 GPa. But the $T_c$ jumps up above 0.6 GPa and reaches to $T_c(x=0.2)=36.3$ K under 6 GPa. The behavior of $T_c$ in the region of $P \leq 0.6$ GPa are unconventional. We will discuss the unconventional behavior from the crystal structure given by X-ray under pressure.

12P-B105 Odd Magnetoresistive Response in Nanostructured Nb Thin Films
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The longitudinal and transverse magnetoresistive responses with regard to the current direction have been experimentally studied for non-patterned and nanostructured epitaxial Nb thin films under magnetic field reversal. Periodic stripe patterns have been fabricated on the films’ surface by (i) focused ion beam (FIB) milling which induce an anisotropic washboard pinning potential (WPP) by order parameter suppression and by (ii) focused electron beam-induced deposition (FEBID) of Co, such that a WPP is provided that influences the vortex movement. Two main effects appear

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due to the nanofabricated pinning potential landscape's anisotropy: guiding of vortices along the WPP 'channels' and anisotropy of the Hall resistivity. The former leads to the appearance of the even transverse resistivity under field reversal and influences the Hall angle, while the latter causes additional odd contributions to the longitudinal and transverse resistivities. The non-patterned films were used to distinguish the 'usual' Hall effect and these new odd resistivities arising owing to the nanostructuring. The results are analyzed on the basis of a model of competing isotropic and anisotropic pinning where the anisotropic pinning force is caused by a WPP.  


12P-B106 Nonadiabatic Ratchet Effect in Superconducting Films With a Tilted Cosine Pinning Potential

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Influence of an alternative current of arbitrary amplitude and frequency on the mixed-state dc-voltage-ac-drive ratchet-response of a superconducting film with a dc-tilted uniaxial cosine pinning potential at finite temperature is theoretically investigated. The results are obtained within the frames of exact solution of the corresponding Langevin equation in terms of a matrix continued fraction. Formulas for dc ratchet response and absorbed power as functions of ac amplitude, frequency, and dc tilting current are analyzed in a wide range of corresponding dimensionless parameters. Special attention is paid for physical interpretation of obtained results in adiabatic and high-frequency ratchet responses taking into account both running and localized states of the (ac+dc)-driven vortex motion in the washboard pinning potential. Our theoretical results are discussed in comparison with a recent experimental work on high-frequency ratchet response in nanostructured superconducting films.


12P-B107 Microscopic Investigation of Vortex-Vortex Interaction in Conventional Superconductors

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We have examined the vortex-vortex interaction microscopically, using the Bogoliubov-de Gennes (BdG) equation. Previously, we have investigated the vortex structures in nano-sized square superconducting plate, using the BdG equation and the finite element method. And we found that quasi-particle bound states around vortices affect the stable vortex structures in such nano-sized superconductors. And this result means the interaction between vortices is affected by the quasi-particle bound states, although phenomenological theory predicts purely repulsive interaction between vortices because of the repulsive force on the magnetic flux of one of vortices from the current surrounding another vortex. In order to confirm this conclusion, we have developed new numerical method for solving the BdG equation around a pair of vortices using elliptic coordinates and Mathieu functions. We examined how interference of between the quasi-particle bound states around two vortices changes when the distance between two vortices changed. Also we investigate the stable distance of two vortices comparing the free energy of self-consistent solution with fixed vortex-vortex distance.


12P-B108 Probing the interplay among superconductivity, pseudogap, and stripe correlations by Zn substitution in high-Tc cuprates

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The effect of Zn substitution on the superconducting transition temperature, Tc, was investigated for the La2-xSrxCu1-yZnyO4 and YBa2(Cu1-yZny)3O7-delta compounds over a wide range of hole concentration, p, and Zn content (y) in the CuO2 planes. Zn induced rate of suppression of Tc, dTc(p)/dy, was found to be strongly p-dependent and showed a monotonic variation with p, except in the vicinity of p = 0.125, i.e., near the 1/8th anomaly where the charge/spin stripe correlations are at its strongest. dTc(p)/dy decreased significantly around this hole concentration i.e., Zn suddenly became less effective in degrading Tc near the 1/8th anomaly. We have discussed the possible scenarios that can give rise to such a non-monotonic dTc(p)/dy near p 0.125. On the other hand, the p-dependent characteristic pseudogap energy scale, Eg(p), shows a nearly linear decrease with increasing p with no noticeable extra feature at p = 0.125. Also, there is no significant effect of the level of Zn substitution on Eg(p). All these findings are indicative of a complex and competing interplay among the superconducting, pseudogap, and stripe correlations in the hole doped cuprates.

12P-B109 Cu-NMR Study of Bi2Sr2−xLaxCuO6+δ Superconductor in Very High Magnetic Fields

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We report the results of 63,65Cu-NMR measurements on single-layered copper-oxide Bi2Sr2−xLaxCuO6+δ (0.0 ≤ x ≤ 0.9) conducted under very high magnetic fields.
up to 45 T. The high magnetic field suppresses superconductivity completely, and the pseudogap ground state is revealed. The $^{63}$Cu-NMR Knight shift shows that there remains a finite density of states at the Fermi level in the zero-temperature limit, which indicates that the pseudogap ground state is a metallic state with a finite volume of Fermi surface. The residual density of states in the pseudogap ground state decreases with decreasing doping (increasing $x$) but remains quite large even at the vicinity of the magnetically ordered phase of $x \geq 0.8$, which suggests that the density of states plunges to zero upon approaching the Mott insulating phase.


12P-B110 Pseudogap in strongly disordered conventional superconductors

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Excited states of Bogliubov-de Gennes equations are examined for two dimensional negative-U Hubbard Hamiltonian with on-site disorder. It is shown explicitly that the temperature (pseudogap temperature) when the superconducting gap opens is different from that (the superconducting transition temperature) the long range order appears. In the excited state solutions the system is self-organized into blocks, which behave like superspins and are coupled with their neighbors. Only if the couplings between these blocks become strong enough, the true long range order can be realized. 1


12P-B111 Occurrence of Fermi Pockets without the Pseudogap Hypothesis and Clarification of ARPES Spectra in Underdoped Cuprates

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Central issues in the electronic structure of underdoped cuprates is to clarify the shape of Fermi surfaces and the origin of pseudogap. In this talk, based on the model proposed by Kaminura and Suwa which bears characteristics born from the interplay of Mott physics and Jahn-Teller physics [1,2], we show that the feature of Fermi surfaces is the Fermi pockets constructed by doped holes under the coexistence of a metallic state and the local AF order. This feature is consistent with recent ARPES experiments by Meng et al [3]. Calculated ARPES spectra below $T_c$ consist of a coherent peak due to the $d$-wave superconducting density of states at the nodal region and the real transitions of photo-excited electrons from the occupied states below the Fermi level to a free electron state in the antinodal region. Hole-concentration- and temperature-dependences of the latter transition energies are in a good agreement with experimental results [4,5]. Finally the origin of $T^*$ is discussed.


12P-B112 STM imaging of broken symmetry states in cuprate superconductors

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We use scanning tunneling microscopy to image the interactions between two broken symmetries, inversion symmetry and rotational symmetry, within the CuO$_2$ unit cell of the cuprate superconductor (Bi$_{1-y}$Pb$_y$)$_2$Sr$_2$CuO$_{6+x}$. In Bi-based cuprates, a bulk structural buckling known as the “supermodulation”, breaks these symmetries. We use Pb doping to suppress the supermodulation and therefore address the native electronic symmetry breaking states. We find a dominant inversion symmetry breaking, which leads to the appearance of a nematic order. We define a new nematic order parameter which disentangles the two effects of inversion symmetry breaking and rotational symmetry breaking.

12P-B113 The Meissner effect in a strongly underdoped cuprate well above its critical temperature

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The Meissner effect and the associated perfect bulk diamagnetism are, besides zero resistance and gap opening, characteristic features of the superconducting state. In the pseudogap phase of cuprates unusual diamagnetic signals as well as anomalous proximity effects have been detected but a Meissner effect has never been observed. Here, we have probed by low energy $\mu$SR the local diamagnetic response in the normal state of an underdoped (UD) La$_{1.94}$Sr$_{0.06}$CuO$_4$ layer (up to 46 nm thick, critical temperature $T_c \leq 5$ K) brought in close contact with two nearly optimally doped (OP) La$_{1.4}$Sr$_{0.6}$CuO$_4$ layers ($T_c \approx 32$ K). We show that the entire barrier layer of thickness much larger than typical c-axis coherence lengths of cuprates exhibits Meissner effect for temperatures well above $T'_c$ but below $T_c$. We determine the temperature dependence of the effective penetration depth and superfluid density in the different layers. The results indicate that superfluidity with long-range phase coherence is induced in the underdoped layer by the proximity of optimally doped
layers; however, this order is very sensitive to thermal excitation.\(^1\)


12P-B114 Manifestation of superconducting correlations above the critical temperature

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Phase transition to the superconducting/superfluid state occurs when the gauge symmetry of a system spontaneously breaks down due to appearance of the complex order parameter \(\psi = \chi e^{i\phi}\). Its amplitude \(\chi\) corresponds to the density of Bose-Einstein condensed fermion pairs (manifested indirectly by energy gap at the Fermi level) whereas rigidity of the phase \(\phi\) controls coherent behavior of the pairs (for instance \(\nabla \phi \neq 0\) generates the supercurrents). In the case of charged particles, such as e.g. conduction band electrons, \(\phi\) couples to the vector potential of electromagnetic field and through the Higgs mechanism triggers the ideal diamagnetism (Meissner effect). We shall discuss how similar phenomena might be observable upon approaching the true phase transition \(T_c\) form above. For this purpose we explore the short-range superconducting correlations between the preformed pairs (of whatever origin). Using nonperturbative method, originating from the numerical renormalization group procedure, we find evidence for the remnants of superconducting features such as the Bogoliubov-type quasiparticles, enhancement of the pairing susceptibility, residual diamagnetism as well as signatures of the collective Goldstone mode above \(T_c\). We shall confront our study with the recent experimental data obtained for cuprate superconductors and ultracold fermion superfluids.

12P-B115 Dynamically induced Fermi arcs and pockets: A model for the pseudogap in underdoped cuprates

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We investigate the effects of the dynamic bosonic fluctuations on the Fermi surface reconstruction in two dimensions as a model for the pseudogap in underdoped cuprates. At energies larger than the boson energy \(\omega_b\), the dynamic nature of the fluctuations is not important and the quasi-particle dispersion exhibits the shadow feature like that induced by a static long range order. At lower energies, however, the shadow feature is pushed away by the finite \(\omega_b\). The detailed low energy features are determined by the bare dispersion and the coupling of quasi-particles to the dynamic fluctuations. We present how these factors reconstruct the Fermi surface to produce the Fermi arcs or the Fermi pockets, or their coexistence. Our principal result is that the dynamic nature of the fluctuations, without invoking a yet-to-be-established long range order, can produce the Fermi pocket centered away from the \((\pi/2, \pi/2)\) towards the zone center which may coexist with the Fermi arcs. This is discussed in comparison with the experimental observations.

12P-B116 A Model and Calculation of Evolving Tunneling Spectra for the Superconducting Gap and Pseudogap in \(\text{Bi}_2\text{Sr}_2\text{CaCu}_2\text{O}_{8+\delta}\)

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By the short-pulse interlayer tunneling spectroscopy using intrinsic Josephson junctions in \(\text{Bi}_2\text{Sr}_2\text{CaCu}_2\text{O}_{8+\delta}\) (Bi2212), we have found that, with the increase in doping, the superconducting coherence peak becomes greater and sharper and the pseudogap peak diminishes. It is also found that these changes are accompanied by a significant almost exponential increase in the maximum Josephson current density. In order to explain the experimental results, we propose a model, in which mobile carriers reside only in limited areas in the k-space, like a situation as represented by so-called Fermi arcs, and are closely related to the d-wave superconducting order parameter in these directions in the k-space. The range of the area in which mobile carriers reside depends on the doping level and outside these areas the density of states is absent and a semiconducting gap is assumed for the carriers to be mobile. Based on this model, the tunneling spectra between a normal metal and Bi2212 are calculated at various doping levels. With appropriate values for the semiconducting gap as a function of doping, we obtain the result that the superconducting peak increases from a cusp at the shoulder of the pseudogap to a dominantly strong peak as the doping increases. The results are in qualitatively good agreement with the experimental tunneling spectra observed.

12P-B117 Superconducting Fluctuation and Electric Transport Properties Revealed from the Phase Diagram of Ca-doped Cuprates

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In this study, we analyzed the temperature-dependent transport properties of Ca-doped YBCO films with various oxygen contents from overdoped region to underdoped region. The second derivative of the temperature-dependent resistivity reveals a rich phase diagram, including the superconducting fluctuation region and pseudogap phase. These experimental results are consistent with the estimation of the fluctuation theory based on a model of the Ginzburg-Landau type. Amplitude fluctuations of Cooper pairs in the vicinity of the transition temperature provide a clear framework in which to understand dynamic properties such
12P-B118 Unifying Fermi arcs and protected nodes in cuprate superconductors
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We show how, within a preformed pair scenario for the cuprate pseudogap, the nodal and antinodal responses in angle-resolved photoemission spectroscopy (ARPES) necessarily have very different temperature \( T \) dependences, which lead to Fermi arcs above \( T_D \) which collapses into nodal points upon phase coherence below \( T_c \). We examine the behavior and the contrasting \( T \) dependences for a range of temperatures both below and above \( T_c \). Our calculations are based on a fully microscopic \( T \)-matrix approach for addressing pairing correlations in a regime where the attraction is stronger than BCS and the coherence length is anomalously short. Instead of the “two-gap” scenario of the cuprates in which the pseudogap competes with superconductivity, our theory supports a unified picture in which the pseudogap derives from pairing correlations, identifying the two gap components with non-condensed and condensed pairs. It leads to reasonably good agreement with a range of different experiments without explicit curve fitting.


12P-B119 Pseudogap state of (Bi,Pb)\textsubscript{2201} studied by muon Knight shift
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Despite decades of focused research using almost every experimental technique available to date, the microscopic origin of pseudogap in cuprates is still elusive. One of the problems in gaining a coherent understanding of the pseudogap is that the reported results disagree with each other, where the arbitrary definition of the gap energy or characteristic temperature \( T^* \) entails further confusion. The muon Knight shift \( \left( K_\mu \right) \) is a direct measure of the electronic density of states (DOS) probed at the interstitial site, comprising information complementary to NMR. In this contribution, we report \( K_\mu \) measurements performed in single crystals of Bi\textsubscript{1.7}Pb\textsubscript{0.3},Sr\textsubscript{1.8}CuO\textsubscript{6+1/2} [(Bi,Pb)2201] over a wide range of carrier doping covering both ends of the superconducting phase (the dome of \( T_c \)), where doping was controlled by excess oxygen to minimize the perturbation to CuO\textsubscript{2} planes. The magnitude of pseudogap, defined as an activation energy of the Arrhenius type, was deduced from the temperature \( T \) dependence of \( K_\mu \) for each sample. The remarkable results are that, 1) the pseudogap is clearly inferred from reduction of \( K_\mu \) (\( \propto \) DOS) at low temperatures in the non-superconducting sample situated in the overdoped region, 2) a residual \( K_\mu \) is observed at low temperatures with the magnitude depending on the doping concentration.


12P-B120 Intrinsic Tunneling Spectroscopy for Pb-Substituted BSCCO
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It is known that the c-axis critical current density \( J_c \) of BSCCO is significantly suppressed in the underdoped region. \(^1\) On the other hand, partial substitution of Bi with Pb in BSCCO increases \( J_c \) even at temperature dependence of the c-axis resistivity exhibits intense upturn like underdoped BSCCO. We measured intrinsic tunneling spectroscopy (ITS) in mesa structures \((S = 1 \times 1 \mu m^2)\) of Bi\textsubscript{1.9}Pb\textsubscript{0.1}Sr\textsubscript{2}CaCu\textsubscript{2}O\textsubscript{8+\delta} (PbBi2212) and Hall effect in PbBi2212 cleaved thin crystals. The ITS measurements reveal large superconducting gap of \( 2\Delta \sim 700 \mu \)eV (at 10 K). This result corresponds to a typical value of an underdoped Bi2212. The Hall coefficient at 300 K was obtained as \( R_H \sim 2 \times 10^{-3} \Omega m^2/C^-1 \). The doping level \( p \) of the PbBi2212 is estimated through the comparison with LSCO as 0.13, which is in the underdoped region. It is found that \( J_c \) of PbBi2212 is less deviated from Ambegaokar Baratoff critical current density \( J^{AB} \sim \pi \Delta/2eR_N S \) than the case of underdoped Bi2212. Here \( R_N \) is the normal tunneling resistance obtained from high voltage extrapolation of the current-voltage characteristics. It is interpreted that the Pb substitution makes the tunnel barrier lower, resulting in a reduced anisotropy in k-space and a high superconducting pair density even with a lower doping.


12P-B121 Logarithmic flux-flow resistivity across the cuprate phase diagram
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The microwave response of vortices in high quality YBa\textsubscript{2}Cu\textsubscript{3}O\textsubscript{6+\delta} and Tl\textsubscript{2}Ba\textsubscript{2}CuO\textsubscript{6+\delta} samples has been studied using high resolution microwave spectroscopy in an applied magnetic field. Measurements of the flux flow resistivity and vortex viscosity probe dissipation from electronic states near the vortex cores. These quantities have been accurately measured for \( T < T_c \), and \( B < B_{c2} \), at a number of dopings that span the
12P-B122 Doping Evolution of Normal State Transport Properties in BiPb2201 Cleaved Thin Crystals
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Wide-range doping evolution of a series of BSCCO materials is less known than other typical cuprates like LSCO and YBCO. This is because severe oxygen reduction of BSCCO to reduce doping would cause decomposition of materials. So far, we have investigated systematic doping dependence of transport properties in a Bi2212 cleaved thin crystal. By annealing the cleaved crystal with thickness less than 100 nanometers either in oxygen or in argon atmosphere, Tc varies reversibly from ≈ 90 K (nearly optimum doping) to 0 K (superconductor-insulator transition) \(^1\). In this paper, we report on doping dependence of in-plane transport properties of Bi\(_{1.7}\)Pb\(_{0.3}\)Sr\(_{1.65}\)La\(_{0.35}\)CuO\(_{6+\delta}\) (BiPb2201) cleaved thin crystals annealed under various conditions and Hall resistivity in pulsed high magnetic fields up to 60 Teslas. With decreasing carrier concentration from the optimum doping, Tc decreases more rapidly than the generic phase diagram empirically suggested by Tallon. This is attributed to the increase of carrier scattering of CuO\(_2\) planes due to oxygen reduction through systematic measurements of in-plane Hall effect and resistivity. Hall ratio below Tc obtained by extrapolating the high-field Hall resistivity to H ≈ 0 shows saturation to a finite value at T = 0 in a slightly under-doped sample.


12P-B123 Pressure Dependence of Nernst Effect for La\(_{2-x-y}\)Nd\(_x\)Sr\(_y\)CuO\(_4\)
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Anomalous Nernst effect well above Tc in high-Tc cuprates is now a well-known experimental result, and it has long been discussed as a clue to the mechanism of superconductivity. At present, there considered to be two explanations for it. One is that the large Nernst signal is attributed to the movement of vortices which survives far above Tc \(^1\). The other is that Nernst signal is enhanced by stripe order \(^2\). We have previously measured the Nernst effect of La\(_{2-x}\)Sr\(_x\)CuO\(_4\) with controlling the strength of the stripe order by Nd-doping and found that the stabilization of the stripe order enhances the Nernst signal \(^3\). Here, we measured pressure dependence of the Nernst effect to confirm the above result. Hydrostatic pressure is known to quite effectively control the stripe strength with using the same sample \(^4\). In the static pressure, we found the enhancement of the Nernst signal below superconducting fluctuation temperature T\(_{fl} \sim \approx 60K\). This indicates that the suppression of the stripe strength by applying pressure lead to the enhancement of the superconducting fluctuation. On the other hand, upturn of Nernst signal around 150K could consider to the temperature where fluctuation of the stripe order develops.


12P-B124 Magnetic-field dependence of the c-axis infrared response of underdoped (UD) YBa\(_2\)Cu\(_3\)O\(_{7-\delta}\) (Y-123) interpreted in terms of the multilayer model and implications concerning superconducting fluctuations above Tc
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We report on results of our study of magnetic-field (H \perp CuO\(_2\)) dependence of the c-axis infrared response of UD Y-123, motivated by recent experimental observations [A. D. LaForge et al., Phys. Rev. B 76, 054524 (2007), ibid. 79, 104516 (2009)] of spectacular field-induced changes of the transverse plasma mode (TPM) at ca 400 cm\(^{-1}\). The response has been analyzed using the multilayer model involving the conductivity of the spacing layers and that of the bilayer units. The two conductivities have been expressed as weighted averages of the superconducting state ones and the normal state (NS) ones representing contributions of the vortex cores, the weight of the latter increasing linearly with the field. For the input conductivities obtained by fitting the (H = 0) data of UD Y-123 with Tc = 58 K [Dubroka et al., Phys. Rev. Lett. 106, 047006 (2011)], and the weight of the NS (T \approx Tc) component given by (\mu_0 H/25 T), the calculated field induced changes of the reflectivity around the TPM are in quantitative agreement with the data. This suggests that the response at H = 0 and T \approx Tc is close to that at H \approx 25 T \ll H\(_{c2}\) and T < < Tc, in accord with theories attributing the above Tc state to a superconductor without the long range phase coherence, thus complementing indications based on the Nernst, magnetization, STM, infrared, specific heat and photoemission data.

12P-B125 STM Imaging of Spatial Variations in the Charge-Ordered states of BSCO
Michael M. Yee, E. Main, T. Williams, A.
We use scanning tunneling microscopy to investigate the competition between charge density wave and superconducting states. We image the disorder charge modulation in the cuprate superconductor ($\text{Bi}_2\text{Pb}_y\text{Sr}_2\text{Cu}_8\text{O}_{b+x}$). We correlate the local charge modulation wavevectors with other local properties such as the local pseudogap, and local breaking of 4-fold rotational symmetry.

12P-B126 Two-dimensional Quantum Critical Point in Underdoped $\text{Bi}_2\text{Sr}_2\text{CaCu}_2\text{O}_{b+x}$ Revealed by Superfluid Density Measurements

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With the goal of comparing quantum critical scaling in a highly anisotropic cuprate with the three-dimensional (3D) scaling seen in moderately-anisotropic $\text{YBa}_2\text{Cu}_3\text{O}_7$ (YBCO), a series of both sputtered and pulsed laser deposited $\text{Bi}_2\text{Sr}_2\text{CaCu}_2\text{O}_{b+x}$ (Bi-2212) films have been fabricated with a wide range of hole underdoping, such that $T_c$ extends as low as 5 K. For films near optimal doping, superfluid density is linear at low-$T$, and displays a sharp downturn near $T_c$. However, with underdoping the sharp downturn gradually fades, and superfluid density becomes roughly linear all the way to $T_c$. The disappearance of critical thermal fluctuations may be explained, at least in part, by strong quantum critical fluctuations. The superfluid density at $T=0$ scales linearly with $T_c$, which indicates that superconductivity disappears at a 2D quantum critical point (QCP) in Bi-2212, unlike the 3D QCP seen in YBCO. The difference likely traces back to the much higher $ab$- vs. $c$-axis anisotropy in Bi-2212.

12P-B127 Electronic Symmetry of the Cuprate Pseudogap States from SI-STM

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Direct visualization of the electronic structure within each crystalline unit cell of a solid is a new frontier in condensed matter physics (M. J. Lawler et al., Nature 466, 347 (2010)). We use this approach to study the pseudogap phase of cuprate high temperature superconductors. Recent experiments provide evidence that this phase may be associated with spontaneously broken electronic symmetries. By studying the Bragg peaks in Fourier transforms of Spectroscopic Imaging STM (SI-STM) images, and in particular by resolving both the real and imaginary components of these Bragg amplitudes, we find strong evidence for intra-unit-cell nematicity - the breaking of $C_{4v}$ symmetry of the crystal lattice. We also find that the co-existing smectic modulations couple to the intra-unit-cell nematicity through the 2r topological defects. Finally intra-unit-cell inversion symmetry breaking of the cuprate pseudogap states is discussed.

12P-B128 Intrinsic tunneling study of $\text{Bi}_2\text{Sr}_{1.6}\text{La}_{0.4}\text{CuO}_{6+\delta}$

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We report on a tunneling study of submicron $\text{Bi}_2\text{Sr}_{1.6}\text{La}_{0.4}\text{CuO}_{6+\delta}$ intrinsic Josephson junctions, whose self-heating was sufficiently suppressed. The tunneling spectra were measured from 4.2 K up to the pseudogap opening temperature of 260 K. The gap value found from the spectral peak position was about 35 meV and had a weak temperature dependence both below and above the superconducting transition temperature of 29 K. Since the superconducting gap should have a value of 10-15 meV, our results indicate that the pseudogap plays an important role in the $\text{Bi}_2\text{Sr}_{1.6}\text{La}_{0.4}\text{CuO}_{6+\delta}$ intrinsic tunneling spectroscopy down to the lowest temperature of 4.2 K.

12P-B129 Theoretical investigation of superconductivity and antiferromagnetism in trilayer cuprate superconductors

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Recent ARPES experiment on the optimally doped trilayer cuprate superconductors Bi2223 has revealed a layer variation of both doping density and d-wave gap. In particular, the two outer layers are overdoped with a gap which is larger than the gap for optimally doped single layer cuprates while the inner layer is underdoped with an even larger gap. Here we propose a minimal model composed of three layer t-J model, single particle interlayer tunneling as well as Cooper pair tunneling terms. By using renormalized mean field method, both the superconducting and antiferromagnetic properties are theoretically investigated. Both tunneling effects may influence the phase configurations of both d-wave superconducting and antiferromagnetic order parameters on each layer which plays a crucial role in determining the electronic structures of trilayer cuprate superconductors. The inphase state for both superconducting and antiferromagnetic phases is found to be relevant to the Bi2223 trilayer system. In such a state,
the superconducting order parameter of inner plane will be further enhanced due to the constructive proximity effect from the two outer planes and the hole density of inner plane will be much suppressed. This work is in collaboration with Chun Chen and A. Fujimori.

Session 12P-C:

C2 Novel Magnetic Phases

Friday August 12, 16:00 – 18:00

Exhibition Hall 1

12P-C001 Two-dimensional Criticality in a Three-dimensional Spin Ising Model

Abbas Saberi

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The discovery of unconventional superconductivity in Sr$_2$RuO$_4$ evokes considerable interest about the electronic properties of ruthenates. One of the related compounds, Ca$_{2-x}$Sr$_x$RuO$_4$, has rich ground states and the origin of these ground states has not been clarified yet. Most surprisingly, a heavy-mass Fermi liquid behavior is observed at $x=0.5$. In this presentation, we investigate electronic states in Ca$_{2-x}$Sr$_x$RuO$_4$ by using the Gutzwiller approximation of the three-orbital Hubbard model. We obtain the renormalization factor for each $t_2g$-orbital as a function of the on-site Coulomb interactions and discuss the relation with the experimental result.

12P-C002 Theoretical Study of Electronic States in Ca$_{2-x}$Sr$_x$RuO$_4$


We have investigated magnetization process of $\alpha$-Dy$_2$S$_3$ single crystal after cooling in the high magnetic field of 18 T. According to the previous report, which treats the anisotropic magnetization process after Z.F.C. (zero field cooling), the magnetization along the $a$-axis of orthorhombic system is smallest of those along three crystallographic axes at the conditions of $T = 1.5$ K and $\mu_0 H = 18$ T. The value for one Dy atom is small as 6 $\mu_B$ which corresponds to 60 % of full saturation moment.

In the present study, the magnetization under the field of 18 T along the $a$-axis on the cooling process from 150 K shows step-like rises at 70 and 40 K and reaches about 9 $\mu_B$ at 1.5 K. After cooling, the magnetization isotherm of 1.5 K shows step-like drops at 3.0 and 1.7 T while decreasing field, and comes to 0 $\mu_B$ at 0 T. Then, while increasing field, the magnetization demonstrates a similar curve to that obtained after ZFC without step-like rise below 13.1 T. At $\mu_0 H = 13.1$ T, the magnetization rises abruptly and agrees with the curve for the decreasing process. This irreversible magnetization process yields extremely broad hysteresis having width of $\mu_0 \Delta H = 11.4$ T. Such hystereses having different widths are observed also at 4.2 and 10 K.

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12P-C003 Extremely broad hysteresis in the magnetization process of $\alpha$-Dy$_2$S$_3$

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We have investigated magnetization process of $\alpha$-Dy$_2$S$_3$...
carbon. The ESR measurements of $\Theta_p$ were performed on frequency 9.3 GHz in $T_{E102}$ rectangular cavity in the temperature range from 4.2 to 300K. Well known, intensity $\chi_{\text{ESR}}(T)$ of ESR signal is proportional to magnetic susceptibility. In general, the magnetic susceptibility is a tensor. Because the view of the Curie-Weiss’s law can depend on directions. Surprising, but it is quite explainable that the paramagnetic temperatures $\Theta_p$, obtained for EuCd$_2$Si$_2$ and EuZn$_2$As$_2$ from the $1/\chi_{\text{ESR}}(T)$ dependence, have positive sign. For EuBa$_2$-xC$_2$ $\Theta_p$ was $\sim +8$ K in case of a magnetic field along [111] axis, and $\Theta_p \sim -7$ K (!) for the field along [100] axis. Large deviation ($\Delta \Theta \sim 0.03$) of the $g$-factor from $g=1.99$ free Eu$^{2+}$ ion indicates on the strong hybridization of the f-states Eu$^{2+}$ with the p- s- states of the band electrons and possible formation of Kondo-like bound states. The obtained data are interpreted in terms of indirect exchange interaction between localized magnetic moments of Eu$^{2+}$ by the electrons of the valence band (Bloembergen-Rowland’s modified RKKY interaction).

12P-C006 Substitution Effect on the Magnetic Transitions of Fe$_2$MnSi

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The Heusler compound Fe$_2$MnSi shows intriguing magnetic properties. It exhibits a ferromagnetic transition at $T_C \sim 220$ K, and, below, another magnetic transition at $T_R \sim 65$ K, which is supposed to be a ferrimagnetic transition. In the present study we investigate the effects of the substitution of Co and V for Fe and Mn, respectively, on these transitions. They are interesting because the end compound Co$_2$MnSi is considered to be a half-metallic ferromagnet and, moreover, the compounds (Fe$_1-y$Co$_y$)$_2$MnSi for larger $y$ ($\geq 0.5$) were shown to be candidates for half-metals.$^1$ Another end compound Fe$_2$VSi exhibits an antiferromagnetic transition. These transitions of (Fe$_1-y$Co$_y$)$_2$MnSi ($y \leq 0.1$) and Fe$_2$Mn$_{1-x}$V$_x$Si ($x \leq 0.2$) are investigated with the measurement of magnetization and electrical resistivity. The substitution for either case leads to decreasing $T_R$ and increasing $T_C$. For (Fe$_1-y$Co$_y$)$_2$MnSi $T_R$ appears to vanish at $y \sim 0.07$. For Fe$_2$Mn$_{1-x}$V$_x$Si $T_R$ appears to vanish in the vicinity of $x \sim 0.2$. For Fe$_2$Mn$_{1-x}$V$_x$Si from resistivity measurement in magnetic field $T_R$ is found not to vanish and to be $\sim 6$ K at 0 T, and decreases with increasing magnetic field. The destruction of this transition is estimated to occur at $\sim 6$ T.$^3$

12P-C007 Hall effect in La$_{0.67}$Ca$_{0.33}$MnO$_3$ thin films with anisotropic strain

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It has been demonstrated that controlled relaxation of the in-plane anisotropic strain in thin films of La$_{0.67}$Ca$_{0.33}$MnO$_3$ grown on orthorhombic NdGaO$_3$ (001) substrates can induce a charge ordering state.$^3$ Three identically grown LCMO films on NGO, (PLD at 735°C and 45 Pa O$_2$ pressure, 45 nm thick) were annealed at 780°C in flowing O$_2$ for 1, 10 and 20 hours respectively to produce increasing degrees of strain relaxation. Hall measurements were performed. In all three samples, the Hall resistivity takes on two distinct slopes in the paramagnetic phase: a negative slope at low fields, which varies with temperature, and a temperature-independent positive slope at high fields. Notably, the switching field for the Hall slope decreases linearly with temperature and extrapolates to the paramagnetic Curie temperatures of the samples. The observation is similar to the behavior of the nonlinear Hall effect in EuBa$_2$ in paramagnetic phase and suggests that the switches occur at a constant critical magnetization over a broad temperature range.$^2$ In apparent correlation with the appearance of charge ordered insulating state, dips in the Hall resistivity emerge when approaching $T_C$, and become more pronounced in the sample annealed for longer time. The origins of these observations will be discussed. Work supported in part by NSF DMR-0908625.

1. Z. Huang et al., JAP 105, 113919 (2009).
2. X. Zhang et al., PRL 103, 106602 (2009).

12P-C008 Controlling phase separation in La$_{0.67}$Ca$_{0.33}$MnO$_3$ thin films via oxygen deficiencies

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La$_{0.67}$Ca$_{0.33}$MnO$_3$ with fixed thickness as 40 nm, were grown coherently on orthorhombic NdGaO$_3$(001) [NGO(001)] and cubic (LaAlO$_3$)$_3$(Sr$_{0.2}$AlTaO$_6$)$_0$(001) [LSAT(001)] substrates under various deposition oxygen pressures ($P_O$) by pulsed-laser deposition method. The temperature dependent resistivity ($\rho$-$T$) and magnetization ($M$-$T$) were carefully examined. For all the as-grown films on LSAT(001) and NGO(001) substrates, the $\rho$-$T$ curves show bulk-like ferromagnetic-metallic (FMM) ground state, of which the Curie temperature ($T_C$) changes with $P_O$. After ex-situ anneal in floating O$_2$, FMM ground state with improved $T_C$ was found in La$_{0.67}$Ca$_{0.33}$MnO$_3$ films on LSAT(001). The double-exchange interaction enhances with decreasing oxygen deficiencies, which was widely observed in other groups. Surprisingly, $\rho$-$T$ behavior of shear-strained LCMO/NGO(001) films are greatly relied on $P_O$. For details, the films ($P_O>30$ Pa) show multiple metal-insulator transitions and an “overshot” hysteresis, indicating phase separation (PS) in those samples. By contrast, only metal-like $\rho$-$T$ is observed in the films under $P_O<30$ Pa. In addition, the evolution of structure and surface were also examined via X-ray diffraction and atomic force microscopy respectively. All these results reveal the close relationship between PS and
12P-C009  Anisotropic transport in phase-separated La_{0.67}Ca_{0.33}MnO_{3}/NdGaO_{3}(100) film

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Electrical transport anisotropy, as a reflection of strong coupling among spin, charge, lattice and orbital degrees of freedom, has been widely investigated in strong correlated materials like cuprates and manganites*. In this work, strong transport anisotropy was observed in epitaxial La_{0.67}Ca_{0.33}MnO_{3} (LCMO) thin films grown on orthorhombic NdGaO_{3}(100) substrates. Due to the enhanced orthorhombic lattice distortion induced by the pseudomorphic strain, the films show phase separation (PS) with coexistence of ferromagnetic-metal (FM) and antiferromagnetic-insulator (AFI) below ~250 K (Bulk LCMO is safely doped in FM ground state). More strikingly, the temperature dependent resistivity \( \rho(T) \) is strongly dependent on the current direction (along [010] or [001] axes). Especially in the PS temperature region, the in-plane resistivity anisotropy \( \frac{\rho(T)[100]}{\rho(T)[001]} \) exceeds ~100, demonstrating that PS and the strong phase competition should play an important role in the transport anisotropy. And this speculation can be further confirmed by the measurements of magnetic hysteresis loops and the low-temperature X-ray diffraction. Specifically, we argue that the highly oriented FM domain walls between the different AFI domains could be responsible for the transport anisotropy in the epitaxial manganite films.


12P-C010  Interplay between the Kondo effect and randomness in \( M_x \text{TiSe}_2 \) (\( M = \text{Co, Ni, and Fe} \)) single crystals

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We report interplay between Kondo effect and randomness in \( M_x \text{TiSe}_2 \) (\( M = \text{Co, Ni, and Fe} \)) single crystals. Although the typical low-\( T \) upturn of resistivity is measured to imply Kondo effect around the single-ion Kondo temperature \( T_K \), positive magnetoresistance linearly proportional to magnetic field and power-law scaling of magnetization suggest the forbidden coexistence between Kondo effect and time reversal symmetry breaking. This puzzling result is resolved from the Griffiths scenario, that is, disorder-induced distribution of the Kondo temperature causes an effective Kondo temperature \( T_K^{eff} \) much lower than \( T_K \), allowing unscreened local moments above \( T_K^{eff} \) and resulting in non-Fermi liquid properties in \( M_x \text{TiSe}_2 \) below the percolation threshold \( (x < x_c) \). We demonstrate that magnetoresistance is an another important tool for investigating non-Fermi liquid.

12P-C011  Magnetic properties of monophasic \( \epsilon = Fe_2O_3 \) nanoparticles system

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In this work the results of investigation of magnetic properties of ultra small size (2 ÷ 5 nm) \( Fe_2O_3 \) nanoparticles embedded in silica matrix are presented. This system is superparamagnetic with blocking temperature about \( \approx 120K \). In region of high temperatures nanoparticles show ferrimagnetic behavior with Curie temperature about \( \approx 800K \).

Additionally, in the low temperatures region the strong paramagnetic signal is observed. This paramagnetic signal is conditioned by \( \epsilon = Fe_2O_3 \) particles of the smallest size (2 nm), in which the magnetic ordering is unlikely due to less quantity of iron atoms.

12P-C012  Correlation between A-site Randomness and Magnetic Phase Transition in \( Pr_{0.5}Ba_{0.5}MnO_3 \)

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The interplay between A-site randomness and magnetic phase transition in \( Pr_{0.5}Ba_{0.5}MnO_3 \) (PBMO) was extensively investigated. A step-like transition in magnetization and resistivity with a sharp width of \( \Delta H/H = 10^{-3} \) was observed in the A-site partially ordered PBMO at 2 K, indicating that the metamagnetic transition is associated with a competition between randomly distributed short-range ferromagnetic and antiferromagnetic phases. It provides evidence that the A-site randomness not only suppresses A-type antiferromagnetism also moderately weakens long-range ferromagnetism. In addition, the \( H/M \) versus \( M^2 \) isotherms show that the A-site ordered PBMO undergoes a second-order magnetic phase transition from paramagnetism to ferromagnetism, whereas the A-site disordered PBMO exhibits a fluctuation-driven first-order transition arising from a competing order phase possibly existing in the paramagnetic state.

12P-C013  Magnetic Ordering and Magnetocaloric Effect in PrPdIn and NdPdIn

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Equiatomic ternary compounds \( RPdIn \) (\( R \)=rare earth) crystallize in the hexagonal ZrNiAl-type crystal structure. A great variety of interesting magnetic properties of this family has been reported in number of works. Among them, the data previously reported in the literature show ferromagnetic ordering for NdPdIn at about...
26 K, whereas no sign of magnetic ordering was detected for PrPdIn down to 1.7 K.\textsuperscript{1} We have performed a systematic investigation on the well-annealed polycrystalline PrPdIn and NdPdIn samples by ac and dc susceptibilities, high field magnetization, magnetic relaxation, specific heat and electrical resistivity measurements. Our new results indicate that both PrPdIn and NdPdIn exhibit long-range ferromagnetic ordering with the transition temperature $T_C=11$ and 34 K, respectively. For NdPdIn, an additional phase transition was observed at $T_0=18$ K caused by the antiferromagnetic coupling. Below $T_C$, both samples show metastable magnetic properties, behaving as the irreversibility of the temperature dependence of magnetization and the long time magnetic relaxation behavior. On the other hand, evident magnetocaloric effect was also observed for PrPdIn and NdPdIn compounds with large magnetic entropy change at $T_C$ caused by a field change of 7 T.\textsuperscript{1}

\textsuperscript{1} L. Gondek, A. Szytuła, D. Kaczorowski, and K. Nenkov, Solid Sate Commun. \textbf{142}, 556 (2007).

\subsection*{12P-C014 NMR study of successive magnetic transitions in A-site-ordered perovskite LaMn$_3$Cr$_4$O$_{12}$}

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In a simple ABO$_3$ perovskite, when 75% of the A-site cations are substituted by another element, an A-site-ordered perovskite with a chemical formula of A$^t$A$_3$B$_3$O$_{12}$ can be formed. These materials have attracted much attention, because they show a rich variety of physical phenomena, such as heavy-fermion behavior in CaCu$_3$Ru$_4$O$_{12}$, due to the A-A and/or A-B exchange interactions in addition to the usual B-B exchange interaction seen in simple perovskite materials. Recently, new A-site-ordered perovskite, LaMn$_3$Cr$_4$O$_{12}$, was prepared by using high-pressure synthesis. The measurements of magnetic susceptibility and specific heat suggest two antiferromagnetic transitions at 150 K and 50 K in LaMn$_3$Cr$_4$O$_{12}$. In this conference, we report microscopic investigation on the magnetic properties of this material probed by LaNMR. The temperature dependence of Knight shift in La-NMR spectrum indicates that the transition at 150 K is associated with the B-site Cr spin ordering and the other at 50 K is due to the A-site Mn spin ordering.

\subsection*{12P-C015 Magnetic structure and magnetocaloric effect in NdNiAl$_4$}

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We have carried out neutron diffraction and heat capacity measurements for the polycrystalline NdNiAl$_4$ compound. The structure of this compound is orthorhombic of the YNiAl$_4$-type, space group Cmmm. It exhibits an antiferromagnetic type of order with a low Néel temperature of 9.5 K. The contribution of the transition metal to the magnetism of NdNiAl$_4$ is negligible. Using the neutron diffraction studies we have corroborated the previous observations concerning the magnetic structure. The profile analysis has been performed employing the FullProf program. Additionally, we have measured the specific heat of NdNiAl$_4$ in magnetic fields up to 9 T. Due to the metamagnetic transition known to appear in this compound at $H = 4$ T significant changes of the specific heat, magnetic entropy and the magnetocaloric effect occur after crossing this threshold.

\subsection*{12P-C016 $^{27}$Al-NQR Study on Novel Phase Transition in CeOs$_2$Al$_{10}$}

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We have performed $^{27}$Al-NQR measurements in CeOs$_2$Al$_{10}$ which attracts much interest in the novel phase transition occurring at high temperature $T_0=29$ K. The phase transition is recently ascribed to a long range antiferromagnetic one by neutron scattering. However, the reason why the $T_0$ is so high despite of the long Ce-Ce distance of 5.2 Å is not clear at present. The NQR parameters as for four Al sites within the five inequivalent Al sites were determined. These values provide the evidence of a similar local symmetry around Al sites to those in CeRu$_2$Al$_{10}$ and CeFe$_2$Al$_{10}$. The novel phase is known to disappear under pressure more than about 2 GPa. We have performed NQR measurements under pressure. The distinct NQR splitting below $T_0$ under 0.6 GPa excludes a possibility of coexistence of regions with splitting and no splitting, indicating homogeneous phase transition. Thus the reduction of the entropy decrease associated with the transition $\Delta S$ with increasing pressure is not due to the change of the volume fraction of the novel phase. Even in relatively low pressure 0.6 GPa, the nuclear spin-lattice relaxation rate $1/T_1$ is suppressed over whole temperature range compared with that in ambient pressure. $1/T_1$ does not show any critical slowing down at $T_0$, rather promotes the behavior seen in ambient pressure that the gap opens at higher temperature than $T_0$.

\subsection*{12P-C017 The lattice and magnetic and electronic properties of the antiperovskite Mn$_3$XN ($X=Zn$, In, Sn) prepared under high pressure}

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The antiperovskite Mn$_3$XN(C) compounds have at-
Doped rare-earth manganites have attracted tremendous interests due to the discovery of a variety of electronic, magnetic, and structural transitions. In this paper, we present the magnetic and electrical properties of high quality single crystal of Pr$_{0.5}$Ca$_{0.5}$MnO$_3$ under high pressure and low temperature. It has been measured magnetic properties under pressure up to 1.5 GPa by commercial SQUID magnetometer with miniature-pressure cell and electrical resistivity under pressure up to 6 GPa with CuBe-CrNiAl hybrid piston-cylinder and cubic anvil. The spin reorientation temperature at 150 K along c-axis increases monotonically with increasing pressure up to 0.8 GPa. Above 0.8 GPa, temperature variation of magnetization along c-axis suddenly changes to that along a-axis. It seems to be magnetic structure should be changed by applying pressures. The Metal-Insulator (M-I) transition around 150 K is gradually disappeared by applying pressure. At 6 GPa, the insulator phase at low temperature is completely disappeared. These results claim that pressure should affect the Jahn-Teller distortion, and consequently, change the physical properties of Pr$_{0.5}$Ca$_{0.5}$MnO$_3$ via the variation of Mn-O-Mn bond length and angle.

12P-C019 Spin-State Transition in RCoO$_3$ (R = La, Pr, and Nd): Single-Crystal $^{59}$Co NMR Measurements
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A thermally-induced transition from a nonmagnetic to a paramagnetic state, so-called spin-state transition, in RCoO$_3$ (R: rare earth) is a long-standing issue of strongly correlated electron system. It has attracted much interests whether the transition from a low-spin ($S=0$) to a high-spin ($S=2$) state takes place through an intermediate spin ($S=1$) state. We address a microscopic study of the orbital state in RCoO$_3$ (R = La, Pr, and Nd) by single-crystal $^{59}$Co NMR measurements. The $^{59}$Co nuclear spin-lattice relaxation rate and Knight shift measurements revealed the spin-state transition with the critical slowing down of fluctuations at 50 K in LaCoO$_3$. On the other hand, PdCoO$_3$ and NdCoO$_3$ exhibit no clear transition but a small continuous change in the local spin susceptibility at high temperatures above 300 K. Subtracting the contribution from the magnetic rare-earth spins to the $^{59}$Co Knight shift, we obtained the magnetic hyperfine coupling constant between a $^{59}$Co nuclear spin and 3d spins in the paramagnetic state with the finite 3d spin susceptibility in PrCoO$_3$ and NdCoO$_3$. The hyperfine coupling tensors of PrCoO$_3$ and LaCoO$_3$ are axially symmetric and dominated by a sum of dipole hyperfine fields from the 3d orbitals theoretically expected in the high-spin state.

12P-C020 Theoretical Study of Resonant Inelastic X-ray Scattering Spectrum in Nickelates
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The two-dimensional nickelate La$_{2-x}$Sr$_x$NiO$_4$ has received special attention as a reference system of high-$T_c$ cuprates. The undoped nickelate ($x=0$) has the charge-transfer gap in the optical conductivity. Upon doping of holes, a broad spectrum appears in the gap. We have shown theoretically that the broad spectrum comes from excitations to the low spin states. In the Ni $K$-edge resonant inelastic X-ray scattering (RIXS) measurement, the momentum–resolved charge excitations are obtained. In this study, we examine theoretically the RIXS spectra on nickelates by using numerically exact diagonalization techniques on the two-band Hubbard model. We also calculate other spectra such as the dynamical charge density function and discuss what excitations appear in the RIXS spectrum.

2 E. Collart et al., Phys. Rev. Lett. 96, 157004 (2006); S. Waki-
12P-C021  Substitution Effect on the Magnetic State of Delafossite CuCrO₂ Having a Spin-3/2 Antiferromagnetic Triangular Sublattice

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We have investigated a substitution effect on transport, magnetic, and thermal properties of delafossite CuCrO₂ having a spin-3/2 antiferromagnetic triangular sublattice by measurements of resistivity, magnetization, specific heat, and neutron scattering. In the presentation, we will discuss unique effects of hole-doping by a substitution of Mg²⁺ ions for Cr³⁺ ions (S = 3/2), randomness between CrO₂ layers by a substitution of Ag⁺ ions for Cu⁺ ions, and spin-dilution induced in CrO₂ layers by a substitution of Al³⁺ ions for Cr³⁺ ions upon the magnetic state in CuCrO₂.

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12P-C022  Quantum Phase Transition at Critical Magnetic Field

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Since the exchange interaction between the localized 4f moments in the rare earth compounds is usually mediated by conduction electrons, the on-site and intersite exchange can be affected the character of c.e. The strength of both on-site and inter-site exchange is strongly depends on the number or nearest neighbour magnetic ions and the inter-atomic space defined by the metamagnetic character. Even though the strength of onsite exchange which tend to screen away the spin of magnetic ion resulted to competition of on-site and intersite exchange, the existence of the phenomena on the Gd-IMC is a puzzle. In spite of the above phenomena the related character of Tk, TN the effects of magnetic field on the field induced of metamagnetic character which is much smaller than the broken Kondo temperature is investigated. A critical quantum phase transition is manifested at a critical external magnetic field at which the unstable of F.M phase transition collapse to completely P.M with Kondo lattice behaviour.

12P-C023  Magnetic Properties and Improper Ferroelectricity in LaFeO₃/LaCrO₃ Superlattices

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We investigate the electronic and magnetic properties of LaFeO₃/LaCrO₃ superlattices. It is found that the magnetic structures of [LaFeO₃ₙ][LaCrO₃ₙ] superlattices are much sensitive to the stacking direction and to the stacking periodicity of (n,m). In the case of superlattices with (1,1), the magnetic ground states of the systems growing along [001] and [110] directions are C-type and A-type antiferromagnetic insulators, respectively, whereas a ferromagnetic insulator is achieved when Fe and Cr layers are atomically stacked along [111] direction. In the case of superlattices with (2,2) and (3,3) growing along [001] direction, Fe layers are ferromagnetically coupled with the nearest neighboring Cr layers, while Fe (Cr) layers are antiferromagnetically coupled with the adjacent Fe (Cr) layers. These results are consistent with Konamori-Goodenough (KG) rule, and are in good agreement with experimental observations. Furthermore, we predict that the superlattice with (2,2) growing along [110] direction is E-type antiferromagnetic insulator with finite ferroelectric polarization, namely, the system is multiferroic.

12P-C024  d⁰ Ferromagnetic Surface in HfO₂


Recent theoretical studies have proposed a way to induce magnetism in simple oxides without containing magnetic transition metal ions (therefore, called d⁰ magnetism). For instance, it has been proposed that a simple oxide such as CaO can be ferromagnetic with a small amount of cation vacancies. It has been also shown theoretically that C- and N-doped CaO becomes ferromagnetic and half metallic. Two pathways to induce d⁰ magnetism in simple oxides with no magnetic ions involved. First principles simulations based on density functional theory are performed to study surface magnetic properties of low index cubic, tetragonal, and monoclinic HfO₂ surfaces with different terminations. Our systematic calculations reveal that only O rich non-stoichiometric surfaces can be ferromagnetic. The origin of ferromagnetism found here is attributed to O surface electronic states with large O 2p spin exchange energy. We also discuss a possible reason for recent controversial experimental observations of ferromagnetism in HfO₂.

12P-C025 Longitudinal Magnetic Excitation in KCuCl₃ Studied by Raman Scattering under Hydrostatic Pressures

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The pressure-induced quantum phase transition in a three-dimensional spin-dimer system KCuCl₃ has been studied by using Raman scattering at low temperatures under hydrostatic pressures \(P\) with He gas as a pressure medium. Around 3 K, we observe a one-magnon Raman peak above a quantum critical point at \(P_c\) = 0.82 GPa. The origin of the one-magnon Raman peak above \(P_c\) is related to the change of the magnetic ground state. Below \(P_c\), the ground state is a spin-singlet state together with a spin gap. Above \(P_c\), the ground state is a mixed singlet-triplet one, resulting in emergence of two massless transverse modes and a massive longitudinal one in magnetic excitations.

Because the longitudinal magnon mode is Raman active, the observed one-magnon Raman peak is assigned to it. The peak energy, the Raman intensity, and the halfwidth increase as a function of \(\sqrt{P-P_c}\) above \(P_c\). These \(P\) dependences are discussed based on the bond-operator mean-field theory taking decay channels from one longitudinal mode to two transverse ones into consideration.

12P-C026 Spin-Orbit Mott State in the Novel Quasi-2D Antiferromagnet Ba₂IrO₄

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Recent extensive studies on the electronic state in Sr₂IrO₄ have revealed that a novel Mott insulating state can be realized by Coulomb interaction in cooperation with large spin-orbit interaction in the 5d system. It is proposed that the unconventional \(J_{ab} = 1/2\) magnetic ground state originating from the strong spin-orbit coupling is realized in the Mott state. In this presentation, we report on electronic and magnetic states in the spin-orbit Mott insulator Ba₂IrO₄, which is a new compound recently found by us. Ba₂IrO₄ crystallizes in a K₂NiF₄-type structure including IrO₂ square planar layers with straight Ir-O-Ir bonds. The magnetic susceptibility and μSR studies revealed that the magnetic ground state is antiferromagnetic long-range order (\(T_N \sim 240\) K) in which the magnetic moment (\(\sim 0.34 \mu_B/\text{Ir-atom}\)) is significantly reduced by a low-dimensional quantum spin fluctuation with a large intra-plane correlation \(|J|\). The behavior is similar to those in parent materials of high-\(T_c\) cuprate superconductors such as La₂CuO₄.

12P-C027 R-site randomness effect on spin/orbital order in perovskite RVO₃

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Perovskite RVO₃ (\(R\): rare earth elements or Y) has orbital degrees of freedom between \(d_{yz}\) and \(d_{xz}\) orbitals in \(V^{3+}\) ions, and shows two types of spin/orbital order: G-type orbital order (G-OO) accompanied with C-type spin order (C-SO), and C-OO with G-SO. In this system, the transition temperature of each spin/orbital order depends on the R-site ionic radius and structural randomness caused by the size mismatch of the cations at the R-site. We have investigated the R-site randomness effect on spin/orbital order in RVO₃ with several R-site ionic radius. In YVO₃ and EuVO₃ with the small R-site ionic radius and located near the phase boundary, the randomness suppresses C-SO/G-OO, while it stabilizes the other SO/OO. By the neutron and resonant X-ray scattering measurements, the other order was confirmed as G-SO/C-OO. In NdVO₃ with large R-site ions, however, C-SO/G-OO is so stable that the randomness cannot induce the other SO/OO.

12P-C028 Transport Properties of the Novel Quasi-1D Cobalt Oxide (Ca,Na)CoO₃

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Cobalt oxides have attracted much attention from many scientists because of the unusual large thermoelectric power and unconventional superconductivity. Most of their interests are directed toward “2D” CoO₂ layers in layered oxides such as Na₂CoO₃ or Na₂CoO₂·2H₂O, because the 2D lattice is a main stage of the electronic conduction showing the unusual properties.

However, to our knowledge there has been no report on “1D” effect on transport properties in cobalt oxides, because there has been no metallic 1D cobalt oxide so far. In this presentation, we report on transport properties of the novel quasi-1D metallic cobalt oxide (Ca,Na)CoO₃. (Ca,Na)CoO₃ crystallizes in the calcium-ferrite-type structure, which consists of an edge- and corner-shared CoO₆ octahedral network including quasi-1D CoO₂ double chains along the \(b\)-axis. Since the Co \(t_{2g}\) orbital directly overlaps with the nearest neighbor Co \(t_{2g}\) orbitals, the charge transport is controllable by the carrier doping. The metallic conduction \((dp/dT > 0)\) appears for the highly Na doped phases. The non-zero Sommerfeld constant \((\gamma ~\sim 20 \text{ mJ/Co-mol K}^2)\) indicates finite density of states at Fermi level.
12P-C029  Spin-Peierls transition in TiPO$_4$

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We investigated the magnetic and structural properties of the quasi-one dimensional 3$d^1$-quantum chain system TiPO$_4$ ($J \sim 965$ K) by magnetic susceptibility, heat capacity, ESR, x-ray diffraction, NMR measurements, and by density functional calculations. TiPO$_4$ undergoes two magnetostructural phase transitions, one at 111 K and the other at 74 K. Below 74 K, NMR detects two different $^{31}$P signals and the magnetic susceptibility vanishes, while density functional calculations evidence a bond alternation of the Ti...Ti distances within each chain. Thus, the 74 K phase transition is a spin-Peierls transition which evolves from an incommensurate phase existing between 111 K and 74 K.

12P-C030  A field-induced IM-type transition observed in low-energy H$_2^+$ ion implanted epitaxial La$_2$/3Ca$_1$/3MnO$_3$ thin films

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Epitaxial La$_2$/3Ca$_1$/3MnO$_3$ thin films on LaAlO$_3$ substrates were implanted with 120 keV H$_2^+$ ions over a range of doses from 10$^{12}$ to 10$^{17}$ ions/cm$^2$. An implantation-induced metal-insulator transition is observed at a dose around 8.0×10$^{15}$ ions/cm$^2$, which is accompanied by a structural change. The specified sample at this critical implantation dose is semiconductor-like, but can be driven to a metal at intermediate temperatures in an applied field of 4 T or higher. As a consequence, an unusual insulator-metal-insulator transition and thus an enormous magnetoresistance are observed. At 5 K, the field-cooled sample in 5 T shows a drastic resistance upsurge with the decreasing field and presents a very sharp peak as the field is reversed. The results are interpreted in terms of changes in magnetoresistive properties with the displacement of oxygen atoms or lattice distortions, most probably associated with a spin glass ground state, which can be provoked by ion implantations and suppressed by magnetic fields.

12P-C032  Elastic Constants of NdCu$_2$Ge$_2$

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The rare-earth compound NdCu$_2$Ge$_2$ crystallizes into the tetragonal ThCr$_2$Si$_2$ type structure. Recently, Shigeoka et al. reported the physical properties of NdCu$_2$Ge$_2$. The magnetic susceptibility along the $c$-axis shows a cusp-like anomaly at $T_N = 4.7$ K. On the other hand, those in the $ab$-plane increase even below $T_N$ and no clear anomaly is detected around $T_N$. These results imply that the degeneracy of the internal degrees of freedom still exists below $T_N$. We consider that this characteristic magnetic transition in NdCu$_2$Ge$_2$ is similar to the "component-separated magnetic transition" in DyB$_4$ or TbCoGa$_5$. Because the degeneracy of quadrupolar degrees of freedom plays an important role in the magnetic transitions in DyB$_4$ and TbCoGa$_5$, it is necessary to investigate the behavior of the quadrupole moment in NdCu$_2$Ge$_2$. We grew single crystals of NdCu$_2$Ge$_2$ and measured their magnetic susceptibility, specific heat, and elastic constants. The magnetic entropy change reaches $R\ln 2$ at $\sim 6$ K and $R\ln 8$ at $\sim 72$ K with increasing temperature. This result indicates that the crystalline electric field ground state of NdCu$_2$Ge$_2$ is a Kramers doublet. In addition,
the results of the elastic constants suggest that the degeneracy of quadrupolar degrees of freedom should not remain below \( T_N \).


12P-C033 Itinerant-electron metamagnetism of magnetocaloric material RCo\(_2\) and their borides

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The itinerant-electron metamagnetic transition of Co-based cubic Laves phase has been investigated theoretically and experimentally. In ErCo\(_2\), a discontinuous change of the temperature dependence of the magnetic susceptibility at \( T_C = 46 \) K due to the magnetic transition, which is accompanied by a large volume transition.\(^1\) This result implies that the magnetic coupling is exclusively determined by the volume of the compound. In the present work, we investigate of the volume dependence of \( T_C \) and magnetocaloric effect of ErCo\(_2\) by doping boron. Several ErCo\(_2\)B\(_x\) compounds of \( x < 0.2 \) were prepared by arc melting in an argon gas atmosphere. The x-ray powder diffraction patterns of all the specimens identified as a cubic C15 Laves structure. The lattice parameter is increased by doping boron. On the other hand, The value of \( T_C \) is increased significantly to 64 K at \( x = 0.07 \).


12P-C034 Room temperature ferromagnetic behavior of GaN nanocramics

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The effect of grain size of GaN nanocrystallites subject to high pressing has been manifested in a strong deformation of grains of nanocramics. The most surprising result was observed for the GaN nanocramics built from the largest grains characterized by strongest deformation which demonstrated the superconducting like behavior. In the present work we have focused on the effect of applied pressure on magnetic properties of GaN nanocramics. It is shown that the GaN nanocramics fabricated by low temperature high pressure technique exhibit the room-temperature ferromagnetic behavior. Our measurements reveals that the magnetization of GaN nanocramics increased with the sintering pressure applied in fabrication process of nanocramics. It is concluded that for observed increase of ferromagnetism is responsible the magnetostriction mechanism. The magnetization of GaN nanoceramic measured at 2 K decreases nonlinearly with applied pressure by two order of magnitude reaching a minimum at 4 GPa. It was found that magnetization of GaN nanocermics demonstrates hysteric behavior characteristic to giant magnetostrictive material.

12P-C035 The role of Ru\(^{5+}\) in increasing \( T_C \) of Cr-doped SrRuO\(_3\) system

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Two series of samples with nominal composition \( \text{Sr}_{1-x} \text{La}_{x} \text{Ru}_{1-x} \text{Cr}_{x} \text{O}_3 \) (SLRC) and \( \text{Sr}_{1-x} \text{Ca}_{x} \text{Ru}_{1-x} \text{Cr}_{x} \text{O}_3 \) (SCRC) \( (x = 0.04, 0.08 \) and 0.12) have been prepared and investigated in order to explore the mechanism of the Curie temperature increase in Cr-doped SrRuO\(_3\). The magnetic experiment results demonstrate that the Curie temperature \( (T_C) \) of SLRC decreases with an increase in \( x \) while in SCRC, \( T_C \) slightly increases with Cr doping. It indicates that the enhancement of the ferromagnetism by Cr doping is more significant in the system containing Ru\(^{5+}\). We suggest that the exchange interaction between Ru\(^{5+}\) and Cr\(^{3+}\) plays an important role in enhancing the ferromagnetism in the system.

12P-C036 Magnetic Phase Transition in the Verdazyl Biradical Crystal p-BIP-V\(_2\)

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Organic radical compounds have attracted much attention since the discovery of the first organic ferromagnet.\(^1\) A lot of organic radical compounds are synthesized during the two decades. Verdazyl radicals are one of the stable radicals and have a delocalized \( \pi \)-electron system expanded over a molecule,\(^2\) which is expected to result in relatively strong intermolecular interactions. Actually, several verdazyl radical crystals show interesting magnetic properties originating from the intermolecular exchange interactions. We have succeeded in synthesizing verdazyl biradical crystal p-BIP-V\(_2\). The crystal structure belongs to the monoclinic system, space group \( P2_1/n \). The magnetic susceptibility and specific heat showed anomalous behavior at 7.5 K, indicating some kind of magnetic phase transition. We performed high-field magnetization measurements below 7.5 K and discussed magnetic structure to investigate low-temperature phase in detail.


12P-C037 Magnetic and Transport properties of Cr\(_{1-x}\)Ti\(_2\)N solid solution nitrides

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We have synthesized Cr\(_{1-x}\)Ti\(_2\)N \( (x = 0.1 \sim 0.7) \) solid solution nitrides by the standard arc melting technique. The crystal structure of Cr\(_{1-x}\)Ti\(_2\)N is face-centered cubic which is the same as CrN and TiN. The magnetic
and transport properties were measured under wide temperature and magnetic field ranges. It changes from the ferromagnetic phase to the paramagnetic phase with increasing temperature. The Curie temperature is 131 K for $x = 0.1$. It reaches the maximum value of 135 K for $x = 0.5$ and then decreases for higher Ti composition. Coercivity has the maximum value for $x = 0.1$ specimen. Those samples display soft ferromagnetism. The coercivities are 15.5 Oe at 5 K and 4.5 Oe at 50 K for $x = 0.5$ specimen. The magnetization is weaker when doping ratio $x$ is decreasing. The resistivity of $\text{Cr}_1-x\text{Ti}_x\text{N}$ was investigated by standard four-point technique. It displays a transition from nonmetallic phase to metallic phase as temperature decreases and the transition temperature is in agreement with the Curie temperature. The magnetoresistance was observed in the ferromagnetic regime for all samples. Electron Paramagnetic Resonance study of $\text{Cr}_1-x\text{Ti}_x\text{N}$ ($x = 0.4 \sim 0.7$) nitrides above $T_c = 140$ K illustrations that the resonance absorption intensity decreases as the Ti composition increases.

12P-C038 Supersolid Mechanism of Dipolar Bosons and Double Peak Structure in Momentum Distribution

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We study the checkerboard supersolid$^1$ of the hard-core Bose-Hubbard model with dipole-dipole interactions. This supersolid is qualitatively different from all other supersolids found in lattice models in the sense that superflow paths for interstitials or vacancies are absent in the crystal. We reveal that the long-range repulsive interaction plays an important role for the appearance of this supersolid. By exact quantum Monte Carlo simulations, we also observed the double peak structure in the momentum distribution of bosons, indicating the coexistence of superfluidity and solidity. This can be measured by time-of-flight experiment in optical lattice systems.


12P-C039 Variational Monte Carlo Study of Two-Dimensional Multi-Orbital Hubbard Model on Square Lattice

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The Mott metal-insulator transition is an interesting and important issue in condensed matter physics. Especially, Mott transitions in multi-orbital systems have been investigated extensively. Prototypical examples are the orbital-selective Mott transitions in ruthenium alloys and the unconventional superconductivity in iron pnictides. In these systems, Hund’s coupling as well as inter- and intra-orbital Coulomb interactions plays important roles. To understand the effects of orbital degeneracy, it is necessary to study these effects systematically. In this study, we investigate a two-dimensional two-orbital Hubbard model on a square lattice at half filling. Applying the variational Monte Carlo (VMC) method, we address the Mott transitions in two-orbital systems. With this method, we can accurately estimate the ground-state properties. As a variational trial wave function, we consider Gutzwiller’s on-site correlations and nearest-neighbor doublet-holon correlations because Mott transitions cannot be described correctly within Gutzwiller’s wave function in finite dimensions.

We calculate the ground-state energy and obtain the phase diagram at zero temperature. The momentum distribution and the structure factors for the spin and charge density are also calculated. From these data, we discuss how Hund’s coupling affects the Mott transitions in multi-orbital systems.

superconducting niobium contacts

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The Andreev reflection hole current at ballistic point contacts, which results from the conversion of single electrons into Cooper pairs, is suppressed at large bias voltages. Based on experiments with ultra-high purity Ta, Hahn et al.\textsuperscript{1} have suggested that a huge hot spot or normal bubble, with diameter up to several times the superconducting coherence length, forms in the superconductor by trapping high-energy electrons between the contact and the normal-superconducting interface of the hot spot itself. We have investigated contacts with superconducting Nb ($T_c = 9.2$ K) and found a similar behaviour. The difference between the current in the superconducting (S) and the normal (N) state, called the excess current, drops nearly exponentially with increasing bias voltage like $I_{\text{exc}} = I_0 V/\exp(-V/V_0)$. For contacts with normal resistances in the 1 $\Omega - 100$ $\Omega$ range, the decay constant is $V_0 = 10$ mV. In contrast to the interpretation given by Hahn et al., we attribute the suppression of the excess current to the phonon drag: Electrons accelerated across the contact generate non-equilibrium phonons which scatter not only at electrons, but also at holes that are retro-reflected from the superconductor. Since the hole-phonon scattering length is very short at large bias voltages, the probability that an Andreev-reflected hole returns through the contact to be recorded as excess current, is strongly reduced.


12P-D004 Normal reflection at superconductor - normal metal interfaces due to Fermi surface mismatch

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Electrons can be normal reflected at an interface between two metals because of a dielectric barrier or different Fermi wave vectors. The most simple description uses a one-dimensional free-electron approximation\textsuperscript{1} to derive the transmission coefficient $\tau = 1/(1 + Z^2)$ where $Z^2 = Z_0^2 + (1 - r)^2/Ar$ with $r = k_F1/k_F2$ the ratio of the Fermi wave numbers and $Z_0$ the contribution of the dielectric barrier. Andreev reflection allows a direct measurement of $Z$ when one of the metals is a superconductor. We have investigated normal reflection of normal metals in contact with superconducting Nb ($T_c = 9.2$ K) and Al ($T_c = 1.2$ K). The distribution of $Z$ values of a large number of contacts of a specific metal combination indicates a well-defined onset which we attribute to Fermi surface mismatch. The distribution is broadened possibly due to varying polycrystal orientations of the contacts. It also has a weakly resolved tail at large $Z$ expected for the additional dielectric barrier. Our Andreev-reflection derived transmission coefficients are generally larger than those predicted theoretically\textsuperscript{2} or those based on proximity-effect studies of normal-superconductor bi-layers\textsuperscript{3}.


12P-D005 Size-dependent Anomalous Dielectric Behavior in La$_2$O$_3$ : SiO$_2$ Nano-glass Composite System

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An intriguing anomalous dielectric behavior is observed in nanoparticle (NP) La$_2$O$_3$ : SiO$_2$ nano-glass composite system synthesized via sol-gel route at different calculation temperatures. Temperature dependent dielectric properties exhibit a notable dielectric broadening, indicating of diffuse phase transition with high $\varepsilon'$, quite different from and much higher than pure bulk La$_2$O$_3$ and SiO$_2$. We postulate such dielectric effect in the context of the oxygen vacancies of the rare earth oxide nano-glass composite, where lattice strain related with NPs and their size plays a vital role. Such a material might be treated as a potential candidate to solve the problem of devices miniaturization.

12P-D006 Determination of a soft gap in the density of states of a granular carbon

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In this work we discuss the application of variable range hopping model for the electrical transport in carbon-black, a granular and disordered kind of carbon. We analyze the measured resistivity of samples with different volumetric densities, from room temperature to 1.2 K, using the Mott resistivity equation, and connects smoothly to the ES equation, at low temperatures. With this function we obtain good fits to the experimental data and determine a value for the gap half width around 1.4 meV for the sample with the lowest density. This gap decreases with the powder density. We argue that transport in carbon nanoparticles and agglomerates occur through localized states and that a soft gap is most probably to exist in the density of states, at Fermi level, due to the Coulomb interactions.

12P-D007 Electrical and galvanomagnetic properties of AuAl$_2$+6%Cu intermetallic compounds at low temperatures

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12P-D008  Magnetic Field Tuned Quantum Phase Transition in the Insulating Regime of Ultrathin Amorphous Bi Films

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A surprisingly strong variation of resistance with perpendicular magnetic field, and a giant peak in \( R(B) \) has been found in insulating films of a sequence of homogeneous, quench-condensed films of amorphous Bi undergoing a thickness-tuned superconductor-insulator transition. Isotherms of magnetoresistance, rather than \( R(B) \) were found to cross at a well-defined magnetic field higher than the field corresponding to the peak in \( R(B) \). For all values of B, \( R(T) \) was found to obey an Arrhenius form. At the crossover magnetic field the prefactor became equal to the quantum resistance, \( h/4e^2 \), and the activation energy returned to its zero field value. Magnetoresistance data near the crossover magnetic field are consistent with finite size scaling. The critical exponent product found in the scaling analysis, is consistent with the universality class of the (2 + 1)D XY Model assuming that the dynamical exponent \( z \), which is not measured, is unity. We suggest that these observations are evidence of a quantum phase transition between two distinct insulating phases, which might be identified as Bose and Fermi insulators. This work was supported by the National Science Foundation under grant NSF/DMR-0854752.

12P-D009  From Ward Identity to Exact Transport Equation: Complement to Éliashberg’s Derivation of Landau-Silin Equation and beyond

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Transport equation of interacting fermions is reconsidered in the light of the conservation law. We show that the exact equation for the particle-hole excitation is derived directly from the Ward identity by simply transforming it. Retaining the linear terms in the frequency, it is similar to that derived diagrammatically by Éliashberg1, but takes two significant corrections along with it. The first is the dynamical wavefunction renormalization multiplying the frequency, which results in scaling other renormalizations. The second is the symmetrization of the collision integral with respect to the scatterings in and out. We also discuss the problem of hidden ultraviolet divergence in Éliashberg’s treatment of transport coefficients, thus claiming that the microscopic justification of Landau-Silin theory has not yet been completed. This divergence is shown to be removed by incorporating the particle-particle and hole-hole pairs of excitations into the above equation, without sacrificing its rigour. This requires re-identification of the distribution function, but the resultant transport equation for the new distribution function is identical, in its appearance, to the original one for the particle-hole pair.


12P-D010  Exact wave functions and excitation spectra of the one-dimensional double-exchange model with one mobile electron

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Motivated by recent studies of the in-gap (or nonquasiparticle) states in the half-metallic ferromagnets, we study the one-dimensional double-exchange model with one mobile electron. We solve the Schrödinger equation analytically and obtain the energies and wave functions for all the eigenstates exactly. As an application, we compute the single-particle Green’s function and dynamical density correlation function. We show that the single-particle spectrum is entirely incoherent and the lowest band has an infinite band mass; i.e., the single electron is localized due to its interaction with the spin excitations, whereas the density correlation function consists of a single sharp peak with a very simple dispersion. Implication on the observed in-gap states in the half-metallic ferromagnets is considered. See Ref. [1] for details.


12P-D011  The temperature dependence of Hall mobility of the oxide thin film \( \text{In}_2\text{O}_3-\text{ZnO} \)

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We report that temperature dependence of Hall mobility of the strongly disordered films \( \text{In}_2\text{O}_3-\text{ZnO} \). We made targets by mixing \( \text{In}_2\text{O}_3 \) with ZnO at the ratio \( 0 \sim 4 \% \). Sputtering those targets on glass
substrate by DC magnetron method, amorphous films with 25 nm thickness were obtained. By annealing at \( T = 150 \sim 350^\circ C \) in the air, these films were crystallized and oxygen defect decreased and the conductance decreased. We obtained polycrystalline films with conductivity \( 0.2 mS/m \sim 300S/m \). These conductivity changes due to environment such as light and gas. The grain size \( \sim 20nm \) of films was measured by scanning electron microscopy. In the temperature range \( T = 90 \sim 300K \), we measured the Hall effect of these films. The density of electron was \( 4 \times 10^{18} \sim 7 \times 10^{22}m^{-3} \) at the room temperature. The Hall mobility \( \mu \) shows the thermal-activation-like temperature dependence \( \mu \sim \exp(E_B/k_BT) \). Where \( E_B \) is activation energy. By fitting, we obtained \( E_B = 17 \sim 67meV \).

12P-D012 Quantum Phase Transition Induced by Chemical Substitution in the valence fluctuating System \( \alpha-YbAlB_4 \)

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The Yb-based heavy fermion system, \( \alpha-YbAlB_4 \), has a noncentrosymmetric crystal structure, while the structure of the isochoiometric system, \( \beta-YbAlB_4 \) is centrosymmetric\(^1\). \( \beta-YbAlB_4 \) is a rare example of the Yb based heavy fermion systems that shows pronounced non-Fermi-liquid behaviors and a superconducting transition at 80 mK under ambient pressure and field\(^2,3,4\). On the other hand, \( \alpha-YbAlB_4 \) at low temperatures is well fit to a Fermi liquid type description\(^4\). Both \( \alpha \) and \( \beta-YbAlB_4 \) are valence fluctuating systems with the valence of \( Yb^{2+,7+} \) and \( Yb^{2+,75+} \), in spite of showing Kondo lattice behaviors\(^5\). We have succeeded in substituting Fe for Al in \( \alpha-YbAlB_4 \), and found a magnetic order at 10 K by magnetic susceptibility measurements. We will discuss the thermodynamic and transport properties in the vicinity of quantum phase transitions found in \( \alpha-YbAl_{1-x}Fe_xB_4 \), comparing with \( \beta-YbAlB_4 \).

12P-D013 Effect of intrinsic luminescence of alkali halide amplification by low temperature deformation

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The influence of low temperature (100K) on elastic uniaxial deformation on self-trapped excitons (STE) luminescence intensity strengthening and on STE configuration at the time of irradiative relaxation in alkali halide crystals (AHC) using luminescence spectroscopy method is determined by the authors. The face-centred AHC experiences luminescence intensity’s re-distribution from asymmetric STE configuration to symmetric one (III \( \rightarrow \) II \( \rightarrow \) I-types); and in body-centred AHC, vice versa, to the favour of asymmetric (polarized) STE configuration (I \( \rightarrow \) II-types). The effect of luminescence’s amplification of self-trapped excitons with symmetric configuration is explained by the compression of self-trapped exciton along its length, and the luminescence’s amplification with asymmetric configuration - by self-trapped exciton stretching at the influence of low temperature uniaxial elastic deformation.

12P-D014 Size effect and the quadratic temperature dependence of the transverse magnetoresistivity in “size-effect” tungsten single crystals

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The transverse magnetoresistivity of pure tungsten single crystals with a residual resistivity ratio \( \rho_{993K}/\rho_{23K} \) of about 75.00 was measured from 2 to 75 K and in magnetic fields of up to 15 T. The size effect, i.e. the linear dependence of the magnetoresistivity on the inverse cross sample dimensions, was studied in detail at high fields. We show that the size effect can be used for the separation of the contributions from the electron-surface and the electron-phonon scattering mechanisms to the full conductivity. We demonstrate that the electron-surface scattering results in a temperature independent term, the electron-phonon scattering leads to the exponential temperature dependence of the conductivity, and the interference between the electron-phonon and the electron-surface processes leads to a new scattering mechanism “electron-phonon-surface” with a quadratic temperature dependence of the magnetoresistivity. This work was partly supported by the Austrian Academy of Sciences.

12P-D015 Thermal Hall Effect in Ferromagnetic Insulators

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It is commonly believed that the Hall effect and thermal Hall effect are limited to systems of charged particles since they are driven by the Lorentz force. However, neutral quasi-particles such as phonons and magnons can carry heat current and potentially be responsible for the thermal Hall effect without resorting to the Lorentz force. We show both theoretically and experimentally that magnons exhibit the anomalous Hall effect in insulating ferromagnets with the Dzyaloshinskii-Moriya (DM) interaction, which acts as a vector potential for magnons.\(^1,2\) We study various types of insulating ferromagnets, including a pyrochlore ferromagnet \( Lu_2V_2O_7 \), and find that the observed temperature and magnetic-field dependence of the thermal Hall conductivity can be well explained by the analytic expression...
Dopant-dependence on charge/orbital ordering in layered manganite La0.55Sr1.5MnO4

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Manganites are intensively studied because of their unique features such as colossal magnetoresistance effect and multiferroic behavior. When impurity ions are substituted for the manganese ions in the compound, a new local electronic state often emerges. In this study we have investigated the dopant effect on a typical charge/orbital ordered system, a layered manganite La0.55Sr1.5MnO4, using resonant x-ray scattering (RXS) technique. The layered manganite La0.55Sr1.5MnO4 shows charge/orbital ordering below 230 K. We have studied how the ordered states are changed by the 3% substitution of Cr, Fe and Ga ions for Mn ions. As a result, it is revealed that the charge/orbital ordered states are strongly suppressed by the substitution of impurity ions in all doped compounds, but the degrees of suppression of the ordering depend on dopant ions. We assume that the difference of the dopant effect between impurity ions is caused by the difference of the spin value.

Transparency Conducting AZO Films by Using DC Sputtering and RF Sputtering

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The transparent conducting thin films were sputtered at 2, 4, 6, 8, and 10mtorr by DC sputtering method, and at 4, 6, 8, and 10mtorr by RF sputtering method, respectively. A DC power and an RF power were introduced into the cathode of the sputtering system respectively to deposit AZO films. The RF power was kept at 150W, and the DC power was kept at 80W during deposition. Five substrate temperatures, 225, 250, 275, 300, and 325 °C were chosen for deposited. Transmittances of the films are all above 80% within 400-800nm incident light. No blue shift of the transmission has been observed for the RF sputtering method, but has been observed for the DC sputtering method. The blue shift of the transmittance with higher deposition temperature for the DC sputtering method could be due to Burstein-Moss shift. The X-ray diffraction peak intensity increases with the increasing substrate temperature both for DC and RF sputtering methods. Another diffraction peak of (331) was observed as the substrate temperature increases to 275 °C. This could be due to the phase changes of the AZO films. As the substrate temperature increases from 225 to 325 °C, the increasing diffraction peak intensity of (002) is primarily due to the crystallization of the AZO film.

Electric-Field-Driven Phase Transition in Vanadium Dioxide

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We report on local probe measurements of current-voltage and electrostatic force-voltage characteristics of electric field induced insulator to metal transition in VO2 thin film. In conducting AFM mode, switching from the insulating to metallic state occurs for electric field threshold E ~ 6.5 10^6 V/m at 300 K. Upon lifting the tip above the sample surface, we find that the transition can also be observed through a change in electrostatic force and in tunneling current. In this non-contact regime, the transition is characterized by random telegraphic noise. These results show that electric field alone is sufficient to induce the transition, however, the electronic current provides a positive feedback effect that amplifies the phenomena.
12P-D020  Theory of inverse Faraday effect in disordered metal in the THz regime

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Photo-induced magnetization induced by a circularly polarized light (inverse Faraday effect) has been studied since the 1960s. Recently, the induced effective magnetic field is shown to be as strong as a few Tesla due to the development of laser technology. So far the mechanism of the inverse Faraday effect was considered in the case of optical light. In this paper, we calculate the magnetization dynamics induced by the inverse Faraday effect in a disordered metal in a THz regime by using the diagrammatical method. We show that the induced magnetization is proportional to the frequency of light and that the induced effective magnetic field reaches 10 Tesla in a strong spin-orbit coupling material.


12P-D021  Break-junction experiments on the zero-bias anomaly of non-magnetic and ferromagnetically ordered metals

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One of the many mysteries of point-contact spectroscopy is the so-called zero-bias anomaly (ZBA), an unexplained maximum or minimum of the differential resistance at zero bias. Over a narrow range of contact resistances the size of the ZBA can vary by several orders of magnitude, making the anomalies appear irreproducible. However, we have shown earlier with shear-anvil and shear-type contacts that on a global scale of resistances between 1 Ω and 10 kΩ the ZBA is reproducible. The size δR of the ZBA varies like δR ∼ (9π/16)R2/RK where R is the estimated zero-bias resistance without ZBA. This magnitude corresponds to Kondo scattering at a single impurity in the unitary limit or to the on/off switching of a single conductance channel. Here we report on experimentally controllable break junctions of ferromagnetic Co, Fe, and Ni as well as the non-magnetic normal metals Al, Cd, and Cu in the 1 Ω − 10 kΩ range. In their spectra ZBAs similar to those of the shear-anvil and shear contacts are present. Co and Fe contacts show the expected δR ∼ R2 behaviour, while the other metals have a slightly weaker δR ∼ R3/2 dependence. The magnitude of the anomalies of atomic-size Co, Fe, and Ni contacts agrees well with that observed by others.


12P-D022  Self-dual Josephson junction arrays: quantum dissipation and the quantum Hall effect

S. Sakhi*, a College of Arts and Sciences b Department of Physics, American University of Sharjah, United Arab Emirates

Quantum dissipation and the quantum Hall effect are studied in a self-dual Josephson junction planar array (JJA) in the presence of commensurate offset charges and magnetic field frustration. The quantum phase model of JJA is mapped at low energy into a U(1) × U(1) mixed Chern-Simons Landau-Ginzburg theory consisting of disorder fields associated with electric and magnetic charges. The dual theory viewpoint offers a new insight into the study of the superconducting and insulating phases in JJA systems. I explore the interplay between the emergence of condensates in this model and intrinsic quantum dissipation effects. I evaluate the electromagnetic response functions of the system and I find, among other things, that in the presence of commensurate electric and magnetic frustrations, bound objects made up of electric and magnetic topological excitations are formed, and their condensation leads to the Hall effect. This effect is robust in the presence of quantum dissipation which originates from the production of internally generated gapless bosonic excitations. The ensuing longitudinal and transverse resistivities are found to be finite and universal, and satisfy a relation analogous to that found in the QHE of two-dimensional electron systems.

12P-D023  Decoherence in Aharonov-Bohm Ring with Embedded Quantum Dot in Kondo Regime

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In an Aharonov-Bohm (AB) ring with an embedded quantum dot, the coherence in the quantum dot can be detected by the transport. In the Kondo regime, the transport through the quantum dot is totally elastic at temperature T = 0, whereas inelastic processes become dominant at large T. To examine the decoherence by the inelastic processes, we theoretically examine the conductance in an AB ring with an embedded quantum dot in the Kondo regime. First, we adopt the “poor man’s” scaling method. We derive an analytical expression for the conductance at T ≪ Tk. The term of T2 decreases the amplitude of the AB oscillation. Second, we evaluate the conductance by elastic and inelastic processes separately using the Kubo formula, in order to elucidate the origin of the decoherence. We find that the magnetic-flux dependence of the inelastic part of the conductance is different from that of the elastic part. The decoherence due to the inelastic scattering is enhanced with increasing the temperature.

12P-D024 Activation like behavior on the temperature dependence of the carrier density in In$_2$O$_3$-ZnO films

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We focus on the effect of annealing effect in high vacuum to the transport properties for In$_2$O$_3$-ZnO films. We prepared indium zinc oxide films by the DC-magnetron sputtering method using an In$_2$O$_3$-ZnO target (89.3 wt % In$_2$O$_3$ and 10.7 wt % ZnO). The annealing temperature in our experiments is from 373 to 773 K. From the XRD analysis, we find that all as deposited films are amorphous, and films are crystallized by annealing at a temperature above 773 K over 2 hours. The temperature dependence of resistivity $\rho(T)$ of all amorphous films shows metallic behavior. On the other hand, $\rho(T)$ of poly In$_2$O$_3$-ZnO films shows semiconducting behavior. We carry out a detailed analysis of the temperature dependence of Hall effect. The activation energy $E_a$ has been obtained from the slope of the carrier concentration $N_c$ vs the inverse temperature plot at high temperatures. We find that the $E_a$ values between 0.43 and 0.19 meV. Meanwhile, temperature dependence of $N_c$ for poly-In$_2$O$_3$-ZnO films did not show activation-like behavior. This behavior is thought to be causally related to impurity conduction band.

12P-D025 Hollandite ruthenate K$_2$Ru$_8$O$_{16}$ as a new Tomonaga-Luttinger-liquid system

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The electronic structure of hollandite ruthenate K$_2$Ru$_8$O$_{16}$ is calculated using the generalized gradient approximation (GGA) in the density functional theory, where the Hubbard-type repulsive interaction is taken into account (GGA+$U$). We find that the electronic structure near the Fermi level consists only of a single band coming predominantly from the 4$d_{yz}$ and 4$d_{zx}$ orbitals of Ru ions with strong admixture of the 2$p_z$ orbitals of corner-shared O ions connecting the double RuO chains. The band structure near the Fermi level is highly quasi-one-dimensional, exactly at half filling, and has a pair of two nearly parallel sheetlike Fermi surfaces separated by $\pi/c$. The calculated results are consistent with observed quasi-one-dimensional transport properties of this material [1]. These results establish that K$_2$Ru$_8$O$_{16}$ belongs to a class of the simplest possible Tomonaga-Luttinger-liquid materials. See Ref. [2] for details.

12P-D027 Aharonov-Bohm-type Oscillations in a System of Two Tunnel Point-Contacts in the Presence of a Single Scattering: Determination of the Depth of the Buried Impurity

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The conductance of a system containing two tunnel point-contacts (geometry of double-tip STM experiment) and a single subsurface scatterer nearby is investigated theoretically. It is shown that in the presence of a magnetic field the conductance undergoes Aharonov-Bohm type oscillations. They result from a magnetic flux penetrating through the area which is formed by the line connecting the contacts and the trajectories of electrons moving from one contact to the scatterer and after the scattering event arrives at the second contact. In a weak magnetic field the mentioned area is a triangle with a known base (distance between the contacts). A measurement of the period of oscillations which is defined by the magnetic flux quantum is a simple way to find the square of the electron trajectory and hence a depth of the defect below the sample surface. In this work analytical expressions for the wave function and the conductance of the system are obtained. The de-
dependence of the conductance on the value and direction of the magnetic field is analyzed. On the basis of these theoretical investigations a new method to determine the defect position below the surface is proposed.

Session 12P-E:

E2 Josephson Effect / SQUID Techniques
Friday August 12, 16:00 – 18:00
Exhibition Hall 1

12P-E001 Size-dependent transformation from triangular to rectangular fluxon lattice in Bi-2212 mesa structures
H. Motzkau\textsuperscript{a}, S.-O. Katterwe\textsuperscript{a}, A. Rydh\textsuperscript{a}, V.M. Krasnov\textsuperscript{a}, \textsuperscript{a}Department of Physics, Stockholm University, Stockholm, Sweden

We present a systematic study of the field and size dependencies of the static fluxon lattice configuration in Bi-2212 intrinsic Josephson junctions and investigate conditions needed for the formation of a rectangular fluxon lattice required for a high power flux-flow oscillator. We fabricate junctions of different sizes from Bi\textsubscript{2}Sr\textsubscript{2}CaCu\textsubscript{2}O\textsubscript{8+x} and Bi\textsubscript{1.75}Pb\textsubscript{0.25}Sr\textsubscript{2}CaCu\textsubscript{2}O\textsubscript{8+x}, single crystals using the mesa technique and study the Fraunhofer-like modulation of the critical current with magnetic field. The modulation can be divided into three regions depending on the formed fluxon lattice. At low field, no periodic modulation and no ordered fluxon lattice is found. At intermediate fields, modulation with half-flux quantum periodicity due to a triangular lattice is seen. At high fields, the rectangular lattice gives integer flux quantum periodicity. We present these fields in dependence on the sample size and conclude that the transitions between the regions depend only on \(\lambda_3(J_c)\) and occur at about 0.4 and 1.3 fluxons per \(\lambda_3\). These numbers are universal for the measured samples and are consistent with performed numerical simulations.

12P-E002 Effect of field gradient and disturbance on the ultra-low field NMR signal detecting using a high-\(T_c\) dc-SQUID
Y.R Jin\textsuperscript{a}, N. Wang\textsuperscript{a}, H. Deng\textsuperscript{a}, J. Li\textsuperscript{a}, Y.L Wu\textsuperscript{a}, Y. Tian\textsuperscript{a}, D.N Zheng\textsuperscript{a}, \textsuperscript{a}Institute of Physics of Physics, Chinese Academy of Sciences, Beijing, China

We have detected the ultra-low field nuclear magnetic resonance signal from water samples using a high-\(T_c\) dc-SQUID sensor. The measurements were carried out in a home-made magnetically shielded room. Resonance spectra of \(^1H\) from tap water and other substance samples were obtained in the field range from 7 to 70 \(T\), corresponding to resonance frequency 300 – 3k Hz. The signal to noise ratio in a single-shot measurement is around 4 for about 15ml water, which would be increased to about 40 after 100 times averaging. The residual magnetic field in the magnetically shielded room is about 100 \(nT\) and shows slow variation with time. A field gradient associated with the residual field is also observed. The effect of residual magnetic field in the magnetically shielded room was investigated by applying purposely a field gradient and slow variation field disturbance. Additionally, we have also investigated the signal detection using a Cu coil that is inductively coupled to the SQUID sensor.

12P-E003 SQUID development for multiplexed cryogenic detectors
M. Kiviranta\textsuperscript{a}, L. Grönberg\textsuperscript{a}, \textsuperscript{a}ViTT Technical Research Centre of Finland, Espoo, Finland

We are developing multiplexed SQUID readout techniques for multi-pixel focal plane arrays of Transition Edge Detectors. Space missions such as the submillimetre wave telescope SPICA and the X-ray telescope XIUS are targeted. We discuss design and experiments regarding the SQUID circuits with large signal bandwidth, high linearity, and low power dissipation at millikelvin temperatures, as required to implement the large Shannon capacity of the readout channel.

12P-E004 Comparative analysis of optical-physical schemes of gyroscopes based on macroscopic quantum effects of superfluid helium isotopes (3He & 4He)
V.S. Chernichenko\textsuperscript{a},\textsuperscript{b}, A.I. Bendenko\textsuperscript{a},\textsuperscript{b}, N.V. Tribulev\textsuperscript{a},\textsuperscript{b}, N.I. Krobka\textsuperscript{a}, \textsuperscript{b}Scientific&Research Institute for Applied Mechanics named after academician V.I. Kuznetsov \textsuperscript{b}Moscow State Technical University named after Bauman

Measuring fluctuations in Earth’s rotation rate requires a sensitive laboratory instrument. Now, two groups of researchers have exploited the peculiar quantum properties of superfluid helium to build novel gyroscopes that can sense Earth’s spin. Richard E. Packard, a physicist of the University of California, Berkeley, has demonstrated a new kind of gyroscopes that can detect absolute rotation at a very sensitive level. In principle, the new device has the potential to surpass the most sensitive gyroscopes available today for high-precision measurements of rotation rates. Eric Varoquaux of the University of Paris-South in Orsay, France, and his coworkers presented their findings last year at a conference in Prague. And now my group (the first group in Russia) has started doing a research. Gathering the worldwide experience (in patents, scientific efforts etc.), we aim to achieve the purity of our developments. A superfluid helium gyroscope takes advantage of the fact that the flow of a superfluid filling a doughnut-shaped container is quantized. In this case, the flow velocity multiplied by the length of the path along the center of the toroidal channel must be zero or a whole-number multiple of a fundamental quantity determined by Planck’s constant and the mass of a helium atom.

12P-E005 Low Temperature Analysis of Nickel Nano Particles by SQUID Based AC Susceptibility
J. R. O’Brien\textsuperscript{a}, A. Stroyd\textsuperscript{b}, W. G. Coors\textsuperscript{b}, \textsuperscript{a}Quantum Design, San Diego, CA, 92121 \textsuperscript{b}Department of Physics, University of Johannesburg, South Africa \textsuperscript{c}Ceramatech, Salt Lake City, UT 84119

The solid oxide fuel cell material 10 percent yttria stabilized zirconia (10YSZ) plus addition of 1 mass percent NiO serves as a model system. With electronic field assisted reduction (e-FAR) technique, the dissolved Ni\textsuperscript{2+} ions transform into super-paramagnetic Ni metal particles. The temperature dependence of the AC susceptibility response confirms reasonably narrow size dis-
tribution on the bulk scale. The unique capability of SQUID based AC to run at low 1 Hz frequency broadens transition towards lower temperatures. The onset for out-of-phase component scales with particle size and the 3.5 K blocking temperature suggests 2-3 nm range. Extending the analysis to 0.5 K with helium-3 insert enables further characterization of these smallest Ni nano particles. Finally, the size dependent function for small DC biased fields to suppress AC response is presented.

12P-E006 Josephson effects of High-Tc YBCO variable-thickness bridges
C. H. Wu, F. J. Jhan, J. T. Jeng, Institute of nanoscience, National Chung Hsing University, Taichung 402, Taiwan  
Department of Mechanical Engineering, National Kaohsiung University of Applied Sciences, Kaohsiung 807, Taiwan

The high-Tc Josephson junctions were successfully fabricated by using the variable-thickness bridges (VTB) technique, which controls the thickness of the link region to several nanometers. The VTB of YBCO thin film were fabricated by standard Ar ion beam and Focused ion beam mill. The properties of variable-thickness bridges were investigated. A set of voltage-current curves measures in a junction after irradiation with microwaves at f =5.97 GHz and various powers from 0 to 15 dBm was obtained. The voltage-current is in good agreement with resistivity-shunted-junction (RSJ) model. These bridges of YBCO with VTB have well agreed d.c. and a.c. Josephson effects and have revealed the superconductor-normal-superconductor weak link character.

12P-E007 Fabrication of rhenium Josephson junctions
G. M. Xue, H. F. Yu, Y. F. Ren, Ye Tian, S. P. Zhao, Beijing National Laboratory for Condensed Matter Physics, Institute of Physics, Chinese Academy of Sciences, Beijing 100190, China

Rhenium is a hardly oxidizable metal which is often used in superconducting circuits and qubit applications. In this work, superconducting Re/Al-AlO$_x$/Re tunnel junctions were fabricated using a selective film-etching process similar to that developed in Nb trilayer technology. The Re films had a superconducting transition temperature of 4.8 K and a transition width of 0.2 K. The junction characteristics had good quality with low leakage current and showed a superconducting gap of 0.55 meV. These junctions were found to be reproducible and stable against thermal cycling.

12P-E008 Four electrons transport of a supercurrent in Josephson junction and anharmonic dependence by a current-phase
D. Sergeyev, S. Dzhumanov, Aktobe State Pedagogical Institute, Aktobe, Kazakhstan

In work the hypothesis about 4e transport of a supercurrent in Josephson junction (JJ) is offered by much lower critical temperature. In work the microscopic theory of persistence pair Bose-Einstein condensation (PBEC) is considered. As known, that there is a model of considering superconducting transition, as BEC. In our case, PBEC - bi-Cooper pairs consisting from two Cooper pairs. It is determined, that at 4e realization of transport of a supercurrent in JJ the current - phase dependence becomes anharmonic. It is shown, that in result 4e transport of a supercurrent in JJ is observed occurrence half-integral of Shapiro’s steps on current-voltage characteristic under action of a microwave of a signal, increase of size of plasma frequency, occurrence in dependence a current - flux of minima at fractional meanings of the normalized magnetic flow.

Session 12E: Celebration of the Centennial of Superconductivity

Chair: Zhongxian Zhao
Friday August 12, 19:30 – 22:00
Convention Hall 1

12E-1 Kamerlingh Onnes’s Notebooks and the Discovery of Superconductivity
Peter H. Kes
Kamerlingh Onnes Laboratory, Leiden Institute of Physics, Leiden University, Netherlands

A century ago Heike Kamerlingh Onnes and his collaborators were the first to observe superconductivity. Although accidental, his retracted notebooks tell us today that this was the result of a well planned research program which was started after liquid helium temperatures were reached.


12E-2 High Tc Superconductivity in copper oxides - from retrospective to outlook
J. Georg Bednorz
IBM Research - Zurich säumerstrasse 4, CH-8803 Rüschlikon, Switzerland

The centennial of the discovery of superconductivity coincides with the 25th anniversary of the discovery of high-Tc superconductivity. In retrospective the guiding ideas and decisive circumstances will be described which in January 1986 lead to the discovery of the new cuprate superconductors. A less than one year, time was left for the Zurich team to test different La2CuO4 based compounds, to confirm the Meissner Effect and to study flux trapping in the new materials. It was also the time where the news of the discovery started to spread out and experienced mixed reactions were obtained ranging from silent skepticism to polite (cautious) congratulations. This changed dramatically to excitement with the confirmation of the Zurich results by research teams in Japan, China and USA and culminated with the take-off of the new field at the famous “Woodstock Meeting of Physics”after the discovery of the 90K superconductor.Today- after 25 Years the field is ready to present a broad spectrum of large-scale applications. Some have been envisaged already since the early days of superconductivity. However, only with the new cuprate superconductors does it now become possible - after one century - to finally realize these ideas. Large-scale applications will however have to overcome the usual problems of a new technology - but superconductivity will definitively become a key technology for the 21st century.

12E-3 Heavy-Fermion Superconductivity Mediated by Antiferromagnetic Spin Fluctuations
F. Steglich
Max Planck Institute for Chemical Physics of Solids, Dresden, Germany

The phase diagram of the prototypical heavy-fermion superconductor CeCu2Si2 contains a quantum critical point (QCP) of three-dimensional (3D) spin-density-wave (SDW) type. Recently, inelastic-neutron-scattering measurements have been performed on S-type CeCu2Si2, located on the paramagnetic side close to the QCP. The magnetic response in the superconducting state is characterized by an inelastic signal resulting from the transfer of spectral weight to energies above a spin-excitation gap. In the normal state, a slowing down of the quasielastic magnetic response is observed that conforms to the scaling expected for a 3D-SDW QCP. According to its momentum dependence this quasielastic (Lorentzian) line can be considered an overdamped dispersive mode (“antiferromagnetic paramagnon”) whose coupling to the heavy charge carriers is strongly retarded. These results highlight Cooper pairing mediated by nearly quantum critical SDW fluctuations. Work done in cooperation with O. Stockert, J. Arndt, M. Loewenhaupt, H.S. Jeevan, C. Geibel, S. Kirchner and Q. Si.


12E-4 A Common Thread: the pairing mechanism in the unconventional superconductors
D. J. Scalapino
University of California, Santa Barbara, CA 93106-9530, USA

The structures, the phase diagrams, and the appearance of a neutron resonance signaling an unconventional superconducting state provide phenomenological evidence relating the heavy fermion, cuprate and Fe superconductors. Single- and multi-band Hubbard models have been found to describe a number of the observed properties of these
materials so that it is reasonable to examine the origin of the pairing interaction in these models. Here based on
the experimental phenomenology and studies of the pairing interaction for Hubbard-like models, we suggest that
spin-fluctuation mediated pairing is the common thread linking this broad class of superconducting materials. We
will also discuss possible ways to increase $T_c$ based upon these ideas.
Session 13H1: Half Plenary Lectures
Chair: Jukka Pekola
Saturday August 13, 09:00 – 10:30
Convention Hall 3

13H1-1 Mechanical resonators in the quantum regime
A. N. Cleland*, "Department of Physics, University of California, Santa Barbara
I will describe our recent experiments, representing about ten years’ development of nanomechanical and quantum
circuit technology, which culminated in our formulating and creating a quantum mechanical resonator that could
“easily” be prepared in quantum (non-classical) states of mechanical vibration. Key requirements included a
mechanical design that supported a microwave-frequency mechanical resonance; using a piezoelectric material in
order to achieve very strong electromechanical coupling; and employing a Josephson junction, implemented as a
phase quantum bit (qubit), to measure and interact with the mechanical resonator. Operating at 25 mK on the
mixing chamber of a dilution refrigerator, this integrated electromechanical system can be cooled to its quantum
ground state without additional intervention. Then, employing the extraordinary nonlinearity provided by the
Josephson qubit, and the coherent interactions of this qubit and the mechanical resonator, we were able to prepare
and measure non-classical mechanical states of motion in the resonator.

13H1-2 Spin Qubits and Qubit Gates with Quantum Dots
S. Tarucha*, "Department of Applied Physics and QPEC, The University of Tokyo, Tokyo, Japan
To date electron spin qubits have been demonstrated using various techniques with quantum dots (QDs), and
it is now getting crucial to prepare multiple qubit systems and perform gate operation as the next step. We
have recently developed a micro-magnet technique for making spin qubits with double QDs, which might suit the
qubit multiplication and logical gate operations. I will show this technique is useful to realize multiple qubits,
entanglement modulation, and non-destructive readout. Electron spin resonance (ESR) is the fundamental concept
of spin qubits, in which two Zeeman states are superposed by an ac magnetic field normal to the Zeeman field.
A micro-magnet placed on top of a double QD imposes an out-of plane field gradient local to each QD under an
in-plane external field. By laterally oscillating an electron in each QD with a microwave field, ESR local to each
QD can be established. We first demonstrate two individual spin rotations using this technique, and then combine
it with a pulsed operation of spin exchange coupling to modulate the spin singlet-state as a partial entangled state.
We propose that the inhomogeneous magnetic field across the double QD can provide novel concepts of
\( z \)-rotation gates and fidelity control of SWAP and \( \sqrt{\text{SWAP}} \). We also show that the micro-magnet technique is useful for
spin readout in a nondestructive manner.

13H1-3 Generating and Detecting Propagating Photons in Superconductive Circuits
Andreas Wallraff*, "ETH Zurich, Zurich, Switzerland
Using modern micro and nano-fabrication techniques combined with superconducting materials we realize quantum
electronic circuits to create, store, and manipulate individual microwave photons on a chip. The strong interaction
of photons with superconducting quantum two-level systems allows us to probe the fundamental quantum prop-
erties of light. In particular, I will discuss experiments in which we realize an on-demand microwave frequency
single photon source which we characterize by correlation function measurements. In the absence of efficient single
photon counters, we use on-chip 50/50 beam splitters with off-chip linear amplifiers and quadrature amplitude
detectors for which we have developed efficient methods to separate the detected single photon signal from the
added noise. We verify the operation of the single photon source by demonstrating single photon coherence and
photon antibunching in first and second-order correlation function measurements\(^1\). I will also present measure-
ments in which we reconstruct the Wigner function of itinerant single photon Fock states and their superposition
with the vacuum\(^2\). The techniques and methods demonstrated in this work may find broad application in the
analysis of microwave radiation emitted from mesoscopic devices, in future linear optics and quantum information
processing experiments.

1 D. Bozyigit et al., Nat. Phys. 7, 154 (2011)
Saturday morning, 13 13H2: Half Plenary Lectures
Chair: Fuchun Zhang
Saturday August 13, 09:00 – 10:30
Convention Hall 2

13H2-1 Fullerene Superconductivity 20 Years on
Kosmas Prassides*, a Department of Chemistry, Durham University, Durham DH1 3LE, UK

A3C60 (A=alkali metal) superconductors were known to adopt fcc structures with their superconducting Tc increasing monotonically with increasing interfullerene spacing, reaching a 33 K maximum for RbCs2C60; this physical picture had remained unaltered since 1992. Trace superconductivity (< 0.1%) at 40 K under pressure was also reported in 1995 in multiphase samples with nominal composition Cs3C60. Despite numerous attempts by many groups worldwide, this remained unconfirmed and the structure and composition of the material responsible for superconductivity unidentified. Thus the possibility of enhancing fulleride superconductivity and understanding the structures and properties of these archetypal molecular solids had remained elusive. Here I will present our recent progress in accessing high-symmetry hyperexpanded alkali fullerenes in the vicinity of the Mott-Hubbard metal-insulator boundary and at previously inaccessible intermolecular separations. The physical picture that emerges for the alkali fullerenes is that, contrary to long-held beliefs, they are the simplest members of the high-Tc superconductivity family. We demonstrated this by showing that in the two hyperexpanded Cs3C60 polymorphs (fcc- and A15-structured), 1 superconductivity emerges upon applied pressure out of an antiferromagnetic insulating state and displays an unconventional behaviour, a superconductivity dome, explicable by the prominent role of strong electron correlations.


13H2-2 Electric Field Induced Interface Superconductivity
Y. Iwasa*, a Quantum-Phase Electronics Centre & Department of Applied Physics, University of Tokyo, Tokyo, Japan. b Correlated Electron Research Group, RIKEN-ASI, Wako, Japan.

Electric double layer (EDL), a nano-gapped capacitor self-organized at the solid-liquid interfaces, is an electro-chemical concept proposed by Helmholtz 150 year ago. Because of its large capacitance and high density charge accumulation, EDL has been used in market as capacitor devices, called Supercapacitor or EDLC. We used EDL as a gate dielectric of a transistor device, which is named as EDL transistor (EDLT), and have demonstrated that EDLT can be a powerful tool for controlling interface quantum phases. An amazing example is the realization of electric field induced superconductivity in several insulators without any help of chemical doping, which has been anticipated for the last 50 years without success. In this paper, we describe a basic concept of EDLT and variety of electric field induced phenomena including superconductivity. This work has been carried out in collaboration with H. T. Yuan, J. T. Ye, Y. Kasahara, M. Kawasaki, K. Ueno, T. Fukumura (University of Tokyo), H. Shimotani, T. Nojima, S. Nakamura (Tohoku University), and T. Hatano, M Nakano, S. Ono (RIKEN).

13H2-3 Laser ARPES on High-Temperature Cuprate Superconductors
X. J. Zhou*, a National Lab for Superconductivity, Institute of Physics, Chinese Academy of Sciences, Beijing 100190, China. Email: XJZhou@aphy.iphy.ac.cn

After more than two decades, the superconductivity mechanism of high temperature copper-oxide (cuprate) superconductors remains an outstanding issue in condensed matter physics. Angle-resolved photoemission spectroscopy (ARPES) is a powerful tool to directly probe the electronic structure and superconductivity mechanism in cuprate superconductors. The utilization of the Vacuum Ultraviolet (VUV) laser as a new light source has elevated the ARPES technique to a new level by possessing unique advantages such as super-high energy resolution (better than 1 meV), high momentum resolution, super-high photon flux and enhanced bulk sensitivity [1]. The high-precision laser ARPES measurements have provided new insights on the Fermi surface topology and energy gap in cuprate superconductors [2,3]. Particularly, it has become a powerful tool to investigate many-body effects in cuprates[4,5,6,7]. In this talk, we will highlight some recent results obtained from the VUV laser-based ARPES on high temperature cuprate superconductors. Future developments will also be discussed.

13m-A1 The Proximity Effect at the Interface between Superfluid 3He-B and 97.5% Porosity Aerogel
O. Ishikawa, S. Ogawa, A. Fukui, K. Obara, H. Yano, T. Hata, Graduate School of Science, Osaka City University, Osaka, Japan

Recently, a novel feature of condensate state in liquid 3He is predicted theoretically, which consists of spin triplet s-wave Cooper pairs. Such a spin triplet s-wave state will appear inside aerogel near the surface boundary contacting with superfluid 3He-B. This interface between superfluid 3He-B and aerogel changes the way of quasiparticle scattering to have not only p-wave scattering but also other types of them. As a result, spin triplet s-wave pair amplitude will be dominant with odd symmetry in time region, so called an odd frequency Cooper pair. In order to detect this proximity effect, we made the interface in columnar glass tube, and set three saddle shape NMR coils on outside of the glass tube at bulk 3He, the interface, and 97.5% porosity aerogel. We are now performing cw-NMR measurements down to 0.5mK at 24 bar.


13m-A2 Structure of A-like Phase of 3He in Anisotropic Aerogel
V.V. Dmitriev, D.A. Krasnikhin, N. Mulders, A.A. Senin, G.E. Volovik, A.N. Yudin, P. L. Kapitza Institute for Physical Problems RAS, Moscow, Russia
bDepartment of Physics and Astronomy, University of Delaware, Newark, Delaware, USA
cLow Temperature Laboratory, Aalto University, Espoo, Finland; L. D. Landau Institute for Theoretical Physics RAS, Moscow, Russia

In the A-like phase of 3He in uniaxially deformed aerogel different spatial distributions of the Anderson-Brinkman-Morel order parameter can be realized. In case of stretching deformation two glass phases can exist. Both phases represent the anisotropic glass of the orbital vector \( \mathbf{L} \) (the orbital glass) and differ by the spin structure: the spin vector \( \mathbf{d} \) can be either in the ordered spin nematic (SN) state or in the disordered spin glass (SG) state. SN and SG states also exist in squeezed aerogel, while in the orbital space two states can be formed - orbital glass or orbital ferromagnet, the latter corresponding to homogeneous spatial distribution of \( \mathbf{L} \) oriented along the axis of squeezing. We demonstrate that NMR signatures of different states allow to measure the parameter of the global anisotropy of the \( \mathbf{L} \)-distribution. The case of biaxial anisotropy will also be considered in the talk.

13m-A3 New Types of Magnon BEC in Superfluid 3He in Aerogel.
P. Hunger, Yu.M. Bunkov, E. Collin, H. Godfrin, Institut Néel, CNRS et Université Joseph Fourier, BP 166, F-38042 Grenoble Cedex 9, France

The Spin Supercurrent and Bose-Einstein condensation of magnons similar to an atomic BEC was observed in 1984 in superfluid 3He-B. Recently we discovered 2 new types of BEC in superfluid 3He in deformed aerogel. The orbital part of the wave function orientates along the deformation and changes the magnon-magnon interaction. In some cases it forms a magnon trap. We can do it for 3He-A by uniaxially compressing the aerogel along the magnetic field. The other BEC state was observed in 3He-B in aerogel stretched along the magnetic field. Both states show all properties of magnon BEC. We have also observed a splitting of NMR lines near \( T_c \), which seems to indicate the formation of a new phase of superfluid 3He in aerogel. The latter looks like an analog of the 3He-A phase with strongly enhanced magnetic field.

1 T. Kunimatsu, et. al. JETP Lett. 86, 216 (2007)

13m-A4 Phase diagram of superfluid 3He in 10% uniaxially compressed aerogel
J. Parpia, R. Bennett, N. Zhelev, E. Smith, J. Pollanen, W. Halperin, Department of Physics, Cornell University, Ithaca, NY 14853, USA
bDepartment of Physics and Astronomy, Northwestern University, Evanston, IL 60208, USA

We measure the pressure dependent superfluid fraction of 3He entrained in axially compressed 98% open aerogel using a torsion oscillator. The aerogel was grown in a slab geometry and compressed axially by 10% to a 400 \( \mu \)m height. We observe an enhanced region of the temperature-pressure phase diagram to be occupied by a metastable A phase all in zero applied magnetic field. Crucially we observe the reappearance of the A phase upon warming from the B phase before the superfluidity of the “dirty” 3He is extinguished at the suppressed \( T_c \), in contrast to
the coincidence of the B to A transition with $T_c$ upon warming in uncompressed aerogel. The re-entrant A phase is seen to extend well below the polycritical pressure. The A to B transition (observed while cooling) and the B to A transition (sampled by “turnarounds”) exhibit finite widths in temperature. The presence of this region of reentrant A phase (between the normal and dominant B phase) that is enhanced by the anisotropic disorder of the compressed aerogel together with the disappearance of the polycritical point are the principal modifications of the phase diagram from its bulk form. However the expected alignment of the A phase texture by compression of the aerogel is not observed in the measured superfluid fraction.

**13m-A5 Drag Force on a High Porosity Aerogel in Liquid $^3$He**

H. Takeuchi*, S. Higashitani*, K. Nagai*, *Graduate School of Integrated Arts and Sciences, Hiroshima University, Kagamiyama 1-7-1, Higashi-Hiroshima 739-8521, Japan

When a body is immersed in liquid $^3$He and there is a velocity difference between them, a drag force acts on the surface of the body. The drag force can be characterized by the linear size of the body, $a$, and the quasiparticle mean free path, $l_m$, originating from inelastic mutual collisions. In the Knudsen limit $l_m \gg a$, the drag force depends on the geometry of the body through the cross-sectional area, as can be found from analysis of the Landau transport equation with an appropriate boundary condition at the surface. In the opposite limit $l_m \ll a$ (the hydrodynamic limit), it is well known that the drag force is proportional to the linear size $a$; e.g., for a spherical body of radius $a$, the hydrodynamic drag force obeys the Stokes law $6\pi \eta a v$ with $\eta$ the viscosity of liquid and $v$ the flow velocity relative to the body. We discuss the crossover from the Knudsen limit to the hydrodynamic limit in a high porosity silica aerogel filled with liquid $^3$He. In this system, $a$ corresponds to the size of the silica particles ($\sim 3$ nm). Then it is expected that the crossover occurs at $\sim 100$ mK as a result of the decrease of the quasiparticle mean free path $l_m$ with increasing temperature. Such a crossover seems to be observed by the ultrasound attenuation measurements reported by Choi et al., as rapid increase of the attenuation at around 100 mK.

Session 13m-B₁: Recent Discovery and Properties of AFeₓSe₂ (A=K, Rb, Cs, Tl)

Chair: Zhu-An Xu
Saturday August 13, 10:50 – 12:30
Convention Hall 3

13m-B₁.1 Superconductivity in iron selenide K₀.₈Fe₂Se₂

Research & Development Center for Functional Crystals, Beijing National Laboratory for Condensed Matter Physics, Institute of Physics, Chinese Academy of Sciences, Beijing 100190, China National Center for Nanoscience and Technology, Beijing 100190, China

Since the discovery of superconductivity in doped LaOFeAs, a series of superconducting iron-based compounds were found. Among them, FeSe has a substantially simplified structure stacked only by FeSe layers and no interacting cations. We reported a new iron-based superconductor K₀.₈Fe₁.₇Se₂ with transition temperature at about 30 K, which was synthesized by intercalating alkali-metal K in between FeSe layers. This new superconductor adopts a similar structure to BaFe₂As₂ while with a considerable amount of Fe vacancies in the FeSe layers. Phase transitions due to the Fe vacancy order occur at different temperatures. Meanwhile, Superconductivity at 43 K was often observed in resistivity and magnetization curves. Altering the synthesizing or annealing conditions result in enhancing or weakening the superconductivity at 43 K, implying the existence of an unknown superconducting phase. Furthermore, the rapid suppression of superconductivity by magnetic Co-doping is also reported. The pairing mechanism of the material has been proven to be different with all other known iron-based superconductors. The results may have important implications for understanding the superconductivity mechanism of iron-based superconductors and may shed a new light on exploring new high-temperature superconductors.

13m-B₁.2 Electronic structure of iron chalcogenides

D. L. Feng, State Key Laboratory of Surface Physics, Department of Physics, and Advanced Materials Laboratory, Fudan University, Shanghai, China

In the newly discovered AₓFe₂₋₉Se₂ (A=K,Cs) with a superconducting transition temperature of about 30 K, large electron Fermi surfaces are observed around the zone corners with an almost isotropic superconducting gap of ~10.3 meV, while there is no hole Fermi surface near the zone center, which demonstrate the inter-band scattering or Fermi surface nesting is not a necessary ingredient for the unconventional superconductivity in iron-based superconductors. Thus, the sign change in the s± pairing symmetry driven by the inter-band scattering as suggested in many weak coupling theories becomes irrelevant in describing the superconducting state here. A more conventional s-wave pairing is likely a better description. The electronic structure of other iron chalcogenides will be discussed as well.


13m-B₁.3 Neutron Scattering Study on the Newest 245 Family of Fe-based Superconductors

W. Bao, Department of Physics, Renmin University of China, Beijing, China

Recently a new family of metal intercalated iron selenide superconductors of Tc above 30 K has been discovered. We will present the determination of the sample composition, crystal structure and magnetic order using neutron diffraction technique. Contrary to previous belief, the materials are mostly charge balanced, instead of heavily electron doped, with the chemical formula close to AₓFe₂₋ₓ/₉Se₂ and the Fe valance close to +2. In superconducting samples x ~ 0.8, the Fe vacancies order into an almost perfect pattern in a five times larger unit cell and a large moment block checkerboard antiferromagnetic order is found to coexist with superconductivity. This is so for all the superconductors discovered so far: A=K, Rb, Cs, (Tl,K), and (Tl,Rb) and their appropriate chemical composition is close to A₀.₈Fe₁.₅Se₂ or A₂Fe₄Se₅. For non-superconducting samples, the Fe vacancy order is only partial and a transport gap is present at low temperature. These results demonstrate a very different kind of superconductors from all previous iron based high Tc superconductors, and a new mechanism is anticipated.

**13m-B1** 4  **Electronic structures and magnetic orders of iron-pnictides or chalcogenides**  

Zhong-Yi Lu
department of Physics, Renmin University of China, Beijing 100872, China  

The first-principles electronic structure calculations play an important role on study of high Tc superconductor iron-pnictides or chalcogenides. Iron-pnictides were first predicted by the theoretical calculations to be antiferromagnetic semimetals. Based on the calculations, Arsenic-bridged antiferromagnetic superexchange interaction was proposed. The bi-collinear antiferromagnetic order was then predicted for iron-chalcogenide \( \alpha \)-FeTe. Recently, the parent compounds of superconductors iron-chalcogenides \( K_yFe_{2-x}Se_2 \) with ordered Fe vacancies were further shown to be antiferromagnetic semiconductors, in which the superconductivity emerges upon electron or hole doping, especially, the superconductivity and antiferromagnetic long-range order coexist. It was then proposed that the superconductivity is driven by mediating coherent spin wave excitations in these materials \( K_yFe_{2-x}Se_2 \).  

5. arXiv:1102.4575

**13m-B1** 5  **Electron Correlations and Superconductivity in Iron Pnic- tides and Selenides**  

Qimiao Si
department of Physics and Astronomy, Rice University, Houston, TX 77005, USA  

I will summarize the description of iron pnictides as bad metals close to a Mott transition. As a particular consequence, isoelectronic substitution that increases the kinetic energy will suppress antiferromagnetic order and give rise to a quantum critical point; this is by now extensively verified by experiments in P doped compounds of parent iron arsenides (for a recent review, see Ref. [1]). Within the same framework, I will also consider the implications of the recently discovered 122 iron selenides for Mott transition and local-moment magnetism [2]. Finally, I will discuss how this description makes it natural that the pairing strength of the 122 iron selenides is similar to that of their pnictides counterparts in spite of very different Fermi surfaces [3].  


**Session 13m-B2:** Heavy Fermion Superconductivity

**Chair:** Frank Steglich

**Saturday August 13, 10:50 – 12:30**

Room 305

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### 13m-B21 YFe$_2$Al$_{10}$: a New Fe-based Quantum Critical System

M. Aronson$^a$, L. Wu$^b$, K. Park$^c$, Y. Janssen$^a$, M. Kim$^a$, C. Marques$^a$, $^a$Stony Brook University, Stony Brook NY 11794, USA $^b$Brookhaven National Laboratory, Upton, New York 11973, USA

It is increasingly evident that quantum critical points (QCPs) where magnetic order is suppressed to $T=0$ play a central role in the phase diagrams of most classes of strongly correlated electron materials. Novel critical phenomena are found near QCPs, and when coupled to the electronic structure result in novel metallic states, whose instabilities include unconventional superconductivity. Despite current interest in Fe-based compounds, most detailed information about QCPs comes from experiments on f-electron based heavy fermion compounds. We present here measurements of the magnetization $M$, ac susceptibility $\chi'$, and specific heat $C$ in metallic YFe$_2$Al$_{10}$, where there is no indication of magnetic order above 0.05 K. In zero field, power law divergences are observed for $C/T\propto T^{-0.4}$ and $\chi'\propto T^{-1.26}$, suggesting that YFe$_2$Al$_{10}$ lies close to a $T=0$ magnetic phase transition. Magnetic fields suppress these quantum critical fluctuations, leading to scaling behavior with $M(H,T)=T^{-\beta}F(H/T^{\gamma+\beta})$ and the suppression of the $T\rightarrow0$ divergence in $\chi'$. A Fermi liquid regime emerges in field for $T\leq T_F(L,H)$, where the quasiparticles are strongly interacting, and the Sommerfeld coefficient $C/T=\gamma(H)-(H^{-1/2})$, indicating that their masses are enhanced by $\approx10$ for $H=1$ T, and even more near the $H=0$ quantum critical point. Our experiments establish that YFe$_2$Al$_{10}$ can be considered a d-electron relative of the heavy fermion compounds.

This work was supported by the Department of Energy, Office of Basic Energy Science.

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### 13m-B22 Nodal gap structure in weak-coupling non-centrosymmetric superconductors

H. Q. Yuan$^a$, J. Chen$^b$, J. L. Zhang$^b$, L. Jiao$^b$, M.B. Salamon$^a$, J. Akimitsu$^c$, J. Singleton$^a$, $^a$Department of Physics, Zhejiang University, Zhejiang 310027, China $^b$School of Natural Sciences and Mathematics, The University of Texas at Dallas, 800 W. Campbell Road, Richardson, Texas 75080, USA $^c$Department of Physics, Aoyama-Gakuin University, 6-16-1 Chitosai, Setagaya, Tokyo 157, Japan $^d$NHMFL, Los Alamos National Laboratory, MS E536, Los Alamos, NM 87545, USA

In non-centrosymmetric superconductors, the antisymmetric spin-orbital coupling (ASOC) may split the degeneracy of conduction electrons and allows the admixture of spin-singlet and spin-triplet pairing state. However, such a pairing state could be complicated by strong electronic correlations and its coexistence with magnetism in heavy fermions. It is, therefore, desired to study weak-coupling superconductors which pairing states can be solely tuned by adjusting their ASOC strength. Here we will present the evidence of nodal gap structure in weak-coupling non-centrosymmetric superconductors Li$_2$(Pd$_{1-x}$Pt$_x$)$_3$B$^1$ and Y$_2$C$_3$$^2$ by measuring the magnetic penetration depth. It is found that Li$_2$Pd$_3$B shows BCS-like superconductivity, but gapless superconductivity eventually develops while substituting Pd with Pt. Similarly, evidence of line nodes is also observed in Y$_2$C$_3$. We argue that these results are best understood as arising from the admixing of spin-singlet and spin-triplet order parameters as a result of the broken inversion symmetry, which ratio can be tuned by ASOC.

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### 13m-B23 Pressure-induced novel superconductivity and heavy electron state in rare earth compounds

F. Honda$^a$, Y. Hirose$^b$, S. Yoshiuchi$^b$, S. Yasui$^b$, T. Takeuchi$^b$, I. Bonalde$^c$, K. Shimizu$^d$, R. Settai$^b$, Y. Ônuki$^b$, $^a$Graduate School of Science, Osaka University, Osaka, Japan $^b$Low Temperature Center, Osaka University, Osaka, Japan $^c$Centro de Fisica, IVIC, Caracas 1020-A, Venezuela $^d$Kyokugen, Osaka University, Osaka, Japan

In rare-earth compounds, various kinds of electronic ground states such as magnetic ordering, heavy fermion, and unconventional superconductivity are realized as a result of the competition between the RKKY interaction and the Kondo effect. We have carried out the electrical resistivity measurements under high pressures on CePd$_3$Al$_2$, CeIrGe$_3$ and Yb$_2$Zn$_{20}$ (T: Co, Rh, Ir) in order to investigate quantum criticality and superconductivity. An antiferromagnet CePd$_3$Al$_2$ with a Néel temperature $T_N=4.1$ K, which is an isoostructural family of a heavy fermion superconductor $\text{NpPd}_3\text{Al}_2$, shows superconductivity around the critical pressure $P_c\approx10$ GPa. CeIrGe$_3$ with $T_N=8.7$ K, which crystallizes in the BaNi$_2$Sn$_3$-type tetragonal structure without inversion symmetry, also shows superconductivity above 20 GPa, which shows a huge upper critical field for $H\parallel [001]$.$^1$ On the other hand, YbIr$_2$Zn$_{20}$ exhibits a heavy fermion state exceeding 10 J/(K$^2$mol) around $P_c\approx5.2$ GPa.$^2$

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13m-B₂₄ Tracing the Kondo lattice in YbRh₂Si₂
S. Kirchner, S. Ernst, C. Krellner, C. Geibel, G. Zwicknagl, F. Steglich, S. Wirth, Max Planck Institute for Physics of Complex Systems, Dresden, Germany, Max Planck Institute for Chemical Physics of Solids, Dresden, Germany, Institut für Mathematische Physik, TU Braunschweig, Germany.

The quantum superpositions underlying entanglement are at the heart of the intricate interplay of localized spin states and itinerant electronic states that gives rise to the Kondo effect. In a Kondo lattice, this interplay gives rise to the emergence of charge carriers with enhanced effective masses, but the precise nature of the coherent Kondo state responsible for the generation of these heavy fermions remains highly debated. Here, we report on the phase diagram of YbRh₂Si₂ and discuss novel Scanning Tunneling Microscope results on a generic Kondo lattice system, YbRh₂Si₂, which trace the onset of this entanglement.

1 S. Ernst, S. Kirchner, C. Krellner, C. Geibel, G. Zwicknagl, F. Steglich, S. Wirth, Nature 474, 363 (2011)

13m-B₂₅ Intra-band Quasiparticle Interference and Direct Determination of the Anisotropic Superconducting Energy-Gap Structure in LiFeAs
M. P. Allan, T.-M. Chuang, A. W. Rost, Y. Xie, K. Kihou, H. Eisaki, J. C. Davis, Laboratoire de Solid State Physics, Department of Physics, Cornell University, Ithaca, NY 14853, USA; CMPMS Department, Brookhaven National Laboratory, Upton, NY 11973, USA; SUPA, School of Physics and Astronomy, University of St Andrews, St Andrews, Fife KY16 9SS, UK; Institute of Physics, Academia Sinica, Nankang, Taipei 11529, Taiwan; Institute of Advanced Industrial Science and Technology, Tsukuba, Ibaraki 305-8568, Japan; Kavli Institute at Cornell for Nanoscale Science, Cornell University, Ithaca, NY 14853, USA.

Cooper pairing in iron-based high temperature superconductors is often conjectured to occur via exchange of antiferromagnetic spin-fluctuations. These models generally lead to two characteristics that should be, in principle, accessible to experiments. The first is s± symmetry of the order-parameter. The second is that the momentum-space structure of the gap Δ(ki) should be markedly anisotropic. While there is growing evidence for s± symmetry, direct in plane high-precision spectroscopy of Δ(ki) has not been achieved. Here we report temperature dependent intra-band Bogoliubov quasiparticle scattering interference (QPI) in the iron-based superconductor LiFeAs, and we measure directly the strong anisotropy of the gap Δ(ki) on the hole-like band. This opens a direct high precision approach to understanding the anisotropic momentum-space structure Δ(ki), and to testing spin-fluctuation exchange pairing theories, in iron-based superconductors.
Session 13m-C: Quantum Criticality and Novel Phases I

Chair: Leon Balents
Saturday August 13, 10:50 – 12:30
Room 5B

13m-C1 Imaging Heavy Fermion Hybridization in URu$_2$Si$_2$

Collin Broholm$^{a}$,  *Johns Hopkins University
(to be announced)

13m-C2 Landau forbidden continuous quantum phase transition between two topologically valence bond solid states

Guang-Ming Zhang,  *Department of Physics, Tsinghua University, Beijing, 100084, China

The Haldane gap phase of a quantum Heisenberg antiferromagnetic spin-1 chain can be regarded as an example of a topological order phase in one dimension, where nonlocal string order parameters were proposed to describe the dilute antiferromagnetic order in the ground state. Moreover, a unitary nonlocal transformation was also established to convert the nonlocal string order parameters to the local ones and reveal the hidden discrete $Z_2 x Z_2$ symmetry. Recently, we have successfully generalized such a description scheme for the topological ordered ground states of higher integer spin chains with $SO(2S+1)$ symmetry. Then for a one-dimensional quantum Heisenberg spin-2 chain, there exist two topologically distinct valence bond solid states in two different solvable limits. In order to construct the ground state phase diagram, we apply the infinite time evolving block decimation algorithms to the model Hamiltonian. Surprisingly, a continuous quantum phase transition appears between these two valence bond solid states, and is forbidden by the conventional Landau phase transition theory. From the scaling relation between the entanglement entropy and correlation length, we give rise to the quantum critical properties around this critical point.


13m-C3 Quantum criticality and superconductivity in CeCu$_2$Si$_2$

O. Stockert$^{a}$,  J. Arndt$^{a}$,  E. Faulhaber$^{a}$,  K. Schmalzl$^{a}$,  W. Schmidt$^{a}$,  H. S. Jeevan$^{a}$,  C. Geibel$^{a}$,  M. Loewenhaupt$^{a}$,  F. Steglich$^{a}$,  *Max-Planck-Institut für Chemische Physik fester Stoffe, Dresden, Germany *Institut für Festkörperphysik, technische Universität Dresden, Dresden, Germany *Jülich Centre for Neutron Science JCNS, Forschungszentrum Jülich, Outstation at ILL, Grenoble, France

The heavy-fermion compound CeCu$_2$Si$_2$ displays unconventional superconductivity and is already at ambient pressure located in the vicinity of a quantum critical point (QCP) where long-range antiferromagnetism vanishes. Using elastic and inelastic neutron scattering we studied in detail the antiferromagnetic order and the spin excitations spectrum around the QCP. Antiferromagnetism and superconductivity exclude each other on a microscopic scale. While for magnetically ordered samples critical slowing down of the spin fluctuations above $T_N$ is observed, shows the normal state response of superconducting CeCu$_2$Si$_2$ an almost critical slowing down for $T \rightarrow 0$. Its temperature dependence and scaling behavior are in line with the expectations for an itinerant spin-density-wave QCP. This interpretation is substantiated by an analysis of specific heat data and the momentum dependence of the magnetic excitation spectrum. In contrast, the magnetic response in the superconducting state is characterized by a transfer of spectral weight to energies above a spin excitation gap. Our results strongly imply that the coupling of Cooper pairs in CeCu$_2$Si$_2$ is mediated by overdamped spin fluctuations.

13m-C4 Imaging Heavy Fermion Hybridization in URu$_2$Si$_2$

A. R. Schmidt$^{a,b}$,  M. H. Hamidian$^{b}$,  I. Firme$^{b}$,  P. Bradley$^{c}$,  J. D. Garrett$^{d}$,  T. Williams$^{e}$,  G. Luke$^{e}$,  Y. Dubi$^{f}$,  A. V. Balatsky$^{f}$,  J. C. Davis$^{f}$,  *Department of Physics, University of California, Berkeley, USA *Department of Physics, University College Cork, Co Cork, Ireland $^{b}$Brockhouse Institute for Materials Research, McMaster University, Hamilton, ON, Canada $^{c}$Department of Physics and Astronomy, McMaster University, Hamilton, Ontario, Canada $^{d}$Theory Division, Los Alamos National Lab., Los Alamos, NM, USA

Within a Kondo lattice, the strong hybridization between electrons localized in real space (r-space) and those delocalized in momentum space (k-space) generates exotic electronic states called ‘heavy fermions’. Here we use the unique capabilities of the spectroscopic imaging scanning tunneling microscope to image the electronic structure of the heavy fermion material URu$_2$Si$_2$ simultaneously in r-space and in k-space. Utilising quasiparticle interference imaging, we observe in k-space a light band at high temperatures that on cooling rapidly splits into...
two new heavy bands with a structure consistent with Kondo lattice hybridization. Simultaneously, in r-space, we image the local atomic scale structure of a 'Kondo-hole' generated by substituting a spinless Thorium atom for a magnetic Uranium atom. The high degree of internal consistency between the r-space and k-space analysis and the excellent agreement with theory provides confidence in the atomic-scale understanding of the Kondo lattice.

**13m-C5  Continuous metal-insulator transition at 410 K of the 5d oxide NaOsO$_3$**

**K. Yamaura**, *Superconducting Materials Center, National Institute for Materials Science, Tsukuba, Japan*

The perovskite NaOsO$_3$ shows a Curie-Weiss metallic nature at high temperature, and suddenly turns into an insulating state on cooling at 410 K. The metal-insulator transition (MIT) is coupled with an antiferromagnetic transition. Electronic specific heat is absent at the low-temperature limit, suggesting that the band gap fully opens. In situ observation in electron microscopy undetected any lattice anomalies associated with the MIT. Differential scanning calorimetry indicated that the MIT has little thermal hysteresis. The features are qualitatively comparable with what were observed for Cd$_2$Os$_2$O$_7$ ($T_{MIT} = 226$ K) [Mandrus et al., PRB 2001], and not at all with what were observed for LnNiO$_3$ ($Ln = Pr$, Nd, Sm) [Lacorre et al., J. Solid State Chem. 1991]. In this talk an overview of our research is presented and a possible mechanism of the MIT of NaOsO$_3$ is discussed. In addition, if time allows, I will introduce new correlated oxides crystalizing in the K$_4$CdCl$_6$-type structure (an infinite chain-type structure) recently synthesized such as Ca$_3$LiOsO$_6$ and Sr$_3$CoO$_6$, which display distinct magnetism.

Session 13m-D: Single Spin Devices / Qubits

Chair: Lieven Vandersypen
Saturday August 13, 10:50 – 12:30
Room 201

13m-D1  Single-shot readout of an electron spin in silicon
A. Morello\textsuperscript{a}, J. Pla\textsuperscript{a}, F. Zwanenburg\textsuperscript{a}, K. W. Chan\textsuperscript{a}, K. Y. Tan\textsuperscript{a,d}, H. Huebl\textsuperscript{a}, M. Möttönen\textsuperscript{a,c,d}, C. D. Nugroho\textsuperscript{a}, C. Yang\textsuperscript{a}, J. van Donkelaar\textsuperscript{a}, A. D. C. Alves\textsuperscript{b}, D. N. Jamieson\textsuperscript{b}, C. C. Escott\textsuperscript{a}, L. C. L. Hollenberg\textsuperscript{b}, R. G. Clark\textsuperscript{a}, A. S. Dzurak\textsuperscript{a},\textsuperscript{a}

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We report the experimental demonstration of single-shot time-resolved readout of an electron spin in silicon\textsuperscript{1}. The device consists of implanted phosphorus donor, coupled to a metal–oxide–semiconductor single-electron transistor.\textsuperscript{2,3} We observed a spin lifetime of \( \sim 6 \) seconds at a magnetic field of 1.5 tesla, and achieved a spin readout fidelity exceeding 90 percent. High-fidelity single-shot spin readout in silicon opens the way to the development of a new generation of quantum computing and spintronic devices based on silicon\textsuperscript{4}.

\textsuperscript{1} A. Morello et al. Nature 467, 687-691 (2010)
\textsuperscript{2} S. J. Angus et al. Nano Letters 7, 2051-2055 (2007)
\textsuperscript{3} A. Morello et al. Physical Review B 80, 081307(R) (2009).

13m-D2  Single-shot correlations and two-qubit gate of electron spins in a double quantum dot
K. C. Nowack\textsuperscript{a}, M. Shafiei\textsuperscript{a}, G. Prawiroatmodjo\textsuperscript{a}, L. R. Schreiber\textsuperscript{a}, W. Wegscheider\textsuperscript{b}, L. M. K. Vandersypen\textsuperscript{a},\textsuperscript{a}

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We have realized an independent single-shot read-out of two electron spins in a double quantum dot. The read-out method is all-electrical, cross-talk between the two measurements is negligible and measurement fidelities are about 80% on average. This allows us to directly probe the anti-correlations between the spins when they are prepared in an entangled spin singlet state. Furthermore, we use the independent read-out capability to demonstrate the operation of the two-qubit exchange gate\textsuperscript{1} on a complete set of basis states. This work opens the way to the realization and efficient characterization of multi-qubit quantum circuits based on single quantum dot spins.

\textsuperscript{1} J. R. Petta et al., Science 309, 2180 (2005).

13m-D3  Investigation of the dephasing of tunneling systems in glasses using two-pulse polarisation echo experiments
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Low temperature properties of glasses are governed by atomic tunneling systems. Many aspects are well described within the phenomenological standard tunneling model. Via their elastic and electric dipole moments tunneling systems interact mutually and with external fields. The dynamics of tunneling systems can be investigated by two-pulse polarisation echo experiments. Here the echo amplitude is measured as a function of the delay time between the two excitation pulses. Different dephasing mechanism contribute to the decay of the echo amplitude. In amorphous dielectrics at very low temperatures the dominating dephasing mechanism is spectral diffusion, which is the interaction of resonant tunneling systems with non-resonant thermally fluctuating ones. We have performed such echo decay measurements with an improved setup allowing us to observe echoes at very long delay times where the echo has decayed five orders of magnitude from its original amplitude. The data obtained in this way allows a precision test of the model of spectral diffusion and the distribution of parameters of the tunneling systems given by the standard tunneling model. We will show experimental results form measurement on BK7 and will discuss them in the framework of spectral diffusion and the standard tunneling model.

13m-D5  Readout and Control of Spin Systems with Superconducting Circuits
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Quantum Nanoelectronics Laboratory, Department of Physics, University of California Berkeley, Berkeley, California 94720, USA

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All electrical readout and control of spin systems with superconducting circuitry is an attractive route for implementing hybrid quantum information processing. Isolated spins, in general, have much longer coherence times than present day superconducting qubits, and thus could be utilized as memory elements. Species with a zero-field splitting (ZFS), such as bismuth doped silicon or NV centers in diamond, are particularly attractive as the absence of a strong magnetic bias field facilitates compatibility with low-loss superconducting circuitry. We present progress towards observation of strong coupling between such spin systems and a superconducting resonator. Information swapping between the spin ensemble and a qubit via the resonator will also be discussed. Furthermore, we will present data on a dispersive nanoSQUID magnetometer with a flux sensitivity of $26 \, \text{n}\Phi_0/Hz^{1/2}$, capable of detecting a small number of spins.
Flow visualization in superfluid $^4\text{He}$ is challenging, yet crucial for attaining a detailed understanding of quantum turbulence. Two problems have impeded progress: finding and introducing suitable tracers that are small yet visible; and unambiguous interpretation of the tracer motion. Metastable He$^*_{\text{3pa}}$ triplet molecules are promising tracer candidate due to their small size and their relatively simple behavior in superfluid helium. He$^*_{\text{3pa}}$ molecules are easily produced by electron bombardment of the helium or by field ionization. To detect and image the molecules, we have developed laser-induced-fluorescence techniques. At temperatures above 1 K, helium molecules follow the motion of the normal-fluid component without being affected by quantized vortices. We shall summarize our recent progress on studying the normal-fluid flow using He$^*_{\text{3pa}}$ molecule tracers and present evidence showing that the normal fluid can become turbulent in a thermal counterflow at relatively large heat flux. The coexistence of turbulence in both the normal fluid and the superfluid components in thermal counterflow presents us with a theoretically challenging type of turbulent behavior that is new to physics.

Turbulent and Laminar Dynamics of Superfluid $^3\text{He-B}$ at Low Temperatures

V. B. Efimov$^a$, R. de Graaf$^a$, J. J. Hosio$^a$, P. J. Heikkinen$^a$, M. Krusius$^a$, R. Hänninen$^a$, V. S. L'vov$^b$, G. E. Volovik$^c$.

The dynamics of superfluids in applied flow was thought to be fully turbulent in the zero-temperature limit, when the density of the normal component vanishes and the associated mutual friction damping rapidly decreases. We have studied how the superfluid $^3\text{He-B}$, contained in a cylinder, is put into rotation at temperatures below 0.2$T_c$ and how the rotation is stopped. Unexpectedly we have found that laminar dynamics, i.e. motion of approximately straight vortices without reconnections, plays an important role even at these low temperatures. In the experiment the motion of vortices is observed using nuclear magnetic resonance techniques and the dissipated energy is directly measured with a bolometer. A remarkable example of the non-trivial dynamics is the vortex front, which separates non-rotating vortex-free superfluid and rotating superfluid with vortices. The turbulent front propagates axially in a nearly steady-state configuration towards the vortex-free part, while the approach to equilibrium rotation behind the front is laminar. We compare the observations to numerical simulations of vortex dynamics and discuss potential links to novel phenomena like decoupling of the superfluid from the rotating reference frame in the zero-temperature limit and dissipation mechanisms which differ from the standard mutual friction.

Nonstationary phenomena in second-sound acoustic turbulence in He II

A. N. Ganshin$^{a,b}$, V. B. Efimov$^{a,e}$, G. V. Kolmakov$^{a,d}$, L. P. Mezhov-Deglin$^a$, P. V. E. McClintock$^{a}$.

We report an investigation of transient phenomena in the evolution and decay of second sound acoustic turbulence in He II, considering both the direct and inverse energy cascades. During growth of the direct cascade, after first switching on the thermal driving force, the initial growth rates of the harmonics increase rapidly with harmonic number. This corresponds to a propagating front in frequency space, precisely as predicted by a theoretical description based on self-similarity. During growth of the inverse cascade, rogue waves arise in direct analogy with the oceanic rogue waves that endanger shipping. The decay of a fully-established cascade after switching off the driving force sometimes exhibits oscillations. We also report a study of the decay of the direct cascade in the case where the system is initially driven by two resonant drivings at different frequencies. It was found that the energy redistribution between the interacting harmonics can result in the growth of some modes after one of the harmonic drives is removed. These diverse phenomena will be discussed and set in context.

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13a-A4 Turbulence in superfluid $^4$He generated and probed by injected ions
A.I. Golov$^a$, P.M. Walmsley$^a$, P.A. Tompsett$^a$, $^a$School of Physics and Astronomy, University of Manchester, Manchester, M13 9PL, UK

We investigated several turbulent flows, characterized by different ratios of classical (large-scale) and quantum (small-scale) kinetic energy, in cold superfluid $^4$He forced by injected ions: (i) a cloud of polarized quantized vortex rings in which rare binary collisions of rings trigger an onset of turbulence; (ii) a compact tangle of quantized vortex loops in which trapped ions in an applied electric field exert body force on the liquid resulting in a propagating giant classical vortex ring; (iii) space-filling turbulence continuously pumped by a jet of injected ions; (iv) free decay of all the flows mentioned above. The experimental container had a shape of a cube. The characterization of the density, polarization and spread of the vortex tangle was done through measurements of the transport of negative ions either trapped by the tangle or propagating on probe vortex rings. Most observations are performed at $T < 0.5$ K (i.e. with negligible density of thermal excitations), although the effect of small mutual friction at 0.6–0.8 K will also be reported. A comparison with the properties of turbulent flows induced by an impulsive spin-down will be made. The results of numerical simulations of short-range interactions of individual quantized vortex rings and of large-scale flows forced by injected ions will be reported.

13a-A5 Visualization of Quantum Turbulence
E. Fonda$^{a,b}$, M. S. Paoletti$^c$, M. E. Fisher$^a$, K. R. Sreenivasan$^{a,d}$, D. P. Lathrop$^a$, $^a$University of Maryland, College Park, USA $^b$Università degli studi di Trieste, Trieste, Italy $^c$University of Texas at Austin, Austin, USA $^d$New York University, New York, USA

The evolution of the quantized-vortex tangle in superfluid $^4$He, also known as quantum turbulence, is dominated by reconnection and ring collapse. We visualize the dynamics of quantized vortices and the normal component using micron and nano-sized ice particles. We review past results obtained tracking these particles, including a direct confirmation of the two-fluid model, a distinction between classical and quantum turbulence, and the characterization of vortex rings, vortex reconnections and thermal counterflow. We discuss the reconnection dynamics and the particle-vortex interaction, presenting the latest theoretical, numerical and experimental results from our group.
Session 13a-B: Theory for Fe-based Superconductors

Chair: Wei Ku
Saturday August 13, 14:00 – 15:40
Convention Hall 3

13a-B1 Nature of Correlations and Spin-Orbital Symmetry in Iron-Based Superconductors

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The iron-based family of high-temperature superconductors exhibits more moderate correlations than their cuprate relatives. This makes the itinerant description a reasonable starting point. But, with five iron d-orbitals and multiple electron and hole bands in play, what kind of a relatively simple model can capture the essential physics of these complex materials? Does such simplified description even exist or is everything in the details? And even if a simple model can be fashioned for pnictides will it also work for chalcogenides, which, by most accounts, appear to be more strongly correlated? I will discuss one such theoretical model, based on the U(4)xU(4) symmetry of spin and band (orbital) degrees of freedom (J. Kang and Z. Tesanovic, Phys. Rev. B 83, 020505(R) (2011).) Several experimental predictions of the theory will be discussed and various differences and similarities between pnictides and chalcogenides highlighted.

13a-B2 Unified paradigm for Cuprates and Iron-based High Temperature Superconductors

Jiangping Hu, Institute of Physics, Chinese Academy of Sciences, Beijing and Department of Physics, Purdue University, West Lafayette, IN 47906, USA

I discuss the existence of strikingly identical paradigm applicable to cuprates, iron-pnictides and iron chalcogenide in understanding magnetism, superconductivity and the interplay between the two. By determining magnetic interactions in parent compounds of high temperature superconductors, one can successfully predict the pairing symmetry in superconducting states. I will discuss recent experimental results that support this simple paradigm. This study suggests that the pairing symmetry is determined by the combination of the local magnetic exchange coupling in real space and the topology of Fermi surface in reciprocal space for both cuprates and iron-based superconductors. High superconducting transition temperatures are also achieved by matching pairing form factors provided by local antiferromagnetic exchanges with Fermi surface topology. This paradigm will serve a guide to search for new high temperature superconductors.

13a-B3 Spin and Charge Excitations in the Antiferromagnetic Metallic Phase of Iron Arsenides: Inelastic Neutron Scattering and Resonant Inelastic X-Ray Scattering

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Sendai National College of Technology, Sendai, Japan
Synchrotron Radiation Research Center, JAEA, Sayo, Japan

The ground state and band dispersions of the antiferromagnetic (AF) metallic phase in iron arsenides are calculated by mean-field theory for a five-band Hubbard model by assuming stripe-type AF order. We then investigate dynamical susceptibilities in the AF phase for both spin and charge channels by the random phase approximation. We find that spectral distribution in the bare susceptibility through particle-hole channel is crucial for obtaining anisotropic spin-wave excitation fully consistent with inelastic neutron scattering data. Resonant inelastic x-ray scattering (RIXS) for Fe L-edge can reveal not only charge but also spin excitations. We calculate RIXS spectra by making use of a fast-collision approximation for intermediate states, and find that momentum-independent spin-orbital composite excitations in addition to spin and charge collective excitations with weak intensity. These composite excitations as well as the collective excitations will be observed in RIXS experiments in the near future.


13a-B4 Superconductivity and structure transition in Fe-based superconductors: analysis based on the orbital fluctuation theory

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Department of Applied Physics, Nagoya University, Nagoya, Japan

The main features in Fe-based superconductors are summarized as (i) orthorhombic transition accompanied by
remarkable softening of the shear modulus $C_{66}$, (ii) high-$T_c$ superconductivity close to the orthorhombic phase, and (iii) stripe-type magnetic order induced by orthorhombicity. To understand them, we analyze the multiorbital Hubbard-Holstein model with Fe-ion optical phonons. In the random-phase-approximation (RPA), a small electron-phonon coupling constant ($\lambda \sim 0.2$) is enough to produce large orbital (=charge quadrupole) fluctuations. The most divergent susceptibility is the $O_{x^2}$-antiferro-quadrupole (AFQ) susceptibility, which causes the $s$-wave superconductivity without sign reversal ($s^{++}$-wave state). The $s^{++}$-wave state is robust against impurities, consistently with experimental observations. At the same time, divergent development of $O_{x^2-y^2}$-ferro-quadrupole (FQ) susceptibility is brought by the “two-orbiton process” with respect to the AFQ fluctuations. The derived FQ order not only triggers the orthorhombic structure transition, but also induces the instability of stripe-type magnetic order. Therefore, abovementioned features (i)-(iii) are well explained based on the orbital fluctuation theory.


13a-B5  Volovik Effects of the $\pm S$-wave state in the Iron-based Superconductors

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We studied the field dependencies of specific heat coefficient $\gamma(H) = \lim_{T \to 0} C(T, H)/T$ and thermal conductivity coefficient $\lim_{T \to 0} \kappa(T, H)/T$ of the $\pm S$-wave state in the mixed state. We showed that the Doppler shift of the quasiparticle excitations (Volovik effect) will produce a strongly field dependent low energy excitations in this fully gapped $\pm S$-wave state when the gap sizes are different, $|\Delta_+| \neq |\Delta_-|$. It is, however, proportional to $H$ in contrast to the $\sqrt{H}$ dependence of the $d$-wave state. Impurity scattering effect on the $\pm S$-wave state makes this generic $H$-linear dependence to sublinear approaching to the $\sqrt{H}$ behavior. Our calculations of $\lim_{T \to 0} \kappa(T, H)/T$ successfully fit the experimental data of $\text{Ba(Fe}_{1-x}\text{Co}_x\text{)}_2\text{As}_2$ with different Co-doping $x$ by systematically varying the gap size ratio $R = |\Delta_+/|\Delta_-|$. We also resolved the dilemma of a substantial value of $\gamma(H \to 0)$ but very small value of $\lim_{T \to 0} \kappa(T, H \to 0)/T$, observed in many pnictide superconductors.$^1$

13a-C1 On the phase diagram of UGe2
Vladimir Mineev, CEA Grenoble

13a-C2 Coherent dynamics of macroscopic electronic order through symmetry-breaking transitions: superconductors and charge-density waves
Dragan Mihailovic*, Roman Yusupov*, Tomaz Mertelj*, Viktor V. Kabanov*, Primoz Kusar*, Serguei Brazovskii*, aDept. of Complex Matter, Jozef Stefan Institute, Jamova 39, Ljubljana, SI-1000, Ljubljana, Slovenia bLPTMS-CNRS, UMR8626, Univ. Paris-Sud, Bat. 100, Orsay, F-91405 France

The study of system trajectories undergoing symmetry breaking phase transitions (SBTs) - whether in condensed matter physics, cosmology or finance - is difficult because they are hard to repeat, or they occur very rapidly. Here we report for the first time on a high-time-resolution study of the nonergodic evolution of bosonic and fermionic excitations through an electronic charge-ordering SBT in charge-density-wave systems1-2, and La1.9Sr0.1CuO4 superconductors3 using a novel multi-pulse femtosecond laser spectroscopy technique. Quenching our system with intense optical pulses, we subsequently detect hitherto unrecorded coherent aperiodic undulations of the order parameter, critical slowing down of the collective (Higgs) mode, and evolution of the particle-hole gap as the system evolves through the transition. Modeling based on Ginzburg-Landau theory is used to reproduce the aftermath of the transition without free parameters1-2. However, in both systems the behavior departs from TDGL predictions in the close vicinity of the transition, and preceding it. Of particular interest is the observation of spectro-temporal distortions arising from spontaneous annihilation of topological defects, analogous to those discussed by the Kibble-Zurek cosmological model and the incoherent annihilation at long times.

1 R.Yusupov et al., J.Supercond Nov Magn 24, 1191 (2011)
3 P.Kusar et al. (unpublished, 2011).

13a-C3 Magnetic cooling through quantum criticality

The proximity of a quantum critical point can significantly affect a material’s thermodynamic properties even at finite temperatures. Here we demonstrate that the accumulation of entropy around a B-induced quantum critical point opens up new possibilities for realizing a very efficient low-T magnetic coolant. For the proof of principle, we focus on a simple model substance - a Cu2+-containing coordination polymer [Cu(μ-C2O4)(4-aminopyridine)2(H2O)]n - a very good realization of a spin-1/2 antiferromagnetic Heisenberg chain with a weak intrachain coupling constant J/kB = (3.2 ± 0.1) K, corresponding to a saturation field BS = 4.09 T. To investigate its potential as a coolant, demagnetization experiments have been performed from B1 > BS under almost adiabatic conditions. While the cooling process is initially linear in B - such as is seen in standard paramagnets - it becomes superlinear upon approaching the QCP at Bs. In addition, the quantum critical system excels by its high efficiency ΔQf/ΔQm, which exceeds the figures found in state-of-the-art paramagnetic coolants by a factor 2-3. Here ΔQf is the heat the material can absorb after demagnetization to a final field Bf, and ΔQm the heat of magnetization released to a precooling stage held at a temperature Ti, the initial temperature of the cooling process.

13a-C4 Patterns of Coexisting Condensates Forming Domes Preventing the Quantum Critical Point
G. Varelogiannis*, A. Aperis*, P. Kotetes**, P.B. Littlewood**, aDepartment of Physics, National Technical University of Athens, Greece bDepartment of Physics, Cavendish Laboratory, University of Cambridge, UK

Different quantum ordered states are in competition in any correlated fermionic system. Very often, a single order parameter dominates and is the one observed. We show that when this dominating order parameter is sufficiently weakened by doping, pressure, magnetic fields etc., a full pattern of coexisting condensates develops that prevents its elimination. These patterns are made of fundamental quartets of order parameters1 that we can identify systematically. We argue that all dome states observed near the quantum critical points in the
phase diagrams of materials as diverse as high-\(T_c\) cuprates, manganites ruthenites and various heavy fermion and organic compounds, they are all associated to specific patterns of coexisting condensates that develop as domes, preventing the formation of the quantum critical point. These domes of patterns of coexisting condensates have a common universal behavior that we put forward connecting thus situations apriori unrelated such as the high field superconducting states in CeCoIn\(_5\)\(^2\) with doping or pressure induced domes in various oxides.


13a-C5 Following elementary excitations to finite temperatures at the pressure-induced quantum phase transition in TlCuCl\(_3\)

B. Normand\(^a\), P. Merchant\(^b\), Ch. Rüegg\(^b,c\), K. W. Krämer\(^d\), M. Boehm\(^e\), D. F. McMorrow\(^b\), *Department of Physics, Renmin University of China, Beijing, China. \(^b\)London Centre for Nanotechnology, University College London, London WC1E 6BT, U.K. \(^c\)Laboratory for Neutron Scattering, Paul Scherrer Institute, CH-5232 Villigen, Switzerland. \(^d\)Department of Chemistry and Biochemistry, University of Bern, CH-3000 Bern, Switzerland. \(^e\)Institut Laue Langevin, BP 156, 38042 Grenoble, Cedex 9, France.

We control the ground state and elementary excitations of the quantum antiferromagnet TlCuCl\(_3\) by the application of pressure and temperature. The magnetically ordered phase is “melted” by both quantum and thermal fluctuations, and we map the behaviour of the triplet excitations across the quantum critical regime by inelastic neutron scattering. We use a bond-operator formalism with hard-core boson statistics to describe the evolution of the finite-temperature spectrum from spin waves into gapped magnons. Because the quantum disordered and finite-temperature disordered phases are continuously connected, quantum and thermal fluctuations show very similar effects in opening a gap. One degenerate magnon mode of the disordered phase becomes the longitudinal excitation of the ordered phase.\(^1\) We measure the linewidth of this critically damped mode across the phase transition and show within our model how the universal behaviour governed by the pressure parameter is altered due to thermal broadening.

Session 13a-D: Single Spin Devices / Spin Transport

Chair: Christian Enss
Saturday August 13, 14:00 – 15:40
Room 201

13a-D1 Non-local Spin Current Injection into a Superconductor
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Recently the ferromagnetic metal/superconductor hybrid structure has been studied intensively since the interplay between superconductivity and ferromagnetism entails incompatible spin order. As for the spin current in the superconducting state, there are some experiments using the current-perpendicular-to-plane structure. This configuration, however, is not preferable for future low energy consumption devices. In this work, we have studied the non-local injection of pure spin current into the superconducting state using the current-in-plane geometry.

Our device is based on the lateral spin valve structure, consisting of Ni$_{81}$Fe$_{19}$ and Nb wires bridged by a Cu wire. The pure spin current is induced in the Nb wire via Cu by flowing the charge current non-locally from the Ni$_{81}$Fe$_{19}$ wire.\textsuperscript{1} Above the critical temperature ($T_c$) of Nb, the pure spin current are strongly absorbed into the Nb wire because of its strong spin-orbit interaction. Below $T_c$, on the other hand, we still observe a large spin current absorption.\textsuperscript{1} This fact indicates that the injected pure spin current is absorbed not in the superconducting state but in the quasi-particle state of Nb. With decreasing the injection charge current, the spin current absorption rate is getting small, which supports the above scenario.


13a-D2 Rashba spin-orbit interaction in vertical In$_{0.05}$Ga$_{0.95}$As/GaAs quantum dots
S. M. Huang\textsuperscript{a}, A.O. Badrutdinov\textsuperscript{a}, L. Serra\textsuperscript{b}, T. Kodera\textsuperscript{b}, T. Nakaoka\textsuperscript{b}, N. Kumagai\textsuperscript{c}, Y. Arakawa\textsuperscript{c}, D. A. Tayurskii\textsuperscript{d}, K. Kono\textsuperscript{c}, K. Ono\textsuperscript{c}, \textsuperscript{a}Low Temperature Physics Laboratory, RIKEN, Wako-shi, Saitama 351-0198, Japan \textsuperscript{b}Institut de Física Interdisciplinar i de Sistemes Complexos IFISC (CSIC-UIB), E-07122 Palma de Mallorca, Spain \textsuperscript{c}Nanoquim, The University of Tokyo, 4-6-1 Komaba, Meguro, Tokyo 153-8904, Japan \textsuperscript{d}Physics Department, Kazan Federal University, 420008, Kazan, Russia

We study the spin splitting energies of different orbital states in In$_{0.05}$Ga$_{0.95}$As/GaAs quantum dots. The measured results show that the spin splitting energies of $|0,0\rangle$ are larger than those of $|0,-1\rangle$. The theoretical analysis is done with a generalization of the Fock-Darwin states in the presence of spin-orbit interactions. The Rashba spin-orbit intensity is in the range of 80 meVÅ $\leq \lambda_R \leq$ 120 meVÅ. The enhancement of spin-orbit intensity can be understood as the penetration of wavefunction into quantum well. Due to the strong deviation of wavefunction distribution in a quantum well, Rashba spin-orbit intensity increases significantly in this type of low potential barrier heterostructure.

13a-D3 InAs spin-filter cascades in magnetic fields
T. Benter\textsuperscript{a}, H. Lehmann\textsuperscript{a}, A. Buhr\textsuperscript{a}, J. Jacob\textsuperscript{a}, U. Merkt\textsuperscript{a}, \textsuperscript{a}Institut für Angewandte Physik und Zentrum für Mikrostrukturforschung, Hamburg, Germany

To utilize the charge and the spin of an electron together in the field of spintronics, efficient generation and detection of spin-polarized currents is mandatory. One can achieve generation and detection injecting a spin-polarized current from a ferromagnet into a semiconductor and extracting it again into a ferromagnet. However, scattering at the interface and the conductivity mismatch between the ferromagnet and the semiconductor inhibit a sufficient polarization of the injected current. These obstacles can be bypassed creating spin-polarized currents in a Y-shaped all-semiconductor spin filter using the intrinsic spin Hall effect (iSHE) as the spin separating agent. By cascading two such filters the second filter’s outputs reveal the spin polarization at its input as a conductance difference.\textsuperscript{1} We present transport measurements under the influence of an out-of-plane magnetic field to get insights into the mechanism as well as the strength of the iSHE. In-plane magnetic fields add to the effective Rashba fields and thus change the spin precession length. This allows studies on the iSHE and the so-called Zitterbewegung, that is a combination of the iSHE and the spin precession.\textsuperscript{2}


13a-D4 Magnetic Monopole Generated by Spin Damping with Spin-Orbit Coupling
Akihito Takeuchi\textsuperscript{a}, Gen Tatara\textsuperscript{a}, \textsuperscript{a}Department of Physics, Tokyo Metropolitan University, Hachioji, Tokyo 192-0397, Japan

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Aim of spintronics is to manipulate electron’s spin degree of freedom besides its charge one. Today we can control spins by electric, magnetic, thermodynamic and optic means, and the spin transport is realized in various materials; in metals, in semiconductors and even in insulators. Although various spin-related phenomena have been discovered, it has not been explored so far how the spintronics is integrated in the conventional electromagnetism.

In this paper, we analyze spintronic phenomena theoretically from the viewpoint of the Maxwell’s equations. We particularly focus on the case of electron transport in the presence of magnetization dynamics and spin-orbit coupling. We calculate an electric current and density, and derive the Maxwell’s equations. Surprisingly, the Maxwell’s equations constructed by this way involve generally a magnetic monopole contribution. This magnetic monopole arises from a conversion of the spin damping into the angular momentum by the spin-orbit interaction, and thus is called a spin damping monopole. We will discuss in detail the spin damping monopoles generated in a ferromagnetic-nonmagnetic junction, and their electric observation by use of the Ampère’s law for monopoles. The monopole signal is expected in a similar geometry as the inverse spin Hall signal, and we will show a way to distinguish those two origins.


13a-D5  Dynamics of Josephson-phase coupled with spin waves

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Coupling of Josephson-phase and spin-waves is theoretically studied in a ferromagnetic Josephson junction, in which two superconductors (S’s) are separated by a ferromagnet (F). Electromagnetic (EM) field inside the junction and the Josephson current coupled with spin-waves in F are calculated by combining Maxwell and Landau-Lifshitz-Gilbert equations. In the SFS junction, it is found that the current-voltage (I-V) characteristic shows two resonant peaks. Voltages at the resonant peaks are obtained as a function of the normal modes of EM field, which indicates a composite excitation of the EM field and spin-waves in the ferromagnetic Josephson junction. We examine a ferromagnetic Josephson junction, in which an insulator (I) is inserted in one of interfaces between S and F. In such an SIFS junction, three resonant peaks appear in the I-V curve, since the Josephson-phase couples to the EM field in the insulating layer.
Session 13a-E: THz and Nanomechanical Technologies
Chair: Juha Tuoriniemi
Saturday August 13, 14:00 – 15:40
Room 305

13a-E1 Development of Transition-Edge Sensor Arrays at NIST
J. Ullom*, a National Institute of Standards and Technology (NIST), Boulder CO, USA
Superconducting Transition-Edge Sensors (TESs) consist of thin superconducting films electrically biased in the resistive transition. When combined with a radiation coupling structure such as an antenna or a bulk foil, TESs operated at sub-Kelvin temperatures can measure photons from microwave to gamma-ray energies with unprecedented precision. In this presentation, we describe the development and deployment of arrays of up to ten thousand TES sensors at NIST. SQUID multiplexing circuits are a critical enabling technology for these arrays. We briefly describe several instruments incorporating TES arrays with SQUID readout and their intended applications. These include gamma-ray sensors for nuclear materials accounting, x-ray sensors for ultrafast time-resolved absorption spectroscopy and industrial materials analysis, and submillimeter and millimeter-wave sensors for astronomy including active efforts to measure B-mode polarization in the cosmic microwave background.

13a-E2 Low Loss and tunable superconducting terahertz metamaterial
B. B. Jin*, C. H. Zhang*, J. B. Wu*, J. Chen*, P. H. Wu*, a Research Institute of Superconductor Electronics, School of Electronic Science and Engineering, Nanjing University, Nanjing, China
Superconducting planar terahertz (THz) metamaterials (MMs) are fabricated on 200 nm thick niobium nitride (NbN) films deposited on MgO substrates. They are characterized by time-domain THz spectroscopy over a temperature region from 8 K to 20 K, crossing the critical temperature of NbN films. The unloaded quality factor reaches as high as about 178 at 0.6 THz and 8 K, which is about 24 times as many as gold MMs with the same pattern, demonstrating low loss property. Meanwhile, four MMs with different resonant frequencies are also investigated. As the gap frequency \( f_g \) is 1.18 THz, the experimentally observed THz spectra span a frequency region from below \( f_g \) to above it. We found that the MMs exhibit a wide relative tuning range of 30% as the resonance frequency approaches to \( f_g \) due to remarkably large variance of inductance. This stimulates us to realize a larger tuning range about 41% as the film thickness is reduced to 100nm. All these experimental observations are well understood in the framework of Bardeen-Cooper-Schrieffer theory and equivalent circuit model. Our work offers an efficient way to design and make high-performance THz electronic devices.

13a-E3 Cryogenic Large Liquid Xenon Detector for Dark Matter Searches
D.-M. Mei*, a Department of Physics, The University of South Dakota, Vermillion, USA
b for the LUX Collaboration
Observation of rotational curve of spiral galaxies shows that a large fraction (\( \sim 23\% \)) of the mass density of the universe is unaccounted for. Such a significant percentage of missing “dark matter” suggests that the universe may consist of new types of elementary particles. A compelling explanation for the new particles is the existence of Weakly Interacting Massive Particles (WIMPs), which are non-baryonic particles characterized by particle physics theories beyond the Standard Model. A terrestrial direct observation of WIMPs would have enormous intellectual merit. WIMPs are believed to only interact through the weak force and gravity; hence the interaction cross section with ordinary matter is extremely small. Therefore, experimental techniques that combine low radioactivity, low energy thresholds, efficient discrimination against electronic recoil backgrounds, and scalability to large detector masses can only be performed at a deep underground environment where the interference of cosmic rays is obviated. In this paper, we report a cryogenic large liquid xenon detector for dark matter searches at Sanford Lab in the Homestake Mine, USA. The goal of the large underground xenon (LUX) two-phase detector is to clearly detect (or exclude) WIMPs with a spin independent cross-section per nucleon of \( 7 \times 10^{-46} \text{ cm}^2 \), equivalent to \( \sim 0.5 \) events/100 kg/month in an inner 100 kg fiducial volume (FV) of a 300 kg LXe detector.

13a-E4 Low temperature nanomechanical probes: from linear to nonlinear regimes
E. Collin*, O. Bourgeois*, Yu.M. Bunkov*, H. Godfrin*, a Institut Néel, CNRS et Université Joseph Fourier, BP 166, 38042 Grenoble Cedex 9, France
Low temperature physics has always been concerned with mechanical devices used as tools for condensed matter experiments: from vibrating wires, oscillating spheres to torsional oscillators and quartz tuning forks probing
Quantum Fluids. Solid-state matter is under intensive investigation using mechanical devices as well, and for instance quartz tuning forks are also widely used for low temperature STM or μSQUID experiments. We have developed and studied at low temperatures micro and nanomechanical cantilever-based oscillators, using standard fabrication processes and lock-in detection techniques. Sizes range from mm long and 10 μm thick structures (kHz resonance), to 10 μm long and 150 nm thick (MHz resonance). The devices can be used immersed in a fluid, or as probes for solid matter deposited as a coating. We demonstrate that these structures operate in an extremely broad dynamic range, from a linear to a very nonlinear regime. The nanomechanical oscillators make use of parametric amplification, enabling gains up to a factor of 100, for oscillations ranging from Angströms to fifty nanometers. We demonstrate that a 0.5 % resolution on the measurement of friction processes can be achieved. Analytic mathematical tools are available to describe their dynamics, in the full dynamic range.

13a-E5 Microwave amplification in nanomechanical systems
Francesco Massel*, Low Temperature Laboratory Aalto University

In the recent past, an intense theoretical and experimental effort has been devoted to the analysis of the cooling of mechanical resonators by radiation pressure forces. On one hand these, studies are motivated by their interest in connection with their application as measurement devices, for instance in the detection of gravitational waves and ultra-high precision measurements. On the other, their analysis in the quantum regime allows to address fundamental questions such as quantum limits in measurement and amplification and quantum properties of mechanical objects.

In my talk I will demonstrate the possibility of using the resolved-sideband regime of an optomechanical system as a signal amplifier. I will then characterize its stability and noise properties, defining the conditions allowing to approach the quantum limit on the added noise, providing comparison between theoretical results and experimental data.
Session 13P-A:

A4 Superfluid He-3 in Aerogel
A5 Vortices and Quantum Turbulence
A8 Others

Saturday August 13, 16:00 – 18:00
Exhibition Hall 1

13P-A001 Phase diagram of superfluid \(^3\)He in uniaxially compressed aerogel
R. G. Bennett\(^a\), N. Zhelev\(^b\), E. Smith\(^a\), J. Pollanen\(^b\), W. Halperin\(^b\), J. Parpia\(^b\), \(^a\)Department of Physics, Cornell University, Ithaca NY 14853, USA \(^b\)Department of Physics and Astronomy, Northwestern University, Evanston, IL 60208, USA

A torsion pendulum was used to measure the dissipation \((Q^{-1})\) and period shift for \(^3\)He confined in a 98% open aerogel that was axially compressed by 10% along the axis of the torsion pendulum. We map out the phase diagram by examining the superfluid fraction at pressures between 0 and 34 bar, taking data whilst warming and cooling. The cooling traces show evidence of the metastable A phase existing over a wider region in temperature than what is seen in other, uncompressed aerogel, as well as a much smaller reduction of \(T_c\), relative to bulk \(T_c\). On warming, we observe a narrow region of A phase before the normal liquid behavior is recovered. A study of “turn arounds”, in which the cell was repeatedly warmed to temperatures approaching \(T_c\) and then cooled, reveals the transition from B\(\rightarrow\)A to be quite broad (\(\approx 70\) mK), similar to that observed for the A\(\rightarrow\)B transition while cooling. The dissipation in the A phase shows a rapid rise at a temperature just above the A\(\rightarrow\)B transition. While we expect that the A phase would be stabilized by the compression (which provides an axial direction similar to the application of a magnetic field), textural alignment of the order parameter consistent with \(\rho_{\perp}\) is not seen. Our observations show that the “so-called” poly critical point is removed from the superfluid phase diagram, resulting in an equilibrium A phase sliver interceding between the normal and B phases in the zero field phase diagram of disordered \(^3\)He.

13P-A002 Torsion pendulum measurements of normal \(^3\)He in axially compressed aerogel
N. Zhelev\(^a\), R. Bennett\(^a\), E. Smith\(^a\), J. Pollanen\(^b\), S. Higashitani\(^c\), P. Sharma\(^d\), W. Halperin\(^b\), J. Parpia\(^b\), \(^a\)Department of Physics, Cornell University, Ithaca NY 14853, USA \(^b\)Department of Physics and Astronomy, Northwestern University, Evanston, IL 60208, USA \(^c\)Faculty of Integrated Arts and Sciences, Hiroshima University, Hiroshima 739-8521, Japan \(^d\)Department of Physics, Royal Holloway, University of London, Egham, Surrey TW20 0EX, UK

A torsion pendulum was used to measure the dissipation \((Q^{-1})\) and period shift of \(^3\)He confined in a 98% open aerogel, compressed by 10% along the axial direction. After subtraction of the bulk fluid inertial and dissipative contributions, the remaining \(Q^{-1}\) tends to a constant \(\approx 2.5 \times 10^{-6}\) (about ten times larger than the empty cell background) below 10 mK. The behavior is consistent with an inelastic scattering time \(\tau_{\text{in}}\) (due to quasiparticle-quasiparticle \((qp-qp)\) scattering) limited by an elastic scattering time \(\tau_{\text{el}}\) (due to \(qp\)-aerogel scattering). This gives us a mean-free-path \(\lambda_{\text{eff}} = v_F \tau_{\text{eff}}\), where \(\tau_{\text{eff}} = \tau_{\text{in}}^{-1} + \tau_{\text{el}}^{-1}\) and \(v_F\) is the Fermi velocity. The low temperature \(Q^{-1}\) arises from the finite velocity difference between aerogel and \(^3\)He at their common interface that gives rise to a frictional drag force on the torsion pendulum. The drag force can be parameterized by a frictional relaxation time \(\tau_F\), which does not have a significant temperature dependence. The relative velocity profile across the aerogel-filled flow channel is temperature dependent only near the channel walls and is otherwise flat far from them. We find \(\tau_F \approx 2 \times 10^{-7}\) and a weakly pressure dependent crossover temperature \(T^* \approx 10\) mK where \(\tau_{\text{el}} = \tau_{\text{in}}\).

13P-A003 Aerogel as a non-ideal gas of impurities in superfluid \(^3\)He
I.A. Fomin\(^a\), E.V. Surovtsev\(^b\), P.L. Kapitza Institute for Physical Problems, Russian Academy of Sciences, Moscow, Russia

The standard theory of superconducting alloys disregards possible correlations between impurities. Such idealization is not sufficient when impurities form a random network, like aerogel in superfluid \(^3\)He. That creates discrepancies in the observed properties of this physical object with predictions of the standard theory. As a step to a better approximation we consider a situation when correlations are weak and can be treated as a perturbation. It is possible if correlation radius \(R\) meets the condition \(R^2 \ll \xi_0\), where \(\xi_0\) is the coherence length of the superfluid and \(l\) is a mean free path. In a principal order on the ratio \(R^2/(\xi_0l)\) only binary correlations are important. Effect of correlations is significant, when \(R > \xi_0\). Corrections to the suppression of the \(T_c\) and to the temperature dependence of the square of the order parameter \(\Delta^2\) within the Ginzburg and Landau region caused by the correlations are expressed in terms of the structure factor of aerogel. In comparison with the non-correlated impurities \(T_c\) for \(^3\)He increases and temperature dependence of \(\Delta^2\) on \(T_c-T\) significantly deviates from linear. Reasonable agreement with experimental data for \(^3\)He is obtained for a realistic value of the correlation radius \(R\). The obtained results can be of importance for impure superconductors with a short coherence length \(\xi_0\) as well.

13P-A004 Identification of \(^3\)He Superfluid B-phase Order Parameter Structure in Aerogel
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We have performed pulsed NMR on \(^3\)He-B in 98.1% porosity aerogel with different anisotropy. The aerogel anisotropy was fully characterized. In the isotropic aerogel sample at \(P = 26\) bar two peaks are observed in the NMR spectrum for superfluid B-phase, which indicates two domains with different order parameter structure. The peak with no frequency shift relative to Larmor Frequency represent a domain with order pa-
13P-A005 Anisotropy Stabilized Equal-Spin Pairing State of $^3\text{He}$ in Radially Compressed Aerogel

J. Pollanen$^1$, J.I.A. Li$^2$, C.A. Calle$^2$, W.J. Gannon$^2$, W.P. Halperin$^2$, *Department of Physics and Astronomy, Northwestern University, Evanston IL, 60208.

Anisotropic quasiparticle scattering has been predicted to stabilize anisotropic superfluid states of $^3\text{He}$.$^1,^2$ We have performed pulsed nuclear magnetic resonance (NMR) experiments on $^3\text{He}$ in a homogeneously anisotropic 97.6% porosity aerogel. From the NMR frequency shifts on warming we find a single superfluid state throughout the full P-T phase diagram down to our lowest temperature $T = 0.65$ mK. Susceptibility measurements indicate this phase is an equal-spin pairing (ESP) state. The anisotropy of our cylindrical aerogel sample was induced during the growth and drying stages in the form of 14.3% radial compression. The sample was characterized with an optical, cross-polarization technique$^2$ to confirm the presence of a homogeneous optical axis aligned with the cylinder axis. Similar experiments and characterization have been performed on a homogeneously isotropic 98.1% aerogel and, in this case, we find the non-ESP aerogel B-phase is the stable state. We are currently studying the tip angle dependence of the NMR frequency shift to identify which of the ESP states we have stabilized. This work was supported by the National Science Foundation, DMR-0703656.

13P-A007 NMR Properties of $^3\text{He}$-A in Biaxially Anisotropic Aerogel

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Theoretical model of G.E. Volovik for A-like phase of $^3\text{He}$ in aerogel suggests formation of Larkin-Imry-Ma state of Anderson-Brinkmann-Morel order parameter. Most of the results of NMR studies of A-like phase are in a good agreement with this model$^1$, except for some of previous experiments in weakly anisotropic aerogel samples, e.g.$^2,^3$ We report that these results can also be well described in frames of the same theory in suggestion of biaxial anisotropy. From the NMR data, we determined anisotropy parameters of spatial distribution of orbital vector L in these experiments.


13P-A008 Measurements of Spin Diffusion in Liquid $^3\text{He}$ in “Ordered” Aerogel

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We report measurements of spin diffusion in normal phase of $^3\text{He}$ confined to a new type of aerogel$^1$ which was recently used in experiments with superfluid $^3\text{He}$.$^2$ This “ordered” aerogel consists of Al$_2$O$_3$ strands which are nearly parallel to each other$^1$. We observed two superfluid phases: low temperature phase and high temperature phase. NMR properties of the low temperature phase correspond to Balian-Werthamer order parameter. The origin of the high temperature phase is not yet clear. Spin susceptibility measurements show that this phase belongs to the family of equal spin pairing states. NMR properties of the low temperature phase qualitatively well correspond to both A phase in Larkin-Imry-Ma state and to polar phase, which is predicted to be more favorable for such a geometry. However, the absolute value of the NMR shift is less than it is expected for the pure polar phase, but greater than it should be for the A phase. It is possible that we observe the polar-like phase with the order parameter suppressed near the aerogel strands.$^1$


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Values of spin diffusion for these two directions of the gradient were found to be different at temperatures less than 15-20 mK. In the low temperature limit the obtained principal values of the spin diffusion tensor are $D_\parallel \approx 0.04 \text{cm}^2/\text{s}$ and $D_\perp \approx 0.02 \text{cm}^2/\text{s}$. In isotropic aerogel this would correspond to the quasiparticle mean free path of 800 nm and 400 nm. In further experiments we plan to investigate an influence of $^4\text{He}$ coverage on spin diffusion.\(^F\)


2 R.Sh. Askhadullin, V.V. Dmitriev, D.A. Krasminkin, et al., this conference.

13P-A009 NMR/MRI Study of Superfluid $^3\text{He}$ in Aerogel

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We have studied NMR properties of superfluid $^3\text{He}$ in aerogel with our state-of-the-art ULMRI. In contrary to the case of bulk superfluid $^3\text{He}$, A-like and B-like phases in aerogel showed hysteretic coexistence near the phase boundary without an artificial temperature nor field gradient across the sample. OCU group reported that two phases are separated in space.\(^1\) To further investigate the coexistence state, we started MRI study of the coexistent state of superfluid $^3\text{He}$ in aerogel. Our MRI measurement indeed showed spatially separated coexistence of the two phases. The interface between two phases was stable as far as the temperature was kept constant. However a shape and reproducibility of the interface suggest that the coexistence is related to some inhomogeneity in aerogel. Addition to the coexistent state, we found the suppression of superfluidity by adding extra amount of $^4\text{He}$ on the silica strands covered with 2.5 atomic layers of adsorbed solid like $^4\text{He}$. We also found the existence of modified superfluid state near the surface of the aerogel. This new surface state behaves differently from the bulk state.


13P-A010 Numerical simulations of the interaction between thermal quasiparticles and a three-dimensional vortex tangle in superfluid $^3\text{He}$-B

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We have developed a numerical method which enables us to simulate the interaction of a three dimensional vortex tangle of quantized vortices and thermal quasiparticles moving in the velocity field of the vortices. The method is based on an algorithm to solve stiff ordinary differential equations. We present results which refer to different vortex configurations. In particular, we show the dependence of the thermal conductivity on (i) the total circulation induced by a lattice of straight vortices, (ii) the vortex length density and curvature of a fully developed isotropic vortex tangle, (iii) Kelvin waves along a straight vortex line.

13P-A011 Flow Visualization in Superfluid $^4\text{He}$ Using Metastable Helium Molecules as Tracers

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Flow visualization in superfluid $^4\text{He}$ is challenging, yet crucial for attaining a detailed understanding of quantum turbulence. Two problems have impeded progress: finding and introducing suitable tracers that are small yet visible; and unambiguous interpretation of the tracer motion. Metastable He$_2$ triplet molecules are promising tracer candidate due to their small size and their relatively simple behavior in superfluid helium. He$_2$ molecules can be easily produced by electron bombardment of the helium or by field ionization. To detect and image the molecules, we have developed laser-induced-fluorescence techniques. At temperatures above 1 K, helium molecules follow the motion of the normal-fluid component without being affected by quantized vortices. We shall summarize our recent progress on studying the normal-fluid flow using He$_2$ molecule tracers and present evidence showing that the normal fluid can become turbulent in a thermal counterflow at relatively large heat flux. The coexistence of turbulence in both the normal fluid and the superfluid components in thermal counterflow presents us with a theoretically challenging type of turbulent behavior that is new to physics.

13P-A012 Equilibrium rotation of a vortex bundle terminating on a lateral wall

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Probably, in the theory of quantum vortices the most significant result (apart from the discovery of the quantum vortices themselves) was the forming of the vortex lattice in the rotating helium. Paradoxically, but the question how this lattice appears is open up to now. Currently this process was thoroughly investigated in superfluid $^3\text{He}$-B theoretically and experimentally in the Helsinki group. Vorticity is generated at the container bottom and propagates upward along the cylindrical container axis in the form of a vortex bundle flaring to lateral container walls. The structure and dynamics of this flaring bundle, whether it is turbulent or laminar, what is the velocity of its propagation - that are questions, which need theoretical description. In the present work the trial, equilibrium states of the corresponding vortex structure are built and studied. These states possess the “own” angular velocity obtained from
the standard conditions, that the thermodynamic potentials of system below an above the front are equal, and variation of the structure with respect to the shape is zero. If the container rotates with the same angular velocity neither dissipation nor propagation of the vortex front along the container axis is possible. If the angular velocities of the flaring vortex bundle and the container differ and there are dissipative mechanisms (interaction with the normal component and/or pinning on the lateral walls) then the front should propagate with the velocity evaluated on the basis weakly nonequilibrium theory.

13P-A013 Acoustic Radiation Modes of Quartz Tuning Fork in the Ballistic Regime of the Scattering of Thermal Excitations

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Experimental studies of acoustic radiation of quartz tuning fork immersed in He II in the regime of ballistic scattering of thermal excitations for different types of the radiation (monopole, dipole or quadrupole), are carried out. The quartz tuning forks with different resonant frequencies (32, 37, 77 and 97 kHz) were used. Measurements were carried out at temperature 0.35 K in pressure range SVP to 24 bar. Type of acoustic radiation of tuning fork was identified by the dependence of the resonance line width on the ratio between the size of a tuning fork and the wavelength of sound \( r/\lambda \). The value of \( r/\lambda \) changes, by pressure one order of magnitude. Experimental data suggest that, in the ballistic regime of scattering, a tuning fork is not a quadrupole radiator of acoustic waves for which \( \Delta f \propto (r/\lambda)^6 \). When \( r/\lambda > 0.225 \) the \( \Delta f \propto (r/\lambda)^4 \), whereas for \( r/\lambda < 0.225 \) the emission of sound is missing and the dissipative processes are only due to scattering of thermal excitations.

13P-A014 Numerical Study on the Free Decay of Vortex Tangle at Zero Temperature

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The results of numerical simulation on the free decay of the inhomogeneous vortex tangle when mutual friction is absent are reported. The calculations were performed both with the use of the localized induction approximation (LIA), which neglects the nonlocal effects, and with the use of the full Biot-Savart law. The approximation in the time step was done by the Runge-Kutta method of the fourth order. Different boundary conditions were considered. One of them is an infinite volume, the another one is a cube with smooth walls. It was shown that the number of reconnections result of the breakdown of the loop significantly larger in the case of full Biot-Savart law, than in the LIA approach. We performed the proper monitoring of various mechanisms responsible for attenuation of the vortex line length. They are the changes of length owing to an escape of the small loops from the volume, the reconnection processes, the annihilation of small vortices below the space resolution, the insertion and removing of points. These mechanisms have a numerical nature (e.g. numerical loss of length at reconnection event), but clearly they have also obvious physical meaning. The obtained numerical results demonstrate that the diffusive-like smearing of the vortex tangle into ambient space, initially localized in the small region, is the major mechanism responsible for attenuation of the vortex length. The temporal evolution of vortex line density agrees with the ones, obtained from the solution of diffusion equation. The work was supported by RFBR (grants 10-08-00369, 10-02-00514).

13P-A015 The Mechanism of Acoustic Dissipation of an Oscillating Quartz Tuning Fork Immersed in He II

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The dissipative processes due to viscous friction and acoustic radiation from vibrating tuning fork prongs, in the hydrodynamic and ballistic regimes of the scattering of thermal excitations, are investigated by measuring current - voltage characteristics of a quartz tuning fork immersed in He II. The vibrating tuning forks with different resonant frequency (32, 37, 77 and 97 kHz) were used and measurements were carried out at saturated vapor pressure in temperatures range 0.35 K - 1.5 K. It was found that at \( T \geq 1 \) K for the hydrodynamic flow regime in He II, the main dissipative process is the viscous friction, and acoustic dissipation mechanism is significant only at frequencies above 70 kHz. At \( T \leq 0.5 \) K, for the ballistic regime, the scattering mechanism of the dissipation due to scattering of thermal excitations by vibrating tuning fork prongs predominates only for tuning forks with low frequency (32 kHz) and acoustic dissipation mechanism dominates in almost the entire frequency range.

13P-A016 Additional Dissipation Mechanism of the First Sound in the Development of Quantum Turbulence

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We present the data of experimental investigations of the sound waves radiated by the vibrating quartz tuning fork immersed in He II. Measurements were carried out at a saturated vapor pressure in temperature range from 0.1 K to 2.5 K. Amplitude of the sound waves emitted by a quartz tuning fork, was determined using a piezoelectric receiver sound, depending on the velocity of vibrations at different temperatures. It is shown that, for laminar flow of He II, the emission amplitude of the sound wave is proportional to the velocity fluctuations. Increasing the velocity of vibrations leads to the development of quantum turbulence, recorded with a quartz tuning fork. Under these conditions, besides the scattering of thermal excitations, there is an addi-
tional mechanism of dissipation of sound waves caused by scattering by quantized vortices. The amplitude of the fluctuations in the wave of sound is drastically reduced.

13P-A017 Vortex Interactions in Superfluid $^4$He in the Zero Temperature Limit
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We have investigated the interactions of quantized vortex rings with each other and with vortex tangles in superfluid helium below 0.5 K. Seed charged rings, of radii in the range $R_0 \approx 0.5 \pm 0.2 \mu m$, were injected into the drift space where an applied electric field was used to increase the ring radii $R$. At high injected densities and large radii $R$ most rings reconnect leaving behind a slow moving charged tangle, so only a density $n_c \approx 5 \times 10^{-2} R^{-3}$ of rings keeps propagating forward -- the measured value of $n_c$ being independent of the initial ring density, duration of injection and applied field. Numerical simulations of $10^4$ forward-moving charged rings, such that when two rings collide geometrically their radii are changed so that the total impulse is conserved but a random amount of energy is dissipated, reproduce key features of the observed current transients and yield a comparable critical density of $n_c \sim 10^{-3} R^{-3}$. When charged rings are injected into an existing vortex tangle of density $L \sim 10^4 cm^{-2}$ that fills the whole container, a fraction of charge travels through the tangle with the drift velocity $\sim 20 cm s^{-1}$. Such fast transport of charge does not occur at the slightly higher temperature of 0.7 K. These observations can be explained if, at $T \leq 0.5$ K, vortex reconnections within the tangle lead to the re-emission of very small charged rings ($R < 0.1 \mu m$) -- that initially propagate rapidly in the direction of field until growing and reconnecting with the tangle. We are thus getting an insight into the dynamics of vortex lines on small length scales in the zero-temperature limit -- when frequent self-reconnections are expected to occur.

13P-A018 Quantum turbulence and the free decay of grid oscillations in He II
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We have measured the decay of free oscillations of a circular grid in superfluid $^4$He for pressure $P = 5$ bar, and temperatures $10 < T < 1500$ mK. In the $T \to 0$ limit, we observe three distinct decay regimes. At high grid velocities $v > v_c \approx 1-2 cm/s$, the oscillation amplitude decays very fast. For $v_c < v < v_2$, the decay is less fast but still non-exponential. When $v < v_2 \approx 0.3-0.5 mm/s$ the decay is exponential with a decay constant $\tau \sim 80 s$ consistent with the small-amplitude grid quality factor $(Q \sim 2.5 \times 10^5)$. We tentatively attribute the high-attenuation regime to the creation of quantum turbulence; the low-attenuation regime to pure "nuisance damping" due to nonidealities in the grid and possible internal friction, with no significant influence by the superfluid or pinned vortices; and we shall discuss possible interpretations of the intermediate regime. Other phenomena, including a switching regime during steady driving of the grid, and evidence for two distinct long-lived states of the system characterised by a relative frequency shift of $\sim 50$ mHz and different free-decay characteristics in the intermediate regime, will also be discussed.

13P-A019 Vortices and vortex rings as a source of electrical activity of superfluid systems
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It is shown that besides a common polarization caused by electrical field, non-uniformity of the medium as well as the motion of the medium give rise to polarization. In superfluid systems vortices and vortex rings are accompanied by specific velocity fields and density inhomogeneity. It results in a unique electrical activity of superfluid systems. In particular, in an electrically neutral superfluid system subjected by magnetic field the vortices carry electrical charge, the vortex pairs and rings carry dipole moment (polarization by Lorentz force). The dipole moment of the vortex pairs and vortex rings is also created by relative motion of normal and superfluid components (polarization by Magnus force). Vortices localized near the boundary and vortex rings of radius comparable with the vessel radius produce near-wall dipole momentum whose value depends considerably on temperature. In this report we consider the factors that influence the effects predicted and discuss the possibilities of experimental observation of such effects.

13P-A020 Diffusion and ballistic expansion of a two-dimensional quantum vortex bundle
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Quantum vortices are topological defects which are observable experimentally in superfluid $^4$He and $^3$He and in atomic Bose-Einstein condensates. In a two-dimensional system the sign of the winding number of the phase field around a vortex core determines if they are clockwise or anticlockwise. Vortices with winding numbers $\pm 1$ are stable, interact with each other and produce sound waves in the background fluid.

By using the Gross-Pitaevskii equation we numerically simulate a two-dimensional turbulent vortex bundle characterized by a superposition of $N$ vortices (both clockwise and anti-clockwise) which are initially confined in a circular region of radius $R$. The initial vortex coordinates are uniformly distributed with minimum
distance $d$.

We study the evolution of the system, sampling over random initial conditions. We use a numerical algorithm to track the trajectories of the vortices. We estimate the diffusion time scale of the vortex configuration, and how it is affected by frequent ballistic expulsions of vortex dipoles from the bundle.

13P-A021 Propagation of Quasiparticles in a Cluster of Vortices in Superfluid $^3$He-B

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The rotatory flow associated with quantized vortices can constrain the trajectories of thermal excitations in $^3$He-B. An excitation propagating through the superfluid flow field created by vortices may not find a forward-propagating state and therefore retracts its trajectory and changes flavor from quasiparticle to quasi-hole. This mechanism is called Andreev reflection. We describe the first measurement on Andreev scattering of thermal excitations from a vortex configuration with known density, spatial extent, and orientations in $^3$He-B superfluid. This configuration is created by rotating the $^3$He-B sample at constant angular velocity. We use two quartz tuning fork resonators embedded inside a blackbody radiator. One resonator creates a controllable density of excitations at 0.2 $T_c$ base temperature and the other records the thermal response. The results are compared to numerical simulations of ballistic propagation of thermal quasiparticles through a cluster of rectilinear vortices with taking into account the exact experimental geometry. Our studies suggest that the current understanding of Andreev reflection is correct and it can be used as a quantitative tool to visualize vortices in the low temperature limit. In particular, possible applications for studying Kelvin-wave excitations of vortex lines are discussed.


13P-A022 Visualisation of Liquid $^4$He Flows

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The first laboratory in Europe for the visualization of liquid helium flows is currently being established at the Charles University in Prague. Interesting and puzzling results recently obtained in overseas laboratories*2 are in fact posing more questions than providing clear answers. In particular, the trapping mechanisms of tracer particles into the cores of quantized vortices and the macroscopic eddies observed in thermal counterflow past circular cylinder certainly deserve further attention and study.*3 The use of flow visualization techniques for the analysis of cryogenic flows of normal and superfluid $^4$He is introduced and their specific features discussed. The newly implemented equipment was in particular designed in order to be potentially capable of obtaining novel results that are crucially needed for deeper understanding of the underlying physics. We present preliminary results showing that our new flow visualization system is well suited for the task of analyzing in unprecedented detail the complex interactions between tracer particles, quantized vortices and macroscopic eddies.


13P-A023 Two Types of Quantum Turbulence: Mechanically versus Thermally Driven $^4$He Superflow in a Channel

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We report an experimental study of $^4$He quantum turbulence for 1.3 $K < T < 2.0$ $K$. A flow was generated by a stainless steel compressible bellows pushing liquid helium through a channel $7 \times 7 \ mm^2$ in cross-section with ends blocked by silver sinter superleaks, thereby obtaining a net flow of the superfluid component only. We have deduced the density of quantized vortex lines in the middle of the channel length from the extra attenuation of second sound propagating perpendicular to the flow. We have identified the onset, and studied the steady state and the temporal decay of turbulence as a function of superflow velocity and temperature. The nature of quantum turbulence emerged is significantly different from that of a previous study [PRL 100, 315302 (2008); JLT 153, 162 (2008)], where the very same flow channel and detection technique were used, but the flow was driven thermally by a helium fountain pump. In the present study turbulence onsets at ten times lower velocity and in the steady state the observed vortex line density is about an order of magnitude higher, proportional to the square of the flow velocity, with no indication of a transition to a linear behavior at high velocity as seen before. This difference suggests strongly that the manner in which quantum turbulence is generated in our channel critically determines its nature.

13P-A024 Damping of quartz forks in superfluid $^4$He in the zero-temperature limit

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We report that the low-drive resonant linewidths $\Delta f$ of nominally 32 kHz quartz forks oscillating in He-II at $\sim 10 \ mK$ are critically dependent on their environment

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and on the frequency excited. A fork still inside its own cylindrical can (with a tiny hole for fluid access) has $\Delta f \sim 30-50\,\text{mHz}$ (cf. the vacuum linewidth of 28 mHz) and an approximately Lorentzian lineshape; its first overtone appears at 5.9× the fundamental frequency, with a $\Delta f$ that is $\sim 10^3$× larger and a non-Lorentzian lineshape. A fork removed from its can and mounted inside a 10 mm ID cylindrical tube exhibits a grossly broadened fundamental resonance with $\Delta f \sim 50\,\text{Hz}$, apparently formed from many overlapping resonances, each of width $\sim 2\,\text{Hz}$. The resonant frequencies and lineshapes are accurately reproducible over short times, but drift significantly over longer times. We present evidence that the drift is associated with tiny pressure variations. We note that these would give rise to tiny changes in the fluid density and the velocity of sound, shifting the pattern of nodes and antinodes in acoustic standing waves generated by the fork. For the fork in its can we have observed two critical velocities: $v_{c1} \approx 0.6\,\text{cm}\,\text{s}^{-1}$, where the drag increases; and $v_{c2} \approx 10\,\text{cm}\,\text{s}^{-1}$ where there is a clear transition from quasi-laminar to turbulent flow. The results will be discussed.

13P-A025 Dynamics of twisted vortex bundles and laminar propagation of vortex front

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The interest to twisted vortex bundles arose in connection with experimental studies of the transient process of establishing of stable vorticity in rotating superfluid $^3$He-B. The twisted vortex bundle appears in an originally vortex-free rotating container with a superfluid when vortex lines being injected at container’s bottom expand into the rest part of the container. The focus of previous experimental and theoretical studies was possible turbulence of the vortex front and the transition from the laminar to the turbulent regime. Meanwhile a proper dynamical theory of the laminar regime of the propagating vortex front is still lacking aside from rough estimations of the dissipation rate and the velocity of the vortex front. However, without a satisfactory theory of the laminar regime it is impossible to have a reliable physical picture of the more complicated turbulent regime or of the transition between the laminar and the turbulent regime. The present work suggests the theory of twisted vortex bundles on the basis of the dynamical equations describing slow vortex motion taking into account Tkachenko rigidity. The developed theory is applied to a twisted bundle terminated at the container lateral wall when the vortex front (the bundle segment diverging to the wall) propagates along the container axis. Special attention was devoted to the $T = 0$ zero limit, when mutual friction vanishes and the transition to the turbulent regime is expected as confirmed in experimental observations.

13P-A026 Simulations of the Charge Transport by Quantum Turbulence in $^4$He at $T \to 0$

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We analysed the results of experiments with two limits of quantum turbulence: a dilute cloud of polarized vortex rings of similar radii and a compact tangle of charged vortex lines under a body force. In the former, short pulses of up to $10^5$ charged vortex rings (CVRs) were injected into the drift space subject to an applied electric field where they propagated to the charge collector while growing in radius $R$. Numerical simulations were run whereby axially polarised CVRs of a small random radius were stochastically injected into a uniform electric field. If two parent CVRs collide, two daughter CVRs are produced conserving momentum and dissipating a random amount of energy; the charge is redistributed between the daughter CVRs in proportion to their radii. The simulations qualitatively reproduce features of experiment, such as broadening of the spatial distribution, culminating in the production of an elongated tail. Experimentally we observe a critical density of $n_c \sim 4 \times 10^{-4} R^{-3}$ above which CVRs do not propagate due to reconnections. Simulations yield a comparable critical density, $n_c \sim 10^{-3} R^{-3}$. In the latter, an initially compact charged tangle of vortex loops was propagating and evolving under an applied electric field; the time of flight and spatial spread of its charge were monitored by the currents detected at three different electrodes. By comparing these currents with those found by numerical simulations of a moving Gaussian distribution of charge, reasonable agreement was reached, and suggested the transverse spread of charge, after crossing the cell of length $4.5\,\text{cm}$, was $\sim 1\,\text{cm}$.

13P-A027 Nonstationary phenomena in second-sound acoustic turbulence in $^4$He II

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We report an investigation of transient phenomena in the evolution and decay of second sound acoustic turbulence in $^4$He II, considering both the direct and inverse energy cascades. During growth of the direct cascade, after first switching on the thermal driving force, the initial growth rates of the harmonics increase rapidly with harmonic number. This corresponds to a propagating front in frequency space, precisely as predicted by a theoretical description based on self-similarity. During growth of the inverse cascade, rogue waves arise in direct analogy with the oceanic rogue waves that endanger shipping. The decay of a fully-established cascade after switching off the driving force sometimes exhibits oscillations. We also report a study of the decay of the direct cascade in the case where the system is initially driven by two resonant drivings at different frequencies. It was found that the energy redistribu-
tion between the interacting harmonics can result in
the growth of some modes after one of the harmonic
drives is removed. These diverse phenomena will be
discussed and set in context.
(2010).

13P-A028 Size and Dynamics of Vortex Dipoles in Dilute Bose–
Einstein Condensates
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Being the hallmark of superfluidity, quantized vor-
tices have been under intense research in dilute Bose–
Einstein condensates (BECs) of alkali-metal atoms.
Lately, there has been great experimental and the-
oretical interest in so-called vortex dipoles, pairs of
quantized vortices of opposite circulation. In particu-
lar, Freilich et al. recently observed stationary vortex
dipoles for the first time in a BEC experiment. To ex-
plain their observations, we perform simulations based
on the Gross–Pitaevskii equation and obtain excellent
quantitative agreement on the size of the stationary
dipole. We also investigate how their multishot imag-
ing method, in which atoms are repeatedly extracted
from a single condensate, affects the vortex dynamics.
We find that it mainly induces isotropic size oscillations
of the BEC without otherwise disturbing the vortex tra-
jectories. Thus, the imaging technique appears to be
a promising tool for studying vortex dynamics in real
time.
1 D. V. Freilich, D. M. Bianchi, A. M. Kaufman, T. K. Langin,
2 P. Kuopanportti, J. A. M. Huhtamäki, and M. Möttönen,

13P-A029 Generation and Detection of Vortex Rings in Superfluid 4He at Very
Low Temperature
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A vortex ring flights in a superfluid sea, propelled by
quantized circulation around a vortex core. Although
a vortex core is very thin, tracer particles attached to a
core enable to observe the motion of a vortex ring. It is,
however, very difficult by this method to study the mo-
tion of a vortex ring itself, with no effect of tracer parti-
cles. In the present work, we report the flight of vortex
rings with no tracer particles, by using vibrating wires
as a generator and a detector of vortex rings. A vortex-
free vibrating wire enables to detect a vortex ring. The
time of flights of vortex rings are distributed, because
vortex rings flight in any directions from the generator
and the detector responds only to a reachable vortex
ring. By measuring the time-of-flights many times, we
find that the distribution is exponential with an un-
detected period, which corresponds to the time of the
fastest flight of a vortex ring. This result indicates that
generated vortex rings are limited in size, resulting in a
finite flight velocity. Increasing generation power of
vortex rings modifies a simple exponential distribution,
suggesting the generation of vortex clouds. These ex-
perimental results are confirmed by simulations of the
generation and the detection of vortex rings.
1 R. Goto, S. Fujiyama, H. Yano, M. Tsubota, et al.,

13P-A030 Time-development of energy spectra in the simulation of quantum tur-
bulence
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Bradley et al. studied experimentally emission of vor-
tex rings by a vibrating grid in superfluid 3He-B.1 They
observed a sharp transition from ballistic propagation
of vortex rings at low grid velocities to quantum tur-
bulence at higher velocities. We could understand the
transition from the full Biot-Savart numerical simula-
tion of the vortex filament model.2 In this work we
study numerically the time-development of the energy
spectra of vortices following the simulation of Ref. 2.
As the vortices are emitted densely to become turbulent
through lots of vortex reconections, the energy spectra
changes from that characteristic of a group of vortex
rings to some power law peculiar to a vortex tangle.

13P-A031 Vortex Front in Rotating 3He-B in the Zero-Temperature Limit
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The propagating vortex front is studied in superfluid
3He-B at low temperatures. The turbulent front1 moves
axially along a rotating cylindrical container of 3He-B
and replaces vortex-free flow with vortex lines at con-
stant density. At temperatures above 0.37Tc, the vor-
tex density behind the front approaches the equilib-
rium value. We present the first measurements on the
thermal signal from dissipation as a function of time,
recorded during the motion of the front and the subse-
quent relaxation to the equilibrium vortex state.2 The
time dependence, measured at 0.2Tc, with sensitivity
better than 0.1 pW, allows us to conclude that the den-
sity of vortices behind the front falls well below the
equilibrium value. Similar behavior is observed in our
numerical simulations of the vortex front. We present
an interpretation based on the decoupling of the vor-
tex dynamics from the container reference frame in the
limit of vanishing mutual friction, when T → 0. This
interpretation allows us also to explain two different
functional dependencies of the front velocity on the an-
gular velocity of the container, which are observed in
the coupled and decoupled regimes.
13P-A032 Kelvin Spectrum for a Harmonically Driven Vortex at Low Temperatures

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Currently one important interest in the quantum turbulence community is the dissipation and the decay of quantum turbulence in the zero temperature limit. As $T \to 0$ the coupling between vortices and normal fluid becomes negligibly small. Vortices in helium superfluids are quantized and therefore the traditional Kolmogorov energy cascade becomes impossible at scales smaller than the intervortex distance. To be able to dissipate, energy must be cascaded from the intervortex scales to scales of the order of the vortex core. This cascade is expected to occur via Kelvin wave excitations. Here we numerically determine the steady state spectrum for Kelvin waves on a superfluid $^4$He vortex that is driven by shaking its endpoints and damped by mutual friction, a situation easily realized in vibrating wire/grid/fork experiments. The resulting spectrum depends weakly on temperature and, for small drives, is independent of the drive amplitude. Due to the spatially sharply peaked drive no high-$k$ cutoff is observed, even when the mutual friction is large. At low drives, the accumulation (so-called bottleneck effect) of Kelvin waves in the region above the drive is absent. For higher drives the bottleneck effect is difficult to determine since the Fourier representation fails before a proper spectrum develops. We also determine the power dissipated due to mutual friction, as a function of the number of Kelvin modes present in the system, using different Kelvin spectra. Additionally, we show that the cascade is not totally absent in the Local Induction Approximation (LIA) provided that the Kelvin amplitudes are not small.

Most of the reconnections occur within a thin boundary layer, whose thickness slowly increases as the temperature drops. Future simulations will hopefully show, whether the thickness of the boundary layer remains finite or not, as $T \to 0$. A controllable perturbation to the initial state can be introduced by tilting the cylinder with respect to the rotation axis. By increasing the tilt, we observe a transition from laminar to turbulent decay. Similar turbulent responses are also displayed by our calculations on a cubic container. Even if the overall decay is turbulent, the tangle is inhomogeneous and partly polarized along the direction of the initial rotation.

13P-A033 Spin-Down of the Superfluid Component of $^3$He-B in Different Geometries

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The spin-down of classical fluids from rotation is generally unstable. In superfluids the flow of quantized vortices is also expected to become turbulent when the temperature is low enough and the dissipation from mutual friction becomes negligible. This impression comes mostly from $^4$He experiments where the pinning of vortices to the container walls is important. In superfluid $^3$He-B pinning is weak and it is expected to behave like an ideal superfluid. We can therefore compare its responses to calculations with the vortex filament model. Here we numerically study the behavior of the superfluid component after a sudden stop of rotation (spin-down). Similar to experiments, we find that in cylindrically symmetric containers the decay of vorticity remains laminar down to $T = 0.20T_c$, which corresponds to a superfluid Reynolds number $\text{Re}_s \sim 10^3$.

13P-A034 Vortices and the Superfluid Phase Transition in $d$ Dimensions

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The role of vortices in the superfluid phase transition will be discussed for general $d$ dimensions, with $d$ ranging between 2 and 4. A single set of recursions relations gives the results of Kosterlitz and Thouless in $d = 2$, reproduces the vortex-loop renormalization of Williams and Shenoy in $d = 3$, and approaches mean-field results in $d = 4$. Although the derivation of the recursion relations is phenomenological in nature, predictions for universal behavior in the scale dependence of the superfluid density near $d - 2$ should be possible to test with perturbative RG calculations. Comparison to experimental results will be discussed, including thermodynamic properties such as the specific heat, and the dynamics of the transition. The crossover from $d = 2$ to $d = 3$ in helium films adsorbed in porous materials has allowed the first measurements of the vortex core size in submonolayer superfluids. Research supported by the US National Science Foundation, Grant No. DMR 09-06467.

13P-A035 The coupled dynamics of micron-size particles and quantized vortices

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Recently, thermal counterflow quantum turbulence was experimentally studied by Paoletti et al. who visualized not only the normal flow but also the superflow by using solid hydrogen tracers. The tracer particles divide into two groups. In one group a particle is trapped by, and follows the motion of, the vortices; in the other group a particle is free and, owing to viscosity, follows the motion of the normal fluid. In this way Paoletti et al. obtained the velocity distributions of the normal fluid and the vortices. We study the coupled dynamics of particles and vortices, and their velocity distributions. The dynamics of vortices is described by the usual vortex filament model. The dynamics of a free
particle is given by Newton’s equation of motion with the Stokes drag force and the inertial force of the fluid. A trapped particle obeys Newton’s equation with the addition of the vortex tension force. We solve these equation of motion simultaneously to obtain a dynamical behavior and velocity distribution similar to that observed experimentally.  

13P-A036 Catalysis of Impurity Coalescence by Quantized Vortices in Superfluid Helium  
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Any guest particles immersed in superfluid helium possess an affinity to quantized vortex. On the example of hydrogen injected into the HeII it was proved that such impurity concentrating in practically 1-D core of vortices causes a tremendous acceleration of coagulation process and that its primary products should be nanowires. This phenomenon was then used for the production of metallic nanowires. The materials were supplied by laser ablation of targets submersed in liquid helium at T = 1.6 K. Long (up to 1 cm length) bundles of wires (with thickness from 1.5 up to 7 nm) were grown in HeII and as the parent vortices they were pinned by metallic bonds to the tips of electrodes intentionally introduced in reactor. That allows carrying out the electrical studies just at low temperature. The nanowires made of well-conductive Cu and Ar, of ferromagnetic Ni as well as of superconducting Sn, Pb and In were grown and studied. Electron microscopy of the nanowires warmed up to 300 K showed that they had regular crystalline structure. Being conductors of metallic type they demonstrated strong size effects inherent in nanowires, in particular, the strong increase in resistivity and, for superconductors, transformation and temperature shift of the phase transition. Due to their high length and small radius the bundles of nanowires demonstrated powerful field-induced electron emission at rather low voltage. The mechanism of nanowires formation in HeII has been discussed.

13P-A037 When does acoustic turbulence begin?  
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Any nonlinear wave distorts at moving in a medium, but this distortion as well as formation of multiple harmonics from “sine” wave doesn’t need an interaction of high frequency mode inter se. One of the key questions in experimental investigation of acoustic turbulence is when interaction between waves in energy cascade really begins. Experimental study of strong nonlinear second sound waves in superfluid helium in a high quality resonator demonstrates the interaction of derivative of the pumping signal harmonics (secondary multiple harmonics and subharmonics). The pumping of the system by two incommensurate resonance frequencies leads to format combination frequencies, which are ensued from interaction of secondary harmonics inter se. The similar combinational frequencies create at interaction subharmonics with multiple harmonics at formation of an inverse energy flux cascade. The probability density function of the high frequency multiple harmonics remains Gaussian-like due to stochastic interaction between the waves themselves. Experimental investigation indicated that the enhancement of the pumping excitation to a critical level (q_e ∼ 10 – 20 mW/cm²) lead to a change in the behavior of the energy transmission across the frequency range. Therefore these experimental results imply the formation of a turbulent state of multiple harmonics of the standing one dimensional second sound waves.

13P-A038 Vortex nucleation and transition to binary quantum turbulence in two-component Bose–Einstein condensates  
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We theoretically study the instability of countersuperflow, i.e., two counter-propagating miscible superflows, in uniform two-component Bose–Einstein condensates. When the relative velocity of the counterflow exceeds a critical value, the instability causes the nucleation of vortex rings whose size and number strongly depend on the relative velocity. The nucleated vortex rings expand and the vortex line density grows up with the momentum exchange between two components. A lot of reconnections with vortices are caused and lead to binary quantum turbulence, where both components become turbulent. In binary quantum turbulence, the tangled vortices in one component interact with those in the other component. We investigate statistical properties of the binary quantum turbulence. Binary quantum turbulence shows different behavior from single turbulence and offers a new avenue for study of turbulence.

13P-A039 Formation of Quantum Turbulence from Dark Solitons in Atomic Bose-Einstein Condensates  
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We theroreticaly propose a new method of making quantum turbulence from many dark solitons in atomic Bose-Einstein condensates. We solve numerically the two-dimensional Gross-Pitaevskii equation. We set many solitons which are parallel and perpendicular to each other for initial states. A dark soliton is known to be stable in one-dimensional system, but unstable in two- or three-dimensional systems and decay to vortices. Our simulation shows that these solitons decay to a lot of vortices which move around the system and eventually lead to two-dimensional quantum turbulence. The probability distribution function of the superfluid velocity obeys a Gaussian distribution in the low-velocity region and a power-law distribution in the
high-velocity region. This scenario may be experimentally realized through interference of Bose-Einstein condensates in a trap potential.

13P-A040 Capture of He\textsubscript{2} Molecules by Vortex Lines in Superfluid \textsuperscript{4}He at \( T < 0.2 \text{ K} \)

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We report preliminary results of experiments on decorating quantized vortex lines in superfluid \textsuperscript{4}He by ex-cimer molecules He\textsubscript{2}. The molecules, created by electrons field-emitted from a tungsten tip, travelled several centimetres to gridded detector electrodes subject to electric field \( 10^2-10^3 \text{ V cm}^{-1} \). The detector current of polarity correlated with the polarity of the detector field was observed below \( T = 0.2 \text{ K} \), but it can be suppressed by rotating the cryostat at angular velocity above \( \Omega = 0.2 \text{ rad s}^{-1} \) normal to the molecule path. The temperature dependence of the current has a sharp peak at \( T = 0.13 \pm 0.01 \text{ K} \), below which it gradually increases with cooling before saturating at \( T < 0.06 \text{ K} \). We suppose that the molecules travel trapped on the cores of vortex lines, which are created and propelled away from the tip by injected electrons. Collisions of trapped molecules result in ionization of one of them, after which the detector field can separate the resulting ions. We tentatively attribute the peak at \( T = 0.13 \text{ K} \) to the condensation of \textsuperscript{4}He impurities on vortex cores – these might affect the rate of diffusion of trapped molecules.

13P-A041 Capillary Turbulence on the Surface of Quantum Liquids

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Liquid hydrogen and superfluid helium He-II are very suitable liquids to study turbulence phenomena in the system of capillary waves due to their extreme low viscosity and density. These properties allow us to investigate wave turbulence and an influence of the discreteness of the wave spectrum, caused by finite size of the experimental cell, on the turbulent distribution. We observed\textsuperscript{1} for the first time a wave energy accumulation at high frequencies – a local maximum in the turbulent spectrum – when the He-II surface was pumped by low-frequency harmonic force. Qualitative model of this phenomenon in the frames of weak wave turbulence approach that takes into account discreteness of the spectrum of surface oscillations in the cylindrical resonator was developed. The formation of local maximum can be explained by a detuning effect of nonlinear harmonic frequencies and eigenfrequencies of surface oscillations in the cell. At high frequencies in the dissipative domain the very fast decreasing turbulent cascade was studied\textsuperscript{2}. This fall off could be described very well by “quasi-Plank” function in wide frequency range for turbulent state formed by a broadband noisy excitation. Thus our experiments confirmed the theoretical predictions on an important role of discreteness in the formation and decay of turbulent cascade\textsuperscript{3}.

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\textsuperscript{2} M. Yu. Brazhnikov, L. V. Abdurakhimov, S.V. Filatov, A. A. Levenchenko, JETP Lett. 93, 34 (2011)
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13P-A042 Nucleation of 1/3-vortices in a rotating and rapid quenched \( F = 2 \) spinor Bose-Einstein condensate in the cyclic state

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By solving the stochastic projected Gross-Pitaevskii equation, we theoretically study the formation of the fractional vortices of \( F = 2 \) spinor Bose-Einstein condensates in the cyclic state during the rotating evaporative cooling. Our numerical calculations show that stable 1/3-vortices of the spinor BEC in the cyclic state can be created in the resultant spin textures. The core structures and modulational instabilities of the single 1/3-vortices are investigated. By solving the stochastic projected Gross-Pitaevskii equation, we theoretically study the formation of the fractional vortices of \( F = 2 \) spinor Bose-Einstein condensates in the cyclic state during the rotating evaporative cooling. Our numerical calculations show that stable 1/3-vortices of the spinor BEC in the cyclic state can be created in the resultant spin textures. The core structures and modulational instabilities of the single 1/3-vortices are investigated.

13P-A043 Power spectrum and higher-order structure functions of quantum turbulence in superfluid \textsuperscript{3}He-B

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We report on studies of quantum turbulence produced by a vibrating grid in \textsuperscript{3}He-B at low temperatures. Quantum turbulence consists of a tangle of quantized vortex lines which interact via their self induced flow. At very low temperatures there is no normal fluid component and no associated viscosity, nevertheless our measurements show that the frequency spectrum of quantum turbulence displays a power law of \(-5/3\), reminiscent of the Kolmogorov energy spectrum for classical turbulence. The higher-order structure functions are also consistent with predictions from classical turbulence. At the highest frequencies, we see evidence for a cross-over to a -3 power law behaviour. This might give us the first experimental probe of turbulent dynamics at small length scales.
13P-A044 Large eddy simulations analysis of coupling force effect on the evolution of energy spectrum in superfluid
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The reliability of the filtered HVBK model is now investigated via some large-eddy simulations of freely decaying isotropic superfluid turbulence. The filtered HVBK model is solved using a fully pseudo-spectral method, which is an extension of the classical Rogallo’s method to the two-fluid model. In this paper, we analyze the evolution of various terms in the momentum equations of model HVBK via the equilibrium equation of the function of energy spectrum. The evolution of the different terms is presented in both cases with and without coupling force. Results show that this coupling force decreases energy dissipation in normal part of HVBK model and energy transfer is more significant when this force is taken in account.

13P-A045 Structure functions of capillary wave turbulence on the surface of He-II.

We present new experimental results of investigation of capillary wave turbulence on the surface of superfluid He$^4$ at the temperature of $T=1.7K$. The experiments were carried out in an optical cell placed in helium cryostat. Oscillations on the surface were excited by applying AC electric field perpendicular to the surface. Two types of excitation were used: monochromatic pumping at resonance frequency or noisy pumping at broadband frequency range. Waves on the surface of liquid were registered by measurements of the power of laser beam reflected from the surface. In our experiments wave elevation of the surface was proportional to the time variation of the laser beam power. From obtained experimental results we calculated wave elevation of the surface was proportional to the time variation of the laser beam power. From measurements wave elevation of the surface was proportional to the time variation of the laser beam power. From obtained experimental results we calculated wave elevation of the surface was proportional to the time variation of the laser beam power. From measurements wave elevation of the surface was proportional to the time variation of the laser beam power.
filled Two-dimensional Ionic Hubbard Model

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The quantum phase diagram of a half-filled two-dimensional ionic Hubbard model is investigated by the variational cluster approach (VCA).\textsuperscript{1} For weak Coulomb repulsion $U$, the system is a band insulator (BI) with a band gap $2\Delta$ induced by the alternative on-site energies $\pm \Delta$. For the strong-coupling limit $U \gg (\Delta, t)$, the Hamiltonian can be mapped onto an effective Heisenberg model where the ground state is a Mott-insulator (MI) with an anti-ferromagnetic long-range order. In this work, we present explicit evidence for the tendency toward a novel intermediate phase, the bond-located spin density wave (BSDW) phase characterized by a bond-located magnetization, in this model. To determine the possible phase between the BI and MI, we have used a variety of Weiss fields including the one for BSDW, which is found to be favored from an energy point of view. The phase diagram we obtained shows the width of BSDW region shrunk with increasing $\Delta$. Whether there is a critical value $\Delta_c$ beyond which the BSDW vanishes is hard to be determined within the VCA. The bond-located spin density wave competes with the antiferromagnetism while the charge-density modulation exists all the way due to the staggered potential $\Delta$.


13P-A051 The Mean Energy in the Canonical and Grand Canonical Ensemble

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For many particles quantum systems, calculating thermodynamical quantities in the canonical ensemble is a very hard task, while it is tractable in the grand canonical ensemble. The second ensemble is then used. The results are supposed to be the same in the thermodynamic limit [1]. Is this actually the case? In this work, we compare the mean energy obtained in the canonical ensemble to that of the grand canonical one. We consider a system of $N$ bosons distributed among two, three and four energy levels. We can calculate the canonical partition function in this case and deduce the canonical mean energy. We compare it to the result of the grand canonical ensemble. The two values differ noticeably. We plot the relative discrepancy as a function of the temperature, for different $N$ values ranging from $10^3$ to $10^8$. The curves have a gaussian shape, with a maximum of 0.20.


13P-A052 Neutron transparency measurements in cryogenic $^3$He vapour

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We present a new experimental method for the investigation of critical collective excitations based on the use of neutrons to probe critical opalescence. We collected transmission data through $^3$He vapour within the temperature range (1.4 K ~ 50 K) and use the information obtained to infer the apparent $^3$He vapour density. Our preliminary data demonstrate unexpected behavior. In particular, near the critical temperature (~3.32 K) the neutron transmission is significantly higher than would be expected, just based on the average density of $^3$He atoms. We compare our data with the results obtained earlier using conventional methods (based on the measurement of refractive index and permittivity). Away from the critical point all methods yield similar results but, in the critical regime, our results are lower than previously reported. This is where critical opalescence effects are expected to become significant and where any microscopic thermal fluctuations become strongly correlated, leading to large-scale density fluctuations. This new experimental approach opens opportunities for the use of neutrons to probe opalescence near the
The liquid-crystal phase transition of two-dimensional (2D) electron system over a liquid helium surface is studied experimentally. Two AC electric potentials are used in the experiment. The first one with frequency 3 MHz and low amplitude is used for transport properties measurements. The second one (damaging potential) has substantially higher amplitudes (50 - 300 mV) and frequency 40 MHz. The phase transition was observed as abrupt change of both components of the electron layer response to AC exciting voltage depending on temperature. The damaging potential is found to shift the phase transition to the lower temperatures. The damaging potential of about 300 mV suppress the transition to the ordered state. One of possible explanations is overheating 2D electron system by driving damaging electric field.

13P-A056 Comparison of the Non-Linear Phase Transitions in 2D Electron System and 2D Helium Film

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The two-dimensional electron crystal over liquid helium undergoes the non-linear phase transition induced by the electric field $E_1$ in the layer plane. The complex inverse conductivity of the layer $\sigma^{-1} = \chi = \chi_1 + i\chi_2$ is measured through the transition depending on surface electron density, frequency and temperature. The field dependencies $\chi_1(E_1)$ and $\chi_2(E_1)$, which reflect the energy losses and inertia in the layer are compared qualitatively with the velocity dependencies of dissipation $Q^{-1}$ and inertia moment change (proportional to the superfluid density) in the helium film measured by the torsional oscillator method. Similarities between these phase transitions are found. The superfluid phase transition can be treated on the base of Berezinskii-Kosterlitz-Thouless theory, and the similarities allow to consider the non-linear transition in the electron crystal as dynamic melting.

13P-A055 Extremely Efficient Clocked Electron Transport on Superfluid Helium

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Electrons floating on the surface of superfluid helium have been suggested as promising mobile spin qubits. 3μm wide channels fabricated with standard silicon processing are filled with helium by capillary action. Photoemitted electrons are held by voltages applied to underlying gates running under 120 parallel channels. The underlying gates are connected as a 3-phase charge-coupled device (CCD). By applying an appropriate voltage sequence to the 3 phases, electrons are clocked along the 120 channels in parallel. Electrons are detected by the voltage they induce on a sense gate. Starting with approximately one electron per channel, no detectable transfer errors occur while clocking $10^3$
pixels. One channel with its associated gates is perpendicular to the other 120, providing a CCD which can transfer electrons between the others. Again, no transfer errors were detected after transferring 10^9 pixels, including transfers between the two orthogonal CCDs. Full control of an electron's position within an array of about 4000 sites is demonstrated with only 5 gate leads. Supported by the National Science Foundation through the EMT program under Grant No. CCF-0726490, and through DMR under Grant No. DMR-1005476

13P-A058 Universal behavior of the heat transport properties of molecular glassy crystals
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A comparative analysis of experimental data on the thermal conductivity has been made for two types of molecular glassy crystals: orientational glasses (ethanol, freon112, cyanocyclohexane, cyclohexanol) and clathrate gas hydrates (CH_4(5.5H_2O), Xe6(2H_2O) and THF(16H_2O)) in the temperature region from 2 K to the glass transition temperature Tg. The temperature dependence of the thermal conductivity \( \kappa(T) \) of these substances is similar to that of amorphous atomic solids. The temperature dependence of the thermal conductivity is well described by a sum of two contributions: \( \kappa(T) = \kappa_1(T) + \kappa_2(T) \), where \( \kappa_1(T) \) accounts for the heat transport by long living acoustic excitations and \( \kappa_2(T) \) is for the heat transfer by delocalized vibrational excitations (diffusons). It is shown that the contribution of \( \kappa_1(T) \) is well described by the universal curve in the soft potential model and \( \kappa_2(T) \) corresponds to short wavelength acoustic phonons with the minimum allowed value of the phonon relaxation time \( \tau_{\text{min}}(\omega) = \pi/\omega \) according to Cahill-Pohl model.

13P-A059 Metal Clusters in a Helium Matrix
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Capturing atoms in ^4He nanodroplets allows to assemble cold nanoclusters in a well controlled step-by-step way. A challenge for the theorist is the multi-scale description of all degrees of freedom of such a system: the electrons of the cluster, the motion of the ions of the cluster and the motion of the ^4He atoms surrounding the cluster. We present calculations of small Mg_N clusters within ^4He droplets. We employ density functional theory in the local density approximation (LDA) for the electronic structure of Mg_N and Path Integral Monte Carlo simulations for the superfluid ^4He droplet. The interaction between the cluster and the surrounding ^4He is modeled in a such a way that the known He-Mg interaction is reproduced for the dimer, and the polarization of the Mg valence electrons is treated, consistently with the rest of the system, in the LDA. The Mg_N clusters are annealed including the response of the ^4He environment. We discuss the effect of the ^4He matrix on the structure and the response of the Mg_N cluster.
We have performed quantum Monte Carlo simulations of $N_2^+$ ions in $^4$He clusters and of $Rb_2$ in the triplet ground state, $^3S_{1/2}$, adsorbed on a $^4$He surface. For that purpose we have obtained the potential energy surface for the $N_2^+$–$^4$He interaction and for the $Rb_2$–$^4$He interaction by ab initio coupled cluster calculations. Due to the weak attraction between $Rb_2$ and He, the ground state is an Andreev state, with the $Rb_2$ axis oriented parallel to the surface. The anisotropic dimple formed in the $^4$He surface by $Rb_2$ is shallow, which explains why we found almost free $Rb_2$ rotation parallel to the surface. Out-of-plane rotation is hindered by the surface. We furthermore used correlated basis function theory to calculate damping of $Rb_2$ vibrations due to coupling to the $^4$He surface. $N_2^+$ is solvated inside $^4$He due to the strong attraction between the ionic molecule and $^4$He. We calculated binding energies, the structure of the $^4$He “shell” around $N_2^+$, and the rotational dynamics of $N_2^+$–$^4$He$_N$ clusters. We discuss the effect of the additional He–$^4$He repulsion due to the dipole moments induced by $N_2^+$ on the chemical potential and on the $^4$He density around $N_2^+$. Regarding rotational dynamics, $N_2^+$ is an interesting case of a light rotor (favoring weak rotational coupling with $^4$He) with a strong interaction with $^4$He (favoring strong coupling). We present our results of rotational excitations of $N_2^+$–$^4$He$_N$. 

**13P-A063 A Tool for Production of Ultra Cold Neutrons in Superfluid He-II**

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Recently we have elaborated two ideas based on the use of impurity-helium nanocluster condensates (quantum gels) in He-II as a tool for production of ultra cold neutrons (UCN) at high densities. The first idea consists in the equilibrium cooling of very cold neutrons down to the He-II bath temperature, cooled preliminary to a few mK, owing to their many quasielastic collisions with nanoparticles made of low-absorbing materials ($D_2$, $D_2O$, $O_2$, etc.) during diffusion motion of neutrons through a macroscopically large ensemble of nanoparticles. The second idea consists in modernization of the existing now source of UCN on superfluid He-II: diffusive propagation of cold neutrons through the gel sample placed inside container with liquid He-II at high gel densities should lead to a strong increase of effective time of the neutron propagation through the container, resulting in sharp increase of the probability of transformation of very cold neutrons to UCN owing to their inelastic interaction with liquid He-II permeating the pores between clusters even at the bath temperature $T \geq 0.5$ K. Of a strong interest is a question on spectrum of excitations of He-II in these pores. The report will include results of our experimental study of the thermal neutron interaction with $D_2$ and $D_2O$ samples made at the bath temperature $T \geq 1.6$ K.

**13P-A064 Low Energy Electron Source for Low Temperature**

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It is necessary to develop a new electron source for low energy, since the accumulation of electrons onto liquid He surface is considered to occur in the condition of low electron kinetic energy. There are several way to make electron sources; one is thermal cathode (filament), another is electric field emission, and the other is photo cathode type. In the electron source we developed, we employed the thermal cathode type, because the construction is simpler than the photo cathode, and it is easier to get low electron energy compared to the field emission type electron sources. We added some electrodes to the new electron source other than the filament itself. Important electrodes are “suppress” and “extract”. These are rather common electrodes as usual electron sources, but sometimes ignored in the study of low temperature physics in order to make the experiment simpler. The suppress electrode controls the angle of electron emission, and results in the higher electron current onto the sample surface. The extract electrode gives us high electron flux by keeping the enough electric field at the filament to extract electrons. We measured the energy resolution and electron flux of the new electron source. The energy resolution is about 0.6 eV FWHM. The electron current is enough at the kinetic energy of 1 eV.

**13P-A065 Evolution of the Temperature Parameter in Texts**

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In recent papers [1,2], we suggested a new set of parameters to be used in the analysis of texts. The parameters are defined by mapping word rank–frequency distributions onto the Bose-distribution within the grand-canonical approach. The respective physical analogues are the power of the excitation spectrum $\alpha$ and the temperature $T$. The analogue of the fugacity $z$ is determined from the number of words occurring only once (so-called hapax legomena). The values of $\alpha$ typically fall in the domain between 1 and 2. The calculated “temperature” values behave so that the relation $\tau = lnT/lnN$ (where $N$ is the number of words) does not vary significantly as the length of text increases. The values of $\alpha$ and $\tau$, however, show the relation to the type of language grammar. In this work, we analyze in detail the evolution of the $\tau$ and $\alpha$ parameters in texts of several kinds, namely: translations of the Gospel of John and The Little Prince, a novel by Antoine de Saint-Exupéry, into several dozens of languages from different language families, as well as several works of the long-prose fiction by Ivan Franko, a famous Ukrainian writer from the turn of the 20th century.

13P-A066  Studies of Fast Negative Ions in Superfluid Helium
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The normal negative ion in liquid helium consists of an electron confined in a bubble of radius approximately 19 Å. These bubbles have been studied in many experiments. Time-of-flight mobility measurements have revealed that there are other types of negative ion of higher mobility and unknown structure. In this note we report on a study of the fastest of these and discuss the conditions under which it can be observed.

13P-A067  Melting Pressure of $^3$He–$^4$He Mixtures
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At the lowest temperatures, the melting pressure of a helium mixture increases quadratically as a function of temperature. This is because the melting curve is essentially determined by the entropy of $^3$He in the liquid phase. The solid phase can be assumed to be pure from $^3$He. As temperature is raised, increasing amount of $^3$He dissolves into the solid, whereby the melting pressure turns over and begins to decrease. The maximum pressure is obtained at approximately 300 mK. The melting pressure of dilute mixtures drops below that of pure $^4$He at about 0.5 K and reaches a minimum around 1 K, beyond which a positive slope is observed again. The melting pressure of pure $^3$He is widely used as an empirical thermometric standard. In a similar manner, the melting pressure of helium mixtures can be used for thermometry. It gives superior resolution compared to $^3$He at very low temperatures. Most importantly, the relation between pressure and temperature in dilute mixtures can be computed from theory. We study the temperature and concentration dependencies of the melting pressure by using thermodynamic considerations and a previously determined effective interaction potential between $^3$He quasiparticles in the liquid mixture.

13P-A068  Neutron imaging study of the phase separation of $^3$He–$^4$He liquid mixtures at low temperatures
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Liquid $^3$He–$^4$He mixtures have been of technical importance for obtaining very low temperatures, mainly because dilution refrigerators, which are widely used for cooling in the milliKelvin range, are based on their properties. One major advantage is the possibility to vary $^3$He concentration and thus the isotopic phase separation temperature. We have performed a set of neutron imaging experiments on $^3$He–$^4$He mixtures, where $x_3$ ($^3$He concentration) was 9.7%. The predicted phase separation temperature, $T_{ps}$ is $\sim$300 mK which turned out to be in a very good agreement with the experimental value $\sim$294 mK. Images, in the temperature range of from 1.5 K to 150 mK, were taken for 18 hours, with 30 second time intervals, using a high resolution CCD camera.

The results have clearly shown two distinctly separated phases, $^3$He-phase on the top of $^4$He-phase. In addition, the dynamics of $^3$He atoms during the phase separation process has been studied.

13P-A069  Localization of electrons in liquid parahydrogen from Density Functional calculations.
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We have developed a finite-temperature density functional approach to describe the properties of parahydrogen (pH$_2$) in the liquid-vapor coexistence region. Our scheme is based on a finite-range free density functional which, while it is fitted to reproduce bulk pH$_2$ properties only, it is shown to yield liquid-vapor interface properties in good agreement with experiments in the whole temperature range from the triple point to near the critical point. We have studied the localized states of electrons in liquid pH$_2$ using a suitable representation for the electron-hydrogen interaction potential. The effect of electrons as seeds of heterogeneous cavitation is also investigated.

13P-A070  Mechanical resonators in the quantum regime
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I will describe our recent experiments, representing about ten years’ development of nanomechanical and quantum circuit technology, which culminated in our formulating and creating a quantum mechanical resonator that could “easily” be prepared in quantum (non-classical) states of mechanical vibration. Key requirements included a mechanical design that supported a microwave-frequency mechanical resonance; using a piezoelectric material in order to achieve very strong electromechanical coupling; and employing a Josephson junction, implemented as a phase quantum bit (qubit), to measure and interact with the mechanical resonator. Operating at 25 mK on the mixing chamber of a dilution refrigerator, this integrated electromechanical system can be cooled to its quantum ground state without additional intervention. Then, employing the extraordinary nonlinearity provided by the Josephson qubit, and the coherent interactions of this qubit and the mechanical resonator, we were able to prepare and measure non-classical mechanical states of motion in the resonator.

13P-A071  Observation of metastable hcp solid helium
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Ilic, A. D. Fefferman, H. G. Craighead, and J. M. Parpia, D. R. Southworth, R. A. Barton, S. S. Verbridge, B. 1
same substrate, will be presented.

13P-A073 Hydrodynamics of Superfluid Bose Liquid as Hydrodynamics of One-component System

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Standard hydrodynamics of superfluid Bose liquid was elaborated by Landau and Khalatnikov. Domain of app-
licability of this theory is discussed in the literature 1. Idea that the superfluid liquid consist of two subsys-
tems with different properties is very attractive. How-
ever, this liquid consists of identical particles. Here hydrodynamics of the superfluid Bose liquid is formul-
ated as a hydrodynamics of one-component liquid with additional variable (order parameter) which describes its broken symmetry. We introduce mass velocity by usual formula \( \pi_n = \sigma \nu_n \) where \( \pi_n, \sigma \) are total mo-
momentum and mass density of the liquid. This relation and standard definition allow expressing of ve-
locity of superfluid \( \nu_{nl} \) and normal \( \nu_{nl} \) components by formulæ \( \nu_{nl} = \nu_0 - \sigma \omega_1/\sigma, \nu_{nl} = \nu_0 + \sigma \omega_1/\sigma \) \( (\sigma \equiv \sigma_s + \sigma_n, \omega_1 \equiv \nu_{nl} - \nu_0) \). Now we can write down all transformation laws (taken from usual hy-
drodynamics of one-component liquid) from laboratory reference system (RS) to local RS which moves with the velocity \( \nu_1 \). Reversible contributions to energy and momentum fluxes in the last RS are given by expres-
sions \( q_\alpha = (s_0 T + \alpha \pi_0^2) \alpha \pi_0, \Gamma_\alpha = \rho_0 \delta_{\alpha m} + \alpha \pi_0 \Gamma_0 \) \( (\alpha \equiv \sigma_\alpha/\sigma_{nl}) \). These formulæ show that deviation of hydrodynamics of superfluid liquid from usual hydro-
dynamics of one-component liquid is defined by parameter \( \alpha \) (\( \pi_0 \) is momentum in the RS of the superfluid component and is considered as the order parameter).

1 S. J. Putterman, Superfluid hydrodynamics, New York, Else-

13P-A072 A Fibre Interferometer for Low Temperature Measurements of High-Stress Silicon Nitride Nano-
mechanical Devices

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We present both room and low temperature optical in-
terferometry measurements on several different types of nanomechanical resonators made from pre-stressed sto-
ichiometric silicon nitride on a silicon substrate. Me-
chanical resonances have been measured in doubly-
clamped beams, three paddle torsional resonators and
cantilevers at frequencies ranging from 5 MHz to above
10 MHz. Previous research has measured the tempera-
ture dependent dissipation in silicon nitride membranes and cantilevers to 1 K 1. The fiber interferometer dis-

cussed here has been specifically designed and con-
structed to enable measurements on nanomechanical systems at temperatures below 1 K. As the devices are
cooled the quality factors increase substantially. As an example, the quality factor of one of the doubly
clamp beams increases from \( \sim 10 \times 10^5 \) at room tem-
peratures to \( > 250 \times 10^5 \) at low temperature. The tem-
perature dependence of the dissipation in the different types of resonator, all fabricated simultaneously on the same substrate, will be presented.


13P-A074 Multiple Spin Echoes and Instabilities in Hyperpolarized \(^3\)He-\(^4\)He Solutions

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Hyperpolarized He mixtures, obtained by dissolution of laser polarized \(^3\)He gas into liquid \(^4\)He, offer a rich play-
ground to investigate non-linear spin dynamics induced by long-range magnetic interactions. Such residual in-

13P-A076 Energy Dissipation Effects in the Dynamics of a Josephson Junction Between Two Binary Bose-Condensed
Mixtures
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The dissipative dynamics of a pointlike Josephson junction in binary Bose-condensed mixtures is analyzed within the framework of the model of a tunneling Hamiltonian. The transmission of unlike particles across a junction is described by the different tunneling amplitudes $I_1$ and $I_2$. The effective action that describes the dynamics of the phase differences $\varphi_1$ and $\varphi_2$ across the junction for each of two condensed components is derived employing the functional integration method. In the quasiclassical low-frequency limit the dynamics of a Josephson junction can be described by two coupled dynamical equations in terms of the potential energy $U(\varphi_1, \varphi_2)$ and dissipative Rayleigh function $R(\varphi_1, \varphi_2)$ using a mechanical analogy. The Ohmic-like energy dissipation appears in the second-order terms in the tunneling amplitudes and intensifies infinitely with approaching at the demixing point. The interplay between mass currents of each mixture component results from the crossed second-order term in the tunneling amplitudes due to interspecies hybridizing interaction.

13P-A077 Higher Order Propagators for Path-integral Monte Carlo Study: Application to Quantum Quadrupolar Rotors
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For quantum Monte Carlo simulations the primitive propagator whose time step error is proportional to $\tau^3$, has been widely employed. A fourth-order propagator Chin proposed some years ago could produce more accurate results with small enough time step since it involves a time step error proportional to $\tau^5$. Its application, however, requires a great deal of computer time increase, limiting its efficiency. Zillich et al. recently developed extrapolated higher-order propagators which could allow more efficient calculations to be carried out. In their scheme any even-order propagator can be generated through the multi-product (MP) expansion of the primitive propagator, whose accuracy and efficiency were systematically tested for liquid $^3$He. We here apply the MP higher-order propagators to path-integral Monte Carlo (PIMC) simulations on asymmetric quadrupolar rotors, which is a model system to study orientational ordering in a molecular solid of hydrogen deuteride at low temperatures under high pressures. Through comparison of the accuracy of these new calculations with the ones of using the old propagators, we investigate availability of MP propagators to a quantum-many system with rotational degrees of freedom. Finally we present PIMC phase diagrams of quantum quadrupolar rotors fixed at the face-centered cubic lattice sites and compare them with the one determined experimentally for solid hydrogen deuteride.

13P-A078 Thermodynamic Grounds
for the bcc-hcp Transition in Solid Helium Isotopes
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The analytic approach to the destabilization mechanisms of the hcp and bcc phases is applied to both solid helium isotopes, $^3$He and $^4$He. Three different types of excitations, zero-point and thermal phonons and thermal vacancies, are analyzed from this point of view. Thermal phonons are considered within the classical Debye theory, contribution of zero-point phonons to thermodynamics is taken according to strong molar volume dependence (see Ref. [1]), and vacancies are treated as wide-band quasi-particles according to Hetherington's model.\textsuperscript{2} For the bcc-hcp pressure-temperature line we estimate vacancy concentration, $x_V$, using molar volume dependence of the vacancy activation energy, $Q_V$, obtained in Ref.[3]. Based on similarity of $x_V$ vs $V_m$ dependences along the bcc-hcp equilibrium lines for both helium isotopes and on huge $x_V$ values near the melting curve, we suppose that in high temperature range the hcp lattice is destabilized by high values of $x_V$ and the transition to the bcc phase. The second reason for hcp phase destabilization in a case of $^3$He is zero-point phonons which become a main factor in low temperature region.

13P-A079 Spin Waves and Moving Domain Walls in Dilute Spin Polarized $^3$He-$^4$He Mixtures
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Early experiments by Nunes et al.\textsuperscript{1} showed that following a single 180 degree NMR pulse acting on a very dilute, polarized mixture of $^3$He in $^4$He (350 ppm) in a 9.4 Tesla magnetic field, a sequence of spin echoes at intervals ranging from 0.1-1.0 seconds was observed. We have recently interpreted these data as being associated with spin wave resonances in the cell excited by a domain wall moving through a magnetic field gradient. Each echo corresponded to a different spin wave mode. A variety of echo patterns were observed depending on the temperature and field gradient. The data will be discussed in terms of models based on the Leggett - Rice equation.\textsuperscript{2}

13P-A081 Universal Behavior of Quantum Chaotic Gas
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We discover numerically that a moving wave packet in a chaotic billiard will always evolve into a quantum state, whose density probability distribution is exponential. This exponential distribution is found to be universal for quantum chaotic systems with rigorous proof. In contrast, for the corresponding classical system, the distribution is Gaussian. We find that the quantum exponential distribution can smoothly change to the classical Gaussian distribution with coarse graining. This universal dynamical behavior can be observed experimentally with Bose-Einstein condensates.


13P-A082  Interplay of quantum and classical fluctuations near quantum critical points

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Near a quantum critical point (QCP), above its lower critical dimension $d_L$, there is a line of classical phase transitions that separates the broken symmetry phase at finite temperatures. The phase transitions along this line are governed by thermal critical exponents that are different from those associated with the quantum critical point. This is an inevitable consequence of the relevance of temperature near a QCP, i.e., that temperature moves away from this point under scale transformations. Quite generally this leads to an intermingling of classical and quantum critical fluctuations near the zero temperature phase transition. This is a robust, but subtle phenomenon that implies an entanglement of classical and quantum critical fluctuations. A clear experimental manifestation of this effect is the suppression of the amplitude of classical fluctuations near the line of finite temperature phase transitions as the critical temperature is reduced approaching the QCP.

13P-A083  Generation and Annihilation of $^4$He Negative Crystals

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When a relatively large $^4$He crystal sticking on a vertical sample cell wall fell slowly along the wall, a number of small superfluid droplets or negative crystals spontaneously appeared in the host crystal. The negative crystals rose in the host crystal due to the buoyancy, and finally merged into bulk superfluid surrounding the host crystal. The rising velocity of the negative crystals was almost constant regardless of the host crystal’s falling motion, even when the host stayed on a bottom of the cell. This indicates that the falling of the host crystal is the result of the crystallization in the lower parts of the host crystal and the melting in the upper part and that the rising of the negative crystals is also caused by the melting of the host crystal in the upper part of the negative crystal and by crystallization in the lower part. We also observed that the rising of the negative crystal was accelerated by applying acoustic waves to the host crystal.


13P-A084  Equilibrium Shape of $^4$He crystal under $mG_E$

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The gravity on the Earth $(G_E)$ has not been taken seriously except for some critical phenomena of superfluid $^4$He, though it could definitely mask the fundamental phenomena on quantum solids and liquids. We are investigating the effect of gravity on the equilibrium shape of solid $^4$He at low temperatures. The experiment has already got started and some preliminary results are obtained. The reduced gravity less than 10 $mG_E$ is obtained by a jet plane’s parabolic flight for a period of 20 seconds. Recently we successfully cooled solid $^4$He down to 0.6 K on the small jet plane and were able to observe the crystal shape under $mG_E$. Before the entry of the reduced gravity, it experienced 2.0 $G_E$ and the interface became sharper due to the reduced capillary length. As soon as $mG_E$ was achieved, the crystal began to change its shape to the equilibrium in a second. The time constant is consistent with the calculation based on the surface tension and the growth coefficient. The crystal remained stuck all the time of the 20 seconds to the wall. We also applied acoustic waves to the crystal to shake it during the parabolic flight and observed some responses to the waves.


13P-A085  Spectroscopic studies of impurity-helium condensates containing stabilized N and O atoms

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We present optical spectra of impurity-helium condensates during the process of formation by injection of gas mixtures N$_2$–Rg–He (Rg=Ne, Kr) into bulk superfluid helium after passing through an rf discharge. Atomic lines of He, Rg, N, O atoms and N$_2$ bands (1+ and 2+) are present in the spectral range 320–1100 nm studied in these experiments. We also studied spectra emitted by the samples during their destruction, stimulated by warming through the temperature range 1.5–15 K. The most intense features of emission spectra of the N–N$_2$–He and N–N$_2$–Ne–He samples during their destruction were α- and β-groups (corresponding to transitions N(2D–4S) and O(1D–1S)). For the N–N$_2$–Ne–He sample the transformation of the α-group spectra was detected: at the onset of sample destruction, the α-group spectra were similar to those of N atoms in Ne matrices, but as time progressed the spectra became similar to that of N atoms in N$_2$ matrices. In the emission spectra of the N–N$_2$–Kr–He samples the intense β-group
of O atoms and M-bands of NO molecules were found. Differences in the spectra obtained during destruction of N–N₂–N₂–Ne and N–N₂–Kr–He samples may be explained by a different shell structure of the nanoclusters formed during impurity-helium condensate preparation.

13P-A086 The Features of Liquid ³He - ⁴He Mixture Phase Diagram in Narrow Geometry

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The influence of van der Waals forces on the decay of liquid solutions of helium isotopes is studied theoretically and the conditions for the phase co-existence in a confined geometry are investigated. We consider the thermodynamics equilibrium conditions in presence of the field of van der Waals forces. As the models to account the influence of van der Waals forces on the helium isotope solution the gap between two parallel planes and the cylindrical channel are considered. For each of the models we calculated the concentration space profile inside the channel depending on the van der Waals constant, the initial solution concentration and the size of the channel. We modify the phase diagram of the solution in narrow geometry in comparison with that in bulk. A rather good agreement between theoretical and experimental phase diagrams is obtained for liquid helium mixture in aerogel with porosity \( \lesssim 95\% \).

13P-A087 Mechanical Response of Noble Gas Films to an Oscillating Substrate

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Krim and co-workers measured the sliding friction of Kr monolayer films adsorbed on Au substrate (Kr/Au) using the quartz-crystal microbalance (QCM) technique. They reported that the films are partially decoupled from an oscillating substrate. Recently, we have performed QCM experiments for Kr and Xe films on graphite substrate (Kr/Gr and Xe/Gr) at around 80 K. It was found that both films undergo almost decoupling from an oscillating substrate until the first layer completion. In addition, the slip time of Kr/Gr is about 10 times larger than that of Kr/Au. We are also preparing a QCM experiment for Kr adsorbed on mica substrate (Kr/mica). In this conference, the mechanical response of Kr/Gr, Xe/Gr, and Kr/mica will be reported.

13P-A088 The Pomeranchuk Effect and Broken Symmetry Phase (BSP) Transitions in Solid Hydrogens under Pressure

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It is shown that there is a very close analogy between the BSP transition in solid hydrogens under pressure and melting of solid ³He. The theory of the BSP transitions is developed taking into account the Pomeranchuk effect. The same entropy-based considerations which are characteristic for the Pomeranchuk effect may be applied to the BSP transition lines in solid HD and in thermodynamically equilibrium ortho-para (even-\( J \) - odd-\( J \), \( J \) being the rotational quantum number) mixtures. We found that the phase transition lines in these species display a minimum, indicating that the disordered phase is reentrant. Two limiting cases are considered: mixtures at thermodynamic equilibrium and frozen mixtures when the conversion time is large compared with the thermalization time. Experimentally, conditions to find the reentrant BSP transition line are most favorable for H₂ mixtures whereas the frozen monotonic phase line should be the case for D₂ ortho-para mixtures. Phase diagrams and thermodynamics of the systems have been calculated including the pressure behavior of the hcp lattice distortion parameter.

13P-A089 A non-perturbative approach to freezing of superfluid He-4 in density functional theory

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It is known that density functional theory (DFT) fails to describe the freezing of superfluid He-4. In fact, DFT gives too stable solid phase and the superfluid phase does not exist at finite pressures within a second order perturbation. In this paper we try a non-perturbative version of DFT, that is modified weighted density approximation (MWDA) to go beyond second order perturbation for the freezing of superfluid He-4. By utilizing a recently introduced analytic continuation method (GIFT method), which enables us to extract information on real time dynamics from quantum Monte-Carlo (QMC) imaginary time correlation functions, we obtain the compressibility and the density response function at various densities of superfluid He-4 at zero temperature. Contrary to second order perturbation, by employing these QMC data as DFT input we find a ‘too stable superfluid phase’, preventing freezing around the experimentally observed freezing pressure. We find the same pathological behavior by using another model energy functional of superfluid He-4 (Orsay-Trento model). We conclude that the straightforward MWDA calculation gives poor result when liquid-gas transition is present.

13P-A090 Mode Analysis for an Immersed Quartz Tuning Fork Coupled to Acoustic Resonances of the Medium in a Cylindrical Cavity

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It is known that density functional theory (DFT) fails to describe the freezing of superfluid He-4. In fact, DFT gives too stable solid phase and the superfluid phase does not exist at finite pressures within a second order perturbation. In this paper we try a non-perturbative version of DFT, that is modified weighted density approximation (MWDA) to go beyond second order perturbation for the freezing of superfluid He-4. By utilizing a recently introduced analytic continuation method (GIFT method), which enables us to extract information on real time dynamics from quantum Monte-Carlo (QMC) imaginary time correlation functions, we obtain the compressibility and the density response function at various densities of superfluid He-4 at zero temperature. Contrary to second order perturbation, by employing these QMC data as DFT input we find a ‘too stable superfluid phase’, preventing freezing around the experimentally observed freezing pressure. We find the same pathological behavior by using another model energy functional of superfluid He-4 (Orsay-Trento model). We conclude that the straightforward MWDA calculation gives poor result when liquid-gas transition is present.
Quartz tuning forks are precise electromechanical oscillators mass produced in variety of sizes around one millimeter for the purpose of providing the reference frequency for watches and such. Usually, they are designed to operate at $2^{15} = 32768$ Hz in vacuum at room temperature. When refrigerated to cryogenic temperatures, they may show very high Q-values beyond several millions. Immersion of such an oscillator to fluid medium changes its response due to inertial forces and dissipation exerted by the medium. This makes it very useful in studies of pure and mixed helium fluids at low temperatures. When the wavelength of sound in the medium, determined by the frequency of oscillation and the speed of sound, corresponds to typical dimensions of the fluid volume, the oscillator may produce standing acoustic waves, observed as strong anomalies in the oscillator response. This can happen in helium fluids for both first and second sound under variety of conditions.

We study the character of these modes by computational methods for typical fork geometries in a cylindrical volume. Reasonable correspondence with measurements in helium mixtures both below and above 1 K is obtained. This is the regime of vigorous second sound resonances, since the speed of this unusual mode compares nicely with the typical dimensions and frequency of the tuning forks. The nontrivial geometry of the fork in the cylinder makes the problem somewhat challenging for computations.

13P-A092 Low Temperature Properties of the Mermin-Ho Texture of Superfluid $^3$He-A in a Cylinder

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Existence of a coreless vortex texture in the A phase of superfluid $^3$He was predicted by Mermin and Ho in 1976. Recent rotating cryostat experiments indicate the existence of the Mermin-Ho texture in a cylinder and call a renewed attention to this texture. Theoretical studies of the texture have been limited, however, to the GL temperature range. In this report, we consider the low temperature properties of the Mermin-Ho texture in a cylinder using the quasiclassical theory. One of the interests is the total angular momentum. We obtain the self consistent order parameter of the Mermin-Ho texture in a cylinder and calculate the angular momentum of the system from the mass current distribution. We show that the profile of the bending angle $\beta$ of the $\hat{l}$ vector significantly changes at low temperatures $T < 0.5T_c$ in contrast to the behavior of the energy gap. Accordingly, the total angular momentum also changes at low temperatures, but it seems to tend to $\frac{1}{2}N\hbar$ when $T \to 0K$, which is in agreement with McClure and Takagi. 1


13P-A093 Fourth Sound Resonance of Superfluid $^3$He in Slab Geometry

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Superfluid $^3$He is one of the spin triplet p-wave condensates and gives us an ideal system to study the property of p-wave condensates. We have studied the sound propagation mechanism in superfluid $^3$He by using the fourth sound resonance technique, which is a peculiar sound propagating in a narrow space where normal-fluid component is clamped to walls by viscosity. To study the anisotropic feature of the fourth sound propagation in superfluid $^3$He, we made three kinds of stack of parallel plates as a narrow space: thickness of slab is 12, 25, and 50 $\mu$m. Such slab geometry has an advantage of controlling the texture in superfluid $^3$He. The sound experiments were performed at 29 bar in the magnetic field perpendicular to parallel plates of about 30 mT. We clearly observed the jump of the resonance frequency at the AB transition temperature with only 50 $\mu$m slab but did not observe with 12 and 25 $\mu$m slabs. Similar result has been found by Kojima$^1$; they found the kink of superfluid density at AB transition temperature with 50 $\mu$m slab. It is thought that $\ell$-texture in 50 $\mu$m slab is different from that in 12 and 25 $\mu$m slabs. We also observed the jump of the quality factor of resonance, the energy loss, at AB transition temperature with all slabs. It seems that the energy loss mechanism in hydrodynamic region is different between the anisotropic A phase and the isotropic B phase.

13P-A094 Moderate Magnetic Field Transverse Acoustics Experiments in Superfluid $^3$He-B

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We present the results of transverse acoustics studies in superfluid $^3$He-B at fields up to 0.12 T. Using acoustic cavity interferometry, we observe the acoustic Faraday effect1,2 for a transverse sound wave propagating along the magnetic field, and we measure Faraday rotations of the polarization of the sound up to 2070°, significantly more extensive than has been previously reported. We use these results to extend previous calculations of the Landé g factor. We also find the field dependence of cavity interference oscillations resulting from coupling to the imaginary squashing mode (ISQ), a collective mode of the order parameter with total angular momentum $J = 2$. Measurements in large magnetic fields were performed at frequencies up to the pair breaking threshold, where there has been a recent report3 of a new collective mode with $J = 4$. Acoustic minima near this new mode are reported, along with their intersection with rotations from the ISQ. Support for this work from the NSF, grant DMR-0703656, is gratefully acknowledged.


13P-A095 Development of a $^3$He-hydraulic actuator for spin pump in superfluid $^3$He-A$_1$


The superfluid $^3$He A$_1$ phase contains a spin-polarized condensate. This property allows novel superfluid spin current experiments. In the mechano-spin effect (MSE) of the A$_1$ phase a mechanically applied pressure gradient and a superleak-spin filter enable to directly boost spin polarization of $^3$He in a small chamber. Using a flexible membrane as an electrostatically actuated pump, we carried out such MSE experiments and observed 50% enhancement of spin density in a chamber1. We are currently developing a new $^3$He-hydraulic actuator for achieving greater enhancement of spin density. The actuator consists of two liquid $^3$He chambers located at a 4.2 K plate and in the interior of the cell. The pressure in the 4.2 K chamber is heater-controlled and it transmits a force onto a membrane in the cell. The motion of the membrane induces spin-polarized current into an accumulation chamber. The details of the apparatus and the latest results using the new actuator and facilities of ISSP, Univ. Tokyo, are presented.


13P-A096 Energy of Stable Half-Quantum Vortex in Equal-Spin-Pairing

Sh. Haghdani*, M.A. Shahzamanian*, **Department of Physics, Faculty of Sciences, University of Isfahan, 81744 Isfahan, Iran

In the triplet equal-spin-pairing states of both $^3$He $-$ A phase and $^3$He-B at fields up to 0.12 T. Using acoustic cavity interferometry, we observe the acoustic Faraday effect1,2 for a transverse sound wave propagating along the magnetic field, and we measure Faraday rotations of the polarization of the sound up to 2070°, significantly more extensive than has been previously reported. We use these results to extend previous calculations of the Landé g factor. We also find the field dependence of cavity interference oscillations resulting from coupling to the imaginary squashing mode (ISQ), a collective mode of the order parameter with total angular momentum $J = 2$. Measurements in large magnetic fields were performed at frequencies up to the pair breaking threshold, where there has been a recent report3 of a new collective mode with $J = 4$. Acoustic minima near this new mode are reported, along with their intersection with rotations from the ISQ. Support for this work from the NSF, grant DMR-0703656, is gratefully acknowledged.


13P-A097 Spin Diffusion Coefficient of A Phase of Liquid $^3$He at Low Temperature and Stable Half Quantum Vortex

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We theoretically investigate the spin diffusion coefficient tensor in the A phase of liquid $^3$He in term of quasiparticle life-time by using the Kubo formula approach at low temperatures. In general the coefficient is a fourth rank tensor for the anisotropic states and can be defined as a function of spin current normal component in the superfluid state and magnetization. The quasiparticle life-time is obtained by using the Boltzmann equation. We find that components of the spin diffusion coefficient are proportional to $T^2$ at low temperatures. The normal components of spin current, hence, are strongly diffusive and one can ignore the contribution of these components to the stability of half quantum vortices (HQVs) in the equal-spin-pairing of $^3$He $-$ A state. So to make a HQV stable, It is enough one considers weak interaction and effects of Landau Fermi liquid. We have considered $l = 2$ order effects of Landau Fermi liquid. We have shown that the effects of Landau Fermi liquid interaction with $l = 2$ are negligible. An effective Zeeman field exists in the HQV state of the equal-spin-pairing condensate. In thermodynamic equilibrium such an effective Zeeman field will produce a nonzero spin polarization in addition to that created by external fields.

13P-A098 Ultrasound Propagation in Dense Aerogels Filled with Liquid $^4$He

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Longitudinal ultrasound propagation was studied in dense aerogels filled with liquid $^4$He. Sound velocity and attenuation were measured at the frequency of 6 and 10 MHz in both normal and superfluid phases. The aerogels used had porosities about 85%. They had two different types of structure, tangled strand structure and aggregated particles structure. Their pore size...
were homogeneous with narrow pore distribution. Superfluid suppression mainly depended on not porosity but mean pore size. The structure of gel played an important role in sound velocity and attenuation. Pressure dependence of sound velocity and attenuation in these dense gels were also studied.

13P-A100 Observation of electric response in He II under excitation of second sound waves


Experiments on observation and research of the electric response of superfluid helium are carried out under excitation of the waves of second sound in it. The new acoustic resonator with the dielectric case was applied in which, owing to the accommodation on a face wall of both a measuring electrode and bolometer, the registering the electric and thermal signals were spent simultaneously. By means of a resonant method, the peak-frequency characteristics of several fashions of the second sound were measured and is shown, that the signal of the electric response is \( \approx 10^{-7} \) V at amplitudes of temperature oscillations in a wave \( \approx 3 \) K. It is established, that in the temperature range 1.42.1 K, the ratio between amplitudes of temperature oscillations and electric voltage in a wave of the second sound, does not depend on temperature. Using a method of short circuit, internal wave resistance of a source of electric activity of superfluid helium is measured.

13P-A101 Imaging Focused Ultrasound Pulses in Superfluid \(^4\)He


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Focusing of sound pulses emitted by an hemispherical piezo-electric transducer in liquid \(^4\)He at 1.1 K and 24 bar is studied in detail. Time variations of the density map are recorded by using an optical interferometric method. Numerical integration of elastic wave equations by a finite difference scheme is used for comparison. A good agreement is found between both density maps. The amplification factor from the transducer surface to the focus is deduced. Second-harmonic amplitude generated by nonlinearities near focal point is also recorded.

13P-A102 Anomalous Suppression of Superfluidity for \(^4\)He in Gelsil Glass


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Suppression of the superfluidity in nanometer-size pores has attracted the interest of researchers. We have studied the superfluid behavior for liquid \(^4\)He filled in a nanoporous glass, Gelsil, whose nominal pore size is 2.5 nm. First, we cut a cylindrical sample of Gelsil (\( \phi \) 0 mm x L18 mm) into three pieces 2-3.5 mm in thickness, and examined the pore size distribution by measuring the \( N_2 \) adsorption isotherm. Then, we found that the ratio of surface area to pore volume (S/V) ranges from 2.0 to 2.4 \( \mu \)mol/m\(^2\), depending on piece. The superfluid transition temperature around the saturation vapor pressure is 0.6 K for the piece with the smallest S/V ratio, and 1.4 K for the piece of the largest one. Furthermore, for the smallest S/V ratio, the suppression of superfluid transition by pressurization becomes weaker as the pressure is increased, which is different from the conventional pressure dependence observed in various nanoporous glasses. The results demonstrate that the suppression of superfluidity is strongly related to the pore size.

13P-A103 Viscosity of Liquid \(^4\)He and Quantum of Circulation: Why and How Are They Related?

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Following the 1953 Lars Onsager's Introductory talk at Int. Conf. of Theor. Phys. in Kyoto and Tokyo, we examine the relationship between the apparently unrelated physical quantities – kinematic viscosity of liquid \(^4\)He, \( \nu \), and quantum of circulation, \( \kappa = 2\pi h/m_4 \), where \( h \) is the Planck constant and \( m_4 \) denotes the mass of the \(^4\)He atom – in the vicinity of the superfluid transition occurring at (pressure dependent) \( T_\lambda \) temperature in liquid \(^4\)He due to Bose-Einstein condensation. A model is developed, leading to the surprisingly simple relation \( \nu \approx \kappa/6 \). We have critically examined the experimental data on the transition to superfluidity at various external pressures and found that in the relevant region of parameters (\( T \approx T_\lambda \) and at low applied pressures) the agreement is \( \approx 10^3 \) times better then one may expect from dimensional analysis. One can estimate the probability of this agreement, \( \approx 10^{-3} \), as totally accidental. This raises many questions, for example: (i) Why does it happen? (ii) Why do ideal-gas considerations work so well for the real liquid? (iii) Could it be thanks to cancelations of effects of some as yet not known factors, which are definitely ignored in our suggested approach? (iv) Are these cancelations accidental or are there some deep physical reasons yet to be discovered? We also predict that the relation \( \nu \approx \kappa/6 \) ought to hold even better for the metastable stretched liquid along the \( \lambda \)-line at negative pressures.

We critically examine the available experimental data for \(^4\)He relevant to this simple relation and predict the kinematic viscosity for the stretched liquid \(^4\)He along the \( \lambda \)-line at negative pressures.

13P-A104 Mobility of the surface electron in quasi-zero-dimensional system

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We present results of experimental study of surface electron transport over liquid helium covering a quasi-zero-
dimensional substrate. The substrate consists of a silicon plate of the thickness 0.2 mm with the cylinder orifices etched in it of the characteristic size 2 microns in diameter and mean distance of 4 microns between the orifices located periodically in two in-plane directions. Mobility was measured in temperature range from 2 K to 0.5 K at various thicknesses of a helium film covering the substrate, surface electron density, amplitude and frequency of a driving electric field in the plane of electron layer. The results obtained demonstrate the strong dependence of surface electron transport characteristics on the ratio between electron density and mean orifice surface concentration.

13P-A105 The analysis of nanoroughnes substrates with use of levitating electron over a superfluid helium film
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The method and tool for researching of substrate nanoroughnes by the analysis of surface electron conductivity over a helium film in function of its thickness. The device contains the chamber for superfluid helium and a measuring cell with substrate horizontally located over measuring electrodes which in a vertical direction moves by means of electromechanical draft. Under measured electron transport characteristics, the possibility to identify nanoroughnes from some nanometers (for nonsaturated helium film) to $10^2$ nanometers (at the saturated helium film) is demonstrated.

13P-A106 Possible Formation of Autolocalized State of Quasi-One-Dimensional Surface Electrons in Dense Helium Vapor
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The experimental study is carried out of the mobility of surface electron localized in quasi-one-dimensional (Q1D) conducting channels over liquid helium in temperature range of 1.5 - 3 K. The channels are formed between parallel dielectric threads, where liquid helium surface is curved by the capillary forces. It is observed that, under temperature increase, the mobility decreases according to kinetic regime of conductivity limited by electron scattering by helium atoms in vapor phase. However, at $T > 2$ K, one observes a rather strong decreasing the mobility relative to that in kinetic regime. Such behavior of mobility can be attributed to a formation of an autolocalized electron state in dense helium vapor accompanying by the appearing a macroscopic regions with non-uniform distribution of vapor density. The temperature of autolocalized state formation was estimated theoretically basing on the analysis of condition for the occurrence of the minimum in the system free energy. Such an analysis made for both 2D and Q1D surface electrons manifests the decrease of the temperature of the state formation in Q1D in comparison with familiar two-dimensional surface electrons. The formation temperature tends to that in 2D under increase of the curvature radius. The estimated values of the temperature in Q1D are close to those observed experimentally for different curvature radii of helium in conducting channel.

13P-A107 Dynamics of Condensate as aSubsystem of Superfluid Bose Gas
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Consideration is based on closed set of equations which describe nonequilibrium state of superfluid Bose gas by parameters: amplitude $\eta(x,t)$ of condensate wave function, velocity $v_n(x,t)$ of the condensate, the Wigner distribution function $f_p(x,t)$ of the Bogolyubov quasi-particles in local reference system (RS) of the condensate rest $K$ with spectrum $\varepsilon_p(\eta)$. These equations were obtained in our paper in perturbation theory in interaction and gradients of the mentioned variables. By this way time equation for phase $\varphi(x,t)$ of the condensate wave function was obtained too. In fact we start from the Gross-Pitaevskii equation generalized for the case of presence of the quasi-particles in kinetic state. Here we build the Gross-Pitaevskii equation for the case of presence of the quasi-particles in hydrodynamic state in which they are described with drift velocity $\omega_n(x,t)$ in the RS $K$ and temperature $T(x,t)$. One can consider this set of equations as a modification of the Landau-Khalatnikov hydrodynamic equations. The construction is based on a generalization of the Chapman-Enskog method in which distribution function $f_p(x,t)$ is considered as a functional $f_p(x,\eta(t),v(t),T(t),\omega(t))$. The temperature $T(x,t)$ and the drift velocity $\omega_n(x,t)$ are defined by standard relations using the Planck distribution. On the base of these results stability of equilibrium subsystem of the quasi-particles and possibility of creation of the quasi-particles by the condensate in the evolution of the Bose gas have been discussed.

13P-A108 Magnetization of $^3$He films in ferromagnetic regime: Cluster size effects

The thermodynamics of low dimensional spin-1/2 Heisenberg ferromagnets in an external magnetic field is investigated within a second-order two-time Green function formalism. The proposed approach describes properly the behavior of both infinite and finite-sized systems in the whole temperature range and at arbitrary fields.

The obtained results are applied to interpret a great variety of the experimentally observed temperature dependences of the magnetization $M(T)$ for $^3$He monolayers and $^3$He-$^4$He mixture films adsorbed on graphite. A good quantitative agreement between the theory and experiment has been obtained in the whole temperature range for different values of the external
magnetic fields. The experimentally observed 'ferromagnetic anomaly' and cluster size effects in helium monolayers have been interpreted.


13P-A109 Properties of the Trapped Dipolar Ultracold gases at Finite Temperatures
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Interest in dipolar gases has been growing since the realization of Bose-Einstein condensates (BECs) of $^{52}$Cr atoms, which have large magnetic dipole moments. The anisotropic and long-range nature of the dipolar interaction confers interesting properties to the equilibrium and dynamics of dipolar gases. On the other hand, the experimental effort is put into creating heteronuclear polar molecules whose large electric dipole moments give rise to strong dipolar interactions. However, despite many groups conducting experiments, no groups have succeeded in cooling polar molecules down to the quantum-degenerate regime. It is thus important to investigate the temperature range in which the dipolar interaction has appreciable effects. We study the properties of dipolar Bose and Fermi gases at finite temperatures. By developing a variational ansatz for the phase-space distribution function of a dipolar gas at finite temperatures, we discuss the effect of dipolar interactions on thermal equilibrium both of the Bose and Fermi systems. In addition, we study the stabilities and the dynamics of the dipolar gases and discuss how the dipolar effects can be observed in the relatively high-temperature regime, which is relevant to the current experiments.


13P-A110 Roton–Roton Crossover in Strongly Correlated Dipolar Bose–Einstein Condensates
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We study the effect of pair-correlations on the ground state and the excitations of a polarized, dipolar Bose–Einstein condensate by using the hypernetted-chain Euler Lagrange method for ground state calculations and the correlated basis function Brillouin-Wigner perturbation theory for excitations. The dipolar gas is trapped in the polarization direction by a harmonic potential. Because of the anisotropy of the dipole–dipole interaction the strength of the correlations can be tuned by the trap frequency. The correlations in the parallel, infinite dimension increase with increasing confinement strength, whereas the correlations in the perpendicular, i.e. polarization direction increase with decreasing confinement. In both limits of strong and weak confinement, we observe a roton–maxon excitation spectrum whereas there is no roton in the intermediate region. This crossover between two roton regimes is interesting since the two rotons have different physical origins. In the strong confinement regime the roton is due to the strong repulsion in the parallel direction, whereas in the weak confinement regime it results from the attractive part of the interaction. In the latter case the roton is directly related to the instability of dipolar Bose–Einstein condensates found in previous mean-field calculations. We studied the dynamic structure function to obtain information not only about the excitation energies but also about their lifetimes.

13P-A111 Anomalous Sound Absorption of Finite Amplitude Sound in Liquid $^4$He
The finite amplitude sound in both normal- and superfluid $^4$He were studied, and we found an anomalous non-linear response. The experimental setup was as follows: the piezo-electric driver and the receiver transducers were attached at the both ends of the cylindrical cavity, and the standing wave was excited and detected by them. The frequency was kept around the resonance frequency of the liquid column, so that the maximum of the pressure field always came to the surface of the driver. As a result, in the low driving-amplitude regime, I/O ratios were linear. However, in the high driving-amplitude regime, an anomalous response were found; in the superfluid state, the signals suddenly disappeared—they were repeated with random intervals. In the normal-fluid state, the signals disappeared but never recovered as long as the excitation was applied. These absorptions are expected to be the result of the sequence of the heterogeneous nucleation, the growth and the rupture of the vapor bubbles at the surface of the driver transducer, not to be the homogeneous one because the frequency and the pressure amplitude were not high enough. We propose that the difference between the absorption in normal- and superfluid states can be characterized by the difference of the thermal penetration length in both states. The condition of stability and the dynamics of the single vapor bubble will be discussed.


Session 13P-B:
B6 Recent Discovery and Properties of K(Tl) Fe$_3$Se$_2$
Structural and physical properties of iron chalcogenide thin films

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The arsenic-free iron chalcogenide possesses the simplest structure in the families of iron-based superconductors though its transition temperature is relatively not too high under the ambient pressure, while the very recently discovered K/Tl intercalating iron chalcogenide possesses the ordered Fe-vacancies and relatively high transition temperature. We deposited single-phased, epitaxial, superconducting FeSe, Fe(Se,Te), and FeTe thin films, studied their structural and physical properties, found that the non-superconducting parent compound FeTe goes to superconduct in the form of thin films, and further found that the superconducting FeTe films possess the so-called second long-range order of several hundreds nanometers long. We also deposited successfully the single-phased, epitaxial KFe\textsubscript{2}Se\textsubscript{2} thin films. Structural and physical properties of such newly obtained KFe\textsubscript{2}Se\textsubscript{2} thin films are under investigation and will also be reported.

NMR Study of Pairing Symmetry and Spin Fluctuations in K\textsubscript{2}Fe\textsubscript{2−x}Se\textsubscript{2} and (Tl,Rb)\textsubscript{y}Fe\textsubscript{2−x}Se\textsubscript{2} Superconductors

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Distinctive properties have been observed in the newly discovered iron selenides by many probes. The NMR study, as a local probe, is found essential to reveal intrinsic properties of the superconducting phase. Here we discuss our recent NMR results on K\textsubscript{2}Fe\textsubscript{2−x}Se\textsubscript{2} and (Tl,Rb)\textsubscript{y}Fe\textsubscript{2−x}Se\textsubscript{2} with T\textsubscript{c}≥32 K. Singlet superconductivity is decisively determined by a sharp drop of the Knight shift below T\textsubscript{c}. However, the Hebel-Slichter coherence peak is not observed in the spin-lattice relaxation rate, inconsistent with conventional s-wave superconductivity. Just above T\textsubscript{c}, the spin-lattice relaxation rate indicates a Fermi-liquid behavior, whereas Curie-Weiss type spin fluctuation is not found even though the T\textsubscript{c} is high. Upon warming, however, the Knight shift increases dramatically with temperature, and then saturates at above 400 K. The spin-lattice relaxation rate also increases substantially with temperature up to 400 K. These behaviors indicate a pseudogap opening phenomenon at about 400 K, below which a thermal activation behavior of spin fluctuations is suggested. Our NMR disclosure of the pairing symmetry and the spin fluctuations puts strong constraints to the theory of magnetism and superconductivity in this new structure family of the iron-based superconductors.


Angle-resolved photoemission studies on A\textsubscript{x}Fe\textsubscript{2}Se\textsubscript{2} (A=K, Cs)

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Pairing symmetry is a fundamental property that characterizes a superconductor. We have conducted angle-resolved photoemission spectroscopy (ARPES) experiment on A\textsubscript{x}Fe\textsubscript{2}Se\textsubscript{2} (A=K, Cs).\textsuperscript{1} We found A\textsubscript{x}Fe\textsubscript{2}Se\textsubscript{2} (A=K, Cs) is the most heavily electron-doped amongst all iron based superconductors. Large electron Fermi surfaces are observed around the zone corners with an almost isotropic superconducting gap of 10.3 meV, while there is no hole Fermi surface near the zone center. Thus, the sign change in the s± pairing symmetry driven by the inter-band scatterings as suggested in many weak coupling theories becomes conceptually irrelevant in describing the superconducting state here.

13P-B005  High-temperature NMR Evidence of Pseudogap Opening in Superconducting Tl$_{0.47}$Rb$_{0.34}$Fe$_{1.03}$Se$_2$

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In many iron-based superconductors, the increase of the susceptibility with temperature has been widely reported, whereas its origin is still controversial. The NMR Knight shift, as a local probe of intrinsic susceptibility, also shows an increase with temperature in many superconducting compounds. In the newly discovered superconducting compounds, the iron selenide K$_y$Fe$_{2−y}$Se$_2$ and (Tl,Rb)$_y$Fe$_{2−y}$Se$_2$, a substantially increase of the Knight shift with temperature, as well seen in the spin-lattice relaxation rate, has been observed in the normal state of the nonmagnetic, superconducting phase. High-temperature NMR study on Tl$_{0.47}$Rb$_{0.34}$Fe$_{1.03}$Se$_2$ indicates that the Knight shift levels off above 400 K$^2$. The change of the temperature behavior clearly suggests a pseudogap opening phenomenon, observed for the first time in the iron-based superconductors. The Knight shift is nearly isotropic with field orientation, and shows three-dimensional coupling characters, which set strict constraints to the possible scenario of the pseudogap formation. We propose that the pseudogap is associated with a low-temperature spin gap, which draws a possible correlation between superconductivity and magnetism in the newly discovered iron selenide superconductors.


13P-B006  Raman scattering study on the new FeSe superconductors (LT26)

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We have performed Raman-scattering measurements on high-quality crystals of the newly discovered Fe-based superconductors A$_{0.4}$Fe$_{1.6}$Se$_2$ (A=Tl, Tl, Rb). More than ten phonon modes were observed in the wavenumber range 10−300 cm$^{-1}$. The spectra possess a four-fold symmetry indicative of bulk vacancy order in the Fe-deficient planes. We perform a vibration analysis based on first-principles calculations, which both confirms the ordered structure and allows a complete mode assignment. We observe an anomaly at $T_C$ in the 180 cm$^{-1}$ $A_g$ mode, which indicates a rather specific type of electronic-phonon coupling. Furthermore, we will present some very recent results on electronic and magnetic Raman scattering in the superconductors.

13P-B007  Distinct Fermi Surface Topology and Isotropic Gap Symmetry in A$_x$Fe$_{2−y}$Se$_2$ Superconductor (LT26)

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High resolution angle-resolved photoemission measurements have been carried out to study the electronic structure and superconducting gap of the newly discovered A$_x$Fe$_{2−y}$Se$_2$ [A=K,(Tl,K),(Tl,Rb)] superconductor. Distinct Fermi surface topology consists of two electronlike Fermi surface sheets around the Γ point revealed in all different samples, which indicates this is a common Fermiology in A$_x$Fe$_{2−y}$Se$_2$. Both Fermi Surface around Γ and M point show nearly isotropic gap of 8 meV and 12 meV respectively. The information on Fermiology and superconducting gap will provide key insights to understand the superconductivity mechanism in iron-based superconductors.$^{1,2}$


13P-B008  Orbital character of electron bands in A$_x$Fe$_{2−y}$Se$_2$

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Newly discovered superconductor has high transition temperature ($T_C$ ~ 30 K) without Arsenic and caused interest in understanding mechanism in Fe-based superconductivity. We have performed angle-resolved photoemission spectroscopy (ARPES) experiments on A$_x$Fe$_{2−y}$Se$_2$ (A=Tl, K, Cs Rb) with $T_C$ ~ 30K. By changing incident photon energy ($k_z$) and polarization, we find out a strong $k_z$ dependence of electronic band at zone center (Γ-Z) and almost 2-D like electron band at zone corner ($\pi, \pi$). By using different incident photon polarization to tune ARPES intensity of each band, and in combination with matrix element analysis, we identify the geometry symmetry of each orbitals close to Fermi Level and the orbital character of each bands. The band at zone center is not predicted in current calculation, the possible origin is discussed based on ARPES results.

13P-B009  Effect of iron content and potassium substitution in A$_{0.8}$Fe$_{1.6}$Se$_2$ (A=Tl, K, Rb) superconductors studied by Raman scattering

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We have performed Raman-scattering measurements on high-quality superconducting K$_{0.8}$Fe$_{1.6}$Se$_2$ ($T_C ~ 32$K), Tl$_{0.5}$K$_{0.5}$Fe$_{1.6}$Se$_2$ ($T_C ~ 31$K) and Tl$_{0.4}$Rb$_{0.6}$Fe$_{1.6}$Se$_2$ ($T_C ~ 29$K) crystals and parent compound KFe$_{1.6}$Se$_2$ at various temperatures. We carried out first-principles nonmagnetic calculations on vibration modes at zone center in K$_{0.8}$Fe$_{1.6}$Se$_2$. The observed modes in K$_{0.8}$Fe$_{1.6}$Se$_2$ can be well assigned with symmetry analysis and the calculations. Over
ten modes are observed for each crystal, far more than expected for a normal 122 syste. This suggests that vacancy ordering is an intrinsic feature in AFeSe system. On basis of the assignment, we compare Raman modes in AFeSe compounds. For most phonon modes, a clear frequency difference between superconducting and non-superconducting potassium intercalated crystals is revealed. Potassium substitution by Ti or Rb makes no substantial frequency shift on Raman modes above 60 cm$^{-1}$. It demonstrates that the substitution of Ti or Rb for K has little effect on microstructures of FeSe layer. The results suggest that superconductivity is linked with particular microstructures of FeSe layer in A$_{0.8}$Fe$_{1.4}$Se$_2$ system. However in the Ti- and Rb-substituted samples, several additional modes appear below 60 cm$^{-1}$, which can be attributed to vibrations of Ti or Rb atoms. Anomalously the modes become very weak with decreasing temperatures, similar to 66 cm$^{-1}$ Se modes. This may reveal an ordering process of (Ti, K/Rb)-layer at low temperatures.

**13P-B010 Coexistence of Superconductivity and Magnetism in K$_{0.8}$Fe$_2$Se$_1.4$S$_{0.4}$**

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High-quality single crystals of K$_{0.8}$Fe$_2$Se$_1.4$S$_{0.4}$ are successfully synthesized by self-flux method with the superconducting transition temperatures $T_{\text{onset}} = 32.8$ K and $T_c(0 \text{K}) = 31.2$ K. In contrast to external pressure effect on superconductivity, the substitution of S for Se does not suppress $T_c$, which suggests that chemical doping may mainly modulate the anion height from Fe-layer rather than compressing interlayer distance. The investigation of electron spin resonance shows clear evidence for strong spin fluctuation at temperatures above $T_c$. Accompanied by the superconducting feature spectra, a novel resonance signal develops gradually upon cooling below $T_c$, indicating the coexistence of superconductivity and magnetism in K$_{0.8}$Fe$_2$Se$_1.4$S$_{0.4}$ crystal.

**13P-B011 Effect of non-magnetic Zn impurity in iron chalcogenide K$_{0.8}$Fe$_{2-\delta}$Se$_2$**

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A series of Zn doped iron chalcogenide single crystal samples with nominal composition of K$_{0.8}$Fe$_{2-\delta}$Zn$_x$Se$_2$ (0 $\leq x \leq 0.03$) are prepared, and their transport and magnetic properties are investigated. Two sets of reflections are observed in the room temperature x-ray diffraction spectra, implying that the samples may be intrinsically inhomogeneous. The undoped sample with a nominal composition of K$_{0.8}$Fe$_2$Se$_2$ shows a large hump in resistivity around 180 K and then it is followed by a superconducting transition with $T_c$ of 30 K. Slight Zn doping does not affect $T_c$, but remarkably increases the magnitude of resistivity. Meanwhile, the hump in resistivity is quickly shifted to lower temperatures with increasing Zn content. Meanwhile, the volume fraction of superconducting magnetic shielding which is derived from the susceptibility measurements decreases gradually with Zn doping, indicating that the proportion of superconducting phase decreases. The results suggest a scenario of phase separation in these samples. Namely the Zn impurity does not affect the superconducting phase, but it could enhance the volume proportion of the insulating phase.

**13P-B012 Pressure-Driven Quantum Criticality in An Iron-Selenide Superconductor**

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The discovery of superconductivity of about 30K in iron selenides with very large magnetic moments simulates the examination of completing orders. Here we report a finding of pressure induced suppression of the superconducting transition temperature $T_c$ and enhancement of the temperature of the resistance hump $T_H$ through charge transfer between two iron sites with different occupations. The activation energy for the electric transport of the high temperature resistance is observed to go to zero at a critical pressure of 8.7GPa, at which superconductivity tends to disappear and the semiconductor to metal transition takes place. Beyond the critical point, the resistance exhibits a metallic behavior over the whole temperature range studied. All these features indicate the existence of quantum criticality in iron selenide superconductors.

**13P-B013 Observation of a Small Superconducting Energy Gap in K$_{0.7}$Fe$_1.8$Se$_2$ by Optical Spectroscopy**

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We report an optical spectroscopy study on the newly discovered iron-selenide superconductor K$_{0.7}$Fe$_1.8$Se$_2$. In the far-infrared region, there is a clear signature of the superconducting energy gap with a gap ratio $2\Delta/k_BT_c \sim 1.3$, far below the usual weak-coupling BCS value. The large energy gap in the electron Fermi pocket observed by angle-resolved photoemission (ARPES) technique is completely absent in the infrared probe. The complex behavior may imply the presence of both dirty and clean channels of superconductivity. Our measurements also reveal a surprisingly low carrier density for the compound: both the carrier density in the normal state and the condensed carrier density in the superconducting state are about one order smaller than other iron-pnictide superconductors.
13P-B014 Optical Study of the New Iron Selenide $K_{0.83}Fe_{1.53}Se_{2}$ Single Crystals


The recent discovery of superconductivity with $T_c$ exceeding 30 K in $K_xFe_{2}Se_2$ has attracted much attention of the scientific community [1]. Since the superconductivity in ternary iron selenide is in close proximity to the insulating phase [2], identifying the nature of the insulating parent compound becomes an essential step towards understanding the mechanism of the newly found superconductivity. Therefore, we perform infrared spectroscopy investigation on single-crystalline $K_{0.83}Fe_{1.53}Se_2$ samples [3]. The optical spectra indicate that this insulating parent compound should be considered as a small band gap semiconductor. Moreover, the infrared spectra of $K_{0.83}Fe_{1.53}Se_2$ single crystals show two peculiar features which are absent in all other iron-pnictides/chalcogenides: a double peak structure between 4000-6000 cm$^{-1}$ and abundant phonon modes much more than those expected for a standard 122 structure. We elaborate that the two peculiar spectral features could be naturally explained from the blocked anti-ferromagnetism [2] due to the presence of iron vacancy ordering.


13P-B015 Transport Properties and Phase Diagram in KxFe2-ySe2 Superconductors


We successfully grew the high quality single crystals of $A_2Fe_{2-y}Se_2$ ($A = K, Rb, Cs, Tl/K$ and $Tl/Rb$) with nearly 100% shielding fraction. We measure the resistivity and magnetic susceptibility in the temperature range from 5 K to 600 K. An antiferromagnetic transition is observed in susceptibility at Neel temperature ($T_N$) as high as 500 K to 540 K depending on $A$. This indicates the coexistence of superconductivity and antiferromagnetism in this intercalated iron selenides. A sharp increase in resistivity arises from the structural transition due to Fe vacancy ordering at temperature slightly higher than $T_N$. We also report electronic and magnetic phase diagram of $K_xFe_{2-y}Se_2$ system as a function of Fe valence. We find two AFM insulating phases and reveal that the superconducting phase is sandwiched between them, and give direct evidence that the superconductivity in $K_xFe_{2-y}Se_2$ originates from the AFM insulating parent compounds.

13P-B016 Field-induced quantum critical point and nodal superconductivity in the heavy-fermion superconductor $Ce_2PdIn_8$

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The in-plane resistivity $\rho$ and thermal conductivity $\kappa$ of the heavy-fermion superconductor $Ce_2PdIn_8$ single crystals were measured down to 50 mK. A field-induced quantum critical point, occurring at the upper critical field $H_{c2}$, is demonstrated from the $\rho(T) \sim T$ near $H_{c2}$ and $\rho(T) \sim T^2$ when further increasing field. Large residual linear term $\kappa_0/T$ at zero field and the rapid increase of $\kappa(H)/T$ at low field give evidences for nodal superconductivity in $Ce_2PdIn_8$. The jump of $\kappa(H)/T$ near $H_{c2}$ suggests a first-order-like phase transition at low temperature. These results mimic the features of the famous CeCoIn$_5$ superconductor, implying that $Ce_2PdIn_8$ may be another interesting compound to investigate the interplay between magnetism and superconductivity.

13P-B017 Local electronic structure around an impurity in superconductor without an inversion center

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Recent discoveries of noncentrosymmetric superconductors have raised an interest in the theoretical investigation of superconductivity in these systems. Among interesting questions, the most important one is concerned with the underlying symmetry of the superconducting order parameter. We in this paper investigate theoretically the impurity resonance states where both s-wave and p-wave Cooper pairings coexist. Due to the nodal structure of gap function as a result of the interference between the spin-triplet and the spin-singlet components of the superconducting order parameters, we find that a single nonmagnetic impurity induced resonance state appears in the local density of states where both s-wave and p-wave Cooper pairings coexist. Due to the nodal structure of gap function as a result of the interference between the spin-triplet and the spin-singlet components of the superconducting order parameters, we find that a single nonmagnetic impurity induced resonance state appears in the local density of states where both s-wave and p-wave Cooper pairings coexist. Due to the nodal structure of gap function as a result of the interference between the spin-triplet and the spin-singlet components of the superconducting order parameters, we find that a single nonmagnetic impurity induced resonance state appears in the local density of states where both s-wave and p-wave Cooper pairings coexist.

13P-B018 Isotope Effect in Rattling-Induced Superconductor

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Recently, superconductivity in $\beta$-pyrochlore oxides $AO_2$O$_6$ ($A = K, Rb$, and $Cs$) have attracted much attention due to the relatively high superconducting transition temperature $T_c$. In these materials, an alkali atom in a cage composed of oxygen and osmium ions oscillates with large amplitude and such anharmonic
oscillation is called rattling. When the alkali atom oscillates in the anharmonic potential with wide and flat bottom, it has been found that phonon eigenenergy is totally suppressed and the energy difference between adjacent eigenstates is decreased in the low-energy region. Then, even if the original electron-phonon coupling is weak, a strong-coupling situation is virtually realized due to the effect of anharmonicity, leading to the increase of $T_c$, in spite of the decrease of average phonon energy. In order to confirm the contribution of the rattling, we propose to examine isotope effect on $T_c$. In standard phonon-mediated superconductors, it has been well known that $T_c$ is in proportion to $M^{-\alpha}$ with $\alpha=1/2$, where $M$ is the mass of oscillator. Note that the electron-phonon coupling does not depend on $M$ for harmonic phonons. However, in the rattling-induced superconductor, the magnitude of $\alpha$ should be deviated from $1/2$, since the electron-phonon coupling is effectively changed by anharmonicity, as mentioned above. In particular, we expect an interesting possibility of negative $\alpha$, which suggests peculiar inverse isotope effect. In this presentation, we discuss the evidence of rattling-induced superconductivity from the calculated results on $\alpha$ within the framework of the Migdal-Eliashberg theory.

13P-B019 NMR Study of the FFLO State and Magnetism in CeCoIn$_5$

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A quasi-2D heavy-fermion compound, CeCoIn$_5$, shows number of fascinating superconducting (SC) and magnetic properties. It is believed to host a Fulde-Ferrell-Larkin-Ovchinnikov (FFLO) state and to exhibit a coexistence of modulated magnetic order at a restricted region at high field and at very low temperature. Here, we have measured NMR of the In(1) and In(2) site of CeCoIn$_5$ in the direction of both $H//a$- and $H//c$-axis down to 50mK. [1] In the case of $H//a$-axis, the NMR spectra change dramatically below $T_c^{H_a}$ upon entering the novel SC state. A well-separated peak structure at the In(2b) site shows the spatially-uniform spin density wave (SDW) is induced, and that this magnetic ordering is emerging only in the newly-discovered SC state. We also show that field dependences of the Knight shifts of the spectra at the In(2a) and the In(1) site provide a direct evidence for the emergence of the spatially-distributed normal quasiparticle region. The quantitative analysis for the field evolution of the paramagnetic magnetization and low-lying energy quasiparticle density of state is consistent with the nodal plane formation, which is characterized by an order parameter in the FFLO state. NMR results for $H//c$-axis will be also discussed.


13P-B020 Superconductivity without Local Inversion Symmetry; Multi-layer Systems

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Non-centrosymmetric superconductor has unique properties owing to the antisymmetric spin-orbit coupling (ASOC). One of them is the anomalous properties of spin susceptibility. It has been shown that the spin susceptibility is anisotropic for the direction of applied magnetic field. [1] Recently, artificial superlattices of the heavy fermion superconductor CeCoIn$_5$ and the conventional metal YbCoIn$_5$ attract many attentions. Two-dimensional multi-layer heavy electrons system has been realized in this system. We investigate this multi-layer system with focus on the local inversion symmetry breaking. We shed light on the effect of broken local inversion symmetry to the superconducting property. We analyze two dimensional multi-layer systems with spatially inhomogeneous ASOC assuming superconducting order parameter with mixed parity. Roles of ASOC, the inter-layer coupling and the number of layer on the spin susceptibility are investigated at zero temperature. We show that the spin susceptibility is significantly affected by ASOC. This means that not only the broken global inversion symmetry but also the broken local inversion symmetry plays important roles on the superconductivity. The details will be discussed in the presentation.


13P-B021 Upper critical field of p-wave ferromagnetic superconductors with orthorhombic symmetry

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The theory of the upper critical field in p-wave superconductors with broken symmetry[1] was found to quantitatively fit the experimental data obtained from the ferromagnetic superconductor URhGe with the magnetic field in all three crystal axis directions, assuming a completely broken symmetry state[2]. We have extended the Scharrnberg-Klemm calculations to cases of partially broken symmetry in an orthorhombic crystal as is appropriate for the more exotic superconductor UCoGe. For some partially broken symmetry cases, the upper critical field exhibits upward curvature, as has been recently seen in the ferromagnetic superconductor UCoGe,[3] and reasonably good fits to some of that data are obtained.


13P-B022 Small Angle Neutron Scattering and the Vortex Lattice of UPt$_3$

W. J. Gannon$^a$, W. P. Halperin$^a$, J. A. Sauls$^a$, K
anomalous electrical transport and superconductivity of heavy fermion superconductor URu$_2$Si$_2$


The pressure dependent electrical resistivity of URu$_2$Si$_2$ has been studied in an ultra-clean single crystal at high pressure across the first order phase boundary of $P_c$ where the ground state switches under pressure from “hidden order” (HO) to large moment antiferromagnetic (LAFM) states. The generalized power law $\rho = \rho_0 + A_\alpha T^\alpha$ analysis finds that the electric transport property deviates from Fermi liquid theory in the HO phase but obeys the theory well above $P_c$. This suggests the quantum criticality in the HO phase of URu$_2$Si$_2$. The analysis using the polynomial in $T$ expression $\rho = \rho_0 + \alpha_1 T + \alpha_2 T^2$ reveals the scaling relation $\alpha_1/\alpha_2 \propto T_{sc}$ in the HO phase. While the pressure dependence of $\alpha_2$ is very weak, $\alpha_1$ is roughly proportional to $T_{sc}$. This suggests a strong correlation between the anomalous quasiparticle scattering and the superconductivity and that both have a common origin, possibly rooted in the magnetic excitations $Q_0 = (0,0,1)$ observed only in the HO phase. Similar correlation between the $T$-linear resistivity and $T_{sc}$ has been found in the organic superconductors, the iron pnictide superconductors and the high-$T_c$ cuprate superconductors near quantum criticality.

13P-B024  Scaling relation found in...
13P-B026 Specific Heat Study of the Non-centrosymmetric Superconductor LaPt$_3$Si in Magnetic Fields
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We have measured the specific heat of poly- and single-crystalline LaPt$_3$Si samples in various magnetic fields. In zero magnetic field, we observed distinct superconducting transitions at $T_c \sim 0.64$ K and 0.61 K for the poly- and single crystals, respectively. Temperature dependences of the specific heat of both samples around $T_c$ resembled each other and could be well described by an exponential equation for a conventional superconductor at low temperatures. In a magnetic field, a characteristic peak of $C/T$ appeared while the superconducting transition temperature was considerably suppressed. These trends were pronounced for the single crystal. The transition of the polycrystal became broad above 40 Oe and a characteristic tail appeared at temperatures above the peak of $C/T$. We suggest that the tail is induced by domains that have crystalllographic disorders of the non-centrosymmetry and a higher critical magnetic field than that of the bulk. These domains became superconducting at temperatures above the peak of $C/T$, and then formed the tail. Both the poly- and single-crystalline LaPt$_3$Si samples have been found to show characteristics that are in-between those of type-I and type-II superconductors.

13P-B027 Neutron Diffraction in the Pressure-Induced Superconducting Antiferromagnet CeIrSi$_3$
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Neutron diffraction experiments were performed to investigate a nature of the antiferromagnetic ordered phase of the pressure-induced superconductor CeIrSi$_3$.\textsuperscript{1} We observed magnetic Bragg reflections below $T_N = 5.0$ K for the first time, using a large single crystal grown by Czochralsky pulling method in a tetra-arc furnace. The magnetic structure is characterized by the incommensurate wave vector $Q = (\pm \delta_1, 0, 0.5 \mp \delta_2)$. The antiferromagnetic ordered state can be interpreted as a spin-density wave formation by taking account of the results on de Haas-van Alphen (dHvA) signals in CeIrSi$_3$ where the 4f-electrons of CeIrSi$_3$ are itinerant. In the conference, we discuss the magnetic structure of CeIrSi$_3$ in connection with the results of the iso-structural compound CeRh$_3$Si$_3$.\textsuperscript{2}


13P-B028 Electronic Inhomogeneity and Pair Breaking in Heavy Fermion Superconductors
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Cooper pair breaking by impurity scattering is often described by the Abrikosov-Gor’kov theory. It is, however, slightly different in heavy fermion superconductors, in which impurities may create local vacancies of magnetic f-moments in the periodic Kondo lattice. Here we report detailed analysis of specific heat data in doped heavy fermion superconductors and show that the superconducting condensation energy follows a simple relation versus doping. Our results suggest formation of Kondo holes around impurities, which is further confirmed by nuclear quadrupole resonance measurements.

13P-B029 Coexistence of antiferromagnetism and $d$-wave superconductivity induced by paramagnetic pair-breaking
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The discovery of antiferromagnetic (AFM) order [1] in the high field corner of the $d$-wave superconducting phase of CeCoIn$_5$ has led to a tremendous interest in the genuine picture on the high field and low temperature (HFLT) superconducting phase of this compound in fields parallel to the basal plane which has been identified earlier with the long-sought Fulde-Ferrell-Larkin-Ovchinnikov (FFLO) phase. The detected field-induced AFM order is peculiar in the sense that it is absent outside the HFLT phase and has its incommensurate Q-vector parallel to $(\pi, \pi)$. We develop a theory [2] identifying the HFLT phase of CeCoIn$_5$ as the coexistent phase of AFM and FFLO orders in a $d$-wave superconductor with strong paramagnetic pair-breaking (PPB). At this time, details of the resulting AFM order and its stability against a field-tilt are also examined. It is shown that the incommensurate Q-vector parallel to $(\pi, \pi)$ is a reflection of the fact that the principal Fermi surface of CeCoIn$_5$ has the largest density of states along $(\pi, \pi)$ and that the disappearance of the AFM order due to the field tilt is naturally understood if the AFM staggered moment of the PPB-induced AFM order or fluctuation is locked primarily along the c-axis irrespective of the orientation of the applied field.

Session 13P-C:

C3 Quantum Criticality and Novel Phases

C5 Heavy Fermion Systems

Saturday August 13, 16:00 – 18:00

Exhibition Hall 1

13P-C001 Aharonov-Bohm Effect in a Semiconducting Ring With Finite Spin and Angular Momentum

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For the electrons and holes in a semiconducting ring in a magnetic field, the rotation of electrons and holes acquires a phase which affects the excitonic energy. Since, the electron is not in the same band as the hole, it does not acquire the same phase as the hole. Hence, the Aharonov-Bohm phase can become fractional. The effective charge of the electron is not equal to that of the hole due to the spin and orbital magnetic quantum-number-dependent charges so that the flux quantum depends on the inverse charge difference which becomes observable in the effective exciton energy which affects the gap. Similarly, the transmission is found to depend on the phase factor which also admits fractional flux. According to the original Aharonov-Bohm effect, the phase factor is given by \( \exp(i\epsilon/\hbar c) \oint \vec{A}_\mu dx^\mu \) which ceases to be single valued when \( e \) is replaced by \( e^* \) due to the \( j = l \pm s \) in the \( g \) value which multiplies the charge. Since, we have the \( \pm \) sign in the spin, two values are generated in place of a single value. The phase factor depends on the angular momentum quantum number so that multiple values of the phase factor are generated. There is a solution for which the charge becomes zero so that \( \exp(i\epsilon/\hbar c) \) becomes unity.

13P-C002 Electrons in a Magnetic Field: Special Spin in de Haas-van Alphen Effect

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When the magnetic field is applied in a metal, the electrons behave like a harmonic oscillator. When field is increased these harmonic oscillator type levels cross the Fermi energy at a particular point resulting into discontinuities in the population of any particular level at a point. For a large orbital magnetic moment, different from \( L=0 \) and both signs of spin in the total magnetic momentum quantum number, \( j = l \pm s \), the discontinuities in the population of the electrons in a particular level become double valued resulting into doubling of oscillations in the magnetization. There is a double valued change in the energy of the electrons when they transfer from the harmonic oscillator type level to the Fermi level. The magnetization depends on the value of \( j = l \pm s \) so that there is a double valued period in the oscillations. The de Haas-van Alphen effect is usually described for the \( L=0 \) electrons. Hence, we see that the de Haas-van Alphen effect is considerably modified in going from \( L=0 \) to \( j = l \pm s \), with both signs in the spin.

13P-C003 Ground-state behaviors of quantum compass model in an external field (LT26)

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The ground-state (GS) properties of two-dimensional (2D) quantum compass model in an external field on the infinite square lattice are investigated by using the exact diagonalization (ED) method. We obtain the GS energy and evaluate quantities such as the correlation functions, nearest-neighbor entanglement, local order parameter, and so forth. As the external field is presented, the first-order quantum phase transition will be absent and the system exhibits the behaviors of the second-order phase transition.

13P-C004 Nonlinear Interaction of Quasi-Particle with Thermostat and the Problem of Second Order Phase Transitions in Cooperative Phenomena of Condense Mater

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A great deal of attention is currently devoted to the problem of coherence which appears not only between quanta but between groups of quanta too. The generation of non-classical coherent electromagnetic field in multi-photon emission and the interaction of coherent radiation with matter have been the subjects of a number of theoretical and experimental studies in recent years. Examples include the higher-order coherence in multi-photon generation of light, the two-photon micro-maser emission; two-photon lasers the parametric down conversion, four-wave mixing and other effects in optical diapason.

The collective processes in condense matter have many analogical proprieties with cooperative non-linear optics. Examples are superconductivity, super-radiance, ferromagnetism etc. For example the Cooper-pairs created in the processes of non-linear interaction of electrons with lattice vibration contain the single and two-phonon exchange integrals between electrons. The large nonlinearity occurs, when the single-phonon exchange integral between band electrons is smaller than the multi-phonon exchanges. This is possible in the many-band supercondutive materials, in which the nonlinear exchange integral arises through virtual bands of material.

The similar effect of nonlinear interaction can be observed and in the super-radiance theory and ferromagnetism if we consider that the exchange integral between the quasi-spins has the nonlinear character like in superconductivity. Considering that multi-quantum scattering process in condensed matter depends on the mean number of thermal phonons, it is possible the increasing of exchange integral between the electrons or spins, due to the dependence of nonlinear cooperative
processes on the intensity of the thermal field. This report shows that order parameter of correlated quasi-particle in superconductivity, ferromagnetism or super-radiance firstly increases with temperature achieving the maximal value. After that it decreases as in traditional phase transition effects. In this case the competition between single- and two quanta exchange integrals takes place through nonlinear interaction. The behavior of quantum fluctuation of order parameter as function of temperature and single and two-quantum exchange integrals in condensed matter is discussed. The behavior of quantum fluctuation of order parameter as function of temperature and single and two-quantum exchange integrals in condensed matter is discussed.

1. M. O. Scully and M. S. Zubairy, Quantum Optics (Cambridge 1997), W.P. Schleich, Quantum Optics in Phase Space (Wiley 2001)

13P-C005 Low Temperature X-ray Diffraction Study on Phase Transitions


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The low temperature x-ray diffraction (LTXD) is essential technique to study the crystal structure change phase transition. But when the structural phase transition occurs at very low temperatures such as below 1 K, the structure change becomes very small which makes it so hard to observe the crystal structure change by LTXD. In this case we found that the full width at half maximum of the x-ray spectrum (FWHM) increases due to the crystal structure change. This increase of FWHM gives some information about the crystal structure phase transition. In our present report we will mainly discuss the integrated intensity (I.I) of the x-ray spectrum. The temperature dependence of I.I can be expressed by the Debye-Waller factor. As a precursor effect of the crystal phase transition, the softening of the lattice occurs. Due to the softening of the lattice, the I.I drastically decreases down to the crystal phase transition temperature, We observed this effect in many materials. In our present report, we will show some of them, antiferro-quadrupolar ordering compounds CeLa1−x(x = 1, 0.75, 0.70), iron pnictide superconductor SmFe0.925Co0.075AsO, and other compounds PrCu4Ag and Nd2Ti2O7.

13P-C006 Quantum Melting of Valence Bond Crystals as a New Route for Super-solidity

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Itinerant strongly correlated particles on frustrated lattices are at the heart of many recent theoretical developments. These are largely motivated by exciting new exotic experimental behaviors; A number of electronic pyrochlore (a typical 3D frustrated lattice) systems show heavy fermion behaviors and proximity to a metal-insulator transition thought to be connected with the interplay between strong correlations and frustration. Taking into account the latter is also probably very important for describing the additional superconducting behavior in some of these systems (e.g. LiTi2O4). In this presentation, I will consider both bosonic and fermionic Hubbard models on the checkerboard lattice, the two-dimensional analog of the pyrochlore lattice, for infinite on-site repulsion. At fractional particle density n=1/4 and strong nearest-neighbor repulsion, insulating Valence Bond Crystals (VBC) of resonating particle pairs are stabilized. Melting of these bosonic/fermionic crystals into superfluid/metallable phases under increasing hopping will be discussed at T=0K. More specifically, I will show the presence of an unconventional commensurate VBC supersolid region, precursor to the melting of the bosonic mixed-anisotropic crystal.


13P-C007 Ground-State Ferromagnetism in a model with Anderson-Hubbard centers


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Ferromagnetic ordering stabilization is studied within a model of narrow energy band hybridized with energy levels of electrons localized on Anderson-Hubbard centers. Besides the spin-spin interactions and strong on-site Coulomb interaction, due to hybridization, the indirect hopping and indirect exchange interactions are pronounced in the model. Configurational representation of Hamiltonian with X-operators describing the localized spin subsystem has been built. On this base the effective Hamiltonian has been constructed for the case of strong Coulomb correlation and classification of effective exchange and effective hopping parameters within the model has been proposed. Criteria for the ferromagnetic ordering stabilization have been found for low-temperature strongly correlated regime. Ground state energy and zero-temperature magnetization of the localized spin subsystem has been calculated. Analytical solution for magnetization as a function of the effective bandwidth, electron concentration and model parameters obtained in zero-temperature limit with rectangular bare density of states indicate that the ferromagnetic ordering can be stabilized by the hybridization through the mechanism of effective exchange interaction. The region of electron concentrations favorable for low-temperature ferromagnetic phase stabilization depends substantially on hybridization-to-intra-site correlation ratio.

13P-C008 High Pressure Measurement...
ments on the Itinerant Ferromagnet ZrZn$_2$

L.A. Sibley$^a$, E. Pugh$^a$, G.G. Lonzarich$^a$, N. Kimura$^b$, S. Takashima$^c$, M. Nohara$^c$, H. Takagi$^c$, M. Hanfland$^d$

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We present a high pressure, low temperature study of the weak itinerant ferromagnet ZrZn$_2$. The low Curie temperature and small ordered moment make it an ideal candidate to tune the ferromagnetic transition to high pressures, with pressures less than 2GPa. Using a Diamond Anvil Cell, with a low noise four terminal resistivity set up, we observe the suppression of the ferromagnetic transition, and formation of a Quantum Critical Point at 2GPa. Previous measurements show deviations from the Fermi Liquid description of matter at low temperatures below the critical pressure (evidenced by a $T^{5/3}$ form of the resistivity) which can most likely be explained in the framework of a marginal Fermi Liquid. Above the critical pressure a new phase was previously observed (as evidenced by a $T^{3/2}$ form of the resistivity). The exact nature of this new phase is as yet unknown. In our resistivity measurements we have confirmed the existence of this new phase and investigated its extent to higher pressures. X-ray Powder Diffraction measurements, performed at the European Synchrotron Radiation Facility to high pressures are also presented contributing to our understanding of the structural nature of the phase transition.

13P-C009 Josephson Effects in Insulating Quantum Spin Systems?

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We propose an experiment in which two magnetic insulators that both show field-induced magnetic-ordering transitions are weakly coupled to one another and are placed into an external magnetic field. If the respective magnetic states can be interpreted as phase coherent Bose-Einstein condensates of magnetic bosonic quasiparticles, one expects the occurrence of Josephson effects. For two coupled magnetic insulators with different critical fields, an alternating quasiparticle current should develop with a leading oscillation frequency $\omega_{osc}$ that is determined by the difference between the critical fields. As a result of the coupling, additional sidebands appear in the frequency spectrum of the coupled device that would be absent without phase coherence. We discuss the primary conditions for such an effect to take place and conclude that its detection is feasible for a proper choice of compounds with suitable and realistic material parameters.$^1$

$^1$A. Schilling and H. Grundmann, cond-mat/arXiv:1101.1811v4

13P-C010 Experimental Observations of Magnetic Bose Glass

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The turn of millennia marked a milestone in quantum many-body physics with first reports of Bose-Einstein condensation in quantum magnets.$^1$ A natural question to ask is: what happens to the phase transition in the presence of magnetic disorder? Theory predicts that disorder may disrupt the formation of condensate at the phase boundary and lead to an intermediate Bose Glass (BG) phase before entering the BEC state. Recently, experimental evidence of a magnon Bose Glass have been reported for several materials, including IPA-CuCl$_2(1-x)$Br$_2$$_3$ and Th$_1-x$K$_x$CuCl$_3$. In the present work we compare those results with new experiments on the disordered spin gap systems (C$_4$H$_{12}$N$_2$)Cu$_2$Cl$_4$Br$_2$ and SuL-Cu$_2$Cl$_4$(1-x)Br$_4$. Indeed, we find that even weak disorder has a profound effect on the magnon BEC phenomenon. However, to date there is no clear evidence that the BEC phase persists at high fields, as predicted by BG theory. In its place one observes a gradual spin freezing, and probably a glassy short-range-ordered phase at high fields. Does this call for re-evaluation of BG physics for quantum magnets?


13P-C011 Phase Structure of the t-J Model of Hard-Core Bosons in Three-Dimensions at Finite Temperatures

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In relation with the t-J model of strongly correlated electrons, it is interesting to study its bosonic counterpart, the bosonic t-J model. It has two versions, (i) the canonical bosons with anisotropic spin coupling, and (ii) the hard-core bosons with isotropic spin coupling. In the paper, we consider the version (ii) which describes a system of isotropic antiferromagnet with doped bosonic holes, and is closely related to systems of two-component bosons in an optical lattice. The bosonic “electron” operator $B_{\sigma}$ at the site $x$ with a two-component spin $\sigma(=1,2)$ is treated as a hard-core boson operator, and represented by a composite of two slave particles; a spinon described by a Schwinger boson (CP$^1$ boson) $z_{\sigma}$ and a holon described by a hard-core-boson field $\phi_{x}$ as $B_{\sigma} = \phi_{x}^a z_{\sigma} \phi_{x}^a$. By Monte Carlo simulations we study its phase diagram in the density-temperature plane and the possible phenomena like appearance of antiferromagnetic long-range order, Bose-Einstein condensation, phase separation, etc. Obtained results show that the hard-core bosonic t-J model has a phase diagram that suggests some interesting implications for high-temperature superconducting materials, although the difference of statistics is still crucial.

13P-C012 Multifractal Quantum Spin Phases at Kondo-Anderson Transitions

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13P-C013 Non-extensive thermodynamics for the Ginzburg-Landay theory of phase transitions in the strongly-correlated systems

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The existence of strong correlations in many systems makes these systems non-separable from the thermodynamics point of view and all thermodynamic functions like entropy become non-extensive functions 1. That is why recently a number of theoretical models has been proposed with use the statistical distributions different from the Gibbs one. In the present work it is investigated how the non-extensive nature of the thermodynamic functions makes an influence on their changes in the vicinity of critical point and it is proposed the corresponding model based on the Ginzburg-Landau free energy expansion in the series on order parameter as well as on a non-extensivity parameter the value of which is determined by the strength of correlations in the system. The dependence of heat capacity jump on the non-extensivity parameter is predicted and the analytical formula for this jump is derived. This work is supported by the Ministry of Education and Science of the Russian Federation (FTP “Scientific and pedagogical personnel of the innovative Russia” contract N 02.740.11.0797).


13P-C014 Electronic structure of Ta2NiSe5 as a candidate for excitonic insulators

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We make the electronic structure calculations of Ta2NiSe5 known as a new candidate for excitonic insulators where the semiconducting or semimetallic ground state becomes unstable against the coherent formation of excitons [1,2]. We use the generalized gradient approximation (GGA) in the density functional theory, where the Hubbard-type repulsive interaction is taken into account (GGA+U). We find that the system is metallic for small values of U but an indirect band gap opens for larger values of U ≥ 3 eV. A flat band appears around the Γ point of the Brillouin zone but the minimum of the gap occurs away from the Γ point. Our results for the band dispersion are in contrast to the previous tight-binding bands [3] but are in reasonable agreement with recent angle-resolved photoemission spectra [1]. We discuss possible origins of observed unusual properties [1-4] of this material. Details will be reported in


13P-C015 Exotic Quantum Phase Transitions in the Spin Nanotubes

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Recently some quantum spin systems on tube lattices, so called "spin nanotubes" 1, have been synthesized. As the first step of theoretical study on the spin nanotube, we investigate the S=1/2 three-leg spin tube, which is the simplest one, using the DMRG and the numerical diagonalization, combined with a precise finite-size scaling analysis named level spectroscopy 2. The spin gap, which is one of the most interesting macroscopic quantum effects, was revealed to be open for any finite rung exchange couplings, in contrast to the three-leg spin ladder system which is gapless. It is consistent with the previous effective Hamiltonian approach. We also found a new quantum phase transition caused by an asymmetric rung interaction. When one of the three rung coupling constants is changed, the spin gap would vanish. In addition we theoretically predict some new field-induced quantum phase transitions. A chirality-mediated novel superconductivity mechanism will be also proposed.

1 See, for example, T. Sakai et al., J. Phys.: Condens. Matter 22, 403201 (2010)

13P-C016 Two-impurity Kondo Effect in Al/AlO x/Y Tunnel Junctions

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We have fabricated a series of Al/AlO\textsubscript{2}/Y tunnel junctions and measured the differential conductance \( G(V,T) \) at liquid-helium temperatures. We found that the zero-bias conductance \( G(0,T) \) increases with reducing \( T \) below \( \sim 40 \) K, i.e., \( G(0,T) \) obeys a \(-\ln T\) law at a higher \( T \) regime (\( \sim 10-25 \) K) and crosses over to a \(-\sqrt{T}\) law at an intermediate \( T \) regime (\( \sim 5-20 \) K). The unique \(-\sqrt{T}\) feature is suggestive of a novel Kondo effect. In particular, in this intermediate \( T \) regime, we observed that the finite-bias \( G(V,T) \) curves at different \( T \)'s collapse closely and can be expressed by \[ G(0,T)-G(V,T))/\sqrt{T}=f(\sqrt{eV/k_B T}); \] where \( f \) is a universal scaling function characteristic of the two-impurity Kondo effect. Furthermore, we have varied the junction area and the barrier thickness in different samples by adjusting the fabrication conditions. As a result, while the \( G(V,T) \) behavior is essentially similar for all junctions at not too low \( T \), we found two kinds of distinct \( T \) dependences of \( G(0,T) \) at \( T<4 \) K. In the first kind, \( G(0,T) \) saturates as \( T \to 0 \) \( K \), while in the second kind, \( G(0,T) \) passes over a maximum and then decreases with reducing \( T \). We explain that the first group of samples possesses a Kondo-screened ground state, while the second group possesses a singlet ground state owing to strong antiferromagnetic interimpurity coupling. The two-impurity Kondo effect arises from a minute number of spin-\( \frac{1}{2} \) yttrium impurities which diffused into the insulating barrier during the junction fabrication process.

13P-C017 Renormalization of quantum information measures: an approach to quantum criticality

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A quantum renormalization group (QRG) – based on the Kadanoff block RG – to investigate the quantum information aspects is introduced. This method provides a powerful alternative approach to studying quantum information properties of various quantum spin models. We elaborate the idea through two examples. In particular, the evolution and finite-size scaling of entanglement (concurrence) and its derivative close to the quantum critical point of the Ising model in transverse magnetic field (ITF) is investigated. We obtain that the derivative of concurrence of two blocks, each comprised of half of the system, diverges at the critical point with an exponent directly associated to the divergence of the correlation length. Moreover, we calculate the quantum fidelity susceptibility for the ITF model, and find its scaling behavior in the vicinity of the quantum criticality. Next, the QRG is applied to the anisotropic Heisenberg model (XXZ). Here our scheme demonstrates how the minimum value of the first derivative of concurrence scales with the system size. We also study the effect of a Dzyaloshinskii-Moriya interaction on the quantum information properties of the ITF and XXZ models near their quantum critical boundaries. Our method is inherently fairly general and can hopefully shed more light on properties of a wide spectrum of quantum critical systems.

13P-C018 Atomic type magnon Bose-Einstein condensation in antiferromagnet.

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The Spin Supercurrent and Bose-Einstein condensation of magnons similar to an atomic BEC was observed in 1984 in superfluid \( ^3\text{He}-\text{B} \). The same phenomena should exist in solid magnetic systems. We report the first observation of magnon BEC in solid easy plain antiferromagnet CsMnF\textsubscript{3}. We have observed magnon BEC on a mode of coupled Nuclear-Electron precession. The dynamical properties of this mode have many similarities with NMR of superfluid \( ^3\text{He}-\text{A} \). The frequency changes with deflection of nuclear magnetization. Furthermore, the involvement of electron ordered subsystem gives the magnon-magnon interaction, spin waves and spin supercurrent, while the nuclear subsystem gives the relatively long time of relaxation. Our experiments were done at the temperature of 1.5 K at a frequency of 566 MHz. The line of CW NMR at small RF excitation corresponds to 325 mT field. If we increase the excitation and sweep down the field, the BEC states creates, nuclear magnetizations deflects and precess on the frequency of radiation.\textsuperscript{1}

\textsuperscript{1} Yu.M. Bunkov et al., JETP Letters, in print. This work is supported by the Ministry of Education and Science of the Russian Federation (FTP “Scientific and scientific-pedagogical personnel of the innovative Russia” contract N02.740.11.5217)

13P-C019 3d Electron Quadrupole Moments in Vanadium Oxides

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Vanadium oxides, such as VO\textsubscript{2}, V\textsubscript{2}O\textsubscript{3}, and Magnéli phases V\textsubscript{n}O\textsubscript{2n+1}, are conventional examples of the Mott transition. The metal-insulator transition in these systems has been recently revisited from a view of orbital physics. We have investigated the orbital occupancy in V\textsubscript{2}O\textsubscript{3} (3\(d^2\)), V\textsubscript{2}O\textsubscript{5} (3\(d^4\)), and V\textsubscript{2}O\textsubscript{13} (3\(d^6\)) via the single-crystal 51\textsuperscript{V} NMR measurements. Determination of the hyperfine coupling tensor revealed almost equivalent occupation of \(a_1g\) and \(e'_g\) orbitals, which leads to the vanishing electron quadrupole moment, in the paramagnetic metallic state of V\textsubscript{2}O\textsubscript{3}. We observed the appearance of the quadrupole moment in the low-temperature metallic state under pressure of 2.5 GPa, where the development of antiferromagnetic correlations was observed in the nuclear spin-lattice and spin-spin relaxation measurements. In contrast, a large quadrupole moment was found in the metallic state of V\textsubscript{2}O\textsubscript{5} and V\textsubscript{2}O\textsubscript{13}. We observed the formation of local spin-singlets accompanied by orbital order in these two compounds. The \(t_{2g}\) orbital state changes across the
metal-insulator transition, which is manifested in the asymmetric electric field gradient at the $^{51}$V nucleus. The significant interplay among the spin, charge, and orbital degrees of freedom in the vanadium oxides is discussed.

13P-C020 Spin Density Wave In Chromium Under High Pressure

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The phase diagram of the magnetic phases of body-center cubic chromium is elucidated from a simple Hamiltonian taken into account the essential nearest and next nearest neighbor spin-spin interactions. It is shown that the relative stability of various magnetic structures is determined by a delicate balance of these interactions. This is confirmed by First Principles density functional calculations augmented with a model Hubbard Hamiltonian. The results also show the magnetic structures of Cu are very sensitive to the lattice constant and the choice of the Hubbard $U$ parameter. The electronic of the magnetic phases at ambient pressure can be described adequately with the spin-polarized local density approximation with a small effective Hubbard parameter. The effect of increase on site coulomb repulsion at high pressure mimicked by larger $U$ values helps to rationalize the recently observed quantum phase transition.

13P-C021 Collapse of Charge Ordering Due to Disorder in Quasi One-Dimensional Electron Systems

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Charge ordering (CO), which has been observed in molecular conductors with a quarter filled band, is a fascinating phenomenon that electrons are localized inhomogeneously but regularly. The origin of such charge localization is the long range component of the repulsive interaction. On the other hand, disorder due to impurities is known to lead to electron localization. In this case, random charge distribution is realized. Therefore, localization by Coulomb interaction and by disorder compete against each other. In the present study, effects of disorder on CO in quasi one-dimensional electron systems are investigated. We consider the system where one-dimensional chains expressed by the extended Hubbard model are coupled by the interchain interaction. This is the simplest model which can describe the finite temperature CO transition observed in actual materials.\(^1\)\(^2\) The forward scattering is taken into account as an impurity potential. The CO transition temperature $T_{\text{CO}}$ and the resistivity for $T > T_{\text{CO}}$ are discussed based on the bosonization method with $T$ being the temperature. Suppression of both quantities are obtained due to the impurity potential.

13P-C022 Transport properties in spin-orbit Mott insulator Ba$_2$IrO$_4$ under high pressure

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The recent findings of the novel Mott insulating state in Sr$_2$IrO$_4$\(^1\) have developed a new research field on solid-state physics. The cooperation of the large spin-orbit (SO) interaction and the moderate on-site Coulomb interaction between 5d electrons yields $\lambda_{\text{eff}} = 1/2$ Mott ground state, similar to Mott states in parent materials of high-$T_c$ cuprates such as La$_2$CuO$_4$. Recently, we successfully synthesized a novel layered iridate Ba$_2$IrO$_4$, which is isostructural to Sr$_2$IrO$_4$, but has flat IrO$_2$ square planar lattice with straight Ir-O-Ir bonds. In this presentation, we report on results of the electric resistivity ($\rho$) under pressure of up to 15 GPa. Ba$_2$IrO$_4$ is an insulator at ambient pressure, however undergoes a phase transition to a metallic state above 13.8 GPa. The temperature dependence of $\rho$ is well-described by the Mott variable-range-hopping regime in the insulating side. However, in the metallic side, the non-Fermi-liquid behavior was observed below $\sim$20 K. These results indicate that the both the disorder and the electronic correlation contribute to the transport property of Ba$_2$IrO$_4$. Our sample is probably located on the verge of the phase boundary between the Anderson and the Mott insulator.

13P-C023 Magnetic ordering in spin-orbit Mott insulator Ba$_2$IrO$_4$ probed by $\mu$SR

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The magnetic ground state of novel spin-orbit Mott insulator Ba$_2$IrO$_4$ has been investigated by muon-spin rotation/relaxation ($\mu$SR) technique. The amplitude of the zero-field $\mu$SR signal rapidly decays with decreasing temperature from 300 K to 240 K. We found that the signal oscillates due to the muon-spin precession below 240 K. It clearly indicates that there exists a coherent internal magnetic field induced by long-range ordered spins at low temperatures. It means that the magnetic ground state in Ba$_2$IrO$_4$ is an antiferromagnetic long-range ordered state. The internal local field obtained from the precession frequency of the time spectra indi-
cates that the effective magnetic moment of the iridium ions is estimated to be $|\mu| = 0.34(4) \mu_B$/Ir-atom. It is surprising that the size of the magnetic ions is much smaller than the integer moment $1\mu_B$ expected in the case of $J_{eff} = 1/2$. The moment reduction is probably attributed to a low-dimensional quantum spin fluctuation with large intra-plane antiferromagnetic correlation $|J|$.

13P-C024 Magnetic phase separation in Eu$_{1-x}$Ca$_x$B$_6$

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The magnetic properties of Eu$_{1-x}$Ca$_x$B$_6$ (0$\leq x$$\leq$0.26) single crystals have been studied in the wide range of temperatures (1.8-300 K) and magnetic fields (up to 5 T). The effective magnetic moment of Eu$^{2+}$ was found to decrease from the free ion value $\mu_{eff}$$\approx$7.93$\mu_B$ to $\mu_{eff}$$\approx$7.3$\mu_B$ ($\mu_B$ - Bohr magneton) when Ca doping increases crossing the critical concentration of metal-insulator transition (MIT) $x_c$$\approx$0.2$^1$. At the same time, a universal behavior of magnetic susceptibility $\chi(T)$$\times$$T$($T$-\Theta)$^a$ ($\alpha$=1.5) was observed near the Curie temperature in the paramagnetic phase of both metallic ($x$$<$x$_c$) and dielectric ($x$$\geq$x$_c$) compositions of Eu$_{1-x}$Ca$_x$B$_6$. The anomalous magnetic properties of the Ca-doped compounds are discussed in terms of the magnetic and electronic phase separation realized in the vicinity of the concentration driven quantum MIT.$^2$ Support by RFBR 11-02-00623 project is acknowledged.

1 V. Glushkov et al., JETP 111, 246 (2010).

13P-C025 Partial Disorder in the Periodic Anderson Model on a Triangular Lattice

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Rare-earth compounds exhibit many fascinating behaviors, such as heavy quasi-particle formation, superconductivity, and non-Fermi liquid behavior. In these systems, two competing interactions originating from the interplay between localized electrons and conduction electrons play an important role, i.e., the Ruderman-Kittel-Kasuya-Yosida(RKKY) interaction and the Kondo coupling. The former tends to stabilize magnetic ordering and the latter tends to screening of the localized moments by spin-singlet formation. Their competition gives rise to a quantum critical point(QCP), and enhanced fluctuations near QCP are the source of the interesting behaviors. In the present study, as a new paradigm for the QCP-related phenomena, we investigate the effect of geometrical frustration in the competing region. We study the ground-state phase diagram for the periodic Anderson model at half-filling on a triangular lattice within the Hartree-Fock approximation, and find a partial-disordered(PD) state between a RKKY-driven noncollinear antiferromagnetic metal and a Kondo insulator.$^1$ The PD state is stabilized by releasing the frustration with self-organizing the system into the coexistence of collinear antiferromagnetic order on an unfrustrated honeycomb subnetwork and nonmagnetic state at the remaining sites. We discuss the nature of the PD state in detail, in comparison with the previous result for the Kondo lattice model.$^2$


13P-C026 Partial Disorder in the Periodic Anderson Model on a Triangular Lattice

S. Hayami$^a$, M. Udagawa$^a$, Y. Motome$^a$. $^a$Department of Applied Physics, University of Tokyo, Tokyo, Japan

Rare-earth compounds exhibit many fascinating behaviors, such as heavy quasi-particle formation, superconductivity, and non-Fermi liquid behavior. In these systems, two competing interactions originating from the interplay between localized electrons and conduction electrons play an important role, i.e., the Ruderman-Kittel-Kasuya-Yosida(RKKY) interaction and the Kondo coupling. The former tends to stabilize magnetic ordering and the latter leads to screening of the localized moments by spin-singlet formation. Their competition gives rise to a quantum critical point(QCP), and enhanced fluctuations near QCP are the source of the interesting behaviors. In the present study, as a new paradigm for the QCP-related phenomena, we investigate the effect of geometrical frustration in the competing region. We study the ground-state phase diagram for the periodic Anderson model at half-filling on a triangular lattice within the Hartree-Fock approximation, and find a partial-disordered(PD) state between a RKKY-driven noncollinear antiferromagnetic metal and a Kondo insulator.$^1$ The PD state is stabilized by releasing the frustration with self-organizing the system into the coexistence of collinear antiferromagnetic order on an unfrustrated honeycomb subnetwork and nonmagnetic state at the remaining sites. We discuss the nature of the PD state in detail, in comparison with the previous result for the Kondo lattice model.$^2$


13P-C027 Theoretical study of $J_{eff} = 1/2$ Mott insulator in Ir oxides: cooperation of a strong spin-orbit coupling and local electron correlations

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Recent experiments on Sr$_3$IrO$_4$ have revealed a novel
Kramer’s doublet \( J_{\text{eff}} = S - L = 1/2 \) Mott insulator induced by a strong spin-orbit coupling (SOC) and local Coulomb interactions (U). To clarify the nature of electronic and magnetic properties of this system, we have studied a two-dimensional three-band Hubbard model consisting of the \( t_{2g} \) manifold of 5d electrons with SOC.\(^1\)

The exact diagonalization and variational cluster approximation\(^3\) based on the self-energy functional theory\(^4\) are used to calculate various physical quantities including the single-particle spectra. Our results of the projected single-particle spectra onto \( J_{\text{eff}} = 1/2 \) and \( J_{\text{eff}} = 3/2 \) states have revealed a physical picture of the \( J_{\text{eff}} = 1/2 \) Mott insulator. We also examine the roles of SOC and U to stabilize this novel \( J_{\text{eff}} = 1/2 \) Mott insulator.

\(^{1}\) B. J. Kim, et al., Science 323, 1329 (2009)


13P-C028 High Sensitive Capacitive Dilatometer for Investigation of Quantum Critical Phenomena near Absolute Zero

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We have developed the capacitive dilatometer for measuring the small length change of heavy fermion compounds in order to investigate the critical phenomena at ultralow temperatures, because thermal expansion and magnetostriiction are more singular than specific heat in the approach to a quantum critical point. With decreasing temperature blow 1 K, thermal expansion becomes small in an approximately proportional to the square of temperature, thus, high sensitivity and reproducibility are necessary for the dilatometric measurements in millikelvin temperatures. The cylindrical shape of a single crystal CeRu\(_2\)Si\(_2\) with 3-mm-diameter and 5-mm-length was glued by the silver paste to the dilatometer made of oxygen-free copper. The dilatometer with 12-mm-diameter and 15-mm-height was installed in the 52 mT superconducting solenoid on the dilution refrigerator or in the helium 4 gas flow cryostat of 15 T magnet. Our dilatometer and the capacitance bridge using a lock-in amplifier, the decade transformer operated by hydraulic pressure, as a detailed description of instrumentation including a mechanical heat-switch operated by hydraulic pressure of superfluid \(^4\)He.


13P-C030 Deuterium degrees of Freedom of Selectively deuterated (DMe-DCNQI)\(_2\)Cu Systems (LT26)

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We have studied thermal properties of the selectively deuterated (DMe-DCNQI)\(_2\)Cu system to investigate deuterium degrees of freedom in a methyl basis. Specific heat measurements are systematically performed for systems having various methyl bases of CH\(_3\), CH\(_2\)D, CHD\(_2\) and CD\(_3\) by a method based on DTA (Differential Thermal Analysis). In these systems, we discovered an anomalous specific heat due to the deuterium degrees of freedom. We systematically clarified the specific heat of the selectively deuterated methyl bases in the (DMe-DCNQI)\(_2\)Cu system. Under an equilibrium condition, these systems do not show a sharp peak induced by a phase transition, but exhibit a Schottky type specific heat in systems having CH\(_3\)D and CHD\(_2\) bases. Their energy schemes are determined only by positions of the deuterium atoms in the methyl bases.

13P-C031 Novel phase transition in spin frustrated Et\(_2\)Me\(_2\)Sb\([Pd(dmit)]\(_2\)2 System (LT26)

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A new type of phase transition has been discovered in the Et\(_2\)Me\(_2\)Sb\([Pd(dmit)]\(_2\)2 system of organic semiconductors. In this transition, Pd\((dmit)]^2_2\), which has localized magnetic moments \(s = 1/2\), changes into neutral Pd\((dmit)]^2_2\) spinless states. To clarify the mechanism of this novel phase transition.
accompanied by the charge separation, we have studied the thermal properties of this system. We discovered a broad hump above the critical temperature as well as a sharp peak with small hysteresis in the vicinity of the phase transition. The resulting total entropy ascribed to the transition reaches 13 J/mol-K. It is significantly large and is more than four times larger than the total excess entropy in an α-ET₂I₃ system, that undergoes the charge order transition without a lattice distortion.\(^1\) We concluded that the spin, charge degrees of freedom and lattice modulation cooperatively drive this novel phase transition.


**13P-C032 Neutron scattering Studies of Spin-Ladders**

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Spin-ladders consists of two parallel antiferromagnetic chains of magnetic spin-1/2 ions (legs of ladder) coupled together (rungs of ladder). In the limit of strong rung coupling, the magnetic spectrum is dominated by the excitations of an antiferromagnetic dimer i.e. a gapped magnon mode: introduction of leg coupling modulates this mode but the gap remains. In the limit of weak rung coupling the excitations are similar to the multi-spinon continuum of the one-dimensional, spin-1/2, Heisenberg antiferromagnet. The gap remains in the presence of finite rung coupling but can be suppressed by cyclic exchange interactions. Inelastic neutron scattering of some spin-ladder compounds will be presented.

\(\text{La}_3\text{Sr}_{10}\text{Cu}_{24}\text{O}_{41}\) has strong rung coupling and its excitations consist of a gapped one-magnon mode and a two-magnon continuum, a substantial cyclic exchange reduces the gap and destroys the bound two-magnon excitations. In contrast \(\text{CaCu}_2\text{O}_3\) has a weak rung interaction and a large cyclic exchange which drives the system gapless and quantum critical. At high energies the excitations resemble the multi-spinon continuum of the antiferromagnetic, spin-1/2 chain. At low energies however the excitations are gapless and quantum critical. Comparison to theory suggests that the spinons are bound by the rung coupling and the ladder is close to the Wess-Zumino-Novikov-Witten quantum critical point.

**13P-C033 Measurement of the Fano resonance and hybridization gap in URu₂Si₂ with point-contact spectroscopy**

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The hidden order transition in the Kondo lattice URu₂Si₂ remains a mystery after more than two decades of study. Our reproducible point contact spectroscopic measurements reveal a direct measurement of the Fano resonance and hybridization gap as a distinct double-peaked structure, opening at \(T \sim 27\) K, smoothly growing with decreasing temperature to 12 meV at 4.2 K.\(^[1]\) There is no detectable signature when crossing the hidden order transition at 17.5 K, although this transition is clearly seen in the resistivity vs. temperature data. Intriguingly, when fitting our data to a recent theoretical model\(^[2]\), the renormalized f-level is found to cross the Fermi level at the hidden order transition temperature thereby providing a link, and constraints, on the relationship between the hybridization gap and hidden order parameter. Theoretical analysis\(^[3]\) of scanning tunneling spectroscopic results\(^[4,5]\) assigns a gap opening as the hidden order parameter, but more recent STS results show their observed gap is due to the hybridization\(^[6]\). Relationships between our measured hybridization gap and the hidden order will be discussed.

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\(^[1]\) W.K. Park, P.H. Tobash, F. Ronning, E.D. Bauer, J.L. Sarrao, J.D. Thompson, L.H. Greene (preprint)


\(^[6]\) J. Scamus Davis (private communication)

**13P-C034 Quantum impurities and resultant two-channel Kondo problem in ZrAs₁.₅₈Se₀.₃₉**

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Low-T electrical resistivity \(\rho(T)\) of the closely related phases \(\text{ZrAs}_{1.58}\text{Se}_{0.39}\) (3% of vacancies within the monoatomic As layers)\(^[1]\) and \(\text{ZrP}_{1.54}\text{S}_{0.46}\) (the 2a site fully occupied with P atoms) has been investigated along the c axis down to \(T \geq 0.08\) K and in \(B \leq 14\) T. Whereas for both systems a \(-AT^{1/2}\) term in \(\rho(T)\) was observed below \(T \approx 15\) K, their response to the magnetic field was found to be \textit{qualitatively} different: for the As-based compound, a coefficient \(A = 0.167\ \mu\text{Ohm}\cdot\text{K}^{-1/2}\) remains virtually unchanged even in the highest available magnetic fields. For the P-based compound, however, the \(A\)-coefficient value is linearly reduced from 0.038 to 0.008 \(\mu\text{Ohm}\cdot\text{K}^{-1/2}\) with increasing \(B\) up to 14 T, \textit{i.e.}, by factor nearly 5. These distinctly different observations indicate qualit-
tatively different phenomena occurring in the material with (ZrAs$_{1.58}$Se$_{0.39}$) and without (ZrP$_{1.54}$S$_{0.48}$) broken pnictogen-pnictogen chemical bonds: a $\rho(T, B)$ behavior of the latter system is characteristic for the 3D electron-electron interactions, while the $B$-independent $-A T^{1/2}$ term points at a two-channel Kondo problem due to non-magnetic quantum impurities in the As layers.


13P-C035 Quantum Phases and Entanglement Renyi Entropy
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We investigate crossing behavior of ground state entanglement Renyi entropies of quantum critical systems. We find a novel property that the ground state in one quantum phase cannot be locally transferred to that of another phase, that means a global transformation is necessary. This also provides a clear evidence to confirm the long standing expectation that entanglement Renyi entropy contains more information than entanglement von Neumann entropy. The method of studying crossing behavior of entanglement Renyi entropies can distinguish different quantum phases well. We also study the excited states which still give interesting results.

13P-C036 Scaling Analysis in the Numerical Renormalization Group Study of the Sub-Ohmic Spin-Boson Model
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The spin-boson model has nontrivial quantum phase transitions in the sub-Ohmic regime. For the bath spectra exponent $0 \leq s < 1/2$, the bosonic numerical renormalization group (BNRG) study of the exponents $\beta$ and $\delta$ is hampered by the boson state truncation which leads to artificial interacting exponents instead of the correct Gaussian ones. In this paper, guided by a mean-field analysis, we study the order parameter function $m(\tau = \alpha - \omega, \epsilon, \Delta)$ using BNRG. Scaling analysis with respect to the boson state truncation $N_b$, the logarithmic discretization parameter $\Lambda$, and the tunneling strength $\Delta$ are carried out. Truncation-induced multiple-power behaviors are observed close to the critical point, with artificial values of $\beta$ and $\delta$. They cross over to classical behaviors with exponents $\beta = 1/2$ and $\delta = 3$ on the intermediate scales of $\tau$ and $\epsilon$, respectively. We also find $\tau/\Delta^{1-s}$ and $\epsilon/\Delta$ scalings in the function $m(\tau, \epsilon, \Delta)$. The role of boson state truncation as a scaling variable in the BNRG result for $0 \leq s < 1/2$ is identified and its interplay with the logarithmic discretization revealed. Relevance to the validity of quantum-to-classical mapping in other impurity models is discussed.

13P-C037 Ferromagnetic Phase Transition in Charged Spin-1 Bose Gases
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It is indicated that ferromagnetic phase transition occurs in chargeless spinor Bose gases with ferromagnetic couplings, in spite of the magnitude of the ferromagnetic coupling. In an ideal charged spin-1 Bose gas, diamagnetism is introduced by the orbital motion due to charge degree of freedom. We find that diamagnetism is stronger at lower temperature. Within mean-field theory, we investigate the magnetic properties of charged spin-1 Bose gases with ferromagnetic interactions, and significance is given to diamagnetic effect on the ferromagnetic phase transition. It is shown that the internal field due to spontaneous magnetization cannot prevent the occurrence of spontaneous magnetization. There exists a phase transition from paramagnetic phase to ferromagnetic phase, and the critical ferromagnetic coupling value $I_c$ increases with increasing temperature. Our work may provide further insight into the still not fully understood magnetic properties of ferromagnetic superconductors.


13P-C038 Investigations of Quantum Critical Metamagnetism in Sr$_3$Ru$_2$O$_7$ with Hydrostatic Pressure
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The nematic phase observed near the metamagnetic quantum critical end point (QCEP) in Sr$_3$Ru$_2$O$_7$ for magnetic fields near the $c$-axis has been the subject of intense interest. We have applied pressure to Sr$_3$Ru$_2$O$_7$, and show that, for fields parallel to $ab$, hydrostatic pressure gradually suppresses the first order jump in the magnetization at the metamagnetic transition, producing a new QCEP at $13.6 \pm 0.2$ kbar. Magnetic susceptibility measurements near this QCEP show that, surprisingly, the uniform magnetization is not the metamagnetic order parameter. Moreover, we do not find clear evidence of nematic phase formation at this QCEP. These and other aspects of our ongoing high pressure studies of the metamagnetism of Sr$_3$Ru$_2$O$_7$ will be presented.

1 e.g. A. W. Rost, R. S. Perry, J. F. Mercure, A. P. Mackenzie, and S. A. Grigera, Science 325, 1360 (2009)

13P-C039 Magnetic excitations of the quantum dimer antiferromagnet Sr$_3$Cr$_2$O$_8$
Sr$_3$Cr$_2$O$_8$ displays a rich and complex variety physical phenomena. Firstly it is a dimerised quantum magnet with gapped excitations which displays Bose-Einstein condensation in an applied magnetic field. Secondly it has highly unusual lattice and orbital fluctuations over an extended temperature regime below its Jahn-Teller distortion. Sr$_3$Cr$_2$O$_8$ consists of triangular bilayers of magnetic Cr$^{5+}$ ions that are stacked in a AB-CABC sequence. The dominant antiferromagnetic bilayer coupling pairs them in dimers, and the interdimer couplings are geometrically frustrated. The Cr$^{5+}$ ions have one electron in the 3d shell and a spin value of $\frac{3}{2}$. At 285K Sr$_3$Cr$_2$O$_8$ undergoes a cooperative Jahn-Teller distortion which lifts the frustration. We will describe single crystal growth, DC susceptibility, high field magnetization and powder and single crystal inelastic neutron scattering which lifts the frustration. We will describe single crystal growth, DC susceptibility, high field magnetization and powder and single crystal inelastic neutron scattering of Sr$_3$Cr$_2$O$_8$. The data reveals a singlet ground state and gapped dispersive triplet excitations. The magnetic exchange interactions were extracted using the first moment sum rule and a random phase approximation. Our results will be discussed in the context of the current experimental data for Sr$_3$Cr$_2$O$_8$ as well as being compared with the related compounds Ba$_3$Cr$_2$O$_8$ and Ba$_3$Mn$_2$O$_8$.

13P-C040 Attractive interactions between critical fluctuation modes near ferroelectric and ferromagnetic quantum phase transitions

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We present evidence in displacive ferroelectrics and itinerant d-electron magnets that suggest the effective interactions between critical fluctuation modes near to quantum critical points may become attractive. This leads to a break-down of the traditional self-consistent field descriptions of such systems over a range of temperatures and tuning parameters close to the quantum phase transition. The attractive interactions can lead to a first-order phase transition at low temperature and a possible textured ordering of the magnetic or electric polarization. The origin of the attractive interactions may arise from different mechanisms some of which will be discussed.

13P-C041 Pressure Tuned Magnetism

C. R. S. Haines,

There are now many examples of phase transitions that can be suppressed to near 0K. At 0K, phase transitions are necessarily from one ordered state to an equally ordered state. This degeneracy of possible ground states leads to quantum mechanical fluctuations in the suppressed order parameter. These fluctuations have a profound effect on the properties of the system and have been proposed as the mediating attractive potential of the novel superconductivity often observed in these quantum critical systems. Magnetisation and resistivity measurements of Fe2P under hydrostatic pressure will be discussed in this context.

13P-C042 Following elementary excitations to finite temperatures at the pressure-induced quantum phase transition in TiCuCl$_3$


We control the ground state and elementary excitations of the quantum antiferromagnet TiCuCl$_3$ by the application of pressure and temperature. The magnetically ordered phase is “melted” by both quantum and thermal fluctuations, and we map the behaviour of the triplet excitations across the quantum critical regime by inelastic neutron scattering. We use a bond-operator formalism with hard-core boson statistics to describe the evolution of the finite-temperature spectrum from spin waves into gapped magnons. Because the quantum disordered and finite-temperature disordered phases are continuously connected, quantum and thermal fluctuations show very similar effects in opening a gap. One degenerate magnon mode of the disordered phase becomes the longitudinal excitation of the ordered phase. We measure the linewidth of this critically damped mode across the phase transition and show within our model how the universal behaviour governed by the pressure parameter is altered due to thermal broadening. 1 Ch. Rüegg et al., Phys. Rev. Lett. 100, 205701 (2008).

13P-C043 Pressure Effects on Ferromagnetic Superconductors

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Pressure effects on ferromagnetic superconductors are investigated theoretically. As the example, the pressure differential of the Curie temperature is studied numerically. In our previous study, the pressure differential of the Curie temperature was shown based on the Hamiltonian derived by Linder et al. by making the mean field approximation in terms of the electron-electron interaction analytically. There have been no numerical results of the pressure differential of the Curie temperature originated from the microscopic model. In this study, the numerical results are reported.


13P-C044 Lifshitz transition with interactions in high magnetic fields: Application to CeIn$_3$

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The Néel ordered state of CeIn$_3$ is suppressed by a mag-
netic field of 61 T at ambient pressure. There is a second transition at \( \sim 45 \) T, which has been associated with a Lifshitz transition [1,2]. Skin depth measurements [2] indicate that the transition is discontinuous as \( T \to 0 \) and that the transition has a weak pressure dependence until it merges with the Néel transition. Motivated by this transition we study the effects of Landau quantization and interaction among carriers on a Lifshitz transition. The Landau quantization leads to quasi-one-dimensional behavior for the direction parallel to the field. Repulsive Coulomb interactions give rise to a gas of strongly coupled carriers [3]. The density correlation function is calculated for a special long-ranged potential [4]. It is concluded that in CeIn\(_3\) (a) an electron pocket (and not a hole pocket) is being emptied as a function of field and (b) in the ground state the electron pocket is emptied in a discontinuous fashion. This discontinuity is gradually smeared by the temperature in agreement with skin depth experiments [2].

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**13P-C045** **Collapse-Like Decrease of RKKY Interaction and Kondo Effect in Heavy Fermion Compounds \((\text{Ce}_{1-x}\text{Gd}_x)\text{Ni}\) \((0.03 \leq x \leq 0.20)\)**

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CeNi is one of the most famous heavy fermion compounds and magnetically is inactive where both Ce and Ni are non-magnetic. On the other hand, the GdNi, which has the same structure as that of CeNi, is a ferromagnet and not only Gd but also Ni are magnetic. That is, the Ni is non-magnetic in CeNi and magnetic in GdNi. It follows that in \((\text{Ce-Gd})\)Ni systems, Ni and even Ce are expected to change the electronic states according to the content of Gd. In this study, we analyze thoroughly the temperature dependence of magnetization \(M(T)\) at low content of Gd \((x=0.03-0.20)\) in \((\text{Ce}_{1-x}\text{Gd}_x)\)Ni. The magnetization behaviors in low contents of Gd are characterized as both the sensitivity to applied magnetic field \((x=0.03-0.20)\) and the linear relationship of the \(M(T)\) \((x=0.10-0.20)\). By employing the molecular field analysis of two-sublattice model, we have revealed that the exchange interactions between Gd and Gd, \(J_{\text{Gd-Gd}}\), that is RKKY interaction, are extremely suppressed. This collapse-like decrease of RKKY interaction is the unique solution for reproducing the linear decrease of \(M(T)\) and the sensitivity to applied magnetic field. The details are to be discussed.

**13P-C046** **Electrical and magnetic properties as well as crystal and electronic structure of non-stoichiometric DyNi\(_2\)Mn\(_x\) compounds**

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The electrical and magnetic properties as well as the crystal and electronic structure were studied in DyNi\(_2\)Mn\(_x\) \((0 \leq x \leq 0.25)\) alloys. It was found that the alloys crystallize in a cubic MgCu\(_2\) Laves phase structure, in spite of the R to 3d-metal ratio changing from 1:2 to 1:3.25. The binary DyNi\(_2\) compound is characterized by a low temperature of magnetic ordering, \(T_C = 35\) K, since the 3d-band is almost filled by the valence electrons of Dy. The ordering temperature increases very sharply with the addition of Mn, reaches maximum value of 113 K at \(x = 0.5\) and then slightly decreases. A monotonic decrease of the magnetization and the magnetostriction and an increase of the coercivity are observed with increasing Mn content. The resistivity also varies with increasing \(x\) reflecting the changes in the conductivity band. The XPS results show an increase of Mn 3d-states close to the Fermi level. A comparison of the valence band spectra taken at the resonance and non resonance excitations made it possible to identify Mn 3d-, Ni 3d-, Dy 4f-related features in the valence band. This work was partly supported by the Austrian Academy of Sciences and by the Russian Foundation for Basic Research (Grant Nos 11-02-01221; 10-02-96019).

**13P-C047** **High Pressure Resistivity Measurements on the Heavy Fermion System CeAl\(_2\)**

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An investigation on the heavy fermion system CeAl\(_2\) is presented at high pressures and low temperatures (down to 20 mK). CeAl\(_2\) is a well known heavy fermion compound which orders antiferromagnetically at low temperature. At ambient pressure it is antiferromagnetic below 3.8K, with antiferromagnetism thought to be due to the formation of a spin density wave (SDW). Performing low noise four terminal resistivity measurements in a Diamond Anvil Cell we observe changes in CeAl\(_2\) as the antiferromagnetism is suppressed until it reaches a quantum critical point at a critical pressure of 3.2GPa. The conventional Fermi Liquid theory of matter at low temperatures has been observed to break down in previous measurements performed on CeAl\(_2\) around the critical pressure\(^1\). The nature of these deviations including a peak in the residual resistivity and the nature of the temperature dependence of the resistivity at the critical pressure are unclear. In our measurements we have performed a detailed study on higher quality samples around the quantum critical point to further investigate this unusual behaviour.

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13P-C048  Transport properties of La$_{1-x}$Ce$_x$Cu$_4$Al alloys
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We report on the transport properties (thermal conductivity, electrical resistivity) of La$_{1-x}$Ce$_x$Cu$_4$Al (0 $\leq x \leq 1$) alloys. The hexagonal CeCu$_4$-type structure was confirmed by the powder X-ray diffraction technique. Susceptibility measurements give effective magnetic moments in a good agreement with the Ce$^{3+}$ ion value. The analysis of the magnetic resistivity at low temperatures revealed that only CeCu$_4$Al shows a maximum in $\rho(T)$ typical of the Kondo lattice. The measured thermal conductivity of the La$_{1-x}$Ce$_x$Cu$_4$Al compounds increases with increasing temperature. The scattering of electrons and phonons on the lattice imperfections is elastic and this mechanism is most important at low temperatures. In contrast, the phonon-electron and phonon-phonon interactions may have elastic as well as inelastic character and they are described by the normal and the Umklapp processes. A large reduced Lorentz number $L/L_0$ indicates that the dominant heat carriers are phonons, and the spin scattering of charge carriers does not play a significant role.

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13P-C049  Co-NQR Study on Successive Magnetic Phase under Pressure in Non-centrosymmetric CeCoGe$_3$
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Non-centrosymmetric CeCoGe$_3$ is known to exhibit a complex magnetic phase in approaching to the quantum critical point (QCP) in about 5.5 GPa, around which the superconductivity arises. We have performed Co-NQR study to clarify the complex magnetic phase and the Cooper paring symmetry in the non-centrosymmetric heavy Fermion superconductor as a final goal. In ambient pressure, CeCoGe$_3$ shows ferrimagnetic-like order at $T_N1=21$ K and the successive transitions at $T_N2=12$ K and $T_N3=8$ K. The Co-NQR spectrum consists of four kinds of internal field directing along the c-axis. The direction of the internal field suggests Ising-like spin system of Ce moments with easy c-axis. The successive transitions at $T_N2$ and $T_N3$ are confirmed by the spectral changes of Co-NQR. However no critical slowing down of the nuclear spin-lattice relaxation rate $1/T_1$ or the nuclear spin-spin relaxation rate $1/T_2$ at these temperatures suggests 1st order transitions at $T_N2$ and $T_N3$. When pressure is applied, the four Co sites change into two sites having the relative integrated intensity of about 1:2 above 0.7 GPa. Two kinds of Co sites is consistent but the integrated intensity is not necessarily consistent with the basic antiferromagnetic structure proposed by the neutron scattering experiment. No successive transitions are observed under 1.5 GPa, although the slower decrease of the sublattice magnetization than that expected in the mean field approximation is seen.

13P-C050  Drude response of slow and fast electrons in heavy-fermion compound UNi$_2$Al$_3$
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The characteristic mass enhancement of heavy fermions at low temperatures goes hand in hand with a reduced transport relaxation rate, which can directly be studied with optical spectroscopy: the characteristic Drude roll-off moves to very low frequencies. Here we combine microwave and THz spectroscopy to study thin films of the heavy-fermion compound UNi$_2$Al$_3$ at temperatures down to 1 K. At frequencies of less than 1 cm$^{-1}$ ($\approx 30$ GHz $\approx 124$ µeV), a full Drude response indicates the dynamics of the heavy electrons in UNi$_2$Al$_3$. This dynamical conductivity is anisotropic along the crystallographic a- and c-axes, in accordance with dc measurements. Surprisingly, at considerably higher frequencies (around 10 cm$^{-1}$) we observe in the optical conductivity a similar structure that mimics the lower-frequency Drude conductivity in anisotropy, temperature dependence, and absolute value. We interpret these two features as the Drude response of - at low frequencies - correlated, slow electrons and - at higher frequencies - uncorrelated, fast electrons: depending on the optical probing frequency, the conduction electrons appear either heavy or light. These results also shed new light on previous studies of the related material UPd$_2$Al$_3$.


13P-C051  Mott transition in the Hubbard model on the anisotropic kagomé lattice: Variational cluster approach
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We study the Mott transition and ferrimagnetism in the Hubbard model on the anisotropic kagomé lattice using the variational cluster approximation. The phase diagram of the model at half-filling and zero temperature is thereby analyzed. We find that the ferrimagnetic phase rapidly grows as the geometric frustration is relaxed, and the Mott-insulating phase disappears in moderately frustrated region, indicating that the ferrimagnetic fluctuations stemming from the relaxation of the geometric frustration is enhanced by the electron correlations. In the metallic phase, heavy fermion behavior is observed and mass enhancement factor is computed. Enhancement of effective spatial anisotropy by the electron correlations is also confirmed in moderately frustrated region, and its effect on the heavy fermion behavior is examined.

13P-C052 Vibrational and AF-instabilities and metal-insulator transition in Tm$_{1-x}$Yb$_x$B$_{12}$

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Low temperature charge transport (resistivity, Hall and Seebeck coefficients) and thermodynamic properties (magnetization and heat capacity) have been studied in substitutional solid solutions Tm$_{1-x}$Yb$_x$B$_{12}$. It was shown that the depression of antiferromagnetic (AF) state is accompanied with a development of metal-insulator transition (MIT) in the range of Yb content $x$ above the quantum critical point $x_c$~0.3. Moreover, when the MIT occurs, simultaneously with the gap opening ($E_g$~200K) a short radius (5-9Å) many-body states’ formation is observed at intermediate temperatures 50-300 K with effective masses of the heavy fermions $m^*$~20$m_0$. The coherent regime of charge carriers’ transport is consistent with a conduction via the intra-gap states (manybody resonance) with the bound energy $E_b$~55-75K. An analysis of thermodynamic properties and Raman spectra transformation in RB$_{12}$ allows to conclude in favor of development of vibrational instability and cage-glass state formation at $T^*$~60K.

1 N.E.Sluchanko et al., JETP Lett. 89, 236 (2009).
3 N.E.Sluchanko et al., JETP in print (2011).

13P-C053 Novel ferromagnetic Kondo lattices Ce$_3$RhSi$_3$ and Ce$_3$IrSi$_3$

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The physical properties of two novel Ce-based intermetallics Ce$_3$RhSi$_3$ and Ce$_3$IrSi$_3$ have been studied by means of magnetization, electrical resistivity and heat capacity measurements, performed down to 350 mK in magnetic fields up to 9 T. The compounds crystallize with an orthorhombic structure of the Y$_3$Ni$_3$Si$_3$ type (space group Immm) that can be considered as a combination of AlB$_2$- and W-type units. There are two inequivalent sites for Ce atoms in the unit cell and both are occupied by trivalent ions, as inferred from a Curie-Weiss analysis of the magnetic susceptibility. The magnetic and electrical transport data distinctly manifest Kondo interactions with the characteristic temperature scale of about 6-10 K. Nevertheless, the two compounds order ferromagnetically at low temperatures, namely at $T_C$ = 4.4 K for Ce$_3$RhSi$_3$ and $T_C$ = 10.5 K for Ce$_3$IrSi$_3$. Moreover, the latter silicide undergoes a ferromagnetic-like order-order transition at $T_I$ = 3 K. In the ordered state, the electrical resistivity and the specific heat of both ternaries are governed by ferromagnetic spin-waves contribution. In turn, their low-temperature specific heat shows a large enhancement [C/T = 700 and 460 mJ/(mol K$^2$)] for the Rh- and Ir-containing phase, respectively, thus implying the formation of heavy-electron ground states.

13P-C054 A proposal of the kinetic energy functional for the pair density functional theory

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The diagonal element of the second-order reduced density matrix, which is called the pair density (PD), has much information about the electron correlation. Therefore, the density functional scheme to calculate the PD is expected to be effective for describing the electron correlation of various solids such as heavy fermion systems, magnetic materials and etc. We have recently developed the computational PD functional theory. In order to perform the actual calculations on the basis of the computational PD functional theory, the approximate form of the kinetic energy functional is indispensable. In this paper, we propose a new kind of approximate forms of the kinetic energy functional. Approximate forms are developed by using as restrictive conditions two exact relations that should be satisfied with the kinetic energy functional. In order to check their abilities, we perform the test calculations for the neutral neon atom. It is shown that the root-mean-square error of the external potential and electron-electron interaction energies is much reduced as compared to the previous one. This means that correlation effects are reasonably incorporated into the resultant PDs.


13P-C055 Susceptibility measurements in Pr$_x$La$_{1-x}$InAg$_2$ with $\Gamma_3$ doublet ground state

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Recently, Pr-based compounds with the cubic symmetry have attracted much attention because of the discovery of their fascinating features. These features are believed to be related to the quadrupolar Kondo effect proposed by Cox. We have studied the low-temperature properties of Pr$_x$La$_{1-x}$InAg$_2$ for a wide concentration range of Pr ions. We reported that the susceptibility above $T=15$ K is well reproduced by the crystal-electric-field level scheme with a non-Kramers $\Gamma_3$ doublet in the ground state for each concentration, while that below $T=15$ K shows a non-Fermi-liquid (NFL) behavior with a logarithmic temperature dependence. However, the quadrupolar Kondo theory does not predict NFL behavior in the susceptibility. In order to clarify the origin of NFL behavior in the susceptibil-
ity below $T=15$ K, we measured the susceptibility and magnetization in the lower temperature region down to $T\sim 0.5$ K by SQUID magnetometer with a home-made $^3$He insert.


13P-C056  Electronic structures of Plutonium compounds with the NaCl-type monochalcogenides structure

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Some of the uranium and the transuranium compounds are characterized as strongly correlated f electron systems and have attracted particular interest because of rich variety of anomalous physical phenomena such as the valence fluctuation, the Kondo lattice, exotic magnetism, unconventional superconductivity, etc. Among such compounds, the plutonium monochalcogenides display a variety of anomalous physical properties. For PuX (X=S, Se, Te) have been studied intensively both theoretically and experimentally. To understand the electronic properties of these materials, the features of the ground state should be first clarified. The calculations for the energy band structure have been done by using the relativistic linear augmented-plane-wave (RLAPW) method. Note here that relativity should be taken into account, because of large atomic numbers of the constituent atoms. In the presentation, we try to understand what the key issues are to construct the energy band structures around the Fermi energy for PuS, PuSe and PuTe.


13P-C057  Electronic property of ThSn$_3$ in comparison with uranium and transuranium compounds

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Recent rapid expansion of the research frontier of condensed matter physics from uranium to transuranium compounds has stimulated renewed attention and much interest on exotic properties of actinides and related compounds. It is a challenge to modern electronic-structure theory to understand the appearance of a large number of exceptionally complicated crystal structures of actinide metal. It is important to clarify electronic structure of actinide compounds which exhibit exotic magnetism and unconventional superconductivity. By using a relativistic linear augmented-plane-wave (RLAPW) method with the one-electron potential in the local-density approximation, we investigate energy band structures and the Fermi surfaces of transuranium compounds ThSn$_3$, USn$_3$, NpSn$_3$ and PuSn$_3$. It is found in common that the energy bands in the vicinity of the Fermi level are mainly due to the large hybridization between $5f$ and Sn $5p$ electrons. Thorium contains no occupied $5f$ states, thorium compounds provide good comparative systems for investigating the role of $5f$ electrons. In the presentation, we try to understand what the key issues are to construct the energy band structures around the Fermi energy for ThSn$_3$, USn$_3$, NpSn$_3$ and PuSn$_3$, we attempt to unveil $5f$ electron properties purely originating from actinide atoms.

13P-C058  Pressure Effects on Electrical Resistivity of Heavy-Fermion Antiferromagnet Ce$_2$PdGa$_{12}$

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Many Ce-based intermetallics have been noticed owing to their attractive electronic properties, such as unconventional heavy-fermion superconductivity and magnetic transition. Pressure can change the magnetically ordered ground states of Ce-based systems to non-magnetic one. Furthermore, in some cases anomalous phenomena such as non-Fermi liquids and heavy-fermion superconductivity appear in the vicinity of quantum critical point. We have succeeded in growing high purity single crystalline Ce$_2$PdGa$_{12}$ which crystallizes in the tetragonal system (space group P4/mnm). The electrical resistivity of Ce$_2$PdGa$_{12}$ behaves as typical heavy-fermion antiferromagnets. The magnetic ordering temperature is 11 K at ambient pressure. We investigate the pressure effects on the electrical resistivity up to 8 GPa. With pressure, the ordering temperature is dramatically suppressed to 3.5 K at 3 GPa. Whereas above this pressure, the ordering temperature gradually increases, and then shows a broad maximum around 6 GPa. We speculate that the non-magnetic ground state of Ce$_2$PdGa$_{12}$ might appear around 10 GPa.


13P-C059  Non-Fermi Liquid Behavior on Heavy-Fermion System Ce$_2$Pt$_6$Ga$_{15}$

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In recent years, quantum critical phenomena have been attracting many attentions in the area of the strongly correlated electron systems. In the systems of which electronic states are located around the boundary between magnetic and non-magnetic ground states, the temperature dependences of several physical quantities deviate from a Fermi liquid. In many cases such phenomena, namely non-Fermi liquid behaviors can be induced by pressure, magnetic field and changing atomic concentration. Recently, we have succeeded in synthesizing single crystalline Ce$_2$Pt$_6$Ga$_{15}$ which crystallizes in the hexagonal systems (space group P6$_3$/mmc). We have measured the temperature dependences of the electrical resistivity, magnetic susceptibility and spec-
pecific heat. The resistivity shows typical features of heavy-fermion systems. The susceptibility obeys the Curie-Weiss law above 50 K. Below 10 K, both the susceptibility and specific heat increase with decreasing temperature showing a -logT dependence indicative of a non-Fermi liquid behavior. The observed -logT dependence of the specific heat at low temperatures is distinctive feature of a non-Fermi liquid state mediated by an antiferromagnetic spin fluctuation. The Sommerfeld coefficient reaches about 700 mJ/(Ce-molK²) at 2 K. These features indicate that the electronic ground state of CePt₄Ga₁₅ is near the quantum critical point even at ambient pressure.


13P-C060 Low Temperature Electron Spin Resonance in Dense Intermetallics

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One of the most important problems in condensed matter physics involves the microscopic understanding of how localized electrons at high temperatures turn into itinerant heavy quasi-particles in a low temperature metallic state. The fundamental mechanism of this evolution lies at the heart of heavy-electron physics and depends on the Kondo coupling between the conduction electrons (CE) and the localized d or f electrons. Electron spin resonance (ESR) probes microscopically both the local moment (LM) spins and CE in different strongly correlated electron materials such as high-temperature superconductors, pnictides, heavy fermion systems. CE spin resonance (CESR) can be detected in metallic systems based on light elements exhibiting an enhanced Pauli susceptibility. We discuss here the ESR studies in several undoped Yb-, Ce-, and Eu-based intermetallics which share the nature of both, the LM-like and CESR-like ESR signals. The ESR measurements below 25 K in the new ternary phosphides YbRu₆P₄ and CeRu₂P₄ are reported. Different theoretical approaches which were proposed to explain the origin of such unexpected ESR behavior are discussed.

13P-C061 Co substitution effect of Kondo semiconductor CeFe₂Al₁₀

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We have performed the measurements of electrical resistivity ρ, magnetic susceptibility χ and specific heat C for single crystalline Ce(Fe₁₋ₓCoₓ)₂Al₁₀ (0≤x<0.17), which is the Co substituted system for Fe site in a recently discovered Kondo semiconductor CeFe₂Al₁₀. The χ(T) for CeFe₂Al₁₀ shows a broad peak centered at Tₘₐₓ≈70 K, which is typical of valence fluctuation compounds. The Tₘₐₓ decreases with increasing x, and disappears for x~0.17, indicating decrease in Tₖ with increasing x, which is also supported by decrease in χ(0) with increasing x. The ρ(T) for CeFe₂Al₁₀ shows two negative temperature coefficient region at high and low temperatures accompanied with a broad peak centered at ~70 K. Only 5% Co substitution vanishes the low temperature increase. The high temperature negative slope decreases gradually with x, and turns into metallic behavior for x~0.17. The C(T) of CeFe₂Al₁₀ indicates a small electronic specific heat coefficient γ~5 mJ/K²mol. The γ value strongly increases with x, and attains γ~150 mJ/K²mol for x~0.17. These results indicate that the Co substitution destroys the gap rapidly and CeFe₂Al₁₀ turns from valence fluctuation regime into heavy fermion one.


13P-C062 Equal volume dilution effect of CeRu₂Al₁₀

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Orthorhombic YbFe₂Al₁₀-type CeRu₂Al₁₀ is a Kondo semiconductor and undergoes a mysterious phase transition at T₀~27 K. Tanida et al. examined nonmagnetic substitution system Ce₁₋ₓT₁ₓRu₂Al₁₀ (T=La, Y), and found that x dependence of T₀ is quite different between La- and Y-substitution. The reason for the difference is assumed to be due to the difference of ionic radii, where the ionic radii of La (Y) is larger (smaller) than that of Ce. In this work, we present equal volume dilution system Ce₁₋ₓ(La₀.₆₃Y₀.₃₇)ₓRu₂Al₁₀ in addition to th above La and Y systems studied mainly by the electrical resistivity ρ for the single crystals grown by the Al-self melt flux method. The ρ(T) for Ce₁₋ₓLaₓRu₂Al₁₀, Ce₁₋ₓYₓRu₂Al₁₀ and Ce₁₋ₓ(La₀.₆₃Y₀.₃₇)ₓRu₂Al₁₀ roughly resemble one another. The ρ(T) for the La-, Y- and (La₀.₆₃Y₀.₃₇) substituted system turn into suddenly metallic behavior between x=0.5 and 0.7, x=0.7 and 0.9, and x=0.7 and 0.9, x=0 and 0.1 for all the systems show conventional metallic behavior and and Kondo effect, respectively. Here Kondo temperature increases with Y content as expected from impurity Kondo effect. This suggests that Kondo effect and semiconducting behavior related with each other.


13P-C063 Magnetization of Tm₁₋ₓYbₓB₁₂ in pulsed and steady magnetic fields


The magnetization studies of substitutional solid solutions Tm₁₋ₓYbₓB₁₂ have been carried out at low tem-
13P-C065 Ground states, quantum phase transitions and electron spectroscopies in 5f-systems

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Intermetallic compounds containing actinide ions exhibit a broad spectrum of physical phenomena at low temperatures. The latter include heavy quasiparticles, unconventional superconductivity and various forms of long-range (magnetic) ordering. The sometimes enigmatic properties of these compounds derive from the competition between the strong correlations among the 5f electrons and band formation. Previous model calculations suggested that the intra-atomic Hund’s rule-type correlations may lead to the dual nature of 5f electrons which is reflected e.g. in the co-existence of itinerant 5f-derived heavy quasi-particles and local magnetic excitations. Here we present model calculations starting from the Anderson model in the intermediate valent regime. Adopting a slave-boson formulation we calculate ground states for extended crystals and discuss quantum phase transitions which may occur upon field- or pressure tuning. Focussing on small clusters we calculate the spectral functions for valence band and core level photoemission spectroscopy. The central focus are characteristic features reflecting the dual nature of the 5f electrons.

13P-C064 Phase Transitions of Dense Neutron Matter with Generalized Skyrme Interaction to Superfluid States with Triplet Pairing in Strong Magnetic Field

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A generalized non-relativistic Fermi-liquid approach was used to find analytical formulas for temperatures $T_{c,1}(n, H)$ and $T_{c,2}(n, H)$ (which are functions nonlinear of density $n$ and linear of magnetic field $H$) of phase transitions in spatially uniform dense pure neutron matter from normal to superfluid states with spin-triplet p-wave pairing (similar to anisotropic superfluid phases $^3\text{He} - A_1$ and $^3\text{He} - A_2$) in steady and homogeneous strong magnetic field (but $\mu_B H \ll E_c < \varepsilon_F(n)$, where $\mu_n$ is the magnetic dipole moment of a neutron, $E_c$ is the cutoff energy and $\varepsilon_F(n)$ is the Fermi energy in neutron matter). General formulas for $T_{c,i}(n, H)$ (valid for arbitrary parametrization of the effective Skyrme interaction in neutron matter) are specified here for generalized BSk18 parametrization of the Skyrme forces (with additional terms dependent on density $n$) on the interval $0 < n < n_c(BSk18) \approx 2.7952 n_0$, where $n_0 = 0.17 \text{ fm}^{-3}$ is nuclear density and at critical density $n_c(BSk18)$ triplet superfluidity disappears, $T_{c,0}(n, H) = 0$. Expressions for phase transition temperatures $T_{c,0}(n) < 0.09 \text{ MeV}$ (at $E_c = 10 \text{ MeV}$) and $T_{c,1,2}(n, H)$ are realistic non-monotone functions of density $n$ for BSk18 parametrization of the Skyrme forces (contrary to their monotone increase for all previous BSk parameterizations). Phase transitions to superfluid states of such type might occur in liquid outer core of magnetars (strongly magnetized neutron stars).


13P-C066 Dense Superfluid Neutron Matter with Generalized Skyrme Interaction and Spin-Triplet Pairing without Ferromagnetic Instabilities

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Dense superfluid neutron matter (relevant to physics of neutron star cores) at sub- and supranuclear densities (in the range $0.3 n_0 < n < 2.5 n_0$, where $n_0 = 0.17 \text{ fm}^{-3}$ is nuclear density) with the Skyrme effective forces and spin-triplet p-wave pairing of the $^3\text{He} - A$ type in the presence of a strong magnetic field is studied within the framework of non-relativistic generalized Fermi-liquid theory. General formula (valid for arbitrary parametrization of the Skyrme forces) is derived for magnetic susceptibility of superfluid neutron matter at zero temperature and it is specified then for generalized BSk18 parametrization of the Skyrme interaction. As it is known most of the Skyrme forces (and in particular all previous variants of BSk parametrizations) predict spin instabilities in normal neutron matter beyond the saturation nuclear density. At the same time we have obtained for the model of superfluid neutron matter with new generalized BSk18 parametrization that such phase transition to ferromagnetic state does not occur neither at subnuclear nor at supranuclear densities, i.e., the paramagnetic susceptibility is not divergent, but it is non-monotone function of density which attains maximum at the density $n_{cr}(BSk18) \approx 1.64 n_0$. Thus, the high-density ferromagnetic instability is removed in neutron matter with BSk18 parametrization of the Skyrme forces not only in normal but also in superfluid state with spin-triplet pairing.

1 N. Chamel, S.Goriely, and J.M. Pearson, Phys. Rev. C 80,
the scope of thermal properties exhibited by compounds in the isostructural tetragonal stannide series CeSn. Low-temperature properties of these compounds have been an exceptionally rich source of new physics. The essential features of the strongly correlated electron class of systems. Cerium-based antiferromagnetic order is prevalent among the series at temperatures typically below about 4 K, but with a particularly large enhancement of the electronic specific heat in the neighborhood of $T_N$. The title compound of the present study, CeRh$_2$Sn$_2$, is a heavy-fermion compound and exhibits competitive Kondo and RKKY interactions, both originating from the magnetic cerium 4$f^1$ electron. In the work of Beyermann et al., an unusually broad peak feature in the specific heat of CeRh$_2$Sn$_2$ at low temperature was ascribed to antiferromagnetic order setting in below $T_N = 0.47$ K. Here we present results of low-temperature studies of the specific heat, magnetic susceptibility, and electrical resistivity of CeRh$_2$Sn$_2$ in order to map its low-temperature behaviour, and to demonstrate the magnetic field dependence of salient electronic and transport features of its ground state.


13P-D002 Probing the Nuclear Spin Environment in a Quantum Dot Resonator System

P.-Q. Jin, M. Marthaler, A. Shnirman, G. Schön, a Institut für Theoretische Festkörperphysik, Karlsruhe Institute of Technology, Germany b Institut für Theorie der Kondensierten Materie, Karlsruhe Institute of Technology, Germany c DFG Center for Functional Nanostructures (CFN), Karlsruhe Institute of Technology, Germany Circuit quantum electrodynamics (cQED) setups with superconducting qubits coupled to electromagnetic circuits, display many quantum optics effects and have attracted much attention. Recently different cQED setups have been proposed, where spin qubits realized by semiconductor double quantum dots are coupled to a transmission line. To achieve a sizeable coupling strength, charge degrees of freedom need to be involved, which reduces the coherence time of the spin qubit. We suggest that, by exploiting a sharp lasing resonance condition, this cQED setup allows for probing and resolving a small nuclear-spin induced Zeeman splitting difference between the two dots, which is interesting for manipulations of the spin qubits. Driving a current through the double dots can create a population inversion in the dot levels and, within a narrow resonance window, a lasing state in the resonator. The Zeeman splitting difference leads to two separate peaks in the photon number and the transport current as a function of detuning, which can be resolved due to the narrow resonance condition. This application imposes less stringent conditions on the coherence time. Remarkably, relaxation processes may even enhance the resolution of the resonances by releasing a trapped population in the off-resonant spin channel.

13P-D003 Preservation of bipartite pseudo-entanglement in solids using dynamical decoupling

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A crucial challenge for future quantum technologies is to protect fragile entanglement against environment-induced decoherence. Here we demonstrate experimentally that dynamical decoupling can preserve bipartite pseudo-entanglement in phosphorous donors in a silicon system. In particular, the lifetime of pseudo-entangled states is extended from 0.4 μs in the absence of decoherence control to 30 μs in the presence of a two-flip dynamical decoupling sequence.

13P-D004  Coherent and Incoherent Current Drag in Coupled Quantum Dots

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When two mesoscopic regions are coupled by the Coulomb interaction, the current through a region induces the current through the other region, reflecting the correlated motion of electrons. This current drag was recently observed in a pair of double quantum dots (DQDs). We theoretically study the current drag considering the coherent motion of electrons in a nonequilibrium situation and the dephasing effect by the phonon emission. The coherence of this system is an important issue to perform the two-charge-qubit operations for the quantum information processing. We examine two DQDs (DQD1, DQD2) in parallel. The level spacing between the quantum dots in DQD1 (DQD2) is denoted by $\Delta_1$ ($\Delta_2$). A large bias is applied to DQD1, whereas no bias to DQD2. The current $I_1$ ($I_2$) through the DQD1 (DQD2) is formulated using the density matrix method. In the absence of phonon emission, the coherent motion of electrons results in a large drag current $\pm I_2$ when $\Delta_1 \approx \mp \Delta_2$ (quantum mechanical regime). The ratio of $I_2/I_1$ is determined by the Coulomb interaction between DQDs and tunnel coupling to the leads. When the phonon emission is dominant in the transport, the current drag is still observed by the correlated sequential tunnelings (classical regime), where $I_2/I_1$ is small. We examine the crossover between the two regimes to explain the experimental data.\(^1\)


13P-D005  Spin Qubits and Qubit Gates with Quantum Dots

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To date electron spin qubits have been demonstrated using various techniques with quantum dots (QDs), and it is now getting crucial to prepare multiple qubit systems and perform gate operation as the next step. We have recently developed a micro-magnet technique for making spin qubits with double QDs, which might suit the qubit multiplication and logical gate operations. I will show this technique is useful to realize multiple qubits, entanglement modulation, and non-destructive readout. Electron spin resonance (ESR) is the fundamental concept of spin qubits, in which two Zeeman states are superposed by an ac magnetic field normal to the Zeeman field. A micro-magnet placed on top of a double QD imposes an out-of-plane field gradient local to each QD under an in-plane external field. By laterally oscillating an electron in each QD with a microwave field, ESR local to each QD can be established. We first demonstrate two individual spin rotations using this technique, and then combine it with a pulsed operation of spin exchange coupling to modulate the spin singlet-state as a partial entangled state. We propose that the inhomogeneous magnetic field across the double QD can provide novel concepts of z-rotation gates and fidelity control of SWAP and sqrt(SWAP). We also show that the micro-magnet technique is useful for spin readout in a nondestructive manner.

13P-D007  Parallel resistor induced by the spin-state crossover in the Sr-Co-O system

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It is now becoming more generally recognized that strongly correlated electron systems may owe their drastic physical phenomena to a phase separation or dynamic phase segregation. The intrinsic inhomogeneous effects on physical properties observed for several cobalt oxides have not been fully understood. It also remains elusive whether a straight or parallel response to the external fields such as electric field and temperature gradient is effective for fulfilling a better condition as thermoelectric materials. This situation is partially due to a lack of actual observations of the latter response. This study, therefore, is motivated by the desire to explore a new material in which both the phase separation and parallel response occur. In this study, we report the synthesis of the Sr-Co-O single crystal, and its transport and magnetic properties. In contrast to the typical metallic or semiconducting conductivity, the in-plane electrical resistivity below 80 K is almost independent of temperature. Taking the data derived from several experimental probes into consideration, this peculiar behavior is attributable to the coexistence of the metallic and semiconducting phases probably caused by the spin-state crossover below 150 K, rather than a zero gap by the massless Dirac particles; carriers in both the phases are associated with the electrical conduction.

13P-D008  Quantitative analysis of Spin hall effect in nanostructures

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Spin transport in nano structured devices depends on interface resistance, electrode resistance, spin polarization and spin diffusion length. Spin Hall Effect (SHE), caused by spin-orbit scattering in nonmagnetic conduc-
tors gives rise to the conversion between spin and charge currents in a nonlocal device. Recently, SHE has been observed using nonlocal spin injection in metal-based nanostructured devices\(^1\), which paves the way for future spin electronic applications. In present work we have developed a theoretical model to explain the SHE phenomena based on experimental results obtained till date. We focus on the comparative study of the above fact based on DC spin Hall effect, Effects of epitaxial strain and AC spin Hall effect. we have defined the model equations to describe the charge and spin transport in nanostructures using the Spin diffusion length \(\lambda_s\), spin relaxation time \(\tau_{SR}\) and diffusion constant \(D\) as the characteristic parameters. The electrical current density is calculated using the fundamental equation based on equilibrium carrier density \(n_e\) with spin \(\sigma\).


13P-D009 Effect of thermobaric treatment and severe plastic deformation on the structural and electronic properties of X-Y-Z Heusler alloys (X = Co, Ni, Fe; Y = Cr, Mn; Z = Ga, Al, Sn)\(^\dagger\)

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Heusler and Heusler-like alloys are of great interest due to their unique functional properties, such as the magneto- and temperature operated shape memory, the half-metallic state, the giant magnetocaloric effect etc. The structural, optical, electrical, magnetic and galvanomagnetic properties of Heusler and Heusler-like alloys based on X-Y-Z (X = Co, Ni, Fe; Y = Cr, Mn; Z = Ga, Al, Sn) were studied in the temperature range 10\(^\dagger\)1.5K. The analysis of the curves \(\Delta \rho \sigma\) interpreted in the framework of the spin Hall effect. Recently, SHE has been naturally interpreted for CeAl\(_6\) in terms of spin-polaron model, the (i) nonlinear ferromagnetic components were also observed. According to the procedure\(^\dagger\) where these contributions were naturally interpreted for CeAl\(_6\) in terms of spin-polaron model, the (ii) components should be ascribed to the ferromagnetic nanodomains (spin-polarized 5d-states) embedded in the metallic matrix of RB\(_6\) (R=Pr, Gd).

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13P-D010A New Type of Low Temperature Conductivity in Semiconductors


Studies of transport properties of p-InSb single crystals doped with manganese in the range of manganese concentration \(N_{Mn}=1*10^{17}\)–2*10\(^{17}\)cm\(^{-3}\) revealed that resistivity-temperaturedependence \((\rho-T)\) in p-InSb(Mn) crystals in the temperature range T=10\(^\dagger\)1.5K can be described by exponential quadrant function \(\rho = \rho_0 \exp(\Delta_1/kT)^2\) where \(\Delta_1\) increased with the decrease of manganese concentration from \(\Delta_1=0.25\)meV to zero and \(\rho_0\) varied from \(\sim 0.1\) to 0.04\(\Omega\)cm in the above concentration range. Hall effect, magnoelectrical conductivity and transport studies at hydrostatic pressure \(\sim 0\) showed that unusual \(\rho-T\) dependence could be related to interplay of two charge carriers types, i.e. electrons with spin s=1/2 and heavy holes with s=3/2. It gave the ground for the model of excitonic insulator \[2\]. Following the Keldysh and Kopaev’s model we suggest that \(\rho-T\) dependence in the temperature range 10\(^\dagger\)1.5K was the result of insulating permanent excitons input into conductivity. So with the temperature lowering we observed not only exponential increase of resistivity determined by exciton binding energy \(\Delta_1\), but also increase of resistivity caused by exponential decrease of charge carriers concentration . At temperature below \(\sim 1.5K\) we observed Bose condensation of excitons and formation of excitonic insulator which gap energy \(\Delta\) approximately three times exceeded exciton binding energy \(\Delta_1\).


13P-D011 Magnetoresistance of PrB\(_6\) and GdB\(_6\)

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The comprehensive study of transverse magnetoresistance (MR) has been carried out on the high quality single crystals of PrB\(_6\) (\(T_N \approx 6.7K\)) and GdB\(_6\) (\(T_N \approx 15.5K\)) in the wide range of temperatures 2-40K and magnetic fields up to 8T. The data obtained allow to establish the crossover of MR from negative (T>T\(_N\)) to positive (T<T\(_N\)) regime. The maximal value of positive MR does not exceed \(\sim 15\%\) and \(\sim 11.7\%\) for PrB\(_6\) and GdB\(_6\) respectively. The analysis of the curves \(\Delta \rho(\theta)\) interpreted in the framework of Yoshida model\(^2\), (ii) a linear (\(\sim H\)) and (iii) nonlinear ferromagnetic components were also observed. According to the procedure\(^\dagger\) where these contributions were naturally interpreted for CeAl\(_6\) in terms of spin-polaron model, the (ii), (iii) components should be ascribed to the ferromagnetic nanodomains (spin-polarized 5d-states) embedded in the metallic matrix of RB\(_6\) (R=Pr, Gd).

\(^\dagger\) M.A.Anisimov, A.V.Bogach, V.V.Glushkov et al., JETP 109, 815 (2009).


\(^\dagger\) N.E. Sluchanko et al., JETP 8, 793 (2004).

13P-D012 Novel blockade due to spin-filtering with spin-orbit interaction

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We present the experimental finding of current blockade in a quantum dot (QD), which effect originates from spin-filtering (spin dependent blocking of the transport) in the tunneling through a quantum point contact (QPC) with spin-orbit interaction (SOI). 1 Possible spin-filtering effect due to many body correlation and SOI has claimed for the observation of conductance quantization to half- conductance quantum \((G_q/2 \approx e^2/h)\). Our (In,Ga)As (In content 10%) QD consists of such a QPC on a \(G_q/2\) quantized plateau and the other one with the conductance around \(G_q\), and showed clear Coulomb oscillation in spite of nearly open dot condition. A Coulomb valley with the Kondo effect was picked up for the clarification of the spin state in the dot through the I-V characteristics and the temperature dependence. And the second next valley with spin 1/2 but without the Kondo effect was used to see the effect of spin-filtering. The valley is bounded by ordinal Coulomb peaks, one of which disappears with the application of a finite source-drain bias voltage \(V_{sd}\) while the other grows in height. The sign reversal of \(V_{sd}\) transposes the heights of the two peaks. Further increase in \(|V_{sd}|\) recovers the dual peak configuration. Every aspect of the above characteristics behavior is explained under the hypothesis of spin-filtering in the QPC at the plateau of \(G_q/2\). From the peak height ratio, the lower bound of the filtering efficiency is known as above 80%.

1 S.W. Kim et al., arXiv: 1102.4648.

13P-D014 Experimental Observation of Temperature Dependence of Circular Photogalvanic Effect in GaAs/Al0.3Ga0.7As Heterostructures

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We report on the investigation of near-infrared radiation induced circular photogalvanic effect (CPGE) in a two-dimensional electron gas (2DEG) formed in a (001)-oriented GaAs/Al0.3Ga0.7As heterostructures with 1ML InAs inserting layer at the interface from liquid nitrogen temperature up to room temperature. We observe a sign inversion of the CPGE current at 140 K and 170 K. Since the CPGE is often related to the structure inversion asymmetry, which is insensitive to the temperature, we suggest that there is other physical origins that give rise to the CPGE current. We also study the temperature dependence of the photocconductivity and the capacitance of the sample in order to better understand the anomalous phenomenon.

13P-D015 Magneto-Resistance Enhancement due to Self-Hole-Doping in LaMnO3 produced by Low Temperature Heat Treatment

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As respects the spin dependent conduction, we have observed the magneto-resistance (MR) enhancement due to self-hole-doping (SHD) in LaMnO3 (LMO) produced by low temperature heat treatment (LTHT). The LMO polycrystalline samples were produced by solid-state-reaction, using stoichiometrically mixed powders of La2O3 and Mn2O3. After the calcination at 1100°C for 18 hours under oxygen gas flow (OGF) and grinding, the powders were pressed into pellets and were sintered at 1100°C and 1300°C under the OGF. Although the bulk single crystal of LMO is almost insulator, our LMO samples showed large electrical conductivity due to the SHD and especially the sample sintered at 1100°C indicated the metallic conduction. We consider that during the sintering process in sufficient oxygen gas atmosphere, excess oxygen was primarily introduced into the grain boundary regions (GBR) which were amorphous-like, in LMO and the SHD was mainly caused in the GBR. The LTHT generated large GBR in LMO and itinerant holes shows the strong spin scattering in the absence of magnetic field. Therefore we consider that the MR enhancement was observed in LMO samples produced by the LTHT.

13P-D016 Two-Terminal Spin Filter Using Quantum Dot with Spin-Orbit Interaction in Magnetic Field

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The spin injection in semiconductors is an important issue for the spin-based electronics, “spintronics.” We propose an efficient spin filter utilizing a quantum dot (QD) with spin-orbit interaction. In the absence of magnetic field, a QD must be connected to three or more leads (or conduction channels) for the spin filter.1 We show that the conventional geometry of a two-terminal QD works as a spin filter in a magnetic field. First, we examine a QD with two energy levels, [1] and [2], as a minimal model. The levels are mixed by the SO interaction, \( \langle 2 | H_{SO} | 1 \rangle \equiv \sigma \cdot h_{SO} \), and the magnetic field, \( \langle e/2m^* \rangle (2 \langle p \cdot A + A \cdot p \rangle | 1 \rangle \equiv ib \), where \( A \) is the vector potential. The spin-dependent conductance is given in an analytical form around current peaks of the Coulomb oscillation where the electron-electron interaction can be neglected. When an unpolarized current is injected to the QD from a lead, the spin-polarized current is ejected to the other lead. The spin polarization is enhanced to \( \sim 80\% \) by the resonant tunneling if the magnetic field is tuned to be \( b \sim | h_{SO} \rangle \). Second, a realistic model for the QD and tunnel barriers is made by discretizing the space.2 The efficiency of the QD spin filter is evaluated by the numerical calculation.


13P-D017 How can SDW change the unstable F.M to stable AF.M in Gd-IMC
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Great exchange dispersion, as distribution of local magnetic field and fluctuation about it, is observed in AC susceptibility of some Gd-Intermetallic compounds (IMC). In order to interpret the suppress of the magnetic broad range transition as a dynamic nonequilibrium process of transition (high entropy with low value of \( ?(T) \)), the effect of bathing on AC susceptibility and X-R is considered. The dependence both AC susceptibility and X-R on heat treatment is the cause of short range order by which the strong correlated electron system leads to the decreasing of correlation length - where the displacement of magnetic ions in the range of \( ?x=0.058? \), \( ?y=0 \), \( ?z=0.74? \) is investigated. Even though, it will be a question whether the exchange interaction or atomic displacement is the main cause of this phenomenon, the decrease of the correlation length from 3.6? for Gd to Rc\( ?3.3? \) should be considered. This effect could increasing the density of states, as increasing of amplitude of condensation on which the on-site and inter-site exchange can compete. In this case, the effective mass is large and consequently the magnetic phase transition is derived from condensation energy which is approximately equal to \( N(\varepsilon_0) \). At \( TN=48-60K \) above this gap system behaves completely paramagnetic.

13P-D018 Spin polarization versus life-time effects at point contacts between superconducting niobium and normal metals
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During the last decade point contact Andreev reflection spectroscopy has emerged as a versatile technique to measure the spin polarization of metals. However, the analysis of point-contact spectra with ferromagnets has encountered a number of serious challenges.1 And only few of the many relevant publications mention explicitly how difficult it is to distinguish between the effect of polarization and that of a finite quasi-particle lifetime2 although one would expect an enhanced pair breaking at the interface of a superconductor with a ferromagnet. We have recently confirmed the polarization-lifetime ambiguity for Nb-Co and Nb-Cu contacts and suggested to use Fermi surface mismatch, the normal reflection due to the difference of Fermi wave vectors of the two electrodes, to solve this dilemma.3 Here we present further experiments on contacts between superconducting Nb and the ferromagnets Fe and Ni as well as the noble metals Ag and Pt that support our previous results and their interpretation. Our data indicate that the Nb-normal metal interfaces have a transparency of up to about 80% and a small, if not negligible, spin polarization.


13P-D019 Surface Spin-Valve with an Exchange Bias

Magnetoresistance R(H) at \( V=0 \) and differential resistance R(V) (R=\( dV/dI \)) at \( H=0 \) of point contacts between nonmagnetic Cu tips and single ferromagnetic films (FM - Co) exchange-pinned by antiferromagnetic layers (AFM - Fe50Mn50) have been investigated. Analysis of measured R(V) and R(H) characteristics confirms recently proposed model of the point contact surface spin-valve (SSV).1 Magnetoresistance R(H) of SSV in the point contacts to ferromagnetic films exchange-pinned by antiferromagnets shows an exchange offset that depends on a mutual orientation of the applied magnetic field in respect to a pinned magnetization of the AFM/FM layer. We have found that switching of this ferromagnet bulk occurs at lower fields than switching of surface spin layer. In addition, it has been shown that point contact SSVs based on an amorphous alloy Co40Fe40B20 (3.6,9,20 nm) also have the same properties as spin-valves with a geometrically controlled structure. The experiments showed that an increase of an exchange bias under decreasing of CoFeB films thickness is observed both at the surface and in
the SSV bulk. A negative magnetoresistance of some point-contact SSVs based on CoFeB was also observed.

13P-D020 Aharonov-Casher Effect in Bi$_2$Se$_3$ Square-ring Interferometers

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Bi$_2$Se$_3$ nanoplates were synthesized via a chemical vapor deposition method and square-ring-loop devices were fabricated by micro-fabrication tools and reactive ion etching. Electrical control of spin dynamics was investigated in the ring-type interferometers. Aharonov-Bohm (AB) and Altschuler-Aronov-Spivak (AAS) resistance oscillations against magnetic field, and Aharonov-Casher (AC) resistance oscillations against gate voltage were observed in the presence of a Berry phase of $\pi$. While the AAS oscillations appear at low fields, the AB oscillations last to rather high fields, 8 T. More importantly, a very large spin precession tunability by gate voltage has been obtained. By a comparison of the AC oscillations in AB and AAS regions with theoretical predications, the tunability was estimated to be an order of magnitude larger than that of InAlAs/InGaAs devices, and more than two times larger than that of HgTe/HgCdTe devices, indicating that Bi$_2$Se$_3$-related materials are promising candidates with strong spin-orbit coupling for constructing novel spintronic devices. Moreover, electrical control of spins in Bi$_2$Se$_3$ also provides a powerful tool to investigate the surface states of topological insulators.

13P-D021 Intensified Magnetoresistance by Rapid Thermal Annealing in Magnetite (Fe$_3$O$_4$) Thin Film on SiO$_2$ Glass Substrate


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We have observed large magnetoresistance (MR) intensified by rapid thermal annealing (RTA) in magnetite (Fe$_3$O$_4$) thin film (MTF) on SiO$_2$ glass substrate. The MTF was produced by the RF magnetron sputtering method (RF-MSM). The electrical resistivity (ER) of as-grown MTF’s (AG-MTF’s) showed the Mott’s variable range hopping behavior, which indicates that AG-MTF’s are amorphous-like. Although the MR ratio of bulk single crystal of magnetite is very small except around the Verwey transition temperature (VTT), that of AG-MTF’s is moderately large below room temperature. Due to the RTA of AG-MTF’s using the infrared image furnace, the MR ratios of MTF’s were drastically enhanced, especially by the annealing around the Curie point (585°C). Furthermore, the ER of MTF’s treated by RTA (RTA-MTF’s) showed a jump around the VTT, which implies the high crystallinity of RTA-MTF’s. The MTF’s made by the RF-MSM are composed of nano-sized magnetite particles (NMP’s). By the RTA of MTF’s around the Curie point, the magnetic moments of NMP’s are mutually randomized. As a result, the MR ratios of MTF’s are drastically increased by the RTA, on the spin dependent scattering.

13P-D022 Low-Temperature Resistance and Magnetoresistance Hysteresis in Polycrystalline (La$_0.5$Eu$_{0.5}$)$_{0.7}$Pb$_{0.3}$MnO$_3$


The behavior of temperature dependencies of electrical resistance and magnetoresistance of polycrystalline substituted lanthanum manganite (La$_0.5$Eu$_{0.5}$)$_{0.7}$Pb$_{0.3}$MnO$_3$ at low temperatures was studied. A broad hysteresis was found in the field dependences of electrical resistance in the low-temperature region. Above 40 K, no hysteresis feature was observed. The temperature $T = 40K$ coincides with the temperature of minimum electrical resistance and temperature $T_N$ of the antiferromagnet-paramagnet phase transition of the material of the intergrain boundaries. In this work we propose the model which explains the observed features of the $\rho(T)$ and $\rho(H)$ curves at temperatures below $T_N$ by the formation of a network of ferromagnet-antiferromagnet-ferromagnet tunnel contacts.

13P-D023 Spin current manipulation through a Rashba dot by tunable nonequilibrium Fano-Kondo effect

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The Rashba-type spin-orbit interaction, which is generated by the potential asymmetry perpendicular to the semiconductor device plane, opens up a possibility of controlling electron’s spin totally by electric field. It has been argued, however, that the mere existence of spin-orbit interaction is insufficient to realize such spin-dependent transport; it must be combined with ferromagnetic leads, magnetic field, or multilevel effect of the dot etc. In the present work, we show that, even for a single-level dot without magnetic field (or apparent time-reversal breaking effect), spin dependent transport is possible in nonequilibrium. This is the outcome of an intertwining effect of spin-orbit interaction, Fano-Kondo Effect, and finite bias voltage. The phenomena may be regarded as a “nonequilibrium correlation effect” in every sense since this spin current vanishes either at zero bias or in a noninteracting dot. We analyze these results within the finite interaction (spin-invariant) slave-boson mean field theory, which gives consistent results with NRG in equilibrium cases and also has recently successfully described linear/nonlinear conductance profile through a carbon nanotube dot $^1$. In addition, we examine the effect of explicitly time-breaking field such as longitudinal and transverse magnetic field to control this spin dependent transport.

13P-D024 Spatial Distribution of Electronic Spins in a Quasi-One-Dimensional Tight-Binding Model with Spin-Dependent Hopping

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We have theoretically studied intrinsic spin Hall effect (SHE) in a quantum wire (QW). Our numerical calculations show that the distribution of electronic spins has characteristic spatial dependence reflecting SHE in a quasi-one-dimensional tight-binding model with spin-dependent hopping. We consider the two-terminal configuration giving the charge current where electronic reservoirs are connected to the both ends of the finite-length QW by ideal leads. The spatial distribution of spins is calculated by Büttiker's method\textsuperscript{1} using local potential probes under the appropriate boundary conditions for charge and spin currents. The difference between the numbers of up and down spins, or spin polarization, shows spatial oscillation in a direction perpendicular to the charge current and reaches the maximum around one edge and the minimum around the other edge, which suggests spin accumulation localized around edges in a QW due to SHE.


13P-D025 Supramolecular spin valve based on terbium nanomagnets and carbon nanotube

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Molecular quantum spintronics is an emergent field linking the principles of spintronics, molecular electronics and quantum information processing. On the one hand, molecular nanomagnets (MNM) are promising candidates for single spin experiments due to their exciting properties [1]. On the other hand, carbon nanotube quantum dots (QD) are very interesting platforms to deal with spins, notably because its very long spin coherence length. We developed an original device geometry based on a three terminal carbon nanotube QD, laterally coupled to several MNMs [2] through supramolecular interactions. The latters act on the conduction electron through the QD as spin polarizer and analyzer. This spin-valve effect gives access to the behavior of a single localized spin by standard electrometry. Here we report a full characterization of a single Terbium molecule at low temperature (40mK). In particular, we show for the first time stochastic tunneling between entangled electronic and nuclear spin states [3].

\textsuperscript{1} Wernsdorfer, W. and Sessoli, R. Science 284, 133-135 (1999)
\textsuperscript{2} Bogani L. and Wernsdorfer W. Nature Mat. 7, 179 - 186 (2008)
\textsuperscript{3} M. Urdampilleta, J.-P. Cleuziou, S. Klyatskaya, M. Ruben, W. Wernsdorfer, to be published in Nature Materials

13P-D026 Gate-induced zero-field Kondo splitting in a quantum dot

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We report on measurements of the conventional spin-1/2 Kondo effect and a gate-induced zero-field splitting of the Kondo resonance for the N = 9 charge state of a single quantum dot formed in an InGaAs quantum well. Low temperature transport measurements showed a clear zero-bias conductance resonance, consistent with the spin-1/2 Kondo effect. From the width of the Kondo resonance in the differential conductance we determine a Kondo temperature of $T_K = 1.4$ K and from the Coulomb blockade peaks and Kondo valley conductance in the linear response regime we extract $T_K = 0.9$ K. We also study the effect of a decreased barrier gate voltage asymmetry on the N = 9 Coulomb diamond and observe an induced dip within the larger Kondo resonance. We identify two low-energy scales of this system, $K_B T_{K1} = 400 \mu$eV associated with the broad Kondo resonance and $K_B T_{K2} = 100 \mu$eV associated with the dip. We also observe a non-monotonic behavior of the zero-bias differential conductance as a function of both in-plane magnetic field and temperature with maximum conductance at $B_{\text{max}} = 225$ mT and $T_{\text{max}} = 300$ mK. The Zeeman energy of $B_{\text{max}}$ and thermal energy $T_{\text{max}}$ are in qualitative agreement, $\sim 30 \mu$eV, suggesting that the same physical mechanism give rise to the observed phenomenon. Our findings are in qualitative agreement with the two-stage Kondo effect.

13P-D027 Tunable Rashba Spin Splitting with Liquid Gated Transistors

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Manipulation of spin polarized electrons is a critical step for developing semiconductor spintronics applications. Tuning the spin-orbit interaction (SOI) and Rashba-type spin splitting by gate voltages is one of the important means for manipulating spin polarizations. However, the demonstration of gate tuning of spin polarization or SOI interactions is still limited to a few examples of mainly III-V semiconductor heterostructures. A part of the reasons is the low electric filed available in all-solid filed effect transistor (FET) devices. In this study, we introduced a FET device with a liquid/solid interface, where extremely high electric fields over 10 MV/cm, one order of magnitude larger than those in the all-solid FETs, are available. We fabricated a liquid gates FET using a transition metal dichalcogenide semiconductor WSe$_2$, combined with an ionic liquid as a gate dielectric. We successfully observed the gate-tuned Rashba parameter, and found that the Rashba splitting reaches over 0.1 eV under a high electric field. The present result indicates that a liquid gating FET technique could be a useful platform for manipulating spin polarization in variety of materials.
Session 13P-E:
E3 Terahertz Techniques
E7 Others
Saturday August 13, 16:00 – 18:00
Exhibition Hall 1

13P-E001 Suspended Tunnel Junction Bolometers for THz Imaging
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Implementation of high resolution passive THz cameras operated at cryogenic temperatures of a few Kelvin benefits from large number of pixels. At present, building a cryogenic multiplexed read-out circuit represents a challenging task. Here we propose and demonstrate broadband niobium-based tunnel junction bolometers operating in equilibrium regime at 4 K to meet the requirements for a single pixel in a multiplexed array read out with a room temperature amplifier. We present new experimental and preliminary optical measurements of the detectors. We propose that they are potentially more practical for multiplexing in contrast to the hot-spot bolometers where two-stage thermal circuits are suggested to overcome the issue of limited power gain bandwidth.

13P-E002 Coherent broadband THz spectroscopy in high magnetic fields and low temperatures: a fiber-based setup using photomixers

We present the first successful results of the integration of a continuous-wave THz spectrometer into a magneto-cryostat for operation at low temperatures and/or high magnetic fields. The spectrometer employs photomixing of two NIR lasers for generation and phase-sensitive detection of THz radiation from 60 GHz to 1.8 THz. A fast phase-modulation technique using two fiber stretchers is used to accurately determine the amplitude and the phase at a given frequency. Thus, the complex dielectric function can be determined with a very high resolution in the MHz range. This spectrometer in combination with the magneto-cryostat is one of the very few compact experimental setups that allow for THz spectroscopic investigations at high magnetic fields up to 8 T and low temperatures down to 3 K with excellent reliability. The response of the photomixers and the general operation of the spectrometer in these experimental conditions will be outlined. Thus, a new door is opened for exploring low-energy electronic excitations of novel materials, lying in the sub-phonon energy regime.

13P-E003 Stripline-based resonant microwave spectroscopy at cryogenic temperatures
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Optical spectroscopy can directly probe electronic excitations and dynamics if the frequency of the radiation is tuned to the characteristic energy scales of the material under study. For exotic conductors, such as strongly correlated metals and superconductors, this often means frequencies below 30 GHz (≈ 1 cm⁻¹ ≈ 124 μeV), i.e. the microwave range, and temperatures below 10 K are required. In recent years, there has been substantial experimental progress to perform microwave spectroscopy on metals and superconductors at cryogenic temperatures, but the techniques have so far been limited (e.g. no phase information or only thin film samples). Here we present a spectroscopic technique that employs microwave stripline resonators, where one of the ground planes is replaced by the (bulk) sample under study. Due to this resonant approach, we are sensitive enough to resolve the microwave losses of single crystals of metals and superconductors. Furthermore, the one-dimensional stripline geometry allows us to use several modes of the resonator to obtain frequency-resolved information. Although we have also employed metallic striplines, we focus on superconducting stripline resonators which are particularly sensitive. We present experimental results both on metallic samples (such as high-quality single crystals of heavy fermions) as well as superconductors, for frequencies between 2 GHz and 10 GHz and for temperatures down to 1 K, and we discuss the observed frequency dependences both for well-known as well as previously inaccessible regimes.

13P-E004 Terahertz Radiation from Bi₂Sr₂CaCu₂O₈₊₆. Intrinsic Josephson Junctions above Critical Current
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Two types of THz radiation from mesa structures of Bi₂Sr₂CaCu₂O₈₊₆ (Bi2212) single crystals have already been reported. One is referred as type IR, and the other is referred as type R. The IR radiation is observed reversibly when a jump from a branch to lower branch in the I-V curve occurs with reducing bias voltage. The R radiation is observed reversibly in negative dI/dV region of the I-V curve. In a mesa structure with the size of 80 × 400 × 1 μm³ fabricated in this work, we found another type of THz radiation referred as type W in addition to the two types of radiation. All types of radiation were detected reproducibly even in a single I-V cycle. The type W emerges in the reversible region of the I-V characteristics at currents higher than those of R and IR radiations. Since the W radiation is observed in the relatively broader current range even above the global critical current of the stacked junctions unlike the two radiations, the mechanism of the W radiation
is possibly different from that of the two. Furthermore, the emission power of the type W is the most intensive among the all types observed here and is estimated as the order of $\mu W$.


**13P-E005** THz wave emission from intrinsic Josephson junctions controlled by surface impedance and in-plane magnetic field: Numerical study

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THz wave emission from intrinsic Josephson junctions was confirmed without external magnetic fields,[1] and the surface impedance $Z$ was found out to play a crucial role.[2] Various emission states such as the in-phase state or $\pi$-phase-kink states are characterized by dynamical phases controlled by the bias current and $Z$. When the in-plane magnetic field is introduced, field dependence of emission intensity also strongly depends on $Z$. Cavity resonance modes are stabilized for $Z \geq 3$, and the fundamental mode gives the strongest emission. As the in-plane magnetic field increases for a fixed number of junctions, dynamical phase transitions seem to occur between the $\pi$-phase-kink state, various incommensurate-phase-kink states, and in-phase state. As $Z$ varies, a crossover of the field profile of emission intensity takes place for $Z \approx 50$ between characteristic peaks for smaller $Z$ and monotonic decrease for larger $Z$. The double-peak structure reported in a recent experiment [3] can be explained for $Z = 30$ by finite-size analysis with respect to number of junctions. The critical in-plane field between the $\pi$-phase-kink and incommensurate-phase-kink states converges to zero as the number of junctions increases, while characteristic emission peaks remain nonvanishing for finite in-plane fields.


**13P-E006** Current dependence of heat leak on the terminals in the superconducting DC transmission and distribution system of CASER-2

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Superconductivity can solve the energy problems in the world as energy saving technologies. Among them, superconducting direct current (DC) transmission and distribution (T&D) systems should be promising, as it can be easily enlarged to the large scale energy transmission systems as energy sharing. We are developing low temperature systems for the effective cooling for superconducting T&D systems. In the cooling experiments on the 200 m-class superconducting DC transmission and distribution system (CASER-2), we have estimated several performances of systems as superconducting applications. For example, our superconducting cable is connected to the outside terminals using the Peltier current lead (PCL). PCL is constructed by a thermoelectric material and a copper lead. 1 Small thermal conductivity and large thermopower of thermoelectric ones can effectively insulate the heat leak to the low temperature end. We measured the temperature on the current leads and the heat leak on the terminals. As current leads have optimal shape factor, and then the optimum operation current exists. The current dependence of the systems performance will be discussed.


**13P-E007** Millikelvin LEED apparatus: a feasibility study

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Two-dimensional (2D) adlayers of helium on graphite have rich phase diagrams with various exotic quantum phenomena including supersolidity and the gapless spin liquid state. However, experimental information on structure of each phase is rather limited by technical reasons. So far, only the lattice constants of the commensurate phase in the first layer and incommensurate phases both in the first and second layers were studied by neutron diffraction. H.J. Lauter, H. Godfrin, V.L.P. Frank, and H.P. Schildberg, Physics B 165, 597 (1990).

The low-energy electron diffraction (LEED) technique has various advantages over neutron and X-ray diffraction methods. For instance, one can distinguish diffraction peaks of adlayers more easily from those of substrate as was demonstrated in the previous experiment on 2D hydrogen on graphite at $T = 5$ K.1 We have made a feasibility study of LEED measurement of 2D helium below 300 mK. A cell, which contains a single-crystal graphite sample as well as Grafoil for ballast surface area, will be installed at the bottom of the mixing chamber of a cryogen-free dilution refrigerator. A small hole at the bottom of the sample cell will be opened for incident and diffraction electrons after preparing adsorbed samples below 4 K. We will keep the LEED optics near 80 K and use a tilted electron beam gun to suppress radiation heats as much as possible. We will present details of the feasibility study and designing of actual apparatus.


**13P-E008** Integrating Complex Magnets with the Cryogen Free Dilution Refrigerator


Magnets built using both NbTi and Nb3Sn have now been integrated onto a single 4K pulse tube cooler that
has the primary function of running a dilution refrigerator. Solenoids at various fields, three axis vector magnets and magnets with field cancellation regions have recently been integrated onto a number of cryogen free dilution refrigerators using a single, 1W at T=4.2K pulse tube. The minimal effect of this system integration on the dilution refrigerator is detailed for a number of the configurations. Finally, some of the current developments to further open out this new era of magnetic field provision at ultra low temperatures are described.

13P-E009 Cryogenic Dark Matter Search Status and Plans
J. Zhang*, a University of Minnesota, Minneapolis, USA
The Cryogenic Dark Matter Search Experiment (CDMS) operated cryogenic Ge and Si detectors at sub 50 mK in the Soudan Underground Laboratory for years, searching for the evidence of interactions between Weakly Interacting Massive Particles (WIMPs) and ordinary matter. The cryogenic detectors measure the ionization and phonon signals from the interactions between incoming particles and the detector. Excellent electromagnetic background discrimination was achieved using the ionization yield and phonon pulse shape parameters. Detector performance and Soudan low-background environment allowed CDMS to provide the leading sensitivity for WIMP-nucleon interactions for most of the past decade. A summary of recent CDMS results will be discussed in this talk. Future plans, with emphasis on the development of larger Ge detectors, will also be discussed.

13P-E010 Performance of Superconducting Hot Electron Bolometers at Terahertz Waveband
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Low noise receivers based on superconducting niobium nitride (NbN) hot electron bolometers (HEBs) have been designed, fabricated and measured for applications in astronomy and cosmology at terahertz (THz) waveband. The NbN HEB consists of a planar antenna and an NbN bridge connecting across the antenna’s inner terminals on high-resistivity Si substrates. Double sideband (DSB) receiver noise temperatures of 698 K at 0.65 THz, 904 K at 1.6 THz, 1026 K at 2.5 THz and 1386 K at 3.1 THz have been obtained at 4.2 K without corrections. It is about 9 times of the quantum limit noise temperature at 2.5 THz and same with the performance of the HEB used in the Herschel Satellite. The excess quantum noise factor of about 4 has been estimated using a quantum noise model. Also, the stability of the HEB has been characterized using the Allan variance measurements. Allan time (T_A) of about 1 s has been obtained using a Gunn oscillator plus its multipliers as the LO source, and the stability of the HEB receiver is dependent on that of the LO. Using microwave injection with a feedback loop, the stability of the receiver is improved; and a T_A value of about 20 s is obtained.

13P-E012 An Active Feedback Scheme for Improved Low Field NMR Detection
K. Safiullin*, E. Baudin*, P.-J. Nacher*, G. Tastevin*, a Laboratoire Kastler Brossel, ENS; CNRS; UPMC; Paris, France
The mandatory strive for high signal to noise ratio (SNR) in low field NMR must take into account all specific constraints on the characteristics of the detection scheme. For instance, in liquid NMR a reduced coupling between the sample and the detection coil is desirable to avoid significant radiation damping and frequency pulling. For MRI a broad detection bandwidth is desirable to avoid overdamping of the finest details in the image. More generally, broadband detection allows for fast ring-down and for prompt recovery from saturation in pulsed NMR. We describe a solution based on a simple active feedback scheme whose major advantage is to fully preserve SNR, in contrast with the traditional Q-damping scheme. We report on implementation at low temperature for the study of hyperpolarised liquid 3He-4He mixtures, where active feedback is used to either enhance or reduce radiation damping. Further illustration is provided by application to MRI and diffusion measurements in small animal lungs with hyperpolarised 3He gas at 300 K.

13P-E013 Cryogens production and distribution at TIFR, Mumbai, INDIA
K.V. Srinivasan*, a Low Temperature Facility, Tata Insti-
Low temperature facility (LTF) of Tata Institute of Fundamental Research, (TIFR) Mumbai, India, is one of the largest facilities in India under the R & D sector and has been operating and maintaining cryogenic plant for about five decades. LTF provides liquid helium and liquid nitrogen along with the cryogenic support services to various facilities and laboratories of the institute. LTF supports the on-demand needs of cryogens to the more than 40 users, including the instrument facilities such as NMR, SQUID, PPMS, VSM, milli-kelvin to micro Kelvin refrigerators, Mössbauer, nano-kelvin, spectrosopes etc. Our annual consumption is about 1,00,00 liters of liquid helium and 2,25,000 liters of liquid nitrogen. LTF handles more than 75 liquid nitrogen and 32 liquid helium dewars along with high pressure helium gas cylinders (about 1300 cylinders), vacuum systems, gas analyzers, gas flow meters, sensors, detectors etc. TIFR also houses a helium refrigerator to cool the quarter wave resonating cavities for the superconducting linear accelerator. The liquid nitrogen for the above LINAC and the beam hall, is supplied from the 5000 liters storage vessel by the vacuum insulated tube, which is about 175 meters long pipeline. We will present the in depth details about the cryogen production and distribution at our institute.
Session 15H1: Half Plenary Lectures

Chair: Moses Chan
Monday August 15, 09:00 – 10:30
Convention Hall 3

15H1-1 Surface Andreev Bound State of Superfluid $^3$He and Majorana Fermion

Y. Okuda*, **Department of Physics, Tokyo Institute of Technology, 2-12-1 O-okayama, Meguro, Tokyo 152-8551, Japan

A Majorana fermion state is an exotic state in which a particle and an antiparticle are equivalent. Such a fermion has not been identified so far in the elementary particle physics. However, recent theoretical studies anticipate its existence in some exotic condensed matter systems. The surface Andreev bound state of superfluid $^3$He-B is drawing attention as one of its accessible candidates. The shear mode resonance of the wall immersed in the superfluid $^3$He was strongly affected by quasi-particles scattering, which enabled us to investigate the surface bound state in a spectroscopic way. We have succeeded in observing the state by this method to find interesting properties concerning to the Majorana state. The fantastic point of $^3$He experiment is that we can change the boundary condition of quasi-particles from diffusive to specular limit by coating the wall with superfluid $^4$He film. The systematic measurement clearly revealed that the spectral density at $E=0$ (Fermi energy) was decreased, and enhanced at higher energy towards specular limit, and strongly suggested the realization of the Majorana cone in the Andreev bound state. Further experiments to search for more direct evidences is undergoing.

15H1-2 Stability of Impurity Phases of Superfluid $^3$He

W.P. Halperin*, J. Pollanen*, J. Li*, C.A. Collett*, W.J Gannon*, **Department of Physics and Astronomy, Northwestern University, Evanston, Illinois, USA

It is well established that superfluid $^3$He within highly porous silica aerogel can be understood in terms of a model of correlated scattering of $^3$He quasiparticles from the aerogel strands, including both transition temperature and amplitude of the order parameter. Additionally, the texture of the order parameter can be affected. Until recently, quantitative interpretation of nuclear magnetic resonance (NMR) observations has been complicated by extraneous effects on the texture from inhomogeneous and ill-characterized aerogel. Our recent NMR experiments with homogeneous aerogel samples permit identification of the order parameter texture and as a consequence, a clear identification of the superfluid phases themselves. These are impurity phases of the axial and isotropic $p$-wave states, more familiarly known as the A and B-phases of pure $^3$He. There are predictions that anisotropic scattering should favor anisotropic states, and conversely for isotropic scattering. To explore this idea, we have made a homogeneous anisotropic aerogel and we have discovered that the A-phase can be stabilized over the entire available range of pressure and temperature down to 0.6 mK. This is in contrast to a homogeneous isotropic aerogel where it is the isotropic superfluid state that is stable, except for a narrow temperature region near the transition temperature. We have compared effects on the superfluid phases from two types of homogeneous, anisotropic aerogel samples, one with uniaxial compression, and one that is stretched. Stability of the A-phase only holds for the stretched aerogel.

15H1-3 Cryogen-free Dilution Refrigerators

K. Uhlig*, **Walther-Meissner-Institute, Garching, Germany

We review briefly our first cryogen-free dilution refrigerator (DR) which was pre-cooled by a Gifford-McMahon cryo-cooler. We then show how today’s dry DRs with pulse tube pre-cooling have developed; a few examples of commercial DRs are explained and noteworthy features pointed out. Thereby we describe the general advantages of cryogen-free DRs, but also show where improvements are still desirable. At present, our dry DR has a base temperature of 10 mK and a cooling capacity of 700 μW at a mixing chamber temperature of 100 mK. In our cryostat, in the most recent work, an additional refrigeration loop was added to the dilution circuit. This $^4$He circuit has a lowest temperature of about 1 K and a refrigeration capacity of up to 100 mW at temperatures slightly above 1 K; the dilution circuit and the $^4$He circuit can be run separately or together. The purpose of this additional loop is to increase the cooling capacity for experiments where the cooling power of the still of the DR is not sufficient to cool cold amplifiers and cables, e.g. in studies on superconducting quantum circuits or astrophysical applications.
Session 15H2: Half Plenary Lectures
Chair: Atsushi Fujimori
Monday August 15, 09:00 – 10:30
Convention Hall 2

15H2-1 Scanning Tunneling Spectroscopy of Dirac Fermions at mK Temperatures
J.A. Stroscio*, "Center for Nanoscale Science and Technology, NIST, Gaithersburg, MD 20899"
Since the beginning of the last century new frontiers in physics have emerged when advances in instrumentation achieved lower experimental operating temperatures. New experimental techniques are continually adapted in order to meet new experimental challenges. A case in point is scanning tunneling microscopy (STM) which has seen a wealth of new measurements emerge as cryogenic STM instruments have been developed in the last two decades. In this talk I describe the design, development and performance of a scanning probe microscopy facility operating at a base temperature of 10 mK in magnetic fields up to 15 T. Current measurements are focusing on Dirac fermions in graphene and in topological insulators. Scanning tunneling spectroscopy of graphene at mK temperatures reveals the detailed structure of the degenerate Landau levels in graphene, resolving the full quartet of states corresponding to the lifting of the spin and valley degeneracies. Significant electron correlation effects are observed when the Fermi level lies inside the four-fold Landau manifold resulting in enhanced energy splittings, as well as new many-body states observed at fractional filling factors of 7/2, 9/2, and 11/2.


15H2-2 Pengcheng Dai*, "Oak Ridge National Lab (to be announced)

15H2-3 Helical Metals on the Surfaces of Topological Insulators
Ali Yazdani*, "Department of Physics, Princeton University"
Topological insulators are a new class of insulators in which a bulk gap for electronic excitations is generated by strong spin-orbit coupling. These novel materials are distinguished from ordinary insulators by the presence of gapless metallic boundary states, akin to the chiral edge modes in quantum Hall systems, but with helical spin textures. I will describe experiments that visualize these novel quantum states of matter and demonstrate their unusual properties through spectroscopic mapping with the scanning tunneling microscope. Specifically experiments demonstrate that spin texture of these states protect them against backscattering. They also demonstrate that unlike conventional surface states, which are localized crystalline defects, these states can penetrate through crystalline barriers. I will describe these experiment and more ongoing efforts focused on unraveling the physics of topological surface states.

Session 15m-A: Low Dimensional Systems

Chair: Robert Hallock
Monday August 15, 10:50 – 12:30
Room 5A

15m-A1  Frustrated Nuclear Magnetism of 2D Helium Three
Hiroshi Fukuyama*, D. Sato*, K. Naruse*, T. Matsui*,  *Department of Physics, The University of Tokyo, Tokyo, Japan
We will discuss recent experimental studies of frustrated two-dimensional (2D) magnetism of helium three (3He) monolayer adsorbed on a graphite surface preplated with monolayer 4He. The gapless spin-liquid nature of the magnetic ground state in the 4/7 phase (the low-density commensurate solid) has been further supported by two experiments, i.e., the magnetization curve measurement up to 11 T showing a 1/2 magnetization plateau and the spin-spin relaxation time (T2) measurement showing a gradual decrease and saturation of T2 with decreasing temperature. This exotic ground state could be ubiquitous in 2D frustrated magnetism near Mott localization. Comprehensive heat-capacity measurements revealed that, in the higher density incommensurate solid, we can introduce frustration into the pure Heisenberg ferromagnet on a triangular lattice and tune it by varying density. This becomes possible due to large and different Grüneisen constants of competing multiple-spin exchanges up to six-spin exchange.

15m-A2  Novel substrates for Helium adsorption: Graphene and Graphene–Fluoride
L. Reatto*, M. Nava*, D. E. Galli*, C. Billman**, J. O. Soto**, M. W. Cole**,  *Dipartimento di Fisica, Università degli Studi di Milano, Via Celoria 16, 20133 Milano, Italy  **Department of Physics and Materials Research Institute, Penn State University, University Park, PA 16802 USA
The discovery of fullerenes has stimulated extensive exploration of the resulting behavior of adsorbed films. Our study addresses the planar substrates graphene–fluoride (GF) and graphane (GH) in comparison to graphene. We present initial results concerning the potential energy, energy bands and low density behavior of 4He and 3He films on such different surfaces. For example, while graphene presents an adsorption potential that is qualitatively similar to that on graphite, GF and GH yield potentials with different symmetry, a number of adsorption sites double that on graphene/graphite and a larger corrugation for the adatom. In the case of GF, the lowest energy band width is similar to that on graphite but the He atom has a significantly larger effective mass and the adsorption energy is about three time that on graphite. Implications concerning the monolayer phase diagram of 4He are explored with the exact path integral ground state method. A commensurate ordered state similar to the √3 × √3 R30° state on graphite is found the be unstable both on GF and on GH. The ground states of submonolayer 4He on both GF and GH are superfluids with a Bose Einstein condensate fraction of about 10%.

1  Research supported by DOE and the Petroleum Research Fund of ACS

15m-A3  Anomalous “Superfluid“ Response with Quantum Criticality of Two- Dimensional 4He in a Triangular Lattice Potential
J. Nyéki*, A. Ho*, A. Philis*, J. Purpia*, B. Cowan*, J. Saunders*,  *Department of Physics, Royal Holloway University of London, Egham, TW20 0EX, United Kingdom  **LASSP, Department of Physics, Clark Hall, Cornell University, Ithaca, NY 14853, USA
The second layer of 4He adsorbed on the surface of graphite shows an anomalous superfluid response that we have studied by the torsional oscillator method over the temperature range 1.5 mK to 3.5 K. This system is a realization of bosons moving in two dimensions subject to a triangular lattice potential, which here arises from the close packed lattice of the 4He first layer. The superfluid density has a highly anomalous temperature dependence, at densities near that at which the second layer of 4He adsorbed on graphite supports a two dimensional solid - a triangular super-lattice with respect to the underlying first helium layer. Both the inferred value of the superfluid density at T = 0, and the characteristic temperature T∗ governing its temperature dependence, are strong functions of the second layer density. We report the scaling form of the superfluid density. The results suggest that the observed quantum critical behaviour belongs to the same universality class as that of the superfluid-insulator transition in the Bose-Hubbard model, in the clean limit.

15m-A4  Microscopic Dynamics of 3He in Two and Three Dimensions
R. Holler*, H. M. Böhm*, E. Krotscheck++, M. Pankholzer**,  *Institut für Theoretische Physik, Johannes Kepler Universität, A 4040 Linz, Austria  **Department of Physics, University at Buffalo, SUNY Buffalo NY 14260
We have developed a systematic and manifestly microscopic theory of the dynamics in 3He. Our description
builds upon the concept of dynamic multi-particle fluctuations which has provided a quantitative picture of the phonon/maxon/roton spectrum of $^4$He far beyond the roton wave-number. The theory includes both, energy-dependent effective interactions and a self-consistent single particle spectrum. A crucial neutron scattering experiment measuring the dynamic structure function of two-dimensional $^3$He shows that an equivalent of the roton minimum can indeed appear below the particle-hole continuum. This effect is correctly reproduced by our theory, whereas the textbook concept of assuming that the location of the collective mode is determined by the quasiparticle effective mass is inconsistent with experiments. Our calculations also clarify a controversy that was raised in recent X-Ray experiments on 3D $^3$He whether or not the zero sound mode at intermediate wave-vectors is Landau damped.

1. H. Godfrin et al., contribution to LT26

15m-A5 QCM Study on 2D Vortex in Superfluid $^4$He and $^3$He-$^4$He Mixture Films

M. Hieda**, T. Oda**, T. Matsushita**, N. Wada**, **Department of Physics, Nagoya University, Nagoya, Japan

Two-dimensional (2D) $^4$He fluid films on various substrates show the Kosterlitz-Thouless (KT) superfluid transition where pairing and unpairing of the thermally excited 2D vortices play a major role. Important vortex parameters (the diffusion constant $D$, the core diameter $a_0$) have been extensively studied on flat and porous substrates by various techniques. Most of the researches have been done for the thicker films above the coverage with $T_{KT} = 1$ K. On the other hand, in the thinner coverage region, there is only a few systematic studies on the vortex properties, and the important vortex parameters $D$, $a_0$, and even the combination of the two parameters $D/a_0^2$ are not well determined. In most of the experiments $D/a_0^2$ is estimated, since $D$ and $a_0$ are the difficult quantities to be estimated independently. Here, we report the accurate determination of the parameter $D/a_0^2$ in the superfluid submonolayer of pure $^4$He and $^3$He-$^4$He mixture films by the frequency dependence of the superfluid onset from 20 to 180 MHz by a quartz crystal microbalance (QCM). By the comparison of the results of pure $^4$He film on planar gold and H$_2$ substrates, the vortex diffusion in our study has the largest value $D \sim \hbar/m$ in the quantum limit. The core diameter $a_0$ is estimated to be the same magnitude as the de Broglie wavelength at $T_{KT}$ between 0.1 and 0.9 K. In terms of $^3$He-$^4$He mixture films, we observe no effect of $^3$He on the vortex parameters up to the $^3$He coverage of 15.1 $\mu$mol/m$^2$. 

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15m-A5 QCM Study on 2D Vortex in Superfluid $^4$He and $^3$He-$^4$He Mixture Films

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References:

1. H. Godfrin et al., contribution to LT26
Session 15m-B: Theory for Superconductivity (Mottness or mostly Cuprates)

Chair: Jianxin Li
Monday August 15, 10:50 – 12:30
Convention Hall 3

15m-B1 Fermionic Quantum criticality and the AdS/CFT correspondence of string theory.
J. Zaanen, Institut-Lorentz for Theoretical Physics, Leiden University, The Netherlands
The central mystery in quantum matter is the general nature of matter formed from fermions. The methods of many body quantum physics fail and one can only rely on the phenomenological Fermi-liquid and BCS theories. However, in heavy fermion systems and cuprates one deals with non Fermi-liquid quantum critical metals, and to understand their superconductivity one needs to understand these normal states first. Remarkably, it might well be that the mathematics of string theory is capable of describing such states of fermion matter. The AdS/CFT correspondence translates this problem into an equivalent general-relativity problem involving the propagation of classical fields in an Anti-de-Sitter space-time with a black hole in its center. Very recently it was realized that AdS/CFT has a great potential to process fermions, creating much excitement: it appears that both emergent heavy Fermi-liquids and non Fermi-liquids can be gravitationally encoded, as well as holographic superconductors having suggestive traits in common with the real life high Tc variety.

15m-B2 Mottness and Holography
P. Phillips*, M. Edalati*, S. Hong*, R. Leigh*, Ka-Wai Lo*, *Department of Physics, Univ.Illinois, Urbana-Champaign, IL
24 years after the discovery of superconductivity in the copper-oxide ceramics (hereafter cuprates), the central problem remains the anomalous properties of the normal state. The key anomaly is the strange metal in which the resistivity scales as a linear function of temperature rather than the characteristic quadratic dependence of Lev Landau’s standard theory of metals. I will present two approaches to this problem. In the first, I will show that correctly integrating out the high-energy physics results in a new degree of freedom at low energies that mediates T-linear resistivity and is also capable of describing the evolution from Fermi arcs at low doping to a big Fermi surface at high doping. In the second, I will show that a class of bottom-up gravitational models exhibits some of the key ingredients of cuprate physics, including UV-IR mixing, the dynamical generation of a gap and strange metal behaviour. The latter opens the possibility that holography can uncloak the nature of strong correlations in the Mott state.1,2 We look forward to seeing you in Beijing in August.
1 P. Phillips, Rev. Mod. Phys. 82 1719, (2010)

15m-B3 Superconducting ground state for a doped Mott insulator
Zheng-Yu Weng*, Institute for Advanced Study, Tsinghua University
In this talk, I will present a d-wave superconducting ground state 1. for a doped Mott insulator, which is distinguished from a Gutzwiller-projected BCS superconductor by an explicit separation of Cooper pairing and resonating valence bond (RVB) pairing. Such a state satisfies the precise sign structure of the t-J model2, just like that a BCS state satisfies the Fermi-Dirac statistics. I will show that this new class of wavefunctions can be understood by intrinsic electron fractionalization with neutral spinons and backflow spinons forming a two-component RVB structure. While the former spinon is bosonic, originated from the superexchange correlation, the latter spinon is found to be fermionic, accompanying the hopping of bosonic holons. The low-lying emergent gauge fields associated with such a specific fractionalization are of mutual Chern-Simons type 3. Corresponding to this superconducting ground state, three types of elementary excitations are identified. Among them a Bogoliubov nodal quasiparticle is conventional, while the other two are neutral excitations of non-BCS type that play crucial roles in higher energy/temperature regimes. Their unique experimental implications for the cuprates will be also discussed.

15m-B4 Doping and Magnetic Field Dependence of Superfluid Density in Cuprate Superconductors

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Within the kinetic energy driven superconducting mechanism, the doping and temperature dependence of the Meissner effect in cuprate superconductors is studied in the linear response approach. The electromagnetic response kernel is evaluated by considering both couplings of the electron charge and electron magnetic momentum with an external magnetic field and employed to calculate the local magnetic field profile, the magnetic field penetration depth, and the superfluid density, based on the specular reflection model for a purely transverse vector potential, then the main features of the doping dependence of the Meissner effect and the weak magnetic field induced reduction of the low-temperature superfluid density in the Meissner state are well reproduced. The theory also shows that the striking behavior of the weak magnetic field induced reduction of the low-temperature superfluid density in the Meissner state is intriguingly related to both depairing due to the Pauli spin polarization and nonlocal response in the vicinity of the d-wave gap nodes on the Fermi surface to a weak magnetic field.


Non-BCS Superconductivity in Cuprates from Attraction of Spin Vortices

P.A. Marchetti, F. Ye, Z.B. Su, L. Yu
Dipartimento di Fisica, INFN, Padova, Italy
College of Material Sciences and Optoelectric Technology, Graduate University of CAS, Beijing, China
Institute of Theoretical Physics, CAS, Beijing, China
Institute of Physics and Institute of Theoretical Physics, CAS, Beijing, China

We propose a non-BCS mechanism for superconductivity in hole-underdoped cuprates based on a gauge approach to the t-J model [1]. The gluing force is a long-range attraction between spin vortices centered on the empty sites of two opposite Néel sublattices, leading to pairing of charge carriers (spinless holons). In the presence of these pairs, a gauge force coming from the single occupancy constraint induces, in turn, an RVB pairing of the spin carriers (spinons), gapped by scattering against spin-vortices. This gives rise to a finite density of incoherent hole pairs, precursor to superconductivity, supporting a Nernst signal whose contour plot is qualitatively consistent with experiments [2]. The true superconducting transition occurs at a even lower temperature via a planar XY-type transition and it involves a kinetic energy gain due to lowering of the spinon gap. Since the short-range AF order and the holon pairing originate from the same term of the t-J model, this approach incorporates a strong interplay between AF and SC, giving rise to a universal relation between the energy of the resonance mode (bound state of spinons) and $T_c$, as observed in neutron scattering experiments [3].

15m-C1 Topological Surface States in Topological Insulators and Superconductors: Discovery and the New Frontiers
M.Z. Hasan*, Princeton University
Three dimensional topological insulators (originally called “Topological Insulators”) are a new phase of matter which realizes a non-quantum-Hall-like topological state in bulk matter and unlike the quantum Hall liquids can be turned into superconductors and magnets.\(^1\,^2\,^3\) In this talk, I will briefly review the basic theory and experimental discovery of topological insulators. I will then discuss experimental results that demonstrate the Topological-Order via the properties of topological insulators such as spin-momentum locking, non-trivial Berry’s phases, mirror Chern number, absence of backscattering or no U-turn, protection by time-reversal symmetry and the existence of room temperature topological order. I will also report the possible exotic roles of superconductivity and magnetism in doped topological insulators and their potential applications.

\(^{1}\) M.Z.H. and C.L. Kane; Rev. of Mod. Phys. 82, 3045 (2010).

15m-C2 Transport experiments on topological insulators
N. P. Ohg*, Jun Xiong*, Dongxia Qu*, Yong Kang Luo*, Stephen Rowley*, R. J. Cava*, Princeton University, USA
I will review high-field transport results on the topological insulators Bi\(_2\)Te\(_2\) and Bi\(_2\)Te\(_2\)Se (BTS). In the former, we observe via Shubnikov de Haas (SdH) oscillations, surface states with mobility of 10,000 cm\(^2\)/Vs while in BTS, the surface mobility is 2,800 cm\(^2\)/Vs. Using the SdH oscillations, we have tracked the Landau levels to the high field limit. I will discuss recent high-pressure experiments which clarify the nature of the residual bulk states in BTS. Research supported by the US NSF through a MRSEC grant DMR 0819860.

15m-C3 Nernst effect in Bismuth and graphite beyond the quantum limit
K. Behnia*, B. Fauqué*, Z. Zhu*, LPEM-ESPCI, 10 Rue Vauquelin, 75005, Paris, France
A rare opportunity to explore the fate of a three-dimensional gas of highly mobile electrons confined to their lowest Landau levels is provided by elemental semi-metals such as bismuth and graphite. Coulomb interaction, neglected in the band picture, is expected to become significant in this extreme quantum limit, with poorly understood consequences. The Nernst response sharply peaks when a Landau tube is squeezed inside the thermally fuzzy Fermi surface. Our study of the angular-dependent Nernst effect in bismuth resolves these peaks with a complex angular dependence in very good agreement with the theory. Beyond the quantum limit, we resolve a set of additional unexpected Nernst peaks of unknown origin. According to our study of the Nernst effect in graphite extended up to 45 T, the onset of the field-induced phase transition leads to a drastic drop in the Nernst response signaling the sudden vanishing of Landau tubes. The magnitude of this drop suggests the destruction of multiple Landau tubes possibly because of simultaneous nesting of the electron and hole pockets.

15m-C4 Magnetoresistance and Hall Effect in Single-Crystals Mn\(_{1-x}\)Fe\(_x\)Si and Mn\(_{1-x}\)Co\(_x\)Si
C. Franz*, A. Bauer*, A. Neubauer*, A. Regnat*, R. Ritz*, C. Pfleiderer*, Physik-Department, Technische Universität München, Munich, Germany
Complex spin textures with non-trivial topology may generate anomalous contributions in the Hall conductivity, the so-called topological Hall effect, that provide direct evidence of non-vanishing winding numbers. We report a comprehensive study of the evolution of the spin structures and spin textures in Mn\(_{1-x}\)Fe\(_x\)Si and Mn\(_{1-x}\)Co\(_x\)Si by means of the magnetoresistance and the Hall effect. Our study identifies the A-phase, located just below the helimagnetic transition, as a syklronion lattice for a wide range of \(x\). Combining the bulk properties and small angle neutron scattering with our Hall effect data additionally suggests the formation of non-trivial spin textures in parameter regimes outside the A phase when approaching quantum criticality under Fe- and Co-doping. Similarities and differences with pure MnSi and the doped semiconductor Fe\(_{1-x}\)Co\(_x\)Si will be discussed.
Quantum many-body systems divide into a variety of phases with very different physical properties. The question of what kind of phases exist and how to identify them seems hard especially for strongly interacting systems. Here we provide a complete answer to this question for 1D gapped interacting quantum spin systems. Based on the local unitary equivalence relation between short-range correlated states in the same phase, we classify all possible gapped quantum phases in 1D. We find that in the absence of any symmetry all states are equivalent to trivial product states, which means that there is no topological order in 1D. However, if certain symmetry is present, many 1D gapped phases exist with different symmetry breaking orders and/or symmetry protected topological orders. The symmetry breaking orders are completely classified by the subgroups of the symmetry group and the symmetry protected topological orders are completely classified by the projective representations and 1D representations of the symmetry group. The symmetric local unitary equivalence relation also allows us to obtain some simple results for quantum phases in higher dimensions when some symmetries are present.
Session 15m-D: Nanowires / Nanotubes

Chair: Pertti Hakonen
Monday August 15, 10:50 – 12:30
Room 201

15m-D1 Dissipation-Induced Quantum Phase Transition in a Resonant Level
H. Mebrahtu\textsuperscript{a}, I. Borzenets\textsuperscript{a}, Y. Bomze\textsuperscript{a}, A. Smirnov\textsuperscript{b}, G. Finkelstein\textsuperscript{a}\textsuperscript{, aDuke University, Durham, USA \textsuperscript{bNorth Carolina State University, Raleigh, USA}

We measure tunneling through a resonant level embedded in a dissipative environment, which suppresses tunneling rate at low energies. The resonant level is formed in a carbon nanotube, and the dissipative environment is realized in resistive leads. We study the shape of the resonant conductance peak, with the expectation that its width and height, both dependent on the tunneling rate, will be suppressed at low temperatures. However, we observe distinct regimes, including a case where the resonant tunneling conductance reaches the unitary limit, despite the presence of dissipation. We discuss the implication of these findings for a dissipation-induced quantum phase transition and extract the scaling exponents.

15m-D2 Time-dependent universal conductance fluctuations in metal oxide nanowires due to mobile defects
Juhn-Jong Lin\textsuperscript{a}, A. S. Lien\textsuperscript{a}, P. Y. Yang\textsuperscript{a}, L. Y. Wang\textsuperscript{b}, C. S. Chu\textsuperscript{b}\textsuperscript{, aInstitute of Physics, National Chiao Tung University, Hsinchu 30010, Taiwan \textsuperscript{bDepartment of Electrophysics, National Chiao Tung University, Hsinchu 30010, Taiwan}

Time-dependent universal conductance fluctuations (UCF) are observed in single RuO\textsubscript{2} nanowires (~50–100 nm in diameter and a few micrometers long) at cryogenic temperatures.\textsuperscript{1} The fluctuations persist up to unprecedentedly high temperatures of ~10 K. Their root-mean-square fluctuation amplitudes increase with decreasing temperature, reaching a fraction of $e^2/h$ at temperatures below ~2 K. These fluctuations are shown to originate from scattering of conduction electrons with rich amounts of mobile defects in artificially synthesized metal oxide nanowires. Furthermore, time-dependent UCF characteristics in both one-dimensional saturated and unsaturated regimes are identified, in quantitative consistency with existing theoretical predictions.\textsuperscript{2} In another case of single IrO\textsubscript{2} nanowires where the mobile defects are less vigorous, time-independent UCF as a function of varying magnetic fields are clearly observed. The variation in the fluctuation amplitude with temperature can be understood in terms of current theoretical concepts, but a quantitative explanation is still lacking.

\textsuperscript{1} A. S. Lien, L. Y. Wang, C. S. Chu, and J. J. Lin, to be published.

15m-D3 Blocking the Phonon Thermal Transport at the Nanoscale
C. Blanc\textsuperscript{a}, J.-S. Heron\textsuperscript{a}, T. Fournier\textsuperscript{a}, N. Mingo\textsuperscript{b}, O. Bourgeois\textsuperscript{a}\textsuperscript{, aInstitut N \textsuperscript{E}EL, CNRS et UJF, 25, rue des Martyrs 38042 Grenoble, France \textsuperscript{bLITEN, CEA, 17, rue des Martyrs 38042 Grenoble, France}

The study of thermal conductance of nanowires at very low temperature is quite complex from an experimental as well as a theoretical point of view. Our approach consists in using the 3-omega method to measure the thermal conductance of free standing nanosystems. We report the measurement of thermal conductance of suspended silicon nanowires (200nm, 100nm and 10nm) between 0.3K and 6K. It is revealed by the non-trivial temperature dependence of the thermal conductance signature; a mix between ballistic and diffusive transport governed by the competition between the mean value of the roughness and the dominant phonon wavelength. The thermalization of the phonon on the surfaces is strongly modified at the nanoscale by the specular reflection implying an increase of the phonon mean free path. To illustrate that point we measured also nanowires having a serpentine nanostructure evidencing that changes in geometrical shape can strongly affect heat flow. By engineering serpentine shaped nanowires, the phonon transmission is reduced by nearly 40% at temperatures below 5K \textsuperscript{1} as compared to the straight nanowires. This amount of reduction is strikingly large demonstrating the blocking of the ballistic phonon transport. We have performed a detailed transmission function analysis going beyond a simple Ziman model. It yields a very satisfactory agreement with experimental measurements.

\textsuperscript{1} J.-S. Heron, C. Bera, T. Fournier, N. Mingo, and O. Bourgeois, Phys. Rev. B. \textbf{82}, 155458 (2010).

15m-D4 Spin States, Spin Correlations, Supercurrent, and Multiple Andreev Reflections in InSb Nanowire Quantum Devices
Bulk InSb is one of the most promising materials for applications in spintronics and quantum information processing, due to the fact that it has the smallest electron effective mass $m_e^* = 0.015 m_e$ and the largest electron magnetic moment $|g^*| = 51$ among all III-V semiconductors. Here, we report on transport measurements of InSb quantum dots and superconductor/InSb/superconductor hybrid devices made from InSb nanowires. Spin states, effective $g$-factors, and spin-orbit interaction energy are measured for the InSb quantum dots. We have also studied strong correlation phenomena and observed a new spin-correlation-induced phenomenon in the devices, namely the conductance blockade at the degeneracy of two orbital states with the same spin. We attribute this conductance blockade to the effect of interference between two equivalent, strongly correlated, many-body states in the dots. In superconductor/InSb nanowire/superconductor hybrid devices, we have observed supercurrent and multiple Andreev reflections, and have found that the fluctuations in the supercurrent are correlated to the conductance fluctuations of the corresponding InSb nanowires in the normal state. We have also observed multiple Andreev reflections and interplay between the Kondo correlation and proximity effect in the Coulomb blockade regime.

15m-D5 Non-linear Mode Coupling in Silicon Nitride Beams

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We report measurements of the non-linear response and harmonic mode coupling in Silicon Nitride beams at very low temperatures. Non-linear effects arise naturally in nanomechanical beams from the stretching of the beam as it is deflected. When a particular mode is strongly excited the non-linearity gives rise both to a Duffing type behaviour in that mode and also a coupling to other modes which shifts their frequencies. Measurements were conducted at a temperature of 115mK on the first, third and fifth flexural mode of a beam with dimensions: $L \sim 25.5 \mu m$, $w \sim 170 \text{ nm}$, $t \sim 170 \text{ nm}$ and a 40 nm thick layer of gold on top. Results for the nonlinear response of each individual mode and the nonlinear modal coupling are presented. The frequency shift of a given mode varies quadratically with the amplitude of a second strongly driven mode in agreement with theory.
15m-E1  Review of Recently Supplied Oxford Instruments UHV/ULT Cryostats (LT26)

Oxford Instruments has recently experienced an increasing demand for UHV sample environments for both its traditional 'wet' Kelvinox, and Triton cryofree™ range of dilution refrigerators. This demand is often accompanied by requests for particular sample handling mechanisms - usually designed to prevent the need to break the hard-won vacuum when changing samples - and other application-specific features to be integrated into the systems. We have recently installed systems for a wide range of applications including STM, magneto-optical tapping of atomic clouds, and for use on synchrotron beam lines. In this paper we review three such systems and their novel features that we have installed in laboratories in Europe and the USA in the last few years.

15m-E2  Heat Transport in Suspended Membranes and Phononic Crystals at sub-Kelvin Temperatures
I. J. Maasilta, N. Zen, T. J. Isotalo, J. T. Karvonen, Nanoscience Center, Department of Physics, University of Jyväskylä, Jyväskylä, Finland

We have studied experimentally and theoretically the thermal conductance of thin free-standing silicon nitride membranes at sub-Kelvin temperatures as a function of membrane thickness between 40 nm and 750 nm, using normal metal-insulator-superconductor (NIS) thermometry. Effects of the expected dimensionality cross-over from 3D to 2D phonons are seen, however not all observations follow the simplest theory. A more detailed modeling is also presented in the limit where phonon scattering is fully diffuse on the membrane surfaces (Casimir limit) and possibilities for extending the model are discussed. In addition, we have also studied membranes with a periodic array of perforated holes. These type of samples act as phononic crystals, where the acoustic phonon modes are strongly modified due to the periodic obstacles. Using finite element method based calculations, we have successfully found the proper geometry which has a complete phononic bandgap in the energy range of the dominant thermal phonons at 100 mK, (around 20 GHz). Initial results using sensitive NIS thermometry indicate that thermal conductance is suppressed strongly at the lowest temperature range of the experiment around 100 mK, but recovers towards the full membrane results at higher temperatures. Thus, we have shown that phononic crystals are promising new avenue for controlling the thermal conductance in micro- and nanoscale.

15m-E3  Liquid helium solutions with 4 K pulse tube cryocoolers
Chao Wang, Cryomech, Inc. 113 Falso Dr., Syracuse, NY 13211, USA

Helium is an irreplaceable resource with a finite supply. Many laboratories around the world are facing price increasing and supply shortage of helium. New generation of 4 K pulse tube cryocoolers, featuring with low vibration and high reliability, provide solutions for liquid helium usages. Some “dry” systems, such as dry dilution refrigerator, dry ADR, dry sorption cooler and dry superconducting magnet etc., have successfully used 4 K pulse tube cryocoolers to replace liquid helium. Latest liquid helium cryostats use 4 K pulse tube cryocooler to recondense helium vapor to realize zero-boil. A helium reliquefier using 4 K pulse tube cryocooler can be inserted into an existing open cryostat to recondense helium boil off. Portable helium liquefiers and helium recovery system provide solutions for laboratories to recover and re-liquefy helium.

15m-E4  Low temperature scanning probe microscopy at high magnetic fields in closed cycle systems: from 4 K down to mK
M. Zech, C. Bödefeld, D. Andres, C. Mitzkus, K. Karrai, attocube systems AG, Königstraße 11a (Rgh), 80539 München, Germany

In view of the rapid increase of the costs for liquid helium, closed cycle cryostats are becoming of paramount importance in low temperature research. Sensitive techniques such as scanning probe microscopy (SPM) require specially designed products optimized for ultra-low vibrations. Combining the latter with high magnetic fields has become possible only very recently due to a proprietary (top-loading) design by attocube systems: mechanical vibrations created by the pulse-tube coldhead are decoupled from the measurement platform, resulting in peak-to-peak vibration amplitudes of less than 4.2 nm at the sample location, while retaining probe cooldown times as
fast as 1 hour. We present vibration spectra as well as examples of several different SPM techniques such as CFM, AFM, MFM, and SHPM at 4 K and up to 9 T. In addition, we show proof-of-principle SPM measurements in a dry dilution refrigerator at less than 100 mK.

15m-E5 Operation of cryogenic facility in e-way at Tata Institute of Fundamental Research
K.V. Srinivasan*, Low Temperature Facility, Tata Institute of Fundamental Research (TIFR), Mumbai - 400005, India
In an attempt towards the development of modern, model and paperless cryogenic facility, the Low Temperature Facility of Tata Institute of Fundamental Research, at Mumbai, India; carried out many automation works using programmable logic controller (PLC) and other modern electronic tools, with the objective of bringing the entire plant operation to your palm whenever and wherever you are. Efficiency in the plant operation by keeping a watch on the plant healthiness, advance indication about the possible plant problem by means of pre-warning alarms, so that the remedial action can be taken well prior to the actual failure affects the plant operation, reduction in plant down time were achieved by the automation works. Large size in our cryogen production, controlling the complicated helium liquefer, meeting the uninterrupted supply of cryogen to the users on “any time availability basis”, safety in handling cryogens and high pressure gas, effective usage of limited skilled manpower etc., all these requirements call for the definite need of modern electronic gears and gadgets. The talk will describe in details about the automation works carried out at our cryogenic facility at TIFR.
Session 15a-A: Electrons on Helium

Chair: Kimitoshi Kono
Monday August 15, 14:00 – 15:40
Room 5A

15a-A1  Vanishing conductance states of microwave-excited electrons on a liquid helium surface

D. Konstantinov a,b, A. Chepelianski c, K. Kono a
a Advanced Science Institute, RIKEN, Japan
b Okinawa Institute of Science and Technology, Japan
c Univ. Paris-Sud, CNRS, France

An ultra-high mobility 2D electron system, which can be formed on the surface of liquid helium, presents a unique classical counterpart to the degenerate Fermi gas in semiconductors. In strong magnetic fields applied perpendicular to the surface, such a system exhibits unusual transport properties when exposed to electromagnetic radiation, which induces quantum transitions of electrons between the surface subbands. In particular, the dissipative conductivity of electrons $\sigma_{xx}$ vanishes, which is reminiscent of radiation-induced zero-resistance states of a 2D electron gas in GaAs/AlGaAs heterostructures. Simultaneously, the radiation causes a highly nonequilibrium spatial distribution of electrons, where a large fraction of charge (more than 50%) is displaced towards the system edge. Possible scenarios of the latter effect include the charge instability caused by absolute negative conductivity and the microwave-assisted trapping of electrons at the system edge.


15a-A2  Anisotropy of c-facet of hcp solid $^4$He

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b P. L. Kapitza Institute, Kosygina 2, Moscow 119334, Russia

Recently we have observed the so-called devil’s staircase of high order facets on the surface of hcp $^4$He crystals at 0.2 K. Such high roughening temperatures of high order facets belonging to family [10-1N] suggest that there must be an anomaly in the stiffness of vicinal surfaces and of the step on basal c-facet at corresponding orientation which was never observed before. With our interferometric technique we were able to measure the stiffness of the step on [0001] c-facet and the azimuthal stiffness of vicinal surfaces at small polar angles ($2^\circ - 10^\circ$). Below 0.2 K we have found a strong anisotropy of the stiffnesses, as high as 5-10. The anisotropy rapidly decreases as temperature increases and seems to saturate at low temperatures. We have adopted the standard theory of renormalizations by thermal fluctuations of the surface by assuming the anisotropy in the bare, unrenormalized surface stiffness. The theory gives a good explanation of the thermal dependence of the step energy on the c-facet and of the anisotropy, while the model of free kinks on the step predicts exponentially fast increase of both the energy and the anisotropy at low temperatures. The measured azimuthal surface stiffness at low temperatures has the value of 1 erg/cm² in maximum which suggests that high order facets with N up to 10 should be present at temperatures below 0.2 K.

15a-A3  Mechanical Response of $^4$He Films Adsorbed on Single-crystalline Graphite

K. Noda a, F. Nihei a, H. Kobayashi a, J. Taniguchi a, M. Suzuki b
a Department of Engineering Science, University of Electro-Communications, Chofu, Tokyo 182-8585, Japan
b Department of Physics, University of Oulu, Finland

It is interesting to study the sliding direction dependence of the sliding friction for physisorbed films. Thus motivated, we carried out quartz-crystal microbalance (QCM) experiments for $^4$He films adsorbed on exfoliated single-crystalline graphite. One QCM oscillated parallel to the a-axis of graphite, while the other one in the direction inclined at about 30° with respect to the a-axis of graphite. Preliminary results show no large difference of the coupled mass between the two directions. Detailed direction and coverage dependences will be demonstrated.

15a-A4  Pendulum in a Fermi liquid

Timo H. Virtanen a, Erkki Thuneberg a
a Department of Physics, University of Oulu, Finland

The Fermi liquid theory formulated by Landau is a basic paradigm of the behavior of an interacting many-body system. We show that the interactions between quasiparticles lead to “Landau force” on a macroscopic object. We show that immersing a pendulum in a Fermi liquid can increase its oscillation frequency. We apply the Fermi liquid theory to study the mechanical impedance of a vibrating wire immersed in $^3$He-$^4$He mixtures at low temperatures. We present numerical results based on a direct solution of Landau-Boltzmann equation for the $^3$He quasiparticle distribution in the full scale of the quasiparticle mean-free-paths from the hydrodynamic to the ballistic limit. The two-fluid nature of the mixture is taken into account in the theory, and the effect of Fermi liquid interactions
and boundary conditions are studied. The results are in fair quantitative agreement with experimental data. In particular, we can reproduce the anomalous increase of the oscillation frequency that has been observed in vibrating wire experiments reaching the ballistic limit. The essential effect of the experimental container and second-sound resonances is demonstrated. Further consequences of the Landau force are discussed.¹


15a-A5 Superfluid Phases of $^3$He Confined in a Single 0.6 Micron Slab

L. V. Levitin, R. G. Bennett, A. J. Casey, B. Cowan, E. V. Surovtsev, J. Saunders. ¹Department of Physics, Royal Holloway, University of London, Egham, Surrey, TW20 0EX, UK ²Department of Physics, Cornell University, Ithaca NY 14853, USA ³P. L. Kapitza Institute for Physical Problems, Moscow, 119334, Russia

We present our NMR study of $p$-wave superfluid $^3$He confined in a well-characterised restricted geometry. The confinement is provided by a nanofabricated cell with a 0.6 micron thick cavity. NMR is used both to identify the phases and make quantitative measurements of the suppression and distortion of the order parameter. The degree of confinement is continuously tuned with pressure and surface quasiparticle scattering is modified by preplating the walls of the cell with $^4$He. Confinement on a length scale comparable to the superfluid coherence length suppresses the order parameter and alters the relative stability of different superfluid phases. We observe a profound effect of confinement on the phase diagram. The A phase ($\Delta(p) = \Delta[\hat{p}_x + i\hat{p}_y][\uparrow\uparrow + \downarrow\downarrow]$) stabilises in a wide range of the phase diagram below the superfluid transition, even at low pressure, and the B phase with a planar distortion ($\Delta(p) = \Delta[\hat{p}_x + i\hat{p}_y][\uparrow\uparrow] + \Delta[\hat{p}_z][\downarrow\downarrow] + \Delta[\hat{p}_x + i\hat{p}_y][\downarrow\downarrow] + \Delta[\hat{p}_z][\uparrow\downarrow], \Delta_\perp < \Delta_\parallel$) is observed at low temperature and higher pressure where the coherence length is shorter. We find evidence for spatial variations of the order parameter across the slab in the B phase. These experiments open the way for studies of many surface and size phenomena in superfluid $^3$He.
Session 15a-B: Physical Properties of Fe-based and Cuprate Superconductors II

Chair: Nan-Lin Wang
Monday August 15, 14:00 – 15:40
Convention Hall 3

15a-B1 Complementary Thermodynamic and Optical Studies of Superconductivity - Induced Anomalies in an Iron Arsenide

A.V. Boris, A. Charnukha, O.V. Dolgov, A.N. Yaresko, C.T. Lin, B. Keimer, Max Planck Institute for Solid State Research, Heisenbergstrasse 1, D-70569 Stuttgart, Germany

We critically examine the interplay between spin fluctuations and superconducting pairing in iron pnictides by complementary studies of the thermodynamic and optical properties of optimally doped BKFA single crystals.\(^1\) We discuss the microscopic origin of superconductivity-induced electronic specific heat and infrared optical anomalies in the framework of a multiband Eliashberg theory with two distinct superconducting gap energies \(6 k_B T_c\) and \(2.2 k_B T_c\). The observed unusual suppression of the optical conductivity in the superconducting state at energies up to \(14 k_B T_c\) can be ascribed to spin-fluctuation-assisted processes in the clean limit of the strong-coupling regime. An unusual complement to these results is the observation of a superconductivity-induced suppression of an absorption band at an energy of 2.5 eV, two orders of magnitude above the superconducting gap energy.\(^2\) This anomaly is explained as a consequence of non-conservation of the total number of unoccupied states involved in the corresponding optical transitions due to the opening of the superconducting gaps and redistribution of the occupation of the different bands below \(T_c\), which can potentially enhance superconductivity in iron-pnictides.


15a-B2 Fermi Surface Studies of Iron-Pnictide Superconductors: BaFe\(_2\)As\(_2\) vs. KFe\(_2\)As\(_2\)

T. Terashima\(^a\), N. Kurita\(^a\), M. Tomita\(^a\), K. Kihou\(^b\), C.H. Lee\(^b\), Y. Tomioka\(^b\), T. Ito\(^b\), A. Iyo\(^b\), H. Eisaki\(^b\), T. Liang\(^c\), M. Nakajima\(^a\), S. Ishida\(^a\), S. Uchida\(^a\), H. Harima\(^d\), S. Uji\(^a\). *JST, Transformative Research-Project on Iron Pnictides (TRIP), Japan *National Institute for Materials Science, Japan *National Institute of Advanced Industrial Science and Technology (AIST), Japan *Department of Physics, University of Tokyo, Japan *Department of Physics, Graduate School of Science, Kobe University, Japan

Recently, we have completely determined the Fermi surface in the antiferromagnetic orthorhombic phase of BaFe\(_2\)As\(_2\) by measuring Shubnikov-de Haas oscillations in \textit{detwinned} single crystals of unprecedentedly high quality (RRR = 40–60) (T. Terashima et al., arXiv:1103.3329). The Fermi surface consists of one hole and two electron pockets, and the carrier number is 0.024 holes and electrons per primitive unit cell. The observed Fermi surface can well be accounted for by an LSDA band-structure calculation using the experimental crystal structure. The mass enhancements \(m^*/m_{\text{band}}\) are found to be 2–3. The Sommerfeld coefficient estimated from the determined Fermi surface and effective masses agrees well with an experimental value. Previous ARPES reports are not very consistent with our determined Fermi surface. We will discuss these data in comparison with corresponding data for KFe\(_2\)As\(_2\), where we have found a remarkable discrepancy between the observed and calculated Fermi surface areas and large mass enhancements (3–20) (T. Terashima et al., J. Phys. Soc. Jpn. 79, 053702 (2010)).

15a-B3 Unconventional temperature-enhanced magnetism in Fe\(_{1.1}\)Te

I. A. Zaliznyak\(^a\), Z. J. Xu\(^a\), J. M. Tranquada\(^a\), G. D. Gu\(^a\), A. M. Tsvelik\(^a\), M. B. Stone\(^b\), *Condensed Matter Physics and Material Science Dept., Brookhaven National Lab, Upton, NY 11973-5000 *NSDD, Oak Ridge National Laboratory, Oak Ridge, TN

There are two common scenarios used to describe the magnetism in the families of Fe-based superconductors. In one, the magnetism originates from local atomic spins, while in the other it corresponds to a cooperative spin-density-wave instability (SDW) behavior of conduction electrons. Both assume clear partition into localized electrons, giving rise to local spins, and itinerant ones, occupying well-defined, rigid conduction bands. We have used inelastic neutron scattering to characterize both the static and the dynamic magnetism in a crystal of Fe\(_{1.1}\)Te, parent to Fe\(_{1+y}\)Te\(_{1−y}\)Se\(_2\), family of superconductors.\(^1\) In contrast to the simple pictures, we find that localized spins and itinerant electrons are coupled together. In particular, we have evaluated the effective magnetic moment by integrating both the elastic and inelastic magnetic scattering. The effective spin per Fe at \(T \approx 10\) K, in the antiferromagnetic phase, corresponds to \(S \approx 1\), consistent with the recent analyses that emphasize importance of Hund’s intra-atomic exchange. However, it grows to \(S \approx 3/2\) in the disordered phase, a result that presents a challenge to current theoretical models. Work at Brookhaven is supported by the Office of Basic

15a-B4  Spin-orbit coupling, anisotropic magnetic fluctuations and nodeless gap in iron-pnictides revealed by NMR

Guo-qing Zheng\textsuperscript{a,b}, \textsuperscript{a}Department of Physics, Okayama University, Okayama, Japan \textsuperscript{b}Institute of Physics, Chinese Academy of Sciences, Beijing, China

We will report on the pairing symmetry and the spin correlations in the Fe(Ni)-based superconductors ReFe(Ni)As\textsubscript{O\textsubscript{1-x}F\textsubscript{x}} (Re=Pr\textsuperscript{1,3}, La\textsuperscript{2,3}), LiFeAs\textsuperscript{4} and Ba\textsubscript{1-x}K\textsubscript{x}Fe\textsubscript{2}As\textsubscript{2} single crystals\textsuperscript{5,6}, based on our extensive NMR measurements. The spin susceptibility measured by the Knight shift decreases below \( T_c \) along all crystal directions, which indicates spin-singlet pairing. Evidences for multiple, fully-opened gaps are given. We find that the antiferromagnetic spin fluctuation is anisotropic in the spin space due to spin-orbit coupling, but becomes isotropic in the zero temperature limit\textsuperscript{6}, which also points to spin-singlet superconductivity with nodeless gap. This work was done in collaboration with S. Kawasaki, K. Matano, T. Oka, T. Tabuchi, M. Ichioka (Okayama U), C.T. Lin (Max Planck Institute, Stuttgart, Germany), C.Q Jin, N.L. Wang, Z.A. Ren and Z.X. Zhao (IOP, CAS, China).

\textsuperscript{1}K. Matano \textit{et al}, EPL 83, 57001 (2008).
\textsuperscript{5}K. Matano \textit{et al}, EPL 87, 27012 (2009).

15a-B5  NMR investigation of iron-based high \( T_c \) superconductors

T. Imai\textsuperscript{a,b}, \textsuperscript{a}Department of Physics and Astronomy, McMaster University, Hamilton, Ontario L8S 4M1, Canada \textsuperscript{b}Canadian Institute for Advanced Research, Toronto, Ontario M5G 1Z8, Canada

NMR (Nuclear Magnetic Resonance) is a highly versatile, non-destructive, low-energy bulk probe of structural, electronic, magnetic, and superconducting properties of solids. In this talk, we will discuss recent progress in NMR research into iron-based high \( T_c \) superconductors, with primary focus on similarities and dissimilarities between K\textsubscript{x}Fe\textsubscript{2-y}Se\textsubscript{2}\textsuperscript{1}, FeSe\textsuperscript{2}, and Ba(Fe,Co)\textsubscript{2}As\textsubscript{2}\textsuperscript{3}. This work was carried out in collaboration with a large number of collaborators, including D.A. Torchetti, M. Fu, F.L. Ning (McMaster), C. Petrovic (Brookhaven National Lab), R.J. Cava (Princeton), A. Sefat (Oak Ridge National Lab), and H.-H. Wen (Nanjing).

Session 15a-C: Multiferroics / Ferroics

Chair: Steve Bramwell
Monday August 15, 14:00 – 15:40
Room 5B

15a-C1  Magnetism and magnetoelectricity of hexaferrite systems
T. Kimura\textsuperscript{a}, K. Okumura\textsuperscript{a}, T. Ishikura\textsuperscript{a}, Y. Kitagawa\textsuperscript{a}, Y. Hiraoka\textsuperscript{a}, M. Soda\textsuperscript{b}, T. Asaka\textsuperscript{c}, H. Nakamura\textsuperscript{a}, Y. Wakabayashi\textsuperscript{a},  
\textsuperscript{a}Graduate School of Engineering Science, Osaka University, Osaka 560-8531, Japan \textsuperscript{b}Dept. of Materials Science and Engineering, Nagaoka Institute of Technology, Nagaoka 480-8555, Japan \textsuperscript{c}Institute for Solid State Physics, University of Tokyo, Kashiwa 277-8581, Japan

Recent extensive studies on magnetoelectric multiferroics have revealed that ferroelectricity is induced by complex magnetic structures in some frustrated magnetic systems. The magnetoelectric frustrated magnetic systems often show giant magnetoelastic effects, i.e., magnetic-field-induced changes in ferroelectric polarization. However, their magnetoelectric effects usually occur at temperatures that are too low and at external fields that are too high to be practically useful. Thus, the quest for robust room-temperature magnetically-induced ferroelectrics is a major challenge in magnetoelectric research. Lately, some ferrites with hexagonal crystal structures, termed hexaferrites, have been found to show magnetoelectric effects at room temperature and low magnetic fields.\textsuperscript{1,2} In the presentation we will introduce structure, magnetism, and resulting magnetoelectricity of some hexaferrite systems which are promising candidates for magnetoelectric multiferroics operating at room temperature and low fields.

\textsuperscript{1} Y. Kitagawa \textit{et al.}, Nature Mater. 9, 797 (2010).

15a-C2  Dynamical magnetoelectric effects in non-collinear magnets
M. Mostovoy\textsuperscript{a},  
\textsuperscript{a}Zernike Institute for Advanced Materials, University of Groningen, Nijenborgh 4, 9747 AG Groningen, The Netherlands

The coupling between the spin degrees of freedom in Mott insulators and an electric field leads to spectacular phenomena, such as the magnetic field control of electric polarization in multiferroic materials with a spiral magnetic ordering. I will focus on two dynamical magnetoelectric effects, which can be observed in non-collinear magnets. The first one is the excitation of magnons in optical absorption by the electric component of light (electromagnons). I will discuss a theory of electromagnons in magnets with non-collinear spin orders and discuss the possibility to observe them in linear magnetoelectric materials with spontaneous monopole and toroidal magnetic moments. The second effect is a new magnetoelectric interaction in multi-orbital Mott insulators. Unlike the well-known ‘inverse Dzyaloshinskii-Moriya’ mechanism and the Heisenberg exchange striction, this interaction is dynamical in nature: it couples electric field to the time derivative of the local magnetization. This coupling gives rise to unusual effects that may find applications in dissipationless spintronics, such as the displacement of spin textures in ferromagnetic insulators induced by an applied electric field. These effects become dramatically enhanced if a spin texture has a non-trivial topology. I will discuss a theory of electromagnons in magnets with non-collinear spin orders and discuss the possibility to observe them in linear magnetoelectric materials with spontaneous monopole and toroidal magnetic moments.


15a-C3  Spiral spin order induced ferroelectricity in various type-II multiferroics
J. M. Liu\textsuperscript{a,b}, S. Dong\textsuperscript{c},  
\textsuperscript{a}Laboratory of Solid State Microstructures, Nanjing University, Nanjing 210093, China \textsuperscript{b}International Center for Materials Physics, Chinese Academy of Sciences, Shenyang 110016, China \textsuperscript{c}Department of Physics, Southeast University, Nanjing 211189, China

In the past decade, one of the milestones associated with multiferroicity researches has been the experimental and theoretical identification of spin orders induced ferroelectricity in various spin frustrated oxide materials. These specific orders include the noncollinear spiral spin order, collinear spin order of exchange striction, E-type antiferromagnetic (AFM) order of double-exchange nature, and so on. Both the ($S_i \times S_j$)-type and ($S_i \cdot S_j$)-type spin interactions may contribute to the ferroelectricity generation. In consequence, experimentally observable multiferroic phenomena can be complex and reflected in multifold dimensions. In this talk, we address the spiral spin order induced ferroelectricity in various multiferroics where the ($S_i \times S_j$)-type spin interaction is believed to contribute to the ferroelectricity. A modulation of such spiral spin order by various approaches is investigated and in particular the complex spin interactions in RMnO$_3$ with magnetic and non-magnetic doping at the R-site and Mn-site will be discussed. Hopefully this talk may allow additional facts to our comprehensive understanding of the multifold interactions which eventually have impact on the magnitude of ferroelectric polarization in those multiferroics.
15a-C4 Functional Heterostructures that Harness Frustration
P. Chandra\textsuperscript{a}, L. Palova, T. Yusufaly\textsuperscript{a}, V. Cooper\textsuperscript{a}, M. Dawber\textsuperscript{a}, K.M. Rabe\textsuperscript{a}, \textsuperscript{a}Center for Materials Theory, Department of Physics and Astronomy, Rutgers University, NJ 08854, USA.

Artificially structured oxides present exciting opportunities for the design of functional materials with specified and/or novel properties. With dramatic advances in epitaxial growth techniques allowing atomic-scale controls, experimental and theoretical attention has focussed on multicomponent strained-layer superlattices and laterally-patterned heterostructures ("nanocheckerboards") that have desirable characteristics distinct from those of their bulk constituents. Here we present two examples of novel functional heterostructures that. In one case, exploiting magnetic frustration, we identify and characterize a multiferroic nanocheckerboard with a combination of first-principles calculations and magnetic modelling that has a coexisting large moment and a large polarization. In another case, using integrated experimental, ab initio and phenomenological approaches, we discuss a two-component superlattice with enhanced piezoelectricity where electrostatic "compromise" occurs. Finally we present current work where we use metallic magnetic oxides as nanoscale dielectrics in heterostructures. These materials, mainly perovskites, are metallic in bulk but become insulating when grown in ultrathin layers; furthermore their magnetic properties are very sensitive to external boundary conditions. Preliminary results on the behavior of these alternative insulating phases embedded in titanium perovskite superlattices will be discussed.

15a-C5 Giant Magnetoelectric Effect in HoAl\textsubscript{3}(BO\textsubscript{3})\textsubscript{4} at Low Temperatures
B. Lorenz\textsuperscript{a}, K.-C. Liang\textsuperscript{a}, R. P. Chaudhury\textsuperscript{a}, Y. Y. Sun\textsuperscript{a}, L. N. Bezmaternykh\textsuperscript{b}, V. L. Temerov\textsuperscript{b}, C. W. Chu\textsuperscript{a}, \textsuperscript{a}TCSUH and Department of Physics, University of Houston, Houston, Texas 77204-5002, USA \textsuperscript{b}Institute of Physics, Siberian Division, Russian Academy of Sciences, Krasnoyarsk, 660036 Russia

The magnetoelectric effect in the system RAl\textsubscript{3}(BO\textsubscript{3})\textsubscript{4} (R = Tb, Er, Tm, Ho) is investigated between 2 K and room temperature and at magnetic fields up to 70 kOe. We show a systematic increase of the magnetoelectric effect with decreasing magnetic anisotropy of the rare earth moment. A giant magnetoelectric polarization is found in the magnetically (nearly) isotropic HoAl\textsubscript{3}(BO\textsubscript{3})\textsubscript{4}. The polarization value in transverse field geometry at 70 kOe reaches 3600 $\mu$C/m$^2$ which is significantly higher than reported values for the field-induced polarization of the known bulk magnetoelectric materials, including linear magnetoelectric or even multiferroic magnetoelectric compounds. The magnetostrictive effect is also measured and compared with the magnetoelectricity. The results cannot solely be explained by the piezoelectric effect that originates from a field-induced change of lattice parameters but they rather suggest the ionic displacements in the unit cell and a change of the polar distortion on a microscopic scale. HoAl\textsubscript{3}(BO\textsubscript{3})\textsubscript{4} may be a candidate for a technological utilization of the magnetoelectric effect. This work is supported by the US Air Force Office of Scientific Research, the US Department of Energy, the T.L.L. Temple Foundation, the J. J. and R. Moores Endowment, and the State of Texas through the TCSUH.
15a-D1  Topological Insulators: non-magnetic vs. magnetic
Zhong Fang, Institute of Physics, Chinese Academy of Science, Beijing 100190

Topological insulator is a new state of quantum matter, characterized by topological invariants like Z or Z2 numbers. Exotic quantum phenomena, such as Majorana Fermions, magneto-electric effect, and quantum anomalous Hall effect, have been expected from topological insulators, while their experimental realizations remain challenging, due to the lack of suitable samples or requirement of extreme conditions. Within recent couple of years, more and more topological insulators were discovered, yet lots of new compounds still wait to be explored. In this talk, I will start from our earlier predictions for Bi2Se3 family compounds [1], and discuss the characteristic of topological nature from the Wannier representation and Willson loop method [2]. I then move to the recent study for the topological aspect and quantum magnetoresistance of Ag2Te [3]. The possible realization of quantized Anomalous Hall effect and Majorana fermions after breaking time reversal symmetry will be discussed from the view point of materials design [4,5,6].


15a-D2  Ultrafast dynamics in Cu$_x$Bi$_2$Se$_3$ and Bi$_2$Se$_2$ single crystals
H.-J. Chen*, K. H. Wu*, C. W. Luo*, T. M. Uen*, J. Y. Huang*, J.-Y. Lin*, T. Kobayashi*, F. C. Chou*, "Department of Electrophysics, National Chiao Tung University, Hsinchu 300, Taiwan 2Institute of Physics, National Chiao Tung University, Hsinchu 300, Taiwan 3Department of Applied Physics and Chemistry and Institute for Laser Science, The University of Electro-Communications, Chofugaoka 1-5-1, Chofu, Tokyo 182-8585 Japan 4Center for Condensed Matter Sciences National Taiwan University Taipei 106 Taiwan 5Center for Condensed Matter Sciences, National Taiwan University, Taipei 106, Taiwan

Ultrafast time-resolved differential reflectivity of Cu$_x$Bi$_2$Se$_3$ and Bi$_2$Se$_2$ single crystals is studied using femtosecond pump-probe spectroscopy. Two oscillations in measured transient-reflectivity-change curves are observed with two distinct frequencies, and are attributed to coherent optical and acoustic phonons, respectively. The coherent optical phonon is consistent with the A$_{1g}$ mode in Bi$_2$Se$_3$ obtained by Raman spectroscopy. We also observe that both the coherent optical and acoustic phonons are affected by the doped atoms. The possible mechanism for the modulation of coherent optical and acoustic phonons is discussed. This project is financially sponsored by the National Science Council (grant no. NSC 98-2112-M-009-006-MY3 and NSC 98-2112-M-009-008-MY3) and the Ministry of Education (2009 MOE ATU program at NCTU) of Taiwan, R.O.C.

15a-D3  ARPES and STM/S Study of the Cu-doped Bi$_2$Te$_3$ and Bi$_2$Se$_3$ based Topological Insulators

Topological insulators (TI’s) provide a new materials platform for the realization of novel states of quantum matter. To identify useful materials for application requires a thorough characterization of the properties of these novel systems. Single crystals of Cu-, Te- and Sb-doped Bi$_2$Se$_3$-based TI’s have been grown using the Bridgman method. The resistivity and Hall effect were measured to check for superconductivity and determine their carrier concentrations. Two surface sensitive techniques, angle resolved photoemission (ARPES) and scanning tunneling microscopy/spectroscopy (STM/S), were then combined to study the robustness of the surface states of the TI’s using the same crystals as the transport measurements. In Cu-doped Bi$_2$Te$_3$, quasiparticle interference scattering originating from defects was observed and the origin of the scattering processes was determined. Two types of scattering processes were found, namely (i) backscattering due to warping of the Dirac cone and (ii) backscattering between the bulk conduction band and the surface states.
15a-D4
Liang Fu*, aMIT
(to be announced)

15a-D5  Superconducting Proximity Effect And Conductance Anomalies in Sn-Bi$_2$Se$_3$ Junctions
*aDaniel Chee Tsui Laboratory, Institute of Physics, Chinese Academy of Sciences, Beijing, China  
bInstitute of Theoretical Physics, Chinese Academy of Sciences, P.O. Box 2735, Beijing 100190, China

We have investigated the conductance spectra of Sn-Bi$_2$Se$_3$ single junction device down to 250 mK and in different magnetic fields. A double-gap structure was observed at the center of the conductance spectra. With the sharpening of the small gap at lower temperatures, a zero-bias conductance peak occurred. This phenomena would reflect the formation of a proximity effect induced new superconducting state at the interface. The new state was found to be competing with the s-wave superconductivity in Sn electrodes, demonstrating presumably an unconventional pairing symmetry. A broad region with enhanced conductance was also observed below $T_c$, which extends well beyond the superconducting gap of Sn. So far, the origin of this structure is not clear.
**Session 15a-E: Sensors**

**Chair:** Pierre-Etienne Wolf  
**Monday August 15, 14:00 – 15:40**  
**Room 305**

**15a-E1**  
**Breakthrough by superconducting particle detector in mass spectrometry**  
M. Ohkubo*, **Research Institute of Instrumentation Frontier (RIIF), National Institute of Advanced Industrial Science and Technology (AIST), Tsukuba Central 2, Tsukuba, Ibaraki, 305-8568, Japan**

Mass spectrometry (MS) is defined as a method to analyze ions that are accelerated by a potential difference ($V$) according to mass/charge-number ($m/z$) ratios. The $m/z$ peak identification always requires the speculation on the ionic charge state. This is one of the fundamental limits of MS. Other MS limit is that there is no way to distinguish different neutral molecules, because neutral molecules exhibit no response to electromagnetic field. It is called neutral loss. The neutral loss turns into an issue in tandem mass spectrometry (MS/MS), in which precursor ions selected by the first MS dissociate into fragments through atomic collision or other dissociation processes and analyzed by the second MS. The MS fundamental limits can be overcome by using superconductivity for the molecule detection with phonon-mediated quasiparticle breaking by particle impact. The superconducting detectors have the capability of kinetic energy (KE) measurement for particle impact in a low energy range of keV. The KE of an ion is expressed by $zV$, so that the KE measurement enables $z$-value determination and thus unique mass measurement is possible.\(^1\) The KE measurement is also effective for separating different neutral molecules in MS/MS.\(^2\)


**15a-E2**  
**Magnetic Johnson-noise thermometry at milli-Kelvin temperatures and below**  
A. Fleischmann*, **Kirchhoff Institute for Physics, Heidelberg University, INF 227, 69120 Heidelberg, Germany**

The thermally driven voltage fluctuations of an electrical resistor can be described by the fluctuation-dissipation theorem, providing a fundamental relation between temperature and independently measurable quantities — one of the prerequisites for primary thermometry. We present a setup for Johnson-noise thermometry at mK and sub-mK temperatures that uses a commercially available dc-SQUID as preamplifier. The noise to be measured is generated by the thermal motion of electrons in a bulk sample of a high purity metal such as gold or copper. These random currents cause fluctuations of magnetic flux in a superconducting pickup coil which is connected to the input coil of a current-sensor dc-SQUID. To characterize the performance of such thermometers we compared prototypes based on different noise source materials to each other and to a superconducting standard reference device (SRD1000) calibrated against the temperature scale PLTS-2000. The thermometer is easy to use, fast and rather insensitive to typical sources of parasitic heating even at lowest temperatures. We present results and discuss general design considerations as well as the dependence of the temperature uncertainty on measurement time.

**15a-E3**  
**Development of Dry Dilution Refrigerator and Temperature Measurement with Quartz Tuning Fork**  
B. Cryogenic Equipment Division, Iwatani Industrial Gases Corporation, Osaka, Japan

We have developed “dry” dilution refrigerator with following purposes. (1) To make world record of the lowest temperature in “dry” dilution refrigerator (2) To establish a new type of thermometer with quartz tuning fork As for (1), this is to apply “dry” dilution refrigerator as a precooling stage for adiabatic nuclear demagnetization stage. About (2), all of the current temperature measurement method in ultralow temperature is high-priced and complicated. As a solution to this problem, the temperature measurement with quartz tuning fork has been performed.\(^4\) Quartz tuning fork has settled in the condensate phase of mixing chamber, and resistance thermometer has mounted on external wall of mixing chamber. From fermi-liquid theory, amplitude of quartz tuning fork is proportional to the temperature of “liquid”. The quartz thermometer has been calibrated from 100mK to 15mK by a Ruthenium Oxide resistance thermometer which has been calibrated by 3He melting curve thermometer. As a result, we will report that we have made world record 4.5mK in “dry” dilution refrigerator, and quartz tuning fork allowed us to measure the temperature easily.\(^5\)

15a-E4  Real-time observation of discrete Andreev tunneling events - influence on a single-electron turnstile and electron coolers

J. P. Pekola\textsuperscript{a}, V. F. Maisi\textsuperscript{b}, O.-P. Saira\textsuperscript{a}, Yu. A. Pashkin\textsuperscript{c}, J. S. Tsai\textsuperscript{c}, D. V. Averin\textsuperscript{d}, *Low Temperature Laboratory, Aalto University, P.O. Box 13500, 00076 Aalto, Finland \hspace{1em} \textsuperscript{b}Centre for Metrology and Accreditation (MIKES), P.O. Box 9, 02151 Espoo, Finland \hspace{1em} \textsuperscript{c}NEC Green Innovation Research Laboratories and RIKEN Advanced Science Institute, 34 Miyukigaoka, Tsukuba, Ibaraki 305-8501, Japan \hspace{1em} \textsuperscript{d}Department of Physics and Astronomy, Stony Brook University, SUNY, Stony Brook, NY 11794-3800, USA

We provide a direct proof of two-electron Andreev transitions in a superconductor - normal metal tunnel junction by detecting them in a real-time electron counting experiment\textsuperscript{1}. Our results are consistent with ballistic Andreev transport with an order of magnitude higher rate than expected for a uniform barrier, suggesting that only part of the interface is effectively contributing to the transport. These findings are quantitatively supported by our direct current measurements in single-electron transistors with similar tunnel barriers. We assess the influence of Andreev current on single-electron transport and electronic cooling.


15a-E5  Detection of Single Electrons or Photons using a Superconducting Nanowire

M. Rosticher\textsuperscript{a}, F.R. Ladan\textsuperscript{a}, J.P. Maneval\textsuperscript{a}, S.N. Dorenbos\textsuperscript{b}, T. Zijlstra\textsuperscript{b}, T.M. Klapwijk\textsuperscript{b}, V. Zwiller\textsuperscript{b}, A. Lupascu\textsuperscript{d}, G. Nogues\textsuperscript{c}, *Laboratoire Pierre Aigrain, ENS, France \hspace{1em} \textsuperscript{b}Kavli Institute of Nanoscience, Delft University, The Neterlands \hspace{1em} \textsuperscript{c}Institut Neel, CRNS, Grenoble France \hspace{1em} \textsuperscript{d}Institute of Quantum Computing, University of waterloo, Canada

We report the detection of single electrons by a 6 nm-thick, 100 nm-wide, Nb0.7Ti0.3N strip deposited on a SiO\textsubscript{x}/Si substrate, already described as a low-noise Superconducting Single Photon Detector\textsuperscript{1}. When operating around 8 K, and biased slightly below the critical current, a meander-shaped device proves able to count the single keV electrons issued from the cathode of a scanning electron microscope (SEM) with an efficiency approaching unity. It is also possible to map the electron detectivity as well as the photon detectivity on the same device. A clear correlation between the two measurements is observed, with a superior spatial resolution though (around 100 nm) for the SEM mapping.

\textsuperscript{1} S.N. Dorenbos et al, Appl. Phys. Lett. 93, 131101 (2008).
Session 15P-A:

A6 1D & 2D Quantum Liquids

Monday August 15, 16:00 – 18:00
Exhibition Hall 1

15P-A001 Measurements and investigations on Helium-FET
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\textsuperscript{b}Low Temperature Physics Laboratory, RIKEN, Hinosawa 2-1, Wako-shi, Saitama 351-0198, Japan

We present an investigation on the transport of electrons on liquid helium films through narrow channels using suitable substrate structures, micro-fabricated on a silicon wafer which resembles Field Effect Transistors. The sample has a Source and Drain regions, separated by a Gate structure, which consists of 2 gold electrodes with a narrow gap (channel) through which the electron transport takes place. We also present investigations on the potential distribution across the silicon wafer. Pulsing the gate for a short time can be used for a determination of the mobility of the electrons through the channel. Results for a wide range of electron densities are reported.

15P-A002 NMR Study of HD Adsorbed in a Z-type Metal-Organic Framework
Yu Ji\textsuperscript{a}, Y. Tang\textsuperscript{a}, J.A. Hamida\textsuperscript{a}, N.S. Sullivan\textsuperscript{a},
\textsuperscript{a}Department of Physics, University of Florida, USA

We report the results of measurements of the nuclear spin-lattice and spin-spin relaxation rates of hydrogen deuteride trapped in the mesoporous cages of a metal organic framework\textsuperscript{1} (MOF) for temperatures 2.2 < T < 50 K. There is considerable interest in the use of this class of material for hydrogen storage because of the high density of adsorption. NMR studies can provide important information about the molecular interactions and dynamics inside the cages of the MOF structure. Samples were studied with filling factors of 0.5 and 1.0 molecules per cage as determined by the adsorption isotherm at 77 K. The results show strong peaks in the relaxation times at several well defined temperatures that are very different from the adsorption energy levels. These peaks are discussed in terms of the quantization of the translational degrees of freedom of the molecules inside the cages and the associated discrete energy levels. Measurements of the nuclear spin-spin relaxation times provide an important measure of the diffusivity of hydrogen through the MOF structure which is a critical parameter for the use of MOFs for storage and transport.

15P-A003 Polychronakos fractional statistics with a complex-valued parameter
Andrij Rovenchak\textsuperscript{a}, \textsuperscript{a}Department for Theoretical Physics, Ivan Franko National University of Lviv, Ukraine

A generalization of quantum statistics is proposed in a fashion similar to the suggestion of Polychronakos [Phys. Lett. B 365, 202 (1996)], with the distribution function given by \( f(\varepsilon) = \frac{1}{(1+\varepsilon T)^{1-\alpha}} \), where \( T \) is temperature, \( \mu \) is the chemical potential, and \( \varepsilon \) is the energy of the respective level. The parameter \( \alpha \) varies between -1 (fermionic case) and +1 (bosonic case). However, unlike the original formulation, it is suggested that intermediate values are located on the unit circle, \( \alpha = e^{i\pi \nu} \), but not on the real axis. In doing so, in particular, one can avoid the case \( \alpha = 0 \) corresponding to the Boltzmann statistics, which is not a quantum one. Such a defined statistics has a seeming drawback as it requires that some physical quantities, like energy or chemical potential, are complex. This is however not a problem as, for instance, complex-valued energy is usually connected to some dissipative processes [G. E. Cragg and A. K. Kerman, Phys. Rev. Lett. 94, 190402 (2005)]. Moreover, approaches involving complex chemical potential have a vast application domain, ranging from quantum chromodynamics [I. M. Barbour et al., Nucl. Phys. B (Proc. Suppl.) 34, 311 (1994)] to the physics of semiconductors [P. K. Chakraborty et al., J. Phys. Chem. Solids 64, 2191 (2003)]. In the work, a system of harmonic oscillators is analyzed. Several cases are considered in detail, namely, the limits of \( \nu \to 0 \) and \( \nu \to 1 \) reproducing small deviations from the Bose and Fermi statistics, respectively. Also, the case of a non-conserving number of excitations, which can be defined as \( \text{Re} \mu = 0 \), is studied. Thermodynamic quantities of these systems are calculated.

15P-A004 Ground-state properties of 2D hard-core bosons in superfluid phase within second-order spin wave theory
T. N. Antsygina\textsuperscript{a}, M. I. Poltavskaya\textsuperscript{a}, I. I. Poltavsky\textsuperscript{a},
K. A. Chishko\textsuperscript{a}, \textsuperscript{a}B. Verkin Institute for Low Temperature Physics and Engineering, Kharkov, Ukraine

An analytical expression for zero-temperature thermodynamic potential of the hard-core bosons on a square and triangular lattices in the superfluid phase is derived using the spin-wave theory. We go beyond the standard linear spin-wave approximation calculating corrections due to spin-wave interaction. The model takes into account the hopping of the particles, the nearest neighbor repulsion, and next nearest neighbor interaction which can be of any sign. The internal energy, superfluid density, boson density and compressibility are calculated for different sets of the system parameters. It is shown that even at small particle density the second order corrections to the linear spin-wave approximation are significant at high enough interparticle interactions.

We compare our analytical results for the internal energy, boson density, and superfluid density with a number of numerical data for hard-core bosons on square\textsuperscript{1} and triangular\textsuperscript{2,3} lattices. In all the cases quite good agreement is obtained.

15P-A005 Semi-Phenomenological Approach of Confined Helium Heat Capacity in Mesopores
K. Chalyy*, a Department of Medical and Biological Physics, National Medical University, Kiev, Ukraine
Influence of finite-size effect on the liquid helium $^4$He heat capacity and the shift of the transition temperature are theoretically examined for the cases of cylindrical and slit-like geometry of mesopores. Correlating properties of the systems are studied in terms of the pair-correlation function and associated correlation length. It is shown that growth of the heat capacity taking place at the new transition temperature, which is calculated from the temperature dependence of correlation length within the present geometrical conditions. Specific features of the liquid helium heat capacity in the slit-like mesopores are studied with the effects of gravity and confinement taken into account. The contributions from the gravity effect and finite-size effect to the shift of transition temperature are examined. The calculated results were verified by comparison with available experimental data for the broad interval of diameters ranged from 30 nm to 8.17 μm in cylindrical pores and for the slit-like pores ranging in thickness from 48 nm to 57 μm. It is shown that the proposed approach gives the results that are in a reasonable quantitative agreement with the high-resolution confined helium experimental data, including those that were obtained under microgravity conditions.

15P-A006 Gas Adsorption in Novel Environments, Including Effects of Pore Relaxation
M. W. Cole*, H.-Y. Kim*, S. M. Gatica*, A. D. Lueking†, a Department of Physics, Penn State University, University Park, PA 16802 USA †Department of Chemistry and Physics, Southeastern Louisiana University, Hammond, LA 70402 USA
Adsorption experiments have been interpreted frequently with simplified models such as ideally flat surfaces and slit or cylindrical pores. Recent explorations of unusual environments, such as fullerenes and metal-organic-framework materials, have led to a broadened scope of theoretical and simulation investigations. This talk reviews a number of such studies undertaken by our group. Among the topics receiving emphasis are these: universality of gas uptake in pores, novel phases of gases on a single nanotube and the relaxation of a porous absorbent due to gas uptake, all of which studies are motivated by recent experiments.

15P-A007 Commensurate-Incommensurate Transition in $^4$He Monolayer Adsorbed on a C$_{60}$ Fullerene
Hyeondeok Shin*, Yongkyung Kwon*, a Department of Physics, Konkuk University, Seoul, Korea
Path-integral Monte Carlo calculations have been performed to study adsorption of $^4$He on a single C$_{60}$ fullerene molecule. In order to account for helium corrugations on the molecular surface, the sum of all interatomic pair potentials between a carbon atom and a $^4$He atom is used for the $^4$He-C$_{60}$ interaction. The radial density distributions reveal a layer-by-layer growth of $^4$He with the first adlayer being located at a distance of $\sim$ 6.2 Å from the center of a C$_{60}$ molecule. This first layer is found to exhibit various quantum states as the number of adsorbed $^4$He atoms $N$ varies. For $N$=32 the helium layer shows a commensurate solid structure with twenty helium atoms being localized on the tops of the hexagon centers of the C$_{60}$ surface and the other twelve atoms above the pentagon centers. As more $^4$He atoms are added, a commensurate-incommensurate transition is observed. After going through various domain wall states the first layer is crystallized into an incommensurate solid for $N \sim 52$. We find that solid states observed for $N$=32,44, and 48 do not show any superfluid response even below 0.2 K while domain-wall fluids formed with 45 to 47 $^4$He atoms show significant superfluid fractions below 0.6 K. Finally different quantum states observed in the first $^4$He layer around a C$_{60}$ are compared with phase diagrams determined for the helium monolayer on a graphite surface.

15P-A008 Superfluid Hydrodynamic in Fractal Dimension Space
D.A. Tayurskii*, Yu.V. Lyogorskiy*, a Institute of Physics, Kazan Federal University, Kazan, Russia
The complex behavior of quantum fluids like liquid $^4$He and liquid $^3$He in nanoporous media is determined by the influence of randomly distributed geometrical confinement described by means of a fractal geometry. The thermodynamic limit conditions are violated in a fractal dimension space so all thermodynamic functions become the non-extensive ones and this non-extensivity property should be incorporated into any theoretical model for superfluids. In the present paper the Fractional Schrödinger equation has been used to derive two-fluid hydrodynamical equations for describing the motion of superfluid helium in the fractal dimension space. Nonlinear equations for oscillations of pressure and temperature are obtained and a coupling between pressure and temperature oscillations is predicted. This work is supported by RFBR (grant 09-02-01253) and Ministry of Science and Education of the Russian Federation.

15P-A009 A BCS-BEC crossover in the extended Falicov-Kimball model: Variational cluster approach
K. Seki*, S. Yamaki*, T. Kaneko*, R. Eder*, Y. Ohta*, a Department of Physics, Osaka University, Chia 268-8502, Japan bKarlsruhe Institute of Technology, Institute for Solid State Physics, 76021 Karlsruhe, Germany
Motivated by recent experimental and theoretical studies of the excitonic insulators, we use the variational cluster approximation (VCA) to calculate the single-particle Green's function $A(k, \omega)$ and anomalous Green's function $F(k, \omega)$ of the Falicov-Kimball model.
extended by a finite f-hole valence bandwidth. We thus determine the single-particle excitation gap due to the bound state formation of an electron and a hole. We also evaluate the order parameter $\Delta$ indicating the coherence between $c$ and $f$ states in the excitonic insulating phase. We thereby discuss the excitonic insulator that typifies either a BCS condensate of electron-hole pairs (weak-coupling regime) or a Bose-Einstein condensate of preformed excitons (strong coupling regime). A BCS-BEC crossover of the model thus manifests itself as a function of the Coulombic coupling strength. Details will be reported in Ref. [1].


15P-A010 Phase transitions of $H_2$ adsorbed on the surface of single carbon nanotubes

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We calculated, by means of the Diffusion Monte Carlo technique, the complete phase diagram of $H_2$ adsorbed outside single armchair carbon nanotubes with index in the range from (5,5) to (16,16), and for hydrogen densities up to a single layer completion. In all cases, but the (16,16) one, the ground state was an incommensurate solid, formed by the arrangement of the hydrogen molecules in configurations with planes perpendicular to the axis of the nanotube. For each tube, there is only one of such phases stable in the density range considered, except in the case of the (5,5) and (6,6) tubes, in which two of these incommensurate solids are separated by novel first order phase transitions. In the (16,16) tube, the ground state is a commensurate solid similar to the one found in graphene.

15P-A011 Third Sound in Superfluid $^4$He Films Adsorbed on Packed Multitwist Carbon Nanotubes

Gary A. Williams$^a$, Emin Menachekanian$^a$, $^a$University of California, Los Angeles, CA 90095 USA

Third sound propagation is observed with thin $^4$He films adsorbed on multitwist carbon nanotubes. At an average diameter of 12 nm and a length of several microns, the powder of nanotubes is lightly packed into a cylindrical resonator, with a resistor bolometer at the cylinder end to detect the temperature oscillations accompanying the waves. The lowest standing-wave mode in the cavity is excited by mechanical vibrations, with FFT analysis allowing measurement of the sound speed as well as the dissipation. A finite-size broadened Kosterlitz-Thouless onset transition is observed with increasing film thickness on the outside nanotube surfaces for temperatures between 1.3 and 1.7 K. At higher thicknesses capillary condensation becomes important, probably at connection points where the nanotubes touch. We have seen no indication of effects that might be attributable to the adsorption of helium on the inner surfaces of the nanotubes.

Research supported by the US National Science Foundation, Grant No. DMR 09-06467.

15P-A012 Universality of heat and entropy transport in 1D channels at arbitrary temperatures

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I show that there is a close analogy between the quantities that describe one-dimensional (1D) quantum transport and the thermodynamic quantities of 2D quantum gases at equilibrium; for example the particle, energy, heat and entropy fluxes are analogous to the particle number, internal energy, heat capacity and entropy, respectively. Based on this, I write analytic expressions for the transport quantities and I show that the heat conductivity and entropy current are independent of statistics at any temperature. The quanta of heat conductance is therefore the low temperature limit of the heat conductance of one channel and is the same, as expected from the analogy above, as the low temperature limit of heat capacity. The physical interpretation of this remarkable universality of 1D transport is interpreted microscopically in terms of configurations of particle populations which carry the same heat fluxes.


15P-A013 Phonon excitation for $^4$He confined in nanometer-size uniform channel under pressure

J. Taniguchi$^a$, M. Suzuki$^a$, $^a$Department of Engineering Science, University of Electro-Communications, Chofu, Tokyo 182-8585, Japan

We have studied the property of pressurized $^4$He confined in the honeycomb structure of a nanometer-size uniform straight channel by heat capacity measurements. In this system, due to the narrow channel, a cross over is expected to take place from the one-dimensional (1D) phonon state which is continuous in the axial direction, to the 3D-like state with the excitation to discrete energy levels in the cross section. However, the observed heat capacity shows the power law close to $T^3$ between 0.3 and 0.7 K. The possibilities are that the excitation energy in the cross section is quite low, or that the $T$-cube term comes from both the honeycomb structure and $^4$He in the channel.

15P-A014 Tortional oscillator measurements for superfluidity of $^4$He confined in a porous Alumina nanopore array

S. Murakawa$^a$, Y. Chikazawa$^a$, T. Tanaka$^a$, R. Higashino$^a$, K. Yoshimura$^a$, K. Kuriyama$^a$, K. Honda$^a$, Y. Shibayama$^a$, K. Shibahama$^a$, $^a$Department of Physics, Keio University, Yokohama, Japan $^b$Department of Biological Science and Chemistry, Yamaguchi University, Yamaguchi, Japan

Superfluid helium-4 ($^4$He) confined in nanoporous materials is an attractive system in the quantum fluid studies. Previous work$^1$ revealed that superfluidity of $^4$He confined in 2.5 nm pore was strongly suppressed
at higher pressures. This result is very surprising because the superfluid coherence length is much smaller than the pore size at the transition temperature inside the pore. Using this anomalous suppression, a novel Josephson device might be realized at arbitrary temperature. As nanoporous media, we employed well-characterized porous alumina (PA). As a preliminary experiment, we started to study superfluid properties with a PA regular triangular nanopore array by developing an annulus-type torsional oscillator. The PA’s pore size is 45 nm and thickness is 165 μm. The frequency shift from normal fluid at the lowest temperature showed that almost all fluid was decoupled. In the vicinity of the transition temperature of bulk 4He, two frequency shift onsets, which were assigned to superfluid transitions inside and outside of the pores, were observed. In addition, many dissipation peaks caused by the second sound coupling were detected.


15P-A015 Suppression of KT transition in 4He film under high pressure 3He
S. Murakawa*, M. Wasis*, K. Akiyama*, R. Nomura*, Y. Okuda*, aDepartment of Physics, Tokyo Institute of Technology, Tokyo, Japan
We observed a superfluid transition of 4He films under high pressure liquid 3He by the transverse acoustic measurements of AC-cut quartz transducers. 4He was first adsorbed on the transducer and thereafter 3He was introduced to pressurize the 4He film. Superfluidity was detected as an enhancement of surface specularity which is calculated from the transverse acoustic impedance. The specularity is not constant but has a large temperature dependence: the specularity is zero at high temperature and begins to increase below an onset temperature $T_0$. The frequency dependence of $T_0$ is well explained by the dynamic KT model. Specularity in the low temperature limit has a linear dependence on 4He thickness as the superfluid density has the linear dependence in KT transition of the pure 4He film. From these frequency and thickness dependences, we can conclude that the enhanced specularity is due to the KT transition of the 4He film. $T_0$ is strongly suppressed at higher pressures although 4He film is thick enough. Because transition temperature was much higher in 4He-3He mixture film experiments than $T_0$, the observed suppression is caused not only by the 3He impurity effect but also by the strong particle correlation at high pressures.


15P-A016 4He Adsorption on H2-preplated C20
S. Shim*, Y. Kwon*, aDepartment of Physics, Konkuk University, Seoul, Korea
We have studied adsorptions of H2 molecules and 4He atoms on the surface of a C20 fullerene molecule by using path-integral Monte Carlo method. Fully-anisotropic substrate potentials described by the sum of all pair potentials between H2 or 4He adatom and twenty carbon atoms are employed to incorporate corrugation effects on the C20 molecular surface. Radial density distributions show layer-by-layer growth and the first adlayer is found to be completed with thirty-two H2 molecules. Detailed analysis of angular density distributions reveals that the completed hydrogen monolayer exhibits an ordered state where each of thirty-two H2 molecules is located either above one of the twelve pentagon centers of the C20 molecular surface or above one of the twenty carbon atoms. We find total suppression of hydrogen superfluidity in the completed monolayer while a partially-filled monolayer may show significant superfluid response at low temperatures below $T = 1.0$ K. On the other hand a single layer of 4He atoms adsorbed on top of the completed hydrogen monolayer around a C20 molecule shows different quantum states depending on the number of helium adatoms. A commensurate solid structure with respect to the underlying H2 monolayer is found in a layer consisting of N = 80 4He atoms. Finally we discuss formation of mobile vacancy states and possible realization of nanoscale supersolidity in this 4He adlayer.

15P-A017 Solidification of Second Atomic Layer of 4He Film Adsorbed on Graphite
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3He and 4He films adsorbed on graphite surfaces are almost ideal two-dimensional (2D) Fermi and Bose systems, respectively. The second atomic layer of 4He film is believed to solidify and form a commensurate phase, the so-called “4/7” phase, with increasing areal density from the fluid phase. The second atomic layer of 4He film has also been thought to form the 4/7 phase for a long time according to the heat capacity measurements by Greywall. However, the recent theoretical study by Corboz et al. has revealed that there is no commensurate phase in the second layer of 4He film. Heat capacities of second layer 3He$_{1-x}$4He$_x$ mixture films have been measured in the temperature range 1-80 mK, where x is the areal density ratio to the 4/7 phase and the first atomic layer consists of 4He. At $x = 0.25$ and $x = 0.5$ the results indicate that the films are solid, while at $x = 0.75$ the results exhibit 2D Fermi fluid behavior although the total areal densities are the same. These results strongly suggest that pure 4He film does not solidify into the 4/7 phase. Preliminary measurements of heat capacities of 4He$_{0.03}$4He$_2$ films also suggest that 4He film does not solidify up to much higher areal density than that of the 4/7 phase. These coincide with the prediction by Corboz et al.


15P-A018 DC SQUID NMR Study of Very Dilute 3He-4He Mixture Films in Nanopores
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We have used DC SQUID NMR and vapour pressure measurements to study very dilute $^3$He-$^4$He mixture films adsorbed in the mesopores of MCM-41, down to 1.7 K. The substrate is a powder of grain size $\sim 300$ nm which consists of a hexagonal array of straight 2.3 nm diameter pores. The pores were initially preplated with 1.12 monolayers of $^4$He before adding 0.01 monolayer of $^3$He. At such low $^3$He coverages this system is expected to exhibit a crossover to a quasi-1D state at temperatures sufficiently below 700 mK. Evidence for such a crossover has been observed on a similar substrate, using heat capacity measurements. In order to get sufficient signal sensitivity at this low $^3$He coverage, we developed a broadband NMR spectrometer based on a SQUID with additional positive feedback (APF), which has an overall coupled energy sensitivity of 30 h with the SQUID at 1.7 K, where $h$ is Planck's constant. NMR relaxation times $T_1$ and $T_2^*$ were measured as a function of temperature at frequencies from 80 to 240 kHz. $T_1$ and $T_2^*$ were found to be independent of $^3$He coverage at very low densities, suggesting that the relaxation times are dominated by single particle effects. These data were consistent with 2D diffusive motion in magnetic field gradients. Changes in the observed relaxation times measured as a function of $^4$He density were found to follow changes in the isothermal compressibility of the film.


15P-A020 Possible Finite-Length 1D Superfluidity of $^4$He Adsorbed in Nanochannels

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Using straight nanochannels in silicates FSM, 1.5–4.7 nm in diameter and about 300 nm in length, the superfluid densities of $^4$He adsorbed in 1D channels and the pore-size dependence have been measured systematically. These studies show that superfluid fraction exists in channels wider than 1.8 nm and that there are qualitative differences between 2.2 and 2.8 nm in diameter. At present, we have examined the superfluid density and accompanying dissipation of $^4$He adsorbed in 2.4 nm channels by the torsional oscillator method. At relatively high densities where $^4$He adatoms do not form film, a large dissipation peak related to $^4$He superfluid in nanochannels is observed at low temperatures, separately from a sharp peak at $T_{cK}$ due to the Kosterlitz-Thouless transition of $^4$He film on grain surface of FSM powder. Correspondingly, the superfluid density in channels grows gradually towards lower temperatures. Recent theoretical studies show that in the 1D system with a finite length, the superfluidity does not vanish by phonon fluctuations, but phase-slip excitations play a major role. The characteristic temperature $T_{ps}$ depends on the 1D $^4$He density and also the system length itself. The $T_{ps}$ is comparable to $T_{cK}$ for 300 nm length, depending on the pore size. The gradual increase of the superfluid density observed in these nanochannels qualitatively agrees with that expected for the finite-length 1D superfluid.


15P-A021 Superfluid Flow and Critical Velocity of Liquid Helium in a Single Nanohole

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We present the first measurements of the normal and superfluid flow of liquid helium through a single nanohole of radius $R < 25$ nm. Our experimental scheme [1] has the sensitivity required for direct measurement of mass flow through a single nanohole. In liquid helium I, it is shown experimentally that there is a classical mass flow that is not clamped in our nanohole of aspect ratio $L/D \approx 1$. The helium mass flow above $T_J$ is successfully described/quantified using a viscous flow model in a cylindrical short-pipe. In the helium II region, the normal contribution to the flow can be subtracted from the total mass flow in order to extract the superfluid contribution. From this superflow, superfluid velocities through the single nanohole are obtained for various densities above saturated vapor pressure and for temperatures down to 1.5 K. These velocities com-
pare well with the intrinsic critical velocities previously observed in larger micro-apertures, and from the vortex half-ring nucleation theory. Finally, we discuss our plan to use helium flow in a ~1 nm diameter nanohole to study one-dimensional behavior in helium where a Luttinger liquid is predicted to occur [2].


15P-A022 Spin-spin Relaxation Time Measurements of 2D $^3$He on Graphite

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Monolayer $^3$He adsorbed on Grafoil (exfoliated graphite) preplated with monolayer $^4$He is an ideal two-dimensional (2D) fermion system. Some years ago, we measured spin-spin relaxation time ($T_2$) of 2D $^3$He in the second layer by the spin echo technique of pulsed-NMR near localization and found unusual behavior not explained by a simple first-order transition between liquid and solid phases. We now extended our measurements to the pure fluid density region ($0.7 < \rho_2 < 5.3$ nm$^{-2}$) where the magnetization shows an expected temperature dependence for Fermi degeneracy with $\rho_2$ and $T_F$~300 mK. The $T_2$ value measured at $T = 100$ mK and $f = 5.5$ MHz shows a broad maximum of 5.7 ms around $\rho_2 = 2$ nm$^{-2}$. This can be related to the fact that the effective Fermi velocity becomes maximum near that density. On the other hand, we observed an unexpected measuring frequency ($f$) dependence of $T_2$, i.e., the inverse $T_2$ varies in proportion to $f$ at least in the range of $1.16 \leq f \leq 5.5$ MHz. This is curious since basically $T_2$ should be independent of $f$ as long as $f \ll k_BT_F/\hbar$ ($\approx$ several GHz). This could be explained by spin diffusion in a microscopic magnetic field inhomogeneity caused by the huge diamagnetism and mosaic angle spread of Grafoil substrate. A similar frequency dependence of $T_2$ was also reported in the earlier pulsed-NMR study of submonolayer solid $^3$He$^1$. We are now preparing new measurements at much lower frequencies where the intrinsic $T_2$ can be determined with good precision by extrapolating to zero frequency.


15P-A023 Helium Adsorption and Superfluidity on Lithium and Sodium

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The lighter alkali metals are of interest for helium surface phase transition studies because they are intermediate strength substrates. This means that they are stronger than cesium so they are completely wet by helium even at $T=0$, but weaker than conventional substrates such as gold or glass, so that no localized solid-like layers are expected to form. We have used in situ low temperature laser ablation to form substrates of lithium and sodium on the surfaces of a quartz crystal microbalance (QCM). Helium adsorption isotherms were measured in the temperature range $0.4K < T < 1.6K$. At temperatures above 1K, the coverage on both substrates is linear in the pressure up to approximately 1 monolayer. The binding energies we obtain for lithium and sodium are -13.7 K and -9.5K, respectively, which are in reasonable agreement with theoretical predictions. Standard models also predict that helium films less than 2 layers should be unstable on sodium, with a first order prewetting transition to a thick film, but our data show continuous growth at all temperatures. For $T > 1K$, superfluid onset is marked by the conventional features of a Kosterlitz-Thouless (KT) transition. At lower temperatures, however, the transition temperature becomes a nonlinear function of the coverage. We discuss the possibility that this behavior is due to an intersection of the KT transition with the 2D liquid-vapor transition.

15P-A024 Superfluid density in quasi-one dimensional systems

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Superfluidity (SF) in quasi-one or one-dimensional (1D) systems has recently attracted much interest. An example is experiments on $^4$He confined in nanopores$^1$. Superfluid behavior of cold atoms confined in a 1D trap has also attracted interest.$^2$ $^4$He atoms are adsorbed on the inner walls of 1D nanopores, forming nanotubes (films). When the density increases, liquid $^4$He fills the nanopores and forms nanobars (rods). We first discuss the similarity and difference between SF in nanotubes and in nanobars. Superfluid density in both cases is strongly suppressed by phase slippage at extremely low temperatures, but the observability of this suppression may significantly differ, because of the difference in the number of thermally excited vortex pairs$^3$. In films, the number of vortex pairs are so small that it is difficult to observe the suppression at low temperatures. In this connection, we also discuss the difference between purely 1D and quasi-1D cases. Again, superfluid density is strongly suppressed at extremely low temperatures in both cases, but the mechanism of the dissipation of superflow and therefore the observability of the suppression may significantly differ between the two cases.


15P-A025 Entanglement spectrum of one-dimensional extended Bose-Hubbard model

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The entanglement spectrum provides crucial informa-
15P-A026 Superfluidity of $^4$He confined in a nanopore array probed by a vibrating wire
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Recent experiments have revealed that superfluidity of $^4$He confined in some nanoporous materials is strongly suppressed under pressure. Since the pore sizes of the materials, which span between 2 and 3 nm, are much larger than the superfluid coherence length ($\sim 0.3$nm), the experiments imply a new suppression mechanism by strong correlation between $^4$He atoms inside the nanopores. Another intriguing possibility is to utilize the suppression phenomenon to realize a superfluid weak link. Here we report on the measurement of the superfluid transition of $^4$He in a regular array of nanopores made of porous alumina (PA). We employ vibrating wire technique, in which a PA flake is glued to the point of a semicircular NbTi wire and is vibrated in superfluid $^4$He at various pressures. In a preliminary measurement using PA with 45 nm diameter nanopores, we have observed superfluid transition inside the nanopores as abrupt changes in resonant frequency and linewidth of the composite wire oscillator. Further measurement using 10-nm nanopores is underway.


15P-A027 Ultrasound Measurement of Confined $^4$He near the Quantum Critical Point
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In a previous torsional oscillator study, we discovered a quantum phase transition (QPT for short) in $^4$He confined in a nanoporous Gelsil glass (pore size: 2.5 nm). The superfluid - nonsuperfluid transition occurs when the pressure is swept around 3.4 MPa (critical pressure $P_c$) near 0 K. Theories with a classical analogue of QPT predict that the characteristic time scales that dominate the quantum fluctuations diverge at the quantum critical point (QCP for short), same as other classical dynamic critical phenomena. If the time scales characterizing superfluidity diverge at QCP, some quantities, such as superfluid density, will become strongly frequency dependent near $P_c$. We study the possible frequency effect on superfluid properties by the ultrasound technique, which provides information on the superfluid density and dissipation at frequencies from 1 to 100 MHz, which are from 3 to 5 orders of magnitude higher than that of the torsional oscillator method. We employ a Gelsil sample with the same pore size as the previous torsional oscillator study. A preliminary result shows that the temperature dependence of sound velocity depends on frequency.


15P-A028 What can we learn about near-resonance quantum gases from 2- and 3-atom problems
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Recently, quite remarkable progress has been made to probe many-body correlations in quantum gases near resonance. Theoretically, although we are reasonably successful in a few special limits, in general the subject of unitary gases represents a major challenge in theoretical physics because of the lack of controllable theoretical approaches. In many cases, even a qualitative picture is absent. In this talk, I am going to discuss a few cases with partial successes and illustrate what we have learned from the few-body physics. Our studies suggest that 3D Bose gases near resonance are nearly fermionized, to certain extend analogous to the one dimensional Tonks-Girardeau gases. Towards the end of the talk, I will also briefly discuss the non-universal aspect of the nearly fermionized Bose gases and the role of Efimov physics.

15P-A029 $^3$He Effect on 2D Superfluidity in $^3$He-$^4$He Mixture Films on Planar Gold
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There have been a number of studies exploring the nature of 2D superfluidity and configuration of $^3$He-$^4$He mixture films on various substrates. At $T = 0$, $^3$He tends to float on top of underlying $^4$He due to the different zero point energies, and the overlayer $^3$He strongly affects the 2D superfluidity. A previous torsional oscillator study, in a thick $^3$He overlayer ($n_3 \sim 136 \text{ mol/m}^2$), reports an extra depletion of the superfluid density at low temperatures and a suppression of the superfluid transition temperature, yet mechanism of $^3$He effect on the 2D superfluidity has not been set-
tled. We present here a result of QCM (quartz crystal microbalance) measurements on planar gold substrate. Our measurements are done by keeping a constant $^3$He coverage (0, 1.7, or 19.0 $\mu$mol/m$^2$) and then adding $^4$He. For the mixture films with $n_3 \sim 1.7 \mu$mol/m$^2$, no effect of $^3$He on the superfluidity is observed. However, for $n_3 \sim 19.0 \mu$mol/m$^2$, we observe a strong effect of $^3$He on the superfluidity as well as the previous study$^1$. It is suggested, as one of possible scenarios, that $^3$He in the mixture films reduces the vortex core energy above a critical value of $^3$He between 1.7 and 19.0 $\mu$mol/m$^2$.


15P-A030 Supersolid Behavior and Inertial Anomalies in Solid $^4$He Formed in Nanoporous Media

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"Non-classical rotational inertia (NCRI)" observed in solid $^4$He formed in a porous Vycor glass [1] has been remaining as a puzzle in theoretical interpretations for possible supersolidity in solid $^4$He. To elucidate the mechanism of NCRI, we have made torsional oscillator studies for solid $^4$He in a nanoporous Gelsil glass, which has much narrower pores (2.5 nm) than Vycor has. Most of the supersolid properties found in bulk solid are also observed in the confined solid. Moreover, we observe an additional decrease in rotational inertia accompanied with a dissipation peak around 1 K. This "high - $T$ inertial anomaly" has a slight, systematic dependence on pressure but no dependence on oscillation velocity, unlike the NCRI seen below 0.15 K. We attribute the high - $T$ anomaly to a relaxation of microscopic excitations in amorphous solid $^4$He. Similar inertial anomaly is observed in thin solid $^4$He films adsorbed on the same porous glass sample. The onset temperature decreases to 0 K as the superfluid critical coverage approaches, suggesting that the inertial anomaly in solid films is related to a quantum phase transition between a gapped solid and a genuine superfluid [2].


15P-B001 Enhancement of d-wave superconducting correlations in the three-band Hubbard model coupled to apical oxygen phonons

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We study the hole binding energy and pairing correlations in the three-band Hubbard model coupled to an apical oxygen phonon, by exact diagonalization and constrained-path Monte Carlo simulations. In the physically relevant charge-transfer regime, we find that the hole binding energy is strongly enhanced by the electron-phonon interaction, which is due to a novel potential-energy-driven pairing mechanism involving reduction of both electronic potential energy and phonon related energy. The enhancement of hole binding energy, in combination with a phonon-induced increase of quasiparticle weight, leads to a dramatic enhancement of the long-range part of d-wave pairing correlations. Our results indicate that the apical oxygen phonon plays a significant role in the superconductivity of high-$T_c$ cuprates.

15P-B002 Superconducting Microcosmic Theory of high-Tc cuprates (I)

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A valid high-Tc superconducting microcosmic theory must concretely use various physics parameters from cuprates to perform theoretic calculations, which must accord with the relevant tested results. Here report we pursue the cuprate superconducting attributes in foundation of many key experimental observations, through the deep logic analyses, “Electric Coupling and Phonon Driving” are concluded as the necessary and sufficient condition for cuprate superconductivity. This article, as Part (I) of our theory, discusses “Electric Coupling” how to self-organize Electron Pairs and how to establish a series of formulas, which concretely use the parameters from cuprates to perform theoretic calculations, for example, the theoretical energy of pair breaking for TI2223, TI2212, (BiPb)2223 and Y123, and the highest temperature of pseudogap appearing for LSCO, Y123 and Bi2212. These data are well accordant to the relevant experiments. Especially, the $T_c$ tested values confirm precisely our $T_c$ calculations for TI2223, TI2212, TI2201, Bi2223 and Bi2212. Besides, we can determine the $\Theta_D$ from the tested $T_c$, for example, Hg1223 theoretical $\Theta_D \approx 290 K (T_c = 135 K)$, Hg1212 theoretical $\Theta_D \approx 278 K (T_c = 124 K)$, and Hg1201 theoretical $\Theta_D \approx 243 K (T_c = 94 K)$. Many theoretical calculations are waiting for the experimental validation. Moreover, we identify the microcosmic origins of such experimental observations as the stripe phase, pseudogap, bare-hand pairing, the $T_c$ suppressed by the curved CuO$_2$ planes, and even Y123 double $T_c$ etc. More relevant contents will be expounded in “Phonon Driving” as Part (II) of our theory.

Session 15P-B:
B8 Mechanisms of Superconductivity
B9 Others
Monday August 15, 16:00 – 18:00
Exhibition Hall 1
15P-B003 Superconducting Microscopic Theory of high-Tc cuprates (II)

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In the theory (I) we achieved “Electric Coupling” formulas and its relevant theoretic data, which are well accordant with the tested results, and we identify yet the microscopic origin of such experimental observations as the strike phase, pseudogap, beforehand pairing, the $T_c$ suppressed by the curved CuO$_2$ planes, and even Y123 double $T_c$ etc. This article, as Part (II) of our theory, discusses dynamic Superatom from “Phonon Driving” and its relevant theoretic calculations, such as $V_{EP}$ (the velocity of Electron Pair) and $R_{VC}$ (the radii of Vortex Current) in the typical cuprates for Y123, Tl2223, Tl2212, Tl2201, Bi2223, Bi2212 and LSCO, and $D_{EPM}$ (the density of Electron Pair in Meissner Effect) and $N_{dH}$ (the number of disappeared holes in Hall effect) etc. Especially, some finite tested results validate effectively such theoretic data as $R_{VC}$ for Y123, Bi2212, (Nb) and (PbIn), and $N_{dH}$ for Y123, Tl2223, Tl2212, Tl2201, Bi2223, Bi2212 and LSCO. Through the deep logic analyses, we conclude that “Zero Resistance”, “Meissner Effect” and “superconducting Perpetual Current” all originate from “Phonon Driving”. Significantly, we reveal that “superconducting Perpetual Current” may imply a profound physics meaning, which should perform an abnormal Thermal Effect. Such a theoretic prediguration and more calculations are waiting for the experimental examinations.

15P-B004 Bogoliubov-de Gennes analysis of d-wave superconductors through an ARPES-parameterized Hubbard model

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Starting from the generalized Hubbard model, in which correlated-hopping interactions are included in addition to the repulsive Coulomb ones [1], we solve numerically the Bogoliubov-de Gennes equations [2] in order to quantify the magnetic-field effects on the critical temperature, d-wave superconducting gap, and the electronic specific heat. Since the z-direction applied magnetic field breaks the translational symmetry on the CuO$_2$ planes, the supercell method is used and the Bogoliubov-de Gennes equations are self-consistently solved [3]. In particular, this Hubbard model involves both single and correlated electron hopping parameters between first and second neighbors. Within the mean-field approximation, we have determined these parameters from the Angle Resolved Photoemission Spectroscopy (ARPES) data [4]. Finally, experimental implications of our numerical results are also discussed.


15P-B005 Microstructure and superconducting properties in GdBa$_2$Cu$_3$O$_{7-δ}$ bulk with additives of nano particles

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It is regarded as an effective method to improve the flux pinning performance by the additives of the secondary phase inclusions in nano sizes into high temperature superconductor bulks. We prepared the single domain superconductor GdBa$_2$Cu$_3$O$_{7-δ}$ bulks with variable additions of (ZnO+ZrO$_2$+SnO$_2$) nano-particles in air by using top seed melt-textured growth process. The effect of nano-particle additions on superconductivity properties has been investigated. An enhancement of the critical current $J_c$ in low and intermediate field at 77K and trapped field was discovered by the additions of the nano-particles. The microstructure measurements show that the nano-particle inclusions enhance with the increase of the content of nano-particles, which may illuminate the $J_c$ of the specimens.

15P-B006 INVESTIGATION OF THE BCS GAP EQUATION FOR d +i d CUPRATE SUPERCONDUCTORS

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We consider a (d$_s$-d$_y$ + i d$_y$) cuprate superconductor and model the functional dependence of the corresponding pairing interaction $V(k,k') = (V_{xy}(k,k') + V_{zy}(k,k'))$ of purely electronic (or a combination of electron-electron (e-e) and electron-phonon(e-ph)) origin by a function of the form $V_{rad} = [(V_{s2-y2}(k_F,k_F) + V_{s2-y2}(k_F,k_F)) \times F(\phi^2')]$, where $V_{s2-y2}(k,k') = V_1 (\cos k'x_1 - \cos k'y_1) (\cos k'x_2 - \cos k'y_2)$, $V_{xy}(k,k') = V_2 \sin k'x_1 \sin k'y_1$. The coupling strengths, $k_F$ is the Fermi momentum, $\phi = \arctan(k'y_1/kx_1)$, and $(kx_1 k'y_1)$ belong to the first Brillouin zone (BZ). Within the BCS framework, the interactions lead to superconducting gap $\Delta_{d+i d}(k)$ with nodes and anti-nodes in the single pairing channel. The gap may be thought of as development of a small d$_y$ superconducting order parameter (OP) phased by $p/2$ with respect to the principal d$_s$-d$_y$ one leading to the violation of both parity and time-reversal symmetry. We show that the zero-temperature superconducting gap, in the antinodal/nodal regions, is non-zero/zero provided the dimensionless coupling strength $g(k_F)cF/2V_2 = 0$, where the quantity $D$ is the density of energy states. This inequality is found to be satisfied if the Fermi momentum components do not get perched anywhere in the regions around $\{(\phi,\pm \pi/2, \pm \pi, 0)\}$ in the first BZ for $V_1<0$ and $V_2<0$, or $V_1<0$ and $V_2>0$. 272
For $V_1>0$ and $V_2>0$ or $V_1>0$ and $V_2<0$, the requirement is just the opposite. The restrictions could be realized by manoeuvring the doping level in a hole-doped system. We find that the OP amplitude ($\Delta_0/h\omega_c$) is an increasing function of $g(k_F)$.

15P-B007 Electronic Raman Response in Electron-Doped Cuprate Superconductors
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The electronic Raman response in the electron-doped cuprate superconductors is studied based on the kinetic energy driven superconducting mechanism. It is shown that although the domelike shape of the doping dependent peak energy in the $B_{2g}$ symmetry is a common feature for both electron-doped and hole-doped cuprate superconductors, there are pronounced deviations from a cubic response in the $B_{1g}$ channel and a linear response in the $B_{2g}$ channel for the electron-doped case in the low energy limit. It is also shown that these pronounced deviations are mainly caused by a nonmonotonic $d$-wave gap in the electron-doped cuprate superconductors.

15P-B008 Charge transfer instability and phase diagram of a model doped cuprate
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Large body of experimental data points towards an unique charge transfer (CT) instability of parent insulating cuprates. True CT gap in these compounds is believed to be as small as 0.4-0.5 eV as derived from the midinfrared absorption measurements rather than 1.5-2.0 eV as usually derived from the fundamental absorption measurements. In fact we deal with a competition of the conventional ($\Delta k^0$) ground state and a CT state with formation of electron-hole (EH) dimers which evolves under doping to an unconventional EH bosonic system, or EH Bose liquid formed by electron and hole CuO$_2$ centers having been glued in lattice due to strong electron-lattice polarization effects. Making use of a quantum Monte-Carlo technique we study the evolution of the phase state of CuO$_2$ planes in a model CT unstable cuprate kind of Li$_2-x$Sr$_x$CuO$_4$. Nonisovalent doping indeed gives rise to a nucleation of the inhomogeneous EH Bose liquid in supersolid CO+BS phase characterized by a charge (CO) and off-diagonal Bose superfluid (BS) order parameters which competition results in a generic T-x phase diagram. The simulation does reproduce main features of the doped cuprates, in particular, fast suppression of antiferromagnetism, a pseudogap regime due to charge ordering and formation of a local superconductivity. We have attempted to incorporate a broad enough collection of experimental (optical, Raman, photoabsorption, photocemission,...) results to demonstrate validity of the main message.

15P-B009 Influence of correlations on transitive electron-phonon couplings in cuprate superconductors
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We study a model for the CuO$_2$ plane of high-T$_c$ superconductors where the charge carriers are coupled to $A_{1g}$ and $B_{1g}$ symmetric out-of-plane vibrations of the oxygen atoms in the presence of local Hubbard correlations. The coupling is implemented via a modulation of the hopping integral and we calculate the renormalization of vertex and pairing scattering functions based on the time-dependent Gutzwiller approximation. Contrary to local electron-phonon couplings we find that the transitive coupling can even be enhanced by correlations for certain momenta and symmetries of the vibrations. While this effect may be important for certain properties, we find that, with regard to superconductivity, electron-electron correlations still generically lead to a suppression of the pairing correlations. Our results allow for an estimate of correlation effects on the electron-phonon induced pair scattering from weak electron-electron interactions up to the Mott regime. For onsite repulsions relevant to cuprate superconductors our calculations reveal a significant contribution of $B_{1g}$ phonons to $d$-wave superconductivity.

15P-B010 Phase Slippage and Josephson Phenomena in Wide Superconducting Films
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Resistive state properties of wide superconducting films of tin have been studied experimentally. This state is connected in our case with the phase-slip lines (PSLs) arising against a dynamic vortex state due to an evolution of the vortex instability. Formation of the first PSL structure occurs at the point of maximum viscosity much earlier, than the thermal instability destroys a superconducting phase - due to an optimal specific resistance of the samples and effective heat removal. We investigated the magnetic field dependencies of the critical currents when the PSL structures appear. Application of an external field results in randomly oscillating I(H) curves. Heights of the peaks and troughs are very variable, and there are no quite definite oscillation periods and central peaks. Nevertheless, these curves are reproducible. To analyze this phenomenon we consider the PSL as a specific Josephson junction

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consisted of a large number of small individual contacts, and suppose that there is enough trapped flux present to make the phases of the contacts random in zero applied fields. This explains why there were no central peaks. In an external field the phases of the individual contacts change, but they remain random. We check this model quantitatively with Fourier analysis to find an autocorrelation function and estimate the widths of individual contacts and PSL as a whole, for different samples and temperatures.

15P-B011 Doping Dependence of Electromagnetic Response in Electron-Doped Cuprate Superconductors
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Within the framework of the kinetic energy driven superconducting mechanism1, the doping and temperature dependence of the electromagnetic response in the electron-doped cuprate superconductors is studied. In the analogy to the hole-doped case2, the low temperature magnetic field profile follows an exponential decay at the surface, while the magnetic field penetration depth depends linearly on temperature except for the strong deviation from the linear characteristics at extremely low temperatures. In particular, the superfluid density exhibits a peak around the critical doping \( \delta \approx 0.22 \), and then decreases at both lower doped and higher doped regimes.


15P-B012 Quasiparticle Scattering Interference in Electron-Doped Cuprate Superconductors
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Within the kinetic energy driven superconducting mechanism1, the quasiparticle scattering interference phenomenon and the related quasiparticle extinction in the electron-doped cuprate superconductors is studied in the presence of a single impurity. By calculation of the Fourier transformed ratio of the local density of states at opposite energy, it is shown that the quasiparticle scattering interference phenomenon can be reproduced qualitatively by a single impurity in the kinetic energy driven nonmonotonic d-wave superconducting state. In analogy to the hole-doped case2, the amplitude of the quasiparticle peak increases at the low energy, and reaches a maximum at the intermediate energy, then diminishes to zero at the high energy.


15P-B013 Superconductivity and pseudo-gap behavior in organic Mott systems, \( \kappa-(BEDT-TTF)_2X \) with triangular lattice
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The \( \kappa-(BEDT-TTF)_2X \) salts are recognized as model systems for Mott physics. \( X=\text{Cu}[\text{N(CN)}_2]_2\text{Cl} \) compound, which has an anisotropic triangular lattice, is a Mott insulator with an antiferromagnetic transition at 25 K. Superconductivity appears under pressure or the substitution of X by \((\text{Cu}[\text{N(CN)}_2]_2\text{Br} \) and \((\text{Cu}[\text{NCS})_2]_2 \). \( X=\text{U}_{2}(\text{CN})_3 \) is also a Mott insulator and a more isotropic triangular-lattice system. It does not show a long range magnetic order down to low temperatures due to strong spin frustrations. It undergoes a superconducting phase transition at 4 K under pressure. The \( \kappa-(BEDT-TTF)_2\text{Hg}_{3-\delta}\text{Br}_8 \) is a doped Mott insulator with a triangular lattice system due to non-stoichiometry of Hg. We have performed \( ^{13}\text{C} \) NMR measurements in superconducting states of the four organic superconductors above. For all of the superconducting phases, \( T_1/2 \) was found to show the \( T^4 \) temperature dependence and no Hebel-Slichter peak. The pseudo-gap behavior is only observed in deuterated \( \text{Cu}[\text{N(CN)}_2]_2\text{Br} \) and \( \text{Cu}[\text{N(CN)}_2]_2\text{Cl} \), which locates just on Mott boundary. This fact suggests that the pseudogap behavior is related to not only Mott transition but also the spin frustrations.

15P-B014 STM Spectroscopy on deuterated \( \kappa-(BEDT-TTF-d[n,n])_2\text{Cu}[\text{N(CN)}_2]_2\text{Br} \)
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We performed the STM Spectroscopy measurements on deuterated \( \kappa-(BEDT-TTF-d[n,n])_2\text{Cu}[\text{N(CN)}_2]_2\text{Br} \) to clarify the relation between the superconducting state and the strength of electron correlation in organic superconductors BEDT-TTF family. It is predicted by the spin fluctuation mechanism that the node direction of d-wave superconducting gap changes depending on the dimerization in \( d[n,n]-\text{Cu}[\text{N(CN)}_2]_2\text{Br} \) corresponding the electron correlation. We report the results for \( d[2,2]\text{Cu}[\text{N(CN)}_2]_2\text{Br} \) and \( d[3,3]\text{Cu}[\text{N(CN)}_2]_2\text{Br} \) with the stronger electron correlation than \( d[0,0]\text{Cu}[\text{N(CN)}_2]_2\text{Br} \). We investigated both the conducting plane and lateral surfaces in the STM measurement. The superconducting gap observed as the differential conductance on conducting plane (a-c plane) has a V-shape functional form, and is explained by the line nodes model with d-wave symmetry. In addition, the gap varied systematically depending on the direction of lateral surface. From the analysis of angular dependent gap function we found that the node direction of d-wave in \( d[2,2]\text{-salt} \) is along \( \pm \varphi \) same as \( d[0,0]\text{-salt} \). We also found that the node direction in \( d[3,3]\text{-salt} \) is \( \pm \alpha \) direction. These directions are confirmed by the observation of ZBCP at the lateral surface near node direction. It suggests that the dimerization in \( d[2,2]\text{-} \) and \( d[3,3]\text{-} \) is still weak although these salts are situated near Mott boundary. While the re-
sults of d[3,3]-salt with larger dimerization suggest that the node direction rotates toward a little to the $c^*$ axis.

**15P-B015** Electronic structure of FeTe$_{1-x}$Se$_x$

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We report the electronic structure of the iron-chalcogenide superconductor, Fe(Fe$_{1-x}$Se$_x$), obtained with high resolution angle-resolved photoemission spectroscopy and density functional calculations. In photoemission measurements, various photon energies and polarizations are exploited to study the Fermi surface topology and symmetry properties of the bands. Meanwhile, since Se-doping only change the chemical pressure in Fe(Fe$_{1-x}$Se$_x$), we try to reveal how the chemical pressure would change the electronic structure of the superconductors and therefore affect superconductivity. This would be significant to reveal the mechanism of superconductivity.

**15P-B016** Superconductivity in ZrB$_{12}$ with various boron isotope content

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In the unconventional superconductor ZrB$_{12}$ with phase transition from type-I to type II/1\(^1,2\) the heat capacity and magnetization measurements have been carried out on high quality single crystals with various boron isotopes. Critical temperature $T_C\approx6$ K and thermodynamic field $H_C\approx420$ G, density of electron states' renormalization effect, electron-phonon interaction $\lambda\approx0.23$ and superconducting gap $2\Delta(0)\approx20.5$ K have been estimated and compared between Zr$^{10}$B$_{12}$, Zr$^{11}$B$_{12}$ and Zr$^{nat}$B$_{12}$ compounds. Our experiments reveal only slight changes both in the aforementioned characteristics and in the frequency of quasi-local mode ($\Theta_{Q}\approx180$ K), which is responsible for BCS-type superconductivity in zirconium dodecaboride. An analysis of field dependent specific heat in the type-II/1 superconducting state allows evaluating the vortex-core contribution in the Zr$^{nat}$B$_{12}$ series under investigation.


**15P-B017** Observation of Pseudogap State in Disordered NbN using Scanning tunnelling Spectroscopy

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We present an experimental evidence of the formation of a "Pseudogap" state in a disordered conventional s-wave superconductor, NbN, as the system is driven towards the Anderson Metal-Insulator transition. Series of scanning tunnelling spectroscopy measurements done on films with increasing disorder shows that for strongly disordered samples the dip in the tunnelling spectra at Fermi level persists much above the superconducting transition temperature. We propose that the gap like feature at Fermi level is associated with superconductivity based on the observation of BCS like spectra with dip at Fermi level and diffused coherence peaks after correcting them with Altschuler-Aronov background. We propose a scenario based on phase fluctuations to understand the pseudogap state in strongly disordered NbN films. The superconducting order is characterized by the complex order parameter consisting of amplitude and phase. In presence of strong disorder superconductor segregates into phase disconnected islands where superconductivity exists locally, but the global superconducting state is destroyed because of phase incoherence.


**15P-B018** Local Density of States Around Magnetic Impurity in Cuprate Superconductors(LT26)

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The local density of states (LDOS) around a magnetic impurity in the gossamer superconductors at $T = 0$ is studied within the two-dimensional $t-J-U$ model. The order parameters are determined in a self-consistent way with the Gutzwiller projected mean-field approximation and the Bogoliubov-de Gennes theory\(^1\).

We find that the LDOS shows the typical $V$-shape asymmetric curve where is far away from the impurity. A peak is induced around the impurity, but it lies far away from the Fermi energy, which is quite different from the nonmagnetic impurity case. At the same time, we find that the magnetic impurity has little effect on the superconducting gap. The obtained results are qualitatively consistent with experiments.\(^2\)


**15P-B019** Inhomogeneous d-wave Superconducting State of The Doped Cuprate Superconductors(LT26)

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15P-B020 Two-orbital view on the origin of the material dependence of $T_c$ in the single-layer cuprates

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While the significant material dependence of $T_c$ even within the single-layer high $T_c$ cuprates has remained a basic puzzle, a recent paper\(^1\) has demonstrated that the usually considered $d_{x^2-y^2}$ orbital is in fact mixed with the $d_{z^2}$ orbital around the Fermi energy, which is shown to affect $T_c$ in the spin-fluctuation mediated pairing with a two-orbital model that incorporates $d_{z^2}$ as well as $d_{x^2-y^2}$. There, the energy offset ($\Delta E$) between the two orbitals has been shown to govern the extent of the $d_{z^2}$ mixture, hence $T_c$. In the present study, we extend this work to identify which key factors determine $\Delta E$ in the cuprates, focusing on the structural difference among broader (La, Hg, Bi, and Tl) single-layer cuprates. We have revealed that the apical oxygen height ($h_O$) above the CuO$_2$ plane and the distance ($d$) between the CuO$_2$ planes are the important parameters that determine $\Delta E$, thereby causing the material dependence of $T_c$. This picture enables us to capture the $T_c$ variation among the single-layered cuprates in a simple lattice parameter space.


15P-B021 Investigation of a Proposed QCP in Overdoped Region at $x \sim 0.23$ in La$_{2-x-y}$Nd$_y$Sr$_x$CuO$_4$

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Strong reduction of $T_c$ is seen around $x = 1/8$ in LTT phase of La-based 214 cuprates. Recent studies of La$_{2-x}$Ba$_x$CuO$_4$ (LBCO) ($x \sim 1/8$), however, demonstrate the existence of superconducting order in a CuO$_2$ plane even in the static stripe phase. From this, the following picture emerges: (i) superconductivity does not compete, but coexists with stripe order in the CuO$_2$ plane; (ii) the superconductivity for $x \sim 1/8$ losses coherence along the is strongly suppressed\(^1\). By extending the doping region in LNSCO, Daou et al. suggests presence of a quantum critical point (QCP) at $x \sim 0.23$ which separates the static stripe ordered phase and the overdoped Fermi liquid phase\(^2\). However, for Nd-free LSCO, the superconducting and non-superconducting regions are separated by the LTO-HTT structural transition at nearly the same $x = 0.22$. To investigate the presence or otherwise of QCP, we performed optical and transport measurements on crystals with various Nd contents. The result of optical measurement clearly indicates that the c-axis Josephson plasma appears edge below $T_c$ for $x = 0.20$, whereas no plasma resonance for $x = 0.24$ which shows apparent SC transition at $T\sim 10 K$. We conclude that both LSCO and LNSCO with $x = 0.24$ are not bulk superconductors, and that both stripe and SC orders disappear at $x \sim 0.23$.


15P-B022 Electronic structure of iron pnictides in electron and hole doped BaFe$_2$As$_2$

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One of the mysterious issues in iron pnictides is that superconductivity can appear upon both hole doping by the chemical substitution of Ba$^{2+}$ with K$^+$ and electron doping by substitution of Fe$^{2+}$ with Co$^{3+}$. With different substitutions, the electronic structure near the Fermi energy can change dramatically. The unconventional superconductivity in iron pnictides is strongly related to the orbital characters near the Fermi energy. Utilizing polarization and photon energy dependent angle-resolved photoemission measurement, the Fermi crossing, chemical potential and the dispersion of the bands with the $d_{3z^2-r^2}$, $d_{xy}$, $d_{yz}$, $d_{y^2-x^2}$ and $d_{xz}$ character have been systematically studied. Compared to parent compound BaFe$_2$As$_2$, the energy shifts of the bands with the $d_{3z^2-r^2}$ character can reach as much as 120 meV in hole doped sample Ba$_{0.6}$K$_{0.4}$Fe$_2$As$_2$, while in the electron doped compound BaCo$_{0.15}$Fe$_{1.85}$As$_2$, little shifts of these bands are observed. In both electron and hole doped compounds, the bandwidths of the bands with the $d_{yz}$ and $d_{xz}$ characters alter only a little which show rigid-band-like behavior. Moreover, the dispersion, Fermi velocity, and effective mass of the bands with the $d_{xy}$ character change in both cases. Our results show that bands with different characters show distinctive behavior in the electron and hole doped compounds and this could help to understand the mechanism of the superconductivity in the iron pnictides.

15P-B023 Variational Monte Carlo
study for superconductivity in multi-orbital systems

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Recently, the roles of orbital degrees of freedom on various physical quantities in strongly correlated electron systems have attracted much attention. A main reason is because the multi-orbital effect is considered to be important for many superconducting materials including Sr$_2$RuO$_4$, Na$_x$CoO$_2$. $\gamma$H$_2$O, heavy-fermion superconductors, and iron-based superconductors. Among them, the iron-based superconductors have been extensively studied because of their rather high transition temperature $T_c$'s. For this class of superconductors, even the details of the superconducting symmetry have not been settled: some theoretical studies propose the unconventional $s^\pm$-wave symmetry and others indicate the conventional $s^{++}$-wave symmetry. Understanding the mechanism of superconductivity in multi-orbital systems is important for searching a novel superconductor with a higher $T_c$. Here, we study the two- and three-orbital Hubbard models to clarify the mechanism of superconductivity observed in multi-orbital systems. The variational Monte Carlo method is used to investigate the ground state properties and establish the ground state phase diagram. We also examine the role of spin-orbit interaction, which is important especially in 4d and 5d electron systems.\(^1\)


15P-B024 S$^{++}$-wave Superconductivity near the Ferro-orbital QCP in Iron Pnictides

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We investigate the electronic states and the superconductivity in the two-dimensional 16-band $d$-$p$ model extracted from a tight-binding fit to the band structure of iron pnictides,\(^1\) in the presence of both the Coulomb interaction between Fe $d$-electrons and the electron-lattice coupling $g$ with the orthorhombic mode which is crucial for reproducing the recently observed ultrasonic softening of the elastic constant $C_{66}$.\(^2\) Due to the cooperative effects of these interactions, the ferro-orbital order with different occupations of $d_{xz}$ and $d_{yz}$ orbitals occurs and induces the tetragonal-orthorhombic structural transition at $T_N$, together with the stripe-type antiferromagnetic (AFM) order below $T_N$. For a large $g$ case, we obtain the phase diagram consistent with the doped iron pnictides with $T_s > T_N$ for $x > 0$, where the $s_{++}$-wave superconductivity is mediated by the ferro-orbital fluctuation which is largely enhanced near the ferro-orbital QCP at $x = 0$ with $T_s \rightarrow 0$. On the other hand, for a small $g$ case, the simultaneous phase transition occurs at $T_s = T_N$ even for $x > 0$, where the $s_{z\pi}$-wave superconductivity is mediated by the AFM fluctuation. Both the $s$-wave states with full superconducting gaps are consistent with most of the experiments but only the former is considered to account for the small $T_s$-suppression against nonmagnetic impurities.


15P-B025 Electronic structure of detwinned BaFe$_2$As$_2$

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The electronic structure of iron based compounds are usually complicated by the mixed information from twinned structure. Here we report the electronic structure of twinned and mechanically detwinned BaFe$_2$As$_2$ by polarization-dependent angle-resolved photoemission spectroscopy at 10K. By comparing the data obtained from the twinned and detwinned samples, we resolved the bands from different domains and their orbital characters. Moreover, the nature of the spin-density-wave is approached by detailed temperature dependence of the electronic structure around Zone center. Our results would help to reveal the intrinsic electronic properties of the spin-density-wave state in iron based compounds.

15P-B026 High-energy Hole-like Excitations and the Evolution Mechanism of Fermi Arc in High-Tc Cuprates

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Recently Yazdani [1] has discussed visualizing Cooper pair formation of the atomic scale in high-Tc cuprates by using the scanning tunneling microscopy. That is, for the optimal and overdoped high-Tc cuprates the onset of the gap is indeed due to pairing, which occurs locally at $T_p$. In addition, it has been suggested that the high-energy (up to about 400meV) hole-like excitations of the normal state are a direct predictor of the strength of pairing, although he cannot present a model for the excitations. The present author\(^2,3\) has proposed the mechanism of T-evolution of the Fermi arc with increasing temperature in high-Tc cuprates, and it is seen that the T-evolution of the Fermi arc is much related to the restoration of the spontaneous symmetry breaking. In this study, we present the evolution mechanism of the Fermi arc with increasing of hole-doping in high-Tc cuprates, and one model for the high-energy (up to about 400meV) excitations, which play an important role on the strength of Cooper pairing.\(^1\)


15P-B027 Possible nature of ground state of HTSC

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We suggest a model for the electron structure of HTSC cuprates that makes it possible to trace the evolution of their electronic structure with the doping and temperature and provides a new explanation for a number of features typical of HTSCs, including the pseudogap and the Fermi arcs. According to this model, unusual properties of these compounds result from their unique electronic structure, favorable for the formation of two-atomic negative-U centers (NUCs) and realization of a peculiar mechanism of the electron electron interaction. One of the basic statements of the model is that charges introduced upon doping remain localized in the vicinity of the dopant ions. The key role of doping is related to the local modification of the electron structure of CuO₆ planes adjacent to the dopants (such a plane being originally a charge-transfer insulator) that results in the activation of NUCs. In turn, free hole carriers appear as a result of the transitions of electron pairs to NUCs.

15P-B028  A possible explanation of Fermi arcs and pseudogap
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In the framework of the model for the electron structure of HTSC cuprates supposed by us earlier, Fermi arcs observed in ARPES appear over the parts of d-gaped Fermi surface (FS) where pair breaking due to pair hybridization (the value of $\Gamma \propto T$ of band states with negative-U centers (NUC) takes place. The transition from the superconducting to the normal state is related to the disappearance of phase coherence, and the pseudogap, which persists in the vicinity of antinodal directions, is of superconductive nature (at optimal doping). At the same time, as the doping is reduced, an insulating gap opens in the FS region from points $(\pm \pi, 0; 0, \pm \pi)$ towards the nodal directions. Other consequences of pair hybridization between the band states and NUCs are nondegenerate distribution of mobile holes and importance of the processes of hole hole scattering through the intermediate states at NUCs, which emerge as the dominant mechanism of carrier relaxation.

15P-B029  High-temperature surface superconductivity in topological flat-band systems
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The restrictions due to requirements of stability for the possible mechanisms of high-temperature superconductivity are discussed. The condition for the static dielectric function to be positive is reexamined. It is argued that the static dielectric function not only can but indeed must be negative in many stable systems, including most of the conventional metals. In the literature up to now a number of incorrect and unfounded statements exist. One of these - that the static dielectric function cannot be negative - is discussed in detail, as well as its consequence, a strong coupling limit on the transition temperature $T_c$. Proofs are given that the static dielectric function not only can but indeed must be negative in many stable systems, including most of the conventional metals. Various types of electron - electron interaction in superconducting cuprates are discussed. An importance of the electron - phonon interaction in cuprates is highlighted. The role of spin-fluctuations effects in novel multiband superconductors is considered.

15P-B030  Superconducting glue: are there limits on $T_c$?
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We systematically studied the transport properties of single crystals Ba(Fe$_2$-xCo$_x$)$_2$As$_2$ $^1$, LaFeAsO and NaFeAs in a pulsed magnetic field up to 60T. Common features were revealed in their magnetoresistance and Hall resistance. Above the structural transition temperature $T_S$, the magnetoresistance is negligible and the Hall resistivity follows regular linear field dependence. Upon cooling down below $T_c$, huge magnetoresistance develops and the Hall resistivity deviates from the conventional linear field dependence. These findings indicate a dramatic change of the electronic structure at $T_S$. Remarkably, we found that the magnetic transition in these samples is extremely robust against magnetic field up to 60T, providing evidence of local-moment magnetism in iron pnictides. We argue that the 3d-electrons of Fe in the iron based superconductors bear a dual nature and the magnetic/structural transitions are driven by magnetic interactions.

We show that the topologically protected flat band emerging on a surface of a nodal fermionic system promotes the surface superconductivity due to an infinitely large density of states associated with the flat band. The critical temperature depends linearly on the pairing interaction and can be thus considerably higher than the exponentially small bulk critical temperature. We discuss an example of surface superconductivity in multilayered graphene with rhombohedral stacking. Our predictions may be used for the search or for an artificial fabrication of layered systems with high- and even room-temperature superconductivity.

Discovery of undoped superconductors, La$_{2-x}$RE$_2$CuO$_4$ and RE$_2$CuO$_4$, brought a question about an electron phase diagram of electron-doped superconductors. In this phase diagram, the superconducting (SC) region is adjacent to the antiferromagnetic (AF) region and the superconductivity suddenly appears at the SC-AF boundary with maximum $T_c$. The discovery is apparently against the phase diagram. Superconductivity in electron-doped superconductors is very sensitive to impurity oxygen at the apical site, whose presence is detrimental to achieving superconductivity. It is hard to control only doping level of charge carrier by conventional sample preparation technique. Hence, we have tried to control the doping level by FET. The $T_c$ of La$_{1.9}$Ce$_0.1$CuO$_4$ increases by 0.1 K with reducing electrons by FET. This result suggests that optimum doping level ($x$) of La$_{2-x}$Ce$_x$CuO$_4$ is $x = 0.1$ and consistent with previous reports. To achieve zero-doping level, FET structure is fabricating on samples of $x < 0.1$.


15P-B033 Study of Electronic Phase Diagram of Electron-doped Superconductors by FET
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Detection of undoped superconductors, La$_{2-x}$RE$_2$CuO$_4$ and RE$_2$CuO$_4$, brought a question about an electron phase diagram of electron-doped superconductors. In this phase diagram, the superconducting (SC) region is adjacent to the antiferromagnetic (AF) region and the superconductivity suddenly appears at the SC-AF boundary with maximum $T_c$. The discovery is apparently against the phase diagram. Superconductivity in electron-doped superconductors is very sensitive to impurity oxygen at the apical site, whose presence is detrimental to achieving superconductivity. It is hard to control only doping level of charge carrier by conventional sample preparation technique. Hence, we have tried to control the doping level by FET. The $T_c$ of La$_{1.9}$Ce$_0.1$CuO$_4$ increases by 0.1 K with reducing electrons by FET. This result suggests that optimum doping level ($x$) of La$_{2-x}$Ce$_x$CuO$_4$ is $x < 0.1$ and consistent with previous reports. To achieve zero-doping level, FET structure is fabricating on samples of $x < 0.1$.

tractive potential between electrons for the forming of Cooper pairs of superconductivity. With this seagull vertex term and a loop model of photon this gauge model gives a unified description of superconductivity and magnetism including ferromagnetism, antiferromagnetism, Bose-Einstein condensation, paramagnetic Meissner effect, Meissner effect, Type I and Type II superconductivity and high-$T_c$ superconductivity. The pseudogap phenomenon and the stripe phenomenon of superconductivity are explained. In this gauge model the doping mechanism of superconductivity is found. It is shown that the condition of two ionization energies of two chemical elements of a material near each other is a factor of the doping mechanism of superconductivity of the material. In this gauge model a formula of the critical temperature $T_c$ is derived. It is shown that the critical temperature $T_c$ is related to the ionization energies of chemical elements of superconductors. From this relation the critical temperature $T_c$ of superconductors can be computed. For the classical superconductors and the high-$T_c$ superconductors such as $La_2-xSr_xCuO_4$, $YBa_2Cu_3O_7$, and $MgB_2$, the computational results agree with the experimental results.

15P-B037 Universal Behaviors and Cross-over from Non-fermi to Fermi Liquid in High Temperature Cuprate Oxides

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Earlier we proposed both U(1) and SU(2) gauge theoretic slave-boson theories of the $t-J$ Hamiltonian for the low dimensional systems of strongly correlated electrons. This theory has been successful in reproducing the dome-shaped phase diagram and consistently fits other physical properties involved with superfluid weight, spectral function and optical conductivity. In this talk, following brief reviews of both experiment and theories, we present studies of both spin and charge dynamics based on our proposed theory. In association we will discuss how the two different spin and charge degrees of freedom are coupled in revealing exotic physical phenomena thus far unseen in other than high temperature superconductivity such as the dome-shaped boson condensation temperature, the boomerang behavior of superfluid weight and peak-dip-hump structures of both spectral function and optical conductivity. Regarding the spin dynamics we unveil physics involved with both temperature and doping dependence of magnetic resonance and associated spin pairing correlations for high $T_c$ superconductivity. We find that the onset temperature of magnetic resonance is the pseudogap (spin gap) temperature $T^*$ and the resonance peak energy $E_{res}$ is shown to have a linear scaling behavior with the superconducting transition temperature, $T_c$, $E_{res}/T_c \approx const$, in agreements with observations. This indicates that the spin pairing correlations or the spin pairing order is responsible for the correlations between $T_c$ and $T^*$ or the spin gap phase and the superconducting phase in high temperature superconductivity. Further the universal scaling behavior in the ratio of $T^*$ to $T_c$ will be revealed and explained. Regarding the charge dynamics we find that the peak-dip-hump structure in optical conductivity is attributed to coupling between the spin and charge degrees of freedom but not to the spin-charge separation for the low (two-) dimensional Mott insulator of present interest. Using the present studies of both the spin and charge dynamics, quantum phase transition point will be located in association with the predicted phase diagram. We find that the spin-charge coupling is essential to reproduce all of the aforementioned physical properties. To put it otherwise, coupling between the charge pairing order and the spin singlet paring order, i.e. the spin fluctuations of the shortest possible correlation length plays a key role for the observed high temperature superconductivity including the universal scaling behaviors mentioned above. In addition, defining a proper supercharge operator we find that a supersymmetric quantum mechanical condition is met only in the vanishing limit of the spin-charge coupling or both the spin and charge pairing orders, at which hole doping a quantum critical point may appear in the phase diagram of high temperature cuprates. In short, coupling between the spin and charge degrees of freedom will be shown to be responsible for the above areas of physics. We acknowledge Sung-Sik Lee, Tae-Hyung Kim, Seung-Jun Shin, Jae-Hyeon Eom and Ki-Seok Kim for valuable helps.


15P-B038 Nonunitary Spin-Triplet SNS Josephson Junction

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In this paper we investigate charge and spin currents in a nonunitary spin-triplet superconductor-normal metal-superconductor Josephson junction using the quasiclassical Eilenberger equation in the clean limit. Superconductors are subjected of a external phase difference. Influence of the misorientation between left and right superconducting gap vectors and thickness of normal metal sandwiched by nonunitary spin-triplet superconductors are studied. Quasiclassical Green functions are used to calculate the transport properties of a system.

15P-B039 Abrikosov vortices in Nb thin films with Nb pillar arrays on top

D. Bothner*, B. Betz*, M. Kemmler*, M. Turad*, R.
15P-B041 Optimization of the Pr doping in the Dy(Bi$_{1.7}$Pb$_{0.3}$)(Sr$_{2-x}$Pr$_{x}$)CuO$_{6+\delta}$ superconducting series

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A series of Bi-2201 having the nominal composition of Dy(Bi$_{1.7}$Pb$_{0.3}$)(Sr$_{2-x}$Pr$_{x}$)CuO$_{6+\delta}$ with 0 < $x$ < 0.50 was prepared by the solid state reaction method. All of them have the orthorhombic phase with a space group of Amma. Orthorhombicity, 2(a-b)/(a+b), decreases with increasing the amount of Pr content. The highest $T_c$ (20.1 K) is found in the sample with $x=0.40$, which has an optimal hole concentration of 0.278(2) analyzed by an iodometric titration. XANES spectra show that valences of the Bi, Pb and Pr are $3+$, $2+$ and $3+$, respectively. Hole concentrations with respect to the amount of Pr substitution investigated by the titration method have the same trend with those obtained by the L-edge Cu XANES spectra.

15P-B043 Pressure-induced superconductivity in Bi$_{1-x}$Sb$_x$ alloy

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We experimentally investigate superconducting Nb thin films with arrays of circular and cross shaped Nb obstacles on top. The samples were fabricated from a single dc magnetron sputtered Nb film by a two step e-beam lithography process in combination with reactive ion etching. With this procedure we can vary the relative thicknesses of the film and the pillars as well as their size, shape and spatial arrangement. When a magnetic field is applied perpendicular to the film, Abrikosov vortices enter the scene. Due to their normal conducting core, these vortices experience the pillars as repulsive antinning sites. Our system provides an easily tunable model for many body systems with repulsive interacting particles in a 2D potential landscape. We investigate the properties of the system by means of transport measurements, from which we deduce the critical current and the critical temperature, that is the complete $I_c(H) - T_c(H)$ phase boundary, in perpendicular magnetic fields $H$ in the milli-Tesla range. We carry out our experiments at a variable temperature between the critical temperature $T_c$ and $T = 4.2$ K with a temperature stability $\Delta T < 1$mK. We focus on commensurability effects between the pillar and vortex arrays and on dynamic trapping of vortices. Furthermore we are superimposing an HF alternating current of variable frequency and amplitude to the dc transport current. This allows us to search for and investigate possible phase-locking phenomena and absolute negative mobility.
We have newly developed a set of phenomenological equations which describe the collective transport in charge density wave (CDW) conductors. In this paper we present our results of numerical study based on these equations. In this calculation, the electron motion and electric field are assumed to be one-dimensional for simplicity. In addition to the ordinary four-terminal configuration (two voltage contacts are attached at the inner side of the current contacts), we also study so-called transposed configuration (voltage contacts at external side of the current contacts). The pinning potential is also introduced phenomenologically. It is shown that the critical current for the sliding of CDW depends not only on the separation of the current contacts but also on the distribution of the pinning potential outside of the current contacts. Current-voltage characteristics of pinned and sliding states of CDW are also studied numerically.

1 A preliminary version of these equations are given in M. Hayashi and H. Ebisawa, Physica C 470 (2010) 5962.

15P-B046 Single crystal growth and physical properties of \( \text{Ba}_1\text{-As}_2\text{Fe}_2\text{As}_2 \)


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Sizable platelet single crystals of \( \text{Ba}_1\text{-As}_2\text{Fe}_2\text{As}_2 \) covering wide K concentrations were grown using a self-flux method. A newly-developed encapsulation technique using commercial stainless steel container allowed the stable crystal growth lasting for more than 2 weeks. For the growth of \( \text{KFe}_2\text{As}_2 \), ternary \( \text{K-Fe-As} \) systems with various starting compositions were examined in order to determine the optimal growth conditions. Employment of KAs flux led to the growth of large single crystals with the typical size of as large as \( 15 \times 10 \times 0.4 \text{mm} \). The grown crystals exhibit sharp superconducting transition at \( 3.5 \text{K} \) with the transition width \( 0.2 \text{K} \), as well as the very large residual resistivity ratio reaching \( 450 \), evidencing the high sample quality. For \( \text{Ba}_1\text{-K}_x\text{Fe}_2\text{As}_2 \), we find that mixture of \( \text{Ba-As} \) and \( \text{K-As} \) flux is also useful for synthesizing large single crystal samples. The superconducting and normal state properties of the grown crystals will be presented.

KFe$_2$As$_2$


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We report the results of cyclotron resonance (CR) experiments in an iron-based superconductor KFe$_2$As$_2$. The CR measurement is a powerful probe to obtain the effective masses directly. In contrast to the quantum oscillations (QOs), it has been believed that the CR effect is attributed to the electron-electron (e-e) interaction. Hence, one can discuss the effective mass ($m^*$) by comparing the experimental results for each sample with the theoretical prediction. The scaling law ($m^*_{\text{dHvA}}$) is the key quantity as well as the conventional DFT and CDFT. Namely, the approximate form of the $m^*$ energy functional is indispensable. We also develop an approximate xc energy functional on the basis of the vorticity expansion approximation (VEA). The $m^*$ energy functional is expressed as the expansion in terms of the anomalous mass. The VEA formula is used as the zeroth-order term of the expansion. The present scheme enables us to predict quantitatively both the critical temperature and critical field of superconductors.


15P-B052 On the scaling analyses of the flux pinning force density estimated for two types of MgB$_2$ specimens

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Magnetic hysteresis loops have been measured for polycrystalline and powder MgB$_2$ samples. Hysteresis loop width $\Delta M$ measured for polycrystalline sample was less than one order of magnitude smaller than that measured for powder sample. Magnetic field dependence of the critical current density estimated from the $\Delta M$ is essentially divided into three regions which may correspond to characteristic vortex states discussed by Blatter et al.$^1$ The irreversibility field $B_{irr}$ for each sample has been derived from so called Kramer plots using relevant magnetic field dependence. The scaling law of the reduced pinning force density was satisfactorily applied to the experimental results for each sample by using thus determined $B_{irr}$. If we define the $B_{irr}$ as a field at which the critical current density becomes $10^6$ (A/m$^2$), such scaling law is apparently applicable to polycrystalline sample and not applicable to powder sample. Such discrepancy may come from that the $B_{irr}$ by two types of definition belongs to different vortex state.


15P-B053 Study of YBCO-BZO pinning properties grown by PLD and MOD techniques

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We present a current-density functional theory (CDFT) for superconductors applied by the magnetic field. The basic variables are the electron density, paramagnetic current density and anomalous density which corresponds to the off-diagonal long-range order. In order to perform actual calculations, the exchange-correlation (xc) energy functional is the key quantity as well as the conventional DFT and CDFT. Namely, the approximate form of the xc energy functional is indispensable. We also develop an approximate xc energy functional on the basis of the vorticity expansion approximation (VEA). $^1$,$^2$,$^3$ The xc energy functional is expressed as the expansion in terms of the anomalous mass. The VEA formula is used as the zeroth-order term of the expansion. The present scheme enables us to predict quantitatively both the critical temperature and critical field of superconductors.
15P-B054 ARPES Evidence of Decoupling of Graphene Film from Ruthenium Substrate by Interface Si-Intercalation (LT26)

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Thermally annealing ruthenium single crystals is a most effective method to fabricate large-scale graphene, but the strong coupling between graphene film and ruthenium substrate makes further research much more complicated. High-resolution angle-resolved photoemission spectroscopy revealed that intercalation of Si on Ru(0001) can lead a decoupling of graphene film from Ru substrate, as demonstrated by the clear and linear bands near the Dirac point.

15P-B055 Guiding Principle of Selection of Substrate Material for Iron Chalcogenide Superconducting Thin Films

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In order to grow high-quality iron chalcogenide superconducting thin film, we investigated the effect of substrates on properties of films. Thin films of FeSe0.5Te0.5 grown on oxide substrates were found to have various structural and transport properties correlated with an occurrence of oxygen penetration from the substrate to the film. The oxygen penetration is surpressed in the higher-Tc films. Because the main driving force of moving oxygen is supposed to be valence change from Fe2+ to Fe3+, substrate materials consisting of only typical elements will work better for the growth of iron chalcogenide superconducting thin film. Based on this idea, we applied fluorides. As an initial trial, we grew FeSe0.5Te0.5 thin films on CaF2 substrate and obtained film shows the superconducting critical temperature of 15 K with sufficient reproducibility. This result strongly indicates that using substrate without valence fluctuation can be effective for the improvement of superconducting properties of FeSe0.5Te0.5 thin films.

15P-B056 Effect of Doping Level on the Crystal Structure of HTSC-copounds at Temperature Range 300-100 K

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Results of diffraction experiments at cooling from 300 to 100 K of HTSC-compounds Bi-2201, Bi-2212, Y,Ca-123 and Hg1-tl-1223 with different charge concentration are presented, unit cell parameters and coefficients of thermal expansion are calculated. Minimum of coefficient of thermal expansion down to negative values was observed at temperature range T1 (≈160 K) - T2 (≈250 K). This behavior is dependent on the doping level of compounds and accompanied by arising of atomic thermal vibration amplitudes in T1 - T2 range. For all systems the coefficient of thermal expansion in this range was minimal for optimal doped samples.

15P-B057 Thickness dependence of structural and electrical properties of electron-doped Sr1-xLaxCuO2 infinite-layer thin films grown by pulsed laser deposition

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As the building blocks for all of the high-Tc cuprate superconductors, the building blocks for all of the high-Tc cuprate superconductors, infinite layer (IL) compounds have the simplest structures and the highest Tc of electron-doped superconductors, enabling fundamental research and improved techniques for synthesizing higher Tc superconductors. However, IL structure is one of the high-pressure forms, which makes it difficult to synthesize a single crystal. Therefore, it is highly desirable to obtain high-quality epitaxial thin films making use of epitaxial effect. Although there are many reported attempts to grow IL thin films on different substrates, no one has systematically studied the
thickness dependence of structural and electrical properties of IL thin films. In this report, electron-doped Sr1-xLaxCuO2 thin films of various thicknesses were deposited on (001) KTaO3 substrate by PLD. IL phase with low resistivity at room temperature was obtained. It is shown that IL peak red shifts with increase of film thickness, indicating the reduction of the tensile strain introduced by the mismatch. With further increase of thickness, there emerges a modulated superstructure phase which is believed to deteriorate superconductivity. Transport measurements showed strong influence of the sample thickness on resistivity and Tc. A moderate thickness is required to obtain IL thin films with optimal properties.

15P-B058 Numerical Study of Radiation Pattern from Intrinsic Josephson Junctions Attached to Finite Size Substrates

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We have numerically studied three dimensional radiation patterns from the mesa-structured intrinsic Josephson junctions attached to finite size substrates. We have considered a model that the mesa is attached to the substrate whose size is similar to that previously used in experiment\textsuperscript{1} and calculated the current and radiation intensity of the mesa as a function of voltage. Then, using these results, we have calculated far field radiation patterns from the mesa at the voltage where the mesa emits high intensity electromagnetic wave and observed the radiation patterns similar to the experimental results. From the similar calculations of radiation patterns for various sizes of substrates, we have found that the radiation pattern changes dramatically with the width of the substrates. This phenomenon can be understood by the diffraction effect at the substrate edges.


15P-B059 Cherenkov Radiation by Josephson Vortex Chain

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We have established, that periodic vortex chain that travels in the long Josephson junction embedded in a dielectric medium emits high-frequency radiation with line spectrum. The radiation of electromagnetic waves from the lateral surface of the sandwich is attributed to the Cherenkov effect and can occur if the velocity of a moving vortex chain is greater than the speed of light in the dielectric. The dependencies of the frequency and power of the radiation lines on the bias current density, which is distributed over the junction and ensures the uniform chain motion with constant velocity, are found. For typical parameters of Josephson sandwiches conditions under which spectrum of radiation lines falls into the terahertz range are pointed out. The spectrum of radiation into a medium with relatively high permittivity consists of a discrete set of harmonics. The frequency of the first harmonic is equal to the ratio of chain velocity to its period. The main frequency of Cherenkov radiation increases proportionally with dc voltage and external magnetic field, that posses to rearrange the radiation spectrum smoothly. Since in the discussed structure the generation arises from large lateral surface, the power of terahertz-band is greater than in the case of radiation from the edges of junction. Results are of interest for use of distributed Josephson junctions as generators of monochromatic radiation. The work was supported by the Presidium of the Russian Academy of Sciences (program no. 22).

15P-B060 Research on the “cos\(\varphi\) term” riddle in Josephson effect (LT26)

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In this paper, we will give a comprehensive analysis and discussion on every term tunnelling current in Josephson effect, especially make to go deep into discussion for the mechanism of “cos\(\varphi\) term” which is one of Josephson tunnelling current, and we advance a new hypothesis successfully. Our work and results not only have greatly theory value, but also have important meanings for practical application of Josephson apparatus.

15P-B061 Critical charge and spin Josephson currents through a precessing spin

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We present a theoretical study of two superconductors coupled over a spin. The spin is treated classically and is assumed to precess with the Larmor frequency due to an external magnetic field. The precession results in spin-dependent Andreev scattering and a non-equilibrium population of the Andreev levels. Charge and spin currents at zero temperature were studied previously.\textsuperscript{1} Here, we focus on the critical current as well as the corresponding spin currents at finite temperatures. At finite temperatures, the spin precession can enhance the supercurrent by a population redistribution. The enhancement leads to a modified current-phase relation and a non-monotonous critical current as function of temperature. This non-monotonous behavior is accompanied by a corresponding change in spin-transfer torques acting on the precessing spin and leads to the possibility of using temperature as a means to tune the back-action on the spin.


15P-B062 Supercurrent through Mono-
layer and Multilayer Graphene

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We have theoretically studied the critical current through superconductor-graphene-superconductor junction using tunneling approximation and diagrammatic technique\textsuperscript{1}. In our theory, electron transfer between superconductors and graphene is treated by tunnel Hamiltonian and the critical current through the junction is calculated by perturbative expansion with respect to the tunneling matrix elements. In this paper, we present our recent development on this topic. We especially pay attention to the differences between tunneling through A- and B-sublattice of graphene. We report the following new results: i) the vanishing density of states at Dirac point in monolayer graphene leads to peculiar temperature dependence of critical current, ii) the critical current of bilayer system oscillates as a function of temperature and junction length, which indicates the existence of intrinsic interference effects in bilayer systems. We also investigate the correspondence of our theoretical results to those obtained by experiments.


15P-B063 Excitation mode characteristics in Bi2212 rectangular mesa structures

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The continuous and coherent electromagnetic waves (EMWs) at THz frequencies with a power of a few μW can be generated from mesa structures of single crystalline Bi$_2$Sr$_2$CaCu$_2$O$_{8+δ}$(Bi2212)\textsuperscript{1}. The emission frequency has been understood to follow two conditions simultaneously: the ac-Josephson effect and the cavity resonance condition\textsuperscript{2}. Recently, we have studied the shape effect of the emission. The obtained results strongly suggest that the cavity resonance condition may be not primarily important for determination of the frequency but the ac-Josephson effect may be responsible for the emission of EMWs from the mesa. Examples of the tunable emission in wide frequencies will be shown.


Monday afternoon, 15

15P-B064 Fluctuation conductance and the Berezinskii-Kosterlitz-Thouless transition in two dimensional epitaxial NbTiN ultra-thin films

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We study on the electric transport properties of epitaxial NbTiN ultrathin films. The film thicknesses in this experiment ranged from 2 nm to 10 nm. The NbTiN films with thickness of 4 nm has mean-field superconducting transition temperature $T_{CD} = 9.44$ K. The excess conductance due to superconducting fluctuations was measured at temperatures near $T_{CD}$. At the low temperatures, the current-voltage characteristic shows a crossover from linear to nonlinear behavior. When the external magnetic field perpendicular to the film surface exceeds the upper critical field, logarithmic temperature dependence of resistance per square is observed at low temperatures, indicating that NbTiN films are nominally 2D in its normal conducting state. We find that there is a consistency between the parametrization of the 2D characteristics of fluctuation paracconductivity above $T_{CD}$ and Berezinskii-Kosterlitz-Thouless type behavior below $T_{CD}$.

15P-B065 Heat capacity measurements of a microgram Pb crystal using ac nanocalorimetry with good absolute accuracy

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Heat capacity measurements using the ac steady state method are often considered not able to provide absolute accuracy. By adjusting the working frequency to maintain a constant phase\textsuperscript{1} and using the phase information to obtain the heat capacity, we have found that it is possible to achieve good absolute accuracy. We present a thermodynamic study of a ~ 2.8 μg Pb superconducting crystal to demonstrate the newly opened capabilities. The sample is measured using a differential membrane-based custom-made calorimeter. The calorimetric cell is a pile of thin film Ti heater, insulation layer and GeAu thermometer fabricated in the center of two Si$_3$N$_4$ membranes. It has a background heat capacity < 100 nJ/K at 300 K, decreasing to 9 pJ/K at 1 K. The sample is characterized at temperatures down to 0.5 K. The zero field transition at $T_c = 7.21$ K has a width < 20 mK and displays no upturn in $C$. The heat capacity jump at $T_c$ and the extrapolation of the Sommerfeld term lead to $\Delta C/\gamma T_c = 3.69$. The deviations of the thermodynamic critical field from the empirical expression $H_c = H_c(0) \left[ 1 - (T/T_c)^2 \right]$ are discussed. Both analyses give results in good agreement with literature. To illustrate the possibility to probe latent heat using the ac method, an investigation of the phase transition in various magnetic fields is also carried out.


15P-B066 Ac susceptibility of a thin type-II superconducting circular washer with and without a radial transport cur-
15P-B: B8 Mechanisms of Superconductivity, B9 Others

Monday afternoon, 15

15P-B067 Mechanism For Superconducting Pairing In Strongly Correlated Layered Systems

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The interplay of charge fluctuations and spin fluctuations is investigated theoretically in the regime of strong fermionic correlations in a low dimensional conducting system. In the weak correlation regime described by the Fermi Liquid phenomenology, the charge and spin response functions can be related in a rather straightforward manner in terms of the Landau parameters. For the strongly correlated fermionic systems however, such connection is highly non-trivial, as the intra-site correlation energy plays the most dominant role. Nevertheless, the spin and charge response functions in this strong correlation regime can be expressed in terms of the corresponding stiffness constants and may be linked to each other. This approach is further extended to explore the possibility of emergence of attractive interaction between the charge degrees of freedom. This has tremendous consequences for the occurrence of intra-layer superconducting pairing instability as well as competition and cooperation with magnetic ordering and phase separation. Introducing a model for inter-layer pair transfer, the emergence of true superconductivity of 3-dimensional character is discussed. The theoretical results are discussed in the light of observations from various experimental systems.

15P-B068 Anisotropic optical spectrum of detwinned Ba(Fe1−xFex)2As2

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An anisotropic electronic state emerging in undoped and underdoped compounds of iron-arsenide superconductors has attracted much interest as the proximate phase to the superconducting phase. To understand the physics of iron-based superconductors, it is important to investigate the electronic properties in this phase. Since free-standing crystals have a twinned structure, which hinders us from observing the genuine anisotropic properties, experiments using detwinned single crystals should be carried out. We performed optical spectroscopy on the mechanically detwinned Ba(Fe1−xFex)2As2 crystals. For the parent compound, in the low-temperature orthorhombic-antiferromagnetic phase, low-energy optical conductivity along the longer a axis is larger than that along the shorter b axis, and the anisotropy is reversed in the high-energy region. Such anisotropy arises from anisotropic gap opening. We will present how the anisotropic spectrum evolves with Co doping to explain the enhanced anisotropy in the dc resistivity of the Codoped compounds.

15P-B069 Large oscillations of the magnetoresistance in nano-patterned La1.48Sr0.16CuO4 superconducting films

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We report the results of magneto-resistance measurements in a unique network of non-interacting La1.48Sr0.16CuO4 nano-loops. The network magnetoresistance exhibits oscillations with field periodicity φ0/A, where φ0 = h/2e is the flux quantum and A is the area of a single loop. Remarkably, the oscillation amplitude is larger by two orders of magnitude than that expected from the Little-Parks effect. We argue that unlike the Little-Parks oscillations, which originate from periodic changes in the superconducting transition temperature, the oscillations we observe are caused by periodic changes in the interaction between thermally-excited moving vortices and the oscillating persistent current induced in the loops. Despite the enhanced amplitude of these oscillations, we have not detected oscillations with a period of h/e, as recently predicted for nanoscale loops of superconductors with d-wave symmetry, or with a period of h/4e, as predicted for superconductors that exhibit stripes.

15P-B070 Dichotomic fluxoid quantization effects in a superconducting double network

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The magnetic-field dependence of the energy and vortex occupation is calculated for the recently realized superconducting double network consisting of two interlaced...
sub-networks of small and large loops. Numerical simulations, based on fluidic quantization and energy minimization, show that while the vortex occupation of the large loops increases linearly with field, the occupation of the small loops grows in steps, resembling the behavior of an ensemble of decoupled loops. This decoupling is also reflected in the waveform of the energy versus applied field. A mean-field analysis which introduces decoupling between the small loops yields results in excellent agreement with the simulations. These findings demonstrate that the behavior of a single loop is reflected in the double network, constituting it as a favorable system for experimental study of quantization effects in superconducting nano-loops.


15P-B071 Metallic dense hydrogen
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Hydrogen at ambient pressures and low temperatures forms a molecular crystal which is expected to display metallic properties under megabar pressures. This metal is predicted to be superconducting with a very high critical temperature Tc of 200-400 K. The superconductor may potentially be recovered metastably at ambient pressures, and it may acquire a new quantum state as a metallic superfluid and a superconducting superfluid. Recent experiments performed at low temperatures T<100 K showed that at record pressures of 300 GPa, hydrogen remains in the molecular state and is an insulator with a band gap of ~2 eV. Given our current experimental and theoretical understanding, hydrogen is expected to become metallic at pressures of 400-500 GPa, beyond the current limits of static pressures achievable using diamond anvils. We found a way for producing metallic hydrogen by pressurizing hydrogen at room temperature. At 220 GPa, new Raman modes arose, providing evidence for the transformation to a new opaque and electrically conductive phase. Above 260 GPa, in the next phase, hydrogen reflected light well. Its resistance was nearly temperature-independent over a wide temperature range, down to 30 K, indicating that the hydrogen was indeed metallic. Releasing the pressure induced the metallic phase to transform directly into molecular hydrogen with significant hysteresis at 200 GPa and 295 K.

15P-B072 Physical properties of the novel layered cobalt oxyphosphide Sr₄Sc₂Co₂P₂O₆
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A noble layered cobalt oxyphosphide Sr₄Sc₂Co₂P₂O₆ crystallizes in a layered structure which represents an alternative stack of ThCr₂Si₂ type Co₂P₂ layer and K₂NiF₄ type Sr₃Sc₂O₆ layer. This material has a similar structure to that of Sr₃Sc₂Fe₂P₂O₆ which exhibits superconductivity below 17 K. The resistivity of Sr₃Sc₂Co₂P₂O₆ is 4.5 mΩcm at room temperature, and decreases with decreasing temperature. The thermoelectric power of Sr₃Sc₂Co₂P₂O₆ is -12 μV/K at room temperature, and it decreases with decreasing temperature, and rapidly increases below 50 K. The thermoelectric power of Sr₃Sc₂Co₂P₂O₆ demonstrates metallic temperature dependence. These features are similar to those of Sr₃Sc₂Fe₂As₂O₆, while polarity of the thermoelectric power does not become positive in Sr₃Sc₂Co₂P₂O₆.

15P-B073 Weak Magnetic Field Sensor Based on High-Temperature Superconductor Ceramic Material
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Weak magnetic field sensors with a resolution of δB<1 nT are developed on the basis of the magnetoresistive effect in high-temperature superconductor (HTS) ceramic thick films. It is proposed to improve the resolution characteristics of the magnetic sensor by one or more orders of magnitude by controlled formation of infinite superconducting and normal open-pore clusters in the HTS ceramic structure. Special software is developed to determine fractal dimension D of the HTS ceramic structure based on the electron microscopy images. The value of D for the infinite normal cluster is highly dependent on its shape and the HTS ceramics properties. Given this fact determined is the optimal value of D corresponding to the maximum change of resistance within the range of magnetic field B=|±10| μT, which correlates to the magnetic sensitivity and other characteristics of the sensor. For example, at the optimal D for the sensor based on HTS ceramic thick film (a strip with dimensions: thickness ~10μm, width ~20μm, length ~500μm) of Bi-2223 system with the operating temperature of 77 K it is possible to reach a resolution of δB≤10 μT.


15P-B074 Superconducting Film Flux Transformer for Weak Magnetic Field Sensor
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The superconducting film flux transformers (SFFT) with high gain factors enable to significantly increase the magnetic sensitivity and thus the performance of weak magnetic field sensors (WMFS). Examined is the geometry of WMFS comprising a magnetosensitive element (ME) based on the giant magnetoresistance effect when ME is separated by the dielectric layer from the...
narrow SFFT active strip above. SFFT active strip is nanostructured in the form of parallel branches with nanometer widths. It is proposed to maximize the SFFT gain factor growth $F_m$ by varying the widths of the slits and branches, their number and topological location, and the SFFT material characteristics. The search for the optimal splitting of SFFT active strip into parallel branches, corresponding to the maximum value of $F_m$ for a given configuration, examines the magnetic fields on ME created by superconducting currents in the branches, allowing for the non-uniform currents distribution and total branches inductance. As an example of a particular SFFT configuration: the critical current density of $10^6$ A/cm$^2$, the London penetration depth of 50 nm, the SFFT active strip width of 7000 nm and thickness of 150 nm, the minimum slits width of 80 nm. In the given configuration the optimal SFFT active strip splitting corresponds to the value of $F_m=100$.


15P-B075 Superconductivity-Induced Optical Anomaly in an Iron Arsenide

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One of the central tenets of conventional theories of superconductivity, including most models proposed for the recently discovered iron-pnictide superconductors, is the notion that only electronic excitations with energies comparable to the superconducting energy gap are affected by the transition. Here we report the results of a comprehensive spectroscopic ellipsometry study of a high-quality crystal of superconducting Ba$_{0.65}$K$_{0.32}$Fe$_2$As$_2$ that challenges this notion [1]. We observe a superconductivity-induced suppression of an absorption band at an energy of 2.5 eV, two orders of magnitude above the superconducting gap energy 2$\Delta$ $\sim$ 20 meV. Based on density-functional calculations, this band can be assigned to transitions from As-p to Fe-d orbitals crossing the Fermi level. We identify a related effect at the spin-density-wave transition in parent compounds of the 122 family. This suggests that As-p states deep below the Fermi level contribute to the formation of the superconducting and spin-density-wave states in the iron arsenides. All of the iron-pnictide superconductors are known to have multiple superconducting gaps. Redistribution of the occupation of the different bands below Tc could explain the optical anomaly we observed. It requires a lowering of the material's chemical potential in the superconducting state. In the presence of large Fe-As bond polarizability it can potentially enhance superconductivity in iron pnictides.

15P-B076 Density of states and Specific heat in extended s-wave superconductors

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We present the physical properties of extended s-wave superconductors, such as s+$g$ wave and point-node superconductors, in comparison with those of a d-wave superconductor. In the framework of the quasiclassical formalism, we mainly focus on the superconducting gap, density of states and specific heat in the presence of impurities. Impurity effects are described by using two parameters: the scattering cross section $\sigma$ and impurity scattering rate $\lambda$. The unitarity limit of the scattering corresponds to $\sigma = 1$, while Born limit is achieved as $\sigma$ approaches zero. Calculations cover the whole range of impurity effect, from the Born limit to the unitarity limit.

15P-B077 Evolution of the Paring Symmetry by the Doping Change in n-type Superconductors

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According to the resistivity method the temperature dependences of the upper critical field of electron-doped superconductor Nd$_{2-x}$Ce$_x$CuO$_{4+\delta}$ single-crystal films with various Ce concentration ($x=0.15, 0.17, 0.18$ and different degree of disorder $\delta$ were studied in magnetic fields up to 12T ($B \parallel c$, $J \parallel ab$) and temperature range 0.4-40K. We have found the crucial difference between the behaviors of the upper critical field slope ($dH_c2/dT$)$_T$ and critical temperature $T_c/T_{c0}$ as the function of the disorder parameter for optimally doped ($x=0.15$) and overdoped films ($x=0.17$ and 0.18). Experimentally observed behaviors corresponds to theoretical predictions for d-wave ($x=0.15$) or anisotropic s-wave ($x=0.17; 0.18$) superconductors. We have demonstrated that the relative stability of the optimal doped n-type superconductor with the d-paring with regard to disordering is associated with the strong anisotropy of d-type impurity scattering. Present result points to possible change of the pairing symmetry: from optimally doped superconductors with d-paring to overdoped anisotropic s-pairing superconductors. This work was done within RAS Program (project N 09-P-2-1005 Ural Division RAS).

15P-B078 Electrostatic Control of the Evolution from Superconductor to Insulator in Ultrathin Films of Yttrium Barium Copper Oxide

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The electrical transport properties of ultrathin YBa$_2$Cu$_3$O$_{7-x}$ films have been modified using an electric double layer transistor (EDLT) configuration employing the ionic liquid, DEMEM-TFSI. The films were grown on SrTiO$_3$ substrates using high pressure oxygen sputtering. A clear evolution from superconductor to insulator was observed in nominally seven unit cell thick films. Using a finite size scaling analysis, curves
of resistance versus temperature, $R(T)$, over the temperature range from 6K to 22K were found to collapse onto a single scaling function, which suggests the presence of a quantum critical point. However the scaling failed at the lowest temperatures suggesting the presence of an additional phase between the superconducting and insulating regimes similar to that found in the semiconductor-insulator transition of granular superconductors. A striking feature of the data is the similarity between the phase diagram and the bulk phase diagram. This is surprising considering that the active layer of the film is the order of one or two unit cells and that there are high electric fields in the double layer of the EDLT. This work was supported by the National Science Foundation under grant NSF/DMR-0709584. JGB thanks the Spanish Ministry of Education for financial support through the National Program of Mobility of Human Resources (2008-2011).

15P-B079 Chemical and Physical Pressure Dependence of the optimally substituted BaFe$_2$As$_2$

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Replacing arsenic by phosphorous in BaFe$_2$As$_2$ induces superconductivity without introducing extra charge carriers; this iso-electronic substitution emulates the effect of physical pressure and is consequently known as chemical pressure. Applying physical pressure on substituted BaFe$_2$(As$_{1-x}$P$_x$)$_2$ therefore provides an interesting way to compare and contrast the interplay between chemical and physical pressure. We have performed AC susceptibility measurements on BaFe$_2$(As$_{1-x}$P$_x$)$_2$ under hydrostatic pressure and found a maximum $T_c$ of 31 K for all combination of chemical and physical pressures. Additionally, we have studied the anisotropic superconducting properties of the optimally substituted BaFe$_2$(As$_{1-x}$P$_x$)$_2$ with $x = 0.35$, and found that the superconducting properties become more anisotropic under pressure despite a decreasing $T_c$.  


15P-B080 Transport Properties in Bi$_2$Te$_3$ under High Pressure up to 8 GPa

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Bismuth telluride (Bi$_2$Te$_3$) has a rhombohedral structure with the space group $R3m$ at ambient condition. X-ray diffraction study reveals no structural phase transition up to 8 GPa, but the lattice parameter ratio $c/a$ shows a minimum at around 2 GPa. Moreover, the temperature dependence of the electrical resistivity changes from metallic to semiconducting with increasing pressure from 1.0 GPa to 6.2 GPa. These results suggest that the electronic structure near the Fermi level changes at around 2 GPa, where $c/a$ shows a minimum. In this study, we investigate the temperature dependence of the electrical resistivity and the Hall effect up to 8 GPa and discuss the effect of pressure on conduction mechanism. The measurements perform using modified Bridgman-anvil cell and piston-cylinder apparatus.

1 A. Nakayama et al., High Pressure Research 81, 245 (2009).

15P-B081 On the Transformation of the Normal-State Band Spectrum of Bi-based HTSC with Increasing Doping Level and Number of CuO$_2$ Layers

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We present the results of the systematic quantitative analysis of the thermopower behavior in doped Bi-based high-temperature superconductors in the framework of a phenomenological narrow-band model. On the basis of this model we have determined the parameters characterizing the energy spectrum structure and properties of the charge-carrier system in the normal state in cases of different numbers of copper-oxygen layers and varied type and level of non-isovalent substitutions for different lattice positions. Both the common tendencies in variations of these parameters with changing sample composition and peculiarities of a specific doping effect were revealed. We have analyzed the band spectrum transformation with increasing number of CuO$_2$ layers for the optimally doped compositions, as well as under doping influence in both the underdoped and overdoped regimes. Possible mechanisms of modification of the band responsible for the conduction process are proposed and their relative role in cases of different ways of varying sample composition is considered together with the observed variations of the critical temperature. A correlation between the width of the conduction band and the critical temperature is revealed and discussed in comparison with the results for other HTSC-systems. This work is supported by grant from the Ministry of Education and Science of the Russian Federation, Contract No. P1237.

15P-B082 The Fermi Level Variation in YBa$_2$Cu$_3$O$_{y}$ Doped by Ca and Pr and Its Influence on the Critical Temperature

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We have studied the electron transport phenomena in three Ca$_x$Pr$_{1-x}$Y doped HTSC-systems, namely, Y$_{0.75-x}$Ca$_x$Pr$_{0.25}$Ba$_2$Cu$_3$O$_{y}$ (Ca$_x$Pr$_y$), Y$_{0.85-x}$Ca$_{0.15}$Pr$_x$Ba$_2$Cu$_3$O$_y$ (Ca$_x$Pr$_y$), and
Y$_{1-x}$Ca$_x$Pr$_2$Ba$_2$Cu$_3$O$_y$ (CaPr). The peculiarities of the thermopower behavior are discussed in comparison with results for systems with single Ca and Pr doping. The variation for the critical temperature, $T_c$, with doping level is observed to have distinctive features in each of investigated systems. In CaPr system a $T_c$ drop with $x$ coincides with the case of single doping both by Pr and Ca, in CaPr$_x$ system the $T_c(x)$ dependence has two different regions remaining to be almost constant up to $x=0.175$ and then falling sharply, in Ca$_2$Pr system this dependence is non-monotonic. The thermopower results were analyzed within a narrow-band model that allowed us to determine the main parameters of the energy spectrum and charge-carrier system, including the Fermi level, $E_F$, position. The obtained $E_F(x)$ dependences are analyzed and explained taking into account a particular influence of Ca and Pr ions on the conduction band structure. The role of the Fermi level variation in modification of the superconducting properties is discussed. The work is supported by grant from the Ministry of Education and Science of Russia, Contract No. P1237.

15P-B083 Asymmetrical ferromagnet-superconductor trilayers in external magnetic field

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We study the critical temperature $T_c$ of F$_1$SF$_2$ and F$_1$F$_2$S asymmetrical trilayers in the presence of external magnetic field $H$ parallel to the film. In these structures the triplet superconducting component is generated at noncollinear magnetizations of the F layers. Assuming that both different F layers and S layer are dirty, we solve the boundary value problem for the Usadel function. The $T_c$ dependence from thicknesses of the F layers ($d_{f1}$ and $d_{f2}$) is numerically calculated at different values of parameters of the FS structure and external field. It is shown that the phase diagrams $T_c$($d_{f1}$,$d_{f2}$) essentially depend from transparencies of both internal boundaries, magnitude the magnetic field and mutual orientation of magnetizations. The solitonic reentrant superconductivity is predicted for both system, and a possibility of the effect observation is discussed. The work is partially supported by the RFBR and the RF MES.

15P-B084 Simulation of spin-valve regime for asymmetrical FS nanostructures in external magnetic field

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The proximity effect for the asymmetrical trilayers F$_1$SF$_2$ and F$_1$F$_2$S systems is theoretically investigated in the presence of external magnetic field $H$ parallel to the boundary plane. The F$_1$ and F$_2$ layers may possess different parameters (magnitudes of exchange field, spin stiffness and free path lengths, correlation lengths, etc.). Our calculations are valid for arbitrary interface transparencies. The behavior of critical temperature, critical magnetic field and current distribution are simulated in the “dirty limit” including triplet superconducting channel. The mutual orientation of the magnetizations of the F layers can be changed by the external magnetic field which also suppresses a superconductivity of the contact. The influence of all these factors is very important for possible application of asymmetrical FS trilayers to the FS spin-valve, which are controlled by external magnetic field. The work is partially supported by the RFBR and the RF MES.

15P-B085 Inhomogeneity of Superconductivity and Stripe Correlations in the Overdoped Regime of La$_{2-x}$Sr$_x$CuO$_4$ at $x \sim 0.21$

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With the aim at investigating the relationship between the anomalous decrease in $T_c$, development of the Cu-spin correlation and the inhomogeneity of superconductivity in the overdoped regime of La$_{2-x}$Sr$_x$CuO$_4$ at $x \sim 0.21$, we have investigated the transport and magnetic properties. It has been found that the temperature dependence of the magnetic susceptibility shows a plateau and the magnetization curve shows the so-called second peak in the superconducting (SC) state at $x \sim 0.21$, both of which are due to the strong vortex pinning in the normal-state regions in the inhomogeneous SC state. On the other hand, the ab-plane electrical resistivity under magnetic field has revealed that the SC transition curve shifts to the low-temperature side in parallel with increasing field above $\sim 10$ T at $x \sim 0.21$, which is similar to that observed at $x \sim 1/8$ where the so-called stripe correlations are developed. Accordingly, it is possible that the stripe correlations are developed under the nano-scale inhomogeneity of superconductivity at $x \sim 0.21$.

2. I. Watanabe et al., unpublished.

15P-B086 Terahertz time-domain spectroscopy on the stripe-ordered La$_{1.84-y}$Eu$_y$Sr$_{0.16}$CuO$_4$

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Recently, a state of two-dimensional fluctuating superconductivity has been reported in stripe-ordered La$_{2-x}$Ba$_x$CuO$_4$ with $x = 1/8$. This is consistent with the results of c-axis (E[c]) infrared optical studies for La$_{2-x}$Ba$_x$CuO$_4$ and La$_{2-x-y}$Nd$_y$Sr$_y$CuO$_4$, that the Josephson plasma resonance originating from Josephson...
son coupling of the CuO$_2$ planes disappears in the stripe phase\textsuperscript{7}. To clarify the universality of this phenomenon, we performed terahertz time-domain reflection spectroscopy measurement, in which one can obtain lower frequency information than the conventional Fourier transform type spectrometer, on stripe-ordered La$_{1.84−δ}$Eu$_δ$Sr$_{0.16}$CuO$_4$ ($y = 0, 0.1, 0.2$). We observed the systematic shift of the Josephson plasma resonance with $y$ and we could observe the Josephson plasma resonance even for $y = 0.2$. This is the first observation of the Josephson plasma resonance in such low $T_c$ sample ($T_c = 13$ K) and low frequency region. Detail of the Josephson plasma resonance will be discussed.


15P-B087 Optical Spectroscopy Study on RT$_3$(R = La, Ce, Er): Evidence for Multiple Charge-Density-Wave Orders

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We performed optical spectroscopic measurement on single crystals of RT$_3$(R = La, Ce, Er), a kind of rare-earth-element tri-telluride charge-density-wave (CDW) compounds. The optical spectra are found to display very strong temperature dependence. In addition to a large and pronounced CDW energy gap that is already present at room temperature, as observed in earlier studies,\textsuperscript{1} the present measurement revealed the formation of another energy gap at smaller energy scales at low temperatures for all the three compounds. Furthermore, the close of the larger energy gap in Er-RT$_3$ is observed above 400 K in our high-temperature measurement. The study yields evidence for the presence of multiple CDW orders or strong fluctuations in the rare-earth-element tri-telluride. However, the new CDW order in the light rare-earth-element tri-telluride RT$_3$(R = La, Ce), which was revealed by the present measurement,\textsuperscript{2} was not identified before by other experimental techniques. We believe that even if the static CDW is not formed, the very strong CDW fluctuations are already present. The larger CDW gap feature well above the transition temperature in Er-RT$_3$ also reveals the substantial fluctuation effects.


15P-B088 Powder x-ray diffraction of BaFe$_2$As$_2$ under hydrostatic pressure

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We measured the electrical resistivity of BaFe$_2$As$_2$ under high pressure using a modified-Bridgman anvil-cell with Fluorinert, which resulted in the superconductivity with $T_c = 35$ K and $P_c = 3$ GPa.\textsuperscript{1} On the other hand, Yamazaki reported that the pressurization using a cubic-anvil cell gives the maximum of $T_c = 17$ K at $P_c = 11$ GPa.\textsuperscript{2} We suppose hydrostatic influence limits not only the values of $T_c$ and $P_c$ but also the structure. In this study, single crystals of BaFe$_2$As$_2$, which were also used for the measurement of resistivity, were broken into powders to perform powder x-ray diffraction. The sample was pressurized up to 16.5 GPa using DAC with a helium gas at room temperature. The diffraction patterns show a tetragonal structure with a space group of I4/mmm in the whole pressure range. The pressurization of our sample does not make 109.47$^o$ of As-Fe-As angle. The difference between our result and other works on structure means that the pressure-induced structural-change in BaFe$_2$As$_2$ depends on the experimental condition.


15P-B089 Josephson Effect in Superfluid Fermi Atoms at Finite Temperature

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By using Green’s function method the Josephson effect of neutral fermions in the crossover from the Bardeen-Cooper-Schrieffer state of weakly bound Cooper pairs to the Bose-Einstein condensate of strongly bound molecular dimers at finite temperature is investigated. Four different hyperfine states of the atoms are assumed to be trapped and to form two superfluids via the BCS-type of pairing. We show that Josephson oscillations can be realized by coupling the superfluids with two laser fields. The laser interaction is assumed to be a small perturbation and its effect is calculated using linear response theory.

15P-B090 Determination of the superconducting gap in Bi$_2$Sr$_{2−δ}$La$_δ$CuO$_{6+δ}$ (x ~ 0.4) from low-temperature specific heat

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Low-temperature specific heat (LTSH) of the monolayer high-$T_c$ superconductor Bi$_2$Sr$_{2−δ}$La$_δ$CuO$_{6+δ}$ has been measured close to the optimal doping point ($x \sim 0.4$) in different magnetic fields. The identification of both a $T^2$ term in zero field and a $\sqrt{T}$ dependence of the specific heat in fields is shown to follow the theoretical prediction for $d$-wave pairing, which enables us to extract the slope of the superconducting gap in the vicinity of the nodes ($\Delta_\perp$, which is proportional to the superconducting gap $\Delta_0$ at the antinodes according to the standard $d_{x^2−y^2}$ gap function). The $\Delta_\perp$ or $\Delta_0$ (~ 12 meV) determined from this bulk measurement shows close agreement with that obtained from spec-
troscopy or tunneling measurements, which confirms the simple $d$-wave form of the superconducting gap. Together with previous findings in La$_{2-x}$Sr$_x$CuO$_4$ over a wide range of doping, our studies demonstrate the virtue of LTSH as a bulk method to probe the superconducting gap near the nodes in high-$T_c$ cuprate superconductors.


15P-B091 FeSe Superconducting Tapes with High Critical Current Density Fabricated by Diffusion Method

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The high $T_c$ value and the very high upper critical fields $H_{c2}$ in iron-based layered superconductors have demonstrated that these materials may be competitive with A15, MgB$_2$ and even with high-$T_c$ cuprate superconductors. Favorable characteristics of FeSe and FeTe$_1-y$Se$_y$ (11 system) are not only the $H_{c2}$ but also the low toxicity of their starting materials compared to the FeAs-based superconductors. Several FeSe and FeTe$_1-y$Se$_y$ wires and tapes have been reported. For tapes or single-core wires of 11 system, critical current density is restricted to 350 A/cm$^2$. With diffusion method, we have fabricated FeSe superconducting tapes. The structural and superconducting properties are studied by the measurements of X-ray diffraction, scanning electronic microscopic images, electrical resistivity, current-voltage characteristics, and magneto-optical images. The transport critical current density $J_c$ as high as 600 A/cm$^2$ at 4.2 K under zero field has been obtained. This value is almost twice larger than the reported values in FeSe single-core wires or tapes. This simple diffusion method is promising and can be extended into FeTe$_{1-y}$Se$_y$ system.


15P-B092 Effects of Swift Xe Irradiation in Ba(Fe$_{1-x}$Co$_x$)$_2$As$_2$ Single Crystals

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We have systematically investigated the effects of particle irradiation in optimally Co-doped BaFe$_2$As$_2$. In the case of 200 MeV Au irradiation with a dose of $D_B = 20$ kG, the value of critical current density ($J_c$) is successfully enhanced around 5 times without appreciable reduction of superconducting transition temperature ($T_c$). By contrast, 3 MeV proton irradiation with a dose of $1.2 \times 10^{16}$ cm$^{-2}$ suppresses $T_c$ more than 10%, while the value of $J_c$ is 2.5 times larger than that in pristine samples. These results are consistent with an introduction of columnar defects and point defects, respectively. The irradiation of Xe ions, on the other hand, introduces cascade defects with increasing doses, which is confirmed by TEM observations. Reflecting such a morphology, $T_c$ in this system should be reduced. Here we report the details of suppression rates of $T_c$ in optimally Co-doped BaFe$_2$As$_2$ irradiated by 300 MeV Xe along $c$-axis without an ambiguity of piece dependencies. We also discuss the more effective pinning center morphology for vortices by comparing the enhancement of $J_c$.

2. T. Taen et al., to be published in Physica C.

15P-B093 Unconventional Superconducting states in Li$_2$(Pd$_{1-x}$Pt$_x$)$_3$B with broken inversion symmetry probed by NMR

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We report NMR study on Li$_2$(Pd$_{1-x}$Pt$_x$)$_3$B without inversion symmetry in the crystal structure. A mixed state of Cooper pairings (spin singlet and spin triplet state) is expected to emerge due to the lack of inversion symmetry. There are experimental reports that the spin triplet pairing dominates in Li$_2$Pt$_3$B, in contrast to Li$_2$Pd$_3$B with the spin singlet pairing. It is considered that the different superconducting properties are due to spin-orbit coupling (SOC) enhanced by the lack of inversion symmetry. To investigate the evolution of the pairing symmetry in Li$_2$(Pd$_{1-x}$Pt$_x$)$_3$B, we measured down to 0.1K $^{195}$Pt Knight shift which is the most effective probe to judge the spin states, as well as spin lattice relaxation rate ($1/T_1$) of $^{11}$B and $^{195}$Pt. We found a dramatic transition from the spin singlet state to the spin triplet state as $x$ is increased We will discuss the relations between the unconventional pairing and the strength of SOC.


15P-B094 Nonlinear Transport at the Superconductor-Insulator Transition in Thin TiN Films

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We investigate experimentally the electronic transport at the insulating side of the superconductor to insulator transition in thin TiN films. At temperatures $T > 50$ mK we observe an Arrhenius-type conductance, with an activation energy depending logarithmically on the sample size. At high bias the current voltage ($I-V$) characteristics display a large current jump into an electron heating dominated regime. For the largest samples
(area > 100 μm x 100 μm), and below 50 mK we observe a low-bias power law $I \propto V^n$ characteristics with an exponent $n > 1$ rapidly growing with decreasing temperature, which is expected for a binding-unbinding crossover of the charge-Berezinskii-Kosterlitz-Thouless type. A competing interpretation in terms of electron heating is investigated and also yields strong evidence for the formation of an unusual insulating state at ultralow temperatures.

15P-B095 Effect of Fluorine on the Phase Formation of Tl-1223 Films Grown Over Silver Substrates

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Tl$\text{Ba}_2\text{Ca}_2\text{Cu}_3\text{O}_y\text{F}_x$ films have been prepared by two step process. First, precursors films of Ba$_2$Ca$_2$Cu$_3$O$_y$ composition were deposited with spray pyrolysis technique and then fluorine and thallium are incorporated by diffusion in a two zone furnace. Silver foils were used like substrates. A Fluorine content in the $x = 1$ to 3.5 range was obtained with a process carried out by 60 to 180 minutes at 850°C. Fluorine improves the formation phase and increases the critical temperature. Grains like plates with $c$ axis oriented in the normal direction to the surface substrate are observed.

15P-B096 Low-temperature Thermoelectric Properties of the Electron-Doped Perovskites Sr$_{1-x}$Ca$_x$Ti$_{1-y}$Nb$_2$O$_3$

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Electron-doped perovskite SrTiO$_3$ is known to be one of candidates for a good n-type thermoelectric (TE) oxide$.^1$ In this study, we have tried to improve the TE property of the lightly-electron-doped SrTiO$_3$ single crystal below room temperature by the substitutions of Ca and Nb for Sr and Ti$^2$. We found that Sr$\text{Ti}_{0.99}\text{Nb}_{0.01}\text{O}_3$ shows a large power factor of about 90 $\mu W/K^2\text{cm}$ at 50 K and the largest dimensionless TE figure-of-merit (ZT $\sim$ 0.07) below 60 K among the ever reported materials, which are perhaps due to the distinct electron-phonon interaction. On the other hand, the Ca$^{2+}$ substitution for Sr$^{2+}$ increases the $ZT$ at 300 K for Sr$_{1-x}\text{Ca}_x\text{Ti}_{0.97}\text{Nb}_{0.03}\text{O}_3$ from about 0.08 to about 0.105. The enhancement of $ZT$ originates not only in a large reduction of a thermal conductivity due to an introduced randomness into the crystal structure and an induced structural transition, but also in an unexpected enhancement of Seebeck coefficient by the Ca substitution.

$^2$ J. Fukuyado, et al., in preparation.

15P-B097 Fabrication of BSCCO Thick Film with Modified Ultrasonic Spray Pyrolysis (USP) Method and their Transport Properties

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This work “Modified Ultrasonic Spray Pyrolysis (MUSP)” method was used to prepare Bi-2223 polycrystalline films. Initially Bi-2223 powders were prepared by solid state reaction technique. After an appropriate heat treatment, powders were ball-milled to reduce the grain size to nano scale. Then powders were mixed with ethanol and atomized with 2.4 MHz ultrasonic nebulizer system. Two different single crystal substrates, MgO and SrTiO$_3$, were used for fabrication of superconducting films. The films were then heat treated at air atmosphere up to metric converter ProductID 8600C860°C with different durations and heating ramps. The structural, electrical and magnetic properties up to 9 T of the films having thicknesses between 800 nm to 1.2 μm were investigated. Nearly all of the films showed two step superconducting transition temperatures. The best films showed a Tc at 112 K and 92 K with a sharp drop to the zero resistance state at ~89 K. However the Jc results obtained showed very promising information for large scale applications.

15P-B098 Growth and Characterization of Superconducting In and Pb Films

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Elemental In and Pb films ranging in thickness from 400 - 2000 nm have been grown on glass (SiO$_2$) and other substrates using vacuum vapor deposition. Film growth was monitored and controlled by in-situ four-point probe resistance measurements. Samples grown concurrently were analyzed using several techniques: X-ray Transmission for thickness measurement and X-ray Diffraction for morphology, structure, and composition of the films. The In films exhibited a tendency to grow in the (101) direction, with slight variations caused by the deposition rate. Ambient temperature transport measurements and temperature scans down to below the superconducting transition temperature ($T_c$) were carried out, with transition temperatures consistent with bulk metals. The films exhibit high residual resistance and temperature coefficients of 0.003/K for Pb slightly lower than published bulk measurements and 0.001/K for In. Using the Matthiessen’s rule and the Drude model for conduction in metals, the crystal-like or grain size was inferred to be an order of magnitude lower as compared to that obtained from X-ray diffraction using the X-ray peaks’ full width at half maximum (FWHM), suggesting a preferred direction growth of the In crystallites on glass, but not for Pb. Some In sample films were annealed at 150 °C in Ar or...
N\textsubscript{2} to improve on their morphology.

15P-B099  Phase diagram of a pressure-induced superconducting state and its relation to the Hall coefficient of Bi\textsubscript{2}Te\textsubscript{3} single crystals

C. Zhang\textsuperscript{b,c}, LL. Sun\textsuperscript{a}, ZY. Chen\textsuperscript{a}, XJ. Zhou\textsuperscript{a}, Q. Wu\textsuperscript{a}, W. Yi\textsuperscript{a}, J. Guo\textsuperscript{a}, XL. Dong\textsuperscript{a}, ZX. Zhao\textsuperscript{a}, \textsuperscript{a}Institute of Physics, Chinese Academy of Sciences, Beijing, China \textsuperscript{b}Pressure-induced superconductivity and its relation to the corresponding Hall coefficient(\(R\textsubscript{H}\)) have been investigated for Bi\textsubscript{2}Te\textsubscript{3}, a known topological insulator, through in situ measurements of magnetoresistance and ac susceptibility with diamond anvil cells. A full phase diagram is presented which shows a complex dependence of the superconducting transition temperature as a function of pressure over an extensive range. High-pressure Hall measurements reveal a close relation to these complex behaviors; in particular, an abrupt change of d\(R\)/d\(P\) is observed in crossing from the nonsuperconducting to the superconducting ambient-pressure phase.

15P-B100  In-plane resistivity and superconductivity of iron-pnictide superconductors

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Revealing the relationship between the normal-state charge transport and superconductivity is one of the important issues in order to understand the mechanism of unconventional superconductivity. We previously demonstrated that the exponent \(n\) of the low temperature resistivity \(\rho(T) \sim T^n\) is correlated with superconducting transition temperature \(T\textsubscript{c}\) for polycrystalline samples of various iron pnictides.\textsuperscript{1}

We performed in-plane resistivity measurement on single crystals of iron-pnictide superconductors, mainly BaFe\textsubscript{2}As\textsubscript{2} system. As is well known, the temperature dependence of resistivity is nearly \(T\)-linear in Co-doped and P-doped cases, while it is \(S\)-shaped in K-doped case. We attempted to fit them in terms of three-component model derived from the decomposition of optical conductivity spectrum; a Drude term (\(\sigma_D \sim T^{-2}\)), an incoherent term (\(\sigma_{\text{in}} \sim \text{const.}\)), and a residual resistivity component (\(\rho_0\)). We investigate how those components vary among different materials and different doping, and explore their correlation with \(T\textsubscript{c}\).


15P-B101  Evolution of the magnetic, thermodynamic, and transport properties of FeSe\textsubscript{1-x}Te\textsubscript{1-x} single crystals with increasing Se concentration

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In our recent research on the mobility analysis of carriers in FeTe thin films \cite{1}, it is suggested that itinerancy of both electrons and holes is crucial for the occurrence of superconductivity. To get more insight into this issue, we investigate the evolution of the magnetic, thermodynamic, and transport properties of FeSe\textsubscript{1-x}Te\textsubscript{1-x} single crystals in detail. Recent single crystals of FeSe\textsubscript{1-x}Te\textsubscript{1-x} (\(x = 0 - 0.4\)) are grown by Bridgman method. The parent FeTe crystal is antiferromagnetic metal with \(T\textsubscript{N} = 65\) K as was already reported. FeSe\textsubscript{1-x}Te\textsubscript{1-x} crystals with \(x = 0.1 - 0.3\) show spin glass behavior at low temperatures and no bulk superconductivity is observed, which would be due to excess Fe in the grown crystals. FeSe\textsubscript{0.6}Te\textsubscript{0.4} shows bulk superconductivity with \(T\textsubscript{c} \sim 15\) K. The Hall coefficient \((R\textsubscript{H})\) of FeTe is almost temperature independent except that the sign changes from positive to negative at \(T\textsubscript{N}\) with decreasing temperature. For samples with \(x = 0.1 - 0.3\), \(R\textsubscript{H}\) is also positive and \(T\)-independent at high temperatures, but increases with decreasing temperature at low temperatures, while \(R\textsubscript{H}\) in superconducting FeSe\textsubscript{0.6}Te\textsubscript{0.4} goes to negative below 30 K. This would suggest that the contribution of electrons on charge transport increases with increasing Se concentration.

15P-B102  Two-dimensional superconductivity of ultrathin Bi films on cleaved GaAs surfaces

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We have performed magnetotransport measurements on ultrathin Bi films on GaAs (110) surfaces. To reduce disorder arising from the substrate, we used cleaved surfaces of insulating GaAs. Based on the technique of the previous works on InAs inversion layers\textsuperscript{1,2}, our experimental procedure is as follows: (1) A GaAs crystal was cleaved at liquid helium temperatures in an ultrahigh vacuum chamber. (2) An amorphous Bi films was produced by quench-condensation. (3) Four-probe transport measurements were performed using Au electrodes on noncleaved surfaces. The critical film thickness for superconductivity was obtained to be 4.2\AA, which is thinner than the previous data for different kinds of substrates.\textsuperscript{3}

In the study of \(I-V\) characteristics, we observed discontinuous jump in the temperature dependence of the power \(\alpha\) in \(V \propto I^\alpha\), which is associated with “universal jump” of the Kosterlitz-Thouless transition. This indicates that the KT transition can occur in amorphous films as well as Josephson-coupled arrays. We also observed the anisotropy of the parallel and perpendicular magnetic dependence of the resistance.


Elastic depinning transition of superconductor vortices
N. Di Scala, E. Olive, Y. Fily, Y. Lansac, J.C. Soret, 

We present numerical simulation results for driven vortex lattices in presence of random disorder. The dynamics of vortices is studied for weak disorder. Unlike the strong disorder case where plastic depinning occurs, the weak disorder produces elastic depinning and elastic dynamical regimes in the whole driving force range. It means that all particles depin simultaneously and with the same average velocity, giving rise to static elastic dynamical regimes in the whole driving force range. A scaling analysis is derived from these results.

Vortex dynamics in type-II superconductors with columnar defects (LT26)
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In experiments, columnar defects are introduced to high-Tc superconductors by heavy-ion irradiation to increase the critical current. A Bose glass (BG) phase and moving BG phase have been predicted theoretically. Recently, possible Bragg-Bose glass (BBG) phase in vortex states of high-Tc superconductors with sparse and weak columnar defects has been proposed. However, the nature of this phase driven by external current is not clear. We have performed large-scale computer simulations in the current-driven 3D frustrated anisotropic XY model with sparse and weak columnar defects by means of resistively-shunted junction dynamics. At low temperature, a moving ordered phase with hexagonal Bragg peaks has been found. At the moment, we can not rule out the possibility of moving BG property with the diverging tilt modulus. With increases of temperature, a moving smectic appears via a first-order phase transition. It is also found that this moving Bragg glass like phase can be destroyed by increasing the density of columnar defects. We also perform 3D numerical simulation on moving vortices in the presence of columnar defects at zero temperature by using Langevin dynamics. The depinning and creep motion of the vortices are studied, and the moving phase diagram is proposed.

Vortex Confinement in Planar Superconducting/Ferromagnet Hybrid Structures

Magnetically coupled superconductor-ferromagnet hybrids offer advanced routes for nanoscale control of superconductivity. Scanning tunneling microscopy and scanning magnetic force microscopy coupled to magneto-transport measurements reveal rich vortex phase diagrams. The magnetic stripe domain of the ferromagnet induces periodic local magnetic induction in the superconductor, creating a series of pinning and anti-pinning channels for vortices observed with scanning tunneling microscopy and magnetic force microscopy at low temperature. Such laterally confined Abrikosov vortices form chains. We also found general equilibrium condition for which vortex-antivortex pairs are spontaneously formed during zero-field cooling. In the non-equilibrium state the strong magnetic pinning of the vortex lattice results in avalanches of antivortices when changing the polarity of the applied magnetic field. The threshold of avalanches depends upon the specific history and temperature.

Simulation of Vortex Penetration into Square Superconducting Network
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The patterns of flux penetration into the superconducting anti-dot arrays and networks depend mainly on the geometry of the samples, as well as on temperature, current, and magnetic field. The motion of vortices is described by the vortex channeling model in which the vortices can move only along the direction between nearest anti-dots. However, anomalous mesoscopic flux penetration patterns appear in the square superconducting networks with a relatively large scale of periodic length. The patterns are enhanced along the diagonal direction of square lattice when the networks have a smaller line width than the holes. Nakai et al. have reproduced the anomalous flux penetrations by the TDGL simulation. Though the phenomenon is confirmed experimentally and theoretically, its origin remains an open issue, To clarify the origin, the pinning in superconducting lines should be considered. Hence, we have simulated the flux penetration into the square superconducting networks by considering the nonlinear current-voltage dependence. A simulation with relatively small holes have shown a pattern enhanced along the parallel direction of networks which is described by the vortex channeling model. Further simulations with larger square holes are in progress.

Vortex cutting and recombination processes in a mesoscopic superconductor
G. R. Berdiyorov, Mauro M. Doria, A. R. de...
We present evidence that a reversible to irreversible flow transition, as reported in driven colloidal particles, occurs in periodically sheared vortices in a Corbino-disk superconductor under increasing a displacement $d$ of vortices per cycle. We determine a threshold displacement $d_c$ for the reversible-irreversible transition as the onset of flow noise. A relaxation toward a steady state is observed both above and below $d_c$ and the relaxation time $\tau$ diverges around $d_c$, indicative of a dynamic transition. The reversible-irreversible transition has also been interpreted in terms of an absorbing transition. Within the interpretation, the irreversible regime corresponds to a fluctuating active state where particles (i.e., vortices) are diffusing, while the reversible regime corresponds to an absorbing state where the particles are self-organized and absorbed into a nonfluctuating quiescent state. We find that the reversible-irreversible transition exhibits a similar critical dynamics to that of the absorbing transition, as predicted theoretically. These results suggest that both transitions are universal phenomena in driven interacting particle systems with quenched disorder. We also study how the transient vortex dynamics or $\tau$ depends on initial vortex configurations. The results look consistent with the view that irreversible vortex motion would occur in correspondence with flow of topological defects in lattice.


15P-B110 Appearance of magnetization around a pair of half quantum vortices in chiral $p$-wave superconductors

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Recently, triplet $p$-wave ($p_x \pm ip_y$) superconductors such as Sr$_2$RuO$_4$ were found. It was phenomenologically suggested that in these superconductors, a pair of half-quantum vortices (HQVs) exists due to spin degree of freedom and in some cases it is more stable than a singly quantized vortex. Although a pair of HQVs has not been discovered directly, recently a half height magnetization steps are observed in micrometer-sized annular shaped Sr$_2$RuO$_4$. In order to investigate quasi-particle excitation around two vortices, we developed a numerical method using elliptic coordinates and Mathieu functions. We applied this method to a pair of vortices and a pair of HQVs cases in $p$-wave superconductors. And we found that a magnetic dipole moment appears along a pair of HQVs, because quasi-particle bound states for up or down spin exist only around each of the HQVs.

amorphous Mo$_x$Ge$_{1-x}$ Films
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Vortex states in type-II superconductors are largely dependent on the dimensionality of superconductors. For ideal thin superconducting films with no pinning the melting line of vortex lattice is predicted to be nearly independent of field at low field. However, the sharp melting transition as well as the peak in the depinning current vs field curve, the so-called peak effect, has not yet been observed in actual thin films. The results suggest that the vortex lattice for the thin films may be unstable against small pinning. The effects of pinning would be much reduced by simply driving the vortices. Here, we conduct a mode-locking (ML) experiment, which enables us to detect the coherent motion of driven vortices, for weak-pinning $a$-Mo$_x$Ge$_{1-x}$ films with thickness ranging from 10 to 350 nm. The clear ML resonance indicative of driven vortex lattices is observed for the thick film, while it is not visible for the thin film. The results suggest that for the thin film the elasticity of the driven lattice is significantly reduced and the lattice is unstable against small pinning. 


15P-B112 Dynamics of Vortices in Nano-Structured Superconductors with Periodic Arrays of Various Antidots
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There are many studies about pinning of vortices by various shaped antidots in superconductors using molecular dynamics method. 1 We have introduced general form of pinning potential for various shaped antidots and using this potential, we have been doing the molecular dynamics simulation of vortices. For example, we take the pinning potential for a triangular antidot as $V = -\frac{1}{2}\frac{f_p}{\pi}(\sum_{q=1}^{n}\{r_j - r_p \cdot n_i\})^{q}\Theta((r_j - r_p \cdot n_i))$, where $r_j$ is the coordinate of the vortex, $r_p$ is the coordinate of the antidot, $f_p$ is the strength of the pinning, $r_p$ is the radius of the antidot, $\Theta$ and $f_l$ defines the roundness and the flatness of the pinning potential of the antidot, respectively. $\Theta((r_j - r_p \cdot n_i))$ is a step function and $n_i = (\cos\frac{\pi q}{n}, \sin\frac{\pi q}{n})$ is the normal vector of edges. We investigated the effect of the various shapes of antidots varying $n, q$ and $f_l$ and found that the maximum number of vortices pinned changes when the shape of the antidots are changed. For example, the longer the edge of the polygon perpendicular to the flow of vortices was, the more vortices the antidot could hold. Also, we investigate the dynamics of vortex flow in superconductors with various shaped antidots.


15P-B113 Plastic Depinning in a Sheared Vortex System with Random Pinning
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A plastic depinning phenomenon is studied in a sheared vortex system in a Corbino-disk superconductor with random pinning, where some vortices are mobile while others remain pinned. We measure the time-dependent voltage $V(t)$, which is proportional to the average vortex velocity, just after the dc current $I$ with a sharp rise is suddenly applied to the vortex system. We find decaying $V(t)$ toward the steady-state voltage, indicating that the moving vortices are gradually pinned. The decay time $\tau(I)$ diverges at around a depinning current, as determined from the static $I-V$ characteristics. 2 By changing the field sweep process prior to measurements as well as the field strength itself, we have changed the initial vortex configuration, namely, the number of pinned vortices. It is found that the value of $\tau$ is dependent on the initial vortex configuration, while the critical dynamics is insensitive to it. The results provide a strong support for the view that plastic depinning is a nonequilibrium phase transition. We also suggest that the depinning transition falls into the same universality class as the absorbing transition.


15P-B114 Magneto-optical Imaging of Flux Turbulence in Ba(Fe$_{1-x}$Co$_x$)$_2$As$_2$ Crystals
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A type-II superconductor which has been remagnetized by a magnetic field of opposite polarity contains both vortices and antivortices. In the 123-type high-$T_c$ cuprates the remagnetization flux front exhibits macroscopic turbulence. However, it is still debated whether this turbulent instability is a generic feature of type-II superconductors. Here we report remagnetization studies on thin single crystals of optimally doped Ba(Fe$_{0.925}$Co$_{0.075}$)$_2$As$_2$ ($T_c = 24$ K) using magneto-optical imaging. We observe enhanced irregular penetration of the remagnetization front above 15 K. Unlike in the 123-system, the irregular flux front patterns appear to conform to the pinning in the sample and are sustained even after successively recycling the temperature to above $T_c$ and cooling down. However, the remagnetization front is accompanied by the appearance of slight humps in the magnetic induction profiles around $B_z = 0$. This could be generated due to the excess current flowing around a "Meissner hole" in the superconductor. The time evolution of the annihilation front shows that it takes ~90 seconds to almost stabilize. The remagnetization features in underdoped and overdoped Ba(Fe$_{1-x}$Co$_x$)$_2$As$_2$, single crystals are also discussed. Finally these results are compared with those in both conventional and high-$T_c$ cuprate super-
15P-B115 Flux-Flow Conductivity in Anisotropic Superconductors with a Cooper Pair Mass-Normal Conductivity Anisotropy Mismatch

A.A. Bespalov

Within the time-dependent Ginzburg-Landau (TDGL) theory we evaluate the Bardeen and Stephen contribution to the flux-flow conductivity for uniaxial anisotropic superconductors. We focus our attention on superconductors with a cooper pair mass - normal conductivity anisotropy mismatch \((\sigma_c/m_c/m_{ab} \neq 1)\). Our interest is driven by experimental data on Fe-based oxypnictide superconductors which seem to reveal such kind of mismatch. Considering the motion of an isolated Abrikosov vortex \((\text{the weak magnetic field limit})\), we derive exact asymptotics for the Bardeen and Stephen contribution in two extreme cases: the \(l_{Eab} \ll \xi_{ab}, l_{Ec} \ll \xi_c\) limit, where \(l_E\) is the electric-field penetration length and \(\xi\) is the coherence length, and the \(l_{Ec} \gg \xi_c\) limit. A variational principle is established which allows us to calculate the Bardeen and Stephen contribution for superconductors with arbitrary parameters \(\xi\) and \(l_E\). The approximate analytical result is compared with numerical calculations. Finally, using the generalized TDGL theory, we prove that the flux-flow conductivity anisotropy may depend on temperature.

15P-B116 Vortex Phase Diagram of Pristine and Irradiated Co-doped BaFe2As2

T. Taniguchi, T. Naito, H.-S. Lee, M. Bartkowiak, J. S. Kim, and H.-J. Lee

15P-C: C4 Topological Order, C6 Multiferroics / Ferroics

Session 15P-C:

C4 Topological Order

C6 Multiferroics / Ferroics

Monday August 15, 16:00 – 18:00

Exhibition Hall 1

15P-C001 Giant Skyrmion and Skyrmion Burst in Thin Ferromagnetic Films

M. Ezawa

In this work we investigate topological solitons in thin ferromagnetic films. First, we propose a new mechanism of skyrmion materialization on the basis of the competition between the magnetic dipole-dipole interaction (DDI) and the Zeeman interaction. DDIs turn a ferromagnet into a frustrated spin system, which allows a nontrivial spin texture such as a giant skyrmion \((\sim 1\mu m)\) for typical sample parameters. We derive an analytic formula for the skyrmion radius. A giant skyrmion is shown to collapse into a singular point by emitting spin waves (skyrmion burst), when external magnetic field is increased beyond the critical one. A giant skyrmion may well be the magnetic domain already found in a TbFeCo thin film. We also study topological excitations in chiral ferromagnetic thin films such as MnSi and FeCoSi, where the Dzyaloshinskii-Moriya interaction (DMI) dominates the DDI at short distance \((\sim 40nm)\). At finite temperature, topological excitations emerge by the competition between the DMI and the Zeeman effect. They are compact skyrmions, merons and bimerons. A distinguished feature is that the topological charge density is strictly confined within compact domains. We construct a phase diagram in the plane of temperature and magnetic field, which is comprised of the helix, meron, skyrmion-crystal, skyrmion-gas and ferromagnet phases.


15P-C002 Spintorques and skyrmions in chiral magnets

Achim Rosch

In this work we investigate topological solitons in thin ferromagnetic films. First, we propose a new mechanism of skyrmion materialization on the basis of the competition between the magnetic dipole-dipole interaction (DDI) and the Zeeman interaction. DDIs turn a ferromagnet into a frustrated spin system, which allows a nontrivial spin texture such as a giant skyrmion \((\sim 1\mu m)\) for typical sample parameters. We derive an analytic formula for the skyrmion radius. A giant skyrmion is shown to collapse into a singular point by emitting spin waves (skyrmion burst), when external magnetic field is increased beyond the critical one. A giant skyrmion may well be the magnetic domain already found in a TbFeCo thin film. We also study topological excitations in chiral ferromagnetic thin films such as MnSi and FeCoSi, where the Dzyaloshinskii-Moriya interaction (DMI) dominates the DDI at short distance \((\sim 40nm)\). At finite temperature, topological excitations emerge by the competition between the DMI and the Zeeman effect. They are compact skyrmions, merons and bimerons. A distinguished feature is that the topological charge density is strictly confined within compact domains. We construct a phase diagram in the plane of temperature and magnetic field, which is comprised of the helix, meron, skyrmion-crystal, skyrmion-gas and ferromagnet phases.

In chiral magnets, for example in MnSi, spins can form a lattice of magnetic vortices\(^1\), a skyrmion lattice, similar to the vortex lattice of type II superconductors. The topology of the skyrmions leads to a very efficient coupling of magnetism and electric currents associated with Berry phases picked up by the electrons when their spins follow the magnetic texture. Using neutron scattering, it was possible to observe directly\(^2\) how currents affect the magnetic structure. Remarkably, the skyrmion lattice starts to move at rather low current densities, more than five orders of magnitude smaller than typically used in spin-torque experiments. We discuss the theoretical concepts underlying the formation of skyrmions, their pinning by disorder and their coupling to currents.


15P-C003 Pairing Symmetry and Magnetic Relaxation in Topological Superconductor \(\text{Cu}_3\text{Bi}_2\text{Se}_3\)

Pradip Das\(^a\), Yusuke Suzuki\(^b\), Masashi Tachiki\(^c\), Kazuo Kadowaki\(^d\), a Institute of Materials Science and Graduate School of Pure and Applied Sciences, WPI-MANA and CREST-JST, University of Tsukuba, Japan

Topological insulators are materials with a bulk-insulating gap, exhibiting quantum-Hall-effect-like behavior in the absence of a magnetic field. The experimental as well as theoretical study show Bi\(_2\)Se\(_3\) has a single surface Dirac cone associated with the topologically protected surface state. Cu\(_3\)Bi\(_2\)Se\(_3\) is of particular interest because of the signature of superconductivity found at low temperatures. Here we report the growth and the observation of bulk superconductivity from dc magnetization measurements in a cylindrical single crystal of Cu\(_3\)Bi\(_2\)Se\(_3\). The magnitude of the magnetization in the Meissner state is very small and the magnetic field dependence of the magnetization just above the lower critical field \(H_{c1}\) is very different from those of usual type II superconductors. We believe superconductivity observed in Cu\(_3\)Bi\(_2\)Se\(_3\) is consistent with the spin-triplet pairing superconductivity with odd parity. We also observed a rapid relaxation phenomenon of the diamagnetic magnetization, indicating the flexible motion of the vortices in that temperature and field regime.

15P-C004 Mott Physics and Topological Phase Transition in Correlated Dirac Fermions

Shun-Li Yu\(^a\), X. C. Xie\(^b\),\(^c\), Jian-Xin Li\(^a\), a National Laboratory of Solid State Microstructures and Department of Physics, Nanjing University, Nanjing 210093, China  bInternational Center for Quantum Materials, Peking University, Beijing 100871, China  cDepartment of Physics, Oklahoma State University, Stillwater, Oklahoma 74078

We investigate the interplay between the strong correlation and the spin-orbital coupling in the Kane-Mele-Hubbard model and obtain the qualitative phase diagram via the variational cluster approach. We identify, through an increase of the Hubbard \(U\), the transition from the topological band insulator(TBI) to either the spin liquid phase or the easy-plane antiferromagnetic(AF) insulating phase, depending on the strength of the spin-orbit coupling. Starting from TBI, the spin-orbit coupling gap \(\Delta_{SO}\) closes first and then the Mott gap opens up but without the gapless edge states for increasing \(U\), which is closely related to the topological properties of the system. The closing process of \(\Delta_{SO}\) driven by the correlations is accompanying with a splitting of both the conduction and valence bands. In the strong spin-orbit coupling regime, the state transiting from TBI is the easy-plane AF Mott insulator. In the weak coupling regime, a spin liquid phase emerges between the TBI and the AF Mott insulators.\(^1\)


15P-C005 \(Z_Q\) topological invariants of gapped quantum systems for integer \(Q\)

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The quantized Berry phase as a local order parameter of gapped quantum liquids at zero temperature is proposed for characterization of a topological or quantum order in various models including strongly correlated electron systems, where the Berry phase is quantized as \(Z_Q\) value, i.e., 0 or \(\pi\), due to the time-reversal, or lattice-inversion symmetry in any dimension.\(^1\) The system can be characterized by a set of \(Z_Q\) values. Recently, we have proved that the lattice-rotational symmetry enables \(Z_Q\) quantization of Berry phases for interacting electrons,\(^2\) where \(Z_{d+1} (Q = d + 1)\) Berry phases are defined for \(d\)-dimensional lattices: Polyacetylene, Kagome and Pyrochlore lattice respectively for \(d = 1, 2\) and 3. The invariants are order parameters for quantum \(Q\)-multimer, and characterize the topological phase transitions by the multimerization. Not only bulk systems but also molecules like C\(_{60}\) have \(Z_Q\) topological invariants, which are topologically protected by the multimerization gap.


\(^2\) Y. Hatsugai, I. Maruyama ArXiv:1009.3792

15P-C006 Quantum Phase Transition at A Critical Composition

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Since the singe and strength of both on-site and intersite exchange is strongly depends on the (i)character and concentration of conduction electron (ii) number of nearest neighbour of magnetic ions and(iii) the interatomic space defined by the correlation length \(R_c = 2k_B T_f R_s\). There exist a critical point at which a competition can occur. For Gd Intermetallic Compound (IMC) which is on its stable s-state, the origin of this should be a puzzle. In spite of the above phenomenon for which the on-site exchange is the cause of screening and gives...
TKᵉTN, the field induced by the metamagnetic character can be changed by increasing of the magnetic ions concentration up to a critical point at which a critical quantum phase transition is manifested for a critical composition where, the unstable F.M phase transition collapses to completely P.M state with Kondo lattice composition which, the unstable F.M phase transition quantum phase transition is manifested for a critical concentration up to a critical point at which a critical field induced by the metamagnetic character can be observed.

15P-C007  Transport property of compensated topological insulator, Bi₂Se₃
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Basic transport properties of compensated Bi₂Se₃ single crystals are present.
Bi₂Se₃ usually shows bulk metallic behavior with n-type carrier because Se vacancies act as the dominant. In order to observe the transport properties dominated by the topological surface states, compensated samples are needed. We synthesized low n- and p-type single crystals (nₑ, nₚ ~ 10¹⁷−¹⁹ cm⁻³) using Mg and Ca as foreign dopants, and also prepared doping-free n-type samples (nₑ ~ 10¹⁷ cm⁻³) with a nominal molar composition ratio of 1:2 (=Bi:Se) in the preparation process. All prepared samples showed metallic behavior down to low temperatures. One p-type Ca-doped sample had insulating behavior below 150 K although the carrier number reached almost 10¹⁹ cm⁻³. Clear ShK oscillations were observed in all samples except Ca-doped ones. These results indicate that kinds of dopants affect the transport properties of the compensated samples. We report elementary transport properties, such as resistivity, Hall coefficient, andSeebeck coefficient, of compensated samples and discuss what dopants are suitable for the best compensation of Bi₂Se₃. We also discuss superconductivity in Cu-intercalated Bi₂Se₃.

15P-C008  Possible 3D Skyrmion Lattice in Chiral Magnet
Jin-Hong Park, Jung Hoon Han, a) Department of Physics and BK21 Physics Research Division, Sungkyunkwan University, Suwon 440-746, Korea.
We calculate the energies of various multiple-spiral spin configurations for the three-dimensional model of chiral magnets. The ground-state phase diagram is obtained in the space of anisotropy, magnetic field, and interaction parameters. Regimes with multiple-spiral, or Skyrmion crystal spin ground states are identified. The uniform chirality, responsible for anomalous Hall effect, is examined for the Skyrmion crystal configurations. A geometric interpretation is given for the three-dimensional Skyrmion lattice structures as the periodic arrangement of hedgehog singularities.

15P-C009  Substrate-Dependent Bonding Anisotropy of Epitaxial Multiferroic DyMnO₃ Thin Films
We investigated the substrate-dependent electronic structure and anisotropic bonding of the Mn 3d states in DyMnO₃ thin films on SrTiO₃(001) and LaAlO₃(110) substrates using polarization-dependent x-ray absorption spectroscopy (XAS) at O K-, Mn L₃- and Mn K-edges for three polarizations, E || a, E || b and E || c. Polarization-dependent x-ray absorption spectra at O K-, Mn L₂,₃- and Mn K-edges of orthorhombic DyMnO₃/LaAlO₃(110) thin films show a strong polarization dependence, whereas orthorhombic DyMnO₃/SrTiO₃(001) thin films show nearly isotropic spectral structure. The main peak in polarized Mn L₂,₃-edge XAS spectra of DyMnO₃/LaAlO₃(110) thin films for the E || b polarization lies at a lower energy than for polarizations E || a and E || c. This indicates a great anisotropy in Mn 3d-O 2p hybridization, reflecting an orbital ordering and a highly anisotropic coplanar Mn-O bonding in DyMnO₃/LaAlO₃(110) thin films. Orbital ordering of ɛ₉-orbital and the highly anisotropic in-plane Mn-O bonding is an indispensable factor to the formation of complicated incommensurate modulated magnetic structures observed in orthorhombic DyMnO₃. The present results provide important implications for the microscopic understanding of the multiferroic DyMnO₃.

15P-C010  Analysis of electron spin resonance of LiCu₂O₂ at low temperature
Meihua Chen, Chong Der Hu, a) Physics Department, National Taiwan University, Taipei, R. O. C.
In LiCu₂O₂, which is a multiferroic material, there are competing superexchange interaction in spin chains and the ground state has spiral spin configuration. In ESR1 there are resonances at ν₁ ~ 30GHz and ν₂ ~ 300GHz. The former does not appear in the spectrum of NaCu₂O₂ which has similar structure but is not multiferroics. We consider a zigzag spin chain with competing nearest and next nearest superexchange interactions. Additionally, we considered anisotropic exchange interaction and Dzyaloshinskii-Moriya(DM) interaction perpendicular to the spiral plane. Based on the classical picture and spin wave theory, we calculate the low lying excitations. We found that the resonance ν₁ corresponds to the spin wave state of wave vector [q] = Q where \[ Q = (0.5,0.174,0) \] is the wave vector of spiral spins. Both DM interaction and superexchange anisotropy can be the mechanism for resonance. For H parallel to the spiral axis, there are two branches. For H perpendicular to the spiral axis, we found only one branch. By comparing with experiment result, the system properties, such as anisotropy and DM interaction can be revealed. We are also going to analyze the line shape by calculating the energy dissipation of the system. Based on this work, one should be able to identify the basic difference between LiCu₂O₂ and NaCu₂O₂.

15P-C011  Low-Temperature Heat Transport in the Quasi-Two-Dimensional Multiferroic CuFeO₂
The delafossite-type CuFeO$_2$, belonging to the space group R3m, has geometrically frustrated antiferromagnetic structure due to its layered triangular lattices of high-spin Fe$^{3+}$ ions. In zero magnetic field, Fe$^{3+}$ ions in ab plane form an Ising-like four-sublattice (4SL) antiferromagnetic ordering at low temperature. In applied magnetic field along the $c$ axis, CuFeO$_2$ exhibits complex phase transitions. Especially, it shows a ferroelectric incommensurate (FEIC) phase and presents multiferroicity.1 We report a study of the low-temperature heat transport of CuFeO$_2$ single crystals. It is found that the zero-field $\kappa(T)$ shows a “dip”-like feature at $\sim 11$ K, which is related to the transition from the partially disordered phase to the 4SL state. The $\kappa(H)$ isotherms for H || c show a drastic suppression at 7 T and a step-like increase at 13 T, which corresponds to the transition from the 4SL phase to the FEIC phase and then to the five-sublattice (5SL) phase, respectively. Moreover, the $\kappa(H)$ shows irreversible behaviors at 7 T and 13 T because of the first order of these transitions.


15P-C012 Hole density of (Ga,Mn)As across its Curie temperature studied via pulsed high magnetic field

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(Ga,Mn)As is the most widely studied III-V ferromagnetic semiconductor, and its ferromagnetism comes from the p-d exchange interaction between manganese magnetic ions and holes. The hole concentration is conventionally determined via Hall measurement at extremely low temperature and high magnetic fields. In order to further clarify the origin of magnetism in ferromagnetic semiconductors, we carried out Hall measurements of (Ga,Mn)As samples at various temperatures (below, at and above the Curie temperature $T_C$) in a pulsed high magnetic field (up to 40 T).

Magnetoresistance and Hall resistance measurements were performed simultaneously on (Ga,Mn)As samples. With the Hall resistivity given by $R_{xy} = R_{xy}^0 + R_{xy}^c = \frac{\rho_{xy}}{\rho_{xx}} + M \frac{R_{xx} R_{xy}}{\rho_{xx}}$, we fit the anomalous Hall resistance $R_{xy}$ on the assumption that the magnetization M follows the Brillouin function and $R_{xy} = \alpha R_{xx}^0$. Subtract $R_{xy}$ from the Hall resistance $R_{xy}$ and we obtain the ordinary Hall resistance $R_{xy}^0$ from which the carriers concentration can be further determined. The hole density measured in this way is almost in accordance with that determined by the conventional method at low temperature. Initial results suggest that the hole density in (Ga,Mn) determined across its Curie temperature at pulsed high magnetic field might allow for a further clarification of the origin of magnetism in ferromagnetic semiconductors.

15P-C014 Phase transitions in TbMnO$_3$

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Magnetic properties of TbMnO$_3$ multiferroic as a function of grain size, temperature and magnetic field have been studied. The nanosize (45, 60 and 70 nm) TbMnO$_3$ manganites were synthesized with a sol-gel method at 800, 850 and 900 °C temperatures. The TbMnO$_3$ film was grown onto the single crystal [001] SrTiO$_3$ substrate using magnetron sputtering technique. The peculiarities of magnetic ordering in polycrystalline, nanosize and film TbMnO$_3$ manganites were compared. Magnetization and the Néel temperature corresponding to antiferromagnetic ordering of the Tb$^{3+}$ sublattice decrease as the particle size is reduced. Magnetization of the TbMnO$_3$ film and specific heat of the nanosize samples exhibit anomalies related to the magnetic ordering of the Tb$^{3+}$ and Mn$^{3+}$ sublattices. The magnetic field and temperature dependences of the electric polarization of TbMnO$_3$ film have shown that the ferroelectric phase appears below 30 K in magnetic field $H > 1$ T applied along both the a and c axis.

15P-C015 NMR studies of Heusler-type...
intermetallic antiferromagnet Mn$_3$Si

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Itinerant electron antiferromagnet Mn$_3$Si is an intermetallic compound with a cubic crystal structure of the Heusler-type. Mn atoms are occupied on two different sites of Mn(I) and Mn(II), whose atoms have different magnetic moments due to their different nearest-neighbor configurations. Mn$_3$Si becomes antiferromagnetic state below the Néel temperature of $T_N=23$ K with a spin density wave (SDW). According to neutron diffraction studies, the most probable spin structure is a transverse sinusoidal structure (TSS), in which the maximum amplitudes of magnetic moments for Mn(I) and Mn(II) were determined as 2.4 and 0.28 $\mu_B$, respectively. In order to investigate the physical properties of Mn$_3$Si microscopically, the $^{55}$Mn NMR have been carried out for both paramagnetic and antiferromagnetic phases in the temperature region between 2.2 and 300 K. The temperature dependences of line width, Knight shift and spin-lattice relaxation time $T_1$ of $^{55}$Mn NMR have been measured for both phases. In the antiferromagnetic phase, two different spectra corresponding to Mn(I) and Mn(II) sites are found at the resonance frequencies of 145 and 6 MHz, respectively, at 4.2 K. From these results, the internal magnetic fields on $^{55}$Mn(I) and $^{55}$Mn(II) nuclei are obtained to be 13.6 and 0.6 T, respectively. According to NMR results, a helical structure in Mn spin states is well explained compared with the TSS.

15P-C017 Magnetic and magneto-dielectric properties in frustrated Cu$_2$Te$_2$O$_5$Br$_2$

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An intriguing magnetodielectric behavior is observed in geometrically frustrated spin-tetrahedral system (Cu$_2$Te$_2$O$_5$Br$_2$). A strongly reduced magnetic transition temperature $T_N=11.7$ K is found in comparison with a dominant magnetic exchange of 40 K. In the dielectric measurement, two main peaks are observed at around $T_1\sim40$ K and $T_2\sim80$ K. When applying magnetic field, both $T_1$ and $T_2$ decrease. The peak at $T_1$ might be due to the magnetic exchange interaction between Cu atoms. While, the peak at $T_2$ might be due to the ferroelectric phase transition, in which a remnant polarization is found to increase when temperature is lower than $T_2$. The similar and different properties between Cu$_2$Te$_2$O$_5$Br$_2$ and its isostructural compounds are compared and discussed.

15P-C018 Bi$_3$$_{x}$M$_{3}O_{11+\delta}$ (M=Cr, Rh, Ir, Pt, Pd): A series of new K$_2$O$_3$-type structural magnetic materials


K$_2$O$_3$-type family is interesting because it can adopt three interpenetrating networks with the composition changing from ABO$_3$ (K$_2$O$_3$ and KIrO$_3$) to ABO$_3$-667 (Bi$_2$Ru$_4$O$_{11}$, La$_3$Ru$_4$O$_{11}$, and Bi$_2$GaSb$_2$O$_{11}$). Recently Belik et al reported a new K$_2$O$_3$-type random ferrimagnet Bi$_3$Mn$_3$O$_{11}$ with high Tc. Here we reported a series of new K$_2$O$_3$-type structural materials Bi$_{3-x}$M$_3$O$_{11+\delta}$ (M=Cr, Rh, Ir, Pt, Pd) synthesized by high pressure and high temperature (HPHT). We investigated the effects of oxygen content on the structural, physical, and chemical properties of these materials, because a wide variation of $\delta$ value (changed from -0.5 to 0.6) in this system keeps the same cubic structure. In addition, we also studied the effects of Bi content on the structure, physical, and chemical properties. The value of $x$ was changed from 0 to 0.4 in Bi$_{3-x}$Cr$_3$O$_{11+\delta}$.

15P-C019 Three-dimensionally aligned V trimers in various vanadates

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We found that V$_3^{2+}$ (3E$^2$) trimers are formed and three-dimensionally aligned as a phase transition in three different series of vanadates [AV$_{10}$O$_{15}$, A$_2$V$_{13}$O$_{22}$, and AV$_{13}$O$_{18}$ (A=Ba, Sr)], in which V ions occupy a part...
of the fcc lattice in the high-temperature phase.\textsuperscript{1} We also found that this V trimerization substantially affects the transport and magnetic properties of these compounds. From various measurements, e.g., resonance x-ray scattering, NMR, and optical measurement, we conclude that this V trimerization and the change of various properties can be attributed to the orbital ordering of V $t_{2g}$ states with spin-singlet formation. The present result implies that such V trimers are local objects that are rather universally observed in a certain class of compounds (3d$^{5}$ ions on a fcc lattice), and can be regarded as “molecules of ions” in the crystal.\textsuperscript{1}


\textbf{15P-C020} Electromagnon excitation in the triangular lattice antiferromagnet CuFeO$_2$

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In multiferroic materials, peculiar magnetoelastic effects are expected. One of the most distinctive examples of such effects is the electromagnon excitation, for which magnon is driven by an oscillating electric field. In this study, from high-field/multi-frequency ESR measurements we investigate the detailed frequency and field dependences of the electromagnon in the triangular lattice antiferromagnet CuFeO$_2$, which was recently found by terahertz time-domain spectroscopy\textsuperscript{1}. Polarization dependence for two kinds of the magnon modes in this material is measured. As a result, the higher frequency mode is shown to be driven by an oscillating electric field as Seki et al. reported. The frequency dependence of the observed magnon modes are analyzed based on a spin wave theory and compared with the excitation spectra measured by neutron scattering experiments. We now plan to measure the polarization dependence of the magnon modes in a field-induced 1/5 plateau phase, which appears above 13 T.


\textbf{15P-C021} Magnetic Structure of Ba$_2$Mg$_2$Fe$_{12}$O$_{22}$ in Ferroelectric Phase

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Recently, it has been established that the ferroelectricity is coupled with the spiral magnetic structure under an applied magnetic field. This feature can lead to a new type of storage devices, such as an electric field controlled magnetic memory. However, the magnetic field in order to switch the direction of ferroelectric polarization is too high ($\sim$1T) for the application of multi-ferroic materials. We focus on recently reviewed Ba$_2$Mg$_2$Fe$_{12}$O$_{22}$ which has a strong coupling between electric polarization $P$ and magnetization $M$. This material holds high possibility for the application, because the working temperatures are relatively high and applied magnetic fields are relatively low. However, the detailed magnetic structure in ferroelectric phase was still unclear because of its complexity. So, we performed crystal structural and precise magnetic structural analyses of Ba$_2$Mg$_2$Fe$_{12}$O$_{22}$ under a magnetic field ($T = 4K$, $H = 0.3T$) using 4 circle neutron diffractometer (FONDER) at JRR-3M Tokai. We collected 109 points of magnetic scattering for $q = (003/2)$ and over 150 points of fundamental scattering. Using these data, we determined the magnetic structure, in which 14 (Mg,Fe) sites have been included. In this conference, we propose a possible model for the magnetic origin of ferroelectricity.

\textbf{15P-C022} Nb-substitution effects in half-metallic double perovskite Ba$_2$FeMoO$_6$

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We studied systematic changes of the structural, electric and magnetic properties in half-metallic double perovskite Ba$_2$FeMo$_{1-x}$Nb$_x$O$_6$ with $0 \leq x \leq 1$. Here, the substitution of Nb$^{5+}$ ($4d^0$) for Mo$^{5+}$ ($4d^1$) is expected to diminish the spin-polarized carriers which play a key role in appearance of ferromagnetism above room temperature in the double perovskite. Polycrystalline samples were prepared by a conventional solid-state reaction method in reduced atmosphere of $H_2$(5%)/Ar. While crystal structure holds cubic $Fm\overline{3}m$ up to $x = 1.0$, the lattice parameter at room temperature linearly increases with $x$. On the other hand, the Curie temperature $T_C$ linearly decreases with $x$. No trace of the ferromagnetic order is observed above $x = 0.8$, which is accompanied by disappearance of metallic character in the ground state judging from divergence in resistivity toward 0 K. These results indicate the strong correlation between the itinerant electrons and occurrence of the ferromagnetic state. The decline of $T_C$, $dT_C/dx \sim 300$ K/Nb, is one order of magnitude larger than that for $A$-site substitutions of such as La and Na. In addition, $T_C$ is almost insensitive to the Fe-substitution in the ferromagnetic region of Sr$_2$Fe$_{1-x}$Mo$_{1-x}$O$_6$. Therefore, the alternative order of Fe and Mo forms a peculiar platform for the ferromagnetism above room temperature.

\textbf{15P-C023} Size effect on magnetic properties of LiFePO$_4$ particles

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15P-C024 Magnetoelectric property in 3d transition metal oxide with tetrahedral structure

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Recently, spin-driven electric polarization is reported in a staggered antiferromagnet Ba\textsubscript{2}CoGe\textsubscript{2}O\textsubscript{7} with CoO\textsubscript{4} tetrahedra. The mechanism of the electric polarization can be explained by the spin-dependent p-d hybridization model. In this work, in order to explore novel multiferroic materials, we have investigated magnetic and dielectric anisotropies of CaBaCo\textsubscript{2}O\textsubscript{7} single crystal, which has layered structure consisting of CoO\textsubscript{4} tetrahedra. The crystallographic symmetry of CaBaCo\textsubscript{2}O\textsubscript{7} is Pbn\textsubscript{2}1 at room temperature, which breaks the inversion symmetry. The magnetic moments along the a- and b-axes rise at 64 K, suggesting a weak ferromagnetism. We have also observed an increase of electric polarizations along the b- and c-axes at the magnetic transition temperature. In addition, the peaks of dielectric constant along the b- and c-axes also emerge at the same temperature. When applying a magnetic field of 8 T along the parallel direction to the electric polarization, the rise of electric polarization shifts toward higher temperatures by 8 K. While in the case of the perpendicular direction, that shifts by 15 K. These results may suggest that the electric polarization is closely related to the induced magnetization. We will discuss the detailed results of experiments that include the poling electric- and magnetic-field dependence of electric polarization.

15P-C025 Ultrafast magnetoelastic and thermoelastic dynamics in hexagonal YbMnO\textsubscript{3} single crystals observed by femtosecond spectroscopy

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Fine tuning of the LiFePO\textsubscript{4} structure and/or of valance of iron ions can change significantly magnetic properties of LiFePO\textsubscript{4}, a candidate material for electrodes in rechargeable Li-ion batteries. It is known that partial lithium extraction from LiFePO\textsubscript{4} affects its intrinsic magnetic properties, leading to an increase of the Néel temperature from 50 K to 125 K (A. Ait-Salah et al., Z. Anorg. Allg. Chem. 632 (2006) 1598). We found for the particles of LiFePO\textsubscript{4} the appearance of an additional antiferromagnetic transition at 125 K as well as the presence of a minor phase showing a spontaneous magnetization with T\textsubscript{C} above room temperature along with the presence of a main antiferromagnetic phase, characteristic of a bulk LiFePO\textsubscript{4} with T\textsubscript{N} of about 50 K. Importantly, the transition at 125 K can be suppressed by relatively small magnetic field of the order of 0.3 T. We attribute the observed behavior to the electronic and/or structural differences between the outer layers and the interior of the LiFePO\textsubscript{4} particles.

15P-C026 The ferroelectric and leakage current properties of Sm-Ta co-doped Bi\textsubscript{4}Ti\textsubscript{3}O\textsubscript{12} Ferroelectric Thin films

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The Sm-Ta co-doped Bi\textsubscript{4}Ti\textsubscript{3}O\textsubscript{12} (Bi\textsubscript{4−x}Sm\textsubscript{x}Ti\textsubscript{3}O\textsubscript{12}Ta\textsubscript{0.08}O\textsubscript{12}, BSTTO) thin films were fabricated on Pt(111)/Ti/SiO\textsubscript{2}/Si(100) substrates by sol-gel technology. The effects of various processing parameters, including Sm content (x = 0−0.08) and annealing temperature (500−800°C), on the microstructure and ferroelectric properties of thin films were investigated. The measured 2P\textsubscript{c} of the highly (117)-oriented BSTTO thin film is larger than that of the Bi\textsubscript{4}Ti\textsubscript{3}O\textsubscript{12} thin film. The leakage currents of Sm-Ta co-doped Bi\textsubscript{4}Ti\textsubscript{3}O\textsubscript{12} films are lower than those of Ta doped specimens. The leakage current of Bi\textsubscript{4−x}Sm\textsubscript{x}Ti\textsubscript{3}O\textsubscript{12}Ta\textsubscript{0.08}O\textsubscript{12} and Bi\textsubscript{3}0.98Sm\textsubscript{0.02}Ti\textsubscript{3}0.92Ta\textsubscript{0.08}O\textsubscript{12} films are 1.25×10\textsuperscript{−5} and 1.47×10\textsuperscript{−5} A/cm\textsuperscript{2}, respectively, at 500 kV/cm. The reason is that the improvement of ferroelectric and leakage current properties in these films can be attributed to the enhanced stability of the oxygen in the Ti-O octahedron layer, which is caused by the substitution of stable rare-earth ions (Sm) for the volatile Bi ions located near the Ti-O octahedron layer. Furthermore, the substitution with high-valent cations (Ta) for Ti\textsuperscript{4+} in BTO thin films assisted the elimination of defects such as oxygen vacancy and vacancy complexes.

15P-C027 Spin Dynamics in Multiferroic Rare-Earth Manganites Probed by Muon Spin Relaxation

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We have conducted μSR experiment on polycrystalline samples of TbMnO$_3$ and GdMnO$_3$ under longitudinal fields up to 5 T, in order to clarify the spin dynamics in multiferroics. In the case of TbMnO$_3$, quite fast spin fluctuation ($\sim$10$^{12}$ s$^{-1}$) was seen at ambient temperature. Moreover, the fluctuation rate drastically decreases with lowering temperature down to 10 K, without showing any signature of magnetic transition both at 27 K and 42 K. In contrast, it was turned out that spin fluctuation in GdMnO$_3$ shows almost temperature independent behavior ($\sim$10$^{9}$ s$^{-1}$). Furthermore, remarkable reduction of the initial asymmetry was seen at 43 K, below which the ordering of Mn magnetic moment was reported. In spite of the quantitative difference of the spin fluctuation rate among these compounds, the dynamic magnetic nature was observed in both samples over the investigated temperature, which may relate to the frustrated magnetism due to the distorted perovskite structure.

**15P-C028 Electromagnons and non-reciprocal directional dichroism in Ba$_2$CoGe$_2$O$_7$**

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We propose a new mechanism to induce non-reciprocal linear directional dichroism in electromagnon absorptions. In multiferroics material, electric polarization and magnetism are strongly coupled, and in some cases, magnetic excitation can be an electric-active mode through the magnetoelectric couplings. Such an excitation mode is called *electromagnon*. When both electric and magnetic components of electromagnetic wave excite an identical mode, the interference between electric and magnetic responses emerges as a cross correlated effects. Such a cross correlated effect can be detected as a non-reciprocal linear directional dichroism, where absorption intensity strongly depends on the propagation directions of the electromagnetic wave. As a typical example, we discuss the magnetic excitation process in an $S = 3/2$ Heisenberg model for two-dimensional antiferromagnet Ba$_2$CoGe$_2$O$_7$. We indicate that, via a spin-dependent metal-ligand hybridization mechanism, one of the magnetic excitations is an electromagnon mode which explains the non-reciprocal linear directional dichroism observed experimentally.\[1\]


**15P-D001 Observation of Supercurrent through Topological Insulator Nanowires of Bi$_2$Se$_3$**

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Topological insulators are exotic materials with bulk band gap and metallic edge states which are protected on their own boundary topologically. Here, we report on the fabrication and measurement results of the superconducting proximity junctions of topological insulator nanowires of Bi$_2$Se$_3$. Single-crystalline Bi$_2$Se$_3$ nanowires are synthesized using the vapor-liquid-solid method, while the superconducting Al electrodes are formed on top of the nanowire. When a magnetic field ($H$) is applied along the nanowire axis, the magnetoresistance data exhibit quasi-periodic oscillations with a periodicity of $H^* \sim 1$ T. Increasing temperature or bias suppresses the oscillations to be vanished, which infers that the oscillations are due to the phase coherent electrical transport. In the superconducting state, the supercurrent branch with a critical current of $I_c \sim 100$ nA is clearly observed in the current-voltage curve. Irradiated with the microwave, the Bi$_2$Se$_3$ nanowire Josephson junction exhibits quantized voltage steps satisfying the Josephson relation.

**15P-D002 All-electrical control of Dirac electron transport (LT26)**

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All-electrical manipulation of electron spin in solids becomes a central issue of the condensed matter physics. Time-reversal invariant topological insulator, a strong spin-orbit coupling system, make it possible to control the spin transport electrically. We demonstrate that electron tunneling through a p-n junction created electrically in HgTe quantum wells with inverted band structure exhibits interesting optic-like propagating behavior. We find a perfect intraband transmission for electrons injected perpendicularly to the interface of the p-n junction. A spin splitter can be realized using the Rashba spin-orbit interaction. The occurrence of a conductance plateau due to the formation of topological edge states in a quasi-one-dimensional p-n junction can be switched on and off by tuning the gate voltage.\[1\] A mechanical control, i.e., strain effect, can also create a waveguide in a bulk graphene and leading a valley-polarized current utilizing the electron-optics-like Goos-Hänchen effect.\[2\] We also demonstrate theoretically an electrical switching of the edge-state transport by means of a quantum point contact in a spin Hall bar. The switch-on/off of the edge channel is caused by the finite size effect of the quantum point contact and therefore can be manipulated by tuning the voltage applied on the split gate.\[3\] We propose to control the surface magnetism of three-dimensional
topological insulators electrically. The helical Dirac electrons lead to the Heisenberg-like, Ising-like, and Dzyaloshinskii-Moriya (DM)-like spin-spin interactions, which can be tuned by changing the gate voltage. The gap opened by doped magnetic ions can lead to a short-range Bloembergen-Rowland interaction. The competition among the Heisenberg, Ising, and DM terms leads to rich spin configurations and an anomalous Hall effect on different lattices.\(^4\)


**15P-D003** Transport properties of defect-controlled Bi\(_2\)Te\(_3\) single crystals: fingerprint of surface Dirac electrons

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We report synthesis and characterization by electrical transport measurements of defect-controlled Bi\(_2\)Te\(_3\) single crystals. By adding extra Te, which reduces naturally-formed antisite defects, we have succeeded in growing Bi\(_2\)Te\(_3\) single crystals, covering heavily hole-doped to heavily electron-doped metals, where intermediate region corresponds to the topological insulator. We have carefully investigated p-doped, insulating, and n-doped samples by magnetoresistance and Hall effect measurements up 55 T. These data are quantitatively compared with a single Dirac theory, revealing nontrivial character of the insulating samples. We will also discuss these results based on surface and bulk conduction channels.

**15P-D004** Disorder Effect in Two-dimensional Topological Insulator

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We conduct a systematic study on the disorder effect in two-dimensional topological insulator by calculating Z\(_2\) topological invariant\(^1\). Starting from the trivial and nontrivial topological phases of the model describing HgTe/CdTe quantum wells\(^2\), we introduce three different kinds of disorder into the system, including: random on-site potential, random hopping amplitude and random topological mass. These kinds of disorder commonly exist in HgTe/CdTe quantum wells grown experimentally. By explicit calculations, we show that all three kinds of disorder have the similar effect: the topological phase in the system is not only robust to them, but also can be brought about by introducing them to the trivial phase. These results make a further confirmation and extendability of the study on the disorder effect in topological phase\(^3\).


**15P-D005** Disorder Effect in Two-dimensional Topological Insulator

Xianglin Zhang\(^a\), Huaiming Guo\(^b\), \(^a\)Department of Physics, Beijing Normal University, Beijing 100875, China \(^b\)Department of Physics, Capital Normal University, Beijing 100048, China

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**15P-D006** Magnetism of Multi-Orbital Edge States in Sr\(_2\)RuO\(_4\)

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Motivated by the multi-band spin-triplet superconductor Sr\(_2\)RuO\(_4\), we investigate the superconducting and magnetic properties of a two-band system. The two bands correspond to the \(\alpha\)-\(\beta\) bands of Sr\(_2\)RuO\(_4\) coupled via inter-band hybridization and spin-orbit coupling. Considering chiral p-wave pairing we analyze the multi-orbital edge states which possess a gapless quasiparticle spectrum but are not topologically protected. We find that the edge states carry both charge and spin current giving rise to anomalous and spin Hall effect. Including electron-electron correlation the edge states develop instability towards an incommensurate magnetic order concentrated at the surface. We analyze the interplay
between magnetism and superconductivity in this context and discuss experimental consequences of the edge states and their magnetic order.

15P-D007 Critical Exponent for the Quantum Spin-Hall Transition
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We study numerically the transport properties of disordered topological insulators. In this paper, we focus on the two-dimensional topological insulators with symplectic symmetry that are known as quantum spin-Hall systems. Some quantities such as critical exponents for divergence of the localization length and the probability distributions of conductance show universal properties at the metal-insulator transitions. The critical properties at the metal-topological insulator transition are expected to be the same as those at the metal-ordinary insulator transition. Recently, however, the critical conductance distributions were shown to be changed dramatically from those of topologically trivial systems to a novel distribution when the system has edge states. On the other hand, whether the critical exponent depends on the topological nature of the system remains to be verified. In this paper, we have confirmed that the critical exponent of the localization length is independent of the topological nature of the insulating phase. Instead of standard MacKinnon-Kramper parameter, we have evaluated the critical exponents for the systems with edge states by analyzing the second smallest positive Lyapunov exponent. We have found that the critical exponent, \( \nu = 2.77 \pm 0.06 \), coincides with that for topologically trivial systems. The case of quantum Hall systems will also be discussed.


15P-D008 The Fluctuation Character on the Existence of Magnetocaloric Effect
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Since the Curie temperature of Gd-metallic system which is on its stable-s-state is reported to be \( =289 \) K even in high pressure, the cause of its higher value in some-Gd-intermetallic compounds with nonmagnetic elements is a question(Tc=340K).A strong exchange fluctuation can be considered where high resistivity, suprising displacement of magnetic ions and even crystal phase transition is manifested. Even though exchange fluctuation is known to be the cause of phenomena, but the anisotropy must plays an important role which can be due to the competition of FM-AFM. But the nature of anisotropy in the Gd case should be cleared up where; the considered system is on its FM phase transition and the competition of two magnetic phases do not exist and even more the hydrostatic pressure effect does not change the behavior except a small change in compressibility. Since in the isostructural compounds the only parameters which determine the magnetic behavior as the sign and the strength of the exchange parameter is depend on; (1) the topological positions of the magnetic ions, and (2) the nature and the density of c.e, both of which are strongly depend not only on the nearest-neighbors but also on the correlation length defined by the , there should exist a critical composite for which the should be on its extremum value. At this value of Re the dominance of dispersion of exchange or even the competition of magnetic ions (intra-cluster exchange) overcome the thermal fluctuations where and consequently the fluctuation can be due to the displacement of the atomic positions in direction lowering of free energy resulted to increasing the entropy.

15P-D009 Electrical transport properties of single-crystal Bi2Te3 nanowires
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Single-crystal Bi2Te3 nanowires of 55 nm and 220 nm in diameters were fabricated by template-assisted electrochemical deposition. The electrical transport properties of the nanowires in the temperature range 1.8-300 K were measured by contact with FIB-deposited non-superconducting Pt or superconducting W-electrodes. When the individual wire is contacted with W-electrodes, a series of exotic quasi-periodic oscillations were observed and the amplitude of the oscillations was unusually intensified near 3.5 K below the Tc, 4.5 K of W-electrodes. When the wire is contacted with non-superconducting Pt electrodes, a series of significant magnetoresistance oscillations were observed in 55 nm wire under perpendicular magnetic field but not seen in parallel field.

15P-D010 \( \mathbb{Z}_2 \) Topological Anderson Insulator
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We report our recent study\textsuperscript{1} on the effects of disorder on two-dimensional \( \mathbb{Z}_2 \) topological insulator using the transfer matrix method. Based on the scaling analysis, the phase diagram is derived for a model of HgTe quantum well as a function of disorder strength and magnitude of the energy gap. In the presence of sz non-conserving spin-orbit coupling, a finite metallic region is found that partitions the two topologically distinct insulating phases. As disorder increases, a narrow-gap topologically trivial insulator undergoes a series of transitions; first to metal, second to topological insulator, third to metal, and finally back to trivial insulator. We show that this multiple transition is a consequence of two disorder effects; renormalization of the band gap, and Anderson localization. The metallic region found in the scaling analysis corresponds roughly to the region of finite density of states at the Fermi level evaluated in the self-consistent Born approximation.
15P-D011 Topological Insulator with Dislocation Lines
K.-I. Imura*, Yoitake Takane*, Akhiro Tanaka, AdSM, Hiroshima University, Higashi-Hiroshima 739-8520, Japan
We report our recent study on protected gapless surface states in a weak topological insulator. We propose a workable model for describing dislocation lines in a three-dimensional topological insulator. We show how fragile surface Dirac cones of a weak topological insulator evolve into protected gapless helical modes confined to the vicinity of dislocation line. We demonstrate that surface Dirac cones of a topological insulator (either strong or weak) acquire a finite-size energy gap, when the surface is deformed into a cylinder penetrating the otherwise surface-less system. This reveals that the topological stability of protected 1D modes stems from this finite-size energy gap associated with the spin Berry phase. The latter has been a subject of much theoretical attention in the context of peculiar Aharonov-Bohm oscillations observed recently in a system of strong topological insulator.

15P-D012 Coexistence of Topological Order and Quantum Well State on Topological Insulator
Chaovu Chen, Wentao Zhang, Lin Zhao, Haiyun Liu, Xiaowen Jia, Daixiang Mu, Shanyu Liu, Junfeng He, Yingying Peng, Aiji Liang, Guodong Liu, ShaoLong He, Xiaolu Dong, Jun Zhang, Zhongxian Zhao, Zuyan Xu, Chuangtian Chen, X. J. Zhou, a Beijing National Laboratory for Condensed Matter Physics, Institute of Physics, Chinese Academy of Sciences, Beijing 100190, China b Technical Institute of Physics and Chemistry, Chinese Academy of Sciences, Beijing 100190, China High resolution Laser-based angle-resolved photoemission spectroscopy (Laser-ARPES) measurements have been carried out on topological insulator Bi2Se3 and Bi2Te3. Intrinsic hexagonal Fermi surface was observed and topological order protected by Time Reversal Symmetry was ascertained even the samples were at room temperature and cleaved in air. Furthermore, Quantum Well State was observed in air-cleaved Bi2Te3. The conformation of topological order and coexistence of Quantum Well State and topological order inspire further research both in physical and industrial field.

15P-D013 Superconducting Proximity Effect And Conductance Anomalies in Sn-Bi2Se3 Junctions
F. Yang, Y. Ding, F.M. Qu, J. Shen, J. Chen, Z.C. Wei, Z.Q. Ji, G.T. Liu, J. Fan, C.L. Yang, T. Xiang, L. Lu, a Daniel Chee Tsui Laboratory, Institute of Physics, Chinese Academy of Sciences, Beijing, China b Institute of Theoretical Physics, Chinese Academy of Sciences, P.O. Box 2735, Beijing 100190, China
We have investigated the conductance spectra of Sn-Bi2Se3 single junction device down to 250 mK and in different magnetic fields. A double-gap structure was observed at the center of the conductance spectra. With the sharpening of the small gap at lower temperatures, a zero-bias conductance peak occurred. This phenomenon would reflect the formation of a proximity effect induced new superconducting state at the interface. The new state was found to be competing with the s-wave superconductivity in Sn electrodes, demonstrating presumably an unconventional pairing symmetry. A broad region with enhanced conductance was also observed below Tc, which extends well beyond the superconducting gap of Sn. So far, the origin of this structure is not clear.

15P-D014 Majorana edge modes at topological insulator-superconductor-junctions in three dimension
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Certain classes of topological insulator-superconductor-junctions in three dimension support Majorana edge modes at line defects. The conditions for the existence of gapless modes at a boundary between two insulators is well known as “bulk-boundary correspondence” which implies that difference of the topological number between two insulators leads to the existence of gapless edge modes. Recently the conditions for the existence of gapless modes in arbitrary topological defects such as the topological insulator-superconductor-junctions is proposed. It is suggested that the existence of gapless modes follows from topologically nontrivial Hamiltonian which varies with material parameters surrounding the defects. In this study, we survey the existence of Majorana edge modes at topological insulator-superconductor-ferromagnet junctions following the approach of Ref. Moreover we compare it with other results obtained from an effective two dimensional theory at an interface, and the topological field theory for Axion electrodynamics.

15P-D015 Fractional Topological Excitations and Quantum Phase Transition in a Bilayer 2DEG Adjacent to a Superconductor Film
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We study a bilayer two-dimension-electron-gas (2DEG) adjacent to a type-II superconductor thin film with a pinned vortex lattice. We find that with increasing interlayer tunneling, the system of half-filling presents three phases: gapped phase-I (topological insulator), gapless critical phase-II (metal), and gapped phase-III (band insulator). The total Hall conductance for phase-I/III is $2/e^2/h$, and has nonquantized values in phase-II. The excitation (response to topological defect, a local vortex defect) in these three phases shows different behaviors due to the topological property of the system, including fractional charge $e/2$ for each layer in phase-I. While in the case of quarter-filling, the system under-

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goes a quantum phase transition from metallic phase to topological insulator phase.

15P-D016 Gate-voltage Tunable Surface Conductance in Bi$_2$Se$_3$
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Bi$_2$Se$_3$ films can be epitaxially grown on SrTiO$_3$ substrate. This allows the chemical potential tuned into the bulk gap with back-gates. We study the weak antilocalization effect in diffusive electron transport and find it can serve as a convenient method for detecting decoupled surface transport. In the high density regime where a bulk Fermi surface coexists with the surface states, the low field magnetoconductivity can be described well by the Hikami-Larkin-Nagaoka equation$^1$ for single component transport of non-interacting electrons. When the electron density is lowered, the magnetotransport behavior deviates from the single component description and strong evidence is found for independent conducting channels at the bottom and top surface.


15P-D017 On the low vibrational states seen in the heat capacity of incommensurate ThBr$_4$
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We report on the thermodynamic investigation of the low vibrational states of the truly incommensurate (IC) 3D compound ThBr$_4$, unique among other dielectrics for the lack of lock-in transition. Heat capacity measured in the T-range from 140 mK to 25 K demonstrates the glasslike anomalous behavior with the power-law contribution below 1 K and the $C_p/T^3$ bump above. We find both features being consequences of the phasons and the amplitudon, the typical IC-excitations in agreement with existing neutron investigation of these excitations. Ultimately, our analysis shows that there must be a low-energy gap in phason dispersion of about 10 GHz, what is considerably lower than the experimental uncertainty of the neutron data.

15P-D018 Quasiparticle Interference in Fe doped Bi$_2$Te$_3$ by Scanning Tunneling Spectroscopy
Wenwen Zhou$^a$, Yoshinori Okada$^a$, D. Walkup$^a$, Chetan Dhital$^a$, Stephen D. Wilson$^a$, V. Madhavan$^a$, $^a$Department of Physics, Boston College, Chestnut Hill, MA, USA

We probe the surface state of Fe doped Topological Insulator Bi$_2$Te$_3$ by performing Fourier Transform Scanning Tunneling Spectroscopy measurements over a wide energy region. The experimental data clearly show several novel scattering channels that reflect the rich physics of 3D topological insulators. By combining our measurements with angle-resolved photoemission spectroscopy data, we find the emergence of forbidden backscattering channel, which provide evidence of time reversal symmetry breaking induced by magnetic impurities$^1$. In addition to this backscattering channel along the ΓK direction, we have recently discovered novel multi scattering channels that emerge at high energies along the ΓM direction. The possible origins including spin-orbit scattering are discussed.


15P-D019 The observation of the novel stripe phase in Bi$_2$Te$_3$
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Topological insulators (TI) with a single Dirac cone exhibit a novel half integer quantum Hall effect. This is an ideal system to achieve dissipationless transport in one dimension i.e., a perfect one dimensional (1D) quantum wire. In magnetic TI, 1D modes are predicted at the boundaries between two adjacent ferromagnetic domains. In this study, we present an alternative route to realizing a quantum wire on the surface of TI. Using scanning tunneling microscopy (STM) we have discovered spontaneously occurring striped periodic patterns on the surface of Bi$_2$Te$_3$. Landau level (LL) measurements across the stripes reveal anomalous properties close to the Dirac point, and we observed the clear systematic variation of the LL energy across the stripe. We propose the possible realization of the (1D) quantum wire based on the experimental results$^1$.

$^1$ Yoshinori Okada et al., in preparation

15P-D020 Examination of inhomogeneous electronic structure in 3D topological insulator Bi$_2$Te$_3$
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Studying the inhomogeneous electronic structure in three dimensional topological insulators (3DTI) is important for understanding the effects of local perturbations like impurities or strain which can in turn help us identify the relative importance of the different terms in the Hamiltonian for the system. However, there have been no systematic studies of inhomogeneity of the local density of states in 3DTI. In this study, we probe the surface of the three dimensional topological insulator Bi$_2$Te$_3$ using scanning tunneling microscopy (STM). Our data allow us to correlate the position dependence of the Landau levels and quasi particle interference patterns with local features. Based on the experimental results, we present a coherent understanding of how the inhomogeneous electronic structure emerges.
15P-D021 Optical spectroscopy study on the normal-state properties of superconducting doped topological Insulator CuxBi2Se3
T. Dong*, N.L. Wang*, *Institute of Physics of Physics, Chinese Academy of Sciences, Beijing, China
We present optical spectroscopy study on pure and Cu-intercalated Bi2Se3 crystals grown by self-melting technique. The pure Bi2Se3 shows a metallic optical response with a sharp plasma edge near 550 cm−1, being consistent with the ARPES measurement showing that the bulk electron-like band already crosses the chemical potential. The Cu-intercalated Bi2Se3 shows a superconducting transition near 3.8 K. Our optical spectroscopy measurement indicates that the plasma edge shifts substantially to higher frequency 1250 cm−1, indicating that Cu-doping supplies extra electrons to the system and further shifts the chemical potential up. Furthermore, our measurement revealed that the plasma edge shifts slightly to higher energies with decreasing temperature. The optical data yield useful information about the bulk electronic band structure of the superconducting doped topological Insulator CuxBi2Se3 (x=0.14).

15P-D022 Surface state charge dynamics of the high-mobility three dimensional topological insulator strained HgTe
We present a time-domain terahertz magneto-optical study of the three-dimensional topological insulator, strained HgTe. We invoke a technique which capitalizes on advantages of time-domain spectroscopy to amplify the signal from the surface states, delivering valuable and precise information regarding the surface state dispersion within <1 meV of the Fermi level. The method allows us to obtain the parameters describing the topological surface states near the Fermi energy, until now not resolved by other experimental techniques, namely free carrier spectral weight, quasi-particle scattering rate, cyclotron frequency, Fermi velocity and Fermi momentum. Prospects for observing the topological magnetoelectric effect will be discussed.

15P-D023 Identifying surface transport on 3D topological insulators with weak anti-localization
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In this talk, we will present our experimental effort on gate-voltage control of chemical potential in topological insulator Bi2Se3 thin films. We demonstrate that the low field magnetocconductivity can be described by the Hikami-Larkin-Nagaoka (HLN) equation in the regime where a bulk Fermi surface coexists with surface states. When lowering the electron density, the magnetotransport behavior deviates from the single component HLN equation. This is attributed to the existence of two independent conduction channels at the bottom and the top surfaces. Corrections to the magnetocconductivity due to the Zeeman energy are shown to be negligible despite non-negligible electron-electron interactions. This work establishes a convenient new method for identifying surface transport with the advantage of not requiring high carrier mobility or high magnetic fields.

15P-D024 Tunable Kondo-Luttinger systems far from equilibrium
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We theoretically investigate the non-equilibrium transport of a quantum dot coupled to two interacting one-dimensional electron leads with a bias voltage V across the dot. In equilibrium (V=0), the system exhibits either a conducting one-channel Kondo (1CK) or an insulating two-channel Kondo (2CK) ground state, as the Luttinger parameter 0 < K < 1 (the interaction strength in 1d leads) is decreased. A quantum phase transition between 1CK and 2CK ground states is reached when K = 1/2. We apply a controlled frequency-dependent renormalization group approach to compute the non-equilibrium current in the presence of a finite bias voltage V for various K. For V → 0, the conductance has its well-known equilibrium form, while with decreasing K it displays a distinct non-equilibrium profile at finite voltage. To clarify this distinct non-equilibrium behavior, we address the interplay between non-equilibrium decoherence, Kondo entanglement and Luttinger physics. The combined effects of large bias voltage and strong electron interactions in the leads stabilize the two-channel Kondo physics, resulting in non-trivial modifications of the conductance. This distinct feature persists at a finite channel asymmetry.

15P-D025 Thermovoltage of a Suspended Carbon Nanotube Heated by Terahertz Radiation
Due to their one-dimensional nature electronic transport through carbon nanotubes at low temperature is described by collective behavior of the charge carriers, instead of single electron excitations. Resonances due to standing charge-density waves in the carbon nanotube are expected in the 100 GHz to 1 THz range. We study the conductance of single, suspended carbon nanotubes under 100 GHz radiation. Due to the absence of direct contact to a gate dielectric, these antenna-coupled nanotubes are expected to show less scattering...
of collective excitations. Furthermore, the thermal contact to the environment is reduced significantly. Hence, cooling of electrons is dominated by out-diffusion to the leads. The conductance of the carbon nanotubes shows power law scaling in temperature and bias voltage ascribed to Luttinger liquid behavior. The response to 100 GHz radiation is characterized by an increase of the effective temperature in the nanotube, leading to a similar change in conductance as seen for conventional heating of the complete substrate-lead-nanotube system. Modeling of the electron temperature in the suspended nanotube under absorption of microwave power shows that the temperature profile sharply drops to the bath temperature at the nanotube-lead interface. This local temperature profile induces a thermovoltage at zero current, not seen in conventional heating of the entire system.

15P-D026 Scanning Tunnelling Microscope Studies of nanowires and nanoparticles
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We reported the scanning tunnelling microscope studies of nanowires and nanoparticles. The growth mechanism and electronic local density of states of a single nanowire and single nanoparticle were explored using low temperature scanning tunneling microscopy (STM) and spectroscopy (STS). Quantum confine effect and surface effect are observed in the samples [1-3]. Recently, we also observed the coexistence of Coulomb blockade and zero bias anomaly both in nanowires and nanoparticles [4-6]. Further analysis is carried out to explore the nature of these behaviors.

References (The author with * as superscript is the corresponding author):

15P-D027 Energy Relaxation in a Diffusive SNS Junction in an AC Field
J. Voutilainen\textsuperscript{a}, T. T. Heikkilä\textsuperscript{a}, \textsuperscript{a}Low Temperature Laboratory, Aalto University School of Science, Finland

In an earlier work, we have studied a diffusive S/(superconductor)-N(normal metal)-S/(superconductor) wire as a detector for electromagnetic radiation.\textsuperscript{1} This brings up many questions regarding the coupling of the absorber to the incoming radiation and the subsequent energy relaxation, namely electron-electron, electron-phonon and energy-outdiffusion processes. Here, the photon-electron coupling in particular becomes complicated due to the proximity-induced superconductivity in the absorber.\textsuperscript{2} In the extreme cases, this results in a huge enhancement of superconductivity due to irradiation. Previously, we have only used a simple model which disregards the proximity effect in photon-electron coupling. Here, we study the relaxation process in a diffusive SNS junction in an AC field, be it optical irradiation or produced by an electrical circuit, with a focus on the effects resulting from the induced superconductivity in the junction.


15P-D028 Dissipation in Stressed Silicon Nitride Beams at Very Low Temperatures
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We report measurements of the dissipation and the frequency shift in gold-coated, high stress silicon nitride nanomechanical resonators. The measurements were carried out in the temperature range 40 mK to 1.5 K using the magnetomotive transduction scheme. Devices of lengths 4.4, 6.4 and 25.5 μm of thickness 170 nm with 80 nm of gold deposited on top and one device with length 25.5 μm and 40 nm of gold were studied. Quality factors and frequency shifts were determined for the fundamental modes with frequencies in the range 5 MHz to 56 MHz and higher harmonics of the longer beams. Throughout most of the temperature range measured, the dissipation decreased linearly with temperature. The resonant frequency increased logarithmically with temperature at the lowest temperatures, with saturation observed at the higher temperatures observed for the flexural modes of the 25.5 μm long beams. The strong variation of the damping and the logarithmic dependence of the resonant frequency on temperature suggest that tunnelling two-level systems are an important source of dissipation in nanomechanical resonators. Our results also confirm that a metallic layer on top of a dielectric resonator can have significant impact on the magnitude and the temperature dependence of the dissipation.

15P-D029 Influence of microstructure on the thermal properties of Si$_3$N$_4$/BN fiber monoliths.
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Detailed measurements and studies of thermal conductivity, $\kappa(T)$, heat capacity and $C_p(T)$ of Si$_3$N$_4$/BN polycrystalline ceramic samples and Si$_3$N$_4$/BN fiber
monoliths (FM) in the directions [0], [90], [0/90] and [0/45] of fibers have been performed between 4 K and 300 K. Sound velocity in the same samples has been also measured in the temperature range 3.5 - 77 K. Our studies indicate that at low temperatures (5-25 K) phonons dominate the scattering and phonons in Si₃N₄/BN [0], [90], [0/90] and [0/45] fiber monoliths are scattered primarily by dislocations. This effect has not not observed in ceramic Si₃N₄ and BN samples. The experimental data have been used for an estimation of the values of the phonon mean free path in polycrystalline Si₃N₄ and BN and of an effective one in the Si₃N₄ [0] FM.

15P-D030 Transport Properties of Bio-ceramics Type Bio-C/Cu (LT26)

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Thermal conductivity, κ, and electrical resistivity, ρ, of pine biocarbon preform/composites (bio-C/Cu) have been measured and studied in the temperature range 4 K – 300 K. Biocarbon preforms have been prepared by pyrolysis of wood in argon flow at two carbonization temperatures 1000 C and 2400 C . Then the sap channels as well as radial channels of the wood have been filled with pure copper . The magnitude of the thermal conductivity of the copper embedded in the preforms has been separated out of the total measured composite thermal conductivity value κ and has occurred to be considerably lower than that of the bulk copper. This result is attributed to the structure of copper in the composite, namely to breaks in the copper fillings. The microstructure of the preform also influences the dependence on the temperature of total ρ of the composites. The resistivity is primarily governed by the specific microstructure of the preform. Parallel channels of an average diameter of about 50 μm separated by systems of thin capillaries occur here to be most important. Copper-filled capillaries of small cross section contribute most to the electrical resistivity of the composites.

15P-D031 Electron tunneling measurements in atomic scale gap filled with liquid ⁴He below 4.2K

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Recently, it has become possible to investigate the electrical property of the atomic-sized metallic contacts by atomic-sized tip, e.g. STM and mechanical controllable break junction (MCBJ). By using MCBJ technique, one can prepare two symmetrical atomic-sized metallic electrodes and control the gap of the two electrodes precisely by piezoelectronic force.

In this presentation, we report the tunneling spectroscopy investigation in atomic scale gap filled with liquid ⁴He. In order to assure the filling of liquid ⁴He between the gap, the following experimental procedure was carried out. We construct a cryostat with a inner vacuum chamber inside the vacuum jacket for the thermal isolation. MCBJ apparatus is installed in the inner chamber with a flexible bellow. After filling liquid ⁴He below 4.2 K, Au electrical electrodes was stretched by the mechanical force generated by piezo device. We observed the increase of the tunnel conductance through liquid ⁴He compared to that in the vacuum environment.

15P-D032 Fermion Zero Modes and Induced-charge on a Domain Wall of a Narrow-gap Semiconductor-dot

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Brooke et al.[1] have investigated InAs self-assembled quantum dots by resonant inelastic light scattering. With resonant inelastic light scattering, they can directly observe the elementary electronic excitations of the few-electron quantum-dot atoms at low temperatures. They observe excitations which they identify as transition of electrons from the s- to the p-shell(s-p transitions) and from the p- to the d-shell(p-d transition) of the quasiatoms. They explain the shift and broadening of the s-p transitions of collective excitations in the experiment to be due to additional excitations at lower energies, which cannot be individually resolved. Recently the present author [2] has indicated the importance of the photo-induced domain-wall in magnetoresistance in diluted magnetic semiconductors. In this study, we will discuss the additional excitations in the quantum dot from collectively induced-charge effects on a domain wall around the semiconductor-dot, extending the previous formula[2] and Callen-Harvey theory[3], and from the p- to the d-shell(p-d transition) of the quasiatoms. They explain the shift and broadening of the s-p transitions of


15P-D033 Fano Effect on Dynamical Conductivity for Perpendicular Polarization in Double-Wall Carbon Nanotubes

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We study the dynamical conductivity of double-wall carbon nanotubes for perpendicularly polarized light to the tube axis by taking into account screening effects, exciton effects and depolarization effects within an effective-mass theory. For single-wall carbon nanotubes, it is known that the dynamical conductivity for perpendicularly polarized light is reduced considerably by a depolarization effect in comparison with that for parallel polarized light, but exhibits prominent exciton peaks in semiconducting nanotubes due to the strong Coulomb interaction. For double-wall carbon nanotubes, the Coulomb interaction is suppressed by
not only intra-wall screening effects but also inter-wall screening effects. This leads to the reduction of exciton binding energies and band gaps; however, clear exciton peaks still survive in the spectra. We also find that the exciton peak of the semiconducting inner tube has an asymmetric line shape due to the coupling with a continuum state of the outer tube, indicating the Fano effect. The Fano coupling strength can be turned by varying the inter-wall distance or tube radius ratio. We discuss both cases of semiconducting and metallic outer tubes.

15P-D034 Hole transport in an InSb nanowire quantum dot with superconductor contacts

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An InSb quantum dot with superconductor contacts is fabricated from an InSb nanowire grown by MOVPE.\(^1\) Due to the narrow band gap ($E_g \approx 0.17$eV) of InSb, the quantum dot can be tuned to the hole transport regime by applying negative voltages to the back gate even though the grown InSb nanowire is originally n-type. In low temperature measurements, abnormal Coulomb staircases are observed in the I-V curves. Every Coulomb step is accompanied by a sharp peak at its edge. This peak can be attributed to the singularity of the BCS density of states (DOS) in the superconductor leads and the conductance shows a maximum when the hole level of the quantum dot is aligned with the DOS singularity in the leads. The hole states in the InSb quantum dot have also been characterized by the magnetotransport and temperature dependent transport measurements. It is found that at slightly higher temperatures, an extra conductance peak is visible. This extra peak can be attributed to the thermal excitation of quasiparticles in the leads and the thermal population of an excited hole state in the dot.


15P-D035 Preparations and Photo-voltaic properties of dye-sensitized solar cell based on ZnO nanowire electrode

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The preferred (002) orientation Zinc oxide (ZnO) nanowire have been deposited on ITO-coated glass substrates by chemical bath deposition technology for use in dye-sensitized solar cells (DSSC). The effects of immersion concentrations (5mM, 10mM, and 20mM) and immersion time (1 h, 2 h, 3h, and 6h) on the microstructure, morphology and optical properties of ZnO nanowire were studied. The ZnO nanowire were characterized by X-ray diffraction (XRD), scanning electron microscopic (SEM) and UV-visible optical transmission spectra analysis. The photoelectric performance of DSSC was studied by I-V curve and the incident photon-to-current conversion efficiency (IPCE), respectively. From the results, the higher efficient of DSSC could be obtained under the concentration of 20 mM.

15P-D036 Fermi liquid description for Andreev-Kondo transport through a quantum dot coupled to normal and superconducting leads

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We provide a Fermi-liquid description for low-lying energy states, at $|\omega| \ll \Delta$, of an Anderson impurity connected to one superconducting with an energy gap $\Delta$ and one normal-metal electrode. In this system the interplay between the Andreev scattering and Kondo effect occurs at low temperatures. Specifically the crossover between the Cooper-pairing singlet and the Kondo singlet affects transport properties. This system has a $U(1)$ symmetry in the Nambu pseudo-spin space in the special cases, i) the particle-hole symmetric case, and ii) the large gap limit $\Delta \rightarrow \infty$. We studied the large gap limit in a previous work \cite{1}, mapping the original Hamiltonian exactly onto a single-channel Anderson model that describes the interacting Bogoliubov particles, the total the number of which is conserved in the two special cases. In the present report, we consider the corrections due to finite $\Delta$, starting from the $\Delta \rightarrow \infty$ limit. Specifically, we calculate order $1/\Delta$ corrections of the conductance. We also show that the conductance can generally be expressed in terms of the phase shift and Bogoliubov angle at zero temperature, using the Ward identity to evaluate the contribution of the vertex corrections.


15P-D037 Low-temperature oscillations of the thermopower in bismuth nanowires

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The emergence of the investigations concerned with various nanostructures is motivated partially by the very interesting thermoelectric and magnetotransport properties of bismuth nanowires that make them potentially useful for device applications. Under the quantum size effect (QSE), several fundamental macroscopic characteristic of solids exhibit an anomalous dependence on reduced size. Therefore, for subsequent applications, a precise determination of the size-dependent parameters of investigated nanostructures is required. If the decreased size of wires or films becomes comparable with the electron wavelength ($d \sim \lambda$), the transverse
motion of carriers is quantized. Thus, the energy spectrum splits into subbands. When the discreteness of the energy subbands becomes significant, an oscillatory behavior of electron and hole density of states as a function of thickness is expected for metal films.

Measurements of the thermopower and resistance of bismuth nanowires with several diameters and different quality reveal oscillations on the dependence of thermopower under uniaxial strain at $T = 4.2$ K. Amplitude of oscillations is significant (30%) at helium temperature with weak smearing at 20 K. Observed oscillations originate from QSE. A simple evaluation of period of oscillations allows us to identify the groups of carriers involved in transport.

15P-D038  Approaching the Depairing Current in YBCO Nanowires and Ultra-low-noise nanoSQUIDs
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Superconductive devices at the nanoscale can have a fundamental role in shedding light into the mechanism leading to High Temperature Superconductivity (HTS). The study of the transport properties of HTS nanowires with dimensions much smaller than the Pearl length gives access to a regime where the local properties of the superconductor have a fundamental role. From the application point of view, the realization of reproducible HTS nanowires can open new perspectives for the realization of HTS nanoSQUIDs with unprecedented performance in a wide temperature range (mK to 80K) and high magnetic fields (Tesla range). Here we report on the transport studies of $YBa_2Cu_3O_{7-x}$ (YBCO) nanowires with varying nominal width ranging from 300nm down to 30nm. All the wires were fabricated by conventional electron beam lithographic technique in combination with a hard carbon mask and Argon ion etching. The dependence of the critical current density as a function of the wire width shows a steep increase below 200 nm, with values approaching the depairing limit ($J_c=3\times10^9 A/cm^2$) for the smallest wires. NanoSQUIDs implementing two YBCO nanowires manifest an exceptional flux sensitivity below 315 K. Theoretical analysis of the flux sensitivity jump, attributed to the lattice parameters relaxation temperature $T_r$ (≈2 K) is about 2.47 and 5.25 J kg$^{-1}$ K$^{-1}$ under 1.5 and 5 T, respectively. The magnetic entropy change is related to the sharp magnetization jump, attributed to the lattice parameters change just at the Curie temperature. The magnetic entropy change for YbTiO$_3$ can be well described by a phenomenological universal curve behavior. The field dependence of the magnetic entropy change can be expressed as $\Delta S_M = H^n$. At the Curie temperature $n(T_C) = 0.633$ for YbTiO$_3$ single crystal. The field dependence of the relativistic cooling power ($RCP$) can also be expressed as $RCP = H^{1+1/4}$. For YbTiO$_3$ single crystal $\delta = 4.95$. The theoretical analysis of the relation between $n(T_C)$ and the critical exponents suggests that the critical behavior of YbTiO$_3$ belongs to the Heisenberg model. This was also confirmed by the heat capacity and thermal conductivity measurement.

15P-E001  Magnetocaloric Properties of Single Crystalline YbTiO$_3$ with Second Order Phase Transition

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Magnetic entropy change and refrigerant capacity in applied magnetic fields up to 5 T have been investigated in the temperature range of 10-90 K for the single crystalline YbTiO$_3$. The sample was prepared through the floating zone method. The maximal magnetic entropy changes at the second-order phase transition temperature $T_C$ (≈42 K) are about 2.47 and 5.25 J kg$^{-1}$ K$^{-1}$ under 1.5 and 5 T, respectively. The magnetic entropy change is related to the sharp magnetization jump, attributed to the lattice parameters change just at the Curie temperature. The magnetic entropy change for YbTiO$_3$ can be well described by a phenomenological universal curve behavior. The field dependence of the magnetic entropy change can be expressed as $\Delta S_M = H^n$. At the Curie temperature $n(T_C) = 0.633$ for YbTiO$_3$ single crystal. The field dependence of the relativistic cooling power ($RCP$) can also be expressed as $RCP = H^{1+1/4}$. For YbTiO$_3$ single crystal $\delta = 4.95$. The theoretical analysis of the relation between $n(T_C)$ and the critical exponents suggests that the critical behavior of YbTiO$_3$ belongs to the Heisenberg model. This was also confirmed by the heat capacity and thermal conductivity measurement.
temperatures. This technique allows the application of variable strain on the same set of InAs quantum dots. At low temperatures InAs/GaAs quantum dots ELO film bonded to Si (MgO) will experience tensile (compressive) strain. Photoluminescence (PL) spectroscopy of the small dots reveals that the tensile strain red shifts the optical transition to as much as 20 meV while compressive strain blue shifts by 13 meV with respect to the As-grown sample at 10 Kelvin. The magnitude of shifting is dependent on the dot size. A reversal in the PL intensity between emissions from the large sized and small size dots is also observed in the ELO film bonded on Si. We attribute this to the suppression of carrier thermalization on both dots due to enhanced carrier confinement in tensile strained InAs films.


15P-E003 Strain Enhancement of Electron Cooling in Silicon-Superconductor Tunnel Junctions

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The silicon-superconductor tunnel junction is analogous to the normal metal-insulator-superconductor (NIS) tunnel junction; it has been previously demonstrated that the normal metal in an NIS cooler can be replaced with a degenerate semiconductor and that an insulating tunnel junction is formed by a Schottky barrier. We have shown that the electron-phonon (e-ph) conductance is reduced when silicon is subjected to biaxial tensile strain and is approximately an order of magnitude lower than that of unstrained silicon. In this work we show that the reduced e-ph conductance results in enhanced electron cooling; we demonstrate cooling to 174 mK from an initial bath temperature of 300 mK. We argue that broadening of the superconductor density of states is responsible for limitation of the cooler performance.


15P-E004 Low temperature NMR relaxation and rattling phonons in type-I Ba$_8$Ga$_{16}$Sn$_{30}$ clathrates

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The atomic motion of guest atoms inside the cage of semiconductor clathrates is considered as one of the important sources responsible for the very low thermal conductivity. $^{69}$Ga and $^{71}$Ga Nuclear Magnetic Resonance (NMR) studies on type-I Ba$_8$Ga$_{16}$Sn$_{30}$ clathrates show a clear low temperature spin-lattice relaxation peak attributed to the influence of Ba rattling dynamics on the framework-atom resonance. Analysis indicates that an electric quadrupolar relaxation mechanism due to atomic motion is the leading contribution. The data are analyzed using a two-phonon Raman process, according to a recent theory involving a localized one dimensional anharmonic oscillator model potential. Excellent agreement is obtained using this model, with the parameters corresponding to a double well potential with very large anharmonicity. We have extended the theory to include a simplified two dimensional anharmonic well. In both models the best fit parameters correspond to very similar average displacement for the cage-center Ba atoms. We also examine the heat capacity behavior using this model, and compare to previously reported results obtained using these and other models for the anharmonic oscillator potential, and to low-temperature two-level system behavior of disordered materials.

15P-E005 Performance of the Helium Circulation System on a Commercialized MEG

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We report the characteristics of the Helium Circulation System (HCS) mounted on a MEG of Nagoya University, Japan, that is the first commercialized HCS. It collects warm helium gas about 300 K, cools it to about 40K and returns it to the Dewar of the MEG to keep it cold. It also collects helium gas just above the liquid helium surface while it is still cold, re-liquifies and returns it to the Dewar. A special transfer tube (TT) about 2 m length was developed to allow the dual helium streams. It separates the HCS with a MEG to reduce magnetic noise. A refiner to collect the contaminating gases effectively by freezing the gases is incorporated. It has an electric heater to remove the frozen contamination in the form of gases into the air. A gas flow controller is also developed, which automatically control the heater to cleanup the contamination. The developed TT has very low heat inflow less than 0.1W/m to the liquid helium ensuring the efficient operation. The HCS can re-liquefy up to 3.5 l/D of liquid helium from the evaporated helium gas using two 1.5W@4.2K GM cry-coolers (SRDK-415D, Sumitomo Heavy Industries, Ltd.). Our MEG system has been used in real brain experiments without any problem over three years. Diameter of insert tube is reduced to the standard 1/2 inch. As the amount of liquid helium used decreases less than one percent, the maintenance cost of the MEG becomes less than one tenth of the previous cost.

15P-E006 Cryogenics for Third Generation X-ray Research

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15P-E007 Sample Loading and Accelerated Cooling of Cryogen-free Dilution Refrigerators

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We present our latest results from bottom and top loading cryogen-free dilution refrigerators which enables samples to be cooled from room temperature to base in 6 to 8 hours. The loading and unloading processes take only a few minutes to perform and the cooling procedure is fully automated. Sample temperatures of less than 10 mK have been achieved with up to 8 semi-rigid coaxes and 25 DC wires connected to the sample holder. We also present results from cool down tests on a beam line dilution refrigerator with a 35 kg mass installed on the mixing chamber. A heat pipe was developed to accelerate the cooling of large experimental payloads and the mass was cooled from room temperature to base in less than 28 hours.

15P-E008 The Vienna Nuclear Demagnetization Refrigerator

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A new nuclear demagnetization system coupled to a powerful dilution refrigerator and a vector magnet was successfully built and operated. Our aim was to construct a versatile, modular cryostat, with a large experimental space providing an excellent platform for various types of ultralow temperature measurements. A powerful dilution unit allows us to cool the mixing chamber down to 3 mK and to precool a massive copper (90 mol) nuclear stage in a field of 9 T to 8 mK in 100 h. After demagnetization the lowest temperature of the copper stage measured by a Pt thermometer was 50.9 K in a field of 20 mT. The cryostat is integrated with a 8 T - 4 T vector magnet system. Furthermore it is equipped with several semi-rigid coaxial lines (SC-219/50-C-TU-L) to the still plate extending to the mixing chamber with semi-rigid superconducting coaxial lines (SC-160/50-NbTi-NbTi) for microwave frequencies up to 65 GHz. The refrigerator is provided with a 50 mm central clear shot tube allowing the insertion of a top-loading probe to carry out measurements inside the vector magnet bore in a reasonably short time of about 4 hours. The system will be used to study the quantum critical behavior of heavy fermion compounds. Acknowledgment Financial support from the European Research Council under the European Community’s Seventh Framework Programme (FP7/2007-2013)/ERC grant agreement no. 227378 and from Vienna University of Technology is gratefully acknowledged.

15P-E009 Magnetocaloric Effect of RM\textsubscript{2} (R=rare earth, M=Ni, Al) Intermetallic Compounds Made by Centrifugal Atomization Process for Magnetic Refrigerator

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Magnetic refrigeration makes use of magnetocaloric effect and has the potential to achieve high thermal efficiency, since reversible thermal cycle is possible in principle.\textsuperscript{8} We have been developing a magnetic refrigerator for hydrogen liquefaction. We have been investigated various magnetic materials that are suitable from 20 K to room temperature.\textsuperscript{8} RM\textsubscript{2} (R=rare earth, M=Al, Ni and Co) compounds have large entropy change and magnetic transition temperatures can be controlled by changing of R and/or M.\textsuperscript{8} In order to improve heat transfer between magnetic material and heat transfer fluid, spherical powdered RM\textsubscript{2} compounds were synthesized by centrifugal atomization process. By measuring the magnetization and heat capacity, we obtained entropy change by magnetic fields and temperature entropy diagrams, which are essential for analyzing the magnetic refrigeration cycle. All samples showed sharp magnetic transitions and had good potentials for use in magnetic refrigeration.

15P-E010 Suppression of temperature oscillation of GM cryocooler

T. Oota\textsuperscript{a}, K. Okidono\textsuperscript{a}, T. Nishioha\textsuperscript{a}, H. Kato\textsuperscript{a}, M. Matsumura\textsuperscript{a}, O. Sasaki\textsuperscript{b}, \textsuperscript{a}Graduate School of Integrated Arts and Sciences, Kochi University, Kochi 780-8520, Japan \textsuperscript{b}Syowa R森ken Seisakuso Co., Ltd., Tokyo 115-0051, Japan

GM cryocooler has the advantage of easily attaining low temperature down to ~4 K. On the other hand, it has the disadvantage of large temperature oscillation. The typical peak-to-peak amplitude is ~0.3 K at around 4 K. This large oscillation prevents precise measurements. The purpose of this study is to suppress the temperature oscillation without losing the cooling power by a simple adapter. The cooling power and the oscillation amplitude are proportional to $\kappa$ and $\kappa/C$, respectively ($\kappa$: thermal conductivity, $C$: heat capacity) from thermodynamic analysis, so that the adapter should satisfy the condition that both $\kappa$ and $C$ are large. In order to achieve this, we constructed “He pot”, which is a Cu
container filled with high pressure He at room temperature. We examined the thickness of the Cu container and the temperature dependence of the oscillation amplitude at several pressures. We have found that the ratio of outer diameter to inner diameter is 1.4 enough for 100 atm of He. We have also found that the temperature oscillation is strongly reduced in the case of liquefying He. The amplitude is less than 10 mK below 4.5 K and 3.7 K for 90 atm and 60 atm of He, respectively. When He does not liquefy, the oscillation is about 1/4. Just attaching this He pot to a GM cooling head, the temperature oscillation is strongly suppressed below certain temperature according to the filled He pressure. The application to THz detector and low temperature precise measurements etc. are expected.

**15P-E011**  \(^1\)H NMR Study of Proton Dynamics in the Ferroelastic Transition of K\(_4\)LiH\(_3\)(SO\(_4\))\(_4\) Single Crystal

Ho Hyoun Kim\(^a\), B. J. Mean\(^a\), Ki Hyoek Kang\(^a\), Jung Seok Sim\(^a\), B. Ndiaye\(^a\), Moohee Lee\(^a\), Ae Ran Lim\(^b\)

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K\(_4\)LiH\(_3\)(SO\(_4\))\(_4\) is known to show a ferroelastic transition at \(T_c = 114\) K. We have performed \(^1\)H nuclear magnetic resonance (NMR) measurements to investigate proton dynamics in the phase transition of K\(_4\)LiH\(_3\)(SO\(_4\))\(_4\) crystals in the temperature range of 80-300 K at 2.68 T. The \(^1\)H NMR spectrum shows a composite structure with dominating broad and weak narrow components. The broad component has an extremely long \(T_1\) whereas the narrow component exhibits a short \(T_1\) at room temperature. The intensity of the narrow peak decreases at low temperature vanishing below 200 K. From this behavior, we find that the narrow component comes from rapidly moving protons whereas the broad component originates from rigid protons. From the temperature dependence of the short \(T_1\) for the narrow component, the activation energy for the proton’s rapid motion is deduced to be \(~1900\) K. On the other hand, the long \(T_1\) for the broad component increases rapidly at low temperature suggesting that the proton dynamics associated with the ferroelastic transition change abruptly across \(T_c\).

**15P-E012** A Cryogen-Free Laboratory Cryostat With Easy Sample Exchange

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\(^a\)ETH Zürich, Institute for Particle Physics, CH-8093 Zürich, Switzerland  \(^b\)Paul Scherrer Institute, CH-5232 Villigen PSI, Switzerland

We report on the development of a versatile cryogen-free laboratory cryostat based upon a 1.5 W pulse tube cryocooler. It provides enough cooling power for continuous recondensation of circulating helium gas at a condensation pressure of about 500 mbar. Further, the cryostat allows for easy exchange of different cryostat inserts as well as fast and easy sample exchange (top-loading) with a fast turn-over time of less than 75 min. In a first test using a \(^4\)He cryostat insert, a base temperature of about 1.1 K was reached within 12 hours starting from room-temperature, employing a 300 m\(^3\)/h roots pump. A cooling power of approximately 25 mW at 1.2 K was established. Currently, we are investigating the possibility to operate a dilution insert in the same cryostat.

**15P-E013** Low temperature scanning probe microscopy at high magnetic fields in closed cycle systems: from 4 K down to mK

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In view of the rapid increase of the costs for liquid helium, closed cycle cryostats are becoming of paramount importance in low temperature research. Sensitive techniques such as scanning probe microscopy (SPM) require specially designed products optimized for ultra-low vibrations. Combining the latter with high magnetic fields has become possible only very recently due to a proprietary (top-loading) design by attocube systems: mechanical vibrations created by the pulse-tube coldhead are decoupled from the measurement platform, resulting in peak-to-peak vibration amplitudes of less than 4.2 nm at the sample location, while retaining probe cooldown times as fast as 1 hour. We present vibration spectra as well as examples of several different SPM techniques such as CFM, AFM, MFM, and SPM at 4 K and up to 9 T. In addition, we show proof-of-principle SPM measurements in a dry dilution refrigerator at less than 100 mK.

**15P-E014** Suppression of temperature oscillation of GM cryocooler

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GM cryocooler has the advantage of easily attaining low temperature down to ~4 K. On the other hand, it has the disadvantage of large temperature oscillation. The typical peak-to-peak amplitude is ~0.3 K at around 4 K. This large oscillation prevents precise measurements. The purpose of this study is to suppress the temperature oscillation without losing the cooling power by a simple adapter. The cooling power and the oscillation amplitude are proportional to \(\kappa\) and \(\kappa/C\), respectively (\(\kappa\): thermal conductivity, \(C\): heat capacity) from thermodynamic analysis, so that the adapter should satisfy the condition that both \(\kappa\) and \(C\) are large. In order to achieve this, we constructed “He pot”, which is a Cu container filled with high pressure He at room temperature. We examined the thickness of the Cu container and the temperature dependence of the oscillation amplitude at several pressures. We have found that the ratio of outer diameter to inner diameter is 1.4 enough for 100 atm of He. We have also found that the temperature oscillation is strongly reduced in the case of liquefying He. The amplitude is less than 10 mK below 4.5 K and 3.7 K for 90 atm and 60 atm of He, respectively. When He does not liquefy, the oscillation is about 1/4. Just attaching this He pot to a GM cooling
head, the temperature oscillation is strongly suppressed below certain temperature according to the filled He pressure. The application to THz detector and low temperature precise measurements etc. are expected.

15P-E015 A novel system for providing a 4.5 Tesla rotating vector with ultra low temperature capability to study quantum effects in semiconductor nanosstructures

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We report the test results obtained on a Leiden Cryogenics cryogen-free Dilution Refrigerator with a 1.5 Watt Pulse tube cryocooler integrated with a Cryogenic Limited Cryogen-free 9T-5T-1T vector magnet also cooled by a separate 1.5 Watt CryoMech Pulse tube cryocooler. The system was developed for use in research in spintronics and in particular the control and manipulation of the spins of spatially confined charge carriers in semiconductor heterostructures such as AlGaAs/GaAs. The entire system cooled from room temperature to operating temperature in 60 hours. The Dilution Refrigerator alone cools to operating temperature in 60 hours. The temperature in 24 hours but the large 3 axis magnet extended the cooldown time. This cooldown time could have been reduced by means of a liquid nitrogen precool circuit which is installed in the system. The base temperature of the system achieved was 10mK with a static field vector of 4.5 Tesla in the XZ plane. Continuous rotation of a 4.5 Tesla field vector in the plane showed a small elevation in temperature up to 18mK due to eddy current heating in the Dilution Refrigerator mixing chamber. The system recovered to 10mK in a few minutes when field rotation ceased.

15P-E016 A novel system for providing a 4.5 Tesla rotating vector with ultra low temperature capability to study quantum effects in semiconductor nanosstructures

R. Hall\textsuperscript{a}, R. Mitchell\textsuperscript{a}, G. Frossati\textsuperscript{b}, A.R. Hamilton\textsuperscript{c}, \textsuperscript{a}Cryogenic Ltd, 29,30,31 and 32 Acton Park Estate, London, W3 7QE, UK \textsuperscript{b}Leiden Cryogenics b.v., Kenauweg 11, 2331 BA Leiden, The Netherlands \textsuperscript{c}School of Physics, University of New South Wales, Sydney, NSW 2052, Australia

We report the test results obtained on a Leiden Cryogenics cryogen-free Dilution Refrigerator with a 1.5 Watt Pulse tube cryocooler integrated with a Cryogenic Limited Cryogen-free 9T-5T-1T vector magnet also cooled by a separate 1.5 Watt CryoMech Pulse tube cryocooler. The system was developed for use in research in spintronics and in particular the control and manipulation of the spins of spatially confined charge carriers in semiconductor heterostructures such as AlGaAs/GaAs. The entire system cooled from room temperature to operating temperature in 60 hours. The Dilution Refrigerator alone cools to operating temperature in 60 hours. The temperature in 24 hours but the large 3 axis magnet extended the cooldown time. This cooldown time could have been reduced by means of a liquid nitrogen precool circuit which is installed in the system. The base temperature of the system achieved was 10mK with a static field vector of 4.5 Tesla in the XZ plane. Continuous rotation of a 4.5 Tesla field vector in the plane showed a small elevation in temperature up to 18mK due to eddy current heating in the Dilution Refrigerator mixing chamber. The system recovered to 10mK in a few minutes when field rotation ceased.

15P-E018 Low T Study of PdH\textsubscript{x} System by Torsional Oscillator Measurements using a New Refrigerator

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Hydrogen atoms dissolve in Pd at densities up to one H atom per Pd, which provides higher atomic H density than in solid H\textsubscript{2}. They are known to have large diffusion coefficient due to quantum tunnelling even at low temperatures. Torsional Oscillator (TO) technique is employed to investigate the phases of H in Pd, which is known to show phase boundaries at the lowest T among metal-hydrogen systems. This TO measurement is a powerful method to investigate superfluidity of He films. We have been performing TO experiments, in order to study the effect of atomic H intrusion and the dynamics in the PdH(D)\textsubscript{x} system. The TO experiments have shown the resonance frequency shift and the Q value change for PdH\textsubscript{x} , 0.16 ≤ x ≤ 0.75 , specimens around over 40K\cite{1}. However, TO data behaved noisy in the temperature region over 60K. So we have planed the stability of the TO system and of the T of the specimen over longer period of time by using a pulse tube refrigerator with great heat capacity. We will show the detail of experimental machine’s improvements and improved experimental result.


15P-E019 Viscous and Acoustic Damping on Tuning Forks Oscillating in Liquid Helium-4

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We present measurements of the dissipative forces on tuning forks, oscillating in both normal fluid and in superfluid 4He, due to viscous drag and acoustic emission. The measurements were made over a temperature range from 1.5 K to 4.2 K. Arrays of several tuning forks were investigated. Each fork has prongs of width 75 μm and thickness 90 μm, but the prong length varies from 0.7 mm to 3.5 mm so that their fundamental mode of vibration covers a wide frequency range (6-200 kHz).
The forks were also driven in their first harmonic mode to extend the frequency range up to 600 kHz. We observe a clear crossover in the behavior: viscous drag dominates at low frequencies whilst acoustic emission dominates at higher frequencies. The dissipative forces are compared quantitatively with available theoretical models.\textsuperscript{1,2} Acoustic emission provides a limiting factor on the practical use of tuning forks for studying fluid properties.


\section*{15P-E020 The cryostat for deformation of crystals at low temperatures}

K. Shunkeyev\textsuperscript{a}, E. Sarmukhanov\textsuperscript{a}, A. Bekeshev\textsuperscript{a}, Sh. Sagimbaeva\textsuperscript{a}, K. Bizhanova\textsuperscript{a}, \textsuperscript{a}Aktobe State Pedagogical Institute, Aktobe, Kazakhstan

The cryostat\textsuperscript{1} was worked out, helped to deform the crystals at 80 K with different degree of deformation and to register luminescence, absorption and thermally activated characteristics of crystals, also to record the ionic and thermally stimulated currents of the dipole defects of depolarization. The degree of crystals deformation is given by compressing screw pitch which is equal to 1 mm at a complete revolution of the crystal holder. The construction of the cryostat allows to set experimentally the desired degree of crystals deformation. Deformation can be removed from the crystal and re-update at different temperatures.


\section*{15P-E021 Rate of the exciton self-trapping in KI and RbI at different temperatures}

Zh. Zhanturina\textsuperscript{a}, K. Shunkeyev\textsuperscript{a}, \textsuperscript{a}Aktobe State Pedagogical Institute, Aktobe, Kazakhstan

There is an important dependence between the rate of exciton’s self-trapping and distribution of annihilation channels of excitons in AHC. Rate of exciton’s self-trapping is defined by inversely time. In RbI measured a growth time of luminescence to be 200 ps. From this deformation the desired degree of crystals deformation. Deformation can be removed from the crystal and re-update at different temperatures.\textsuperscript{1}


\section*{15P-E022 Inhibition of ougassing from a surface of CFRP (Carbon Fiber Re-

\section*{15P-E023 A Cryostat Suitable for Thermal Conductivity Measurements under High Pressure}

Chomsin S. Widodo\textsuperscript{a}, Xin Xu\textsuperscript{a}, Muneaki Fujii\textsuperscript{a}, Yuji Kojima\textsuperscript{a}, Kenji Hosoyama\textsuperscript{a}, \textsuperscript{a}Department of Physics, Kumamoto University, Kumamoto 860-8555, Japan

A cryostat especially designed to be used for measurements of thermal conductivity under high pressure has been constructed. Using this cryostat, the thermal conductivity measurements of laminated superconductors have been sufficiently performed under the pressure up to $10^9\text{Pa}$ at liquid helium temperatures.

\section*{15P-E024 The Potentialities of Quartz Tuning Fork as a Thermometer in Dilution Refrigerator}

S.I. Danilin\textsuperscript{a}, S.T. Boldarev\textsuperscript{a}, R.B. Gusev\textsuperscript{a}, A.Ya. Parshin\textsuperscript{a}, \textsuperscript{a}P.L. Kapitza Institute for Physical Problems, Kosygina 2, Moscow 119334, Russia

Temperature dependences of resonant frequency and the width of resonance of quartz tuning fork, directly immersed into mixing chamber of dilution refrigerator, have been considered for it to be treated as a secondary thermometer. Measurements have been performed both in upper and in lower phase of mixer coolant within temperature range of 15 - 350 mK. The dependences obtained reveal several side effects other
then the temperature affecting the characteristics of the resonator. In the upper phase, superfluid film, covering the surface of tuning fork, has a dominant role, whereas in 4He-rich phase numerous first and second sound resonances are superimposed on its own frequency curve. This will create serious difficulties for the coolant immersed quartz tuning fork be used as the thermometer of the mixing chamber.

15P-E025 Development of an Inductive SINIS Thermometer
Z. Geng, I. J. Maasilta, Nanoscience Center, Department of Physics, University of Jyväskylä, Jyväskylä, Finland
Since Giaever first observed the electron tunneling in Normal metal-Insulator-Superconductor (NIS) junctions in 1960, many applications have been developed based on the strong temperature dependence of the current-voltage characteristics of a NIS structure. One promising application is sensitive thermometry by using a symmetrical normal-insulator-superconductor tunnel junction pair, known as a SINIS structure, to measure temperature below 1 K. In this work, we have developed an on-chip inductive readout for SINIS thermometers. Four superconducting multi-turn niobium coils are fabricated near the SINIS junctions and are connected to an AI – AlOx – Cu – AlOx – Al SINIS junction thermometer to extract the current signal. This temperature dependent current signal is then picked up inductively by a planar inductor under the input coils, separated by a pin-hole free aluminium oxide insulating layer, and finally read out by a two-stage SQUID preamplifier on the cryostat connected by superconducting wires. By using this method, the current signal can be amplified locally by the “DC transformer” structure at the sub-Kelvin temperature already, and is thus expected to have lower noise level and better temperature sensitivity and resolution compared to a direct room temperature preamplifier readout.


15P-E026 Temperature Dependent Measurement of Metals Contained Hydrogen by Vibrating Reed Method
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Department of Culture and Education, SAGA University, SAGA, JAPAN
Department of Engineering, KYUSHU University, Fukuoka, JAPAN
Hydrogen Embrittlement has been known for a long time as a phenomenon. However, this generating mechanism and the generation mechanism have not been necessarily clarified though are advocated many ideas such as hydrogen-enhanced strain-induced vacancy model and lattice decohesion theory. Then, we have developed the experimental apparatus to catch the early phenomenon of hydrogen embrittlement. The measurements technique is the vibrating reed method. In this method, resonance frequency (∼ Young’s modulus) and Q-value can be measured. For the sensitivity test, annealed SUS304 samples were prepared and measured of temperature dependence of resonance frequency and calculated the diffusion constants of hydrogen. This result is same as N.J.Simon, et al.¹ The results of these experiments, it has been understood to be able to detect the existence and the quantity of hydrogen used by our apparatus.


15P-E027 Primary CBT thermometer technology.
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VTT Technical Research Centre of Finland, Espoo
Low Temperature Laboratory, Aalto University, Espoo, Finland
Coulomb Blockade Thermometer (CBT) is a primary thermometer based on electric conductance of normal tunnel junction arrays. One limitation for CBT use at the lowest temperatures has been due to environmental noise heating. To improve on this limitation, we have done measurements on CBT sensors fabricated with different on-chip filtering structures in a dilution refrigerator with a base temperature of 10 mK. The CBT sensors were produced with a scalable ex-situ tunnel-junction process, defined by optical lithography. We will present how the different on-chip filtering affects the limiting saturation temperatures and show that CBT sensors with proper on-chip filtering work at temperatures below 20 mK and are tolerant to noisy environment.


15P-E028 SRD1000, a 13-point reference device for precision thermometry below 8 K
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Kamerlingh Onnes Laboratory, LION, Leiden University, P.O. Box 9504, 2300 RA Leiden, The Netherlands
The SRD1000 superconductive reference device supports precision thermometry along the PLTS-2000 and ITS-90 by offering 10 calibrated reference points between about 15 mK and 1.2 K. Recently the device was equipped with three additional points to cover the range between about 1.2 K and 8 K. A CMN1000 magnetic susceptibility thermometer was developed to support thermometry alongside the SRD1000 in the range from 10 mK to 2 K. We report on the measurements of the quality of the new SRD1000 reference points, and of the sensitivity, reproducibility and response time of the CMN1000 thermometer.

15P-E029 Temperatures of Phase-Slip Centers and Hot Spots in current-driven Superconducting Strips
When carrying a current above the pair-breaking limit, a narrow superconducting wire leaves its homogeneous state, and gets striped into alternating resistance-less and dissipative zones known as Phase-Slip Centers (PSC). Due to dissipation, the latter singularities adopt a core temperature $Tm$ larger than the ambient temperature $T0$, although they still belong to the superconducting state, which implies $Tm$ below $Tc$, the critical temperature. Following an additional excitation (an increase in current, or an external excitation), a PSC may switch into a normal Hot Spot (HS), of core temperature $Tm$ above $Tc$. The phonon escape time to the substrate is a fundamental parameter of the problem. By measuring the PSC differential resistance and the substrate temperature, we can obtain information about the PSC nucleation time, one can provide a consistent description of the temperatures reached in the resistive centres of a current-driven superconducting strip. It applies to High-Tc (YBa2Cu3O7) as well as metallic (Nb) materials.

15P-E030 Sample 3D Magnetometer for a Dilution Refrigerator


In this report, we describe a development of a three-dimensional system for measurements of magnetic field at a wide temperature range of 300K-4K. The system is based on 8th AMR sensors and allows to control magnetic environment in a dilution refrigerator during cool down of a superconducting chip. With a low noise signal processing electronics and special sensor saturation circuit, a magnetic induction resolution below of 1 nT was achieved.

15P-E031 8-coils system to produce an uniform magnetic field in a dilution refrigerator

S. Uchaikin, A. Eltony, X. Han, D-Wave Systems Inc., Burnaby, BC, Canada

Developments of superconducting chips often require an extended region with a highly uniform magnetic field. Frequently used for such purpose Helmholtz, solenoidal and Maxwell coils produce a limited volume where magnetic field is uniform. The report suggests a method of calculations of the multi-coil device with the maximum volume of the equilibrium field. An 8-coil system calculated based on the method. An influence of manufacturing tolerances is discussed in the report.

15P-E032 Physics, micro-fabrication and applications of metallic magnetic calorimeters


Metallic magnetic calorimeters (MMC) are calorimetric particle detectors, typically operated at temperatures below 100mK, that make use of a paramagnetic temperature sensor to transform the temperature rise upon the absorption of a particle in the detector into a measurable magnetic flux change in a dc-SQUID. During the last years a growing number of groups has started to develop MMC for a wide variety of applications, ranging from alpha-, beta- and gamma-spectrometry over the spatially resolved detection of accelerated molecule fragments to arrays of high resolution x-ray detectors. For soft x-rays an energy resolution of 2.7eV (FWHM) has been demonstrated and we expect that this can be pushed below 1eV with the next generation of devices. We give an introduction to the physics of MMCs and summarize the presently used readout schemes as well as the typically observed noise contributions and their impact on the energy resolution. We discuss general design considerations, the microfabrication of MMCs and the performance of micro-fabricated devices. In this field large progress has been achieved in the last years and the thermodynamic properties of most materials approach bulk values allowing for optimal and predictable performance.

15P-E033 Noise Thermometry at Low Temperatures: MFFT Measurements in the Temperature Range From 1.6 K to Below 1 mK

J. Engert, D. Heyer, J. Beyer, H.-J. Barthelmess, Physikalisch-Technische Bundesanstalt, 10587 Berlin, Abbestr. 2 - 12, Germany

At low temperatures, reliable thermometry is a complicated task. Recently, we have developed a dc SQUID-based noise thermometer, the so-called magnetic field fluctuation thermometer (MFFT), for practical thermometry in the low temperature range. Its operational principle is based on the Nyquist theorem ensuring a linear characteristic over a wide range of temperatures. This makes the MFFT a thermometer capable to replace a variety of secondary thermometers which are normally required to cover the whole temperature range of the International Temperature Scale PLTS-2000 from 1 K to 0.001 K. Here we describe a fast, compact, and easy to use MFFT system comprising a metallic temperature sensor with a SQUID gradiometer, a data acquisition unit and a software package. For measurements at very low temperatures, the MFFT setup is specially designed to have a high signal level and, at the same time, a sufficiently high bandwidth for fast measurements. For the first time, we report on MFFT measurements over more than 3 decades in temperature from about 1.6 K down to below 1 mK. The deviations from a high accuracy realization of the PLTS-2000 are found to be $\leq 1\%$.

Session 16H1: Half Plenary Lectures

Chair: Kimitoshi Kono
Tuesday August 16, 09:00 – 10:30
Convention Hall 3

16H1-1 Quantum Criticality and Unconventional Order in Magnetic and Dielectric Material
S. E. Rowley*, S. S. Saxena*, G. G. Lonzarich*, *Cavendish Laboratory, UK
We present an overview of unconventional phenomena arising close to ferromagnetic and ferroelectric quantum phase transitions. The applicability and potential breakdown of traditional field theories of quantum criticality and the emergence of a multiplicity of critical fields in particular will be discussed.

16H1-2 Applications of superconducting bolometers in security imaging
Millimeter-wave (MMW) imaging systems are currently undergoing deployment World-wide for airport security screening applications. Security screening through MMW imaging is facilitated by the relatively good transmission of these wavelengths through common clothing materials. Given the long wavelength of operation (frequencies between 20 GHz to ~ 100 GHz, corresponding to wavelengths between 1.5 cm and 3 mm), existing systems are suited for close-range imaging only due to substantial diffraction effects associated with practical aperture diameters. The present and arising security challenges call for systems that are capable of imaging concealed threat items at stand-off ranges beyond 5 meters at near video frame rates, requiring substantial increase in operating frequency in order to achieve useful spatial resolution. The construction of such imaging systems operating at several hundred GHz has been hindered by the lack of submm-wave low-noise amplifiers. In this paper we summarize our efforts in developing a submm-wave video camera which utilizes cryogenic antenna-coupled microbolometers as detectors. Whilst superconducting detectors impose the use of a cryogenic system, we argue that the resulting back-end complexity increase is a favorable trade-off compared to complex and expensive room temperature submm-wave LNAs both in performance and system cost.

16H1-3 Coherence and Coupling of Two-Electron-Spin Qubits in GaAs
Hendrik Bluhm*, *2nd Institute of Physics C, RWTH Aachen University, Aachen, Germany
Semiconductor spin qubits are promising candidates for quantum computation because of their slow decoherence and potential for scalability. All fundamental single qubit operations have been demonstrated for GaAs based spin qubits, but they suffer from decoherence due to hyperfine coupling to nuclear spins. We have developed effective techniques to mitigate this decoherence channel for two-electron spin qubits in double quantum dots.
By repeatedly inverting the qubit in a way that decouples its evolution from the fluctuations of the nuclear spin bath, its coherence time can be extended to more than 200 μs, two orders of magnitude longer than previously shown. Alternatively, operating the qubit as a feedback loop that controls the nuclear bath also enhances the coherence time and enables universal single qubit control with greatly improved gate fidelities.
Having achieved good single qubit control, a fundamental milestone toward quantum information processing is to couple qubits in order to generate entangling gates. We demonstrate a protocol to implement two-qubit gates using the Coulomb interaction between adjacent double dots while decoupling both qubits from slow electrical fluctuations. Preliminary results indicate that Bell states can be created with sufficient fidelity to demonstrate entanglement.
16H2-1 Peeling high-Tc superconductivity one atomic layer at a time
Ivan Bozovic*, a Brookhaven National Laboratory, Upton NY 11973, USA
Using a unique molecular beam epitaxy system we synthesize digitally (atomic-layer-by-layer) thin films, multi-
layers and superlattices of cuprates and other complex oxides. The constituent layers can be just one-unit-cell
thick and the interfaces atomically perfect. Various heterostructures are designed to enable novel experiments
that probe the basic physics of high-temperature superconductivity (HTS). In this talk, I will review our recent
experiments on such films and superlattices. Some key questions in HTS physics about the dimensionality, relevant
interactions, the roles of (in)homogeneity and fluctuations - are answered as follows. (i) In an isolated single CuO2
plane without holes, quantum spin liquid forms.1 (ii) In a single CuO2 plane doped with holes, HTS can occur
with Tc even higher than in the bulk.2 (iii) HTS cuprate samples can be quite homogeneous (e.g., have a very
sharp and uniform SC gap).3 (iv) HTS and anti-ferromagnetic phases separate on the scale of 1 ? in space and
1 eV in energy.1,4 (v) Pseudo-gap state mixes with the SC state on the 1,000 ? length scale (“Giant Proximity
Effect”)5 (vi) In-plane charge excitations are strongly coupled to out-of-plane lattice vibrations.6 (vii) Local pairs
and vortices exist on the insulating side of the S-I quantum phase transition.7 (viii) Strong phase fluctuations
drive the SC transition, but 10-15 K above Tc they fade out.7
1 Suter et al., PRL 106, 237003 (2011).
2 Bozovic et al., PRL 89, 107001 (2002); Gozar et al., Nature 455, 782 (2008); Smadici et al., PRL 102, 107004 (2009), Logvenov et
5 Bozovic et al., PRL 93, 157002 (2004); Morenzoni et al., Nature Comm. 2, 272 (2011).

16H2-2 Molecular Beam Epitaxy-Scanning Tunneling Microscopy of
Iron-Based Superconductors
Qi-Kun Xue*, a Department of Physics, Tsinghua University, Beijing 100084, P. R. China
We have grown thin films of iron-based superconductors (FeSe and K-doped FeSe) on graphene formed on 6H-SiC
and SrTiO3 substrates by molecular beam epitaxy (MBE). The MBE growth conditions for stoichiometric and
single crystalline high-quality thin films have been established, which allows us to investigate the pairing mechanism
and underlying magnetic order in great detail by using high energy-resolution scanning tunneling microscopy and
spectroscopy (STM/STS). We show robust evidence for the gap function with nodal lines and two-fold symmetry
in FeSe. In the case of K-doped FeSe, phase separation is observed. We show that the superconducting phase
KFe2Se2 contains no iron vacancies, and the iron vacancies are always destructive to superconductivity. Application
of MBE-STM in the study of unconventional superconductivity will also be discussed. * The work was carried out
in collaboration with Xucun Ma, Xi Chen, Ke He, Lili Wang, Jinfeng Jia, Congjun Wu and Jiangping Hu. Email:
qkxue@mail.tsinghua.edu.cn

16H2-3 Spectroscopic-Imaging STM Studies of Superconducting Gap
in Unconventional Superconductors
T. Hanaguri*, a Magnetic Materials Laboratory, RIKEN Advanced Science Institute, Wako, Japan
Information on the superconducting gap is crucially important to elucidate mechanisms of superconductivity.
While the superconducting gap of conventional phonon-mediated superconductor is constant everywhere on the
Fermi surface, that of unconventional counterpart depends on momentum and may change its sign. Spectroscopic
technique which has both momentum selectivity and phase sensitivity is thus indispensable. We use spectroscopic-
imaging scanning tunneling microscopy (SI-STM) for this purpose. In SI-STM, tunneling spectrum is acquired at
every pixel of the atomic-resolution STM topograph and thus atomically-registered spectroscopic images are ob-
tained at many excitation energies. Each tunneling spectrum reflects quasi-particle density of states from which one
can identify the superconducting gap. Fourier-transformed spectroscopic images provide us with the momentum-
resolved information and the relative sign of the superconducting gap can be inferred from the magnetic-field
dependence through the coherence-factor effect. We confirmed that these features work well for a cuprate with a
d-wave gap. We also performed SI-STM on an iron-based superconductor Fe(Se,Te) and obtained the results
which suggest the $s_\pm$-wave gap. Another advantage of SI-STM is a high spatial resolution which allows us to study the effects of impurities. We discuss the defect states in a clean iron-based superconductor LiFeAs in relation to the superconducting-gap structure.
Session 16m-A: Superfluid-He-3

Chair: Norbert Mulders
Tuesday August 16, 10:50 – 12:30
Room 5A

16m-A1 Anomalous spin relaxation and quasiparticle damping in superfluid 3He-B at very low temperatures
D. Bradley\(^a\), M. Človečko\(^a\), S. Fisher\(^a\), E. Gádo\(^a\), A. Guénault\(^a\), R. Haley\(^a\), M. Kupka\(^b\), G. Pickett\(^a\), M. Skyba\(^b\), P. Skyba\(^a\), N. Suramlishvili\(^a\), V. Tsepelin\(^a\). \(^a\)Department of Physics, Lancaster University, LA14 YB Lancaster, United Kingdom

The excitation density in superfluid 3He-B determines many of the low temperature transport properties as well as directly measurable quantities such as the bulk relaxation rate of spin precession, as measured by the lifetime of coherent spin precession modes in NMR experiments, and the damping of mechanical resonators. In T → 0 limit, one might expect that the life time of coherent spin modes will grow and the damping of resonators will fall exponentially on cooling. However, the presence of a surface can significantly change the behavior. The surface violates the symmetry of the superfluid by suppressing Cooper pairs having orbital momentum perpendicular to the surface normal. This leads to an energy gap distortion within a distance of order the coherence length from the surface. The distorted gap allows the creation of the Andreev bound excitations, the density of which depends on the surface quality. Here we present NMR measurements of coherent spin precession at low temperatures which reveal an extra dissipation mechanism in the presence of a nearby surface. This leads to anomalous, temperature independent, spin relaxation at the lowest temperatures. We also discuss the influence of Andreev bound excitations on the damping of mechanical resonators at very low temperatures.

16m-A2 Experiments on Quantum Turbulence in Superfluid 3He-B at Very Low Temperatures
D.I. Bradley\(^a\), M. Človečko\(^a\), M.J. Fear\(^a\), S.N. Fisher\(^a\), G. Foulds\(^a\), D. Garg\(^a\), A.M. Guénault\(^a\), E. Guise\(^a\), R.P. Haley\(^a\), M. Jackson\(^a\), C.R. Lawson\(^a\), G.R. Pickett\(^a\), D. Potts\(^a\), R. Schanen\(^a\), V. Tsepelin\(^a\), P. Williams\(^a\). \(^a\)Department of Physics, Lancaster University, Lancaster, UK.

We describe experiments on quantum turbulence in superfluid 3He-B in the low temperature limit where the normal fluid fraction becomes vanishingly small. Quantum turbulence, a tangle of quantized vortex lines, is easily generated by mechanical resonators such as vibrating wires and vibrating grids. At low temperatures the kinetic energy contained in the turbulent flow greatly exceeds the thermal energy carried by ballistic quasiparticles. This allows us to directly measure the energy released by the decaying turbulence using black-body radiator techniques. We find that the decay is remarkably similar to that expected for the decay of turbulence in a classical fluid. In 3He-B, vortices also have a large cross-section for Andreev scattering thermal quasiparticle excitations. We have utilized this property to directly measure Andreev scattering from quantum turbulence and to investigate the turbulent dynamics. More recently we have studied quasiparticle transmission through quantum turbulence. We discuss recent results.

16m-A3 Simultaneous torsional oscillator and NMR study of solid 3He-4He mixtures at low temperatures
P. Gumann\(^a\), I. Tamini\(^a\), D.G. Cory\(^a\). \(^a\)Institute for Quantum Computing, University of Waterloo, Waterloo, ON, Canada

We have carried out simultaneous nuclear magnetic resonance (NMR) and torsional oscillator (TO) studies of 3He-4He solid mixtures in a cryogen-free dilution refrigerator. Extensive measurements on various samples with one hundred to a few hundred parts per million (ppm) of 3He in solid 4He using NMR/TO methods have been performed in the temperature range of from 1 K to 10 mK. Our double frequency torsional oscillator response appeared to be in very good agreement with previously measured data. Multiple frequencies allowed dynamical studies of 3He-impurities thus a good comparison with the relaxation times obtained from the NMR data. Different relaxation times corresponding to various 'states' of 3He within the 4He crystal have been found. Capability of long measuring times, due to the use of a cryogen-free cryostat, made it possible to a study very long NMR relaxation times and time dependence of the response of TO.

16m-A4 Majorana Fermions Bound at Vortices and Surface of Superfluid 3He
T. Mizushima\(^a\), T. Kawakami\(^a\), Y. Tsutsumi\(^a\), M. Ichikawa\(^a\), K. Machida\(^a\). \(^a\)Department of Physics, Okayama University,
A Majorana fermion is a relativistic particle equivalent to its anti-particle, which was originally proposed by Ettore Majorana in 1937. Recently, it has been predicted that it hides in various materials, such as vortices and surface of superfluid $^3$He. The remarkable fact that the creation operators of Majorana zero modes are self-Hermitian implies that their host vortices obey the non-abelian statistics. Here, we investigate the Majorana fermions bound at (i) half-quantum vortices (HQV's) and (ii) surface Andreev bound states (SABS's) in superfluid $^3$He A- and B-phases, which are expected to involve Majorana fermions. Here, it is demonstrated that although the HQV is expected to appear in rotating $^3$He A-phase confined to a slab, the strong coupling effect which becomes crucial in high pressure regime makes the HQV unstable. Then, we reveal the nontrivial structure of low-lying quasiparticles in phase vortex and coreless vortex which are energetically competitive to the HQV in A-phase. We also discuss the SABS in A- and B-phases, where the former (later) gives rise to spontaneous mass (spin) current along the surface. In particular, based on the quasiclassical Eilenberger and full-quantum Bogoliubov-de Gennes theories, we demonstrate that the Majorana nature of the SABS in B-phase is sensitive to the dipole interaction and the orientation of magnetic field.

References:

16m-A5 Ultra-low Temperature Mobility of Electron Bubbles Formed below the Free Surface of Superfluid $^3$He-B

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RIKEN, Hirosawa 2-1, Wako, Saitama 351-0198, Japan  
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As a topological nature of the spin-triplet Balian-Werthamer (BW) superfluid state, superfluid $^3$He-B phase has zero-gap surface bound states at its surfaces.1,2 These surface bound states show Majorana nature when a surface has the perfect specularly. The free surface of liquid $^3$He is ideal surface with the specular reflection of quasiparticles, and therefore the surface bound states formed there might support the Majorana nature. Here we report the results of the mobility measurements of electron bubbles trapped below the free surface of superfluid $^3$He-B phase down to 250 μK, with the aim of detecting surface bound states. The measured mobility shows the rapid increase below the transition temperature with decreasing temperature, because of the significant reduction of the scattering rate with quasiparticles in the bulk. We also measured the mobilities at several different distances from the surface in a range from 20 to 60 nm, but all data show the same temperature dependence. This indicates that the Majorana surface bound states have a little effect on the mobility of a bubble in the investigated temperature range.

References:
16m-B1  Impurity bound-state as a prove of order-parameter symmetry in iron-pnictide superconductors
Masao Ogata, a *Department of Physics, University of Tokyo, Tokyo 113-0033, Japan, and JST, TRIP, Sanbancho, Chiyoda, Tokyo 102-0075, Japan

It has been clarified experimentally and theoretically that the superconducting gap functions in iron-based superconductors have a wide variety [1]. It seems that there are both materials with nodeless and nodal gap functions. Theoretically it has been pointed out that the gap function is very sensitive to the structure of its multiple Fermi surface [2]. In such situations, it is desirable to develop a systematic way to understand the material dependence and so on. We proposed a simple way to parameterize the gap function in iron pnictides [3]. The key idea is to use orbital representation, not band representation, and to assume real-space short-range pairing. Although this parameterization is very simple, we find that it reproduces fairly well the structure of gap functions obtained in microscopic calculations. Furthermore, it naturally describes the differences of the gap function on each Fermi surface, as well as its anisotropy. Since the present method is simple enough, it is useful for obtaining an intuitive picture and for developing phenomenological theories. Using this method, we studied the temperature dependences of NMR 1/T1 [4], such as the coherence peak and Tc behavior below Tc. In this talk, we discuss a single impurity problem by solving Bogoliubov-de Gennes equation in the five-orbital model constructed from the above analysis. We study the local density of states around a non-magnetic impurity and discuss the bound-state peak structures. These results can be used for distinguishing s+ and s++ superconducting states [5]. The figures below show the local density of states near the impurity for various values of impurity potential. A bound state with nearly zero-energy is found for the impurity potential I 1.0 eV, while the bound-state peaks stick to the gap edge in the unitary limit. Novel multiple-peak structure originated from the multi-orbital nature of the iron pnictides is also found, which is characteristic to the iron pnictides.

References:

Ting-Kuo Lee*, Chung-Pin Chou*, a Institute of Physics, Academia Sinica, Taipei, Taiwan

In this study we present variational Monte Carlo calculation to examine spatial inhomogeneity in hole- and electron-doped cuprates. Since Yamada plot in hole-doped cuprates has been successfully reproduced in a recently proposed t – J-type model with mass renormalization from electron-phonon coupling, we reasonably presume that the same Hamiltonian could be introduced into electron-doped regime. Interestingly, we find that unlike hole-doped cuprates “in-phase” stripe domains with the period as large as lattice length can be stabilized near underdoped region in electron-doped systems. According to the finite lattice size to which we can reach, our results suggest that the pseudogap is a competing order with various symmetry breakings, which is consistent with the signature of the phase transition observed by a Kerr rotation and the time-resolved reflectivity measurements on the nature of the pseudogap in cuprates is a major unsolved problem in condensed matter physics. We studied the commencement of the pseudogap state at temperature T* in the optimally doped Bi2201 by ARPES. The results suggest that the pseudogap is a competing order with various symmetry breakings, which is consistent with the signature of the phase transition observed by a Kerr rotation and the time-resolved reflectivity measurements on the nature of the pseudogap in cuprates is a major unsolved problem in condensed matter physics. We studied the commencement of the pseudogap state at temperature T* in the optimally doped Bi2201 by ARPES. The results suggest that the pseudogap is a competing order with various symmetry breakings, which is consistent with the signature of the phase transition observed by a Kerr rotation and the time-resolved reflectivity measurements on
the same sample. Further, the measurement below Tc suggests that the pseudogap and superconductivity coexist, entangled in an energy-momentum dependent manner.1,2


16m-B4 The relationship between the normal state Fermi liquid scattering rate and the superconducting state

M. Núñez-Regueiro1a, G. Garbarino1a, M.-D. Núñez-Regueiro2b, a Institute Néel, CNRS et UJF, 25 rue des Martyrs, BP 166, F-38042 Grenoble cedex 9, France b Laboratoire de Physique des Solides, Bât. 510, Université de Paris-Sud, F-91405 Orsay cedex, France

Fermi liquids (FL) are ubiquitous in physics: helium, neutron matter, cold atoms, metals. In several bad metal superconductors, e.g. A-15, borocarbides, heavy fermions, the FL scattering time \( \tau \) quadratic temperature dependence, i.e. \( \rho = AT^2 \), dominates the low temperature electrical resistivity \( \rho \) above the superconducting transition temperature \( T_c \). In the first place, we show empirically that there exists a relationship between \( A \) and \( T_c \) when both vary under an external parameter, such as pressure. The more resistive the compound the higher the \( T_c \). Through the analysis of Landau theory of FL, we find that it is a general feature of FL, due to the fact that the scattering that is the main cause of \( \tau \) is the same one that bounds the pairs that condensed at \( T_c \). We devise a method that allows the determination of the coupling constant \( \lambda \), which is validated through application to \(^3\)He’s superfluid transitions and \( \tau \)’s extracted from different properties. This method works for conventional superconductors, but fails with heavy fermions.

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2 deceased

16m-B5 Unconventional Magnetic Phase Diagram of Cuprate Superconductor La\(_{2-x}\)Sr\(_x\)CuO\(_4\) at Quantum Critical Point \( x = 1/9 \)

X. L. Dong1a, P. H. Hor1b, F. Zhou1a, Z. X. Zhao1a, a Institute of Physics, CAS, Beijing 100190, China b Texas Center for Superconductivity and Department of Physics, University of Houston

We have studied field-cooled magnetization of La1.89Sr0.11CuO4 as a function of temperature and magnetic fields. 2D critical fittings1,2 to the entire reversible field-cooled magnetization revealed a new phase boundary \( T_{m2}(H) \) that buries deeply below the first order vortex melting line in the vortex solid phase. We observed a field-induced enhancement of antiferromagnetism (AF) which can be attributed to the proximity to a quantum critical point (QCP) where superconductivity and spin density wave (SDW) coexist microscopically, the SC+CDW phase. In the SC+CDW phase the correction to the lowest magnetic energy mode is \( \sim |\nu|[(H/(2\theta_{Q2}) \times \ln(H/\theta_{Q2})/H)] \) where \( \nu \) is the coupling constant between SC and SDW3. We find that the coupling constant \( \nu \) is negative below \( T_{m2}(H) \) while positive above. We conclude that the microscopically coexisting antiferromagnetism collaborates with the high temperature superconductivity in cuprates below \( T_{m2}(H) \). We present a new unconventional magnetic phase diagram of La\(_{2-x}\)Sr\(_x\)CuO\(_4\) around quantum critical point \( x = 1/9 \).

**Session 16m-C: Magnetic Materials and Devices**

**Chair:** Guangming Zhang  
**Tuesday August 16, 10:50 – 12:30**  
**Room 5B**

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**16m-C1 Coulomb Blockade Magnetoresistance in Magnetic Tunnel Junctions**

Xiu-Feng Han, Beijing National Laboratory for Condensed Matter Physics, Institute of Physics, Chinese Academy of Science, Beijing 100190, China

Since the theoretical predictions and experimental observations of giant tunneling magneto- resistance (TMR) effect at room temperature in magnetic tunnel junctions (MTJs) with single-crystalline MgO(001) barrier have been extensively studied due to their broad potential applications in spintronics devices. In this talk, we show that the Coulomb blockade voltage can be made to depend strongly on the electron spin in a discontinuous nano-magnetic granular layer inserted in the middle of an insulating layer of a tunnel junction. This strong spin dependence is predicted from the local intergranular magneto-resistance effects. The resulting Coulomb blockade magneto-resistance (CBMR) ratio can exceed the magneto-resistance ratio of the nanomagnetic granular layer itself by orders of magnitude. Recent few experimental results have shown such novel CBMR effect. Unlike other magneto-resistance effects, the CBMR effect does not require magnetic electrodes. This feature shall open up broader applications for the CBMR effect.

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**16m-C2 An Unusual Kondo Effect with a Topological Transition in the Honeycomb Kitaev Model**

V. Tripathi, K. Dhochak, R. Shankar, Department of Theoretical Physics, Tata Institute of Fundamental Research, Homi Bhabha Road, Navin Nagar, Mumbai 400005, India  
The Institute of Mathematical Sciences, IV Cross Road, CIT Campus, Taramani, Chennai 600113, Tamil Nadu, India

We have studied the effect of coupling spin-S magnetic impurities to the spin-1/2 Kitaev model in its gapless spin-liquid phase. We find an unusual Kondo effect where an intermediate coupling unstable fixed point separates topologically distinct sectors of the Kitaev model. We show that the strong impurity coupling limit is equivalent to a missing site in the Kitaev system, and is associated with a finite $Z_2$ flux localized at the defect site. Such finite flux states in the Kitaev model obey non-Abelian anyonic statistics upon exchange. We also show that the massless spinons in the spin-liquid mediate a nondipolar interaction between distant impurities unlike the usual dipolar RKKY interaction noted in various 2D impurity problems with a pseudogapped density of states of the spin bath. Furthermore, this long-range interaction is possible only if the impurities (a) couple to more than one neighboring spin on the host lattice and (b) the impurity spin $S \neq 1/2$. We suggest NMR probes for the detection of the non-Abelian anyons.

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**16m-C3 Pressure induced superconductivity in Topological Compounds**

Department of Physics, McCullough Building, Stanford University, Stanford

Topological insulator forms a very interesting new materials category since theory has predicted many novel physics. Right after the theoretically predication of 3 dimensional topological insulators of Bi$_2$Se$_3$, Bi$_2$Te$_3$, Sb$_2$Te$_3$, ARPES experiments show strong evidences of Dirac cone at surface electronic structure. Among the many prospective novel properties predicated by theory, topological superconductivity is one of most excited since its surface supports Majorana fermions since it can support new conception quantum computing. Princeton group reported the observation of superconductivity by intercalating Cu into the Van de Waals gap between Bi$_2$Se$_3$ quintuple layers. Comparing to chemical doping, pressure can be a direct physical measure to modify the electronic structure with the advantages of free defects or impurities. Here we report superconductivity can be realized in the topological no trivial ambient phase of Bi$_2$Te$_3$ induced via pressure where the surface remains gapless Dirac cone. We provide a systematic phase diagram of Bi$_2$Te$_3$ as function of pressure based on investigations of superconductivity versus structures.

Acknowledgments: This work was supported by nsf & MOST of China.
16m-C4  Fermi Surface Properties in the Hidden Order State and in the Antiferromagnetic State on URu$_2$Si$_2$

D. Aoki\(^a\), G. Knebel\(^a\), E. Hassinger\(^a\), T. D. Matsuda\(^a\), F. Bourdarot\(^a\), I. Sheikin\(^b\), V. Taufour\(^a\), J. Flouquet\(^a\), \(^a\)INAC/SPSMS, CEA-Grenoble, France \(^b\)LNCMI-CNRS, Grenoble, France

We present our recent advances on the heavy fermion compound URu$_2$Si$_2$, using a ultra-pure single crystal. Focus is given on the Fermi surface properties both in the hidden order state and in the antiferromagnetic state by the Shubnikov-de Haas experiments. The Fermi surfaces in the hidden order state are well identified by the band structure calculation based on the 5f-itinerant model with the simple tetragonal Brillouin zone. However, there is a still undetected orbit, which amounts approximately a half of the total Sommerfeld coefficient. Unusual split of branch $\alpha$ is detected for the field along the basal plane, which disappears when the antiferromagnetic state is realized, although all the other branches remains the almost same value in frequency. New experimental results of uniaxial stress by neutron scattering is also presented.

16m-C5  Exploring the Antiferromagnetic Superconducting Phase in CeCoIn$_5$

E. Blackburn\(^a\), P. Das\(^b\), M. R. Eskildsen\(^a\), E. M. Forgan\(^a\), M. Laver\(^c\), C. Niedermayer\(^c\), C. Petrovic\(^d\), J. S. White\(^c\), \(^a\)School of Physics and Astronomy, University of Birmingham, Birmingham, UK \(^b\)Department of Physics, University of Notre Dame, Indiana, US \(^c\)Laboratory for Neutron Scattering, Paul Scherrer Institut, Villigen, Switzerland \(^d\)Brookhaven National Laboratory, Upton, New York, US

CeCoIn$_5$ is a heavy fermion type-II superconductor showing clear signs of Pauli-limited superconductivity. CeCoIn$_5$ is also very close to a magnetically ordered ground state; this can be achieved by, for instance, doping with Cd. A variety of measurements give evidence for a transition at high magnetic fields inside the superconducting state, when the field is applied either parallel to or perpendicular to the c axis. In the latter case, antiferromagnetic order develops on the high-field side of the transition, with a magnetic wavevector of $(q 0.5)$, where $q = 0.44$ reciprocal lattice units [1]. We show that this order remains as the field is rotated out of the basal plane, but that the associated moment eventually disappears above 17°C, indicating that anomalies seen with the field parallel to the c axis are not related to this magnetic order [2]. Our measurements emphasise the fragility of this magnetic order.

Session 16m-D₁: 2DEG-related Transport and Spins

Chair: Leo Kouwenhoven
Tuesday August 16, 10:50 – 12:30
Room 201

16m-D₁ The spin polarization of the $\nu = 5/2$ fractional quantum Hall state
L. Tiemann\textsuperscript{a,b}, G. Gamez\textsuperscript{a}, N. Kumada\textsuperscript{a}, K. Muraki\textsuperscript{a,b}. \textsuperscript{a}NTT Basic Research Laboratories, 3-1 Morinosato-Wakamiya, Atsugi, 243-0198, Japan \textsuperscript{b}ERATO Nuclear Spin Electronics Project, Japan Science and Technology Agency (JST)

In two-dimensional electron systems (2DES) under perpendicular magnetic fields, correlation effects are believed to create a non-Abelian state of matter \cite{1}, whose excitations could be exploited for topologically protected quantum operations. This non-Abelian state at a ratio of electrons to magnetic flux quanta of (filling factor $\nu$) 5/2 \cite{2} is currently the subject of intensive experimental and theoretical studies which try to identify its key properties. Among the various theories which have been proposed, the Pfaffian ground state \cite{3} has arisen as the most desirable candidate. Recent experiments \cite{4} were able to substantiate a quasiparticle charge of $e/4$, in agreement with the Pfaffian model. However, in order to rule out other less favorable Abelian states, the knowledge of the quasiparticle charge alone is not sufficient. In this presentation, we will report an experimental study of the electron spin polarization at filling factor $\nu = 5/2$, which is another important key property. The electron spin polarization is extracted from nuclear resonance spectra and their respective (Knight) shift at different filling factors.

Our resistively-detected NMR measurements, performed at $T \approx 10$ mK on a gated 30 nm wide quantum well sample patterned into a Hall bar, reveal that the $\nu = 5/2$ resonance spectrum shows a finite Knight shift which is indicative of a non-zero spin polarization. More specifically, our careful analysis indicates that the spin polarization at filling factor 5/2 is very close to its maximal value over a wide range of electron densities. This, in turn, gives support for the Pfaffian wave function over other proposed wave functions.


16m-D₂ Investigation of cavity mode and excitonic transition in an InGaAs/GaAs/AlGaAs vertical-cavity surface emitting laser structure by variable-temperature photoluminescence, reflectance and photomodulated reflectance
J. L. Yu\textsuperscript{a}, Y. H. Chen\textsuperscript{a}, C. Y. Jiang\textsuperscript{a}, H. Y. Zhang\textsuperscript{a}. \textsuperscript{a}Key Laboratory of Semiconductor Materials Science, Institute of Semiconductors, Chinese Academy of Sciences, P.O. Box 912, Beijing 100083, People’s Republic of China

Variable-temperature photoluminescence (PL), reflectance and photomodulated reflectance (PR) have been used to study an InGaAs/GaAs/AlGaAs vertical-cavity surface emitting laser (VCSEL) structure. PL and PR spectra have been recorded at different temperatures between 80 K and 300 K. By comparing with PR and reflectance results of an etched sample, we find that variable-temperature PL is a powerful noninvasive tool to measure accurate the quantum well transition and the cavity mode alignment. The measured results are found to be in good agreement with calculated results using a six-band $k \cdot p$ model and a Johns matrix approach.

16m-D₃ Factorial cumulants reveal interactions in counting statistics
D. Kambly\textsuperscript{a}, C. Flindt\textsuperscript{a}, M. Büttiker\textsuperscript{a}. \textsuperscript{a}Département de Physique Théorique, Université de Genève, CH-1211 Genève, Switzerland

Full counting statistics concerns the stochastic transport of electrons in mesoscopic structures. Recently it has been shown that the charge transport statistics for noninteracting electrons in a two-terminal system is always generalized binomial: it can be decomposed into independent single-particle events, and the zeros of the generating function are real and negative.\textsuperscript{1} Here we investigate how the zeros of the generating function move into the complex plane due to interactions and demonstrate that the positions of the zeros can be detected using high-order factorial cumulants.\textsuperscript{2} As an illustrative example we consider electron transport through a Coulomb blockade quantum dot for which we show that the interactions on the quantum dot are clearly visible in the high-order factorial cumulants. Our findings are important for understanding the influence of interactions on counting statistics, and the characterization in terms of zeros of the generating function provides us with a simple interpretation of recent
experiments, where high-order statistics have been measured.\textsuperscript{3}
\textsuperscript{2} D. Kambly, C. Flindt, M. Büttiker, Phys. Rev. B \textbf{83}, 075432 (2011), Editors’ Suggestion in PRB

\section*{16m-D\textsubscript{1}4 \hspace{1em} Novel 2D spin system and its interaction with conduction electrons}
\textbf{T. Gang\textsuperscript{a}}, D. Yilmaz\textsuperscript{b}, D. Atac\textsuperscript{a}, E. Strambini\textsuperscript{a}, S.K. Bose\textsuperscript{a}, M.P. de Jong\textsuperscript{a}, J. Huskens\textsuperscript{b}, W.G. van der Wiel\textsuperscript{a}, \textsuperscript{a}NanoElectronics Group, \textsuperscript{b}Molecular Nanofabrication Group, MESA+ Institute for Nanotechnology, University of Twente, Enschede, The Netherlands.

We study the interaction of a dilute 2D spin system with conduction electrons in a metallic host via low-temperature transport measurements. A novel molecular fabrication method is presented, in which the 2D spin system is formed by self-assembly of spin-1/2 paramagnetic molecules on an Au film. This method offers great tunability of the nature and density (and hence coupling) of the spins, while avoiding undesired clustering of magnetic impurities often suffered from in alternative methods. The insertion of the paramagnetic molecules leads to a 2D Kondo impurity system with enhanced spin scattering near and above the Kondo temperature. This gives rise to a logarithmic resistivity increase at low temperatures. Mixed monolayers of paramagnetic and nonmagnetic molecules have been used to systematically vary the spin concentration. Our experimental results are very well described by Hamann’s expression (D.R. Hamann, Phys. Rev. \textbf{158}, 570 (1967)) for the Kondo resistivity correction. The additional spin scattering also leads to a reduced phase coherence length as demonstrated by weak (anti)localization measurements. We discuss the relevance of this model system for further study of spin phenomena that lie at the very heart of solid-state physics: the Kondo effect, RKKY interaction and spin glasses.

\section*{16m-D\textsubscript{1}5 \hspace{1em} Spin-Polarization Control at the Surface of a Topological Insulator}
\textbf{Z.-H. Zhu\textsuperscript{a}}, G. Levy\textsuperscript{b}, B. Ludbrook\textsuperscript{a}, D. Fournier\textsuperscript{a}, P. Syers\textsuperscript{b}, N.P. Butch\textsuperscript{b}, J. Paglione\textsuperscript{b}, A. Ubaldini\textsuperscript{c}, E. Giannini\textsuperscript{c}, G.A. Sawatzky\textsuperscript{a, d}, I.S. Elfimov\textsuperscript{a, d}, A. Damascelli\textsuperscript{a, d}, \textsuperscript{a}Department of Physics & Astronomy, University of British Columbia, Vancouver, BC V6T 1Z1, Canada \textsuperscript{b}Center for Nanophysics & Advanced Materials, Department of Physics, University of Maryland, College Park, MD 20742, USA \textsuperscript{c}Département de Physique de la Matière Condensée, Université de Genève, quai Ernest-Ansermet 24, CH-1211 Genève 4, Switzerland \textsuperscript{d}Quantum Matter Institute, University of British Columbia, Vancouver, BC V6T 1Z4, Canada

Topological insulators, with a gapless topological surface state (TSS) located in a large bulk bandgap, define a new quantum phase of matter. Their uniqueness, and their strong application potential in quantum electronic devices, stem from the TSS combination of spin polarization and protection from backscattering. Unfortunately the exploitation of these properties has so far been hampered by the intrinsic instability of the materials’ surfaces. Here we show, as revealed by ARPES for the case of Bi\textsubscript{2}Se\textsubscript{3}, that the surface electronic properties can be stabilized and controlled by the deposition of potassium in ultra-high vacuum conditions. In addition to accurately setting the carrier concentration, new Rashba-like states with strong spin polarization can be induced by in-situ K deposition; the size of the spin splitting in these new states can be tuned as desired, and reversibly. We also demonstrate that the surfaces prepared this way, and the induced new spin-polarized states, are robust against contamination and can survive at room temperature in vacuum. These results are crucial for understanding the novel physical phenomena of topological insulators and pave the way to controlled approaches for developing room temperature spintronic devices.
Session 16m-D₂: Quantum Dots, Nanowires & Molecular Electronics

Chair: Hongqi Xu
Tuesday August 16, 10:50 – 12:30
Room 305

16m-D₂1  Universality of the Kondo effect in quantum dots with ferromagnetic leads
M. Gaass, A.K. Hütten, K. Kang, I. Weymann, J.V. Delft, Ch. Strunk, Institute for Exp. and Applied Physics, University of Regensburg, 93040 Regensburg, Germany, Department of Physics, Chonnam National University, Gwang-Ju 500-757, Korea, Physics Department, ASC, and C&NS, Ludwig-Maximilians-Universität, 80333 Munich, Germany, Department of Physics, Adam Mickiewicz University, 61-614 Poznań, Poland

We investigate the influence of ferromagnetic contacts on the Kondo effect in quantum dots formed in SWCNTs. As contact material we use PdNi. Transport spectroscopy shows a Kondo-like conductance anomaly around zero bias in every second Coulomb diamond. The ferromagnetic contacts cause a splitting of the Kondo resonance to finite bias values. This splitting can be compensated by a finite magnetic field. Using numerical renormalization group (NRG) techniques, we demonstrated that all salient features of the data can be quantitatively understood in terms of a simple model for the magnetic properties of the leads. The size and field dependence of the splitting as well as its dependence on gate voltage can be explained by spin-dependent renormalization processes of the quantum dot level that include two contributions. The first, largely independent of gate voltage, arises from the macroscopic magnetization of the leads. The second contribution, showing a gate dependence, stems from the spin polarization at the Fermi energy. In the presence of exchange coupling, the Kondo conductance shows a universal dependence on the tunneling induced splitting scaled by the Kondo temperature. This universality is also reproduced numerically within the framework of the applied theory.

16m-D₂2  Lasing and Transport in a Quantum Dot-Resonator System
P.-Q. Jin, M. Marthaler, J.H. Cole, A. Shnirman, G. Schön, Institut für Theoretische Festkörperphysik, Karlsruhe Institute of Technology, Germany, Applied Physics, School of Applied Sciences, RMIT University, Australia, Institut für Theorie der Kondensierten Materie, Karlsruhe Institute of Technology, Germany, DFG Center for Functional Nanostructures (CFN), Karlsruhe Institute of Technology, Germany

Circuit quantum electrodynamics (cQED), one of the applications of quantum information processing with solid state devices, allows exploring quantum optics effects in new parameter regimes, including strong coupling and low temperature, where qualitatively novel behavior has been observed. An example is lasing with a single superconducting qubit which is strongly coupled to an oscillator, where quantum noise influences the linewidth of the emission spectrum in a characteristic way. We propose a different cQED setup, where the role of an artificial atom is played by a semiconductor double quantum dot. A current through the dot system can create a population inversion in the dot levels and, within a narrow resonance window, a lasing state in the resonator. The lasing state correlates with the transport properties. On one hand, it allows probing the lasing state via a current measurement, which may be easier to perform in an experiment. On the other hand, the resulting narrow current peak opens perspective for applications of the setup for high resolution measurements. The effects survive for realistic strength of the dissipative processes. P.Q. Jin et al., arXiv:1103.5051 [cond-mat.mes-hall]

16m-D₂3  Single Electron Transfer Between Distant Quantum Dots
S. Hermelin, S. Takada, M. Yamamoto, A. Tarucha, A. Wieck, T. Meunier, Institut Noel, CNRS and Universite Joseph Fourier, France, Department of Applied Physics, The University of Tokyo, Japan, Lehrstuhl für Angewandte Festkörperphysik, Ruhr-Universität Bochum, Germany

GaAs lateral quantum dots have proven to be good candidates for spin qubit implementation: qubit initialization, rotation and two qubit operations have been demonstrated successfully. However, in order to build quantum information devices, it is necessary to be able to entangle distant qubits. Transferring coherently a single electron spin between two distant quantum dots is a viable solution towards this goal. We demonstrate the experimental realization of high efficiency single electron source and single electron detector for a quantum medium where a single electron is propagating isolated from the other electron. The moving potential is excited by a surface acoustic wave (SAW), which carries the single electron along a gate defined 1D-channel at a speed of 3 μm/ns. When such a quantum channel is placed between two quantum dots, a single electron can be transported from one quantum dot to the other, which is several micrometres apart, with high quantum efficiencies of emission and detection. Furthermore, the transfer of the electron can be triggered on a timescale shorter than the coherence time T2* of GaAs spin qubits. Our work opens new avenues to study the teleportation of a single electron spin and the distant interaction between spatially separated qubits in a condensed matter system.
Single-electron devices with a mechanical degree of freedom


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We have succeeded in integrating a single-electron transistor (SET) and a nanomechanical resonator into one device by suspending the SET island. In this case the island has flexural modes whose resonance frequencies depend on the material parameters and the island dimensions. The device is made of Al and can be studied in both the normal and superconducting state allowing observation of various physical phenomena. To couple mechanical motion to electronic transport, we apply a high, of the order of a few volts, dc voltage to the gate. By driving the resonator with an external force at a frequency close to the fundamental frequency of the flexural mode, we observe a characteristic feature in the dc SET transport, which is due to the mechanical resonance of the island. The resonance frequency as high as 0.5 GHz was detected. The observed response is reproduced in the simulations based on the semiclassical model of single-electron tunneling with the mechanical degree of freedom taken into account. Besides the studies of charge transport in single-electron circuits, the device can also be used for investigation of quantum effects in the charge qubits with a mechanical degree of freedom.
Session 16a-A: Phase Transition in Novel Systems

Chair: Keiya Shirahama
Tuesday August 16, 14:00 – 15:40
Room 5A

16a-A1 Spin Wave Resonances Excited by Moving Domain Walls in Polarized Dilute Liquid $^3$He-$^4$He Mixtures

D.M. Lee*, Department of Physics and Astronomy, Texas A & M University, College Station, TX 77843, USA

Previously observed multiple NMR spin echo patterns following a single 180 degree pulse in a very dilute (350 ppm), highly polarized liquid $^3$He-$^4$He mixture below 20 mK are discussed. Echoes occurred at intervals varying from 0.1-1.0 seconds, with the echo patterns showing extreme sensitivity to the field gradients. These echoes are now believed to be associated with spin waves generated by a moving domain wall as it moves along the cell through the magnetic field gradient. The echoes are generated when the spin wave frequencies correspond to geometric spin wave resonances in the cell. A variety of echo patterns were observed depending on the temperature and field gradient. Simulations, now in progress, will be presented.


16a-A2 Confinement and Collective Behavior of $^4$He near the Superfluid Transition

Francis M. Gasparini*, Justin K. Perron*, Department of Physics, University at Buffalo, the State University of New York, 14260 USA

The uniform confinement of helium near the superfluid transition reveals behavior which relates to finite-size, correlation-length scaling. When two adjoining regions characterized by different length scales are involved, the overall thermodynamic behavior can be approximated as that of the individual separate regions plus a coupling. One would expect this coupling to extend over spatial distances of the order of the temperature-dependent correlation length. We have observed in recent experiments that the extent of this coupling, in magnitude, in range of temperatures, and spatial distance to be much larger than anticipated. These observations apply to both the specific heat and the superfluid density. We will describe recent experiments which demonstrate these effects. Our work is relevant to coupling in systems near their ordering transition, and, in particular, to the case of high $T_c$ superconductors where tunneling and proximity effects are observed across distances much larger than the correlation length.


16a-A3 Observation of metastable solid helium-4 below its melting pressure

J. Dupont-Roc*, F. Souris*, J. Grucker*, Ph. Jacquier*, Laboratoire Kastler Brossel, Ecole Normale Superieure, CNRS, Université Pierre et Marie Curie, Paris 5, France

Production and observation of metastable hcp solid helium-4 below its melting pressure is reported. Transient depressions are produced by sound wave pulses focussed inside a crystal of known orientation at 1.1 K. This is achieved with an especially designed piezo-electric transducer matching the anisotropic pressure wave surface. The density map near the focus is monitored using an optical interferometric technique. Minimum density achieved at focus corresponds to a pressure at least 2 bar below the equilibrium melting pressure. Beyond a threshold located between 2 and 3 bar below the melting pressure at 1.1 K, the crystal seems to undergo an unexpected instability.

16a-A4 Hydrodynamics of Superfluid Flow through a Nanohole: Towards the 1D Regime

G. Gervais*, Department of Physics, McGill University, Montreal, Canada, H3A 2T8

Quantum fluids, whether constituted of atoms, electrons or nucleons, are ubiquitous in nature. In three dimensions, their quantum statistics are restricted to the Bose and Fermi statistics, each of which can be found to be at the heart of the superfluidity and Fermi liquid behavior for $^4$He and $^3$He. In two dimensions more exotic quantum statistics can occur (the so-called anyons), and it has long been known theoretically that in one dimension, fermionic systems should bosonize, and in some ways their quantum statistics be quenched. Such one-dimensional
quantum fluid, known as a Luttinger liquid, might be observable in liquid helium when constrained radially by a lengthscale nearing the nanometric scale [1]. In this talk, we discuss our results and progress of an experiment where the superfluid helium flow across a tailor-made single nanohole with a ~45 nm diameter is measured via mass spectrometry [2]. The measured mass flow is modeled by a two-fluid model which accounts for the end effects of the short-pipe, and the extracted superfluid velocities are compared with existing data from the literature. Finally, we discuss how one might be able to reach the one-dimensional regime, and study the behavior of a helium Luttinger liquid.


16a-A5  Vortices and the Superfluid Phase Transition in d Dimensions
Gary A. Williams*, University of California, Los Angeles, CA 90095 USA
The role of vortices in the superfluid phase transition will be discussed for general d dimensions, with d ranging between 2 and 4. A single set of recursions relations gives the results of Kosterlitz and Thouless in d = 2, reproduces the vortex-loop renormalization of Williams and Shenoy in d = 3, and approaches mean-field results in d = 4.
Although the derivation of the recursion relations is phenomenological in nature, predictions for universal behavior in the scale dependence of the superfluid density near 4 - ε dimensions should be possible to test with perturbative RG calculations. Comparison to experimental results will be discussed, including thermodynamic properties such as the specific heat, and the dynamics of the transition. The crossover from d = 2 to d = 3 in helium films adsorbed in porous materials has allowed the first measurements of the vortex core size in submonolayer superfluids.
Research supported by the US National Science Foundation, Grant No. DMR 09-06467.
Session 16a-B: Physical properties of Fe-based and Cuprate superconductors III

Chair: Setsuko Tajima
Tuesday August 16, 14:00 – 15:40
Convention Hall 3

16a-B1  Novel Ordered Region Preceding The Magnetic And Structural Transition In Underdoped $Ba(Fe_{1-x}Co_x)_2As_2$ And $Fe_{1+y}Te$

H. Z. Arham$^a$, C. R. Hunt$^a$, W. K. Park$^a$, J. Gillett$^b$, S. D. Das$^b$, S. Sebastian$^b$, Z. J. Xu$^c$, J. S. Wen$^c$, S. D. Das$^c$, Z. W. Lin$^c$, Q. Li$^c$, G. Gu$^c$, A. Thaler$^c$, S. L. Budko$^c$, P. C. Canfield$^c$, L. H. Greene$^c$

$^a$Department of Physics, University of Illinois at Urbana-Champaign  $^b$Cavendish Laboratory, University of Cambridge  $^c$Brookhaven National Laboratory  $^d$Ames Laboratory and Iowa State University

Point contact spectroscopy reveals a novel ordered region above the magnetic and structural transition temperatures for underdoped $Ba(Fe_{1-x}Co_x)_2As_2$ and $Fe_{1+y}Te$. The conductance measured across ballistic nanoscale Ag junctions reveals a conductance enhancement starting as high as 177 K for the parent pnictide ($T_N \sim 132$ K) and with decreasing temperature grows reminiscent of a gap opening. Our data indicates that the iron based superconductors are strongly correlated in their ground state. The energy scale and temperature dependence of the spectrum indicates that it may arise from the orbital ordering that persists above $T_N$ as detected by ARPES. Similar results are observed in the chalcogenides. We construct a modified phase diagram for Co-doped Ba122 showing a new ordered region existing above $T_N$ and $T_S$ for the underdoped regime.


16a-B2  Anisotropic Superconducting Gap Revealed by Angle Resolved Specific Heat, Point Contact Tunneling and Scanning Tunneling Microscope in Iron Pnictide Superconductors

H. H. Wen$^a$, B Zeng$^a$, L Shan$^a$, C. Ren$^a$, H. Yang$^a$, B. Shen$^a$, F. Han$^a$, P. Cheng$^a$, C. H. Li$^a$

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Angle resolved specific heat was measured in FeSe0.55Te0.45 single crystals with the in-plane magnetic field. A four-fold oscillation of specific heat was observed when the sample was rotated with a 9 T in-plane magnetic field. The minimum of C/T locates at the direction (H—Fe-As bond), which can be understood as due to the gap modulation on the electron pocket when the intra-pocket scattering plays an un-negligible role in the pairing interactions with the scheme of S pairing manner.[1] Accordingly, by measuring the point contact Andreev reflection spectrum on the BaFe2-xNixAs2 single crystals in wide doping regimes, we found a crossover from nodeless to nodal feature of the superconducting gap. We can also illustrate the systematic evolution of the gap amplitude and the anisotropy on the hole and electron pockets.[2] In K-doped BaFe2As2 single crystals, we performed the low temperature STM measurements. We observed a well ordered vortex lattice in local region. In addition, the statistics on over 3000 dI/dV spectra illustrate clear evidence of two gaps with magnitude of 7.6 meV and 3.3 meV, respectively. Detailed fitting to the tunneling spectrum shows an isotropic superconducting gap.[3]

[3] Lei Shan, Yong-Lei Wang, Bing Shen, Bin Zeng, Yan Huang, Ang Li, Da Wang, Huan Yang, Cong Ren, Qiang-Hua Wang, Shuheng Pan, Hai-Hu Wen, Observation of Lattice and Andreev Bound States of Vortices in Ba0.6K0.4Fe2As2 Single Crystals with Scanning Tunneling Microscopy/Spectroscopy, Nature Physics 7, 325 (2011).

16a-B3  An energy scale directly related to superconductivity in the high-$T_c$ cuprate superconductors: Universality from the Fermi arc picture

S. Ideta$^a$, T. Yoshida$^a$, A. Fujimori$^b$, H. Anzai$^a$, T. Fujita$^a$, A. Ino$^a$, M. Arita$^a$, H. Namatame$^a$, M. Taniguchi$^{b,c}$, Z.-X. Shen$^a$, K. Takashima$^a$, K. Kojima$^a$, A. Thaler$^b$

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In the normal state of cuprate high-temperature superconductors (HTSCs), a pseudogap exists on part of the Fermi
surface (FS) away from the $d$-wave superconducting (SC) gap node, and the FS is truncated into gapless regions called “Fermi arcs”. We have performed a temperature dependent angle-resolved photoemission spectroscopy (ARPES) study of the tri-layer HTSC Bi$_2$Sr$_2$Ca$_2$Cu$_3$O$_{10+\delta}$ (Bi2223), and have shown that the “effective” SC gap $\Delta_{sc}$ defined at the end point of the Fermi arc and the $T_c$ (= 110 K) approximately satisfies the weak-coupling BCS-relationship $2\Delta_{sc} = 4.3k_B T_c$. Combining this result with previous ARPES results on single- and double-layer cuprates, we show that the relationship between $2\Delta_{sc} = 4.3k_B T_c$ holds for various HTSCs. Furthermore, at $T \sim T_c$, the quasi-particle width at the end point of the Fermi arc is found to coincide with $\Delta_{sc}$, consistent with the context of Planckian dissipation.

16a-B4  Quantum Criticality and Superconductivity in Ba(Fe$_{1-x}$Co$_x$)$_2$As$_2$
Investigated by Ultrasonic Measurements
M. Yoshizawa$^a$, D. Kimura$^a$, T. Chiiba$^a$, A. Ismayil$^a$, Y. Nakanishi$^a$, K. Kihou$^b$, M. Nakajima$^c$, A. Iyo$^b$, H. Eisaki$^b$, S. Uchida$^c$,
$^a$Graduate School of Engineering, Iwate University, Morioka, Japan  $^b$National Institute of Advanced Industrial Science and Technology (AIST), Tsukuba, Japan  $^c$Graduate School of Science, The University of Tokyo, Tokyo, Japan
Superconducting phase in iron pnictides is located closely to a magnetic phase, which accompanies a structural change. Such a phase diagram, which is often seen in many systems of oxide superconductors, heavy fermion superconductors and organic superconductors, has been intensively investigated from the viewpoint of superconductivity near quantum critical point (QCP). We have measured elastic constants of Ba(Fe$_{1-x}$Co$_x$)$_2$As$_2$ for the samples with various concentration from under-doped to over-doped regions. The temperature dependence of the elastic constant $C_{66}$ is particularly interesting. It shows a very large softening toward the structural transition temperature for under-doped samples. The anomaly in $C_{66}$ is very large in under-doped region, and tends to disappear with increasing Co concentration for over-doped region. Such behavior can be understood in the frame of the quantum criticality, which has been well investigated for magnetic systems. For Ba(Fe$_{1-x}$Co$_x$)$_2$As$_2$, the elastic constant, which is connected to a strain susceptibility, plays the same role as the magnetic susceptibility for the magnetic QCP systems. Our results suggest a strong participation of the structural instability to the superconductivity.

16a-B5  Nodal $s$-wave superconductivity in BaFe$_2$(As,P)$_2$
T. Shibauchi$^a$, $^a$Department of Physics, Kyoto University, Kyoto, Japan
I will discuss the superconducting gap structure of isovalent P-substituted system BaFe$_2$(As,P)$_2$ system from several experimental results including penetration depth$^1$, thermal conductivity,$^{1,2}$ specific heat$^3$, and laser ARPES$^4$. The crystals used in this study are very clean$^5$, evidenced by the observation of quantum oscillations$^6$. Strong evidence for the presence of line nodes has been obtained from penetration depth and thermal conductivity, both of which are sensitive to the high Fermi velocity parts of the multiband Fermi surfaces. From the thermal conductivity in magnetic field rotating within the $ab$ plane$^2$, we conclude that the observed results are most consistent with the nodal $s$-wave, having closed nodal loops located at the flat part of electron Fermi surface with high Fermi velocity. This work has been done in collaboration with M. Yamashita, Y. Senshu, S. Kasahara, K. Hashimoto, D. Watanabe, H. Ikeda, T. Terashima, Y. Matsuda, I Vekhter, and A. B. Vorontsov.

Session 16a-C: Magnetism & Superconductivity

Chair: Hsiu-Hau Lin
Tuesday August 16, 14:00 – 15:40
Room 5B

16a-C1  Ground state phase diagram of the spin-1 bilinear-biquadratic Heisenberg model on a honeycomb lattice

Hui-Hai Zhao\textsuperscript{a}, Q. N. Chen\textsuperscript{b}, Z. C. Wei\textsuperscript{a}, M. P. Qin\textsuperscript{a}, G. M. Zhang\textsuperscript{a}, T. Xiang\textsuperscript{a,b}, \textsuperscript{a} Institute of Physics, Chinese Academy of Sciences, Beijing 100190, China \textsuperscript{b} Department of Physics, Tsinghua University, Beijing 100084, China

We have precisely determined the ground state phase diagram of the spin-1 bilinear-biquadratic Heisenberg model on a honeycomb lattice using the tensor renormalization group method. We find that the ferromagnetic, antiferromagnetic, and ferroquadrupolar phases are stable against quantum fluctuations. However, in the phase where the ground state is staggered quadrupolar ordered in the classical limit, we find that quantum fluctuations suppress completely all magnetic orders and lead to a magnetically disordered phase with a spin gap.

16a-C2  Metallic dense hydrogen

M. I. Eremets\textsuperscript{a}, I. A. Troyan\textsuperscript{a}, \textsuperscript{a} Max Planck Institute for Chemistry, P. O. Box 3060, 55020 Mainz, Germany

Hydrogen at ambient pressures and low temperatures forms a molecular crystal which is expected to display metallic properties under megabar pressures. This metal is predicted to be superconducting with a very high critical temperature $T_c$ of 200-400 K. The superconductor may potentially be recovered metastably at ambient pressures, and it may acquire a new quantum state as a metallic superfluid and a superconducting superfluid. Recent experiments performed at low temperatures $T<100$ K showed that at record pressures of 300 GPa, hydrogen remains in the molecular state and is an insulator with a band gap of $\sim 2$ eV. Given our current experimental and theoretical understanding, hydrogen is expected to become metallic at pressures of 400-500 GPa, beyond the current limits of static pressures achievable using diamond anvil cells. We found a way for producing metallic hydrogen by pressurizing hydrogen at room temperature. At 220 GPa, new Raman modes arose, providing evidence for the transformation to a new opaque and electrically conductive phase. Above 260 GPa, in the next phase, hydrogen reflected light well. Its resistance was nearly temperature-independent over a wide temperature range, down to 30 K, indicating that the hydrogen was indeed metallic. Releasing the pressure induced the metallic phase to transform directly into molecular hydrogen with significant hysteresis at 200 GPa and 295 K.

16a-C3  Josephson Effects in Insulating Quantum Spin Systems?

A. Schilling\textsuperscript{a}, H. Grundmann\textsuperscript{a}, \textsuperscript{a} Physik-Institut, University of Zurich, Zurich, Switzerland

We propose an experiment in which two magnetic insulators that both show field-induced magnetic-ordering transitions are weakly coupled to one another and are placed into an external magnetic field. If the respective magnetic states can be interpreted as phase coherent Bose-Einstein condensates of magnetic bosonic quasiparticles, one expects the occurrence of Josephson effects. For two coupled magnetic insulators with different critical fields, an alternating quasiparticle current should develop with a leading oscillation frequency $\omega_{a.c.}$ that is determined by the difference between the critical fields. As a result of the coupling, additional sidebands appear in the frequency spectrum of the coupled device that would be absent without phase coherence. We discuss the primary conditions for such an effect to take place and conclude that its detection is feasible for a proper choice of compounds with suitable and realistic material parameters.\textsuperscript{1}

\textsuperscript{1} A. Schilling and H. Grundmann, cond-mat/arXiv:1101.1811v4

16a-C4  Quantum Ice

Nic Shannon\textsuperscript{a}, Olga Sikora\textsuperscript{a}, Frank Pollmann\textsuperscript{b}, Karlo Penc\textsuperscript{c}, Peter Fulde\textsuperscript{b,d}, \textsuperscript{a} H. H. Wills Physics Laboratory, University of Bristol, Tyndall Avenue, Bristol BS8 1TL, UK \textsuperscript{b} Max-Planck-Institut für Physik komplexer Systeme, 01187 Dresden, Germany \textsuperscript{c} Research Institute for Solid State Physics and Optics, H-1525 Budapest, P.O.B. 49, Hungary \textsuperscript{d} Asia Pacific Center for Theoretical Physics, Pohang, Korea

Water ice comprises a loosely-packed lattice of water molecules, held together by hydrogen bonds. This is a very stable structure, but one with a hidden puzzle — chemical bonding alone does not select a unique orientation of the water molecules. As a result each water molecule has a finite ground state entropy $S_0 \approx k_B \log(3/2)$, in violation of the laws of thermodynamics. Exactly the same degeneracy, and the same contradiction, arises problems of frustrated charge order on the pyrochlore lattice, and in the family of rare-earth magnets collectively known as spin ice. Here we use zero-temperature quantum Monte Carlo simulations to explore how quantum mechanical tunneling between different spin- or charge-ice configurations can lead to a resolution of this issue, by stabilizing
a unique “quantum ice” ground state. This quantum ice state has excitations described by the Maxwell action of 3+1-dimensional quantum electrodynamics, and so retains the algebraic correlations and deconfined fractional excitations (magnetic monopoles) associated with classical (spin) ice states.

16a-C5 Single Crystal NMR Study of Frustrated Spin-liquid in S = 1/2 Kagome Lattice ZnCu$_3$(OD)$_6$Cl$_2$

M. Fu$^a$, T. Imai$^{a,b}$, T. H. Han$^c$, Y. S. Lee$^c$, $^a$Department of Physics and Astronomy, McMaster University, Hamilton, Ontario L8S 4M1, Canada $^b$Canadian Institute for Advanced Research, Toronto M5G 1Z8, Canada $^c$Department of Physics, M.I.T., Cambridge, Massachusetts 02139, USA

The spin-1/2 kagome lattice ZnCu$_3$(OH)$_6$Cl$_2$ exhibits no long range magnetic order down to 50mK, which makes it one of the most promising candidates for a quantum spin liquid. Despite the heightened level of interest in this material, the mechanism behind such a novel ground state in ZnCu$_3$(OH)$_6$Cl$_2$ has so far eluded thorough understanding, owing to the difficulty in identifying the location of defects, and in understanding what effects they may have on physical properties of this material. In particular, the bulk-averaged susceptibility reveals a strong enhancement below about 50K, which has been speculated to be a manifestation of Zn-Cu disorder. We investigated the local spin susceptibility of ZnCu$_3$(OD)$_6$Cl$_2$ single crystal$^1$ using NMR techniques$^2$. Our results demonstrate that the large enhancement near T = 0 is not an intrinsic feature of the spin susceptibility of the kagome plane. Instead, it is an extrinsic effect caused by weakly interacting Cu$^{2+}$ defect moments occupying Zn sites with 14 ± 2% probability. We explore the behavior intrinsic to kagome contributions by subtracting the defect contributions.

Session 16a-D: Graphene / Dirac Electrons

Chair: Li Lu
Tuesday August 16, 14:00 – 15:40
Room 201

16a-D1
Cory Dean\textsuperscript{a}, *Columbia University
(to be announced)

16a-D2 Gate tunable normal and superconducting transport through a 3D topological insulator
A. Morpurgo\textsuperscript{a}, *DPMC and GAP, University of Geneva, quai Ernest-Ansermet 24, CH1211 Geneva, Switzerland
We report on transport experiments though very thin Bi\textsubscript{2}Se\textsubscript{3} layers, exfoliated from high quality single crystals and transferred onto a Si/SiO\textsubscript{2} substrate acting as a gate. Low-temperature magneto-resistance measurements exhibit clear Shubnikov de Haas oscillations, which can be tuned by applying a gate voltage. The plot of the resistance as a function of magnetic field and gate voltage exhibit a fan diagram of Landau levels originating from both electrons and holes at the surface closer to the gate electrode, whose quantitative analysis allows us to determine the Dirac character of the charge carriers. Shubnikov de Haas oscillation due to carriers on the surface far away from the gate are also observed as features in the fan diagram that do not depend on the gate voltage (which is screened by the first and by carriers in the bulk). Our analysis also shows that an impurity band is present inside the gap of the bulk bands of Bi\textsubscript{2}Se\textsubscript{3}, with a large density of states that coexist with the surface states. Finally, as the devices are fabricated with superconducting contacts, we succeeded in observing Andreev reflection and proximity induced supercurrent. The critical current is gate tunable and exhibits a bipolar behavior, with a minimum at the same gate voltage observe from extrapolating the fan diagram of Landau levels. This observation indicates that at least part of the supercurrent is carried by Dirac electrons and holes at the surface.

16a-D3 Diffusive charge transport in graphene
Jian-Hao Chen\textsuperscript{a}, *Department of Physics, University of California at Berkeley, Berkeley, CA 94709
I’m going to summarize the recent results from our electrical transport experiments on graphene that revealed a wealth of information about the interaction of conduction electrons with impurities in the diffusive regime. By controllably tuning Coulomb potential scattering\textsuperscript{1}, lattice defect scattering\textsuperscript{2,3}, phonon scattering\textsuperscript{4} as well as the electron-electron interactions\textsuperscript{5} with in-situ electrical measurement, we mapped out ways to get around the major road-blocks to higher mobility graphene devices\textsuperscript{6} and, in some cases, the possibility to engineer new functionalities into graphene using specific types of impurity\textsuperscript{7}. Work performed while the author was at the University of Maryland, College Park
\textsuperscript{5} C. Jang et al., “Tuning the Effective Fine Structure Constant in Graphene”, PRL. 101, 146805 (2008)

16a-D4 Tunable Superconductor-Insulator Transition in tin-doped Graphene
A. Allain\textsuperscript{a}, Z. Han\textsuperscript{a}, V. Bouchiat\textsuperscript{a}, *Neel Institute, CNRS, 25 rue des Martyrs, 38042 Grenoble, France
Over the past twenty years, the superconductor-insulator transition has been studied in a variety of systems, including thin films of Be, Bi, InO\textsubscript{x} and high-Tc superconductors. The parameters used to drive the transition can be film thickness, magnetic field, or, in some recent studies, the electric field\textsuperscript{1,2}. However, this subject remains controversial, as none of the existing theories (namely, the fermionic and the bosonic scenario) accounts for the whole corpus of experiments. Here we report measurements of superconductor-insulator transition in a new kind of device: tin-doped CVD graphene\textsuperscript{3}. Bare CVD graphene exhibits insulating behavior at low temperatures. On the other hand, after Tin deposition, it experiences a Kosterlitz-Thouless transition towards a 2D superconducting state which critical temperature can be gate tuned. We show that upon changes in carrier density ($\pm7.10^{12}$cm\textsuperscript{-2}) and at intermediate magnetic fields, a transition from a superconducting to a truly insulating state can be induced. A phase diagram of the system can thus be inferred, and compared to the previously reported ones. This
hybrid system appears to be an original platform to investigate the current understanding of the physics of the superconductor-insulator quantum phase transition.


16a-D5 Magnetoexciton Superfluidity in Graphene-Dielectric-Graphene Structures

D. V. Fil*, A. A. Pikalov*, “Institute for Single Crystals, National Academy of Sciences of Ukraine, Kharkov, Ukraine

Quantum Hall bilayers with the total filling factor $\nu_T = 1$ may demonstrate superfluidity of spatially indirect excitons that reveals itself in a non-dissipative flow of opposite electrical currents in the layers. In this report we consider the effect of magnetoexciton superfluidity with reference to bilayer graphene structures. We show that in such structures an imbalance of filling factors of the layers is required for the realization of magnetoexciton superfluidity. We analyze the structures “graphene-dielectric-graphene” and “graphene-dielectric-graphene-substrate” and compute the critical (maximum) distance $d_c$, the critical current and the temperature of the Kosterlits-Thouless transition. It is found that the magnetoexciton superfluidity in graphene systems can be realized at rather small magnetic field $B$ and rather large interlayer distances $d$. In particular, in a pure graphene-dielectric-graphene sandwich with $d = 20$ nm and the dielectric constant $\varepsilon = 4$ the critical temperature $T_c \approx 5$ K can be reached at $B \approx 0.8$ T. The effect of reduction of $d_c$ and $T_c$ caused by the interaction with impurities is evaluated. Stationary waves excited by a point defect in a superfluid magnetoexciton gas in bilayers are studied. An observation of such waves for the counterflow currents larger than critical ones can be considered as a hallmark of superfluid transition. It is shown that at small $d$ the stationary wave pattern is similar to one for superfluid weakly non-ideal Bose gases, while at $d$ close to $d_c$ an additional family of waves located inside the Mach cone emerges.
Session 16a-E: Novel Devices and Applications

Chair: Hu-Jong Lee
Tuesday August 16, 14:00 – 15:40
Room 305

16a-E1 Thermoacoustic devices
T. Biwa*, a Department of Mechanical Systems and Design, Tohoku University, Japan

Simplifying heat engine’s hardware design while maintaining the highest possible efficiency has been a longstanding desire since the 19th century. One way to achieve this is to eliminate solid pistons from heat engines. Thermoacoustic devices use acoustic gas oscillations in place of pistons and execute mutual energy conversion between work flow and heat flow through the heat exchange between the gas and the channel walls. Work flow is equivalent to the acoustic intensity used in acoustics. Heat flow, which is absent in adiabatic waves in free space, is the energy flow associated with the entropy oscillation of the gas. Understanding of the acoustic field is necessary to control the resulting energy flows in thermoacoustic devices. We will present from experimental point of view the physical mechanism of a pulse tube refrigerator that is one of the traveling wave thermoacoustic heat engines. Measurements of pressure and velocity oscillations show that pulse tube refrigerator controls the phase difference between them to enhance heat flow through the regenerator. Experiments also show the pulse tube design that can recover the work flow emitted from the regenerator for a better efficiency.

16a-E2 Quartz tuning fork as a multipurpose tool for low temperature research - recent development
L. Skrbek*, a Faculty of Mathematics and Physics, Charles University, Ke Karlovu 3, 121 16 Prague, Czech Republic

Quartz tuning forks (QTFs) are a recent addition to the family of oscillating structures that have been widely used as tools in cryogenic fluid dynamics and in quantum fluids research since the discovery of superfluidity. These cheap, highly sensitive, robust and easy to install piezoelectric oscillators can be used as multipurpose cryogenic tools, via their ability to probe the flow of surrounding cryogenic helium. QTFs can be used as secondary thermometers, pressuremeters, viscometers, turbulence and cavitation generators and detectors, as well as flowmeters in various cryogenic applications in helium gas, normal liquid 3He and He I, in superfluid He II, 3He-4He mixtures as well as in superfluid 3He phases at submillikelvin temperatures (custom-built QTF arrays can be used to visualize quantum turbulence here). Only two shielded wires are needed to drive and readout the QTFs; simple electronic schemes allow detection of their resonant response both in classical and quantum fluids over up to eight orders of magnitude of the driving force. No magnetic field (to which they are highly insensitive) is required to drive QTFs; both the fundamental resonance and overtones can be excited and used for measurements. We discuss recent investigations of acoustic emission by QTFs that, besides being an interesting subject of study in its own right, in practice represents a limiting factor (together with the nuisance damping due to material properties of QTFs) for their sensitivity, especially for their ultra-low temperature applications.

16a-E3 Developments of Multi-Extreme Terahertz ESR System at Low Temperature
H. Ohta*, a S. Okubo*, a E. Ohmichib, T. Sakurai*, a Molecular Photoscience Research Center, Kobe University, Kobe, Japan
b Graduate School of Science, Kobe University, Kobe, Japan c Center for Supports to Research and Education Activities, Kobe University, Kobe, Japan

Recent developments of multi-extreme terahertz ESR in Kobe will be presented. Our system covers the frequency region between 0.03 and 7 THz and the temperature region between 1.8 and 300 K.1 This system can be combined with multi-extreme conditions such as the pulsed magnetic field up to 55 T2 and the high pressure up to 1.4 GPa using the transmission type piston cylinder pressure cell.3 As an example, terahertz ESR results of multiferroic material CuO at low temperature will be shown. Finally another development of a highly-sensitive micro-cantilever terahertz ESR system at low temperature using a torque method will be also discussed.4

16a-E4  New Generation of Cryogen Free Superconducting Magnets for Neutron Scattering Experiments
O. Kirichek*, †ISIS Facility, STFC, Rutherford Appleton Laboratory, Harwell, Didcot, UK

Recent advances in superconducting technology and cryocooler refrigeration have resulted in a new generation of superconducting magnets for beam applications. These magnets have outstanding parameters such as high homogeneity and stability at highest magnetic fields possible, a reasonably small stray field, low neutron scattering background and big sample exposure to neutron detectors. At the same time the pulse tube refrigeration technology provides a complete re-condensing regime which allows to minimise the requirements for cryogens without introducing additional noise and mechanical vibrations. The magnets can be used with dilution refrigerator insert which expands the temperature range from 30mK to 300K. Here we are going to present design, test results and the operational data of the 14T magnet for neutron diffraction and the 9T magnet for neutron spectroscopy developed by Oxford Instruments in collaboration with ISIS neutron source. First scientific results obtained in neutron scattering experiments with these magnets are also going to be discussed.

16a-E5  A 630kVA/10.5kV superconductor substation
Xiao Liye*,†, Dai Shaotao*,†, Lin Liangzhen*,†.  *Key Laboratory of Applied Superconductivity, Chinese Academy of Sciences, Beijing 100190. †Institute of Electrical Engineering, Chinese Academy of Sciences, Beijing 100190

A 630kVA/10.5kV superconductor substation Located in the city of Baiyin in the Gansu province of China is built by the Institute of Electrical Engineering, China Academy of Science (IEE CAS). The substation includes the following systems: a 10.5kV/1.5kA three-phase high temperature superconducting (HTS) fault current limiter (FCL), a 1MJ/0.5MVA superconducting magnetic energy storage (SMES), a 630kVA, 10.5kV/0.4kV HTS power transformer and a 75 m long 1.5kA HTS power cable system, all of which were developed by IEE CAS. The Baiyin substation began operation in February 2011, and is now supplying higher quality, highly reliable electricity with higher efficiency to customers. The Baiyin superconductor substation is one of the most ambitious superconductor projects undertaken to date anywhere in the world. As China’s electricity needs continue to increase, these solutions will be essential to maintain a high level of efficiency and reliability for our homes and businesses.
Session 16P-A:
A7 Helium Surface and Interfaces
Tuesday August 16, 16:00 – 18:00
Exhibition Hall 1

16P-A001 Oscillation Spectra of a Crystal 4He Facet and Its Destruction with Generating Crystallization Waves
S.N. Burnistov\textsuperscript{a, b}, aKurchatov Institute, Moscow 123182, Russia
The wavelike processes of crystallization and melting or crystallization waves are well known to exist at the 4He crystal surface in the rough state. Much less is known about a possibility for existing any crystallization waves at the 4He crystal surface in the smooth well-faceted state below the roughening transition temperature. To meet the lack, we report here the spectrum of facet crystallization waves and its dependence upon the wavelength, perturbation amplitude, and the number of possible facet steps distributed somehow over the wavelength. The continuous generation of crystallization waves will result both in the destruction of a crystal faceting and in the transition to the rough state of a crystal facet. All the distinctive features of facet crystallization waves from conventional waves at the rough surface result from a known cusplike singularity in the angle dependence for the surface tension of smooth crystal facets, which displays itself as a divergent surface stiffness of the vicinal crystal surfaces tilted at small angles.

16P-A002 Neutron Reflection from the Surface of a Liquid 3He–4He mixture
O. Kirichek\textsuperscript{a}, N.D. Vasilyev\textsuperscript{b}, T.R. Charlton\textsuperscript{c}, C.J. Kinane\textsuperscript{d}, R.M. Daglish\textsuperscript{d}, A. Ganshin\textsuperscript{e}, S. Langridge\textsuperscript{f}, P.V.E. McClintock\textsuperscript{g}, aISIS, STFC Rutherford Appleton Laboratory, Harwell Science and Innovation Campus, Didcot, UK
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We have investigated the surface properties of liquid 3He–4He mixtures by small-angle neutron reflection for temperatures in the range 80 < T < 2200 mK. Comparable results were obtained for the two samples studied: commercial helium with \( \sim 0.3 \) ppm of 3He, and stronger mixture containing 0.5\% 3He. In each case, we compare the neutron intensity for different temperatures, and fit a model that describes the collected data. We find that the data are consistent with there being a diffusive 3He layer of a few hundred Å thickness on the bulk 4He liquid surface. Even at high temperatures (\( \sim 2K \)) there is an increased concentration of 3He atoms near the surface. The distribution of 3He with respect to distance from the surface is not strongly temperature-dependent. At low temperatures the neutron absorption increases significantly, which might be an indication of the formation of Andreev states. The fact that the shapes of the reflectivity curves do not change very much with temperature, suggests that the additional 3He layer is very thin \( \sim 10Å \), which agrees well with the concept of Andreev states. We comment that neutron reflectometry has opened up new opportunities in the study of surfaces and interfaces of quantum fluids and solids.

16P-A003 Bulk and Surface Excitations of He II at Interfaces
I.V. Tanatarov\textsuperscript{a}, I.N. Adamenko\textsuperscript{b}, K.E. Nemenchko\textsuperscript{b}, A.F.G. Wyatt\textsuperscript{c}, aNational Science Center “Kharkov Institute of Physics and Technology”, Kharkov, Ukraine
\textsuperscript{b}Karazin Kharkov National University, Kharkov, Ukraine
\textsuperscript{c}School of Physics, University of Exeter, Exeter, UK
We solve the problem of superfluid helium excitations, phonons and rotons, interacting with solid surfaces. A simple hydrodynamic model enables us to describe both phonons and rotons in a consistent and unified way and to derive analytic expressions for the probabilities of transmission, reflection and mode changes of each quasiparticle incident on an interface with a solid; the dispersion curve of the medium acts as the only “input parameter”. Dependence on the energy of the excitations and their angle to the interface, are analysed; backward reflection and refraction for the rotons with negative dispersion are discussed. In the frame of the same approach, we reconstruct the dispersion relation of the surface excitations of superfluid helium, ripplons, from the dispersion relation of its bulk excitations. This approach allows for analytic reconstruction in terms of polynomial roots, for the polynomial approximation of the bulk excitations’ dispersion curve of any given precision. We derive the algebraic equation for the ripplon dispersion relation \( \omega(k) \) and obtain its series expansion both at small wave vectors \( k \) and close to the roton minimum. It is shown that the ripplon dispersion curve ends at the energy of the roton minimum with zero derivative. A new unusual ripplon branch is found above the roton minimum at 2.6Å\(^{-1}\), close to the instability point of the bulk spectrum, and is investigated.

16P-A004 Adsorption of 4He\(_N\) and 4He\(_N\)\_3He clusters on cesium
P. Stipanović\textsuperscript{a}, L. Vranješ Markić\textsuperscript{a}, I. Bešlić\textsuperscript{a}, T. Martinic\textsuperscript{a}, aUniversity of Split, Faculty of Science, Croatia
The ground state properties of helium mixed clusters 4He\(_N\) and 4He\(_N\)\_3He, for \( N \leq 40 \) adsorbed on the surface of cesium are studied using variational and diffusion Monte Carlo calculations. Binding properties are determined using two different He-Cs interaction potentials. For the smallest clusters, cluster self-binding is stronger than in two or three dimensions. For \( N > 10 \) self-binding in three dimensions is stronger for both types of He-Cs interaction potential. Results are compared to recent density functional calculations. The emergence of edge states of 3He, localized along the contact line of 4He cluster with the cesium surface, is studied. First indication that 3He atom prefers to be close to the contact line appears already for 4He\(_1\)\_3He cluster.

16P-A005 Self-organized Criticality in Quantum Growth Regime of 4He Crystals in Aerogel
R. Nomura\textsuperscript{a}, H. Matsuda\textsuperscript{a}, R. Masumoto\textsuperscript{a}, K. Ueno\textsuperscript{a}, Y.
The way of the crystallization of \(^4\)He in aerogel shows a dynamical phase transition due to the competition between thermal fluctuation and disorder: crystals grow via creep at high temperatures and via avalanche at low temperatures. In the creep region, crystal growth is faster at higher temperature and becomes slower with cooling and is consistent with the expectation that interface advances via a thermal activation in the disordered media. In the avalanche region, it slightly increases with cooling and saturates at lower temperatures. This temperature independent growth is presumably the result of the macroscopic quantum tunneling through the disorder. We measured the avalanche size distribution and found that the number of smaller size avalanches is larger. The size distribution follows a power law in a length scale smaller than a cutoff size, indicating that system is in a self-organized critical state. This is the first observation of SOC in the quantum growth regime. The exponent of the power law has a weak temperature dependence while the cutoff size becomes larger with cooling.

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16P-A006  Vibronic spectra of atomic bubbles in liquid and solid \(^4\)He

V. Lebedev\(^a\), P. Moroshkin\(^a\), A. Weis\(^a\), \(^a\)Department of Physics, University of Fribourg, Fribourg, Switzerland

Foreign atoms isolated in liquid and solid helium cryomatrices form nanometer-sized cavities known as atomic bubbles\(^1\). An electronic transition in the atom is followed by a change in the bubble size that induces interface vibrations that are coupled to matrix phonons. We have investigated experimentally and theoretically the vibronic spectra of atomic bubbles formed by Cu, Au and Cs atoms in solid, normal fluid and superfluid \(^3\)He matrices and have observed two regimes of bubble-phonon interactions. The excitation of the dopant’s outer-shell electrons results in quasiclassical bubble dynamics, i.e. by the creation of a large number of lattice phonons. The spectrum of such vibronic transition is several nanometers broad and strongly blueshifted. Conversely, the excitation of inner-shell electrons creates only a small number of phonons in the quantum regime. The spectral profile in this case consists of a narrow unshifted zero-phonon line (ZPL) and a redshifted phonon wing (PW). The shift and the width of PW are larger in solid helium than in liquid, reflecting the differences of the phonon spectra in the two phases. Our spectroscopic observations are in agreement with predictions of a hydrodynamic model that treats helium as a continuous liquid. Taking the matrix compressibility into account results in a strong bubble-phonon coupling that leads to a very fast damping of the bubble vibrations.

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16P-A007  Spin waves in the B-phase of superfluid Helium-3

O.W.B. Benningshof\(^a\), R. Jochensen\(^a\), Kamerlingh Onnes Laboratory, Leiden University, P.O. Box 9504, 2300 RA Leiden, the Netherlands

The experiments of the superfluid B-phase of Helium-3 in a cylindrical container of 1 mm in diameter are presented. Characteristic for this dimension is that the preferred orientation of the order parameter of the B-phase will be locally varying, resulting in a curved configuration into the cell. Exclusive in our case, as it is performed at low pressures and low magnetic fields, we could make a texture (a certain configuration in which the preferred orientation of the superfluid is bent over the sample), which was meta-stable and unchanged for the whole pressure and temperature ranges. As this texture can be considered as a potential to sustain spin waves, we had the unique opportunity to study them for several pressures in nearly the same texture. A positive effect is that this potential (texture) is close to a quadratic one, creating essentially a two dimensional system, in which the intensities of all spin wave modes should be equal. This provides us the perfect condition to observe the increase of the number of spin wave modes by increasing the pressure. Finally we were able to make a textural transition to the in advance expected texture, from which we conclude that the meta-stable texture could be realized if the growing speed is sufficiently slow.

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16P-A008  On Intrinsic Angular Momentum due to Edge Mass Current for Superfluid \(^3\)He A-Phase

Y. Tsutsumi\(^a\), T. Mizushima\(^a\), M. Ichioka\(^a\), K. Machida\(^a\), \(^a\)Department of Physics, Okayama University, Okayama, Japan

Majorana fermions and edge mass current exist in the superfluid \(^3\)He A-phase, which is a topological superfluid phase. When the superfluid \(^3\)He A-phase is confined in a thin slab, the Andreev bound state appears at the edge of the slab. The bound quasiparticles behave as Majorana fermions and they are accompanied with mass current along the edge. We calculate the edge mass current by the quasiclassical Eilenberger theory quantitatively. Numerical calculations are performed in finite temperatures, and an analytical calculation of Riccati equations is carried out at a low temperature limit \(T \to 0\). Then, the so-called intrinsic angular momentum by the edge mass current is evaluated. Contributions to the angular momentum can be divided into those from the bound state and from the continuum state above the superfluid gap in a bulk. As a result, the angular momentum is found to be of the order of \(N\), where \(N\) is the total number of \(^3\)He atoms in the slab. Therefore, the angular momentum by the edge mass current relates to intrinsic angular momentum.

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16P-A009  Odd-Frequency Cooper Pair Cooers near the Surfaces of Superfluid \(^3\)He-B

S. Higashitani\(^a\), S. Matsuo\(^b\), Y. Nagato\(^b\), K. Naga\(^b\), \(^a\)Graduate School of Integrated Arts and Sciences, Hiroshima
There can in general coexist even-frequency and odd-frequency Cooper pairs near the surfaces of superfluids in superfluids owing to broken translational symmetry. We report our recent theoretical study on the odd-frequency pair amplitudes near the surfaces of superfluid $^3$He-B. To calculate the odd-frequency pair amplitudes, we have applied the quasiclassical Green’s function theory taking into account the effect of diffusive scattering at the surface. There appear odd-frequency Cooper pairs with a variety of orbital symmetries even in the diffusive scattering limit. The energy dependence of the odd-frequency pair amplitude below the gap is quite similar to the local density of states in superfluids even in the diffusive scattering limit. The energy data of $^3$He are obtained by the realization that a non-trivial topological invariant can be defined in the bulk. This invariant ensures the existence of gapless states bound at the edge or surface of $^3$He-B. It has been revealed that gapless edge states which behave as Majorana fermions give rise to anisotropic spin susceptibility when the applied field is sufficiently weak. Here, we study the thermodynamics and edge states of the topological superfluid $^3$He confined in a slab geometry, based on both the quasiclassical Eilenberger theory and Bogoliubov-de Gennes theory. The former provides a qualitative theory for $^3$He, while the latter enables us to understand a full quantum nature of low-energy quasiparticles.

In this work, we show the quantitative phase diagram of the superfluid $^3$He in a plane of the thickness and the magnetic field. The first- and second-order phase transitions between A and B phases are induced by changing the thickness and applying magnetic fields, where their edge states exhibit completely different characteristics. Based on the complete phase diagram, we discuss the spectrum of low-energy quasiparticles bound at the edge and magnetic anisotropy under the rotation of strong magnetic fields. We also clarify the role of magnetic dipole-dipole interaction on magnetic anisotropy.


16P-A011 Magnetic Field Induced A-B Phase Transition and Edge States of Superfluid $^3$He Confined in a Slab Geometry
T. Mizushima$^a$, K. Machida$^a$, $^a$Department of Physics, Okayama University, Okayama 700-8530, Japan
Recent interest in the superfluid $^3$He-B has been stimulated by the realization that a non-trivial topological invariant can be defined in the bulk. This invariant ensures the existence of gapless states bound at the edge or surface of $^3$He-B. It has been revealed that gapless edge states which behave as Majorana fermions give rise to anisotropic spin susceptibility when the applied field is sufficiently weak. Here, we study the thermodynamics and edge states of the topological superfluid $^3$He confined in a slab geometry, based on both the quasiclassical Eilenberger theory and Bogoliubov-de Gennes theory. The former provides a quantitative theory for $^3$He, while the latter enables us to understand a full quantum nature of low-energy quasiparticles. In this work, we show the quantitative phase diagram of the superfluid $^3$He in a plane of the thickness and the magnetic field. The first- and second-order phase transitions between A and B phases are induced by changing the thickness and applying magnetic fields, where their edge states exhibit completely different characteristics. Based on the complete phase diagram, we discuss the spectrum of low-energy quasiparticles bound at the edge and magnetic anisotropy under the rotation of strong magnetic fields. We also clarify the role of magnetic dipole-dipole interaction on magnetic anisotropy.

We report recent results of the experimental study of capillary turbulence decay on the surface of quantum liquids: normal and superfluid 4He and liquid hydrogen. In our experiments the turbulent cascade of capillary waves was damped at high frequencies due to viscous dissipation. Turbulent spectrum at high-frequency dissipative regime was described by exponential decay function which was in accordance with the theoretical predictions. Moreover, for the first time two different regimes of the turbulent wave cascade decay were observed depending on the type of pumping excitation. When the surface was excited by broad-band noise pumping, a characteristic frequency \( f_d \) of the cascade exponential decay \( \sim \exp(-f/f_d) \) was close to the high-frequency edge of the inertial range. Otherwise, in the case of harmonic pumping, the characteristic frequency \( f_d \) was close to the low-frequency pumping frequency. Thus, the spectrum decay was more dramatic in the case of harmonic pumping than in the case of broad-band pumping. This difference in the values of \( f_d \) can be qualitatively explained in frames of wave turbulence theory by taking into account a non-locality of 3-wave interactions in the case of harmonic pumping.


16P-A014 Point-Contact Transport Properties of Classical Electrons on Helium

D.G. Rees\textsuperscript{a}, I. Kuroda\textsuperscript{a}, C.A. Marrache-Kikuchi\textsuperscript{a}, M. Hofer\textsuperscript{b}, P. Leiderer\textsuperscript{b}, H. Totsuji\textsuperscript{c}, K. Konô\textsuperscript{c}, \textsuperscript{a}Low Temperature Physics Laboratory, RIKEN, Wako-shi, Japan \textsuperscript{b}Faculty of Physics, University of Konstanz, Konstanz, Germany \textsuperscript{c}Graduate School of Natural Science and Technology, Okayama University, Okayama, Japan

Electrons bound to the surface of liquid helium form an ideal two-dimensional electron system. The Coulomb interaction between electrons on the helium surface is essentially unscreened and, for typical surface densities \((\sim 10^9 \text{cm}^{-2})\), the electron system is nondegenerate. Here we present transport measurements of electrons on the surface of liquid helium in a microchannel containing a nanofabricated split-gate electrode, similar to those used in semiconductor quantum point-contact devices\textsuperscript{d}. We find that the split-gate voltage \((V_{gt})\) threshold of current flow depends on the electrostatic energy, and in turn density, of the electron system. As \(V_{gt}\) is swept positive, and the effective width of the constriction increases, the conductance increases in a step-wise manner. We attribute each conductance step to an increase in the number of electrons able to pass simultaneously through the constriction, due to the strong Coulomb interaction. Close to the threshold, single-electron transport is observed. Below 1 K, the electron system forms a Wigner crystal and evidence of more complex transport dynamics emerges.


16P-A015 4He clusters adsorbed on graphene

L. Vranješ Markić\textsuperscript{a}, I. Bešić\textsuperscript{d}, P. Stipanovič\textsuperscript{c}, R. E. Zillich\textsuperscript{b}, \textsuperscript{a}University of Split, Faculty of Science, Split, Croatia \textsuperscript{b}Institute for Theoretical Physics, Johannes Kepler Universität, Linz, Austria

We report the results of the study of 4He\(_N\) clusters adsorbed on one and both sides of a graphene sheet. Interactions of 4He clusters with graphene are modeled using an averaged helium-carbon potential that depends only on the distance to the graphene sheet, and a potential constructed as a sum of individual helium-carbon interactions. That way, we assess the effect of corrugation on the binding properties of helium clusters. All the calculations have been performed using quantum Monte Carlo methods. At zero temperature the ground-state properties of 4He\(_N\) for \(2 \leq N \leq 50\) have been determined using variational and diffusion Monte Carlo calculations. We find that clusters adsorbed on both sides of graphene are correlated. In addition, we observe the changes in the size of the clusters. For selected larger clusters, calculations have been performed also at finite temperature by path integral Monte Carlo simulations.

16P-A016 Investigation of surface state electrons on He films at high densities

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When electrons are put on thin liquid helium films they form a nearly ideal two-dimensional coulomb systems. Due to the intrinsic stability of the films higher electron densities than on bulk helium can be reached. By increasing the density we investigate the whole phase diagram of these systems including the classical electron gas, the Wigner crystal state and the degenerate Fermi gas\textsuperscript{e}. In the experiment we focus on the transport of the electrons between two metal segments, which are used as a substrate for the helium film. The electron density on the segments is determined by measuring the density-dependent He film thickness using surface plasmon resonance. With a complementary technique we measure the displaced charges in the metal substrate, when the electron density on the liquid helium film is changing. In order to improve on the stability and the maximum density of the electron systems on the film we use in addition bare metal substrates also metal segments covered by thin polymer films.


16P-A017 Effect of rough walls on transport in mesoscopic 3He films

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We discuss the mass transport of a degenerate Fermi liquid $^3$He film over a rough surface, and the film momentum relaxation time, in the framework of theoretical predictions. In the mesoscopic regime, the anomalous temperature dependence of the relaxation time is explained in terms of the interplay between elastic boundary scattering and inelastic quasiparticle-quasiparticle scattering within the film. We exploit a quasiclassical treatment of quantum size effects in the film in which surface roughness, whose power spectrum is experimentally determined, is mapped into an effective disorder potential within a film of uniform thickness. Confirmation is provided by the introduction of scattering centres within the film. We model further studies on $^3$He confined in nanofluidic sample chambers with lithographically defined surface roughness. The improved understanding of surface roughness scattering suggests routes to improve the conductivity of thin metallic films.

16P-A018 Linewidth Broadening in Edge-magnetoplasmon Resonance of Helium Surface State Electrons

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Edge-magnetoplasmon (EMP) is an electron density wave, which occurs in bounded two-dimensional electron gas (2DEG) exposed in a perpendicular magnetic field. EMP propagates within a narrow strip near the edge, while density in the bulk is uniform. We employed EMP resonance technique to study magnetotransport properties of 2DEG where edge states play an important role. We measured EMP frequencies and line widths of 2DES on liquid helium surface under various lateral confinement potentials. The experimental results show that as the lateral confinement potential is reduced measured EMP line width takes minimum at a certain strength of confinement potential and broad signal was obtained on further potential reduction. This broadening behavior is absolutely unexpected from the existing theories of conventional EMP. We consider that it is an oscillation mode transition which is responsible for the line width broadening. The line width behavior in the strong confinement region is reasonably explained by conventional EMP, while the broad signals in the weak confinement region is not. We will show our precise experimental data and discuss the origin of the line broadenings.

16P-A019 Superfluid Phases of $^3$He Confined in a Single 0.6 Micron Slab

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We present our NMR study of $p$-wave superfluid $^3$He confined in a well-characterised restricted geometry. The confinement is provided by a nanofabricated cell with a 0.6 micron thick cavity. NMR is used both to identify the phases and make quantitative measurements of the suppression and distortion of the order parameter. The degree of confinement is continuously tuned with pressure and surface quasiparticle scattering is modified by preplating the walls of the cell with $^4$He. Confinement on a length scale comparable to the superfluid coherence length suppresses the order parameter and alters the relative stability of different superfluid phases. We observe a profound effect of confinement on the phase diagram. The A phase ($\Delta(p) = \Delta[\hat{p}_x + i\hat{p}_y][\uparrow \uparrow + \downarrow \downarrow]$) stabilises in a wide range of the phase diagram below the superfluid transition, even at low pressure, and the B phase with a planar distortion ($\Delta(p) = \Delta[\hat{p}_x + i\hat{p}_y][\uparrow \uparrow + \downarrow \downarrow]$) is observed at low temperature and higher pressure where the coherence length is shorter. We find evidence for spatial variations of the order parameter across the slab in the B phase. These experiments open the way for studies of many surface and size phenomena in superfluid $^3$He.

16P-A020 Majorana Fermions Bound at Vortices and Surface of Superfluid $^3$He

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A Majorana fermion is a relativistic particle equivalent to its anti-particle, which was originally proposed by Ettore Majorana in 1937. Recently, it has been predicted that it hides in various materials, such as vortices and surface of superfluid $^3$He. The remarkable fact that the creation operators of Majorana zero modes are self-Hermitian implies that their host vortices obey the non-abelian statistics. Here, we investigate the Majorana fermions bound at (i) half-quantum vortices (HQV’s) and (ii) surface Andreev bound states (SABS’s) in superfluid $^3$He A- and B-phases, which are expected to involve Majorana fermions. Here, it is demonstrated that although the HQV is expected to appear in rotating $^3$He A-phase confined to a slab, the strong coupling effect which becomes crucial in high pressure regime makes the HQV unstable. Then, we reveal the nontrivial structure of low-lying quasiparticles in phase vortex and coreless vortex which are energetically competitive to the HQV in A-phase. We also discuss the SABS in A- and B-phases, where the former (latter) gives rise to spontaneous mass (spin) current along the surface. In particular, based on the quasiclassical Eilenberger and full-quantum Bogoliubov-de Gennes theories, we demonstrate that the Majorana nature of the SABS in B-phase is sensitive to the dipole interaction and the orientation of magnetic field.

16P-A021 A New Rightful Gapless Dispersion Surfaces instead of the Con-
ventional Erroneous Gappy Dispersion Ones in the Dynamical Theory of X-ray Diffraction

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By use of some roughly indefinable approximate relations in almost all previous works, the hyperbolic dispersion surfaces of the central proper quadrics have been erroneously derived from reduction of the degree of the bi-quadratic equation that has been defined by the existence of the solutions in the homogeneous simultaneous linear propagation equation with two unknowns. Moreover, neglecting the high symmetry of the hyperbola, its both branches have been substituted as the asymmetric surfaces composed of a pair of a branch of the hyperbola and a vertex of the ellipse, without the presentation of reasonable evidence. Based upon the same dispersion surfaces equation, a new original equation with two unknowns.

The report is a part of the extension of our previous works1-4 of our previous works5,6.

1 T. Nakajima, J. Mod. Phys., 146-153 (2011)
2 T. Nakajima, ECM26 held at Darmstadt, Germany
3 T. Nakajima, XTOP2010 held at Warwick, UK
4 T. Nakajima, NACC-1 held at Casablanca, Morocco
6 T. Nakajima, ibidem 153 77-96 (2008)

16P-A022 Operation of Attocube Motors at Low Temperature

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Attocube linear and rotary steppers offer an simple way to realize motion at low temperatures. Complications arise from the fact that these stick-slip motors depend on friction and intrinsically generate heat when moving, that the moving part of the motor is in poor thermal contact, and that the step size is dependent on temperature. We will present a study of these effects over the temperature range from 40 mK to 40 K.

Session 16P-B:

B4 Pairing Symmetry in Fe-based Superconductivity

B5 Magnetism versus Superconductivity

Tuesday August 16, 16:00 – 18:00

Exhibition Hall 1
The discovery of superconductivity in LaFeAsO$_{1-x}$F$_x$ at $T_c = 26K$, followed by that in ReFeAsO$_{1-x}$F$_x$ (Re: Ce, Pr, Nd, Sm) with $T_c$ as high as 55K, has attracted much attention. We have performed As nuclear quadrupole resonance (NQR) measurements on LaFeAsO$_{1-x}$F$_x$ to elucidate its superconducting gap structure and mechanism of the cooper pair forming. Here, we report a systematic study by $^{75}$As nuclear quadrupole resonance in LaFeAsO$_{1-x}$F$_x$. The highest $T_c = 27K$ is realized for $x = 0.06$ with the strongest antiferromagnetic spin fluctuation (ASF) among the family. Upon increasing doping level from $x = 0.06$, the ASF decreases, and so does $T_c$. In the optimally doped compound, the spin-lattice relaxation rate ($1/\tau$) below $T_c$ decreases exponentially down to 0.13 $T_c$, which unambiguously indicates that the superconducting gaps are fully-opened. The temperature variation of $1/\tau$ below $T_c$ is rendered gradually with increasing $x$ to show a seemingly $T^3$ behavior for $x = 0.10$ and 0.15, which can be accounted for by the impurity scattering.


16P-B004 Impurity Effects on the Superconducting Transition Temperatures of Fe pnictides and Superconducting Symmetry of the Order Parameter
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We focus on effects of nonmagnetic impurities on the superconducting transition temperatures $T_c$ and point out, using various experimental evidences obtained for LnFe$_{1-y}$M$_y$AsO$_{0.89-x}$F$_{0.11+x}$ (Ln=La, and Nd; M=Co, Ni, Mn, Ru) systems, that the sign reversing of the order parameters $\Delta$ pointed out theoretically at the early stage of the study does not exist between disconnected Fermi surfaces around $\Gamma$ and $M$ points. We also show that other kinds of the experimental results, which have been believed as the evidences for the sign reversing, can be understood well without the sign reversing. These results imply that a new pairing mechanism, which is different from the spin-fluctuation exchange and possibly related to the orbital degrees of freedom, should be considered seriously.

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2 present address: Dept. of Appl. Phys., Graduate Scool of Engineering, Tohoku University, Sendai 980-8578, Japan.

16P-B005 Metamagnetism, superconducting properties, and intrinsic vortex pinning in 1111 Fe arsenide single crystals probed by torque magnetometry
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Torque magnetometry in the SmFeAsO$_{1-x}$F$_x$ system, for $x = 0$ and 0.1, reveals a sharp and anisotropic metamagnetic transition which is clearly associated with the re-orientation of the Sm moments. Although the Neel temperature is $\sim 5K$, one needs fields in the order of 35 to 40 T to re-orient the associated moments, indicating very anisotropic exchange constants. The transport is affected by the transition, indicating a coupling between the FeAs and SmO layers. We also developed a method to separate the magnetic and the superconducting components which are superimposed onto the reversible component of the angular dependent torque $\tau_{rev}(\theta, H, T)$ in underdoped LaFeAsO$_{1-x}$F$_x$. By using the Kogan formalism we extract a strong $H-$ dependence for the superconducting anisotropy $\gamma$, and a power law dependence, for the penetration depth. At lower $T_s$, one observes the emergence of sharp peaks in $\tau_{rev}(\theta, H, T)$ for $H$ oriented along an angle $\theta_s$ close to the superconducting planes and which are consistent with predictions for the intrinsic pinning of vortices by a layered crystallographic structure as well as a series of smaller structures at higher angles suggesting transitions among kinked vortex structures.

16P-B006 Study of Magnetic Excitation Spectra of Several Fe-pnictide Systems
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Magnetic excitation spectra $\chi''(Q, \Delta E)$ have been measured for several Fe-pnictides including Ca-Fe-Pt-As system ($T_c \sim 30$ K), one of new superconducting systems with FeAs planes. For the system, data were taken with the neutron spectrometer 4SEASONS at J-PARC for a large crystal. Although $\chi''(Q, \Delta E)$ are enhanced with decreasing temperature $T$ through $T_c$ in the broad energy ($\Delta E$) region around $\sim 12.5$ meV, it is not significant as compared with the sharp and strong enhancement in the $Q$ and $\Delta E$ spaces predicted for the $s_\pm$ symmetry, indicating that the observed shape of $\chi''(Q, \Delta E)$ is intrinsic, and difficult to explain, unless the $s_{\pm}$ symmetry is introduced.

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2 present address: Department of Applied Physics, Graduate Scool of Engineering, Tohoku University, Sendai 980-8578, Japan.
Hall effect is investigated in detail for iron-chalcogenide superconductor thin films. In the parent compound, FeTe, Hall resistivity is linear to $H$, and Hall coefficient ($RH$) exhibits a sign reversal from positive to negative associated with antiferromagnetic (AFM) phase transition. Mobility analysis based on a simple two-band Drude model reveals that the hole mobility is suppressed almost to zero in non-superconducting FeTe, while that of superconducting FeTe remains finite, which suggests the importance of itinerancy of holes to superconductivity [I. Tsukada et al., J. Phys. Soc. Jpn. 80, 023712 (2011)]. In FeSe$_{0.5}$Te$_{0.5}$, $RH$ value strongly depends on the lattice parameters of FeSe$_{0.5}$Te$_{0.5}$ at high temperature, indicating the strong correlation between band structure and charge transport in the normal state. At low temperature, nonlinearity of Hall resistivity to $H$ becomes remarkable, and much complicated interplay between electron- and hole-type carriers is expected. In particular, magnitude of $RH$ is significantly scattered at low temperature showing almost no obvious correlations with $Tc$, indicating that charge carriers that belong to different bands may contribute differently to the electrical transport when the superconducting state is approaching.

16P-B010  Phosphor induced heavy hole-doping in BaFe$_2$(As$_{1-x}$P$_x$)$_2$ superconductor

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We have developed a distinct experimental method to study the Andreev reflection in uniquely designed nano-scale metal-superconductor junctions, and applied such a method to investigate a multi-band superconductor Fe$_{1+y}$Te$_{1-x}$Se$_2$. We report the observation of more than four superconducting (SC) gaps in Fe$_{1+y}$Te$_{1-x}$Se$_2$ from Andreev reflection spectra, along with negative differential conductance dips due to the pair breaking related to the largest SC gap. We propose that the observed number of SC gaps be related to the multiple disjoint Fermi surfaces. The evolution of the SC gaps is further investigated as a function of both temperature and magnetic field. For the largest SC gap, the Andreev reflection signal persists above bulk $Tc$, suggesting the possible existence of phase-incoherent Cooper pairs. We expect our experimental approach to be widely applicable for the study of various types of superconductors in future.
K. Suzuki, H. Usui, K. Kuroki. Department of Engineering Science, University of Electro-Communications, IST-TRIP, Tokyo, Japan. Department of Applied Physics and Chemistry, The University of Electro-Communications, Tokyo, Japan. Development of the spin fluctuation has been considered as one of the important features of iron-based superconductors. One of the interesting observations is its electron-hole asymmetry. Namely, when electrons are doped like in Ba(Fe₁₋ₓCoₓ)₂As₂, the magnetic peaks in the neutron scattering experiments tend to deviate from the commensurate (π, 0) to incommensurate positions toward (π, π) (in the unfolded BZ), while in the hole doped cases like KFe₂As₂ it deviates toward (0, 0)¹. In the present study, we first obtain a ten orbital model of BaFe₂As₂ and KFe₂As₂ from first principles calculation. We also obtain a five orbital model in the unfolded Brillouin zone, which can only be done approximately in 122 systems. We apply the random phase approximation to these models and obtain the spin susceptibility for various band fillings. The electron-hole asymmetry of the peak position of the spin fluctuations is nicely reproduced in the calculation, and its origin can be attributed to the different distribution of the orbital characters on the Fermi surface in electron and hole doped cases. We also discuss how these spin fluctuations affect the form of the superconducting gap.


16P-B012 Effective five band analysis on Tc vs. lattice structure correlation in iron pnictides
The discovery of superconductivity in the iron pnictides¹ and its Tc up to 55K² has given great impact to the field of condensed matter physics. From the early stage, much attention has been paid to the correlation between Ts and the lattice structure³. In the present study, we focus on the condition for optimizing superconductivity in the iron pnictides, varying hypothetically the lattice structure. Studying the band structure of the hypothetical lattice structure of LaFeAsO, the hole Fermi surface multiplicity is found to be maximized around the Fe-As-Fe bond angle regime where the arsenic atoms form a regular tetrahedron. Superconductivity is optimized within this three hole Fermi surface regime, thereby providing a natural explanation as to why Ts is optimized around the regular tetrahedron angle. Combining also the effect of varying the Fe-As bond length, we provide a guiding principle for obtaining high Ts.


16P-B013 Enhancement of Thermal Conductivity in the Superconducting State of Co-doped BaFe₂As₂
Y. Nakajima, Y. Kurosaki, T. Tamegai. Department of Applied Physics, the University of Tokyo, Tokyo, Japan. JST, Transformative Research-Project on Iron Pnictides (TRIP), Tokyo, Japan.
We report the thermal conductivity in Co-doped BaFe₂As₂ at under-, optimal-, and over-doping levels. We find the enhancement of the thermal conductivity divided by temperature κ/T in the superconducting state at all doping levels, which is strikingly similar to those in the strongly correlated superconductors, such as high-Tc cuprates¹ and heavy fermion systems². We also find that the enhancement of κ/T is strongly suppressed by applying magnetic fields. The analysis based on the vortex-scattering model, which can discriminate the quasi-particle contribution to the thermal transport from the phononic one, unveils that the enhancement of κ/T originates from the steep increase of the quasi-particle mean-free path possibly due to the reduction of the inelastic scattering in the superconducting state. We will also discuss the possibility of the emergence of nodes in gap structure at over-doping levels, which is suggested by the low-temperature thermal transport measurements along c-axis in this system³.


16P-B014 Effects of the order parameter symmetry on the vortex core structure in the iron pnictides
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Effects of the order parameter symmetry on the cutoff parameter ξₖ (determining from the magnetic field distribution) in the mixed state are investigated in framework of quasiclassical Eliashberg theory for isotropic s± and for s++ pairing symmetries of superconductors using computational methods. In s± pairing symmetry the gap function has opposite sign and equal absolute values of the electron and hole pockets of the Fermi surface and in s++ pairing symmetry the gap function has the same sign of the electron and hole pockets of the Fermi surfaces. The s++ pairing symmetry results in different effects of intraband (Γ₀) and interband (Γ₁) impurity scattering on ξₖ. It is found that ξ₂/ξ₁ decreases with the Γ₀ leading to values much less than those predicted by the analytical Ginzburg-Landau (AGL) theory for high Γ₀. At very high Γ₀ the interband scattering suppresses ξ₂/ξ₁ considerably less then the one in the whole field range making it flat. If Γ₀ and Γ₁ are small and equal then the ξ₂/ξ₁(B/B₂ₕ) dependence behaves like that of the AGL model and shows a minimum with value much more than that obtained for s++ superconductors. With high Γ₁ the dependence of ξ₂/ξ₁(B/B₂ₕ) resides above the AGL curve. Such behavior is quite different from that in s++ pairing symmetry where intraband and interband scattering rates act in a similar way and ξ₂/ξ₁ decreases monotonously with impurity scattering and resides below the AGL curve.

16P-B015 Cutoff parameter versus Ginzburg-Landau coherence length in...
the mixed state of high-$\kappa$ superconductors with impurities: quasiclassical approach

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The influence of impurities on the ratio of the cutoff parameter, $\xi_d$, and Ginzburg-Landau coherence length, $\xi_2$, in the mixed state of high-$\kappa$ s-wave superconductors is investigated in framework of quasiclassical non-local Eilenberger theory using computational methods. Quasiparticle scattering by impurities and lowering of the temperature reduce the value of $\xi_d$ to values much less than $\xi_2$. This is different from the prediction of the local Ginzburg-Landau theory where $\xi_2$ is scaled by $\xi_2$ and the ratio $\xi_2/\xi_2$ is not dependent on impurity scattering. It means that the nonlocal effects are important for the description of the vortex core even in the "dirty" limit. It can explain experimental muon spin resonance results in some low-temperature superconductors, where the ratio $\xi_d/\xi_2 < 1$ is observed in intermediate fields. Detailed comparison with the behavior of the order parameter coherence length $\xi_1$ is done. It is found that impurities influence by different way on $\xi_d$ and $\xi_1$. The curve $\xi_0/\xi_0(B/B_c2)$ shifts downward with increasing of impurity scattering rate while $\xi_1/\xi_2(B/B_c2)$ curve shifts upward in this case. It means the symmetry $\xi_1(B) \approx \xi_2(B)$ is broken in dirty superconductors.

16P-B016 Elastic Anomalies Associated with Structural and Superconducting transitions in Iron-based Superconductor Ba(Fe$_{1-x}$Co$_x$)$_2$As$_2$


Discovery of superconductivity in F-doped LaFeAsO compound causes an outpouring of experimental and theoretical studies of the materials containing Fe-As layers as a structural unit. BaFe$_2$As$_2$ shows a structural/magnetic phase transition at $T_S = 145$ K. By replacing Fe ion by Co, the structural/magnetic order is suppressed, and a superconducting phase comes out. By further Co doping, the phase transition is disappeared. We have measured the elastic constants $(C_{11} - C_{12})/2$, $C_{44}$, $C_{66}$ of this system. We have observed large elastic softening toward the structural transition in $C_{66}$ for under-doped samples. The anomaly in $C_{66}$ tends to disappear with increasing Co concentration for over-doped region. The amount of the anomaly correlates with the superconducting transition temperature $T_{SC}$. On the other hand, $(C_{11} - C_{12})/2$ and $C_{44}$ show no remarkable anomaly at $T_S$, but shows a small anomalies at $T_{SC}$. $C_{66}$ shows a large elastic anomaly associated with the superconducting transition for the optimum doped sample. These experimental facts will give relevant information on the coupling between the superconducting order parameter and the elastic strain, which will be given in the presentation.

16P-B017 A Multiband Model for SmFeAsO$_{1-x}$F$_x$

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A multi-band model within the BCS framework is proposed for the description of iron-based oxypnictide superconductor. s-wave paring symmetry and different doping values are considered. This model is used to describe some properties of oxypnictide SmFeAsO$_{1-x}$F$_x$ superconductor. A non-standard electron-phonon coupling of the corresponding Fe in-plane breathing mode is considered. The Fe isotope effect is evaluated as function of the coupling parameter as well as other relevant parameters of the model.

16P-B018 Optical properties of electron and hole-doped 122 iron-arsenic superconductors

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Superconductivity in the iron-arsenic compounds have various interesting aspects. One of the most distinguishing features of this family of superconductors is that a set of Fe 3d bands are crossing the Fermi Level and can participate in the forming of the Cooper pairs. Multiple superconducting gaps may exist in iron-arsenic superconductors. We present optical conductivity measurements on the electron-doped 122 system Ba(Fe$_{x-1}$Co$_x$)$_2$As$_2$ and hole-doped 122 system Ba$_{1-x}$K$_x$Fe$_2$As$_2$ single crystals. In both samples, a clear signature of the superconducting gap is observed when the temperature is below $T_c$, but a simple s-wave description fails in accounting for the low-frequency response. In the electron-doped sample Ba(Fe$_{x-1}$Co$_x$)$_2$As$_2$, the data and the model can be reconciled by introducing an additional Drude peak which accounts for the additional low energy absorption. In the hole-doped sample Ba$_{1-x}$K$_x$Fe$_2$As$_2$, the low-frequency optical response can be well described by introducing a second isotropic superconducting gap which is a strong evidence for the existence of multiple superconducting gaps in iron-arsenic superconductors.

16P-B019 Flux-Line Lattice State in FeAs-Based Superconductor (Ba,K)Fe$_2$As$_2$

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We have observed temperature and magnetic field de-
We have found that order to clarify the superconducting gap mechanism. We will also report the node in $\Delta_x$. This result is seemingly contradictory behavior, however, it is well interpreted by a two-gap model, $T$-linear behavior is clearly observed below $\sim T_c/2$ with $H \perp c$, suggesting the existence of line node. While the $T$ dependence of $\Delta^2$ observed with $H \parallel c$ is well fitted by a two-gap model, $T$-linear behavior is observed, which is consistent with $\Delta(T)$. In single crystalline $\text{Ba}_x\text{Fe}_2\text{As}_2$ ($x = 0.6, 0.7$ and $1.0$) in $\text{FeSe}_y\text{Te}_z$, single crystals grown by the Bridgman method decreases about $1$ K with increasing $1\%$ of Co content. In the presentation, we evaluate the impurity potential of Co based on $\rho_{\text{res}}$ and discuss the possible pairing symmetry in Fe$_{1-x}$Co$_x$Te$_{0.6}$ single crystals.

16P-B022 Evidence for Quantum Magnetotransport of Dirac Cone States in Ba(FeAs)$_2$

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The observation of Dirac cone states in $\text{Ba(FeAs)}_2$ opened up an interesting physical viewpoint in iron pnictide superconductors. Being the quantum state with high mobility carriers, Dirac cone states are more intriguing in considering the quantum transport that arises from the quantization of the states under magnetic field $B$. We will report the first evidence for the dominant effects of Dirac cone states on the transport properties of $\text{Ba(FeAs)}_2$. In the $B = 0$ limit, the transport properties are governed by the Dirac cone states despite the small number of Dirac carriers. In a larger $B$, a $B$-linear transverse magnetoresistance (MR) up to $B > 17$ T was observed. This $B$-linear MR is consistent with the unique quantum transport of the $0\text{th}$ Landau level in a Dirac cone state. Our results lead to a conclusion on the essential role of Dirac cone states in understanding the physics of iron pnictide superconductors.


16P-B023 Field Angle Dependence of Vortex Lattice Structure in KFe$_2$As$_2$

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The current challenge in iron-based superconductors is to determine the symmetry of the superconducting gap, with a view to identifying the pairing mechanism. Our investigation of the vortex lattice (VL) in KFe₂As₂ (Tc = 3.6 K) [1] have made a prominent contribution to this debate. Measurements of the vortex lattice with the magnetic field applied parallel to the c-axis found no VL structural transitions up to 0.5Hc2, ruling out a strong basal plane anisotropy. However, the diffracted intensity at 0.1 T varied strongly with temperature down to 50 mK, indicating a range of gaps extending down to very low values. This is consistent with having multiple full superconducting gaps on different Fermi sheets or, alternatively, a nodal gap, but with the nodal lines horizontal, circulating around the approximately cylindrical sheets of the Fermi surface. In the present study, by using the technique of small angle neutron scattering, we have extended our measurements of the vortex lattice in KFe₂As₂. We applied the magnetic field at multiple angles away from the c-axis, which allowed us to probe penetration depth anisotropy and possible unconventional effects. We will discuss the superconducting symmetry of the pnictide superconductors.


16P-B024 Disorder induced transition between s± and s++ states in two-band superconductors

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We have reexamined the problem of disorder in two-band superconductors, and shown within the framework of the T-matrix approximation that the suppression of Tc can be described by a single parameter depending on the ratio of intra- and interband dimensionless scattering strength. Tc is shown to be more robust against nonmagnetic impurities than would be predicted in the trivial extension of Abrikosov-Gorkov theory. For some realizations of s± pairing in such systems, we find that a disorder-induced transition between the s± states to a gapless and then to a fully gapped s++ state, which occurs at a critical value of the interband scattering rate. We discuss how this transition can manifest itself in the behavior of the electronic density of states and the magnetic field penetration depth.

16P-B025 Ultrasonic Investigations on Layered Iron Pnictide Superconductor Ba(Fe₀.₉Co₀.₁)₂As₂

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We have carried out ultrasonic pulse echo measurements on single crystals of iron pnictide Ba(Fe₀.₉Co₀.₁)₂As₂ with optimal superconducting transition temperature of TSC = 23 K. The shear elastic constant C₆₆ associated with elastic strain εₓᵧ reveals considerable softening of 28 % below 300 K down to TSC and turns to increasing in superconducting phase below TSC, while other shear elastic constants of (C₁₁−C₁₂)/2 and C₄₄ and longitudinal ones of C₁₁ and C₃₃ show no softening. The softening of C₆₆ is well described by C₆₆ = C₆₆²(1−Δ/(T−Θ)) with Θ = −47.5 K and Δ = 20 K. The negative Weiss temperature Θ indicates antiferro-quadrupole interaction in the system. The softening in C₆₆ is robust in applied magnetic fields. The present ultrasonic experiments indicate that the quadrupole associated with degenerate dₓ²−ᵧ² and dₓᵧ² bands participates in the superconductivity of the present iron pnictide system. The plausible superconductivity symmetry s++ in the iron pnictide will be argued.

16P-B026 Multiband Eliashberg model for pnictides

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Existing experimental data demonstrate multiband character of ferropnictides. We study multiband Eliashberg model based on interband spin-fluctuation interaction. within this model, superconducting gap functions have different signs on electronic and hole pockets, the so-called s± symmetry state. Such a state have a number of interesting features which manifest themselves in thermodynamics and transport properties. Using 4-band model, with 2 electronic and 2 hole pockets, we have calculated energy gaps and specific heat. These results are in a good agreement with experiments on K-doped pnictides. Further, we have studied impurity scattering outside Born approximation and have shown that nonexponential temperature dependencies of superfluid density and NMR relaxation rate can be realized. The origin of this behavior is explained by the fact that s± state, which is gapped in the clean limit, turns gapless when sufficient amount of impurity scattering is introduced. We also provide arguments that s± state is more robust against nonmagnetic impurities compared to predictions of the standard pair-breaking theory.

16P-B027 ⁵⁷Fe-NMR/⁷⁵As-NQR studies in LaFeAsO-based Superconductors

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We report an $^{75}$As-nuclear quadrupole resonance (NQR) study on heavily electron-doped LaFeAsO$_{1-x}$F$_x$ (nominal $x=0.22$) (La1111) with $T_c = 5$ K. Nuclear spin relaxation rate ($1/T_1$) measurement has revealed that a Hebel-Slichter (HS) peak partially recovers in heavily electron-overdoped regimes where the nesting condition of hole and electron Fermi surfaces (FSs) becomes significantly worse. This is in contrast to previous results reported in optimally doped La1111 with $T_c = 28$ K where a lack of the HS peak was reported. It indicates that the interband scattering between the hole and electron FSs is strongly suppressed by an almost vanishing hole FS through the heavily electron-overdoping. Our findings strongly support that the sign reversal of the gap functions on the different FSs, that is, $s_\pm$-wave state is realized in La1111 compounds. We remark that interband scattering on well-nested FSs is essential for stabilizing the $s_\pm$-wave state and enhancing the $T_c$ up to 28 K in LaFeAsO-based superconductors$^5$. We also compare the $^{57}$Fe-NMR results on the other LaFeAsO-based compounds, yttrium-substituted La$_{0.8}$Y$_{0.2}$1111 ($T_c=34$ K) and hydrogen-doped La1111H ($T_c=32$ K), which have higher $T_c$ than optimally doped La1111 ($T_c = 28$ K)$^2$.


16P-B028 Three-dimensional Fermi surfaces and their nesting properties in the iron pnictide superconductor BaFe$_2$(As$_{1-x}$P$_x$)$_2$

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Most of experimental studies on the iron-pnictide superconductors have so far indicated that the superconducting gap opens on the entire Fermi surfaces. However, the isovalent-substituted system BaFe$_2$(As$_{1-x}$P$_x$)$_2$ shows signatures of superconducting gap with line nodes$^1$, which would give critical information to clarify the pairing mechanism. According to the theory of spin-fluctuation-mediated pairing mechanism, three-dimensional nodes in the superconducting gap may appear in the strongly warped hole Fermi surface$^2$. Therefore, it is crucial to reveal the three-dimensional electronic structure of the this system for understanding the superconductivity. By angle-resolved photoemission spectroscopy, we find that one of the hole Fermi surfaces has a highly three-dimensional shape and shows poor nesting with the electron Fermi surfaces at the optimal composition. This hole Fermi surface becomes disconnected along $k_z$ direction for large $x$, which may lead to the suppression of the superconductivity.


16P-B029 Momentum dependent $s_\pm$ superconductivity and isotope effect in electron and hole doped iron pnictides from the small-q phonon mechanism

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We report self-consistent calculations of the gap symmetry for the iron pnictide superconductors (SC) using a realistic small-q phonon mediated pairing potential within a four-band model. When both electron and hole Fermi surface (FS) pockets are present, we obtain the nodeless $s_\pm$ state that was first encountered in a spin-fluctuations mechanism picture. Nodal gap structures are also accessible upon doping$^1$. Focusing on $s_\pm$ solution regime, we present self-consistent calculations of the isotope coefficient and the $\kappa$-anisotropy of the SC gap. We find that the gap is strongly momentum anisotropic in the hole doped side while it becomes almost isotropic on the electron doped side, exhibiting a strong dependency on the FS in agreement with recent ARPES observations. The isotope coefficient changes from negative to positive upon electron doping. We argue that our phonon theory can explain in a unifying manner seemingly uncorrelated phenomena, such as the momentum anisotropy and the magnitude variation over different FS portions of the $s_\pm$ SC gap, as well as the puzzling isotope effect observed in these compounds.


16P-B030 C-axis Polarized Optical Study on Thick Ba$_{0.67}$K$_{0.33}$Fe$_2$As$_2$ Single Crystal

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We report on a c-axis polarized optical measurement on a Ba$_{0.67}$K$_{0.33}$Fe$_2$As$_2$ single crystal. We find that the c-axis optical response is significantly different from that of high-$T_c$ cuprates. The experiments reveal an anisotropic three-dimensional optical response with the absence of the Josephson plasma edge in R(\omega) in the superconducting state. Furthermore, different from the ab-plane optical response, a large residual quasiparticle population down to $T \sim 1.5T_c$ was observed in the c-axis polarized reflectance measurement. We elaborate that there exist horizontal nodes for the superconducting gap in regions of the 3D Fermi surface that contribute dominantly to the c-axis optical conductivity.

doped iron-pnictide superconductor $\text{Ba}_{1-x}\text{K}_{x}\text{Fe}_2\text{As}_2$ ($x = 0.27 \sim 1$) (LT26)

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$\text{Ba}_{1-x}\text{K}_{x}\text{Fe}_2\text{As}_2$ (BKFA) is hole-doped iron-pnictide superconductor with superconducting transition temperature $T_c$ of 38 K ($x \sim 0.4$) - 3.5 K ($x = 1$). Recent experiments have revealed the possibility of the resistively determined upper critical field. Activity at high magnetic fields, the superconducting transition temperature $T_c$ gradually changes from $x = 0.39$ to 1.0. This suggests that the superconducting gap symmetry changes smoothly from full gap to nodal-line structure. Hence, BKFA doesn’t have different symmetry in optimally and end region. One explanation for this gap formation of KFe$_2$As$_2$ is horizontal line node.

16P-B032 Transport Properties of the Iron-Oxypnictide Superconductor PrFeAsO$_{1−y}$ in High Magnetic Fields

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We report the resistively determined upper critical field $H_c2$ of the iron-oxypnictide superconductor PrFeAsO$_{1−y}$ ($y \sim 0.15$), which exhibits superconductivity at $T_c = 44$ K. M. Ishikado, S. Shamoto, H. Kito, A. Iyo, H. Eisaki, T. Ito, and Y. Tomioka, Physica C 469, 901 (2009).

The resistivity $\rho(H,T)$ was measured with a typical four-probe method in static magnetic fields of up to 14 T and in pulsed magnetic fields of up to 52 T. With increasing magnetic fields, the superconducting transition width of the $\rho(T)$ curve for $H$ $\parallel$ c becomes broader than that for $H$ $\parallel$ ab. This behavior is likely to be due to dissipation associated with thermally activated vortex motion. The $H_{c2}(T)$ curves for both $H$ $\parallel$ ab and $H$ $\parallel$ c exhibit a pronounced upward curvature below $T_c$, and are very different from the conventional one-band Werthamer-Helfand-Hohenberg (WHH) behavior. This result suggests that the iron-oxypnictide superconductor is a multiband system, being consistent with band calculations and angle resolved photoemission spectroscopy (ARPES) results. We demonstrate the results of the two-band analysis for $H_{c2}(T)$ and discuss the anisotropy of $H_{c2}$ on some kinds of iron-based superconductors.

16P-B035 Critical currents in superconductor-ferromagnet heterostructures subjected to the injection of spin-polarized tunneling current

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Using state of the art technology we have produced the series of Co2CrAl-L-Pb heterostructures with the ferromagnetic Heusler alloy’s spin-polarization ranged from 0 to 100% and the normal-state interface resistivities varied over the three orders of magnitude range. Extensive measurements of the current-voltage characteristics of the F/S junctions and the critical currents of the Pb films for different levels of the spin-polarized tunneling current injected from the ferromagnet into Pb were performed. Accumulation of the spin-polarized quasiparticles in the interface region significantly modifies the properties of the junction compared to that of N/S junction: (i) the normalized conductivity of a F/S junction depends on the value of the junction’s differential conductivity in the normal state; (ii) the functional shape of IV curves of the F/S junctions is defined by the value of the interface resistivity; (iii) the critical current dependence in Pb film exhibits a plateau for low levels of the injection current and a monotonically decreasing part for the higher levels of injection with the plateau value depending on the normal-state interface resistivity. We propose the explanation of the observed dependences based on the “giant blocking of the tunneling current” phenomenon reported by us earlier, together with the general theoretical model of the proximised F/S contacts based on the Usadel equations formalism, where the suppression of the superconducting order parameter by the current injection is taken into account.

16P-B036 Metamagnetism in ferromagnetic superconductors

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Since the discovery of superconductivity under pressure in the ferromagnet UGe$_2$, two other compounds have been discovered where superconductivity coexists in a non competitive way with ferromagnetism: URhGe and UCoGe. In the three materials, the critical field exceeds the Pauli limit and has unconventional behavior. For example, reentrant superconductivity around 12 T in URhGe and an upward curvature in UCoGe and UGe$_2$. To date, only resistivity measurements were available to study these phenomenon. I will present specific heat measurements under magnetic field and pressure in UGe$_2$ that confirm a bulk magnetic field enhancement of superconductivity. This feature is linked to ferromagnetic instabilities of different nature in the three compounds. Common points and differences will be presented. The occurence of superconductivity near a quantum critical point of a ferromagnetic transition has been theoretically predicted and widely discussed. Nevertheless, the ferromagnetic transition becomes first order at low temperature, not only in UGe$_2$ but in all ferromagnets studied so far. I will also present a re-
investigation of the metamagnetism associated to the first order ferromagnetic transition in UGe$_2$. It allows us to experimentally draw for the first time the wing-structure phase diagram of a ferromagnet, which has been predicted from theory. These results by Hall effect and resistivity measurements are not described by conventional critical end point picture but are required to include a change of Fermi surface.

16P-B037 The Prediction of the Solitary Reentrant Superconductivity in the Asymmetrical Ferromagnet-Superconductor-Ferromagnet Trilayer
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The theory of proximity effect for thin bilayer FS and trilayer FSF, where F is a ferromagnetic metal, and S is superconductor, is investigated on the base of new boundary-value problem for the Eilenberger function. For both systems the dependencies of critical temperature on an exchange field of the F metal, electronic correlations in the S and F metals, and thicknesses of layers F and S are derived. It is shown that the possibility of the Fulde-Ferrell-Larkin-Ovchinnikov (FFLO) state observation is especially increased in the asymmetrical trilayers FSF$^1$ for which solitary reentrant superconductivity is predicted. On the basis of a proximity effect we propose new method of probe of electronic parameters of contacting materials. If well known BCS superconductor S is used as a probe, one can determine the exchange field, the electron-electron constant in various magnetics F for the FS structures or else the order parameter symmetry in high-Tc superconductors (HTS) for the HTS/S structures. It allows us to predict the sign and value of the constant of electron-electron interaction in gadolinium and to explain a surprisingly high critical temperature $T_c$ of gadolinium superconductors. It allows us to predict the sign and value of the high-Tc superconductors (HTS) for the HTS/S structures or else the order parameter symmetry in complicated structures or else the order parameter symmetry in gadolinium superconductors. It allows us to predict the sign and value of the high-Tc superconductors (HTS) for the HTS/S structures or else the order parameter symmetry in gadolinium superconductors.


16P-B038 Low-Temperature Magneto-Optical Studies of Magnetic Flux Local Penetration into HTSC Films on Magnetic and Nonmagnetic Substrates
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Magneto-optical imaging (MOI) is an excellent tool to visualize magnetic flux patterns in superconductors with high spatial as well as temporal resolution. Furthermore, quantitative MOI allows the determination of main properties of the critical state, such as Meissner and critical current density distributions, electric fields, flux velocity fields and the local activation barrier for thermally activated flux creep. Magneto-optical imaging offers also a unique and useful method for quality control of real HTSC tapes. In this report, local flux profiles visualized by MOI technique will be presented at different experimental conditions. Some types of HTSC films on both magnetic and nonmagnetic substrates are used in this study. Two cases are investigated: application of external magnetic fields and application of external pulsed currents. The behaviors and peculiarities of complicated flux penetration into the samples at different conditions as well as calculated local distribution of induced and transport currents will be discussed in detail.

16P-B039 Influence of proximity effect with Umklapp processes on the Josephson current in the SFS nanostructure
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We consider the Josephson effect in symmetric superconductor-ferromagnetic-superconductor (SFS) system. The Josephson current is calculated as a function of the ferromagnetic layer thickness $d_f$. The Fulde-Ferrell-Larkin-Ovchinnikov (FFLO) pairs in the F layer have a nonzero wave vector, and the transformation the BCS pairs to the FFLO pairs (and vice versa) at passing through SF (FS) borders may be proceeded through the Umklapp processes$^1$. To estimate the influence of proximity effect we use the expansion of superconductor energy in the powers of an order parameter (near the critical temperature $T_c$). We take into account the dependence of the critical temperature $T_c$ from the phase difference $\varphi$ between the order parameter in the left and right S side of the SFS contact, respectively, i.e. $T_c = T_c(\varphi) = T_{c\varphi}$. The result expression for critical current incorporates a term proportional to $T_{c\varphi}^0 - T_{c\varphi}$ which gives the main contribution near $T_c$. Our results are compared with known data for the NbCu$_{1.47}$Ni$_{0.53}$Nb nanostructures$^2$ where the critical Josephson current oscillations due to transitions between 0 and $\pi$ phase state were observed. A good agreement is obtained by taking into account the Umklapp processes.


16P-B040 Superconducting transition under long-range ordered antiferromagnetic state in high-$T_c$ cuprates Ba$_2$Ca$_4$Cu$_5$O$_{10}$ (F,O)$_2$: Cu- and F-NMR studies
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In the phase diagrams of high-$T_c$ superconductivity (SC) with doping and temperature, a long-standing problem is the interplay between SC and antiferromagnetism (AFM). Recently, from Cu- and F-NMR studies, we have observed a SC transition in the background of AFM state in a five-layered high-$T_c$ cuprate Ba$_2$Ca$_4$Cu$_5$O$_{10}$ (F,O)$_2$.$^a$. Upon cooling, the internal magnetic field at F sites develops below 175 K, suggesting the long-range AFM ordering with $T_N$=175 K.
On the other hand, the Knight shift $K$ for F-NMR spectra is constant upon cooling from room temperature, but it suddenly decreases below $T_c = 52\, \text{K}$; this is the evidence of SC transition in the long-range AFM state. We report systematic Cu- and F-NMR studies on $\text{Ba}_2\text{Cu}_4\text{O}_{10}(\text{F},\text{O})_2$ samples with different values of hole density $p$. Here, $p$ values are controlled by changing the ratio between $\text{F}^{1-}$ and $\text{O}^{2-}$ at apical sites from undoped to nearly optimally-doped regions. We will discuss the uniform coexistence of SC and AFM, and the layer-number dependence of the AFM-SC phase diagram.


16P-B041 Magnetic and transport properties of FeT(As, Se and Te)
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The recently discovered Fe-based HTS RO1$_{1-x}$F$_x$FeAs display a variety of structural, magnetic, transport transitions and charge ordering effect over a wide temperature range 100-200 K. In this talk we present magnetic and transport measurements revealing that the bazaar behavior also extends to the precursor materials used in preparing these HTcS; namely: FeAs, FeSe, FeTe, SmAs and RhAs.

16P-B042 Magnetic moment in single crystalline BaFe$_{2-x}$Zn$_x$As$_2$
Nature of the magnetism for iron-based superconductors (FeSCs) has been actively studied since the discovery of this new family of compounds in 2008, largely owing to its significance for interpreting the paring mechanism. The approach through impurity substitution to shed light into this issue is always one of major ways. The substitution shows distinct responses to species of impurities, where partially replacement of Fe by parent FeSCs with a variety of $d$-metals like Co, Ni, Ru, Rh, Pd, Ir, and Pt generally results in superconductivity, while recent progress in Zn doped FeSCs gives rather contrary result, where Zn severely degenerates the $T_c$. Herein we show the magnetic and electrical studies on BaFe$_{2-x}$Zn$_x$As$_2$ single crystals. Nonmagnetic Zn doping progressively suppresses the SDW without resulting in superconductivity, while it alternatively develops the spin-glass state, possibly suggestive of local magnetic moment around the Fe sites induced by Zn. The characterizations by X-ray diffraction, magnetic and electrical transport properties, specific heat capacity, and Hall coefficient have been done and the results will be discussed in detail.


16P-B043 High-Field ESR Spectroscopy on GdO$_{1-x}$F$_x$FeAs Superconductors
We address an intensively discussed issue of a possible interplay between magnetism and superconductivity in the iron pnictide high temperature superconductors. For that we have undertaken a detailed investigation of a series of GdO$_{1-x}$F$_x$FeAs samples by means of high-field/high-frequency electron spin resonance spectroscopy (HF-ESR) together with measurements of thermodynamic and transport properties [see, A. Alfonsov, et al., Phys. Rev. B 83, 094526 (2011)]. By performing temperature dependent HF-ESR measurements on Gd$^{3+}$ ions in a broad range of magnetic fields up to 15 T and excitation frequencies up to 350 GHz we have obtained evidence that though the long range magnetic order in the FeAs planes is suppressed upon the fluorine, i.e. electron doping, short range static on the ESR time scale magnetic correlations between Fe spins remain even up to the doping level optimal for superconductivity. This result suggests that GdO$_{1-x}$F$_x$FeAs compounds may feature coexistence of quasi-static magnetism and superconductivity on a large doping range which emerges as a generic property of iron pnictides.

16P-B044 Superconductivity and Magnetism of Fe-based AFe$_2$As$_2$ and B$_2$Fe$_2$Se$_2$ Systems Studied by Magnetization and Mössbauer Spectroscopy (LT26)
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Mössbauer spectroscopy (MS) in conventional superconductors yields little information. However, in the new magneto-superconductors where SC is confined to the Fe-As or Fe-Se layers, Fe MS may contribute much, since the Fe ions are not probes, but rather part of the layers to which SC is confined. MS and Magnetization studies of a large variety of AFe$_2$As$_2$ (A=Ba, Eu) and B$_2$Fe$_2$Se$_2$ (B=K, Rb and Tl) single crystals, including substitutions of Fe by Co or Ni or As by P in the AFe$_2$As$_2$ system have been performed. We shall summarize our present knowledge about the phenomena observed to date, including the results obtained in the new B$_2$Fe$_2$Se$_2$ systems, in which the high AFM state ($T_N > 500\, \text{K}$) coexists with SC (below 30 K) within the same Fe layers. In some SC materials, the paramagnetic Meissner effect up to 20 Oe and double peaks in the hysteresis loop are observed. Of particular interest is the EuFe$_2$(As$_1-x$P$_x$)$_2$ system, for which the two Mössbauer isotopes, $^{57}$Fe and $^{151}$Eu, enable to investigate simultaneously the mutual interactions between
the magnetic Eu and the Fe layers. EuFe$_2$(As$_{1-x}$P$_x$)$_2$ is SC for $0.2 < x < 0.5$. For $x \geq 0.2$ the Eu sublattice is FM ordered along the c-axis but AFM ordered for $x \leq 0.2$ with the moments aligned in the ab planes. In the FM region, the magnetic transitions and the magnetic hyperfine fields (H$_{eff}$) of the Eu nuclei are higher than those in the AFM region. Fe is magnetic for $x \leq 0.2$ but not magnetic for $x \geq 0.2$, yet displays transferred H$_{eff}$ from the Eu sublattice.

16P-B045 Magnetic structure of electronic inhomogeneities in cuprates: Competition between stripes and spirals

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The formation of spin and charge stripes is one of the scenarios in order to account for the formation of the pseudogap in cuprate superconductors. Whereas this kind of electronic inhomogeneity is now well established in lanthanum based cuprates the experimental situation in other compounds is less evident. Here we argue that the magnetic structure is strongly influenced by the next-nearest neighbor hopping parameter $t'$ which distinguishes different families of cuprates. In particular our investigations, based on the unrestricted Gutzwiller approximation of the extended Hubbard model, indicate that uniform spirals get favored by a large $t'/t$ ratio but are unstable at small doping towards stripes and checkerboard textures with spin canting. The structure of these inhomogeneities also depends on $t'/t$ and the associated spin currents may induce a small lattice distortion associated with local dipole moments. We discuss a new kind of stripe which appears as a domain wall of the antiferromagnetic (AF) order parameter with a fractional change of the phase of the AF order. For large $|t'/t|$ spirals can be stabilized under certain conditions in the overdoped regime which may explain the elastic incommensurate magnetic response recently observed in iron-codoped Bi2201 materials.

16P-B046 Phase Structure of Superconductors Coexisting with Ferromagnetism

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Some materials such as UCoGe are known to support both the p-wave superconducting (SC) order and the ferromagnetic (FM) order. These materials have been mainly studied by applying the mean field theory (MFT) to the Ginzburg-Landau (GL) theory in the continuum. However, the minimal coupling between the vector potential for the FM order parameter and the SC order parameter makes a simple MFT approximation assuming, e.g., a constant SC order parameter unreliable for phenomena related to nonuniform field configurations. In this paper, we reformulate the GL theory as a three-dimensional field theory, and study its phase structure and critical behavior nonperturbatively by Monte Carlo simulations. Due to the spatial lattice, topological defects, i.e., vortices, can be generated without cutoff for core singularity. We find a stable SC state in the FM region due to the Zeeman coupling between the FM magnetization of electrons in the normal channel and the “spin” of p-wave SC pairs. Obtained phase diagram has a qualitative resemblance to that of UCoGe in the pressure-temperature plane. We also find that, when the transition temperature of FM is lower than that of SC as $T_{FM}/T_{SC} < 0.7$, coexisting phase of FM and SC appear only near the surface of the lattice with vortices formed in the central region. This result suggests interesting possibility that in some cases the coexisting phase appears only in the surface of materials such as ZrZn$_2$.

16P-B048 Competition between Singlet and Triplet Superconductivity in the Extended Hubbard Model with Exchange Interaction on a Square Lattice

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Phase boundary between spin singlet and triplet superconductivity in the extended Hubbard model with exchange interaction on a square lattice is calculated within meanfield approximation for various band filling. Basically, antiferromagnetic exchange interaction $J$ is advantageous for the singlet pairing, while ferromagnetic $J$ prefers the triplet pairing. When off-site interaction $V$ is repulsive, the singlet phase and the triplet phase are separated by normal state in the phase diagram against $V$ and $J$. If $V$ is effectively attractive, however, the singlet and triplet states can compete against each other. We calculate the phase boundary between singlet and triplet phase for various band filling. It is shown that the triplet phase penetrates rather deeply into antiferromagnetic exchange regime for lower band filling, whereas the singlet phase is confined in a narrow range of ferromagnetic exchange regime.

16P-B049 Superconductivity and Magnetism of Annealed FeSe$_{1-x}$Te$_x$ (0.6 ≤ $x$ ≤ 1) Single Crystals Seen from Specific Heat and $\mu$SR

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We have investigated annealing effects on the superconductivity and magnetism of FeSe$_{1-x}$Te$_x$ (0.6 ≤ $x$ ≤ 1) single crystals annealed at 300 - 500 °C for 100 - 200 h in vacuum. A clear jump of the specific heat at $T_c$ has been observed for 0.6 ≤ $x$ ≤ 0.9, indicating that bulk superconductivity is realized. It has been found that the electronic specific-heat coefficient in the normal state, $\gamma_0$, is much larger than the value estimated from the band calculation and increases with increasing $x$ and suddenly decreases above $x = 0.9$. The large
value of $\gamma_n$ is guessed to be due to the enhancement of the effective mass related to spin fluctuation and/or orbital fluctuation. The decrease in $\gamma_n$ above $x = 0.9$ is due to the antiferromagnetic ordering around $x = 1$. It has been found that there remains a finite value of the electronic specific-heat coefficient at 0 K even in the superconducting state at $x = 0.8$ and 0.9, meaning that there remains normal-state carriers at 0 K. Moreover, $\mu$SR measurement has revealed that magnetic correlation is developed at low temperatures at $x = 0.8$ and 0.9, though no sign of antiferromagnetic ordering is observed in the magnetic susceptibility measurements. Therefore, there is a possibility that the superconductivity coexists with fluctuating antiferromagnetism at $x = 0.8$ and 0.9.

16P-B050  Interplay of Paramagnetic Signal with the Superconductive Environment of (Nd,Eu,Gd)BaCuO Superconductors

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High-Tc superconductors of the 123 type usually exhibit a paramagnetic moment that complicates evaluation of weak superconducting signals, like the thermodynamic reversible magnetic moment. This complication is even worse in the case of melt-textured composites, where Gd-211 particles are commonly used as an effective pinning medium. Such a compound follows Curie-Weiss law above $T_\mathrm{c}$, but the paramagnetic behavior departs from this law on superconductivity onset, still modifying the superconducting response in the whole superconductivity range, as tested up to 5 K. We measured magnetic behavior on both the melt-textured and single-crystalline form of the (Nd$_{0.33}$Eu$_{0.38}$Gd$_{0.28}$)Ba$_2$Cu$_3$O$_y$ superconductor with (in the former case) and without (in the latter case) intentionally added Gd-211 secondary phase and compared it with the magnetic behavior of the single Gd-211 phase. Based on this analysis an attempt to evaluate reversible magnetization of the superconductor and the associated thermodynamic quantities is made.

16P-B051  Magnetism and multiorbital models in the iron-based superconductors

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Magnetism and multiorbital play important role in the iron-based superconductors. We study the orbital-weight redistribution triggered by spin order in the iron pnictides by using the three-orbital model and five-orbital model with the Hund coupling. It is observed that the magnetization in the $xz$ and $yz$ orbitals are markedly different and the Fermi surface presents mostly $xz$ character with are consistent with photoemission experiments. By comparing with the neutron-scattering and angle-resolved photoemission experiments, we find the phase diagrams for the intraorbital Hubbard repulsion $U$ and Hund coupling $J$. In addition, the pairing tendencies in these realistic coupling regions are investigated using the random phase approximation. We further use a Hartree Fock multi-orbital Hamiltonian to study the striped phase in the iron pnictides. Upon electron doping, charge stripes are stabilized to run perpendicular to the direction of the spin stripes of the undoped magnetic ground state. These patterns give implications for recent experiments that reported electronic nematic states and spin incommensurability. We will also show some recent work on the iron selenide ($K, Ti$)Fe$_{1-x}$Se$_2$. Collaborators are M. Daghofer, E. Dagotto, A. Moreo, P. Dai, Q. Luo, J. P. Hu, E. W. Carlson, J. Zhao, et al. References: Nat. Phys. 5, 555 (2009); Phys. Rev. B 81, 180504(R)(2010); Phys. Rev. B 82, 104508 (2010); ArXiv:1103.3743.

16P-B052  The principle of local rotational invariance and the coexistence of magnetism, charge and superconductivity

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In 1950, Vitali Ginzburg and Lev Landau published their phenomenological theory of superconductivity based on the principle of gauge invariance applied to the general theory of second order phase transitions, proposed earlier by Landau in 1937. A consequence of this principle is that the order parameter has to be complex in order to allow a minimal coupling to the magnetic field. We propose here the principle of local rotational invariance to explain the presence of more than one complex order parameter in superconductors. This is a requirement to describe the coexistence of superconductivity and magnetism through minimal coupling. Our phenomenological theory is based on a formalism long ago developed by Élie Cartan, who in 1923, two years before the discovery of spin, introduced the concept of torsion in space and related it to an intrinsic angular momentum of matter. We find that superconductors, which coexist with magnetism, are the true foreground for Cartan’s geometrical theory.

16P-B053  Superconducting heterostructure (FeCr$_x$Fe)VFe: new view on old experiment

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Artificial layered systems FeCr$_x$Fe and Fe$_y$VFe$_z$ are well known due to the effects that discovered in these. First system demonstrates the oscillating coupling of the iron layers with the thickness increasing of the chromium inter-layer and the effect of giant magnetoresistance at the anti-ferromagnetic coupling of the iron layers. In the second system was observed the oscill-
lutions of the superconducting transition temperature ($T_c$) and the reentrant superconductivity \(^2\) effect with the increasing of the iron layers thickness. Together with experiment \(^2\) was performed an experiment\(^3\) on studying the influence of the mutual directions of magnetization of the iron layers on superconductivity of the vanadium layer: structures FeCr$_x$Fe$_{1-x}$ and FeVFe$_x$ were combined into a single epitaxially grown structure MgO (001) - (FeCr$_x$Fe$_{1-x}$)VFe. In next years other groups have performed experiments that confirmed the influence of the magnetization direction on $T_c$ - so-called the effect of the spin valve for superconducting current. However in these experiments, the observed differences of the critical temperatures ($\Delta T_c$) is much smaller ($\Delta T_c \sim 0.2$ K), than in the experiment with the superconducting heterostructure of FeCr$_x$FeVFe ($\Delta T_c \sim 2$ K). Present report is devoted to the analyze of a possible reasons for a too large value of $\Delta T_c$.


16P-B054 Generation of Large Spin Accumulation in S/N/S Josephson Junctions

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Spintronics is a significant research field in terms of both fundamental physics and its applications. Spin accumulation is a key physical quantity since it is essential to a local magnetic field. It can thus be possible to modulate superconducting phases by generating a large spin accumulation in superconductors. However, the spin accumulation signals obtained in previous studies are not sufficient to achieve such modulation. Therefore the enhancement of the spin accumulation is indispensable. In this work, we attempt to enhance the spin accumulation in Ni$_{83}$Fe$_{19}$/Cu lateral spin valve structures, to apply for inducing the superconducting phase transition. By inserting the MgO insulating layer in between Ni$_{83}$Fe$_{19}$ and Cu, the spin accumulation signal is found to be enhanced by a factor of ten compared to the Ohmic case and reaches 10 $\mu$V at 10 K. The spin diffusion length of Cu at 10 K becomes 1.3 $\mu$m, twice larger than the previous study of Ni$_{83}$Fe$_{19}$/Ag lateral spin valves\(^1\). With increasing the interface resistance furthermore, on the other hand, the spin signal exponentially decreases. This can be explained by the large reduction of the spin polarization of the insulating layer. We will also show some results of the spin current injection with such a large spin accumulation into S/N/S Josephson junctions and discuss effects of spin accumulation on supercurrents and a possibility to induce a $0 - \pi$ transition.


16P-B055 Anomalous zero-bias conductivity in superconductor-ferromagnet-insulator-superconductor tunnel junctions

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There has been increasing interest in ferromagnet-superconductor heterostructures. One of the not well understood phenomena is the presence of a weak supercurrent at zero voltage bias in S$_1$/F-I-S$_2$ junctions (here S, I, and F denote a superconductor, an insulator, and a ferromagnetic metal, respectively) without any sign of the energy gap of the S$_1$/F electrode in the tunnel conductance.\(^1\) Here we present results of an experimental and theoretical study of the Nb$_{12}$/Ni/Al-O$_{2y}$/Al/Nb$_{22}$ heterostructures with increased (comparing to that reported in Ref. 1) thickness of the Ni layer. At low temperatures, their electrical characteristics reveal the presence of a zero-bias anomaly that can be associated with the Josephson current. This anomaly, as well as the absence of a gap feature of the Nb$_{12}$/Ni bilayer, is explained in terms of phase-coherent charge transport through a disordered ferromagnetic film with an elastic mean free path being less than its thickness, $d_F$, whereas the phase breaking length exceeds $d_F$.


16P-B056 Electronic structure transition: the driving force behind magnetic and lattice structure transitions in NaFeAs

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One of the mysteries in iron-based high-temperature superconductors is that a spin density wave (SDW) transition is always accompanied by a structure transition. So far there is no hard experimental evidence to establish a general relationship between those two transitions. Here we report a strong evidence to unveil this mystery. The electronic structure of NaFeAs is systematically studied with high resolution angle-resolved photoemission spectroscopy on high quality single crystal. An electronic structure transition with large portions of electronic band shift is found to take place around the lattice structure transition temperature, and the shift smoothly increases as the temperature lowers through the SDW transition. Band folding due to magnetic order emerges around structural transition. Our results manifest that the electronic structure transition rather than the Fermi surface nesting provides the driving force of both the lattice structural and magnetic transitions.
16P-B057 Coexistence of magnetic fluctuations and superconductivity in an unconventional superconductor Ce$_2$PdIn$_8$

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The heavy fermion Ce$_2$PdIn$_8$ has been found to exhibit an unconventional superconductivity below 0.7 K [1, 2]. In this contribution, we present the results of zero-field (ZF-), longitudinal-field (LF-) and transverse-field (TF-) muon relaxation/rotation ($\mu$SR) measurements, performed in the temperature range 0.05 - 4 K and in magnetic fields up to 50 mT on a polycrystalline sample of the superconducting Ce$_2$PdIn$_8$. The ZF-$\mu$SR data demonstrate slowing down of the Ce spin fluctuations when crossing $T_c$ to lower temperature. The relaxation in the LF-$\mu$SR experiments is still observed at 5 mT, and it also becomes stronger with decreasing temperature down to 0.05 K. This finding suggests that the fluctuations are magnetic in origin and coexist with the superconductivity. The magnetic penetration depth, deduced from the TF-$\mu$SR rate, follows a power-law temperature dependence $\lambda^{-2}(T)/\lambda^{-2}(0) = 1 - (T/T_c)^{1.5}$, which is close to the linear temperature dependence of the quasiparticle excitations with line nodes in the gap structure. The $T_c = 0$ fit value $\lambda(0) = 800 \pm 90$ nm is large as for a heavy fermion superconductor.


16P-B058 Structural, electrical and magnetic study of RuSr$_2$Gd$_{1.4}$Ce$_{0.6}$Cu$_2$O$_{10-\delta}$

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Coexistence of superconductivity and ferromagnetism in a hybrid ruthenate-cuprate RuSr$_2$Gd$_{1.4}$Ce$_{0.6}$Cu$_2$O$_{10-\delta}$ (Ru,Gd-1222) with layered perovskite structure has attracted a great deal of interest in the properties of this material. Here we are reporting the low field magnetoresistance in Ru,Gd-1222. The polycrystalline samples of Ru,Gd-1222 were prepared through solid state reaction method. The four-probe resistivity-temperature ($\rho$-$T$) measurements show metallic normal state resistivity with superconducting transition at 25 K. Magnetization measurements with respect to field and temperature were performed by using a SQUID magnetometer. The magnetization (M)-temperature (T) measurement reveals magnetic transitions ($T_{mag}$) at 105 K. The magnetization (M) vs field (H) hysteresis at 5 K showed the ferromagnetic behavior of the samples. The zero field cooled magnetization and field cooled magnetization diverges at 93 K. MR measurements were carried out at different temperatures (24 K, 50 K, 100 K and 200 K) by using applied magnetic fields in the range from $-7.5$ to $+7.5$ kOe. A clear hysteresis was observed in the magnetoresistance data. The samples show negative magneto resistance at all temperature except in superconducting state.

16P-B059 Hysteretic Hall resistance at the LaAlO$_3$-SrTiO$_3$ interface - interplay between superconducting and ferromagnetic properties

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The conducting interface formed between the two insulators LaAlO$_3$ (LAO) and SrTiO$_3$ (STO) has been shown to have both magnetic and superconducting properties. As was reported in an earlier publication, the superconducting and the magnetic phases coexist simultaneously in this system, with superconductivity being tuned by an applied gate voltage. Here we report on the transverse (Hall) magnetoresistance of the interface as a function the gate voltage, which tunes the thickness of carriers at the interface. Not only is the Hall resistance hysteretic, due to the magnetic order in the system, but also highly non-linear in the low field region. The interaction between the superconducting vortices and the combined external and intrinsic (hysteretic) fields gives rise to the complex structure in the Hall data.

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16P-B060 Visualization of Different Regimes of Localized Superconductivity in Superconductor-Ferromagnet-Hybrids by Low-Temperature Scanning Laser Microscopy

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We studied the effect of a stripe-like domain structure in a ferromagnetic BaFe$_{12}$O$_{19}$ substrate on the superconducting properties of Pb thin film microbridges. The nonuniform component of the magnetic field, induced by the ferromagnet leads to a complex $H$ - $T$ phase diagram with various localized states such as reverse domain, domain wall and edge superconductivity. Here we report on low-temperature scanning laser microscopy imaging of these nonuniform superconducting states in a Pb bridge with domain walls perpendicular and a Pb bridge with a single straight domain wall along the center of the bridge. At a temperature slightly below $T_c$ and a bias current smaller than the critical current, the scanning laser spot locally destroys superconductivity by heating up the spot area above $T_c$ or reducing the critical current density below the applied bias current density. This results in a global change of the voltage density.
drop $\Delta V$, which is detected by lock-in technique as a function of the beam spot coordinates $(x, y)$. The acquired voltage images $\Delta V(x, y)$ confirm the formation of inhomogeneous superconducting states and external-field-controlled switching between the normal state and inhomogeneous superconductivity.

16P-B061 Enhanced fractional matching fields in superconducting NbN film with periodic array of antidots

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Type-II superconducting thin films having a periodic array of artificial pinning centers have been of great interest due to their excellence for the studies of the vortex pinning mechanisms. Square antidot lattice has been fabricated on NbN thin film by electron beam lithography. We study the temperature and current dependent matching effect by the artificial hole array in superconducting NbN thin films. We observed the interplay between the vortex quantization and the artificial antidot lattice. Magnetoresistance minima at integer matching fields up to five times of $H_1$ (the first matching field corresponding to one vortex inside each hole) and enhanced fractional matching fields at $1/3, 1/2, 2/3, 2/5$ have been observed. These fractional matching fields are observed till $H_1$. Also the enhanced fractional matching fields are current and temperature dependent. In the previous work the fractional matching fields are not very sharp and repeated after first matching fields.

16P-B062 Coexistence of ferromagnetism and superconductivity of nanosstructured single-phase Bi$_3$Ni

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Here we demonstrate the unique coexistence of superconductivity and ferromagnetism in single-phase Bi$_3$Ni nanostructures. For the production of the structurally confined intermetallic compound, we have developed novel chemical-reaction paths. Under variation of preparation parameters, nanostructures in several aspect ratios have been manufactured. We have characterized their magnetic and superconducting properties by means of magnetometry and electrical transport measurements. Other than in bulk geometry, submicron-sized particles, spherical nanoclusters, and quasi one-dimensional nanoscaled strains of single-phase Bi$_3$Ni undergo ferromagnetic order. Superconductivity in nanostructured Bi$_3$Ni emerges in the ferromagnetically ordered phase and is stable up to remarkably high magnetic fields. Uniquely, superconducting and ferromagnetic material properties evidently complement each other in structurally confined Bi$_3$Ni. Both, Ferromagnetic hysteresis and zero resistance is observed. The coexistence of superconductivity with ferromagnetic order in Bi$_3$Ni nanostructures would most likely be possible in the case of triplet pairing. $^1$


16P-B063 Atomic scale properties of chiral spin-triplet pairing at the interface with normal or magnetic systems

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We analyse the atomic scale behaviour of chiral spin-triplet pairing at the interface with different types of electronic orders. Starting from the interface with a normal metal we consider the evolution of the superconducting order parameter for various types of ferromagnet (including half-metal in the presence of spin-active interface), for a system with tendency to metamagnetism as well as when a magnetic field is applied. The study is performed by solving self-consistently the Bogoliubov-De Gennes equations on a lattice or by linking the modification of the electronic structure in proximity of the interface to the change in the strength of the long-range order. Concerning the proximity with a ferromagnetic (F) system we are able to check its universal character with respect to the nature of the ferromagnet by comparing the case of a F state due to a Stoner type of exchange and that one driven by a spin dependent asymmetry of the electronic bandwidth. Moving to the regime of half-metallicity we show that the breakdown of the superconductivity at the interface is independent of the mechanism that generates the F order for non magnetic interfaces, whereas spin-active barriers interfere with the chiral pairing leading to extra subgap Andreev states. Finally, the application of a magnetic field can drive a transition to a spatially inhomogeneous Fulde-Ferrell-Larkin-Ovchinnikov state, where chirality disappears and a singlet-triplet mixing takes place. A link with the physics of Sr$_2$RuO$_4$ and related eutectic phases is also discussed.

16P-B064 Critical Current Measurements of a Tape in the Hybrid Multi-Stacking High $T_c$ Superconducting Tapes

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A new 200 m high $T_c$ superconducting DC cable test facility was successively constructed in 2010. This coaxial power cable is composed of two superconducting layers of the DI-BSCCO$^®$ tapes spirally and closely surrounding a copper former. The number of the tapes in each layer is different due to their different radii. We have investigated the effect of the way of the tape winding on the critical current ($I_c$) of the tapes in order to optimize the cable configuration for DC transmission. This paper will present the measurements of $I_c$ of DI-BSCCO$^®$ in the hybrid multi-stacking tapes composed of YBCO and BSCCO tapes by controlling the transport current
in each tape independently. $I_c$ measurement is performed with the standard four-probe method at liquid nitrogen temperature. The magnetic field distribution around the tapes by the finite element method is calculated to demonstrate the effects on the self field from the adjacent tapes in the hybrid multi-stacking tapes. The enhancement and degradation of $I_c$ in the hybrid multi-stacking tapes are observed on contract to that of the single tape. Through the experiments, we started to investigate the tape configuration of the DC power cable to enhance the superconducting characteristics.

16P-B065 Escape rate measurements of 0, $\pi$ and 0-$\pi$ ferromagnetic Josephson junctions

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Josephson junctions (JJ) with a ferromagnetic barrier can be used to realize $\pi$ junctions, which have, in comparison to conventional 0 junctions, a phase drop of $\pi$ in the ground state. By joining a 0 and $\pi$ JJ, a 0-$\pi$ JJ can be created with a novel ground-state: a semifluxon. A semifluxon is a vortex, which is formed spontaneously at the 0-$\pi$ boundary. It carries the magnetic flux $\Phi = \pm \phi_0/2$, where $\phi_0$ is the magnetic flux quantum. We have investigated the phase dynamics of underdamped 0, $\pi$ and 0-$\pi$ ferromagnetic Josephson tunnel junctions of intermediate length. The junctions have been fabricated as Nb/$A_2O_3$/$Ni_{60}Cu_{40}$/Nb superconductor-insulator-ferromagnet-superconductor heterostructures. We measured the switching current statistics down to 20 mK and as a function of an applied magnetic field. We analyzed our data in the framework of transition state theory and found good agreement for both, the quantum tunneling and the thermal activation regime, with no indications of additional (spin) noise due to the ferromagnet.


16P-B066 Similar Effects of Nonmagnetic and Electrostatic Impurities on the Cu-Spin Correlation and Superconductivity in La-214 High-$T_c$ Superconductors

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Based upon the recently suggested hole-trapping effect of Ni,1,2 we have investigated substitution effects of Zn as a nonmagnetic impurity and Ni as an electrostatic impurity on the Cu-spin correlation and superconductivity in $La_{2-2x}Sr_xCu_{1-y}(Zn,Ni)_yO_4$ from the muon-spin-relaxation and electrical-resistivity measurements.3 It has been found that the substitution of Ni for Cu suppresses the superconductivity, induces the localization of holes and develops the Cu-spin correlation to the same degree as the substitution of Zn for Cu in the underdoped regime, which is different from the common understanding that Zn tends to affect the dynamics of carriers as well as the Cu-spin correlation more than Ni. It has been concluded that Ni with a trapped hole tends to give rise to scattering of holes by the electrostatic potential in the CuO$_2$ plane to the same degree as Zn, which may be related to the development of the so-called dynamical stripe correlations of spins and holes.


16P-B067 Anomalous correlation between superconductivity and magnetism in iron pnictide superconductor LaFeAsO$_{1-x}$F$_x$ near the phase boundary

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Anomalous correlation between superconductivity and magnetism in LaFeAsO$_{1-x}$F$_x$ near the boundary between these two phases is demonstrated by muon spin rotation ($\mu$SR) measurement. It is inferred from zero field $\mu$SR that a part of the specimen ($x = 0.057$) exhibits magnetism below 100 K, where the volume fraction of the magnetic domain reaches 15% at the lowest temperature ($\sim 4.5$ K). Transverse field $\mu$SR measurements under 0.05 T and 7 T indicate that the signal corresponding to the magnetic domain shows negative frequency shift which is further enhanced below superconducting transition temperature ($T_c \approx 25.5$ K). The magnitude of the shift below $T_c$ reaches 0.1−0.15 MHz at lower temperatures irrespective of external field, indicating that the enhancement below $T_c$ is not due to the artifact of magnetic vortices. Moreover, depolarization rate in magnetic domain exhibits increase below $T_c$. These behaviors are in agreement with our previous observation in a sample of different origin ($x = 0.06$)[1], suggesting close similarity with CeCu$_2$Si$_2$.


16P-B068 Unusual Doping Dependence of Magnetic Ordering and Electronic Band inCo-Doped BaFe$_2$As$_2$

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High resolution angle-resolved photoemission measurements have been carried out on BaFe$_{1-x}$Co$_x$As$_2$, with nominal doping ($x$) from undoped $x=0$ to overdoped $x=0.30$. The detailed doping evolution of Fermi Surface...
and band structure in the magnetic ordering state and paramagnetic state are presented. The unusual doping dependence of the Fermi surface and band structure indicates magnetic order plays an important role in indicating the electronic structure of FeAs-based compounds.

**16P-B069 Charge Dynamics in SDW state of AFe$_2$As$_2$**

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After the discovery of iron-pnictide superconductors, numerous research activities have been done all over the world. In almost cases, superconductivity in iron pnictides appears by suppressing antiferromagnetic ordering (SDW). To clarify the electronic structure in the SDW state of iron pnictides, we have investigated the transport and optical properties using single crystals of AFe$_2$As$_2$ (A = Ba, Eu, Sr), and Co-doped BaFe$_2$As$_2$ with the SDW transition temperature, $T_{SDW} = 100$ K-197 K. In AFe$_2$As$_2$, the resistivity has a sudden change at $T_{SDW}$, and shows a metallic behavior even below $T_{SDW}$. On the other hand, the absolute values of Hall coefficient are clearly enhanced below $T_{SDW}$, indicating the decrease of carrier numbers. The optical reflectivity is suppressed in far-infrared region below $T_{SDW}$, but it approaches to unity at zero frequency, which indicates a metallic behavior even in magnetically ordered state. The low-energy conductivity is severely suppressed and the spectral weight transfers from low to high energy region, indicating the open of SDW gap. In the mid-infrared region, the optical conductivity has two peak structures in the SDW state. These peak energies scale with $T_{SDW}$, suggesting that the observed peaks originate from the SDW gap. All these results have revealed the electronic state of AFe$_2$As$_2$ where the two SDW gaps open partially at the Fermi surface.

**16P-B070 In-Plain Anisotropy of Charge Dynamics in Parent Compounds of Iron Pnictide Superconductors**

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Undoped or underdoped iron pnictides have magnetically ordered phase transition accompanied with the structural phase transition. The magnetically ordered state exhibits the stripe-like antiferromagnetic order and is inherently anisotropic. Although it is natural to consider that the paramagnetic state be isotropic, anisotropic behaviors appear in these compounds not only below but also slightly above the transition points. We have previously investigated the origin of the anisotropy of optical conductivity in magnetically ordered state.$^3$ The current interest is why the anisotropy persists above the critical temperature. Using a five-orbital model Hamiltonian with mean-field approximation, we set parameters by taking into account the orbital ordering and/or other effects to simulate the paramagnetic state with anisotropic charge transport properties. The calculated results are compared with the experimental data, and we discuss the validity of parameter sets taken in our calculation.


**16P-B071 Diamagnetism of quasi-2D charged Bose gases under confinements**

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Recently, the normal state diamagnetism of high $T_c$ superconductors is explained using the normal state Landau diamagnetism of charged bosons based on the preformed real-space pairs scenario.$^1$ This stimulates renewed research interest in the properties of charged Bose gases. It is already indicated that the homogeneous gas does not undergo Bose-Einstein condensation (BEC) in a constant magnetic field.$^2$ We consider a quasi-2D charged Bose gas with some confinement imposed in the xy plane. We show that BEC takes place in this case and the system exhibits exotic magnetic properties different from those of homogenenous gases.


**16P-B072 Evidence for Dirac-like excitations in SrFe$_2$As$_2$ from Quantum Oscillation Experiments**

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The antiferromagnetic parent compounds of the high $T_c$ pnictide superconductors play host to unusual magnetic and electronic properties which may be closely related to the presence of superconductivity in the doped compounds. Recent theoretical$^1$ and experimental$^2$ work have suggested the presence of small Fermi-surface pockets in these compounds with regions in k-space characterized by a Dirac-like dispersion. Here we test this scenario by performing quantum oscillation studies on high quality single crystal samples of SrFe$_2$As$_2$ to 60 T in pulsed magnetic fields. By tracking the ratio of the quasiparticle effective mass $m^*$ to the quantum oscillation frequency as a function of magnetic field angle, we observe a dependence consistent with that expected for the Dirac dispersion scenario. We discuss the implications of this result on understanding the metallic state of the FeAs parent compounds.


**16P-B073 A Superconducting Spin...**
Valve Core Structure based on the FFLO Like State: Studies on Bilayers and Tri-layers of Superconductors and Ferromagnets

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Interference effects of the superconducting pairing wave function in thin film bilayers of Nb as a superconductor (S) and Cu\textsubscript{41}Ni\textsubscript{59} as ferromagnetic (F) material lead to critical temperature oscillations and reentrant superconductivity for increasing F-layer thickness. The phenomenon is generated by the Fulde-Ferrell-Larkin-Ovchinnikov (FFLO) like state establishing in these geometries. So far detailed investigations were performed on S/F bilayers.\textsuperscript{1} Recently, we could also realize the phenomena in F/S bilayers where the S-metal now is grown on top of the F-material. Combining both building blocks yields an F/S/F trilayer, representing the core structure of the superconducting spin valve.\textsuperscript{2} Also for this geometry we observed deep critical temperature oscillations and reentrant superconductivity, which is the basis to obtain a large spin switching effect, i.e. a large shift in the critical temperature, if the relative orientation of the magnetizations of the F-layers is changed from parallel to antiparallel.


16P-B074 Interplay between spin-singlet and spin-triplet ordering in SFF spin valves

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Recently, structures where two F-layers are coupled to a superconductor (FSF or SFF) attracted much attention since they may serve as superconducting spin valves, where transition temperature is controlled by angle $\alpha$ between F-layer magnetization directions. In this work we address the issue of interplay between spin-singlet and spin-triplet superconducting correlations in SFF structures. We show that the magnetization-induced phase slips at both interfaces lead to a number of new phenomena. First, for parallel orientations of magnetizations in the F-layers, $\pi$-state in SFFIS Josephson junction can be realized as a result of two subsequent $\pi/2$ phase shifts at the interfaces. Second, the magnitude of long-range spin-triplet order parameter component generated in SFF structures with varying angle $\alpha$, has anomalous dependence on $\alpha$. Namely, contrary to the standard knowledge based on the analysis of symmetric FSF or SFSS structures, the triplet component in SFF structures does not reach a maximum in the vicinity of $\alpha = \pi/2$ but it vanishes for this configuration of magnetization vectors. We also discuss how these new effects manifest itself in the conductance of F layers and in the realization of $0 \to \pi$ transition in SFFIS tunnel junctions.

16P-B075 Two-Dimensional CrFe-Based Half-Metallic Antiferromagnets

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We report that the substitution of Cr ions for half of Fe ions in Fe-based superconductors such as LaFeAsO, SrFeAsF, and FeSe produces quasi-two-dimensional (2D) half-metallic (HM) antiferromagnets (AFMs),\textsuperscript{1} or fully compensated half-metallic ferrimagnets, that have no net magnetization, yet 100\% spin polarization of the conduction electrons. Using a full-potential augmented plane wave method within density functional theory, we find ordered (striped or checkerboard) structures in the CrFeAs\textsubscript{2} and CrFeSe\textsubscript{2} 2D planes commonly half-metallic in the normal ground state, where two component magnetic ions in a unit cell have antialigned local moments that cancel exactly because of the integer filling of an insulating channel. With stiff spacer layers such as LaO and SrF, the CrFeAs\textsubscript{2} layers show HM-AFM behavior in both striped and checkerboard phases, whereas the spacer-free CrFeSe\textsubscript{2} layers become semi-metallic in the striped phase, being degraded by orthorhombic distortion. The checkerboard phase is energetically favored over the striped phase. Despite the absence of inversion symmetry in the checkerboard phase, spin-orbit coupling of spin-polarized conduction electrons shows little effect on the half-metallicity.


16P-B076 Vortex Lattice Studies in CeCoIn\textsubscript{5} with $H \perp c$

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We report on small-angle neutron scattering measurements on the vortex lattice (VL) in the mixed state of CeCoIn\textsubscript{5} with the magnetic field ($H$) along [100] and [110]. For both field orientations a distorted hexagonal VL is observed, reflecting the penetration depth anisotropy of the screening current plane. With $H \parallel [100]$ the VL is oriented with Bragg reflections along the [001]-axis at all fields. For $H \parallel [110]$ the same VL orientation is observed at low fields, followed by a 90\textdegree first-order reorientation transition as $H$ is increased. For $H \parallel [100]$ we obtain the field dependence of the form factor ($|F|^2$) both within (50 mK) and outside (350 mK) the magnetic $Q$-phase. At both temperatures ($|F|^2$ varies with $H$ in a manner similar to $H \parallel [001]$), due to a paramagnetic alignment of the unpaired electron spins in the vortex cores. Inside the $Q$-phase we observe an
increased disordering of the field cooled VL indicating a subtle coupling to the magnetic phase.

16P-B077 Imaging of Magnetic Domains above the surface of the Superconducting Ferromagnet UCoGe
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We will present recent results on the coexistence of superconductivity ($T_{cS}=0.45$ K) and ferromagnetism ($T_f=2.8$K) in single crystals of the itinerant ferromagnet UCoGe. Macroscopic magnetization measurements will be compared with scanning microSQUID microscopy data taken at temperatures as low as 0.25 Kelvin. Our macroscopic measurements clearly demonstrate the coexistence of the two competitive orders. Notably, diamagnetic screening and a weak Meissner effect were detected in the ferromagnetic state. Our microscopic measurements show the formation of a spontaneous ferromagnetic state at zero applied magnetic field and the formation of ferromagnetic domains. The locally observed domain magnetization agrees with the magnetization derived from bulk measurements. The Ising nature of this ferromagnet is confirmed. The ferromagnetic domain size depends on whether the sample is superconducting and ferromagnetic or only ferromagnetic. The magnetic imaging, taking into account estimates of the penetration depth, is consistent with the formation of a spontaneous vortex lattice. The work is supported by French National Agency of Research (ANR) 09-BLAN-0146-02, J.R.K. acknowledges support from the Nanosciences Foundation of Grenoble.

16P-B078 SANS Studies of the Flux Lattice in YBa$_2$Cu$_3$O$_7$ at Very High Fields
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We present recent results from small angle neutron scattering (SANS) studies of detwinned single crystal YBa$_2$Cu$_3$O$_7$ (YBCO), obtained using the new Birmingham 17 T magnet. This recently commissioned facility allows investigation of the flux lattice at unprecedentedly high fields, with very low backgrounds due to the very small amount of material in the beam path. Measurements of flux lattice structure versus field give an indication of the evolution of the Fermi surface, and the pairing symmetry. The lattice has a number of structural transitions and continues to evolve in shape up to the highest fields observed. We have also investigated the form factor of the Bragg peaks (obtained from the integrated intensity) as a function of both field and temperature. The form factor is related to the spatial variation of the magnetic field, and hence the penetration depth. The FWHM of the peaks also gives information about the perfection of the flux lattice, and both taken together show evidence of pinning at low temperature, and tantalising signs of fluctuations at high fields near the melting line.

16P-B079 Magnetic Field Effect on Antiferromagnetic Insulating State of λ-(BETS)$_2$FeCl$_4$
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A quasi two dimensional organic conductor λ-(BETS)$_2$FeCl$_4$ exhibits a new type of phase transition from a paramagnetic metal (PM) to an antiferromagnetic insulator (AFI) at $T_M$ of 8.3 K under zero magnetic field.\textsuperscript{1} In the earlier studies, it was concluded that the Fe 3d spin dominantly contributed to the formation of AF ordering. Recently, we clarify that the Fe 3d spin in this system maintains most of the degrees of freedom in the AFI phase. This 3d spin enables precise evaluation of the internal field induced by the $\pi$ spin order. In this study, to get information about the influence of magnetic field on the AF order and the PM-AFI transition, we study the specific heat under the magnetic fields up to 7 T. At low magnetic field ($H \leq 4$ T), the observable Schottky specific heat in low temperature indicates very little change with increasing the applied field, whereas its magnetic susceptibility shows the strong anisotropy and spin flop transition at 1 T. The anomalous field dependence can be explained on the basis of the 3d spin paramagnetic model considering the Fe anisotropy. Furthermore, a relationship between the Fe anisotropy and the AF order will also be discussed.\textsuperscript{1}


16P-B080 Control of the electronic state of Ca$_2$RuO$_4$ by uniaxial pressure
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Ca$_2$RuO$_4$ under hydrostatic pressure exhibits a variety of electronic state\textsuperscript{1}: the antiferromagnetic insulating phase, the ferromagnetic metallic phase, and even the superconducting phase\textsuperscript{2}. Importantly, the phase transitions are accompanied by crystal distortions; in particular, the RuO$_6$ octahedra in the crystal are elongated along the $c$ axis in the metallic state while they are flattened in the insulating state\textsuperscript{3}. Hence, the crystal structure is a crucial parameter to determine the electronic state in this system. Anticipating that uniaxial pressure along the $ab$ plane elongates the RuO$_6$ octahedra of Ca$_2$RuO$_4$ more effectively than hydrostatic pressure, we measured the resistance of Ca$_2$RuO$_4$ under in-plane uniaxial pressures by a quasi-four-terminal method and indeed succeeded in inducing a metallic phase. We report on the low-temperature properties
of this induced metallic phase.


16P-B081 Magnetic excitations in the FeAs based superconductors


We have performed various neutron-scattering and x-ray studies on two members of the family of oxyynitrides superconductors: LaOFeAs and LiFeAs. Powder neutron-diffraction experiments reveal a significantly larger Fe magnetic moment in LaOFeAs than previously reported and indicate pronounced structural anomalies appearing already above the long-range structural transition. Comprehensive studies on superconducting single crystals of pure LiFeAs do not yield any evidence for magnetic ordering in this material. However, inelastic neutron-scattering experiments find incommensurate magnetic fluctuations appearing close to the wave vector of the striped antiferromagnetic order in the parent compounds of the other FeAs systems. These incommensurate magnetic excitations clearly respond to the opening of the superconducting gap.


16P-B082 Antiferromagnetic order and high temperature superconductivity in underdoped Hg-based Five-layered Cuprates


We report Cu-NMR study on underdoped Hg-based five-layered cuprates HgBa$_2$Ca$_4$Cu$_{5+\delta}$O$_{12+\delta}$ with $T_c = 72$, 82 and 92 K. From the Knight shift measurements, hole densities at inner planes (IPs) were estimated as 0.053–0.073 on the basis of the relation of Knight shift and hole density. Zero field NMR measurements reveal that the antiferromagnetic (AFM) moments at IPs are in the range of 0.1–0.18 $\mu_B$ at $T=1.5$ K for these compounds, which is smaller than 0.5–0.7 $\mu_B$ for undoped Mott insulators. The mobile holes existing at IP uniformly reduce their AFM moments, indicating that a static AFM metallic state is realized at underdoped IPs. We also present a phase diagram of CuO$_2$ plane based on Hg-based five-layered cuprates, which has been revised after the previous reports. It includes the experimental findings such as the existence of AFM metallic state in doped Mott insulators, the uniformly mixed phase of AFM and high-$T_c$ superconductivity, and the emergence of d-wave superconductivity with a maximum of $T_c$ just outside a critical carrier density, at which the AFM moment disappears.


16P-B083 NMR study of the interplay between magnetic order and superconductivity in YBa$_2$Cu$_3$O$_{6.45}$


Cu NMR measurements were performed up to 28.5 Tesla in an untwinned YBa$_2$Cu$_3$O$_{6.45}$ single crystal for which an electronic liquid crystal state was recently reported. Although the sample is superconducting at $T_C = 35$ K, field-dependent magnetic order is found at low temperatures, in agreement with previous works. Comparison of the results with data from other probes in YBa$_2$Cu$_3$O$_{6.45}$ and with NMR data in underdoped LSCO and YBCO reveals important aspects of the interplay between magnetic order and high temperature superconductivity.


16P-B084 Unconventional temperature-enhanced magnetism in Fe$_{1+y}$Te


There are two common scenarios used to describe the magnetism in the families of Fe-based superconductors. In one, the magnetism originates from local atomic spins, while in the other it corresponds to a cooperative spin-density-wave (SDW) behavior of conduction electrons. Both assume clear partition into localized electrons, giving rise to local spins, and itinerant ones, occupying well-defined, rigid conduction bands. We have used inelastic neutron scattering to characterize both the static and dynamic magnetism in a crystal of Fe$_{1+y}$Te, parent to the Fe$_{1+y}$Te$_{1-x}$Se$_x$ family of superconductors. In contrast to the simple pictures, we find that localized spins and itinerant electrons are coupled together. In particular, we have evaluated the effective magnetic moment by integrating both the elastic and inelastic magnetic scattering. The effective spin per Fe at $T \approx 10$ K, in the antiferromagnetic phase, corresponds to $S \approx 1$, consistent with the recent analyses that emphasize importance of Hund’s intra-atomic exchange. However, it grows to $S \approx 3/2$ in the disordered phase, a result that presents a challenge to current theoretical models.

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16P-B085  On the nature of an energy barrier between $(\pi,0)$ and $(0,\pi)$ magnetic orders in Fe pnictides


As temperature is lowered most of undoped Fe arsenides, parent compounds for recently discovered Fe based superconductors, undergo a transition into a collinear state with stripe-like magnetic order in which anti-ferromagnetic (AFM) Fe chains are ferromagnetically ordered along the direction perpendicular to the chains. Two such collinear magnetic structures, characterized by ordering vectors $(\pi,0)$ or $(0,\pi)$, are connected by infinite number of non-collinear states with two AFM sublattices of second Fe neighbors rotated by an arbitrary angle with respect to each other. In a classical Heisenberg model all these states are degenerate. Band structure calculation show, however, that the degeneracy is lifted already at the mean field LSDA level and that in Fe arsenides $(\pi,0)$ and $(0,\pi)$ magnetic orders are separated by an energy barrier comparable to the energy difference between Neel and stripe AFM orders. We discuss a microscopic origin of the energy barrier and demonstrate that it is caused by closely related to underlying band structure. The results for Fe arsenides are compared to BaMn$_2$As$_2$ and hypothetical KFe$_2$Se$_2$ for which we found that a non-collinear 90-degree spin arrangement is more favorable than collinear ones. A doping dependence of the barrier is also discussed.

16P-B086  Antiferromagnetic spin fluctuations and $s_\pm$-wave Superconductivity in $(\text{Ca}_4\text{Al}_2\text{O}_{6-y})(\text{Fe}_2\text{As}_2)$ probed by $^{75}$As NQR

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We report $^{75}$As-nuclear quadrupole resonance (NQR) study on $(\text{Ca}_4\text{Al}_2\text{O}_{6-y})(\text{Fe}_2\text{As}_2)$ with $T_c = 27$ K, which is characterized by structural parameters such as short $a$-axis length, high pnictgen height, narrow As-Fe-As angle, and thick perovskite-type blocking layer. A measurement of nuclear spin relaxation rate $1/T_1$ revealed a significant evolution of antiferromagnetic (AFM) spin fluctuations in normal state, which originates from the possible well nested hole and electron (AFM) spin fluctuations in normal state, which originating from the possible well nested hole and electron bands. The results for Fe arsenides are compared to BaMn$_2$As$_2$ and hypothetical KFe$_2$Se$_2$ for which we found that a non-collinear 90-degree spin arrangement is more favorable than collinear ones. A doping dependence of the barrier is also discussed.

16P-B087  What do the rich magnetic structures of iron-based superconductors teach us about their electronic structure?

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Recent discovery of iron-based high temperature superconductors (Fe-SC) has reignited the intense interest in the unresolved relationship of anti-ferromagnetism and high temperature superconductivity. Unlike the well known case of the cuprates, however, the magnetic properties of the Fe-pnictides are much richer, leading to diverse (and mostly inconsistent) descriptions in the field. Here, the puzzling nature of magnetic and lattice phase transitions of Fe-SC is investigated. First, via a first-principles Wannier function analysis of representative parent compound LaOFeAs, a rare ferro-orbital ordering is found to give rise to the recently observed highly anisotropic magnetic coupling, and drive both phase transitions — without resorting to widely employed frustration or nesting picture. The revealed necessity of the additional orbital physics leads to a correlated electronic structure fundamentally distinct from that of the cuprates. Second, the rich magnetic correlation across the Fe-based superconducting families are explained via a unified model that encapsulates the essential roles of itinerant and local electrons with double-exchange effects. Interestingly, the ferromagnetic correlation is fond significantly higher in energy, leaving superconductivity the only viable phase to relieve entropy at low temperature upon doping.

16P-B088  From Low $T_c$ to Room $T_c$ in Cuprate- and Pnictide-Like Superconductors

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It is demonstrated that high critical temperature $T_c$ of superconducting transition in optimally doped cuprates and pnictides is provided by Cooper pairing of mobile charge carriers in conducting charge (C) stripes due to delocalized, in-plane, charge-transfer (CT) excitons, propagating in semi-insulating spin (S) stripes, adjacent with C-ones. This conclusion is a result of detailed analysis of in-plane resistive, neutron and optical experimental data in cuprates and pnictides with doping ranged from undoped to optimally doped cases. The crucial rise of $T_c$ in cuprates due to excitons is preceded by moderate rise of $T_c$ due to phonons as a result of partial dielectrization of electron energy spectrum at normal-state magnetic (SDW) phase transition. This transition is accompanied by both formation of SDW-gap (pseudogap) at symmetrical parts of Fermi surface and stripe structure in conducting planes. The picture is consistent with Little-Ginzburg (LG) exciton mechanism of high-$T_c$ superconductiv-
ity (HTSC), in planar geometry of Ginzburg HTSC-sandwich: insulator-metal-insulator. The new way to accelerate immediately experimental search for room-$T_c$ superconductivity in similar complex transition-metal compounds with higher energy of CT-transition in AF-ordered layers is pointed out.

16P-B089 Mesoscopic cross-film cryotrons: Vortex trapping and dc-Josephson-like oscillations of the critical current


In the 1950s Dudley Buck invented the cryotron, a revolutionary electronic device based on superconductors. Since the performance of cryotron device becomes greater as the size of the device is reduced, manufacturing thin-film cryotron integrated circuits was a primary focus for decades. Here, we will present experimental and theoretical investigation of the “quantum limit” of a cryotron device, i.e., when the dimensions become small enough to make evident the discrete character of Nature. Unlike the standard macroscopic cryotron devices, where the transport properties depend monotonically with the control wire current, here we report a highly non-monotonous dependence similar to the Fraunhofer pattern for conventional Josephson junctions. This fascinating feature reopens new possibilities for the design of superconducting interferometer devices based on Superconductors/Electromagnet hybrid structures.


16P-B090 Dispersive high-energy spin excitation in iron-based superconductors

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The discovery of iron-based high temperature superconductivity has triggered tremendous research efforts in searching for novel high-$T_c$ superconductors (SC) and understanding the related fundamental physics. Unlike the cuprate parent compounds which are AF Mott insulators, the iron-based parent compounds are ’spin-density wave’ metals with delocalized electronic structure and more itinerant magnetism. There are cumulative evidence suggesting that the superconductivity in the iron-based SC may be connected with interband pair scattering between quasi-nested Fermi surfaces. However, the observation of spin fluctuations in these materials recommends a compelling hypothesis that they may share a common pairing mechanism with cuprates. Recent developments of high-resolution resonant inelastic X-ray scattering (RIXS) have enabled exploring magnetic excitation in cuprates which show excellent agreement with results from inelastic neutron scattering. Here we demonstrate RIXS can be used to measure collective magnetic excitation in iron-based SC despite their much stronger itinerancy compared to cuprates. The persistence of high-energy spin excitations in doped SC strongly suggests a spin-mediated pair mechanism.

16P-B091 Crystal structure and magnetic correlations of Fe$_{1+y}$Te$_{1-x}$Se$_2$ under ambient and applied pressure

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We will first discuss evolution of the crystal structure and magnetic correlations of Fe$_{1+y}$Te$_{1-x}$Se$_2$ as a function of $x$. Then we will present a recently-found consequence of the complex balance between magnetism and conductivity in the iron chalcogenide, Fe$_{1.0}S_{0.10}Te_{0.90}$. By performing resistivity, bulk susceptibility and neutron diffraction, we show that the both conductivity and magnetism are simultaneously enhanced by the application of external pressure. Surprisingly, the pressure-induced magnetic order is nearly three-dimensional, and incommensurate along both the $c$-axis and $a$-axis, in stark contrast to Fe$_{1+y}$Te under ambient conditions. The correlated conductivity and magnetism is associated with local distortions that increase the bond angle of Te/Se-Fe-Te/Se, and we argue that the local structure play a crucial role in determining the electronic and magnetic properties of iron based compounds. We will also discuss similarities and differences between iron and other nonconventional superconductors such as ruthenate and cuprates.

2 N. Katayama et al., unpublished (2011)

16P-B092 Spin Dynamics in the Pressure-induced Two-leg Ladder Cuprate Superconductors

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Within the two-leg $t$-$J$ ladder, the spin dynamics of the pressure-induced two-leg ladder cuprate superconductors is studied based on the kinetic energy driven superconducting mechanism. It is shown that in the pressure-induced superconducting state, the incommensurate spin correlation appears in the underpressure regime, while the commensurate spin fluctuation appears in the optimal pressure and overpressure regimes. In particular, the spin-lattice relaxation time is dominated by a temperature linear dependence term at low temperature followed by a peak developed below the superconducting transition temperature, in qualitative agreement with the experimental observation on the pressure-induced two-leg ladder cuprate superconductors.
16P-B093 Doping dependence of spin dynamics in bilayer cuprate superconductors

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Within the framework of kinetic energy driven superconductivity, we have studied the spin dynamics of bilayer cuprate superconductors in the superconducting state over a wide doping range. It is shown that the dynamical spin structure factor is split into two non-degenerate modes, odd and even, due to the inter-layer magnetic interaction in a bilayer unit. The doping dependence of the resonant energy of the odd channel forms a dome-like shape while the resonant energy of the even channel decreases for increasing the doping level. Our results are in agreement with inelastic neutron scattering experimental results.

16P-B094 Field trapping property of HTS bulk magnet with reduced voids in pulsed field magnetizing process

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The field-trapping ability of melt-textured bulk superconductors is usually restricted by the mechanical properties because of the magnetic stress induced in the samples during the activation processes which give them intense magnetic fields of several T. Therefore it is of crucial importance to enhance the toughness of materials by means of reinforcing techniques. In this experiment, we adopted a dense Dy-based HTS bulk sample fabricated by means of controlling the concentration of voids inside it during the heat treatment. The single and iterative magnetic pulsed fields up to 7.66 T have been applied in the temperature range down to 31 K with use of GM refrigerator, and the profiles of pulsed fields and the resultant trapped fields are discussed with respect to their performances and distributions. It was found that the trapped field grows as expanding rise time of the pulsed field and lowering initial temperature, and that the trapped field distribution after the pulsed field application strongly affects to the resultant trapped field of the sample.

16P-C001 Spectral functions in the two-dimensional Hubbard model within a spin-charge rotating frame approach

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We have performed electronic spectral function calculations for the Hubbard model on the square lattice using recently developed quantum SU(2)×U(1) rotor approach that enables a self-consistent treatment of the antiferromagnetic state. The collective variables for charge and spin are isolated in the form of the space-time fluctuating U(1) phase field and rotating spin quantization axis governed by the SU(2) symmetry, respectively. As a result interacting electrons appear as composite objects consisting of bare fermions with attached U(1) and SU(2) gauge fields. This allows us to write the fermion Green’s function in the space-time domain as a product of the SU(2) gauge fields, U(1) phase propagator and the pseudo-fermion correlation function. Consequently, the calculation of the spectral line shapes now reduces to performing the convolution of spin, charge and pseudo-fermion Green’s functions. The collective spin and charge fluctuations are governed by the effective actions that are derived from the Hubbard model for any value of the Coulomb interaction. The emergence of a sharp peak in the electron spectral function in the antiferromagnetic state indicates the decay of the electron into separate spin and charge carrying particle excitations.

16P-C002 Ultra-sensitive measurement of magnetisation dependent chemical potential in ferromagnetic materials

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We quantify the chemical potential anisotropy in ferromagnetic materials. Aluminium single electron transistors (SETs) are lithographically fabricated on top of a planar gallium manganese arsenide substrate which acts as an electrostatic gate. The conductance variation of the SET provides a direct probe of the magnetisation dependent change in the chemical potential. These
experiments contrast with previous demonstrations of Coulomb blockade anisotropic magneto-resistance (CB-AMR) 1, 2 since, in our case, the electron transport is decoupled from the magnetic element. Furthermore, since any ferromagnetic material can be used as the electrostatic gate we demonstrate a universal technique to determine the magnetic anisotropy of the chemical potential.


16P-C003 A Haldane-Anderson model study for the iron spin and charge state in Myoglobin

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Heme metalloproteins are responsible for some of the most important biological process of life such as respiration and energy production. Their biological activity is known to be determined mostly by the spin state of the transition metal ions located in the center of their active sites1 Various quantum chemical ab initio methods based on the density functional theory (DFT) have been used to better understand the relation between the spin state and the protein functionalities. However, it is well known that the DFT-based methods often predict the electronic states of transition metals which are not consistent with experimental observations. 2 In this work, we propose a new approach to study the spin and charge states of the transition metal ions in metalloproteins. First, using standard DFT calculations, we construct a tight binding model Hamiltonian coupled to the transition metal ions. Next, we solve the model using various numerical methods developed recently in the field of strongly correlated electrons. We shall demonstrate our new approach applied to Myoglobin, one of the simplest metalloprotein.


16P-C004 Cantilever-detected high-frequency ESR measurement using a backward wave travelling oscillator

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Our cantilever-detected electron spin resonance (ESR) technique 3 is motivated for terahertz ESR spectroscopy of a tiny single crystal at low temperature. In this technique, ESR signal is obtained as a cantilever deflection, which is sensitively detected by a commercial pieoresistive microcantilever 2. So far, ESR detection at 315 GHz was succeeded using a Gunn oscillator. In this study, we combine our ESR technique with a backward wave travelling oscillator (BWO), which covers a wide frequency range 200-1200 GHz, to achieve better spectral resolution. Experiments were carried out at 4.2 K for a single crystal of Co Tutton salt with a newly constructed optical system. We successfully observed two ESR absorption lines in BWO frequencies up to 370 GHz. From multi-frequency measurements, the observed ESR lines shifted linearly with BWO frequency, being consistent with paramagnetic resonance. The estimated g values are g1 = 3.00 and g2 = 3.21. The spin sensitivity was estimated to ~1012 spins/gauss at 370 GHz.


16P-C005 A Haldane-Anderson model study for the iron spin and charge state in Myoglobin

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Heme metalloproteins are responsible for some of the most important biological process of life such as respiration and energy production. Their biological activity is known to be determined mostly by the spin state of the transition metal ions located in the center of their active sites1 Various quantum chemical ab initio methods based on the density functional theory (DFT) have been used to better understand the relation between the spin state and the protein functionalities. However, it is well known that the DFT-based methods often predict the electronic states of transition metals which are not consistent with experimental observations. 2 In this work, we propose a new approach to study the spin and charge states of the transition metal ions in metalloproteins. First, using standard DFT calculations, we construct a tight binding model Hamiltonian coupled to the transition metal ions. Next, we solve the model using various numerical methods developed recently in the field of strongly correlated electrons. We shall demonstrate our new approach applied to Myoglobin, one of the simplest metalloprotein.

interest for both experimenters and theorists for more than a half of a century. Most of physical quantities for spin-1/2 uniform Heisenberg antiferromagnetic chain (AFHC) were calculated accurately. Now, low energy excitations driven by anisotropy and frustration are being actively studied. KCuGaF$_4$ is spin-1/2 AFHC characterized by staggered field that induced perpendicular to applied magnetic field due to its low symmetric crystal structure. Because staggered field plays as anisotropy of exchange interaction in the system, the low energy excitation has a finite gap. It was shown that the excitation energy of the gap is described by elementary excitations in quantum sine-Gordon (SG) spin system.$^{1,2}$ We measured specific heat of KCuGaF$_4$ to investigate the thermodynamics governed by elementary excitations, solitons and breathers, characteristic of quantum SG model. Results will be discussed comparing with results of ESR measurement$^3$ and neutron scattering.


16P-C007 On the Nature of Nonlinearities in HTS Thin Films at Microwaves

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Abricosov magnetic vortices generation influence on nonlinearities in YBCO thin films on MgO substrates is researched in Hakki-Coleman Dielectric Resonator (HCDR) at frequency of 25GHz and in microstrip resonators at 1.985GHz. Microwave properties of MgO substrates are studied in split post dielectric resonator (SPDR) at 10.48GHz. Microwave power P was from -18dBm to +30 dBm. Temperature T was from 15K to 90K. YBCO thin films exhibited nonlinear characteristics in form of S-type dependence of surface resistivity, solitons and breathers, characteristic of quantum SG model. Results will be discussed comparing with results of ESR measurement$^3$ and neutron scattering.


16P-C008 Heat capacity and electrical resistivity of (Pb$_y$Sn$_{1-y}$)$_2$P$_2$S$_6$ chalcopyrites

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In this contribution we present the results of study of heat capacity and electrical resistivity of the chalcopyrites (Pb$_y$Sn$_{1-y}$)$_2$P$_2$S$_6$ where Pb content varies from 0 till 0.6. We have studied the low temperature behaviour of heat capacity from the point of Pb influence on change of phonon contribution. We used Debye and Einstein theory in order to fit the experimentally observed contribution. Moreover, we present the results of study of temperature dependence of electrical resistivity and influence of an applied magnetic fields up to 3 T. The electrical resistivity was studied in the temperature range 50 - 400 K due to low temperature semiconducting behaviour. We studied the influence of phase transition and relaxation processes.
The sign, magnitude, and range of exchange couplings between pairs of Mn ions is determined by high resolution magnetic measurements on thoroughly characterized Ga$_{1-x}$Mn$_x$N and Ga$_{1-x}$Mn$_x$Si epilayers with 1% < x < 3%. The findings allow us to verify a series of ab-initio predictions on the possibility of ferromagnetism in dilute magnetic insulators. We demonstrate that the coupling between neighbor Mn ions is ferromagnetic and it changes to antiferromagnetic when the charge state of the Mn ions is reduced from 3+ to 2+. However the coupling is found to be too short-ranged to lead to ferromagnetic ordering above 1.85 K in the studied Mn concentration range up to 3%.$^1$


16P-C011 Zero-field NMR of 59Co and 55Mn in a Heusler Alloy Co$_2$MnGa

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Zero-field NMR spectra of 59Co and 55Mn are reported for a bulk sample of Heusler alloy Co$_2$MnGa which is a potential candidate for half-metallic ferromagnet. An asymmetric spectrum of 59Co in Co$_2$MnGa has been interpreted as a sum of main peak due to Co sites with nearest-neighbors which consist of 4 Mn and 4 Ga in the L2$_1$ structure (6%), satellite signal due to Co sites with nearest-neighbors which consist of 3 Mn and 5 Ga (24%), one with nearest-neighbors which consist of 2 Mn and 6 Ga (8.6%), and one with nearest-neighbors which consist of 5 Mn and 3 Ga (1.4%). A spectrum of 55Mn in Co$_2$MnGa has been interpreted as a sum of main peak due to Mn sites with 8 nearest-neighbor Co sites in the L2$_1$ structure (81%), satellite signal due to Mn sites with nearest-neighbors which consist of 7 Co and 1 Mn (7.2%), one with nearest-neighbors which consist of 6 Co and 2 Mn (4.9%), one with nearest-neighbors which consist of 7 Co and 1 Ga (3.9%), and one with nearest-neighbors which consist of 5 Co and 3 Mn (3.2%). Atomic disorder in bulk material of Co$_2$MnGa is suggested to be less than that in Co$_2$FeAl, but larger than that in Co$_2$FeSi reported in literatures.$^{1,2}$


16P-C012 Heat capacity analysis of LaB$_6$

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Rare earth hexaborides (RB$_6$) have been attracting much attention because of variety of their electronic and magnetic properties, which include antiferromagnetic (R–Ce, Pr, Nd, Gd, Dy, Tb, Ho), ferromagnetic (EuB$_6$), intermediate valence (SmB$_6$) and heavy fermion behavior (CeB$_6$). At the same time nonmagnetic LaB$_6$ plays the important role in estimating of magnetic contribution of above mentioned systems.$^3$ The goal of present research is to investigate in details the heat capacity C$_p$(T) on the high quality single crystals of LaB$_6$ with the various boron isotopic content (N= 10, 11, 12) in the wide range of temperatures 2-300 K and in magnetic fields up to 9T. The data obtained allow to estimate correctly (i) the electronic component with $\gamma \sim 2.4mJ/(molK)$, (ii) contribution from quasilocal vibrational mode of La$^{3+}$ ion with $\Theta_D \sim 152K$, (iii) the Debye-type term from boron cage with $\Theta_B \sim 1160K$ and (iv) the low temperature defect mode component.$^2$ The quantitative analysis of each contribution is presented.$^4$


16P-C013 Effect of nonstoichiometric aluminum composition on magnetic properties of Fe$_2$VAl system

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Heusler-type Fe$_2$VAl compound shows semiconducting-conducting behavior up to 1300 K and is known as a semimetal with a pseudo-gap at the Fermi level. Magnetic susceptibility of Fe$_2$VAl shows a Curie-Weiss-like behavior whereas band calculations tell that Fe$_2$VAl is nonmagnetic. The magnetic moment in Fe$_2$VAl arises from magnetic Fe cluster, caused by a wrong occupation of V sites by Fe atoms, with a localized nature. Recently, however, Sato et al. reported that itinerant ferromagnetic behavior of Fe$_2$VAl$_{0.95}$ with Curie temperature $T_C=33 K$.$^1$ They suggested that the AI site with Fe and V atoms results in itinerant ferromagnetism with a low carrier density. In this study, we have prepared polycrystalline samples of Fe$_2$VAl$_{1-x}$(x $\leq$ 0.06) with nonstoichiometric aluminum composition and measured magnetization by a SQUID magnetometer to clarify the critical composition of AI to induce itinerant magnetism. With decreasing AI composition up to $\delta = -0.03$, both Curie temperature and susceptibility at 5 K increased and then decreased below $\delta = -0.04$.$^1$


16P-C014 BEC of Non-Equilibrium Quasiparticles in 3He and Beyond

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16P-C015 High-field study of magnetization and magnetoacoustics in UCo$_2$Si$_2$

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Magnetic and magnetoacoustic properties in uranium antiferromagnet UCo$_2$Si$_2$ have been studied at 1.4-100 K. Since the uranium compounds have huge magnetic anisotropy, the study has been performed on the single crystals (grown by the Czochralski method in a tri-arc furnace) in pulsed magnetic fields up to 60 T. The U magnetic moments of 1.4 $\mu_B$ in UCo$_2$Si$_2$ ($T_N = 82.5$ K) lie along the $c$ axis of the tetragonal lattice. The ferromagnetic $c$-planes alter along the $c$ axis in a simple + sequence. In magnetic fields applied along the $c$ axis, we observed the metamagnetic transition (MT) in 45 T (at 1.4 K). The MT is extremely sharp and is certainly of the first order, but exhibits a very small hysteresis. With increasing temperature, the MT becomes broader and vanishes at $T_N$. The magnetization gain upon the MT corresponds roughly to 1/3 of the U magnetic moment. For this reason, we suppose that the state above the MT is ferrimagnetic with the $+++$ arrangement of the magnetic moments like in the isostructural analogue UNi$_2$Si$_2$ where this magnetic structure is realized in the ground state. In fields applied along the $a$ axis of the UCo$_2$Si$_2$ single crystal, only a linear paramagnetic behavior with weak temperature dependence is observed. The ultrasound measurements confirm the transition, which is accompanied by very sharp anomalies in both sound velocity and sound attenuation, and show its rather complicated temperature evolution.

16P-C016 Mechanism of the metal-insulator transition of hollandite vanadate K$_2$V$_8$O$_{16}$

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We make the electronic structure calculations of hollandite vanadate K$_2$V$_8$O$_{16}$ using the generalized gradient approximation (GGA) in the density functional theory, where the Hubbard-type repulsive interaction is taken into account (GGA+$U$). We in particular calculate the electronic structure of the low-temperature phase of this material using the crystal structure reported by Komarek [1]. We thereby find that the electronic wave functions near the Fermi level are predominantly of the $d_{xy}$ character and form the quasi-one-dimensional energy bands. The energy bands are made of the single chains of the VO$_6$ octahedra rather than the double chains. The effects of strong electron correlations play an essential role here. Based on these results, we discuss the origins of the observed metal-insulator transition of the material. Details will be reported in Ref. [2].


16P-C017 Magnetic Properties of La$_{2-x}$Sr$_x$CuO$_4$ Nanoparticles in Mesoporous Silica

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Parent compound La$_2$CuO$_4$ of high temperature superconductor La$_{2-x}$Sr$_x$CuO$_4$ (LSCO) has antiferromagnetic ordering with $T_N \approx 320$ K. As Sr concentration, $x$, increases, the LSCO exhibits sharp decrease in $T_N$, and then shows superconducting state ($0.05 < x < 0.26$) below $T_c \approx 40$ K. The magnetic measurement results for the La$_2$CuO$_4$ with particle size of 0.22-4.1 $\mu$m suggest formation of ferromagnetic anisotropic single-domain clusters at the grain surface. We are interested in the size effects on LSCO nanoparticles with particle size of a few nano-meters. We synthesized LSCO ($x = 0$ and 0.15) nanoparticles in the pores of mesoporous silica SBA-15 and investigated their size effects through magnetic and ESR measurements. X-ray diffraction results indicate formation of the LSCO nanoparticles with particle size of about 11-13 nm. The magnetization curves for $x = 0$, show rapid increase under low magnetic field as in ferromagnetic materials, and the magnetization increases linearly without saturation tendency. In contrast, the magnetization for $x = 0.15$ consistently increases in proportion to magnetic field. The ESR absorption spectra for both $x = 0$ and 0.15 at 77 and 300 K are reproduced by summation of two absorption lines. These experimental results for nanoparticles show the...
different behaviors from those for bulk crystals and suggest the coexistence of two magnetic components.  

16P-C018 Orbital Glass State And Magnetic Anomalies In CoV₂O₄

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In this paper, we investigate the electric, magnetic, structural and thermal properties of spinel CoV₂O₄. Temperature dependence of magnetization shows that in addition to the para-magnetic to ferrimagnetic transition at 142 K two magnetic anomalies exist at 100 K, 59 K. Consistent with the anomalies the thermal conductivity presents two valleys. The heat capacity shows one peak at 59 K, which can not be attributed to the structural transition as revealed by the X-ray diffraction patterns for CoV₂O₄. The AC susceptibility displays the characters of spin glass below the transition temperature T₁ =59 K. By means of the super-exchange mechanism, the phase transition at 59 K is found to be para-orbital to orbital glass transition, which is in agreement with the experimental results. As the Zn²⁺ doping contents increases on A sites, the magnetic anomaly, the valley in thermal conductance and the spin glass behaviors around T₁ becomes weakening to vanishing, which implies the gradual melting of orbital glass.

16P-C019 Disorder Induced Orbital Glass State in FeCr₂S₄

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Effect of disorder on orbital state in spinel FeCr₂S₄ has been investigated with the substitution of Cr by Al, Ga, and Fe, respectively. For polycrystalline FeCr₂S₄, being related to orbital ordering transition around 9 K, temperature dependence of magnetization shows a step-like transition, and specific heat displays a well-defined Λ-type anomaly correspondingly. However for single crystal and the doped FeCr₂S₄ samples, the step-like transition in magnetization disappears, and the Λ-type anomaly of specific heat is replaced by broad hump. Moreover, the specific heat obeys a T² dependence at temperatures below 2 K, suggesting the formation of orbital glass state in these samples. In consistent with different orbital states, the resistivity at low temperature can be better fitted with thermal activated model for polycrystalline FeCr₂S₄ sample, and better described by Mott’s variable-range hopping expression for the others. All these results imply that the disorder induces orbital glass state in FeCr₂S₄.

16P-C020 Magnetic Phase Transition of the Mixed Antiferromagnets Ni₁₋ₓAₓC₁₂·2H₂O (A=Co, Mn)

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Mixed antiferromagnets Ni₁₋ₓC₀ₓC₁₂·2H₂O and Ni₁₋ₓMnₓC₁₂·2H₂O were prepared. The crystal structure of NiC₁₂·2H₂O is different from that of CoC₁₂·2H₂O and MnC₁₂·2H₂O. It is a purpose to examine how Co or Mn spins in NiC₁₂·2H₂O crystal structure behave. We determined precisely the phase transition temperatures by measuring the specific heats and have obtained the concentration dependence of the phase transition temperature. Substitution of Co for Ni increases a little the transition temperature and contrary to this the substitution of Mn decreases the transition temperature rapidly. The results are discussed on the basis of molecular field theory. In the case of Ni₀₋ₓC₀ₓC₁₂·2H₂O, the concentration dependence of the phase transition temperature is well explained by molecular field theory. But, in the case of Ni₁₋ₓMnₓC₁₂·2H₂O molecular field theory cannot explain sufficiently. Thus Mn spins in NiC₁₂·2H₂O crystal show the peculiar behavior. We suppose that this may be attributed to a kind of the instability of Mn spins.

16P-C021 Low-lying spin excitations due to Next-Nearest Neighbour interactions in Ferromagnetic lattices

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Spin excitations due to next-nearest neighbour (NNN) interactions are considered in a simple cubic (SC) and body-centered cubic (BCC) ferromagnetic lattices. Using the three dimensional Heisenberg model, the spin wave dispersions are calculated at low temperatures wherein the system is near the ground state. Threshold ratios between the NNN and NN interactions are found for both lattices that induces two degenerate states with spin wave energies lower than the ground state for wave vectors 0 ≤ q ≤ 2π/a, where a is the lattice constant. Hence NNN interactions can influence many-body phenomena due to fluctuations in the system’s magnetic ordering such as transport of spins and high-temperature superconductivity.

16P-C022 Magnetization and spin polarization of Co₀₋ₓFeₓMnSi Heusler alloys

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We report the magnetization and spin polarization of Co₀₋ₓFeₓMnSi Heusler alloys. Co-based Heusler alloys are the most promising materials for spintronic applications, such as the tunneling magnetoresistance and current-perpendicular-to-plane giant magnetoresistance devices. These alloys are theoretically predicted to be half-metals and generally possess high Curie temperature. We have investigated the magnetization and spin polarization of Co₀₋ₓFeₓMnSi Heusler alloys. The
Rietveld refinements of X-ray powder diffraction patterns showed that all the Co$_{x-2}$Fe$_2$MnSi Heusler alloys had an L2$_1$-type structure without impurity phases. The result of magnetization measurements for $x > 0.5$ coincided with the saturation magnetization expected from the Slater-Pauling rule. This indicates experimentally that Co$_{x-2}$Fe$_2$MnSi Heusler alloys for $x = 0.5$ are expected to be half-metals. Hence, the spin polarization of Co$_{x-2}$Fe$_2$MnSi Heusler alloys was determined by the Andreev reflection technique using planar-type Pb/Co$_{x-2}$Fe$_2$MnSi junction. The differential conductance was able to be fitted very well by the modified Blonder-Tinkham-Klapwijk theory with three parameters: spin polarization, superconducting energy gap, and potential barrier height. We found that the spin polarization changed from 0.42 to $x = 0.75$ to a maximum value of 0.52 for $x = 2$.

16P-C023 Spin polarized conductance in ferromagnet / insulator / conventional superconductor junctions

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The modified Blonder-Tinkham-Klapwijk (BTK) theory has been successfully used to describe the current-voltage characteristics of ferromagnet / insulator / conventional superconductor contacts. The spin polarization $P$ of the Andreev reflection measurements for ferromagnetic materials has been normally determined by using the modified BTK theory. However, the modified BTK theory assumes the elementally sum of only two currents of the fully-polarized state and the non-polarized state. Therefore, based on the BTK theory, we here suggest another theoretical model of the spin polarized conductance $\sigma(eV)$ in the system of ferromagnet / insulator / conventional superconductor contacts. We consider the exchange potential $U_{ex}$ of the ferromagnetic materials corresponding to the parameter of the spin polarization. The zero-bias conductance $\sigma(0)$ gradually decreases with the increase of $U_{ex}$ because the Andreev reflection is suppressed at the junction interface of ferromagnet / superconductor contacts in the case of finite values of $U_{ex}$. Finally, we discuss fitting results of $\sigma(eV)$ and $P$ for Heusler alloy/Pb planar junctions with the theoretical model.


16P-C024 Ultrasonic Investigation of Ground State of Vacancy Orbital in Boron-Doped Silicon

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We have made low-temperature ultrasonic measurements on elastic constants of boron-doped silicon single crystals grown by a floating zone (FZ) method in order to study the ground state of a vacancy orbital. Although the silicon single crystal is considered to be one of the most pure and ideal crystals, there exist two native point defects of a vacancy and silicon-interstitial. In particular, the vacancy plays important roles for dopant diffusion, oxygen precipitate in silicon wafers used for electronic device fabrications. The elastic constants $C_{11}$, $C_{44}$, $(C_{11} - C_{12})/2$ and $C_{L[11]}$ of the boron-doped silicon show a softening with decreasing temperature below 20 K down to 20 mK in zero field. The elastic softening is suppressed with increasing applied magnetic field of up to 10 T and shows anisotropic behavior depending on the field directions. The softening and magnetic field dependence of the elastic constants of the boron-doped silicon are well described in terms of electric quadrupole susceptibility for the vacancy orbital with a $T_g$ quartet ground state in a charge state $V^+$ accommodating three electrons.

16P-C025 Conduction Electron States and Ferromagnetism of Electron-doped EuO

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Based on a simple model, we have studied the conductance states and ferromagnetism of Gd-doped EuO (Gd$_{x}$Eu$_{1-x}$O) theoretically. The model is an extension of s-f model that has been studied for the conduction states of Eu chalcogenides, and includes not only the exchange interaction between a conduction electron and localized $f$ spins but also the nonmagnetic local potential due to the random substitution of Eu$^{2+}$ ion by Gd$^{3+}$ ion in regular EuO lattice sites. We have tried two approaches to the model and compared the results: virtual crystal approximation (VCA) and the dynamical coherent potential approximation (Dynamical CPA).1 The results are compared with the Z dependence of Curie temperature $T_C$ experimentally observed by Sutarto et. al.2 The origin of anomalous magnetization is also discussed. Based on the density of states (DOS) calculated by dynamical CPA, we also discussed the temperature dependence of the optical band edge of Gd$_{x}$Eu$_{1-x}$O observed by Mastumoto et. al.3

1 M. Takahashi, Materials 3, 3740 (2010).

16P-C026 Diamagnetism and electron transport in organic layered conductors

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We have studied theoretically the magnetic susceptibility, magnetoresistance and thermoelectric field in organic layered conductors with an arbitrary form of the electron energy spectrum, which are placed in a quantizing magnetic field at low temperature $T$. At temperatures much lower than the separation between the electron energy levels of charge carriers $\hbar \omega$, quantum oscillations of the magnetization and kinetic coefficients con-
tains the detailed information about energy spectrum and relaxation properties of charge carriers. No less important information may be obtained at $T \gg \hbar \omega_c$. In particular, investigation of the $T$-dependence of the magnetic susceptibility at different orientations of the magnetic field enables the diamagnetic and paramagnetic contributions to the magnetization to be separated. Studies of the dependence of the magnetoresistance on the magnetic field orientation with respect to the layers makes it possible to determine the contribution to the electron transport from different charge carriers groups. In the magnetic field parallel to the layers the magnetization is mainly originated from the spin-splitting of the electron energy levels. Investigation of the $T$-dependence of the thermoelectric field allows to study different relaxation mechanisms in electron system.

Session 16P-D:

D4 2DEG-related Transport and Devices
D6 Graphene / Dirac Electrons
D8 Molecular Electronics

Tuesday August 16, 16:00 – 18:00

Exhibition Hall 1

16P-D005 Ferromagnetic-Paramagnetic Transition in a Tilted Magnetic Field in p-Si/ SiGe/Si Quantum Wells

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Magnetoresistance components $\rho_{xx}$ and $\rho_{xy}$ were measured in two $p$-Si/SiGe/Si quantum well samples with an anisotropic g-factor in a tilted magnetic field of up to 18 T as a function of temperature (20mK-2 K) and tilt angle. We analyzed dependences of the conductivity, its components, the thermoelectric field, and the asymmetry of the heterostructure. The asymmetry of the heterostructure is in itself a form of structural disorder.

16P-D006 The Interplay of Rashba Spin-Orbit Interaction and Landau Level Broadening on a Two-Dimensional Electron Gas Under a Tilted Magnetic Field

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A two-dimensional electron gas in a tilted magnetic field with Rashba spin-orbit interaction was studied. Assuming that opposite spin states of adjacent Landau levels have equal probability, an analytic solution was obtained. The eigenvalues show that tilting the magnetic field lifts the degeneracies brought about by the crossings of energy levels that are normally present in the perpendicular-magnetic-field case. The absence of the crossings resulted to the suppression of the beats in Shubnikov-de Haas oscillations. The Landau level broadening is attributed to disorder while the Rashba spin-orbit interaction (RSOI) is accredited to the asymmetry of the heterostructure where the two-dimensional electron gas is found. Increased Landau level broadening smears the oscillations in the density of states. In contrast, stronger RSOI amplifies them since it is a source of spin-splitting at zero or weak magnetic fields. On the other hand, both the broadening and the RSOI shift the chemical potential to higher values. The similarity in effects can be explained by recognizing that the asymmetry of the heterostructure is in itself a form of structural disorder.

16P-D007 Quasiparticle tunneling in fractional quantum Hall liquids

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Motivated by quasiparticle interference experiments, we discuss the tunneling amplitude for a quasiparticle tunneling along a straight path between the two edges of a fractional quantum Hall annulus. In the Moore-Read state, quasiparticles of charge $e/4$ (non-Abelian) and $e/2$ (Abelian) may co-exist and both contribute to edge transport. The tunneling amplitude for charge $e/2$ quasihole is exponentially smaller than that for charge $e/4$ quasihole, and the ratio between them can be partially attributed to their charge difference. In addition, the tunneling amplitude exhibits scaling behavior originated from the propagation and tunneling of charged quasiparticles in an effective field analysis. The scaling exponent is found to be related to the conformal dimension of the quasiparticles. In the Read-Rezayi $Z_{4k}$-parafermion states, the non-Abelian quasiparticle tunneling amplitudes exhibit nontrivial $k$-dependent cor-
16P-D008   Activated transport in the \( \nu = 1 \) bilayer quantum Hall states with small tunneling energy \( \Delta_{\text{SAS}} = 1 \text{K} \)

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The bilayer quantum Hall state (BQHS) has served as a good example of strongly correlated two-dimensional electron systems having the layer degree of freedom called pseudospin. These correlations manifest themselves in a variety of topological objects involving spins and/or pseudospins. In particular, the Landau level filling factor \( \nu = 1 \) BQHS can be interpreted as an ideal pseudospin XY-ferromagnet, where twin half-quantized vortices of pseudospins called “meron-pair” play an important role in the activated transport. A key feature of the XY-ferromagnet is to detect the Kosterlitz-Thouless (KT) phase transition. We carried out magnetotransport experiments in the \( \nu = 1 \) BQHS using a GaAs/AlAs double-quantum-well sample with tunneling energy as small as 1 K. We especially focus on activation energies and onset temperatures of the BQHS for a wide range of the total density and the layer density imbalance. We have found that the dependency of onset temperature on the total density is different from that of the activation energy. In this conference, we discuss possible phase transitions and topological excitations in the \( \nu = 1 \) BQHS from our experimental results.

16P-D009   Anisotropic nuclear spin relaxation and dynamic polarization rates in the \( \nu = 2/3 \) quantum Hall states

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The Landau level filling factor \( \nu = 2/3 \) quantum Hall states (QHSs) have been getting much attention to realize the spintronics or quantum computing device, owing to the controllability of their electron spin degeneracy. Furthermore, thanks to the weak hyperfine coupling between electron and nuclear spins, a long coherence time of nuclear spins, essential for such quantum devices, can be expected. However, detailed mechanism for the dynamic nuclear polarization (DNP) and spin relaxation, including the morphology of the domain structure consisting of the spin-polarized and spin-unpolarized states, has been unclear. We carried out magnetotransport experiments around the spin transition point in the \( \nu = 2/3 \) QHSs under the in-plane magnetic fields \( B_{//} \), where magnetoresistance is believed to reflect the polarization of nuclear spins. We observed the highly anisotropic spin relaxation time and DNP rate for various source-drain currents \( I \) by mainly comparing with different source-drain currents \( I \) by mainly comparing with different configurations: \( I \perp B_{//} \) and \( I \parallel B_{//} \). In the conference, we present the quantitative analysis of the rate of DNP and relaxation, and infer an anisotropic geometrical domain structure.

16P-D010   Meron-Pair Excitations in Imbalanced Bilayer Quantum Hall Systems

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The bilayer quantum Hall (BQH) system is exceedingly interesting owing to quantum coherence associated with the spin and layer degrees of freedom[1], where the layer degree of freedom introduces a pseudospin into the system. We study the BQH system by changing the density ratio \( \sigma_0 \) between the two layers, where \( \sigma_0 = 0 \) (\( \sigma_0 = 1 \)) represents the balanced configuration (the monolayer limit). The BQH system behaves as if it were an easy-plane ferromagnet with pseudospin SU(2) skyrmion excitations at \( \sigma_0 = 0 \), while it behaves as if it were an easy-axis ferromagnet with spin SU(2) skyrmion excitations at \( \sigma_0 = 1 \). The activation energy exhibits entirely different behaviors when the parallel magnetic field \( B_0 \) is applied. It rapidly decreases at \( \sigma_0 = 0 \), but rapidly increase at \( \sigma_0 = 1 \). The decrease occurs due to the loss of the exchange energy, while the increase occurs due to the Zeeman energy. We analyze in detail how an SU(2) skyrmion at \( \sigma_0 = 0 \) evolves continuously into another SU(2) skyrmion at \( \sigma_0 = 1 \) via an SU(4) skyrmion at \( \sigma_0 = 1 \). The qualitative results explain the experimental data[2] quite well.


16P-D011   Extremely long relaxation times of dynamically polarized nuclei in 3-electron spin-blockade regime in GaAs vertical double quantum dot

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We report about recent study of GaAs vertical double quantum dot. The charge stability diagram of investigated sample shows clear spin blockade area in the vicinity of N=3 Coulomb diamond in the external magnetic field of 3 T. This 3-electron spin blockade is formed when the charge transport through double dot is stuck in 3-electron (1s, 1s1p) charge state, with all the spins aligned, and Pauli exclusion principle preventing (1,2) - (0,3) transition. Within the spin-blockade area, dependence of current through the dot on source-drain voltage shows some steplike features. Position of these features clearly depends on prehistory of measurement.
indicating some mechanisms of dynamic nuclear polarization. We study this dependence in detail and develop a phenomenological model. Within the model, we show that nuclei could be polarized in both directions relative to external field, depending on pumping conditions. Furthermore, we study relaxation of pumped nuclei under several conditions, and find out that relaxation times can be really long, so it takes about one day for nuclei to relax completely. We also investigate temperature dependence of relaxation in the range of 200 mK - 1 K. A. O. B. and D. A. T. are supported in part by Ministry of Education and Science of Russian Federation (contract 02.740.11.0797)

16P-D012 Spin-Dependent Scattering in a Phosphorus Doped Silicon MOSFET

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We report evidence for spin-dependent scattering of conduction electrons off neutral donors in a silicon transistor. The technique of electrically detected magnetic resonance is used to observe the hyperfine splitting of phosphorus donors present in the crystal. An on-chip transmission line is used to generate the oscillating magnetic field allowing broadband operation. The donor spin resonance signal was studied as function of microwave power and the biasing conditions of the transistor. Power broadening of the hyperfine lines is observed in the high power regime, which allows us to relate the power to the magnetic field. The signal intensity scales with the square root of the microwave power, which agrees with spin-dependent scattering theory.

Fitting our data with this theory allows us to extract the electron spin relaxation time $T_1$ of a donor a certain distance away from the Si/SiO$_2$ interface.


16P-D013 Coincidence of the Landau levels in wide HgTe quantum well

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The magnetoresistance components $\rho_{xx}$ and $\rho_{xy}$ were measured in tilted magnetic fields of up to 18 T at temperatures down to 20 mK in a symmetrically doped n-Cd$_x$Hg$_{1-x}$Te/HgTe/Cd$_x$Hg$_{1-x}$Te heterostructure with the quantum well thickness of 20 nm (and the inverted band structure) grown on a (013) GaAs wafer. The electron density $n = 1.6 \times 10^{11}$ cm$^{-2}$, and mobility $\mu = 28$ m$^2$/Vs were calculated from the results acquired in the perpendicular magnetic field. Coincidences of the quantum levels at small filling factors $2 \leq n \leq 8$ were observed on $\rho_{xx}$ and $\rho_{xy}$ at the tilt angle values of about 67, 78, and 83°. We compared our data with the Landau level spectrum in the tilted magnetic field, calculated using a 4-band model for the HgTe quantum well. We obtained good quantitative agreement for the Landau level crossing points, which allowed us to extract the band structure parameters, such as the Dirac velocity, band gap, effective masses and anisotropic $g$-factors, used as fitting variables.


16P-D014 Quantum Point Contact Transistor and Ballistic Field-Effect Transistors

E. Grémion, B. Niepce, A. Cavanna, U. Gennser, Y. Jin, CNRS, Laboratoire de Photonique et de Nanostructures, Route de Nozay, 91460 Marcoussis, France. 2DEG (Two-Dimensional Electron Gas). For turning such 1D devices into real ballistic FETs as building blocks - switches - for digital integrated circuits, the key point is to obtain a voltage gain greater than 1. And the maximum FET voltage gain is determined by the ratio of its transconductance over its output conductance. We report here experimental results and theoretical understanding of the Quantum Point Contact Transistor - a fully ballistic 1D FET. Experimentally obtained voltage gain greater than 1 in our QPC devices at 4.2 K can be explained with the help of an analytical modeling based on the Landauer-Buttiker approach in mesoscopic physics, the lowest 1D subband plays the key role to increase its transconductance, especially reduce its output conductance and thus to achieve a voltage gain higher than 1.

This work provides a general basis for devising future ballistic FETs and quantum limits found in this work may be used to estimate normalized transconductance and channel resilience in 2D FETs.


16P-D015 Depression of positive magneto-conductance due to anti-weak localization effect in annealed In$_2$O$_3$-ZnO thick films

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The depression of positive magnetoresistance caused by anti-weak localization effect was observed in annealed In$_2$O$_3$-ZnO thick films.
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For thick (In$_2$O$_3$)$_{0.965}$-(ZnO)$_{0.035}$ films with different resistivity $\rho$ by post annealing in air, we have investigated $\rho(T)$ characteristics and magneto-conductance $\Delta\sigma$. The weak localization theory for the 3D system has been fitted to data of $\Delta\sigma(T)$ at temperatures below 50 K by the use of suitable inelastic scattering time $\tau_{in}$ and $\tau_{so}$. We have found the $\rho$ dependences of both times $\tau_{in}$ and $\tau_{so}$ for films with $4\times10^{-6}$ $\Omega$m $<$ $\rho(300 K)$ $<$ $1.5\times10^{-3}$ $\Omega$m. As increasing of $\rho$, the ratio of $\tau_{so}/\tau_{in}$ decreases from $\approx4\times10^5$ to $\approx10$ and then, the sign of $\Delta\sigma$ at low temperatures changes from positive to negative. This means localization changes to anti-localization due to the heat treatment. However, strong $\rho$ dependence of the ratio $\tau_{so}/\tau_{in}$ cannot be explained by the simple free electron model under the assumption that the S-O scattering originates from the same atom in the whole region of $\rho$. We suggest a picture that the annealing in air brings the change of the S-O scattering atom from light to heavy atoms, namely, oxygen to indium and/or zinc atoms.

16P-D016 Observation of dynamic nuclear polarization in a high-mobility low-density two-dimensional electron system

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Electron-nuclear spin systems in semiconductors have attracted a great deal of interest because of their potential applications for the emerging field of quantum information processing. Both electron and nuclear spin qubits are promising candidate for solid state quantum computation and they are coupled with each other via hyperfine interaction. It is thus necessary to understand the electron-nuclear spin dynamics in semiconductors from a basic point of view. In this work, we investigated the hyperfine interaction of electron and nuclear spins by using acousto-optical modulator integrated into our time-resolved Kerr rotation setup in a high-mobility low-density two-dimensional electron system. The dependence of the oscillation period versus external magnetic field on the pump helicity revealed the contribution of the Overhauser field. We calculated the magnitude of Overhauser field along the external field $B'_N$: it invert direction when the pump polarization is changed to the opposite with a similar strength. Furthermore, we showed the pump power dependences of $B'_N$ quantitatively. High pump light power reduces $B'_N$ as a result of decreasing time-averaged electron spins due to excessive excitation of holes and unpolarized electron spins, respectively.

16P-D017 Radiation modulation effect of circular photogalvanic effect in two-dimensional electron gas system

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We report on the observation of a modulation on the circular photogalvanic effect (CPGE) 1 imposed by an extra optical radiation in a GaAs-based two-dimensional electron gas system. The wavelength of the radiation for exciting the CPGE is 1064 nm and the wavelength of the modulation is 532 nm. The experiment is carried out from 77 K up to room temperature. The 1064 nm induced CPGE modulated by the 532 nm radiation increases as the increasing temperature. We also vary the power of the modulation beam to investigate the intensity dependence of the modulation effect. The modulation exhibits a linear dependence at low intensity. As the intensity increasing, we observe a saturation at certain level of the intensity and a suppression of the modulation when the intensity is further increased. The investigation of photoconductivity reveals that the change of the photoexcited charge carrier density has little contribution to the radiation modulation effect. Therefore, the microscopic mechanism of the radiation modulation effect can be attributed to the modulation of spin-orbit interaction in the structure.


16P-D018 Nonlinear Transports of Electrons on Liquid 4He in a 1.6 $\mu$m Channel

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Two-dimensional electrons floating on the surface of liquid 4He form a Wigner crystal at low temperatures accompanied with the commensurate deformation of the surface. The coupling of the Wigner crystal with the surface deformation gives rise to peculiar transport properties. Especially at low frequency transports, the Wigner crystal shows the nonlinear behavior associated with the resonant scattering of surface waves caused by the Bragg-Cherenkov (BC) mechanism 1, and it occurs only when the electrons form the crystal structure with the surface deformation. Here we have investigated the nonlinear properties associated with the BC scattering in the quasi-one-dimensional geometry with a few electrons in the confined direction. Because of the fluctuation due to long-wave thermal phonons, no long-range crystalline order is expected for the quasi-one-dimensional crystal, and therefore it is not clear whether the BC scattering would occur. The quasi-one-dimensional electron system is implemented by confining electrons in a channel 1.6 $\mu$m in width. In this channel, only one or two electrons can be present in the confined direction, according to our numerical calculation of the electron distribution in the channel. We observed the clear nonlinear behavior associated with the BC scattering, indicating that the electrons form a crystal-like structure in the channel even though such a small number of electrons are present in the confined direction.

1 M. I. Dykman and Yu. G. Rubo, Phys. Rev. Lett. 78, 4813
16P-D019 Lasing and Transport in a Quantum Dot-Resonator System
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Circuit quantum electrodynamics (cQED), one of the applications of quantum information processing with solid state devices, allows exploring quantum optics effects in new parameter regimes, incl. strong coupling and low temperature, where qualitatively novel behavior has been observed. An example is lasing with a single superconducting qubit which is strongly coupled to an oscillator, where quantum noise influences the linewidth of the emission spectrum in a characteristic way. We propose a different cQED setup, where the role of an artificial atom is played by a semiconductor double quantum dot. A current through the dot system can create a population inversion in the dot levels and, within a narrow resonance window, a lasing state in the resonator. The lasing state correlates with the transport properties. On one hand, it allows probing the lasing state via a current measurement, which may be easier to perform in an experiment. On the other hand, the resulting narrow current peak opens perspective for applications of the setup for high resolution measurements. The effects survive for realistic strength of the dissipative processes. P.Q. Jin et al., arXiv:1103.5051 [cond-mat.mes-hall]

16P-D020 Pervoskite ABO3 Thin Film Growth by Ozone Assisted Molecular Beam Epitaxy
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Ozone assisted Molecular Beam Epitaxy is a powerful tool for the growth of good quality oxide thin film, with two principal modifications of the traditional molecular beam epitaxy technique. The first modification is the creation of an oxidizing ambient; in our case, we have chosen pure ozone produced by a distillation process. The second modification is the inclusion of an in situ non-invasive measurement of atomic fluxes in real time. With atomic layer-by-layer growth, we have successfully grown SrTiO\textsubscript{3} thin film by this modified Ozone assisted MBE system. In-situ ARPES measurement is conducted on the epitaxial film. In spite of some band shift induced by charging effect, the clear valance band peak indicates high crystal quality and clean surface. For future plan, other transition metal pervoskite ABO\textsubscript{3} thin film such as La\textsubscript{1-x}SrxMnO\textsubscript{3}, La\textsubscript{1-x}SrxTiO\textsubscript{3} will be grown and investigated by in-situ ARPES measurement, to reveal the rich physics of transition metal oxide and the interaction between thin film and substrate.

16P-D021 Mobility of Electrons on Helium Film Capillary Condensed on a Two Dimensionally Corrugated Surface of Dielectric Substrate
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Electrical conductivity of electrons on helium film covering a two dimensionally corrugated dielectric substrate was measured in a temperature interval from 0.4 to 1.5 K by using a Corbino electrode. As the temperature decreases from 1.5 K, the electrical conductivity decreases and approaches gradually to zero around 0.4 K. This temperature dependence is different from that measured in 2D electron system on bulk liquid helium. In order to understand the effect of the dielectric substrate, the dependences of electrical conductivity on magnetic field were measured and the mobilities were evaluated in different temperatures. The results revealed that the mobility of electrons increases as the temperature decreases. Combining the data of electrical conductivity and the mobility, it is deduced that the decrease in conductivity as the temperature decreases is due to the decrease in number of mobile electrons.

16P-D022 Magnetotransport of gate confined cavities
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The two dimensional electron gas (2DEG) that forms at the interface of a GaAs/Al\textsubscript{0.3}Ga\textsubscript{0.7}As heterostructure was grown using molecular beam epitaxy at the Wiegmann Institute in Israel. Electrons can be confined in a small region forming a cavity by negatively biasing a pair of metallic gate, depleting the 2DEG ~ 93nm beneath the surface. Cavities with topological area of around 0.5μm\textsuperscript{2} are studied. Conductance oscillations are present in conductance-gate voltage characteristics and source-drain spectroscopy. In the presence of perpendicular magnetic field, two quantum interference effects take place in longitudinal resistances. In high magnetic fields, resistance oscillation occurs at a periodicity of magnetic flux due to Aharonov-Bohm effect. In low magnetic fields, a negative magnetoresistance is obtained and can be ascribed to weak localization effect. By varying confined gate voltage, the line shape of low field MR would transit from Lorentzian linear to Breit-Wigner resonance. This work was supported by NSC grant in Taiwan under project No NSC99-2112-M-009-007 and MOE ATU program.

16P-D023 Transport Properties of Sn and SbI\textsubscript{3} Doped Single Crystal p-Bi\textsubscript{2}Te\textsubscript{3}
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This work was supported by RFBR grant (10-02-90182-a; 11-02-90090-a). The samples were grown by the Czochralski method at the Institute for single crystal growth, the Lebedev Research Institute, Russian Academy of Sciences, Moscow, Russia.
Traditionally impurity energy states fall in the band gap, which leads to statistical distribution of free carriers, contributing to spatial inhomogeneity, and small high-field Shubnikov-de Haas (SdH) oscillations in solid solutions of Bi$_2$Te$_3$ – Sb$_2$Te$_3$, the most common room temperature thermoelectrics. However, in these solid solutions with Sn impurity, the Sn states pin the Fermi level and tremendously improve the spatial homogeneity of carriers. This results in observation of high-amplitude SdH oscillations in lower magnetic field. The Fermi level was estimated to be at the top of the second valence band (heavy holes). However, the additional doping has not been studied. We chose Bi$_2$Te$_3$ doped with Sn and I impurities to shift the Fermi level and investigate the model that best fits the Sn states. The introduction of similar levels of concentration for the two dopants preserves the Sn impurity states but affects the filling factor. Our results of SdH effect show different frequencies around 4.2 K for samples with 0.05 % and 0.1 % of I and no feature in specific heat at low temperature. This indicates that the model for one-electron states in Bi$_2$Te$_3$ doped with Sn is that of two impurity bands with the Fermi level pinned in-between.


16P-D024 Single-electron shuttle in a silicon quantum dot

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We report on single-electron shuttling experiments with a silicon quantum dot. An electron layer is accumulated at the Si/SiO$_2$ interface below an aluminum top gate with two additional barrier gates used to deplete the electron gas locally and to define the quantum dot. Directional single-electron shuttling from the source and to the drain lead is achieved by applying a dc source–drain bias while driving the barrier gates with an ac voltage at frequency $f$. Current plateaus at integer values of $ef$ are observed up to $f=240$ MHz. The observed results are explained by a sequential tunneling model which suggests that the electron gas may be heated substantially by the ac driving voltage. Future device optimization is expected to make these quantum dots serious candidates for a metrological current standard.


16P-D025 Electrical Control of a Flying Charge Qubit

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Electron interference in an open structure usually suffers from a complicated multi-path interference bound to time reversal symmetry. We study electron transport through a hybrid system of an Aharonov-Bohm (AB) ring connected to tunnel-coupled quantum wires whose connection is varied between the adiabatic and non-adiabatic regimes. The non-adiabatic regime is realized when the inter-wire coupling is sufficiently weak that electrons injected from the AB ring to the coupled wire oscillate between the two wires, and the interference is characterized by a pure two-path interference without backscattering. This is in contrast with the one in the conventional adiabatic regime where the inter-wire coupling is so strong that the coupled-wire is equivalent to a single wire or lead connected to the AB ring. The unique two-path interference is used to electrically control a flying qubit state defined by the presence of an electron in either part of the coupled-wire. We demonstrate full electrical control of the qubit with an operation frequency $\nu_F/L$ of order of 100 GHz. Long coherence length of over 100 $\mu$m, more than 2 order of magnitude longer than the length required for each quantum operation, is also confirmed. This flying qubit opens a new avenue for fast and coherent control and transfer of a quantum information.

16P-D026 Low Temperature and High Magnetic Field Ellipsometry System

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We report the design and implementation of a spectral ellipsometry system for samples placed under a low temperature (LT) ($\leq 4.2$ K) and high magnetic field ($\leq 14$ T) environment. Besides the light source (a Ti-sapphire laser at 700 – 1000 nm wavelength), read-out and controlling electronics, the main structure of the system is integrated into an insert to fit an Oxford cryostat with a 50-mm bore. The insert has an optical head containing the polarizer and the rotating analyzer at room temperature (RT), a sample stage with a two-axis piezoelectric goniometer, and a 1.6-m long framework bridging the head and sample stage. After passing the polarizer, the laser beam is guided to the sample stage at LT; it is first reflected by a dielectric mirror before reaching the sample and the outgoing beam from the sample is then reflected to the analyzer at RT by a second dielectric mirror. All three reflections have a 60° incident angle and the same incident plane. To manifest the function and the sensitivity of
this system, the differences of high-field ellipsometry parameters between an intrinsic GaAs substrate and a MBE-grown layer at 4.2 K are demonstrated.

16P-D027 Superradiance in Transport through Ensemble of Double Quantum Dots

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When an ensemble of two-level systems is coupled to a common bosonic field, the Dicke's superradiance takes place.\textsuperscript{1} The emission of a boson creates an entangled state, which results in an enhancement of the subsequent radiation. We theoretically study the superradiance of optical phonons in the transport through an ensemble of double quantum dots (DQDs). We propose an experimental setup to observe the dynamical generation of entanglement, which should be important in the application to charge qubits for the quantum information processing. We consider a set of DQDs, \((L_j, R_j)\) \((j = 1, 2, \ldots , N)\). The current flows through the DQDs in parallel: from the source lead to \(L_j\) and from \(R_j\) to the drain lead. The level spacing, \(\epsilon_{L_j} - \epsilon_{R_j}\), is tuned to the energy of optical phonons. Using the pulse experiment,\textsuperscript{2} \(N\) electrons are confined in \(L_j\) \((j = 1, 2, \ldots , N)\) in the initial state: \(|L_1L_2\ldots L_N\rangle\). The tunneling from \(L_j\) to \(R_j\) is accompanied by the emission of a phonon, which makes an entangled state, \(|(L_1L_2\ldots L_N) + |L_1R_2\ldots L_N\rangle + \cdots + \sqrt{N}/\sqrt{N}\). This state enhances the ratio of the next tunneling event with phonon emission. Using the density matrix, we show the enhanced current due to this superradiance. If a specific DQD is connected to the drain strongly, the measurement of the current breaks the entangled state. The superradiance is hardly observed in such a situation.


16P-D028 Giant current fluctuations in an overheard single electron transistor

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Interplay of cotunneling and single-electron tunneling in a thermally isolated single-electron transistor (SET) leads to peculiar overheating effects. In particular, there is an interesting crossover interval where the competition between cotunneling and single-electron tunneling changes to the dominance of the latter. In this interval, the current exhibits anomalous sensitivity to the effective electron temperature of the transistor island and its fluctuations.\textsuperscript{1} We present a detailed study of the current and temperature fluctuations at this interesting point.\textsuperscript{2} The methods implemented allow for a complete characterization of the distribution of the fluctuating quantities, well beyond the Gaussian approximation. We reveal and explore the parameter range where, for sufficiently small transistor islands, the current fluctuations become gigantic. In this regime, the optimal value of the current, its expectation value, and its standard deviation differ from each other by parametrically large factors. This situation is unique for transport in nanostructures and for electron transport in general. The origin of this spectacular effect is the exponential sensitivity of the current to the fluctuating effective temperature.


16P-D029 Parallel field induced novel phenomena in a weakly interacting 2D electron gas

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Here we report observation of parallel field induced novel phenomena in a weakly interacting and ultra clean 2DEG system. At low temperature, the parallel field is found to induce a nonmonotonic colossal magnetoresistance, which is enhanced by a factor of \(\sim 300\) and shows no saturation at up to 45 T.\textsuperscript{1} More interestingly, its temperature dependence is strongly anisotropic and nonmonotonic: in the configuration \(I \parallel B\), it evolves from metallic (i.e., \(\frac{dR_B}{dT} > 0\)) to insulator-like (i.e., \(\frac{dR_B}{dT} < 0\)) below 10 K with increasing field, but the resistance remains much smaller than the resistance quantum even in the “insulator” regime; on the other hand, when \(I \perp B\), it retains features of metallic phonon scatterings below 10 K and above 40 K, but develops a resistivity saturation in-between with increasing field. We attribute these phenomena to the non-trivial magneto-orbital coupling effect, which might drive the system from 2D to quasi-3D, as well as from the quantum regime (i.e., \(T \ll T_F\)) to the classical regime (i.e., \(T \gg T_F\)).

\textsuperscript{1} Xiaoqing Zhou \textit{et al.}, Phys. Rev. Lett. 104, 216801 (2010).

16P-D030 Electronic Properties of Polar-Metallic Iridium Oxides

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Typical materials where the inversion symmetry of the crystal structure is broken are ferroelectrics, which are of course insulators. Besides them, there are conducting materials with broken inversion symmetry. Such materials are called as “polar metals,” and the emergence of exotic transport properties is theoretically predicted; the electronic transport is affected by spin-orbit interaction which results in, for example, the inverse Faraday effect.\textsuperscript{1} Some members of pyrochlore oxides like \(\text{Cd}_2\text{Re}_2\text{O}_7\) and \(\text{Pb}_2\text{Ru}_2\text{O}_7\) have a polar-metallic nature.
at low temperature (Cd$_2$Re$_2$O$_7$) or room temperature (Pb$_2$Ru$_2$O$_7$). 5$d$ electrons of transition metals show strong spin-orbit coupling. For example, the reconstruction of Ir 5$d$ I$_2$Ir electron band due to spin-orbit coupling have been observed in the optical spectra of Sr$_{n+1}$Ir$_2$O$_{3n+1}$.$^2$ In this study we report on the electronic properties of a pyrochlore oxide Pb$_2$Ir$_2$O$_7$ which has 5$d$ conduction electrons on the inversion-broken lattice at room temperature. The optical spectrum suggests that spin-orbit coupling contributes to the band formation. Moreover, the second harmonic generation shows a large inversion symmetry breaking effect in 5$d$ electron bands. These results indicate a possibility of novel properties in Pb$_2$Ir$_2$O$_7$.


16P-D031 Kondo effect in double quantum dots with magnetic field-tuned coupling

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We study the variation with magnetic field of the Kondo effect in a double quantum dot system which is coupled via an open conducting region. The transport measurements$^1$ indicate a competition between Kondo singlet formation and magnetic alignment via the Ruderman-Kittel-Kasuya-Yosida (RKKY) interaction. This competition has been in the focus of interest in heavy electron systems during the past decade. Tuning the coupling by a magnetic field provides insight into the relative importance of the different interactions (excluded volume, RKKY, etc) between Kondo impurities. Novel features originate from the chirality of the coupling in finite magnetic fields. Theoretically we model the double quantum dot system by two Anderson impurities. The latter are both coupled to individual fermionic baths representing the leads as well as to a central fermionic reservoir representing the common source. We calculate equilibrium and transport properties of this model using a variational ansatz for the ground state and discuss the validity of simplified effective coupling models.

1 Daniel Tutuc et al., arXiv:1010.5692

16P-D032 Strong back-action of a linear environment on a single electronic quantum channel

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Establishing the quantum laws of electricity in mesoscopic circuits is a formidable task in fundamental physics, which has also direct implications in the quantum engineering of nanoelectronic devices. A striking effect of these laws is the reduction of the conductance of a quantum coherent conductor when it is inserted in a circuit. This phenomenon, called environmental Coulomb blockade, results from the circuit back-action in response to the granularity of charge transfers across the coherent conductor. Although extensively studied for a tunnel junction in a linear circuit, it is only fully understood for arbitrary short coherent conductors in the limit of small circuit impedances and small conductance reduction. We have investigated experimentally the strong back-action regime, with a conductance reduction of up to 90%, by embedding a quantum point contact, used as a model single quantum channel of tunable transmission, in an adjustable on-chip circuit of impedance comparable to the resistance quantum $R_K = \hbar/e^2$ at microwave frequencies. Our experiment reveals important deviations from calculations performed in the weak back-action regime, and verifies more recent predictions. We propose a generalized expression for the conductance of an arbitrary quantum channel embedded in a linear environment.

16P-D033 New Frontiers for Einstein’s Electrons: Photoemission Studies of Novel Correlated Materials and Artificial Heterostructures

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Angle-resolved photoemission spectroscopy (ARPES) has played a pivotal role in shaping our understanding of the high-Tc cuprates and a handful of other systems. Unfortunately the vast majority of materials have traditionally remained beyond the reach of photoemission spectroscopy. I will describe a new approach where we have combined oxide molecular beam epitaxy with high-resolution photoemission (MBE-ARPES) which allows us to now synthesize and study the electronic structure of epitaxial thin films of novel correlated materials, interfaces, and heterostructures. As an example of this technique, I will describe our ARPES studies of MBE-grown epitaxial thin films which reveal numerous insights into a number of correlated materials which cannot be studied using conventional ARPES, including colossal magnetoresistive EuO and La$_{1-x}$Sr$_x$MnO$_3$, and the “infinite-layer” electron-doped cuprate Sr$_{1-x}$La$_x$CuO$_2$. I will also describe our work on oxide heterostructures and superlattices such as the ([LaMnO$_3$]$_n$ / [SrMnO$_3$]$_n$) superlattice comprised of alternating LaMnO$_3$ and SrMnO$_3$ blocks where we find that the electronic states evolve from a three-dimensional ferromagnetic metal, to a two-dimensional spin-polarized 2D electron gas, and ultimately to a two-dimensional ferromagnetic insulator with increasing superlattice block thickness $n$. I will conclude with a brief outlook on how this technique may provide new insights into the field of correlated oxide electronics.

16P-D034 Effective temperature of the fluctuation theorem in single-electron counting

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We investigate the direction-resolved full counting statistics of single-electron tunneling through a double quantum dot system and compare with predictions of the fluctuation theorem (FT) for Markovian stochastic processes. Experimental data obtained for GaAs/GaAlAs heterostructures appear to violate the FT. After analyzing various potential sources for the discrepancy we conclude that the nonequilibrium shot noise of the measurement device influence the tunneling statistics. Taking these modifications into account we show how the FT can be violated due to measurement effects and recovered for fast detection by introducing an effective temperature. [Y. Utsumi, D. S. Golubev, M. Marthaler, T. Fujisawa, Gerd Schönn, “Single-Electron Tunneling and the Fluctuation Theorem”, arXiv:0911.5469, Y. Utsumi, D. S. Golubev, M. Marthaler, K. Saito, T. Fujisawa, Gerd Schönn, “Bidirectional Single-Electron Counting and the Fluctuation Theorem”, Phys. Rev. B 81, 125331-1 - 125331-5 (2010)]

16P-D035 Boltzmann Description of Non-Interacting Electrons in Weakly Localized Regime

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The transport processes of non-interacting electrons is formulated, in view of the exact transport equation of interacting Fermi systems reported by the present authors in this conference. The formalism eliminates the hidden ultraviolet divergence and makes the correct correspondence to the Boltzmann theory, covering the weakly localized regime, by incorporating the particle-particle and hole-hole pairs. A number of new aspects emerges from this rather traditional approach. A mass renormalization of purely two-particle nature appears in the transport equation, in distinction from the one-particle dispersion mass representing the group velocity. In the conductivity expression, the latter renormalization is cancelled by the change of the density of states, leading to the Drude formula in terms of the transport mass. The transport equation is solved numerically for the 2D-system with short-ranged random scatterers, taking the maximally crossed diagrams for the proper vertex. The conductivity is positive definite, but vanishes in the elastic scattering limit even with infinitesimally small self energy, while the transport mass reduces to the free-electron mass in the same limit due to the diverging back scattering. The description differs from the self-consistent theory by Vollhardt and Wölfle1, in which the Bethe-Salpeter structure of the scattering vertex is abandoned and, accordingly, the correspondence to the Boltzmann theory is lost.


16P-D036 Breakdown of Universal Dynamical Resistance of a Mesoscopic Capacitor

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Dynamical response of a mesoscopic capacitor is now attracting a renewed interest from a viewpoint of universal transport phenomena. The mesoscopic capacitor is a quantum analog of a classical RC circuit and exhibits universal quantization of dynamical resistance at low frequency $\omega \ll \tau^{-1}_{RC}$. An intriguing question is how the quantized resistance, often referred to as charge relaxation resistance, is modified by electron-electron interactions, which become prominent as the system size is reduced. Recently we have investigated this issue theoretically and revealed that the behavior of the dynamical resistance is strongly dependent on the nature of an electron reservoir. The dynamical resistance is universally quantized even in the Coulomb blockade regime, as long as interaction in the reservoir is sufficiently weak. If the interaction exceeds a critical point, on the other hand, the dynamical resistance diverges due to the Kosterlitz-Thouless transition. A similar divergent behavior occurs also in a mesoscopic capacitor with a noisy gate voltage coupled to an ohmic bath.

1 J. Gabelli et al., Science 313, 499 (2006); G. Fève et al., ibid 316, 1169 (2007).

16P-D037 Interaction-driven Effects in Strongly Correlated Two-dimensional Systems

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Most experiments of measuring dilute electron systems demonstrate activated conduction such as the variable range hopping observed in the insulating side of the 2D metal-to-insulator transition (MIT). This is consistent with disorder-dominated Anderson Insulator developed for non-interacting particles. Important questions on whether electron-electron interaction can fundamentally alter the electron states, e.g. Wigner crystallization in a low disordered environment, remain unanswered. Recently, results from measurements of higher purity, strongly interacting 2D electron systems at low T demonstrate certain nonactivated behaviors that are absent in more disordered systems. Measuring high quality 2D holes in undoped GaAs field-effect-transistors with variable charge densities down to $7 \times 10^{10}$ cm$^{-2}$, we found a power-law like T-dependence of the conductivity for the lowest charge concentrations. The scaling of the exponent, varying between 1.3 and 1.8, with the change of charge density points to an interaction-driven nature. This non-activated characteristic may well be an universal interaction-driven signature for an electron state of strongly correlated (semiquantum) liquid. Moreover, a conductivity kink, indicated via a discontinuous step in the temperature derivative, is also observed for carrier densities below $4 \times 10^{9}$ cm$^{-2}$ which is the critical density of MIT. A
possible phase transition will also be discussed.\textsuperscript{1}
\textsuperscript{1} Jian Huang, L.N. Pfeiffer, K.W. West, Phys. Rev. B. (Rapid Communications) \textbf{83}, 081310 (2011).

\textbf{16P-D038} Effect of electron-hole inhomogeneity on specular Andreev reflection and Andreev retroreflection in a graphene-superconductor hybrid system (LT26)
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The electron-hole inhomogeneity in graphene has been confirmed by recent experiments, and the largest energy displacement of electron and hole puddles with respect to the Dirac point can reach nearly 30meV. Here we focus on how electron-hole inhomogeneity affects the specular Andreev reflection as well as Andreev retroreflection by using a four-terminal graphene-superconductor hybrid system. We find that the Andreev coefficients can hardly be affected even under rather large electron-hole inhomogeneity (typically 30meV), although the charge puddles strength $W = 30meV$ is much larger than the superconductor gap $\Delta = 1meV$. Furthermore when charge puddles are two orders larger than superconductor gap, a specific kind of Andreev reflection can be still obviously detected. In order to quantitatively describe what degree of the boundary blurred, a quantity $\iota$ is introduced, which we confirm that the boundary blurring are much smaller than the charge puddles strength $W$. In addition, we study the effect of Anderson disorder as well for comparison. We found that the boundary is held much more obviously in this case. The retroreflection and specular reflection can be clearly distinguished and detected in the presence of electron-hole inhomogeneity.

\textbf{16P-D039} Stationary Josephson effect in ballistic graphene junctions: effects of inhomogeneous carrier density
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We report our recent study on the stationary Josephson effect in ballistic mono- and bi-layer graphene junctions. In order to capture features specific to the graphene junctions, we model the system as a planar Josephson junction,\textsuperscript{1} in which two superconducting electrodes are deposited on (bi-layer case) the top layer of) a graphene sheet. A tunneling Hamiltonian is then employed to describe the coupling between the graphene layer and the superconducting electrodes. We assume that a constant potential $-U$ is present in the region covered by the superconductors and take account of the fact that the carrier density is higher (lower) in the covered (uncovered) region. Applying the quasi-classical Green’s function approach, we find a general expression for the Josephson current valid whenever the chemical potential is away from the Dirac point. The obtained formula holds true for arbitrary $U$ and coupling strength $\Gamma$ in the mono- and bi-layer cases. We further investigate the behavior of Josephson critical current $I_c$ at zero temperature in the large-$\Gamma$ limit. We find that the decrease of $I_c$ with increasing $U$ is more pronounced in the bilayer case than in the monolayer case, reflecting contrasting electronic properties of a potential junction in mono- and bi-layer graphene sheets.

\textbf{16P-D040} A Numerical Study of the Electronic Properties of Graphene Bilayer with Local Disorder
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We show that the optical conductivity of bilayer graphene can reveal clearly the metal-insulator transition driven by disorder. We choose the rhombohedral stacking configuration to characterize the graphene bilayer, and introduce the kernel polynomial method (KPM) to provide numerical results of the effect of local disorder on the behaviors of optical conductivity for lattices of considerable size. The Drude weight is found to decrease very rapidly with the increase of disorder and drop to zero at a critical strength $W_c$, suggesting that Anderson metal-insulator transition can take place. In the superconducting case, the distribution of the inhomogeneous superconducting gap is obtained by solving self-consistently the Bogoliubov-de Gennes equations under the mean-field description, and we see no appreciable change for the critical strength $W_c$ in the superconducting phase. However, the optical conductivity is found to drop significantly as predicted, especially in the weak disorder region.

\textbf{16P-D041} Anomalous integer quantum Hall effect in AA-stacked bilayer graphene
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The peculiar quantum Hall effects of chiral Dirac fermions in monolayer\textsuperscript{1} and AB-stacked bilayer graphene\textsuperscript{2} have been investigated widely both in theoretical and experimental works and greatly intrigued physicists in recent years. We notice that although AB stacking is predicted to be energetically favored over AA stacking in ab initio density-functional theory (DFT) calculation, AA-stacked bilayer graphene (BLG) has been successfully fabricated in experiments\textsuperscript{3}. Furthermore, we find that the band structure of AA-stacked bilayer graphene is distinct from monolayer and AB-stacked bilayer graphene through tight-binding calculations and therefore expect that the quantum Hall effect (QHE) in the AA-stacked could be quite different from that in the latter two systems. In this work, we calculate the quantized Hall conductivity $\sigma_{xy}$ within linear response theory by using Kubo formula\textsuperscript{4}. Interestingly, we find that QHE in AA-stacked BLG indeed possesses three unique characteristics: the filling factor $\nu = 0$ plateau, the periodic $8e^2/h$ steps, and the strong dependence on magnetic field and chemical potential.
16P-D042 Anomalous transport and spin filtering effect in graphene nanoribbons

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Electronic transport properties of zigzag graphene nanoribbons with defects are explored by using nonequilibrium Green’s functions method in combination with density functional theory. The defects are found to generally decrease the conductance of graphene nanoribbons and the conductance decreases further with the increase of the defect size. Anomalous transport, however, appears when the defects break the symmetry of the nanoribbons: the current of the ribbons with this kind of defects can be much larger than that of the perfect graphene ribbons. This behavior is ascribed to more conducting channels along the edges, provided in asymmetrical graphene ribbons. Perfect spin filtering effect is achieved in zigzag-edged graphene flakes sandwiched between two gold electrodes. The orientation of the spin current is found to be flipped if the flake is doped with N, O, or F atoms. The results indicate that the transport properties of graphene can be tuned flexibly and are potentially useful in future nanoelectronic applications.

16P-D043 Exact results for intrinsic electronic transport in graphene

Shijie Hu\textsuperscript{a}, Wei Du\textsuperscript{a}, Guiping Zhang\textsuperscript{a}, Miao Gao\textsuperscript{a}, Zhong-Yi Lu\textsuperscript{a}, Xiaoyun Wang\textsuperscript{a}, \textsuperscript{a}Department of Physics, Renmin University of China, Beijing 100872, China \textsuperscript{b}School of Physics, University of Chinese Academy of Sciences, Beijing 100080, China

We present exact results for the electronic transport properties of graphene sheets connected to two metallic electrodes. Our results, obtained by transfer-matrix methods, are valid for all sheet widths and lengths. In the limit of large width-to-length ratio relevant to recent experiments, with zigzag interfaces the Dirac-point conductivity is $2e^2/\sqrt{3}\hbar$ and a sub-Poissonian Fano factor of $2 - 3\sqrt{3}/\pi$ is obtained; with armchair interfaces these are respectively 0 and 1. Our results reflect both the intrinsic topology of the sheet and the electronic structure of the electrodes, giving a complete microscopic understanding of the unique transport properties of graphene.

16P-D044 Power-law singularity in the local density of states induced by the point defect in graphene

Wen-Min Huang\textsuperscript{a}, Jian-Ming Tang\textsuperscript{b}, Hsiu-Hau Lin\textsuperscript{c}, \textsuperscript{a}Physics Division, National Center for Theoretical Sciences, Hsinchu 300, Taiwan \textsuperscript{b}Department of Physics, University of New Hampshire, Durham, New Hampshire 03844-3520, USA \textsuperscript{c}Department of Physics, National Tsing Hua University, Hsinchu 30013, Taiwan

Defects in graphene give rise to zero modes that are often related to the sharp peak in the local density of states near the defect site. Here we solved all zero modes induced by a single defect in the finite-size graphene and show that their contributions to the local density of states vanish in the thermodynamic limit. Instead, lots of resonant states emerge at low energies and eventually lead to a power-law singularity in the local density of states. Our findings show that the impurity problem in graphene should be treated as a collective phenomenon rather than a single impurity state.

16P-D045 Quantum transport of graphene nanostructure and its application in quantum information

GuoPing Guo\textsuperscript{a}, \textsuperscript{a}Key Lab of Quantum Information, University of Science and Technology of China, CAS

In this talk, I will report our recent quantum transport experiments on graphene nanostructure, including parallel double quantum dots, integrated single electron transistor sensor and graphene nanoribbon with superconductor leads. Several interesting phenomena such as supercurrent, multiple Andreev reflection, Fabry-Perot interference and Fraunhofer interference are observed in our experiments. The application of these graphene nanostructures in quantum information will also be discussed in this talk.

16P-D046 Chiral Symmetry and Electron-Electron Interaction in Many-Body Gap Formation in Graphene

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Graphene with its Dirac cone dispersion becomes particularly interesting when one takes many-body effects into account. On the one-body level it is well-known that the chiral symmetry associated with the bipartite honeycomb lattice guarantees a topological stability of the doubly Dirac cones against finite perturbations. When the electron-electron interaction is switched on, the chiral symmetry again plays a crucial role. Although several possible many-body states have been proposed as the origin of gap opening of the $n = 0$ Landau level for high magnetic fields, no clear consensus has been reached thus far. Using the exact diagonalization method, we have investigated this with the extended Hubbard model for spinless fermions on the honeycomb lattice$^1$. By fully utilizing the chiral symmetry of the zero modes, we have obtained a perturbatively exact ground state for the half-filled $n = 0$ Landau level (only the $n = 0$ subspace is taken into account). Examination of the non-Abelian Chern number implies the ground state is a Hall insulator with a topological degeneracy of $N_D = 2$. “Bond order” formation$^2$ and existence of the edge states are discussed from a view point of the bulk-edge correspondence.

1. Y. Hamamoto, Y. Hatsugai, and H. Aoki, to be published.
16P-D047  Low Temperature Electrical Transport and Field Effect Transistor Characteristics of Graphene-oxide Thin Films
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We report in this paper the low temperature transport characteristics of graphene-oxide (GO) thin films. GO thin films are now become as attractive due to their unique physical-chemical properties and potential candidate in resistive switching memory (RAM) and as a dielectric layer for graphene based electronic devices. It can be readily obtained through oxidizing graphite with strong oxidants, followed by an exfoliation process. We used modified Hummers method for GO synthesis and thin films of GO prepared using spin-casting. The GO nanoparticles were characterized with UV-vis spectroscopy and XRD techniques for product quality. Approximately 60 nm thick GO film(thickness was confirmed by using AFM) was used for this study in temperatures from 300 K to 90 K. The resistance versus temperature (R-T) measurement shows a semiconducting behavior of GO thin film when the temperature goes down. The current-voltage characteristics reveal an ohmic behavior at room temperature; however, the same behavior is turned into nonlinear characteristics when the temperature goes down. This will be discussed with Poole-Frenkel conduction mechanism in detail. Further the transfer characteristics (IDS versus VGS) of GO-FET device structure show p-type semiconducting property of GO thin films.

16P-D048  Quantum Hall ferromagnetism in graphene on hexa-Boron Nitride substrates
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In graphene, the structure of the honeycomb lattice endows the wavefunctions with an additional quantum number, termed valley isospin, which, combined with the electron spin, yields four-fold degenerate, approximately SU(4) symmetric LLs. The expanded degenerate Landau level manifold makes a wide variety of symmetry breaking ordered states possible; an outstanding question of fundamental interest is which ones nature chooses, which excitations such states support, and to what extent these states can be manipulated. In this paper, I will present recent experimental data obtained on high quality graphene devices fabricated on hexagonal Boron Nitride substrates, focusing on the broken symmetry integer quantum Hall regime. In graphene/hBN devices, all integer plateaus are observed at fields of a few tesla. This allows us to probe the transport of spin textured excitations through the application of an in-plane field, which tunes the Zeeman energy. I will show that for half-filled quartet Landau levels (filling factors \( \nu = 0, \pm 4, \pm 8, \pm 12 \)), with the exception of \( \nu = 0 \), the ground state is spin polarized and supports spin-flip excitations. At \( \nu = 4 \), these excitations contain multiple spins, suggesting that charge is carried by Skyrmions. At \( \nu = 0 \), in contrast, I will argue that the ground state is not spin polarized.

16P-D049 Two distinct ballistic processes in graphene at Dirac point: short time ultra-relativistic vs long time non-relativistic.
M. Lewkowicz*, B. Rosensteinabc, D. Nghiemb, aPhysics Department, Ariel University Center, Ariel 40700, Israel bElectrophysics Department, National Chiao Tung University, Hsinchu 30050, Taiwan, R. O. C. cNational Center for Theoretical Sciences, Hsinchu 30043, Taiwan, R. O. C.

A dynamical approach to ballistic transport in mesoscopic graphene samples of finite length \( L \) and a contact potential difference \( U \) is developed. At ballistic times shorter than both relevant time scales, \( t_L = L/v_F(u_F) \) (Fermi velocity) and \( t_U = h/|eU| \), the major effect of the electric field is to create electron-hole pairs. In linear response this gives rise (for width \( W >> L \)) to conductivity \( \sigma_2 = (\pi/2) (e^2/h) \). On the other hand, at ballistic times larger than the two scales the mechanism of transport is different. The conductivity has its “nonrelativistic” value equal to the one obtained within the Landauer-Büttiker approach resulting from evanescent waves tunneling through the barrier \( U \). \( \sigma_2 = (4/\pi) (e^2/h) \) (for \( W >> L \) and \( t_U << t_L \)). The electron-hole pair creation becomes unimportant in this limit. Between these extremes there is a crossover behaviour dependent on the ratio between the two time scales \( t_L/t_U \). The first mechanism is universal and does not depend on geometry (aspect ration, topology, boundary conditions, properties of leads), while the latter one is quite sensitive to all of them. The ultrarelativistic value was measured precisely in AC conductivity measurements and in DC transport in suspended graphene, while the nonrelativistic value appears in experiments on small graphene flakes.

16P-D050 Properties of Graphene Nanoribbon with Zigzag Edges Attached to Two Normal Metals
H. Yoshiokaa, Y. Mochizukia, aDepartment of Physics, Nara Women’s University, Nara 630-8506, Japan

A graphene nanoribbon with the zigzag shaped edges, which is abbreviated to zigzag GNR in the following, is known to possess the remarkable property that the material is classified into an insulator due to vanishing Drude weight even though the energy gap is closed at the Fermi energy. It originates from the fact that the one-particle states close to the Fermi energy are well localized around the zigzag edges. Thus, it is expected that the unusual transport properties are observed in the material.

We have theoretically investigated the transport properties of the junction where the zigzag GNR is sandwiched by the two normal metals. It has been found that the transport properties are strongly dependent on the parity of the width. Especially, those for \( E \approx 0 \) with \( E \) being the energy of an electron can not be understood from the electronic states of the isolated
zigzag GNR. In the present work, in order to clarify the roles of the zigzag edges on such anomalous transport properties, we investigate the system with the zigzag GNR where the hopping at the two zigzag edges are modified compared to those at the other bonds. In addition, the local density of states of the zigzag GNR sandwiched by the two normal metals are examined and discrepancies from that of the isolated zigzag GNR are discussed.


16P-D051 Flow diagram of the longitudinal and Hall conductivities in ac regime in the disordered graphene quantum Hall system
T. Morimoto*, H. Aoki*, Department of Physics, University of Tokyo, Tokyo, Japan
In the physics of graphene with its realization of a massless Dirac system at low energies, dynamical (ac) responses should be interesting. We have recently shown for the graphene integer quantum Hall effect (QHE) that the plateau structure is retained even in the ac regime. The result shows that the ac flow diagram is not significantly altered for the small-ω region. There, a fixed-point behavior emerges as in the dc case, which we interpret in terms of the dynamical scaling analysis. We also discuss the dependence of the flow diagram on the disorder strength.

16P-D052 Quasienergy Spectra of a Charged Particle in Planar Honeycomb Lattices
W. Zhang*, Institute of Applied Physics and Computational Mathematics, Beijing, China
The low energy spectrum of a particle in planar honeycomb lattices is conical, which leads to the unusual electronic properties of graphene. In this talk we address the quasienergy spectra of a charged particle in honeycomb lattices driven by a strong AC field, which is of fundamental importance for its time-dependent dynamics. We find that depending on the amplitude, direction and frequency of the external field, many interesting phenomena may occur, including band collapse, renormalization of the velocity of “light”, gap opening etc. Under suitable conditions, with increasing the magnitude of the AC field, a series of phase transitions from gapless phases to gapped phases appear alternatively. At the same time, the Dirac points may disappear or change to a line. We suggest possible realization of the system in Honeycomb optical lattices.

16P-D053 Development of superconducting interference device based on graphene
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bDepartment of Applied Physics, Tokyo University of Science, Tokyo, Japan. cNanostructure Innovation Center, NIMS, Ibaraki, Japan. dInstitute of Physics, University of Tsukuba, Ibaraki, Japan. eCREST-JST, Saitama, Japan
Graphene, an atomic layer of graphite, has been attracted attention since the discovery of methods to extract it. When graphene is placed between two superconducting leads, it can support Cooper pair transport by the superconducting proximity effect. Here, we report on the fabrication and operation of graphene-based superconducting interference device (SQUID). The SQUID consists of two superconductor/single layer graphene/superconductor (SGS) junctions connected in parallel on a superconducting loop made of aluminum. Current-voltage characteristic of the device exhibits supercurrent flowing through SGS junctions at T = 35 mK. The critical current can be modulated periodically with the applied magnetic field. The observed period coincides well with that estimated from device geometry, suggesting that our device works as a graphene-SQUID.

16P-D054 Signature of Schwinger’s pair creation rate via radiation generated in graphene by a strong electric current
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bPhysics Department, National Taiwan Normal University, Taipei 11677, Taiwan, R. O. C. cElectrophysics Department, National Chiao Tung University, Hsinchu 30050, Taiwan, R. O. C.
Signatures of Schwinger’s pair creation in graphene have been experimentally observed at a relativistic energy and electric field near the Dirac point in graphene. It is shown that for electric fields $E > hv_g/eL^2$, where $L$ is the length of the sample, the I-V characteristics become strongly nonlinear due to Schwinger’s pair creation rate, proportional to $E^{3/2}$. At recently achievable fields the radiation from the pairs’ annihilation becomes observable. The spectrum of radiation is calculated and exhibits a maximum at $\omega = \sqrt{eE/h}$. The angular and polarization dependence of the emitted photons with respect to the graphene sheet is quite distinctive.

16P-D055 Bilayer graphene pn junction devices
Bilayer graphene is the only material with an electrically tunable band gap. This unique property can provide unprecedented schemes for novel functionalities in future electronic and optoelectronic devices. In this work we prepared double gated structure devices of bilayer graphene to independently tune the charge density and the band gap as a function of the two gate voltages. Note that the top gate electrode is local, so it can be used to form a PN junction between the top-gated and ungated region. We applied relevant gate voltages to perform band engineering i.e. to tune the band gap value and shift the Fermi level and thereby realize the PN junctions. We observed a nonlinear I-V characteristic of PN diodes by successfully controlling the rectified direction of drain source voltage. A gate-tunable band gap value ranging from 20 meV to 180 meV was evaluated by analyzing the PN diode characteristics. Our result indicates that the double gated bilayer graphene devices can be used to construct planar circuits made out of pp and nn channels and pn junctions, which are all gate tunable.


16P-D058 Electron-optical phonon interactions in bilayer graphene
J. K. Viljas*, A. Fay*, M. Wiesner*, P. J. Hakonen*, a Low Temperature Laboratory, Aalto University, P.O.Box 15100, FI-00076 AALTO, Finland b Faculty of Physics, Adam Mickiewicz University, 61-614 Poznan, Poland

Our low-temperature experiments have shown that the current–voltage (I–V) characteristics of diffusive two-lead bilayer graphene (BLG) samples on SiO$_2$ substrates tend to be superlinear at bias voltages $V$ below 0.1 V. The superlinearity is weakly dependent on (n-type) doping by a back gate and is also similar for our short (350 nm) and long (950 nm) samples. These findings are in contrast to monolayer graphene (MLG), where the I–V characteristics are typically linear, apart from very low-mobility samples close to the Dirac point, where superlinearity has previously been attributed to Zener-Klein tunneling. We have also analyzed the I–V characteristics of MLG and BLG with numerical simulations based on solving semiclassical quasi-equilibrium transport equations together with the Poisson equation, assuming carrier scattering to be due to charged impurities. It is concluded that the superlinearity seen in our BLG experiments can be explained by Joule heating. As the electron system heats from 4 K in equilibrium to 200–300 K at $V = 0.1$ V the conductivity increases as a result of the thermal creation of electron-hole pairs. This effect is stronger in BLG than in MLG because of the larger electronic density of states close to the Dirac point in the former. The simulations and the experimental data are in good agreement.


Ti$_{0.33}$Au$_{0.67}$. Then the potential barrier at Gr and Gr/Ti/Au interface induced by charge doping from metal electrodes is also suppressed and the contact resistance should be small.

16P-D060 Graphene Membranes for Cryogenic Nano-Electro-Mechanical Resonators

Z. Han*, A. Allain*, V. Bouchiat*, *Neel Institute, CNRS, 25 rue des Martyrs, 38042 Grenoble, France

Graphene is a very promising material for implementing nano-electromechanical resonators as it combines extremely low mass, very high young modulus (1 TPa) and tunable charge density with excellent carrier mobilities. We present experimental study of graphene membrane resonators obtained by the controlled under-etching of Graphene transistors. Graphene membranes have been fabricated by chemical vapor deposition, and subsequently patterned into an array of back-gated resonators by optical lithography. Actuation is realized by RF irradiation on the gate while measurement of the mechanical resonance is obtained by heterodyne frequency mixing, followed by lock-in detection. Resonances and quality factors for micron-scale doubly clamped membranes are studied at both room temperature and low temperature. The dispersion curves measured at different temperatures show that stress within the membrane determine the resonance properties. Perspective to use these devices in the superconducting state (or even at tens of mK) after controlled doping and realizing suspended Josephson junctions will be presented.


16P-D061 Pumped current and shot noise in adiabatically modulated graphene-based double-barrier structures

R. Zhu*, H. Chen*, M. Lai*, *Department of Physics, South China University of Technology, Guangzhou 510641, People’s Republic of China

Quantum pumping is a transport mechanism which induces dc charge and spin currents in a nano-scale conductor in the absence of a bias voltage by means of a time-dependent control of some system parameters. Quantum pumping processes are accompanied by considerable quantum noise. We study the adiabatic quantum pumping characteristics in graphene modulated by two oscillating gate potentials out of phase. The direction of the pumped current can be reversed when a high potential barrier demonstrates stronger transparency than a low one, which results from the Klein paradox. We also investigated the pumped shot noise properties based on general expressions we derived based on the scattering approach. It is found that comparing with the Poisson processes, the pumped shot noise is dramatically enhanced where the dc pumped current changes flow direction, which demonstrates the effect of the Klein paradox.


16P-D062 Breakdown of the Quantum Hall Effect in Graphene

C. Yanik*, C. Celebi*, A.G. Demirkol*, I. I. Kaya*, *Faculty of Engineering and Natural Sciences, Sabanci University, Istanbul 34956, Turkey

The breakdown of the quantum Hall effect is observed as the abrupt change in the longitudinal resistance by several orders of magnitude with an associated loss in quantization of Hall voltage. Breakdown limits the accuracy of the existing resistance standard. Graphene allows the quantization of the Hall resistance upto the room temperature and hence a good candidate for being used as a high precision metrological characterization. The uncertainty in the resistance quantum measured in graphene rapidly improved in the last couple of years to ~ 1 pb in epitaxial graphene. Sufficiently high breakdown currents and low contact resistances are needed to obtain such high accuracy in determining the resistance quantum. In this work, we report experimental results on the breakdown of quantum Hall effect in graphene. The devices were fabricated on mechanically exfoliated graphene. Single layer, bilayer and a few layer graphene sheets are transferred onto SiO$_2$ substrate where Raman spectroscopy is used to identify the number of graphene layers. Devices were patterned by optical and electron beam lithography. Samples typically exhibit immediate onset of the longitudinal resistance while the Hall plateaus can endure to much higher currents. We elaborate on the physical phenomena underlying this unique behavior in the breakdown of the quantum Hall effect and its possible implications on the improvement of the accurate determination of the plateau levels.


16P-D062 Small carbon clusters as molecular switches: modeling and working principles

D.A. Luzhbin*, *Institute for Metal Physics, National Academy of Sciences of Ukraine, Kyiv, Ukraine

Recent molecular dynamics simulations have predicted existence of the smallest carbon fullerene C8, which has an extremely long lifetime at low temperatures. An example of a molecular current switch built of a single C8 molecule attached to gold electrodes is considered and its zero-temperature electronic and transport properties are calculated from the first principles. It is shown that zero-bias conductance of the switch depends nonlinearly on the length of the junction and develops a sharp drop of an order of magnitude for some particular length. Current-voltage characteristics of the switch can show either metallic or semiconducting behavior depending on the length of the molecular junc-
tion. By tuning the value of interelectrode separation one can change the properties of the junction in a quite wide range from a highly conducting metallic state to a super insulating state, where in a wide range of applied bias voltages the ratio of the currents in these two states exceeds 30. These particular properties can be used for constructing temperature switches whose sensitivity to the temperature changes reaches down to millikelvins. The specific details of the electronic spectrum of the junction, which are important for constructing CS based molecular switches, are also discussed.

1A. Yazdania, N. Kamali Sarvestania, “Tarbiat Modares University, Physics Department, Tehran, Iran

Great exchange dispersion, as distribution of local magnetic field and fluctuation about it, is observed in AC susceptibility of some Gd-Intermetallic compounds (IMC). In order to interpret the suppress of the magnetic broad range transition as a dynamic nonequilibrium process of transition (high entropy with low value of χ(T)), the effect of bathing on AC susceptibility and X-R is considered. The dependence both AC susceptibility and X-R on heat treatment is the cause of short range order by which the strong correlated electron system leads to the decreasing of correlation length - where the displacement of magnetic ions in the range of Δz=0.058Å, Δy=0.4Å, Δz=0.74Å is investigated. Even though, it will be a question whether the exchange interaction or atomic displacement is the main cause of this phenomenon, the decrease of the correlation length from 3.6 Å for Gd to Rc=3.2Å should be considered. This effect could increasing the density of states, as increasing of amplitude of condensation on which the on-site and inter-site exchange can compete. In this case, the effective mass is large and consequently the magnetic phase transition is derived from condensation energy which is approximately equal to N(Ef)Δ, where Δ is the magnitude of the energy gap opened by the transition at which the unstable F.M order collapse to AF.M order at TN=48-60K. Above this gap system behaves completely paramagnetic.

16P-D063 How can SDW change the unstable F.M to stable AF.M in Gd-IMC

A. Yazdania*, N. Kamali Sarvestania*, “Tarbiat Modares University, Physics Department, Tehran, Iran

Great exchange dispersion, as distribution of local magnetic field and fluctuation about it, is observed in AC susceptibility of some Gd-Intermetallic compounds (IMC). In order to interpret the suppress of the magnetic broad range transition as a dynamic nonequilibrium process of transition (high entropy with low value of χ(T)), the effect of bathing on AC susceptibility and X-R is considered. The dependence both AC susceptibility and X-R on heat treatment is the cause of short range order by which the strong correlated electron system leads to the decreasing of correlation length - where the displacement of magnetic ions in the range of Δz=0.058Å, Δy=0.4Å, Δz=0.74Å is investigated. Even though, it will be a question whether the exchange interaction or atomic displacement is the main cause of this phenomenon, the decrease of the correlation length from 3.6 Å for Gd to Rc=3.2Å should be considered. This effect could increasing the density of states, as increasing of amplitude of condensation on which the on-site and inter-site exchange can compete. In this case, the effective mass is large and consequently the magnetic phase transition is derived from condensation energy which is approximately equal to N(Ef)Δ, where Δ is the magnitude of the energy gap opened by the transition at which the unstable F.M order collapse to AF.M order at TN=48-60K. Above this gap system behaves completely paramagnetic.

16P-D064 A Critical Point at Which Magnetocaloric Effect Can Be Manifested

A. Yazdania*, S. Nabavia*, “Tarbiat Modares University, Physics Department, Tehran, Iran

Since in the isostructural compounds of Gd4B3 and Gd4Sb3 the only parameters which determine the magnetic behaviour as the sign and strength of the exchange parameter, Jij, depend on the following parameters (related to the chemical pressure due to the size effect of RBi3:RSb3): (1) the topological positions of the magnetic ions, and (2) the nature and the density of the conduction electrons, both of which are strongly depend not only on the nearest neighbor but also on the correlation length defined by the Rc=2kfRij. The Gd4Bi3 should be the critical composite for which Rc is not its extremum value. At this compound, the dominance of dispersion of exchange or even the competition of magnetic ions (intracluster exchange) overcomes the thermal fluctuations where. This behavior can be the cause of =347 K and its drop to 266 K for Gd4Sb3 and even to 110 K with the change of crystal structure for Gd5Bi3, which means that the internal magnetic energy can change to thermal (for the second one).

16P-D065 Comparative Study of the Structure and Electronic Property of Molecular Chains on Organic Conductor Surfaces

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The surface structures, stability and electronic property of three TCNQ-based charge transfer complexes (CTCs), PrQ (TCNQ)2, MPM (TCNQ)2 and MEM (TCNQ)2, have been investigated by STM and STS. STM observations reveal that only presence of ac-surface in three CTCs surfaces, which are all terminated with TCNQ molecular arrays. For PrQ(TCNQ)2, it is found that a tetramer structure behaves as a wavelike row and posses a angle with about 18 degree between the adjacent molecules. Meanwhile, the dimer structures are resolved on the remainder ac-surfaces. In addition, the tetramer structure is the most stable, which is corresponding to the metal-like I-V curves. However, the dimer structures are unstable, which exhibit a semiconductor feature. The relationship between the surface structure and the electronic property is discussed in detail.

16P-D066 Observation of single electron tunneling in strongly coupled gold-nanoparticle assembly.

Cheng-Wei Jiang*, I-Chi Ni*, Shin-Der Tseng*, Watson Kuo*, aDepartment of Physics, National Chung Hsing University, Taiwan, bDepartment of Physics, National Dong Hwa University, Hualien, Taiwan

This work experimentally studied the charge transport properties of two dimensional self-assembled gold nanoparticles (AuNPs), which were surface-modified by 3-mercaptopropionic acid (MFA). The molecule is short, resulting in a nanoparticle assembly of strongly coupled AuNPs. The samples with e-beam exposure are metallic, while those without exposure are insulting. Showing Coulomb blockade modulated by a gate voltage at the temperature of 40mK, the insulating device demonstrated the electrical conduction nature as a single electron transistor1 2. A magnetic field in perpendicular to the substrate would suppress such single electron tunneling and transistor effect. On the other hand, the metallic devices appeared no gating-effect and showed anti-weak localization at 80mK.

2 Bolotin, K. I., F. Kuenmeeh, et al., Applied physics letters 84
A. G. Demirkol, I. I. Kaya a, S. Bhandari a, T. Löfwander a, W. Wang b, E. Kaxiras a, D. Bell b, A. Bergvall b, H. Park, a, Peng Xu, a, S. Bhandari a, Laifeng Li a, et al.  
3154(2004).

16P-D067  Graphene Nanogap for Coherent Molecular Electronic Devices

T. Löfwander a, W. Wang a, B. Bergvall a, O. Kubatkin, a, “Dep. of Microtechnology & Nanoscience - MC2, Chalmers University of Technology, SE-41296 Göteborg, Sweden

We present calculations of coherent electron transport through a fulleropyrrolidine terminated single molecule trapped in a graphene nanogap. This is a concrete example of using graphene as a platform for single molecule electronics, where the size mismatch between leads and molecule can be avoided in contrast to the more common metallic nanogap set-up. A back gate voltage can be used to tune the Fermi level in the graphene leads and thereby, under favorable circumstances, facilitate control of the device conductance.

16P-D068  Fabrication of Suspended Graphene Nanodevices

W. Wang a, S. Bhandari a, D. Bell b, E. Kaxiras a, R. Westervelt b, a, “Department of Physics and School of Engineering and Applied Sciences, Harvard University, Cambridge, MA USA, bCenter for Nanoscale Systems, Harvard University, Cambridge, MA USA

Graphene has stimulated intensive research on 2D electronic transport and new paradigm for electronics/spintronic, which points to the possibilities of achieving high integration density, high mobility, band gap, and the intriguing spin polarized edge states. To this end, the ultimate graphene device would have well-defined atomic configurations. So far, most graphene devices are limited by either fabrication resolution or uncertainty in device configurations including the exact edge shape and the interactions with the substrate. The latter could have a determining effect on the device performance such as disorder induced electron localization. Here we report fabrication of suspended graphene nanodevices with aberration corrected and monochromated transmission electron microscopy (AC&MC-TEM). This approach allows us to probe electronic transport in atomically well-defined graphene nanostructures that are decoupled from uncontrollable interactions with the environment. With the AC&MC-TEM, the atomic configuration of the graphene nanodevice can be directly observed as it forms into a desired shape. We discuss the effect of the atomic features of our device on the transport of electrons.

16P-D070  Fabrication of Metallic Nanogaps Using in-situ Controlled Thermal Evaporation

A. G. Demirkol a, I. I. Kaya a, “Faculty of Engineering and Natural Sciences, Sabanci University, Istanbul 34956, Turkey

There has recently been a great effort to fabricate nanogaps, two metallic electrodes with a few-nanometer or a sub-nanometer gap, to study the electronic properties of nanoscale structures like single molecules and nanocrystals. Various nanogap fabrication techniques have been already been developed. However, there is still a need to for a high yield well controlled production scheme which is compatible with nanomechanical devices. Here, we report a new fabrication technique based on the controlled-shrinkage of a wide gap down to a vacuum tunneling gap with predetermined conductance. The devices were fabricated on a Si wafer with a SiO2 and a Si3N4 layers on top it. The metallic tips were initially defined by electron-beam lithography. Then the tips were exposed to thermally evaporated Au atoms and the gap size between the electrodes is reduced while the conductance between the gaps was continuously monitored. Evaporation is halted as soon as the desired conductance is achieved. The sizes of the gaps are typically smaller than few nanometers. After the tunneling gap was fabricated, its current-voltage characteristics were measured. The experimental data is fit to the Simmons model to determine the gap size.

2  J. Tian et al., Nanotechnology 21, 274012 (2010).

Session 16P-E:

E6 Novel Device Applications

Tuesday August 16, 16:00 – 18:00

Exhibition Hall 1

16P-E001  An apparatus for the measurements of thermal conductivity and thermal expansion based on GM cryocooler

Huiming Liu a, Dong Xu a, Peng Xu a, Laifeng Li a, Linghui Gong b, a, “The Key Laboratory of Cryogenics, Technical Institute of Physics and Chemistry, Chinese Academy of Sciences, Beijing 100190, China

The thermophysical properties of matters are extremely important for engineering and materials science. This paper describes a multifunctional apparatus based on GM cryocooler for the measurement of thermal conductivity and thermal expansion using longitudinal heat flow steady-state method and strain gauge technique respectively. It consists of a removable sample test bar on which bulk samples can easily be mounted and then placed in the described measurement device. And also the sample holder is changeable, so different sample holders are designed for different measurements of the above properties. The measurements are rapidly and accurately carried out at different temperatures. A set of stability criteria has been followed during the measurements to ensure the accuracy of the experimental data. The setup of the apparatus is calibrated with stainless steel and the experimental results are within 8% of the published results given in the literatures.

16P-E002  Specific HEMTs for...
deep cryogenic high-impedance and low-frequency readout electronics

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For decades, high-impedance and low-frequency readout electronics with the lowest noise level is based on silicon JFETs (Junction Field-Effect Transistors) with an equivalent input voltage noise of about 1 nV/\sqrt{Hz} at 1 kHz. But their operating temperature is limited to be higher than 100 K due to their intrinsic structure. It is well known that HEMTs (High Electron Mobility Transistors) are intrinsically available for very low temperature operation, but conventional HEMTs suffer high gate leakage current and large excess channel low-frequency noise under cryogenic condition. In order to overcome these two major issues, conventional HEMTs have been extensively investigated at 4.2 K as a function of the cooling condition. The correlation between the band diagram at a given working point and gate leakage current or excess channel low-frequency noise has been found out and this has allowed us to devise a new transistor structure. Specific AlGaAs/GaAs HEMTs have then been fabricated. At 4.2 K, our HEMTs can attain a noise level lower than 1 nV/\sqrt{Hz} at 1 kHz with an input gate-source capacitance of less than 30 pF and a power consumption of 0.05 mW and their gate leakage current can be limited below 0.1 pA. This result shows that our specific HEMTs may be a suitable transistor for future ultra-low noise deep cryogenic high-impedance and low-frequency readout electronics.

16P-E003 New Hybrid Magnet System for Structure Research at Highest Magnetic Fields and Temperatures in the Millikelvin Region

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The Helmholtz Centre Berlin (HZB) is a user facility for the study of structure and dynamics with neutrons and synchrotron radiation with special emphasis on experiments under extreme conditions. Neutron scattering is uniquely suited to study magnetic properties on a microscopic length scale, because neutrons have comparable wavelengths and, due to their magnetic moment, they interact with the atomic magnetic moments. At HZB a dedicated instrument for neutron scattering at extreme magnetic fields and low temperatures is under construction, the Extreme Environment Diffractometer ExED. It is projected according to the time-of-flight principle for elastic and inelastic neutron scattering and for the special geometric constraints of analysing samples in a high field magnet. The new magnet will not only allow for novel experiments, it will be at the forefront of development in magnet technology itself. With a set of superconducting and resistive coils a maximum field above 30 T will be possible. To compromise between the needs of the magnet design for highest fields and the concept of the neutron instrument, the magnetic field will be generated by means of a coned, resistive inner solenoid and a superconducting outer solenoid with horizontal field orientation. To allow for experiments down to Millikelvin Temperatures the installation of a dilution cryostat with a closed cycle precooling stage is foreseen.

16P-E004 Operation of cryogenic facility in e-way at Tata Institute of Fundamental Research, Mumbai, INDIA

K.V. Srinivasan*, *Low Temperature Facility, Tata Institute of Fundamental Research (TIFR), Mumbai - 400005, India
In an attempt towards the development of modern, model and paperless cryogenic facility, the Low Temperature Facility of Tata Institute of Fundamental Research, at Mumbai, India; carried out many automation works using programmable logic controller (PLC) and other modern electronic tools, with the objective of bringing the entire plant operation to your palm whenever and wherever you are. Efficiency in the plant operation by keeping a watch on the plant healthiness, advance indication about the possible plant problem by means of pre-warning alarms, so that the remedial action can be taken well prior to the actual failure affects the plant operation, reduction in plant down time were achieved by the automation works. Large size in our cryogen production, controlling the complicated helium liquefier, meeting the uninterrupted supply of cryogen to the users on “any time availability basis”, safety in handling cryogens and high pressure gas, effective usage of limited skilled manpower etc., all these requirements call for the definite need of modern electronic gears and gadgets. The talk will describe in details about the automation works carried out at our cryogenic facility at TIFR.

16P-E005 Efficiency of Heat Transfer in High Rayleigh Number Cryogenic Helium Turbulent Convection

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Being motivated by contradictory results on Nusselt, Nu, versus Rayleigh, Ra, number scaling observed in various cryogenic Rayleigh-Bénard convection experiments, we have re-measured the $Nu(Ra)$ dependence for $7 \times 10^6 \leq Ra \leq 4.6 \times 10^{13}$ at $0.67 < Pr < 2.4$ using a cylindrical cell 0.3 m in diameter and height designed to minimize influence of its structure on the studied convective flow. High Ra are attained with cryogenic helium gas sufficiently far away from its critical point. The measured Nu values (both uncorrected and corrected with respect of adiabatic gradient and conductivity of wall and plates) obey, at least approximately, $Nu(Ra)$ power law scaling with exponent $\gamma \approx 2/7$ in the region $7 \times 10^6 \leq Ra \approx 10^{11}$ where $Pr < 1$; at higher $Ra$ up to $4.6 \times 10^{13}$ on slightly increasing $Pr$ the power exponent approaches $1/3$ and does not indicate transition into ultimate Kraichnan regime. We show that, using an appropriate wall correction, the aspect ratio $\Gamma \approx 1$ Trieste, Grenoble and our cryogenic data sets col-
Superfluid $^3$He-B at ultra-low temperatures is an appealing target material for bolometric particle detection, and particularly for the search of non-baryonic Dark Matter. The main arguments in favor of $^3$He are its non-zero nuclear magnetic moment (allowing therefore to explore the Spin-Dependent interaction channel) combined to the extremely high sensitivity of superfluid $^3$He bolometers and the possibility of efficient neutron background discrimination. We have studied intensively the recoil energy after an event with different types of radiation. We have found the different ways of recoil energy thermalization. The main part is going to quasiparticles creation. Another part is going for the creation of vortices. And the last one is going for dimers formation. We have found experimentally that the $1/4^{th}$ part of this energy radiates photons, while the $3/4^{th}$ part returns back to quasiparticles after a dimers breakdown near the walls of the cell. We are able to use this mechanism for discrimination between nuclear and electrons recoil. The time of vortex decay depends strongly on the history of the sample. It means that in superfluid $^3$He exist some stable defects which can be removed by annealing.

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**16P-E006 Dark Matter Detector on the Basis of Superfluid $^3$He**

Yu.M. Bunkov, A. Collin, J. Elbs, H. Godfrin, Institut Neel, CNRS et Universite Joseph Fourier, 38042 Grenoble, France

Superfluid $^3$He-B at ultra-low temperatures is an appealing target material for bolometric particle detection, and particularly for the search of non-baryonic Dark Matter. The main arguments in favor of $^3$He are its non-zero nuclear magnetic moment (allowing therefore to explore the Spin-Dependent interaction channel) combined to the extremely high sensitivity of superfluid $^3$He bolometers and the possibility of efficient neutron background discrimination. We have studied intensively the recoil energy after an event with different types of radiation. We have found the different ways of recoil energy thermalization. The main part is going to quasiparticles creation. Another part is going for the creation of vortices. And the last one is going for dimers formation. We have found experimentally that the $1/4^{th}$ part of this energy radiates photons, while the $3/4^{th}$ part returns back to quasiparticles after a dimers breakdown near the walls of the cell. We are able to use this mechanism for discrimination between nuclear and electrons recoil. The time of vortex decay depends strongly on the history of the sample. It means that in superfluid $^3$He exists some stable defects which can be removed by annealing.

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**16P-E007 A new SQUID-based magnetometer for temperatures below 1 K implementing an extended motion piezo-motor for the sample movement**

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Here we present a novel design of a magnetometer for a very low temperature environment below 1 K, intended to be used in dilution refrigerators. We have employed a piezo-motor with an extended range of motion (20 mm) for the movement of the sample through the pickup coils of the magnetometer. We have succeeded in thermally decoupling the piezo-motor from the mixing chamber and the sample.

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**16P-E008 Compact, Inexpensive Coaxial Terminations for Low Temperature RF Applications.**

E. Smith*, M. Deshmukh*, V.P. Adiga*, H.S. Solanki*, V. Singh*, R. Bennett*, N. Zhelev*, J. Parpia*, "Department of Physics, Cornell University, Ithaca NY 14853, USA

We have identified a promising family of radio frequency coaxial connectors (the SSMCX range) manufactured by Molex that have characteristics useful for applications at low temperatures. In the past, we used coaxial terminations manufactured and sold under the Microdot name. However, these are now much more expensive and often prove to be difficult to assemble. We will describe the use and assembly of SSMCX connectors including designs for junction boxes and transmission characteristics of typical arrangements using lossy Cooner coaxial cable and specialty low temperature coaxial cable.

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**16P-E009 HDice, Highly Polarized Low-Background Frozen-Spin HD Target for CLAS at Jefferson Lab**


The targets reach a frozen-spin state within a few months, after which they can be cold transferred to 17T). The targets reach a frozen-spin state within a few months, after which they can be cold transferred to 17T). The targets reach a frozen-spin state within a few months, after which they can be cold transferred to 17T). The targets reach a frozen-spin state within a few months, after which they can be cold transferred to 17T).
have been reported that, at low temperature, liquid carbon atoms emitted by discharge cool quickly and start to combine with some amount of energy, enabling creation of carbon nanomaterials with basic structures. Our subsequent work has focused on CNT fabrication in liquid helium, with the goals of achieving both high reproducibility and a better understanding of the details of fabrication that will enable us eventually to fabricate nanomaterials with new characteristics. Hence, we investigate the conditions for fabrication of carbon nanomaterials by arc discharge in low-temperature liquid such as liquid helium by studying the discharge characteristics in liquid helium and the obtained emission spectra of the discharges. Measurements of the discharge characteristics of the resulting plasma and observation of the associated optical emission spectra show that the behaviour of discharge current over time and the associated spectra depend strongly on discharge voltage and both may be related to the temperature of the carbon target. However, changes in discharge voltage and current with time are almost the same regardless of whether the liquid is pure water, liquid nitrogen or liquid helium. Emission spectra from the discharge show a strong dependence on discharge voltage.

16P-E011 Micro NMR Coil for Liquid $^3$He at Ultra Low Temperature

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NMR is a powerful technique to study nuclear spin dynamics of liquid/solid $^3$He at ultra low temperature, such as texture profiles of superfluid $^3$He, spin wave modes of liquid/solid $^3$He. In order to investigate those forming and deforming spatiotemporal processes, however, we need to have higher spatiotemporal resolution without changing static magnetic fields. To achieve this goal, we are developing a CCD type imaging technique by using an array of micro NMR coils. A micro fabrication technique ensures homogeneous production of the array of the micro NMR coils. At RIKEN NanoScience Joint Laboratory, we made the micro NMR coils with the micro fabrication technique. The coil is about 100 $\mu$m long, 20 $\mu$m wide and deposited on a Si wafer. The coil wire is 3 $\mu$m wide, 200 nm thick and made of Au. For electrical insulation, SiO$_2$ layers are added below the wire. According to our calculation of the RF profile, this coil dimension enables us to observe spin dynamics 20 $\mu$m above the coil surface. The resistance through the micro coil is measured to be 17 ohm at room temperature and 4 ohm at 4.2 K. Due to this large remnant resistance, the Q value is estimated less than 1 at 100 MHz. In order to attain higher Q value, we opt to increase the wire thickness and to anneal the micro coils. Improvement will be also reported on the conference.

16P-E012 Compound Torsion Oscillator Driven Simultaneously at Two Frequencies

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A compound torsion oscillator (TO), having two resonant mode frequencies (492 Hz and 1163 Hz) and high Q (0.5–1×10$^6$), has become an important tool for studying the supersolid properties of $^3$He loaded into the main TO bob. It would be interesting for example, to observe critical velocity effects driven by one mode and measured with the other. By simultaneously exciting both modes of this TO, we can observe how changes to the drive amplitude of one mode affect the sample response measured by the other mode. In order to determine the effects due to the sample, knowledge of “background” effects due to the unloaded TO itself is necessary. Thus a series of measurements of the unloaded TO were preformed. The resonant frequency and amplitude of both modes were measured at fixed temperatures (9.7, 23.5 and 56.5 mK) as the drive amplitude of one mode was varied while the other was held fixed, at a low drive amplitude. Unexpectedly, the resonant frequency of the fixed mode decreased as the drive amplitude of the varied mode was increased. In addition the amplitude of the fixed mode decreased as the amplitude of the varied mode was increased. This indicates that the mechanical properties of the TO are affected by increasing the drive amplitude. The change in frequency could be due to a change in the stiffness of the torsion rods at higher amplitude, while the change in amplitude could indicate an increase in internal friction. The varied mode shows similar effects as the drive amplitude is increases.

16P-E013 Preparation and Rectification Function of Multilayer Oxide p-i-n Junctions (LT26)

Feng-jin Xiu*, Yue-ju Fu*, Bo Xu*, Yu-mei Wang*, Jie Yuan*, Hao Wu*, Bei-yi Zhu*, Li-xin Cao*, Zhao-Xue*, Bao-ting Liu*, Ai-zi Jin*, Jun-jie Li*, Bai-ru Zhao*, Beijing National Laboratory for Condensed Matter Physics, Institute of Physics, Chinese Academy of Sciences, Beijing 100190, China

The whole perovskite oxide p-i-n junctions aimed for developing three terminal devices are prepared by means of pulsed laser deposition on SrTiO$_3$ substrate, for which the p-area is the semiconducting $(La_{1-x}Sr_x)MnO_3$ (LSMO) with $x$~0.1–0.2, the n-area is the electron-doped cuprate superconductor $(La_{1-x}C_{x})_2CuO_4$ (LCCO), and the oxide ferroelectric $(Ba_{1-x}Sr_x)TiO_3$ (BST) is inserted in between LSMO and LCCO layers as the depletion layer. The key problem for the fabrication is to solve the contradiction of reduction treatment for the as-deposited LCCO layer and full oxidization treatment for the as-deposited LSMO layer in the deposition process to get high quality multilayer. It is found that the rectification of such p-i-n junctions is strongly dependent on the thickness of BST layer. The largest rectification corresponds to the case that the thickness of BST layer must be identical to that of depletion layer between n-LCCO and p-LSMO layers.
Main Magnet Based on the Low Temperature Stability of NbTi Superconducting Wire
Guoqing Zhang\textsuperscript{a, b}, Ling Zhao\textsuperscript{a}, Feipeng Ning\textsuperscript{a, b}, Xiaoji Du\textsuperscript{a}, Zian Zhu\textsuperscript{a}, \textsuperscript{a} State Key Laboratory of Particle Detection and Electronics, Institute of High Energy Physics, Chinese Academy of Sciences, Beijing, China \textsuperscript{b} Graduate University of Chinese Academy of Sciences, Beijing, China

Some theoretical analysis on the low-temperature stability of NbTi superconducting wire in high magnetic fields has been done in this paper, and we got some appropriate choices of high-field NbTi superconducting wire. The distribution of the field within superconducting coils used for NbTi superconducting wire selected, the idea of Layered coil physical structure for the high-field MRI main magnet design is proposed; Effective control of the maximum magnetic field strength and high-field NbTi superconducting wire usage, the main magnet manufacturing cost savings; Application of this idea, the design of a 9.4T human MRI superconducting magnets of the electromagnetic structure will be introduced.

16P-E015 Low Temperature Scanning Probe Microscope (LT-SPM) operating in a Cryogen-Free Cryostat, 1.5-300K
Ozgur Karci\textsuperscript{a}, Gizem Durak\textsuperscript{a}, Munir Dede\textsuperscript{a}, Yury Bugoslavsky\textsuperscript{a}, Renny Hall\textsuperscript{a}, Ahmet Oral\textsuperscript{a}, \textsuperscript{a} NanoManyetik Bilimsel Cihazlar Ltd., Hacettepe Teknokent, 3 ArGe, No: 31, Beytepe, 06800, Ankara, Turkey \textsuperscript{b} Hacettepe University, Dept. of Nanotechnology and Nanomedicine, Beytepe, 06800, Ankara, Turkey \textsuperscript{c} Cryogenic Ltd., Unit 29/30 Acton Park Industrial Estate, The Vale, London, W3 7QE, United Kingdom \textsuperscript{d} Sabanci University, Faculty of Science and Engineering, Orhanli, \textsuperscript{e} 3 ArGe, No: 31, Beytepe, 06800, Ankara, Turkey

We designed and operated a low temperature Scanning Probe Microscope (LT-SPM) for cryogen-free cryostat systems. The vibration of Pulse Tube (PT) is eliminated by edge welded bellows which decouples microscope from the cryostat platform. We can resolve atomic terraces of mica surface.

16P-E016 mK-Scanning Probe Microscope (mK-SPM) operating in a Cryogen-Free Dilution Refrigerator at 20mK
Ozgur Karci\textsuperscript{a}, Munir Dede\textsuperscript{a}, Ahmet Oral\textsuperscript{a}, \textsuperscript{a} NanoManyetik Bilimsel Cihazlar Ltd., Hacettepe Teknokent, 3 ArGe, No: 31, Beytepe, 06800, Ankara, Turkey \textsuperscript{b} Hacettepe University, Dept. of Nanotechnology and Nanomedicine, Beytepe, 06800, Ankara, Turkey \textsuperscript{c} Cryogenic Ltd., Unit 29/30 Acton Park Industrial Estate, The Vale, London, W3 7QE, United Kingdom \textsuperscript{d} Sabanci University, Faculty of Science and Engineering, Orhanli, \textsuperscript{e} 3 ArGe, No: 31, Beytepe, 06800, Ankara, Turkey

We have designed and operated a mK-SPM for cryogen-free dilution refrigerator systems. The rigid and sturdy design of the microscope design enables us to operate the system in a cryogen-free DR.

16P-E017 A cold atom interferometer for precise gravity measurements
Zhongkun Hu\textsuperscript{a}, Minkang Zhou\textsuperscript{a}, Xiaochun Duan\textsuperscript{a}, Jun Luo\textsuperscript{a}, \textsuperscript{a} Department of Physics, Huazhong University of Science and Technology, Wuhan 430074, China

Precisely measuring gravity acceleration g plays an important role on both geophysics and metrology. Here we describe an experimental realization of a cold atom interferometry gravimeter and gravity gradiometer. The gravimeter is based on a fountain of laser cooled and trapped Rubidium atoms. By coherently manipulating the free falling atoms' wave packet with a counter-propagating linear-per-linear Raman beams, a resolution of after 203 seconds integration time has been achieved on our atom interferometry gravimeter. The gradiometer employs the juggling method to launch two clouds of 87Rb atoms from single MOT. When simultaneously interacting with a pulse of stimulated Raman transition, the two clouds form two equivalent atom gravimeters. From the fringes of the gravimeters the gradiometer phase shift is extracted by ellipse-fit-method, and the corresponding Allan variance is calculated, which shows that a resolution of about with integration time has been achieved on our atom interferometry gradiometer.

16P-E018 Precisely mapping the magnetic field gradient in vacuum with a cold atom Interferometer
Zhongkun Hu\textsuperscript{a}, Minkang Zhou\textsuperscript{a}, Xiaochun Duan\textsuperscript{a}, Jun Luo\textsuperscript{a}, \textsuperscript{a} Department of Physics, Huazhong University of Science and Technology, Wuhan 430074, China

In order to correct the systematic error due to magnetic field inhomogeneity in a cold atom gravimeter, we have experimentally demonstrated a magnetic gradiometer based on the cold-atom interferometry technique. The 87Rb atoms are firstly cooled and launched in an atomic fountain. By coherently driven those atoms with co-propagating phase-locked Raman beams, the magnetic gradient experienced by the moving atoms is recorded in the atom interferometry phase, and the different interferometers with different magnetic sublevels are used to extract the magnetic gradient signal and reject some systematical errors. By using this technique, a resolution of 300pT/mm has been demonstrated with a 90 seconds of integration time and a spatial resolution of 1.4mm. The magnetic field gradient in a vacuum chamber was mapped by this sensitive and high spatial resolution gradiometer, and the data obtained by it could be used to correct the systematical error due to magnetic field inhomogeneity in an atom gravimeter.
Session 17P: Plenary Lectures

Chair: Lu Yu
Wednesday August 17, 09:00 – 12:00
Convention Hall 1

17P-1  From ultracold Fermi Gases to Neutron Stars
C. Salomon*, aDépartement de physique de l’Ecole Normale Supérieure, CNRS, UPMC, 24 rue Lhomond, 75231 Paris, France.

Ultracold dilute atomic gases can be considered as model systems to address some pending problem in Many-Body physics that occur in condensed matter systems, nuclear physics, and astrophysics. We have developed a general method to probe with high precision the thermodynamics of locally homogeneous ultracold Bose and Fermi gases. This method allows stringent tests of recent many-body theories. For attractive spin 1/2 fermions with tunable interaction (6Li), we will show that the gas thermodynamic properties can continuously change from those of weakly interacting Cooper pairs described by Bardeen-Cooper-Schrieffer theory to those of strongly bound molecules undergoing Bose-Einstein condensation. First, we focus on the finite-temperature Equation of State (EoS) of the unpolarized unitary gas. Surprisingly, the low-temperature properties of the strongly interacting normal phase are well described by Fermi liquid theory and we localize the superfluid phase transition. A detailed comparison with theories including Monte-Carlo calculations has revealed some surprises and the Lee-Huang-Yang corrections for low-density bosonic and fermionic superfluids are quantitatively measured for the first time. Despite orders of magnitude difference in density and temperature, our equation of state can be used to describe low density neutron matter such as the outer shell of neutron stars.

17P-2  High Resolution Photoemission Studies of High Tc Superconductivity
Peter Johnson, aBrookhaven National Laboratory

In the last decade Angle Resolved Photoemission (ARPES) has evolved into one of the most powerful probes of condensed matter systems. With its ability to momentum resolve the electronic structure and associated dynamics it has provided important insights into the physics of a range of materials including the high Tc superconductors. In particular it has been shown to provide important information on the mass renormalizations associated with many body interactions, the form of the Fermi surface, and the gaps associated with superconductivity. In the area of the cuprates we show how the Fermi surface evolves on moving from the highly underdoped regime through to the more overdoped regime. Such studies indicate the presence of a quantum critical point associated with the transition from insulating to metallic behavior. There is also good evidence for the presence of preformed singlet pairs in the normal state above the superconducting transition when long range phase coherence is established.

17P-3
Duncan Haldane*, aPrinceton University
(to be announced)

17P-4  Particle physics on a chip; The search for Majorana Fermions
Leo Kouwenhoven*, aKavli Institute of NanoScience, Delft, The Netherlands

Predicted in 1937 but never detected, particles that are equal to their own antiparticles. Could neutrino’s be Majorana Fermions? What about dark matter? I don’t know, but now Majorana’s have also been predicted to exist in specially designed nanoscale devices. So instead of detecting new particles at higher and higher energies, one can alternatively design more and more carefully quantum states in condensed matter in which the low-energy (quasi)-particles obey certain symmetries. We will outline and present experiments geared towards demonstrating Majorana’s based on superconductors and semiconductor nanowires.
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