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June 17, Sunday, Morning

Mercury Telluride: A Topological Insulator

Hartmut Buhmann
Physikalisches Institut, EP3, Universität Würzburg, Germany

The increasing understanding of topological phases in condensed matter physics, which was initiated by the quantum Hall effect, has inspired the search for further topological states. As an example a new topological insulator state, the quantum spin Hall (QSH) effect, was proposed for two-dimensional electron system with strong spin-orbit coupling [1, 2]. This new state is characterized by an insulating bulk and two counter-propagating helical edge states. These so-called Kramers pairs account for a quantized conductance and propagate spin currents without dissipation. After the successful experimental demonstration [3], the concept of topological insulators was extended to three-dimensional systems [4] where Dirac-like surface states dominate electronic and optical excitations resulting in new exotic properties.

In this presentation, the material system of mercury-telluride (HgTe) is introduced. The first experimental realization of a two-dimensional topological insulator (TI) state is shown [3, 5, 6] and the first transport characterization of a three-dimensional TI is presented [7]. Furthermore, it is possible to show evidence for the spin polarization of the QSH edge channels in an all-electrical measurement which demonstrates the potential of the QSH effect for spin injection and detection in spintronics applications [8].

[1] C.L. Kane and E.J. Mele, Phys. Rev. Lett **95**, 226801 (2005).
[2] B.A. Bernevig and S.C. Zhang, Phys. Rev. Lett. **96**, 106802 (2006).
[3] M. König et al., Science **318**, 766 (2007).
[4] L. Fu and C.L. Kane, Phys. Rev. B **76**, 045302 (2007).
[5] M. König et al. Journ. Phys. Soc. Japn. **77**, 031007 (2008).
[6] A. Roth et al., Science **325**, 294 (2009).
[7] C. Brüne et al., Phys. Rev. Lett. **106**, 126803 (2011).
[8] C. Brüne et aL., Nat. Phys. accepted (2012).

Nonlocal transport in a 2D semimetal, a 2D topological insulator and a system of 2D Dirac fermions based on HgTe quantum wells

Z.D.Kvon
Institute of Semiconductor Physics, Novosibirsk, Russia

The talk is devoted to experimental study of three new types of 2D electron systems - a 2D semimetal, a 2D topological insulator and a 2D single valley Dirac fermions realized recently in HgTe quantum wells. More precisely, it is about the peculiar properties of the nonlocal transport in these 2D electron systems. It is well-known that nonlocal transport observed in an ordinary 2D metal in the QHE regime is due to the presence of edge current states. According to the edge current model of the QHE, if the Fermi level lies in the gap between two adjacent Landau levels there is no backscattering in the system and a non-dissipative transport is realized along the edge current states. In that case one observes a zero diagonal resistivity component and a quantized Hall resistivity value. When, however, the Fermi level crosses one of the Landau levels, the innermost edge current state becomes coupled to the bulk and experiences a strong backscattering resulting in a nonzero diagonal resistance and suppression of Hall quantization. In this case a nonlocal dissipative transport is observed in the QHE regime.

In this talk we discuss a dissipative transport of a completely different kind that is observed in a 2D topological insulator at zero magnetic field and in a 2D semimetal in the QHE regime. In both cases the Fermi level lies in the gap in the bulk of the sample and the observed dissipative transport is due to the edge current states behavior. In a 2D TI the transport is realized by the helical edge current states with strong backscattering breaking the topological protection. The dissipative edge states can propagate over a long distance ~ 1 mm. So there is no difference between local and nonlocal electrical measurements in a 2D topological insulator. In the presence of an in-plane magnetic field a strong decrease of the local resistance and a complete suppression of the nonlocal resistance is observed. We attribute this behavior to an in-plane magnetic-field-induced transition from the topological insulator state to a conventional bulk metal state. Dissipative edge states propagating over a macroscopic scale (about 1 cm) are also observed in the QHE regime of a 2D semimetal at ν i.e at the charge neutrality point (CNP). In both cases the edge current states can be viewed as a long single-mode 1D system and it is surprising that no strong Anderson localization is found.

In the system of gapless, single valley Dirac fermions a giant nonlocal response has been detected in the classical magnetic field regime when no edge current states exist. We attribute this to the spin Hall effect induced by the Zeeman interaction recently discussed in graphene.

Ferromagnetism and Electric Field Effect in a Magnetically Doped Topological Insulator

J. G. Checkelsky,[1] J. T. Ye,[2] Y. Onose,[2] Y. Iwasa,[1,2] and Y. Tokura[1,2,3]
[1]*Correlated Electron Research Group, RIKEN-ASI, Wako, Saitama, Japan*
[2]*Department of Applied Physics, University of Tokyo, Tokyo, Japan*
[3]*Cross-Correlated Materials Research Group, RIKEN-ASI, Wako, Saitama, Japan*

Recent theoretical work in topological insulators has shown that breaking of certain symmetries produces exotic electronic states of both fundamental and technological interest. In particular, breaking of time reversal symmetry is predicted to generate an energy-gapped ground state supporting topological magnetoelectric effects and a quantized Hall effect. We present results demonstrating time reversal symmetry breaking in the form of ferromagnetism driven by doped magnetic (Mn) impurities in the topological insulator Bi_2Te_2. We have grown single crystals of Mn and Se doped Bi_2Te_2 and subsequently fabricated devices based on cleaved nanometer scale thickness crystals with electrodes defined by electron beam lithography. Devices have a solid dielectric back gate and ionic liquid top gate, which allows for tuning of the chemical potential μ from bulk to surface bands. By tracking the anomalous Hall effect under the action of the electric field effect, we study the development of ferromagnetism across the electronic spectrum. The experimental observation is an enhanced ferromagnetic ordering temperature as μ approaches the Dirac point of the linearly dispersing surface bands. The details of this dependence of the ferromagnetism on μ suggests a prominent role of the in-gap states stemming from an interaction between the surface electron spin σ with the average z-component of the impurity spins. We discuss further manifestations of this behavior in the electric transport response.

June 17, Sunday, Morning

Probing the Exotic Surface States in Topological Insulators and Superconductors

Yoichi Ando
Institute of Scientific and Industrial Research, Osaka University, Japan

A topological state of matter is characterized by a nontrivial topological structure of the Hilbert space of its wavefunctions. Due to the bulk-edge correspondence, a gapless surface state always accompanies a topologically nontrivial bulk state. In topological insulators (TIs), a nontrivial Z_2 topology of the bulk state leads to the emergence of Dirac fermions on the surface. Similarly, topological superconductors (TSCs) are accompanied by surface Andreev bound states that often consist of Majorana fermions. In this talk, I will present our experiments to address those exotic surface states. For TIs, we discovered that the chalcogen-ordered tetradymite Bi_2Te_2Se presents a high bulk resistivity, allowing one to observe clear surface quantum oscillations [1]; more recently, we demonstrated that in related systems $Bi_{2-x}Sb_xTe_{3-y}Se_y$ [2] and $Bi_{2-x}Sn_xTe_2Se$ [3], it is possible to achieve a surface-dominated transport even in a bulk crystal. For TSCs, in a superconducting doped-TI material $Cu_xBi_2Se_3$, we have succeeded in observing an unconventional surface Andreev bound state, which gives evidence for a new type of topological superconductivity associated with helical Majorana fermions [4]. These works were done in collaboration with A. A. Taskin, Z. Ren, M. Kriener, S. Sasaki, and K. Segawa, and were supported by JSPS (NEXT Program), MEXT (Innovative Area "Topological Quantum Phenomena" KAKENHI), and AFOSR (AOARD 104103 and 124038).

[1] Z. Ren *et al.*, Phys. Rev. B **82**, 241306(R) (2010).
[2] A. A. Taskin *et al.*, Phys. Rev. Lett. **107**, 016801 (2011).
[3] Z. Ren *et al.*, arXiv:1203.6411.
[4] S. Sasaki *et al.*, Phys. Rev. Lett. **107**, 217001 (2011).

Gate-tuned normal and superconducting transport at the surface of a topological insulator

Benjamin Sacépé,[1,2] J. Oostinga,[2] J. Li,[2] A. Ubaldini,[2] N. Couto,[2] E. Giannini,[2] and A. Morpurgo[2]
[1]*Néel Insitute, CNRS & Joseph Fourier University, Grenoble, France*
[2]*Département de Physique de la Matière Condensée, University of Geneva, Switzerland*

Three dimensional topological insulators are a novel quantum state of matter which exhibits an insulating bulk state and gapless metallic surface state. Owing to the large spin-orbit interaction and the ensuing band structure topology, these surface states behave as massless, spin-helical Dirac fermions that are protected against backscattering. In this talk I present recent results of magnetotransport measurements performed on the 3D topological insulator Bi_2Se_3 [1]. The samples studied are nano-connected ultra-thin flakes of high quality Bi_2Se_3 deposited on a SiO_2/Si substrate that acts as a gate electrode. Such back-gated device allows to vary continuously the carrier density by electrostatic doping over the entire Dirac cone of the surface state. Under magnetic field B, sweeping the gate voltage enables us to control the filling of the Landau levels, resulting in Shubnikov-de Haas oscillations of the conductance. The continuous evolution of the SdH oscillations from electron to hole character gives a clear evidence for the Dirac nature of the surface state. After this demonstration of the control of electronic transport through the surface states I'll show that, when the electrodes are superconducting at $B = 0$, Cooper pairs can also be transferred into the surface state leading to a gate-tuned ambipolar supercurrent.

[1] B. Sacepe *et al.* Nature Communications 2:575 (2011).

June 17, Sunday, Afternoon

Protected edge modes without symmetry

Michael Levin
University of Maryland, USA

An important aspect of fractional quantum Hall liquids is that they support protected gapless edge modes. In many cases, these edge modes are extremely robust and cannot be gapped out or localized by any interactions or disorder at the edge. The robustness of these modes does not depend on any symmetries – including charge conservation. In this talk, I will discuss these "symmetry-insensitive" edge modes and investigate their physical origin.

Energy-driven drag in graphene

Leonid Levitov
Department of Physics, Massachusetts Institute of Technology, Cambridge, MA 02139, USA

Graphene is a unique system where intrinsic electron-lattice cooling is slow in wide range of practically interesting temperatures. We will discuss current understanding of cooling pathways, in particular the role of disorder-assisted collisions. Slow cooling makes hot carriers key for a wide range of phenomena involving electricity and light. Several examples will be discussed, including graphene photoelectric response, nonlocal transport and giant enhancement of Coulomb drag near charge neutrality.

Flux quantization in nano-perforated samples of thin graphite and graphene

Yu.I. Latyshev,[1] A.P. Orlov,[1] V.A. Volkov,[1] and P. Monceau[2]
[1] *Kotelnikov Institute of Radio-Engineering and Electronics RAS, Mokhovaya 11-7, Moscow 125009, Russia*
[2] *Neel Institute, CNRS, Rue des Martyrs 25, Grenoble 38042, France*

We found that thin graphite and graphene samples perforated with nanoholes exhibit field periodic oscillations of magnetoresistance with periodicity of flux quantum hc/e per nanohole area [1, 2]. Observation of the Aharonov-Bohm-type oscillations on non-ring-shaped samples is attributed to the existence of the edge states in graphene around a hole. From the experiment we estimate the depth of the edge state λ as being $\lambda \approx 2$ nm. Using temperature dependence of the amplitude of oscillations we can estimate the characteristic energy and velocity of the edge Dirac fermions as being 2 107 cm/s, 5 times less than the Fermi velocity of the bulk Dirac fermions. That is consistent with a theory of the edge states in graphene [3].

The work has been supported by RFBR grants No 11-02-01379-a, No 11-02-90515-Ukr_f_a, 11-02-12167-ofi-m, the state contracts No 16.740.11.0146 and No 16.513.11.3066.

[1] Yu.I. Latyshev, A.Yu. Latyshev, A.P. Orlov et al., JETP Lett., 90, 480-484 (2009).
[2] Yu.I. Latyshev, A.P. Orlov, et al., Journ of Phys.: Conf. Series., 248, 012001 (2010).
[3] V.A. Volkov and I.V. Zagorodnev, Journ of Phys.: Conf. Series., 193, 012113 (2009).

Josephson supercurrent through a topological insulator surface state

M. Veldhorst,[1] M. Snelder,[1] M. Hoek,[1] T. Gang,[1] X. L. Wang,[2] V. K. Guduru,[3] U. Zeitler,[3] W.G. v.d. Wiel,[1] A.A. Golubov,[1] H. Hilgenkamp,[1] and A. Brinkman[1]

[1] *Faculty of Science and Technology and MESA+ Institute for Nanotechnology, University of Twente, 7500 AE Enschede, The Netherlands*
[2] *Institute for Superconducting and Electronic Materials, University of Wollongong, Australia*
[3] *High Field Magnet Laboratory, Radboud University Nijmegen, The Netherlands*

The long-sought yet elusive Majorana fermion is predicted to arise from a combination of a superconductor and a topological insulator. An essential step in the hunt for this emergent particle is the unequivocal observation of supercurrent in a topological phase. Here, we present direct evidence for a Josephson supercurrent in superconductor (Nb) - topological insulator (Bi_2Te_3) - superconductor e-beam fabricated junctions by the observation of clear Shapiro steps under microwave irradiation, and a Fraunhofer-type dependence of the critical current on magnetic

eld. The dependence of the critical current on temperature and electrode spacing shows that the junctions are in the ballistic limit. Shubnikov-de Haas oscillations in magnetic

elds up to 30 T reveal a topologically non-trivial two-dimensional surface state. We argue that the ballistic Josephson current is hosted by this surface state despite the fact that the normal state transport is dominated by diffusive bulk conductivity. The lateral Nb-Bi_2Te_3-Nb junctions hence provide prospects for the realization of devices supporting Majorana fermions.

[1] M. Veldhorst, M. Snelder, M. Hoek, T. Gang, V. Guduru, X. Wang, U. Zeitler, W.G. van der Wiel, H. Hilgenkamp, A. Brinkman, Nature Materials, Advanced Online Publication, doi:10.1038/nmat3255 (2012).

Tunneling Conductance and Surface States Transition in Superconducting Topological Insulators

Ai Yamakage,[1] Yukio Tanaka,[1] Keiji Yada,[1] and Masatoshi Sato[2]

[1] *Department of Applied Physics, Nagoya University, Nagoya 464-8603, Japan*
[2] *Institute for Solid State Physics, University of Tokyo, Chiba 277-8581, Japan*

We develop a theory of the tunneling spectroscopy for superconducting topological insulators (STIs), where the surface Andreev bound states (SABSs) appear as helical Majorana fermions [1, 2]. Based on the symmetry and topological nature of parent topological insulators, we find that the SABSs in the STIs have a profound structural transition in the energy dispersions [2, 3]. The transition results in a variety of Majorana fermions, by tuning the chemical potential and the effective mass of the energy band. We clarify that Majorana fermions in the vicinity of the transitions give rise to robust zero bias peaks in the tunneling conductance between normal metal/STI junctions [3]. Our obtained results are qualitatively consistent with recent experiment by Sasaki *et al*. [4].

[1] L. Fu and E. Berg, Phys. Rev. Lett. **105**, 097001 (2010).
[2] T. H. Hsieh and L. Fu, Phys. Rev. Lett. **108**, 107005 (2012)
[3] A. Yamakage, *et. al*, arXiv :1112.5036.
[4] S. Sasaki, *et. al*, Phys. Rev. Lett. **107**, 217001 (2011).

June 18, Monday, Morning

AC phase dependent response and minigap spectroscopy of diffusive SNS junctions

B. Dassonneville,[1] M. Ferrier,[1] F. Chiodi,[1,2], S. Guéron,[1] and H. Bouchiat[1]

[1] *LPS, Univ. Paris-Sud, CNRS, UMR 8502, F-91405 Orsay Cedex, France*
[2] *IEF, Univ. Paris-Sud, CNRS, UMR 8622, F-91405 Orsay Cedex France*

A long phase coherent normal (N) wire between superconductors (S) is characterized by a dense phase dependent Andreev spectrum. We investigate the current response of Andreev states of an NS ring to a high frequency time dependent Aharonov Bohm flux superimposed to a dc one. Beside the well known Josephson current we identify different contributions to the ac response. A low frequency one related to the dynamics of the thermal occupations of the Andreev states and a a larger frequency one related to transitions above the minigap [1]. These findings are compared to the results provided by Usadel equations as well as recent experiments. In particular we identify a range of parameters for which the phase dependent dissipative response and minigap are simply proportional (with opposite signs).

[1] Chiodi et al, Scientific Reports 1 (2011).

Experiments with Andreev bound states in InAs semiconducting nanowires with superconducting leads

V. Manucharyan
Harvard University, USA

Nonadiabatic Josephson dynamics in junctions with in-gap quasiparticles

Vitaly Shumeiko and Jens Michelsen
Department of Microtechnology and Nanoscience,
Chalmers University of Technology, Gothenburg, Sweden

Conventional models of Josephson junction dynamics rely upon the absence of low-energy quasiparticle states in tunnel junctions of conventional superconductors owing to a large superconducting energy gap. With this assumption the quasiparticle degrees of freedom are frozen out, and the phase difference becomes the only free variable, acting as a fictitious particle in a localized Josephson potential related to the adiabatic and non-dissipative supercurrent across the junction.

We develop a general framework to incorporate the effects of low-energy quasiparticles interacting nonadiabatically with the phase degree of freedom. These quasiparticle states typically exist in junctions of unconventional superconductors, as well as constriction type junctions with high transparency conducting channels or resonant states.

We examine in detail the effect of the zero-energy bound states in Josephson junctions of d-wave superconductors. We identify a reentrance effect in the transition from thermal activation to the macroscopic quantum tunneling regime and discuss the relation to the experiments on YBCO junctions. We also show that the real time Josephson dynamics is sensitive to the resonant interaction with zero-energy states, and demonstrate that this interaction rather than confinement by the Josephson potential, determines the nonlinear Josephson dynamics at small amplitudes.

[1] J. Michelsen and V. S. Shumeiko, Phys. Rev. Lett. **105**, 127001 (2010).
[2] J. Michelsen and V. S. Shumeiko, Low Temp. Phys. **36**, 925 (2010).

Quasiparticle Trapping in Andreev Bound States

Maciej Zgirski,* L. Bretheau, Q. Le Masne, H. Pothier, C. Urbina, D. Esteve
Quantronics Group, SPEC, CEA Saclay, France
presently: Institute of Physics, PAN, Warsaw, Poland

We have observed that the supercurrent across Aluminum atomic-size contacts can be strongly reduced when they are phase biased around π. We attribute this effect to quasiparticle trapping in one of the discrete subgap Andreev bound states forming in each conduction channel of the contact. The ability to tune in-situ and measure the number of channels and their transmissions has allowed us to carry out a detailed characterization of the dynamics of this trapping phenomenon. We found that detectable trapping occurs only in channels of sufficiently high transmission ($\tau > 0.74$) such that the energy of their lowest lying Andreev state is smaller than half the superconducting gap Δ. In this situation we measure lifetimes of trapped quasiparticles exceeding $100\,\mu s$. The origin of this sharp energy threshold is presently not understood.

[1] M. Zgirski, L. Bretheau, Q. Le Masne, H. Pothier, D. Esteve, and C. Urbina, Phys. Rev. Lett. **106**, 257003 (2011).

Measuring entanglement of generic many-body systems

D. Abanin
Department of Physics, Harvard University, Cambridge, Massachusetts 02138, USA

Entanglement entropy has become an important theoretical concept in condensed matter physics, because it provides a unique tool for characterizing quantum mechanical many-body phases and new kinds of quantum order. However, the experimental measurement of entanglement entropy in a many-body systems is widely believed to be unfeasible, owing to the nonlocal character of this quantity. Here, we propose a general method to measure the entanglement entropy. The method is based on a quantum switch (a two-level system) coupled to a composite system consisting of several copies of the original many-body system. The state of the switch controls how different parts of the composite system connect to each other. We show that, by studying the dynamics of the quantum switch only, the Renyi entanglement entropy of the many-body system can be extracted. We propose a possible design of the quantum switch, which can be realized in cold atomic systems. Our work provides a route towards testing the scaling of entanglement in critical systems, as well as a method for a direct experimental detection of topological order.

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June 18, Monday, Afternoon

Tunneling spectroscopy of fluctuating and localized preformed Coopers pairs in highly disordered superconducting films

C. Chapelier,[1] T. Dubouchet,[1] B. Sacépé,[1, 2] M. Sanquer,[1] T. Baturina,[3] M. Baklanov,[4] V. Vinokur,[5] M. Ovadia,[6] D. Shahar,[6] M. Ovadia,[6] M. Feigelman,[7] and L. Ioffe[8]

[1]*SPSMS, UMR-E 9001, CEA-INAC/UJF, 38054 Grenoble cedex 9, France*
[2]*Institut Néel, CNRS-UJF, BP 166, 38042 Grenoble cedex 9, France*
[3]*Rzhanov Institute of semiconductor Physics SB RAS, 630090 Novosibirsk, Russia*
[4]*IMEC, B-3001, Leuven, Belgium*
[5]*Material Science Division, Argonne National Laboratory,Illinois, 60439 Argonne, USA*
[6]*Weizmann Institute of Science, 76100, Rehovot, Israel*
[7]*Landau Institute for Theoretical Physic, 119334, Moscow, Russia*
[8]*Rutgers University, 08854, New Jersey,USA*

We have performed tunneling spectroscopy on superconducting titanium nitride and indium oxide films in the vicinity of the disorder-driven superconductor-insulator transition (SIT). Tunnelling spectroscopy highlights a rather unusual superconducting state with a pseudogap regime above the critical temperature Tc [1]. We demonstrated that this pseudogap is the signature of short lived Cooper pairs that are preformed above Tc. It evolves at low temperature into an inhomogeneous superconducting system due to spatial fluctuations of the disorder at the mesoscopic scale in both materials [2, 3]. However, the SIT in TiN and InO films display different characters. Ultrathin TiN films remain bad metals with dominating two-dimensional thermodynamic fluctuations when disorder is increased. In this case Tc goes to zero at the critical disorder of the SIT, whereas in InO, Tc remains above 1 K on the superconducting side of the SIT. In this latter situation, localization takes over and the preformed Cooper pairs above Tc can locally remain localized at zero temperature. We showed that the absence of BCS coherence peaks at the gap edges in the local one particle density of states is the signature of these localized Cooper pairs. Besides, using our STM, we have continuously analyzed the local conductance between the tunneling regime and the point-contact regime. In the latter, Andreev spectroscopy reveals a new energy scale related to the quantum coherence energy and independent from spatial fluctuations of the pairing energy [4].

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[3] B. Sacépé, T. Dubouchet, C. Chapelier, M. Sanquer, M. Ovadia, Dan Shahar, M. Feigel'man, and L.B. Ioffe, Nature Physics 7, 239 (2011).
[4] T. Dubouchet, *in preparation*

Enhancement of superconductivity by Anderson localization

I.S. Burmistrov,[1] I.V. Gornyi,[2] and A.D. Mirlin[2]

[1]*L.D. Landau Institute for Theoretical Physics, Kosygina street 2, 117940 Moscow, Russia*
[2]*Institut für Nanotechnologie, Karlsruhe Institute of Technology, 76021 Karlsruhe, Germany*

Influence of disorder on the temperature of superconducting transition (T_c) is studied within the σ-model renormalization group framework. Electron-electron interaction in particle-hole and Cooper channels is taken into account and assumed to be short-range. Two-dimensional systems in the weak localization and antilocalization regime, as well as systems near mobility edge are considered. It is shown that in all these regimes Anderson localization leads to strong enhancement of T_c related to the multifractality of wave functions. Screening of the long-range Coulomb interaction thus opens a promising direction for searching novel materials for high-T_c superconductivity.

[1] I.S. Burmistrov, I.V. Gornyi, A.D. Mirlin, Phys. Rev. Lett., **108**, 017002 (2012).

Hybridization of wave functions in one-dimensional Anderson localization

D. A. Ivanov,[1,2] M. A. Skvortsov,[3,4] P. M. Ostrovsky,[5,6,3] and Ya. V. Fominov[3,4]
[1]*ETH Zürich, 8093 Zürich, Switzerland*
[2]*University of Zürich, 8057 Zürich, Switzerland*
[3]*L. D. Landau Institute for Theoretical Physics, 142432 Chernogolovka, Russia*
[4]*Moscow Institute of Physics and Technology, 141700 Dolgoprudny, Russia*
[5]*Max-Planck-Institut für Festkörperforschung, 70569, Stuttgart, Germany*
[6]*Institut für Nanotechnologie, Karlsruhe Institute of Technology, 76021 Karlsruhe, Germany*

A quantum particle can be localized in a disordered potential, the effect known as Anderson localization. In such a system, correlations of wave functions at very close energies may be described, due to Mott, in terms of a hybridization of localized states. We revisit this hybridization description and show that it may produce quantitatively exact expressions for some asymptotic features of correlation functions, if the tails of localized states and the hybridization matrix elements are assumed to have log-normal distributions typical for localization effects.

We apply our method to three one-dimensional models: a strictly one-dimensional wire and two quasi-one-dimensional wires with unitary and orthogonal symmetries. In each of these models, we consider two types of correlation functions: the correlations of the density of states at close energies and the dynamic response function at low frequencies. In the cases, where exact results for these correlation functions are available, our method quantitatively reproduces many of their details.

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Electrical Control of the Superconducting-to-Insulating Transition in Graphene/Metal Hybrids

Adrien Allain, Zheng Han, and Vincent Bouchiat
Neel Institute, CNRS-Grenoble, France

The easily accessible 2D electron gas in graphene provides an ideal platform on which to tune, via application of an electrostatic gate, the coupling between electronically ordered dopants deposited on its surface. I will present recent experimental studies on electrostatically tuned superconducting transition in graphene sheets decorated with tin nanoparticles. The transition towards superconducting state is due to percolation of superconductivity induced by proximity effect within the nanoparticles random array. Depending of the disorder within the graphene layer, superconductivity show different characteristics and significant variations. In case of low disorder exfoliated graphene, the superconducting state results from a Berezinski-Kosterlitz-Thouless transition which leads to an homogeneous 2D superconducting state [1]. In case of disordered Graphene (CVD-grown),we show that upon changes in carrier density ($\pm 7 \cdot 10^{12}$ cm^{-2}, applying a gate voltage), a transition from a superconducting to a truly insulating state can be induced [2]. An intermediate metallic regime is also present at the transition showing sheet resistivity of the order of the resistance quantum $R_Q = \frac{h}{4e^2}$. We interpret this transition within the framework of granular superconductivity found in Josephson junction arrays. The intense positive magnetoresistance observed for fields below the critical field of tin nanoparticles is a signature of the localization of Cooper pairs. This hybrid system appears to be an original platform to investigate the current understanding of the physics of the superconductor-insulator quantum phase transition and offer a original starting material for the realization of superconducting weak links

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Broadband microwave measurements across the zero temperature superconductor-resistive magnetic field tuned transition in InO_x

N. P. Armitage
Department of Physics and Astronomy, The Johns Hopkins University, Baltimore, MD 21218, USA

I will report on our recent results studying the complex ac conductance of amorphous superconducting InOx thin films as a function of both temperature and magnetic field. In these experiments, we measure the explicit frequency dependency of the complex conductance and the phase stiffness over a range from 0.21 to 15 GHz at temperatures down to 350 mK and fields up to 8 Tesla using a novel broadband microwave Corbino spectrometer. The dynamic ac measurements are sensitive to the temporal correlations of the superconducting order parameter in the fluctuation range [1]. For the finite temperature transition, we explicitly demonstrate the critical slowing down of the characteristic fluctuation rate on the approach to the superconducting state and show that its behavior is consistent with vortex-like phase fluctuations and a phase-ordering scenario of the transition. With applied magnetic field, this system with relatively weak disorder ($R_n \approx 1000$ Ohms) makes a transition from a superconducting ground state to a novel metallic state that has superconducting correlations [2] that persists all the way to the lowest measured temperature. We take advantage of the fact that in AC experiments like these the low frequency dissipative response of the system can be quantified even when $R_{DC} = 0$. We demonstrate how many aspects of this transition show a relation to the phenomenology of arrays of resistively shunted Josephson junctions and the dissipation-driven transitions they undergo.

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Beak-up of long-range coherence in ultrathin superconducting NbN films close to the superconductor-insulator transition

T. Cren,[1] Y. Noat,[1] C. Brun,[1] F. Debontridder,[1] D. Roditchev,[1] K. Ilin,[2] M. Siegel,[2] A. Semenov,[3] and H.-W. Hübers[3]
[1]*Institut des Nanosciences de Paris, CNRS and Université Pierre et Marie Curie, 4 place Jussieu, 75252 Paris, France*
[2]*Institute of Micro- und Nano-electronic Systems,*
Karlsruhe Institute of Technology, Hertzstrasse 16, D-76187 Karlsruhe, Germany
[3]*DLR Institute of Planetary Research, Rutherfordstrasse 2, 12489 Berlin, Germany*

We addressed the complex problem of the superconductor-insulator transition (SIT) using scanning tunneling spectroscopy (STS) on homogeneous ultrathin superconducting NbN films of various thicknesses(2.16-15 nm) grown ex situ [1]. Our STS data reveal profound changes in the local behavior of the superconducting films as the SIT is approached. The amplitude of the coherence peaks diminishes to almost vanish right before the insulating transition. Our results also provide evidence that on approaching the SIT the superconducting condensate does not set in on a conventional metallic state anymore, but rather on a correlated electronic background evidenced by a characteristic V-shaped spectral background. In addition, a shallow pseudogap regime is observed in a very narrow temperature window just above T_c. Interestingly, our results on 2D-superconductors present many similarities with the results reported for 3D-NbN films of comparable T_c and $k_F l$ [2] but are in striking contrast with the recently reported large pseudogap regimes observed in TiN and InO [3]. The differences between our results and previous STS studies are attributed to a more homogeneous crystalline structure of our NbN films. Finally, while the vortex lattice was clearly observed in the thickest samples subject to magnetic field, the STS contrast was observed to decrease when reducing the film thickness; the thinnest 2.16 nm film did not show any evidence of the vortex state, thus emphasizing the loss of long-range superconducting phase coherence.

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[3] B. Sacépé et al., Phys. Rev. Lett. 101, 157006 (2008); B. Sacépé et al., Nat. Comm. 1, DOI: 10.1038/ncomms1140 (2010); B. Sacépé et al., Nat. Phys. 7, 239 (2011).

June 19, Tuesday, Morning

Dissipated work, fluctuation relations and Maxwell's demon in electron tunneling

Jukka P. Pekola,[1] Olli-Pentti Saira,[1] Youngsoo Yoon,[1] Aki Kutvonen,[2] Tapio Ala-Nissila,[2]
Paolo Solinas,[1,2] Tuomo Tanttu,[2] Mikko Möttönen,[1,2] and Dmitri V. Averin[3]

[1]*Low Temperature Laboratory (OVLL), Aalto University School of Science, P.O. Box 13500, 00076 Aalto, Finland*
[2]*Department of Applied Physics, Aalto University School of Science, P.O. Box 11000, 00076 Aalto, Finland*
[3]*Department of Physics and Astronomy, Stony Brook University, SUNY, Stony Brook, NY 11794-3800, USA*

I discuss the distribution of dissipated work in gate-driven single-electron and Cooper pair transitions [1–3]. In our recent experiments this distribution was measured in a metallic single-electron box using a readout based on the detection of individual tunneling events [4]. This set-up can be extended and adapted to devise a Maxwell's demon for electrons [5]. As a basic system to investigate quantum fluctuation relations, I discuss the gate-driven Cooper pair box, where Landau-Zener transitions and coupling to environment determine the work and heat, respectively [6].

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[6] P. Solinas, D. V. Averin, and J. P. Pekola, in preparation (2012).

Coherent and incoherent charge pumping with Coulomb blockade devices

Yu. A. Pashkin[1,2,3]

[1]*NEC Smart Energy Research Laboratories and RIKEN Advanced Science Institute, Tsukuba, Japan*
[2]*Physics Department, Lancaster University, Lancaster, UK*
[3]*Lebedev Physical Institute, Russian Academy of Sciences, Moscow, Russia*

In my talk I will describe two charge pumping devices that were studied in collaboration between NEC Research Laboratory in Japan and Low Temperature Laboratory of Aalto University in Finland.

The first device is based on a hybrid single-electron transistor which is capable of transferring single electrons one by one in a controllable fashion [1]. When the device is properly biased and under the external drive, its transport characteristics exhibit well-defined plateaus providing the basis for the current standard. It was found that the plateau flatness can be improved by a factor of 100 by protecting the electron pump from the electromagnetic environment [2]. The output current can be increased using a parallel operation of the devices driven by a common rf gate [3].

The second device is a superconducting single-electron transistor in which coherent Cooper pair current is produced by using the non-adiabatic pulsing technique. Depending on the composite pulse shape, both forward and backward Cooper pair pumping can be realized with respect to the bias direction. Quantum coherence is revealed though the periodic dependence of the measured current on magnetic field [4].

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[4] F. Hoehne, Yu. A. Pashkin, O. V. Astafiev et al., Coherent superconducting quantum pump, Phys. Rev. B, to be published, (2012); cond-mat arXiv:1109.5543.

Spin-orbit-mediated coupling of electron spin dynamics and nanomechanical motion in carbon nanotubes

Mark Rudner,[1] A. Palyi,[2] P. R. Struck,[3] K. Flensberg,[4] and G. Burkard[3]

[1] *Ohio State University and Neils Bohr International Academy, USA*
[2] *Eotvos University, Budapest, Hungary*
[3] *University of Konstanz, Konstanz, Germany*
[4] *University of Copenhagen, Copenhagen, Denmark*

Due to their low masses and high stiffnesses, nanostructures made out of atomically-thin carbon-based materials such as graphene and carbon nanotubes (CNTs) feature high mechanical oscillation frequencies and large zero-point vibration amplitudes. These properties open many avenues for exploring both fundamental phenomena and potential applications based on the coupling of nanomechanical and electronic degrees of freedom. The recently discovered strong spin-orbit coupling in CNTs provides an intrinsic coupling between electron spins and mechanical deflections of the nanotube [1]. For a long nanotube with a quasi-continuous phonon spectrum, we show that this coupling gives rise to a dramatic enhancement of the electron spin relaxation rate near a level crossing in the Zeeman spectrum of a few-electron nanotube quantum dot [2], as observed in recent experiments [3]. For a short suspended nanotube with well-separated discrete phonon modes, this system can provide a natural solid state realization of the Jaynes-Cummings model of quantum optics. Our estimates indicate that, with currently achievable experimental parameters, the strong coupling regime of coherent spin-phonon exchange is within reach [4]. Detection schemes and potential applications will be discussed.

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Enchancement of electron-phonon cooling rate due to Cooper pairing

A. Shtyk,[1] M. Feigelman,[1] and V. Kravtsov[1,2]

[1] *L. D. Landau Institute for Theoretical Physics, 142432, Chernogolovka, Russia*
[2] *The Abdus Salam International Centre for Theoretical Physics, P.O.B. 586, 34100 Trieste, Italy*

We have studied the electron-phonon cooling rate in disordered conductors at low temperatures. Standard theory predicts T^6 temperature dependence for the heat flow between phonon and electron subsystems. We have analyzed the role of two different effects which have not been taken into account previously: i) influence of superconducting fluctuations and ii) incomplete Coulomb screening. The former was found to lead to the heat flow proportional to T^4 being always dominant at sufficiently low temperatures. Incomplete Coulomb screening in 2D electron gas was also found to lead to strong enhancement of electron-phonon heat flow at low temperatures, especially in heterostructures with external screening by the gate. The same effects lead also to the drastic increase of the ultrasound attenuation at low temperatures. Qualitatively, the effects we discuss are related with deviations from the usual adiabatic approximation for the electron-phonon interaction.

Exploring many-body physics with synthetic matter

E. Demler,[1] D. Pekker,[2] A. Maltsev,[3] and A. Prokofiev[3]
[1]*Harvard University, USA*
[2]*California Institute of Technology, USA*
[3]*L. D. Landau Institute, Russia*

I will review recent theoretical and experimental progress in exploring strongly correlated states with ultracold atoms in optical lattices. I will discuss recent observation of the Higgs-Anderson resonance in a superfluid phase close to the transition to a Mott insulating phase [1, 2] and discuss prospects for studying lattice solitons [3] and exploring universal dynamical phase diagram of lattice bosons [4].

[1] D. Pekker *et al.*,, Signatures of the superfluid to Mott insulator transition in equilibrium and in dynamical ramps, arXiv:1206.1648
[2] M. Endres *et al.*, The Higgs Amplitude Mode at the Two-Dimensional Superfluid-Mott Insulator Transition, arXiv:1204.5183, Nature in press
[3] E. Demler, A. Maltsev, Semiclassical solitons in strongly correlated systems of ultracold bosonic atoms in optical lattices Annals of Physics 326:1775 (2011)
[4] Universal dynamical phase diagram of lattice spin models and strongly correlated ultracold atoms in optical lattices E. Demler, A. Maltsev, A. Prokofiev, arXiv:1201.6400

Transverse transport in disordered superconducting films above T_c: the Hall vs Nernst effects

Alexander M. Finlel'stein
The Weizmann Institute of Science, Israel and
Texas A&M University, TX, USA

I will report on the fluctuation corrections in homogeneously disordered superconducting films. We find large contributions to the Hall conductivity near the superconducting transition, which experimentally can be tracked to temperatures well above Tc and magnetic fields well above the upper critical field, Hc2(0). These contributions arise from the superconducting fluctuations, and there is a quantitative agreement between the theoretical analysis and recent data obtained by the Kapitulnik group in Stanford.

I will also discuss briefly our recent calculation of the fluctuation corrections, which is based on the Usadel equation in the real-time formulation. We adjust this approach to derive analytic expressions for the corrections to the longitudinal conductivity in the entire metallic part of the temperature-magnetic field phase diagram. This method allows us to obtain fluctuation corrections in a compact and effective way, establishing a direct connection between phenomenological and microscopic calculations.

The talk is based on works performed in collaboration with Konstantin Tikhonov, Karen Michaeli, and Georg Schwiete.

Nonlinear fluctuation conductivity in disorders films and wires

K.S. Tikhonov and M.V. Feigel'man
L. D. Landau Institute for Theoretical Physics, 117940 Moscow, Russia

Non-ohmic (logarithmical with applied voltage) conductivity of thin metallic films has been observed in several experiments [1, 2]. Different mechanisms were proposed as an explanation, involving i) weak localization, which depends logarithmically on temperature with such dependence transferred to logarithmical voltage dependence due to the heating effect of the electric field [3], or ii) Coulomb interaction correction [4] with nonlinearity coming into play at $E \sim T/\xi_T$.

Another source of such nonlinear effects are iii) corrections due to interactions in the Cooper channel [5, 6]. They become especially important in the vicinity of the superconducting transition due to divergence of the correlation length $\xi_c = \sqrt{D/(T - T_c)}$. In this work we discuss such non-Ohmic effects in fluctuation conductivity of disorders films and wires. We consider 1D and 2D contacts, calculating the leading Aslamazov-Larkin and Maki-Thompson corrections. In the linear response regime in the vicinity of T_c they are determined mainly by lifetime of the Fluctuation Cooper Pairs (FCP) $\tau_{GL}^{-1} = \frac{8}{\pi}(T - T_c)$. As electric field grows above $E_c \sim T_c/\xi_c$, pair-braking effect of electric field becomes essential and strongly nonlinear regime is realized, with electronic subsystem still being in the state of local equilibrium.

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Spin imbalance and spin-charge separation in a Mesoscopic Superconductor

M. Aprili, C. Quay, C. Bena, and D. Chevalier
Laboratoire de Physique des Solides, UMR8502-CNRS,
University Paris-Sud, 91405 Orsay Cedex, France.

When spin-polarised electrons are injected into a superconductor, they create both spin and charge imbalances. While charge imbalances in superconductors have been studied in great detail both theoretically and experimentally, spin imbalances and excitations have received much less experimental attention, despite intriguing theoretical predictions including spin-charge separation [1], [2].

A superconductor at equilibrium contains paired particles in the condensate phase, as well as unpaired, spin-randomised quasiparticles. Imagine injecting two spin up electrons into a small superconducting volume and taking out a Cooper pair. With the condensate chemical potential held constant, the pair is rapidly replaced by one of the 'extra' spin up electrons and a spin down electron, leaving a spin down hole. Thus, at the end, the charge in the volume is the same as that at equilibrium, but the spin has increased by two.

We have performed nonlocal transport measurements at low temperature (50mK) in nanofabricated FISIF lateral spin valves [3]. (F = ferromagnet, I = insulator and S = superconductor.) A current applied between the first F and the S injects spin-polarized electrons in S and removes Cooper pairs. Using a second ferromagnetic electrode located within a spin relaxation length from the first F, we measure the chemical potential difference between the condensate and the up or down spins in the S. Our measurements also allow us to probe the charge imbalance in the S.

The data at low bias ($V < \Delta$) are are consistent with an almost pure spin imbalance in S with very little accompanying charge. The finite magnetic fields at which these measurements are done and the Zeeman-split quasiparticle density of states in the superconductor enhances the visibility of the spin imbalance.

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Manifestations of the long-range triplet pairing in superconductor-ferromagnet proximity heterostructures - theory versus experiment

L.R. Tagirov[1,2], V. I. Zdravkov[2,3], J. Kehrle[2], G. Obermeier[2], D. Lenk[2], H.-A. Krug von Nidda[2], C. Müller[2], S. Horn[2], R. Tidecks[2], M. Yu. Kupriyanov[4] and A. S. Sidorenko[3]

[1]*Kazan Federal University, 420008 Kazan, Russia*
[2]*Institut f́ur Physik, Universit́at Augsburg, D-86159 Augsburg, Germany*
[3]*Institute of Electronic Engineering and Nanotechnologies ASM, Kishinev MD-2028, Moldova*
[4]*Skobeltsyn Institute of Nuclear Physics, Moscow State University, 119992 Moscow, Russia*

For superconductor-ferromagnet (S-F) proximity heterostructures with two or more F layers, the generation of a long-range, odd-in-frequency triplet pairing at non-collinear alignment of the F-layers magnetizations was predicted [1]. Here, we report on the first experimental observation of the triplet pairing manifestation in a $Nb/Cu_{41}Ni_{59}/Nb/Co/CoO_x$ spin-valve type proximity heterostructure [2]. The first, $\sim$ 12.8 nm thick, Nb layer is a conventional s-wave superconductor, while the second, very thin ($\sim$ 6 nm thick) Nb layer, sandwiched by ferromagnetic layers, acts as a normal conducting spacer. The key point of the sample design is that the CuNi-alloy layer has intrinsic equilibrium orientation of the magnetic moment perpendicular to the film plane. At the same time, the second ferromagnetic Co layer has intrinsic, in-plane orientation of the magnetic moment. So, the non-collinear mutual alignment of the F layers magnetic moments can be easily realized. The cobalt-oxide top layer provides exchange bias to the adjacent metallic Co layer allowing to acheve antiparallel alignment of the $Cu_{41}Ni_{59}$ and Co layers magnetic moments. Measuring the resistance of the samples as a function of an in-plane external magnetic field, we observed a sequence of transitions through normal conducting and superconducting phases, when the system goes along the magnetic hysteresis loop, from a parallel through a non-collinear to an anti-parallel and, finally, opposite directed parallel alignment of the magnetizations. The superconducting transition temperature, measured as a function of the in-plane magnetic field, has clearly visible downward cusp associated with the non-collinear alignment of the $Cu_{41}Ni_{59}$ and Co layers magnetic moments. The experimental findings described are consistent with the theoretical picture of the singlet superconductivity suppression by the long-range triplet pairing generation, predicted in Ref. [3].

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Double proximity effect in hybrid planar Superconductor-(Normal metal/Ferromagnet)-Superconductor structures

V. V. Ryazanov,[1] T. E. Golikova,[1] I. E. Batov,[1] F. Hübler,[2] D. Beckmann,[2] T. Yu. Karminskaya,[3] M. Yu. Kupriyanov,[3] and A. A. Golubov[4]

[1]*Institute of Solid State Physics, Russian Academy of Sciences, 142432 Chernogolovka, Russia*
[2]*Karlsruhe Institute of Technology, 76021 Karlsruhe, Germany*
[3]*Lomonosov Moscow State University, Skobeltsyn Institute of Nuclear Physics, Moscow 119991, Russia*
[4]*Faculty of Science and Technology, University of Twente, 7500 AE Enschede, The Netherlands*

The coherent transport in Josephson superconductor - normal metal - superconductor (S-N-S) and superconductor - ferromagnet - superconductor (S-F-S) nanocontacts attracts intense interest nowadays. Ferromagnetic materials suitable for Josephson S-F-S junction fabrication have the superconducting order parameter decay length of about several nanometers [1] which is much smaller compared to the decay length in normal metal. To increase the decay length in structures with ferromagnets different types of Josephson junctions with complex bilayered (NF) and tri-layered (FNF) weak links have been proposed in theoretical work [2]. We report the fabrication of planar Josephson S-N-S and S-NF-S junctions and their characterization down to $T = 300$ mK. Samples were fabricated by electron beam lithography, using two-layer resist, and subsequent shadow deposition at two angles. We used aluminum films with thickness of 100 nm like superconducting banks, while a 15-60 nm thick copper film was used as a normal metal layer and 10 nm thick iron film as a ferromagnetic one in a planar bilayered barrier. Two different types of structures (S-N-S and S-NF-S) with the same geometry were investigated. It was found that current-voltage characteristics become hysteretic as temperature decreases despite the high transparency of SN-interfaces [2]. In the resistive part of current-voltage characteristics, the features related to the multiple Andreev reflections and the presence of a minigap were detected [3]. The nanofabricated S-NF-S structures of the second type had the space L between superconducting banks in the range of 30-200 nm. The Josephson supercurrent was observed in structures investigated. The critical current I_c of S-NF-S junctions was much smaller than that for S-N-S junctions. The rapid decrease of I_c with L increasing is due to the suppression of the superconducting proximity effect by the F-layer. In the differential resistance (density of state) characteristics of S-NF-S junctions a double peak peculiarity was observed at the voltage corresponding to the minigap. The effect observed can be explained by the induced electron spin polarization in the normal layer due to the ferromagnet.

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Subgap states in disordered superconductors

M. A. Skvortsov and M. V. Feigel'man
L. D. Landau Institute for Theoretical Physics, 142432 Chernogolovka, Russia

We revise the problem of the density of states in disordered superconductors. Randomness of local sample characteristics translates to the quenched spatial inhomogeneity of the spectral gap, smearing the BCS coherence peak. We show that various microscopic models of potential and magnetic disorder can be generally reduced to the Abrikosov-Gor'kov model of paramagnetic impurities with some long-range fluctuating field. The resulting form of the density of states is generally described by two parameters: the width Γ measuring the broadening of the BCS peak, and the energy scale Γ_{tail} which controls the exponential decay of the density of the subgap states. We refine the existing instanton approaches [1, 2] for determination of Γ_{tail} and show that they appear as limiting cases of a unified theory of optimal fluctuations in a nonlinear system. Applications to experimentally relevant types of disorder including universal mesoscopic disorder [3] are discussed.

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June 20, Wednesday, Morning

Majorana state on the surface of disordered 3D topological insulator

P. A. Ioselevich,[1,2] P. M. Ostrovsky,[3,1] and M. V. Feigel'man[1,2]

[1] *L. D. Landau Institute for Theoretical Physics, Kosygin str. 2, Moscow, 119334 Russia*
[2] *Moscow Institute of Physics and Technology, Institutsky per. 9, Dolgoprudny, 141700 Russia*
[3] *Max Planck Institute for Solid State Research, Heisenbergstr. 1, 70569 Stuttgart, Germany*

We study low-lying electron levels in an "antidot" capturing a coreless vortex on the surface of a three-dimensional topological insulator in the presence of disorder. The surface is covered with a superconductor film with a hole of size R larger than coherence length, which induces superconductivity via proximity effect. Spectrum of electron states inside the hole is sensitive to disorder, however, topological properties of the system give rise to a robust Majorana bound state at zero energy. We calculate the subgap density of states with both energy and spatial resolution using the supersymmetric sigma model method. Tunneling into the hole region is sensitive to the Majorana level and exhibits resonant Andreev reflection at zero energy.

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Quantum spin liquids in simple model systems

Hong Yao,[1,2] Hong-Chen Jiang,[3,4] Leon Balents,[3] and Steven A. Kivelson[1]

[1] *Department of Physics, Stanford University, Stanford, CA 94305, USA*
[2] *Institute for Advanced Study, Tsinghua University, Beijing, 100084, China*
[3] *Kavli Institute for Theoretical Physics, University of California, Santa Barbara, CA 93106, USA*
[4] *Center for Quantum Information, IIIS, Tsinghua University, Beijing, 100084, China*

Quantum spin liquids are among long-sought exotic states of matter in nature. In this talk, I will discuss two simple model systems which are shown to support gapped quantum spin liquid phases. First, for the spin-1/2 antiferromagnetic Heisenberg J_1-J_2 model on the square lattice, we perform accurate DMRG simulations of it and obtain strong evidence of a fully gapped quantum spin liquid state in the region $0.41 < J_2/J_1 < 0.62$ by showing that there is neither magnetic nor valence bond solid order and that there exists a finite topological entanglement entropy, whose value is remarkably close to $\log 2$ and is consistent with a gapped Z_2 quantum spin liquid. Second, to have a caricature of gapped Z_2 quantum spin liquids on the square lattice, we introduce a generalized quantum dimer model on this lattice and prove that its exact ground state in a finite parameter region is a gapped Z_2 quantum spin liquid. I will also discuss ways to potentially realizing such models in experiments.

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Superconductivity induced by proximity effect in low dimensional systems: Andreev reflection, Josephson effect and vortex states

A.S.Mel'nikov,[1] N.B.Kopnin,[2,3] and I.M.Khaimovich[1]

[1]*Institute for Physics of Microstructures RAS, 603950, Nyzhny Novgorod, GSP-105, Russia*
[2]*Low Temperature Laboratory, Aalto University, P.O. Box 15100, FIN-00076 Aalto, Finland*
[3]*L. D. Landau Institute for Theoretical Physics, 117940 Moscow, Russia*

The approach applicable for spatially inhomogeneous problems associated with the induced superconductivity in low-dimensional electronic systems is developed. The proximity induced gap function is analyzed for the limits of coherent and incoherent tunneling between the two-dimensional (2D) electron gas and bulk superconductor, i.e. for conserving and non-conserving quasiparticle momentum component in the plane of the layer. We consider two generic types of junctions made of a ballistic 2D electron gas placed in a tunnel finite-length contact with a bulk superconducting lead. The transport properties of a normal-superconductor junction are shown to be determined by the interplay of Andreev reflection from the induced gap profile and normal reflection from the 2D system edge. For a Josephson junction between the 2D regions with an induced superconducting order we calculate the spectrum of the bound states and current-phase relation which show a rich structure due to the presence of induced gap and dimensional quantization. The induced superconducting gap is shown to affect strongly the electronic structure of vortex states. The anomalous quasiparticle energy branches and the local density of states are analyzed for different models of tunneling between the two-dimensional system and superconducting electrode. For the limit of coherent tunneling we find two anomalous spectral branches for quasiparticles bound to the vortex core. The resulting profiles of the local density of states (LDOS) reveal a two scale behavior which corresponds to two different coherence lengths defined for the bulk superconductor and for the induced gap in the 2D system. The anomalous branches and LDOS profiles are shown to be strongly affected by the disorder effects caused either by the incoherent tunneling or by the impurity scattering in the bulk superconducting electrode.

June 21, Thursday, Morning

Coherent quantum phase-slip in superconducting nano-wires

Oleg Astafiev
NEC Smart Energy Research Laboratories, Tsukuba, Japan and
RIKEN, Japan

Coherent quantum phase slip (CQPS) — a fundamental phenomenon of superconductivity — is flux tunneling across superconducting nano-wires. It is exactly dual to the tunneling of Cooper pairs across an insulator barrier, known as Josephson Effect. We demonstrate operation of a CQPS qubit — a superconducting loop made of InO_x with a nano-wire [1]. The flux states in the loop are superposed by CQPS in the wire. The loop is coupled inductively to a coplanar resonator. By measuring transmission through the resonator, we observe transitions between the qubit levels, which are possible only when CQPS energy is non-zero. We demonstrate linear energy splitting between the qubit levels at large magnetic flux bias proving linear (non-Josephson) inductances in the system.

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Superinductor with Tunable Non-Linearity

M.T. Bell[1], I.A. Sadovskyy[1], L.B. Ioffe[1], A.Yu. Kitaev[2], and M.E. Gershenson[1]
[1]*Department of Physics and Astronomy, Rutgers University, Piscataway, New Jersey 08854 and*
[2]*Caltech, Institute for Quantum Information, Pasadena, CA 91125*

Many quantum devices operating at low temperatures would benefit from the development of the superinductor, a dissipationless superconducting element whose microwave impedance exceeds the resistance quantum $R_Q \equiv h/(2e)^2 \approx 6.5\,k\Omega$. We report on the realization of a superinductor as a ladder of nanoscale Josephson junctions, which can be frustrated by the magnetic field. The impedance of the proof-of-concept device is an order of magnitude larger than state-of-the-art. Both the inductance and its non-linearity can be tuned by a weak (~ 1 G) magnetic field. The strong non-linearity offers new types of functionality: possible applications of the superinductor include the development of qubits protected from both flux and charge noises, fault tolerant quantum computing, and high-impedance isolation for electrical current standards based on Bloch oscillations.

Quantum quenches and universal non-equilibrium work statistics

Alessandro Silva
Abdus Salam ICTP, Strada Costiera 11, 34100 Trieste, Italy and
SISSA, via Bonomea 265, 34136 Trieste, Italy

In this talk, I will focus on discussing the energy distribution of excitations generated in a many-body system subject to a time dependent change of one of its parameters. Using various connections with boundary statistical mechanics, I will show that they are generically characterized by low energy power-law edge singularities, whose exponents are universal and, for local quenches, independent on the specifics of the time-dependent protocol.

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$1/f$ Noise and Dephasing from Surface Magnetic States in SQUIDs and Superconducting Qubits

R. McDermott, S. Sendelbach, D. Hover, and U. Patel
Department of Physics, University of Wisconsin, Madison, WI 53706 USA

Low-frequency $1/f$ flux noise is a dominant source of dephasing in the Josephson phase and flux qubits [1, 2]. The flux noise inferred from recent qubit experiments is consistent with the noise measured more than 20 years ago in a series of experiments performed on dc Superconducting QUantum Interference Devices (SQUIDs) cooled to millikelvin temperatures [3]. The noise was observed to be "universal", that is, only weakly dependent on a wide range of parameters such as superconducting materials, SQUID loop geometry and inductance, and temperature. Recent work has revealed the presence of a high density of unpaired spins at the surfaces of superconducting thin films [4]; it is now believed that these spins are the source of the noise [5], although the microscopic noise mechanism is not completely understood. Here we describe experiments on SQUIDs and Josephson phase qubits designed to shed light on the underlying noise mechanism, and we report on efforts to develop novel materials with reduced levels of noise. The quasistatic magnetization in SQUID circuits varies as $1/T$ as the device temperature is reduced; the data are compatible with the thermal polarization of upaired electron spins with surface density 5×10^{17} m^{-2}. At a fixed temperature, the SQUID inductance displays a $1/f$ power spectral density; the inductance noise is highly correlated with the conventional $1/f$ flux noise [6]. Recently we have shown that encapsulation of the SQUID washer in PECVD-grown SiN_x leads to a reduction in the flux noise power by more than an order of magnitude. We discuss prospects for incorporating the novel dielectric interfaces into high-performance phase qubit circuits.

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Quantum Noise Measurement of a Carbon Nanotube Quantum Dot in the Kondo Regime

J. Basset,[1] A.Yu. Kasumov,[1] C.P. Moca,[2] G. Zaránd,[2,3] P. Simon,[1] H. Bouchiat,[1] and R. Deblock[1]
[1]*Laboratoire de Physique des Solides, Univ. Paris-Sud, CNRS, UMR 8502, F-91405 Orsay Cedex, France.*
[2]*BME-MTA Exotic Quantum Phase Group, Institute of Physics, Budapest University of Technology and Economics, H-1521 Budapest, Hungary.*
[3]*Freie Universität Berlin, Fachbereich Physik, Arnimallee 14, D-14195 Berlin, Germany.*

Probing the fast dynamics of many-body correlated systems has been the subject of a long-standing research activity. In this regard, nanoscale devices offer unique possibilities. Due to recent progress in nanotechnology, it is now feasible to design nanoscale devices in which correlated effects appear under out-of-equilibrium conditions. The Kondo effect in quantum dots constitutes in this respect a paradigmatic model system, where a single electron spin of the quantum dot is dynamically screened by the conduction electrons, leading to a many-body resonance. This effect has been studied extensively in transport and, more recently, by current fluctuation measurements. However, all previous studies focused exclusively on the low frequency limit, while the high frequency regime, i.e. the dynamics remained experimentally unexplored.

In this work [1], we present the first measurements of the high frequency current fluctuations of a carbon nanotube quantum dot in the Kondo regime by resonantly coupling it to an on-chip detector [2]. Our experiment allows to probe many-body correlations at frequencies of the order of the inverse timescale associated with the creation of the correlated state. The results are in good agreement with theoretical calculations provided that an additional spin decoherence rate is included. This experiment constitutes a new original tool for the investigation of the nonequilibrium dynamics in nanoscale devices.

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June 21, Thursday, Afternoon

Spectroscopy and Coherent Manipulation of Two-Level Defects in Disordered Solid

G. J. Grabovskij,[1] T. Peichl,[1] J. Lisenfeld,[1] P. Bushev,[1] G. Weiss,[1] and A. V. Ustinov[1]

[1]*Physikalisches Institut and DFG Center for Functional Nanostructures (CFN)*
Karlsruhe Institute of Technology, 76128 Karlsruhe, Germany

Microwave spectra of electromagnetic oscillations in Josephson tunnel junctions display signatures of coherent coupling to individual microscopic defects acting as two-level systems (TLSs). These defects manifest themselves by avoided level crossings with the junction plasma resonance and are understood as atomic-scale dipoles emerging from metastable lattice configurations in amorphous dielectrics forming the tunnel barrier of the Josephson junction. I will present recent experiments in which we use a Josephson junction for manipulating the quantum state of a single TLS. We can directly measure of the energy relaxation T_1 and dephasing T_2 times of an individual microscopic defect in amorphous oxide. The multi-photon spectroscopy allows for direct probing of hybridized states in the combined junction-TLS coupled quantum system [1]. New method of direct microwave driving made it possible to study the temperature dependence of coherence times of individual TLSs [2]. The observation of TLSs which have much longer coherence times than the macroscopic Josephson qubit makes them interesting for quantum information processing purposes, which we experimentally explored by generating entanglement between two TLSs mediated by the qubit [3]. In the final part of the talk, I will discuss our recent data on the effect of mechanical stress on the properties of TLSs.

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Dressed state amplification by a superconducting qubit

G. Oelsner,[1] P. Macha,[1] E. Il'ichev,[1] U. Huebner,[1] H.-G. Meyer,[1] M. Grajcar,[2] and O. Astafiev[3]

[1]*Institute of Photonic Technology, P.O. Box 100239, D-07702 Jena, Germany*
[2]*Department of Experimental Physics, Comenius University, SK-84248 Bratislava, Slovakia*
[3]*NEC Nano Electronics Research Laboratories. Tsukuba, Ibaraki, 305-8501, Japan*

We study an amplification of a probe signal, passing the resonator at the frequency of its fundamental mode, by artificial solid-state two-level quantum system strongly driven by coherent field at the frequency of another resonator mode. The two-level system is formed by a conventional flux qubit. The loop of the qubit is inductively coupled to the superconducting resonator. When the driving frequency matches the transition frequency of the two level system, the Rabi splitting is induced. When the Rabi frequency is tuned to the resonance with the oscillator fundamental mode, the latter is driven by the systems relaxation at the Rabi frequency. This mechanism, which can be properly described in dressed-state picture, leads to an amplification (damping) of the probe signal. This effect is demonstrated experimentally for the coherent probe signal as well as for the noise fluctuations.

Quantum dot circuits in microwave cavities

M.R. Delbecq, L.E. Bruhat, J.J. Viennot, S. Datta, A. Cottet and T. Kontos
Laboratoire Pierre Aigrain, Ecole Normale Supérieure, CNRS UMR 8551,
Laboratoire associé aux universités Pierre et Marie Curie et Denis Diderot,
24, rue Lhomond, 75231 Paris Cedex 05, France

We present our recent experiments where we demonstrate a hybrid architecture consisting of a quantum dot circuit coupled to a single mode of the electromagnetic field. We use single wall carbon nanotube based circuits inserted in superconducting microwave cavities. By probing the nanotube dot using a dispersive readout in the Coulomb blockade and the Kondo regime, we determine an electron-photon coupling strength which should enable circuit QED experiments with more complex quantum dot circuits [1]. We extend our architecture to two quantum dot circuits in a microwave cavity. These circuits are separated by 200 times their own size, but share the same anti-node of the cavity field. We demonstrate their interaction mediated by the cavity photons.

[1] M.R. Delbecq et al. *Phys. Rev. Lett.* **107** 256804 (2011).

Quantum devices in ultra clean electron systems

C. Rössler, S. Baer, T. Ihn, K. Ensslin, C. Reichl, and W. Wegscheider
Solid State Physics Laboratory, ETH Zurich, 8093, Switzerland

Since the first observation of the quantum Hall effect, the quality and the mobility of two-dimensional electron gases (2DEGs) have undergone tremendous improvements. 2DEGs defined in $\mathrm{Al_xGa_{1-x}As}$ heterostructures can reach mobilities exceeding $\mu = 10^7\,\mathrm{cm^2/Vs}$ at low temperatures, facilitating the observation of fascinating phenomena like the microwave-induced zero-resistance states, the $\nu = 5/2$ quantum Hall state, and interactions between composite fermions.

We investigate the transport properties of nano structures fabricated in high-mobility 2DEGs. Quantum point contacts (QPCs) profit from a strongly suppressed disorder potential, giving rise to the appearance of transport features that are obscured in standard 2DEGs. Within these conceptually simple structures, we find already a rich variety of effects like the 0.7-feature, enhanced g-factors and Aharonov-Bohm interference between edge channels forming near the QPCs. By combining two QPCs, we define quantum dots and Fabry-Perot interferometers which are investigated in the (fractional) quantum Hall regime.

Strong back-action of a linear circuit on a single electronic quantum channel

Anne Anthore, F.D. Parmentier, S. Jezouin, H. le Sueur*, U. Gennser, A. Cavanna, D. Mailly, and F. Pierre
CNRS / Univ Paris Diderot (Sorbonne Paris Cité),
Laboratoire de Photonique et de Nanostructures (LPN), route de Nozay, 91460 Marcoussis, France
**Current address: CNRS, Centre de Spectrométrie Nucléaire et de*
Spectrométrie de Masse (CSNSM), 91405 Orsay Campus, France

How are the transport properties of a coherent conductor modified by its surrounding circuit? This fundamental question is also of practical importance for the engineering of composite quantum devices. When a coherent conductor is inserted into a circuit, its conductance is reduced due to the circuit back-action in response to the granularity of charge transfers. This phenomenon, called dynamical Coulomb blockade, has been extensively studied for a tunnel junction. However, for arbitrary short coherent conductors, it is fully understood only in the limit of small conductance reductions and low-impedance surrounding circuits.

We have investigated experimentally the strong back-action regime of a linear circuit on a single electronic conduction channel of arbitrary transmission. This was achieved by using a quantum point contact (QPC) as a test-bed for coherent conductors. The QPC was embedded in an adjustable on-chip circuit of impedance comparable to the resistance quantum $R_K = h/e^2$ at microwave frequencies, leading to conductance reductions up to 95 %. A capacitively coupled metallic gate was used as a switch to shunt the surrounding circuit. This in-situ short-circuit technique allows us to extract the back-action signal in the most direct way, by probing the QPC conductance in presence and in absence of the circuit back-action. To further test the strong link between granularity of charge transfers and Coulomb blockade, we are now simultaneously investigating the quantum shot noise of the current across the coherent conductor.

From our results, we propose a generalized expression for the conductance of an arbitrary single quantum channel embedded in a linear environment [1]. The proposed expression is in good agreement with recent predictions derived for a purely ohmic environment. Beyond the circuit back-action on the conductance, I will show that the quantum shot noise of the current accross a single channel is also modified by the surrounding circuit.

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June 22, Friday, Morning

Edge energy current in systems with short-range entanglement

Alexei Kitaev
California Institute of Technology, Pasadena, CA 91125, U.S.A.

Chiral gapless modes on the edge of a two-dimensional system with a bulk energy gap carry a quantized amount of energy [1]. At low temperatures, the energy current is given by the formula $I = \frac{\pi}{12} c_- T^2$, where c_- is the chiral central charge. For spin systems with short-range entanglement (i.e. without topological order or anyonic excitations), c_- must be a multiple of 8. I construct a particular model with $c_- = 8$ by starting from a variant of the honeycomb lattice model [2] with the spectral Chern number $\nu = 16$. If one of the two types of vortices undergoes Bose-condensation, the topological order is destroyed while the chiral central charge remains unchanged. The edge modes for this bulk model are described by eight free chiral bosons compactified over the E_8 lattice. Assuming that a thin strip near the edge remains in the uncondensed phase, we arrive at the representation of the E_8 edge as a combination of the original SO(16) edge and a parallel domain wall that carries only gapped excitations. There are actually two types of such walls, which correspond to the condensation of different vortices.

An analogous $c_- = 16$ system has two nonequivalent edges, which are described by different CFTs. I conjecture that in the absence of special symmetries, the chiral central charge is the only topological invariant of a gapped 2d system with short-range entanglement. In the case where the edge modes are free bosons, this conjecture follows from the known classification of even self-dual lattices up to stable equivalence. (A similar argument was used by Lu and Vishwanath in their recent paper [3].)

An important open problem is how to define the chiral central charge not relying on the conformal hypothesis. For another generalization, a quantity similar to the edge energy current exists in spatial dimensions $2 + 4n$, although its quantization conditions are not obvious.

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Little-Parks Oscillations in an Insulator

Dan Shahar, Gregory Kopnov, Oren Cohen, and Maoz Ovadia
The Weizmann Institute of Science, Rehovot, Israel

When the disorder of a superconducting material is high enough it can undergo a transition into an insulating state. Paradoxically, this insulating state has been suggested to arise from superconductivity itself. We have conducted a study of a highly disordered InO films that were patterned with an array of holes. With the right treatment, the films could be driven across the superconductor-insulator transition. We found that the Little-Parks oscillations in the superconducting state persisted, virtually uninterrupted, into the insulator, supporting the role played by superconducting correlations in the insulating phase.

Onset of superconductivity in a mesoscopic voltage-biased NSN junction

Maksym Serbyn[1, 2] and Mikhail A. Skvortsov[2]

[1]*Department of Physics, Massachusetts Institute of Technology, Cambridge, Massachusetts 02139, USA*
[2]*L. D. Landau Institute for Theoretical Physics, Chernogolovka, Moscow Region, 142432, Russia*

We consider a mesoscopic NSN junction biased by a constant voltage V and address the question of stability of the normal current-carrying state with respect to superconducting fluctuations. Using the linearized time-dependent Ginzburg-Landau equation we obtain the line $V_{\text{inst}}(T)$ below which the normal state becomes absolutely unstable with respect to nucleation of the superconducting order parameter. For sufficiently low biases, a stationary symmetric superconducting state emerges below the transition line. For higher biases, the normal phase is destroyed with the formation of a non-stationary bimodal state with two superconducting nuclei localized near the opposite terminals. We demonstrate that the large-V behavior of the instability line $V_{\text{inst}}(T)$ is highly sensitive to the inelastic relaxation mechanism in the wire. At large voltages the size of the superconducting nucleus is parametrically smaller than the wire length, that allows to resolve the short-scale features of the nonequilibrium distribution function in the wire. In particular, the current which destroys the normal state at zero temperature is not universal but depends on the inelastic relaxation rate and can be parametrically larger than the superconducting critical current. Experimental studies of the instability line $V_{\text{inst}}(T)$ in NSN junctions may be used as a tool to access various parameters of inelastic relaxation in the normal state.

Decoherence in quantum bits due to low-frequency noise

Yuri M. Galperin,[1, 2, 3] Joakim Bergli,[1] and Håkon Brox[1]

[1]*Department of Physics, University of Oslo, PO Box 1048 Blindern, 0316 Oslo, Norway*
[2]*Centre for Advanced Study at the Norwegian Academy of Science and Letters, 0271 Oslo, Norway*
[3]*Ioffe Physico-Technical Institute, 26 Polytekhnicheskaya, St Petersburg 194021, Russia*

The efficiency of the future devices for quantum information processing will be limited mostly by the finite decoherence rates of the qubits. Recently, substantial progress was achieved in enhancing the time within which a solid-state qubit demonstrates coherent dynamics. This progress is based mostly on a successful isolation of the qubits from external decoherence sources. Under these conditions, the material-inherent sources of noise start to play a crucial role. In most cases, the noise that the quantum device demonstrates has a $1/f$ spectrum. This suggests that the environment that destroys the phase coherence of the qubit can be thought of as a system of two-state fluctuators, which experience random hops between their states.

In this talk, we will present a short review of the current state of the theory of the decoherence due to the qubit interaction with the fluctuators. The effect of such an environment on two different protocols of the qubit manipulations, free induction and echo signal, is described. It turns out that in many important cases the noise produced by the fluctuators is non-Gaussian, see for a review, e.g., [1]. Consequently, the results of the interaction of the qubit with the fluctuators are not determined by the pair correlation function alone.We describe the effect of the fluctuators using the so-called spin-fluctuator model. Being quite realistic, this model allows one to exactly evaluate the qubit dynamics in the presence of one fluctuator. This solution is found, and its features, including non-Gaussian effects, are analyzed. We will also discuss the situation when a qubit is driven by external AC field, as well as role of correlation of the noises acting on components of a two-qubit gate.

The above consideration will be extended to systems of large numbers of fluctuators, which interact with the qubit and lead to the $1/f$ noise. We discuss existing experiments on the Josephson qubit manipulation and try to identify non-Gaussian behavior.

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Internal loss of superconducting resonators induced by interacting two level systems

Lara Faoro[1] and Lev B. Ioffe[2]

[1] *Laboratoire de Physique Theorique et Hautes Energies, CNRS UMR 7589, Universites Paris 6 et 7, 4 place Jussieu, 75252 Paris, Cedex 05, France*

[2] *Department of Physics and Astronomy, Rutgers The State University of New Jersey, 136 Frelinghuysen Rd, Piscataway, 08854 New Jersey, USA*

In a number of recent experiments with microwave high quality superconducting coplanar waveguide (CPW) resonators an anomalously weak power dependence of the quality factor has been observed [1–4]. We argue that this observation implies that the monochromatic radiation does not saturate the Two Level Systems (TLS) located at the interface oxide surfaces of the resonator and suggests the importance of their interactions. We estimate the microwave loss due to *interacting* TLS and show that the interactions between TLS lead to a drift of their energies that result in a much slower, logarithmic dependence of their absorption on the radiation power in agreement with the data.

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June 22, Friday, Afternoon

Probing interaction induced quantum Hall states in graphene

Jurgen H. Smet,[1] D.S. Lee,[1] V. Skakalova,[1] R.T. Weitz,[1] B. Krauss,[1] K. Klitzing,[1] B. Feldmann,[2] and A. Yacoby[2]

[1] *Max Planck Institute for Solid State Research, D-70569 Stuttgart, Germany*
[2] *Department of Physics, Harvard University, Cambridge, MA 02138, USA*

Progress in graphene sample quality starts to disclose rich physics related to the interaction induced fractional quantum Hall effect as well as lifting of symmetries associated with the spin and pseudospin degrees of freedom. A key requirement to observe these fragile states has so far been the fabrication of better quality samples. This has been accomplished by placing graphene on a flatter substrate, which is less prone to attract adsorbates, such as BN, or by suspending and current-annealing graphene. In the quest for observing still more fragile or novel incompressible states, probing a smaller area may circumvent the challenges of producing even higher mobility samples, since the sample may be much cleaner on the nanometer scale. Here we demonstrate that fluctuations in the transconductance of a graphene field effect transistor are associated with charge localization which occurs very locally. A systematic study of these fluctuations allows studying fragile interaction induced quantum Hall states even though the measurement is macroscopic [1]. We have also performed local compressibility studies on a suspended graphene flake using a scanning single electron transistor [2]. By combining very clean samples with a local measurement, it has been possible to advance the field further. Higher order fractional quantum Hall states have been observed. The sequence of fractional quantum Hall states partially deviates from the standard composite fermion sequence. The unusual sequence apparently results from a complex interplay between electronic correlations and the SU(4) symmetry in graphene.

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Spin and valley quantum Hall ferromagnetism in monolayer graphene

A. F. Young
Department of Physics, Massachusetts Institute of Technology, Cambridge, MA 02139

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 talk, 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. We use tilted field, temperature dependent magnetotransport to classify the states appearing at different Landau Level filling factors by their real spin structure. We find evidence for real spin polarized states supporting Skyrmionic excitations, charge- or spin- density order, and valley textured excitations at different filling factors[1].

An outstanding theoretical question has been the fate of charge neutral graphene at high magnetic fields. We find that at $\nu = 0$ the 'natural' ground state is a spin unpolarized insulating state; however, with the application of a sufficiently strong in-plane field, a transition to a *conducting* spin ferromagnet can be induced. I will discuss transport and capacitance measurements designed to separately probe the bulk and edge structure of the this transition, and the resulting spin polarized state.

Finally, at the highest perpendicular fields, we observe a number of fractional quantum Hall states, whose pattern reflects the unique structure of the graphene Landau levels[2]. Taken together, our results confirm graphene as a highly isotropic SU(4) ferromagnet, in which symmetry breaking is dictated by the interplay between the Zeeman effect, lattice scale interactions, and disorder.

[1] A. F. Young *et al.*,"Spin and valley quantum Hall ferromagnetism in graphene", Nat. Phys., Published online 13 May 2012.
[2] C. R. Dean, A. F. Young *et al.*, "Multicomponent fractional quantum Hall effect in graphene", Nat. Phys. **7**, 693 (2012).

Spin-droplet state of interacting 2D electron system

M. Reznikov,[1] N. Teneh,[1] A. Yu. Kuntsevich,[2] and V. M. Pudalov[2]

[1]*Solid state institute, Technion, Haifa, 32000 Israel*
[2]*Lebedev Physical Institute, 119991 Moscow, Russia*

We report thermodynamic magnetization measurements of two-dimensional electrons in several high mobility Si-MOSFETs in a wide density range from deep into insulating to the metallic phase. We provide evidence for ferromagnetic interactions between electrons, which leads to the formation of spin-droplets in the insulating phase. These droplets melt in the metallic phase with increasing density and temperature, though survive up to large densities.

Tunneling into a Luttinger liquid revisited

V. Yu. Kachorovskii,[1,2] D. N. Aristov,[2,3] A. P. Dmitriev,[1,2] I. V. Gornyi,[1,2] D. G. Polyakov,[2] and P. Wölfle[2]

[1] *A.F.Ioffe Physico-Technical Institute, 194021 St.Petersburg, Russia*
[2] *Karlsruhe Institute of Technology, 76021 Karlsruhe, Germany*
[3]*Petersburg Nuclear Physics Institute, 188300 St.Petersburg, Russia*

Electron tunneling into a correlated many-electron system is one of the most essential tools to probe the nature of the correlations. A key concept here is that the tunneling density of states reflects how difficult it is for electronic states to rearrange themselves to accommodate the extra charge of the tunneling electron. The hallmark of strong correlations is the "zero-bias anomaly" (ZBA) [1]—the nonlinear behavior of the tunneling current as a function of the bias voltage—resulting from a singularity in the tunneling density of states at the Fermi energy. The prototype model and the best-understood example of a strongly correlated metallic state is the Luttinger liquid (LL) in one-dimensional electron systems [2].

When using the term "tunneling", we often have at the back of our minds that the tunneling probes the properties of the system into which the electron tunnels "noninvasively", i.e., the tunneling amplitude is infinitesimally small. A more subtle and complete understanding of the interplay of strong correlations and tunneling emerges when the latter is treated beyond the lowest order of perturbation theory. It is the purpose of this talk to discuss the junction between a LL and a tunnel electrode for arbitrary strength of tunneling. Apart from the conceptual interest, the "three-way junction" is considered as a key element for device engineering in nanoelectronics.

We first consider the simplest and commonly used model ("point contact") for the tunneling Hamiltonian: $H_{\rm tun} = t_0\psi^\dagger(0)\psi(0) + {\rm H.c.}$, and take t_0 to be real. In the absence of interaction, the tunneling amplitude can be shown to obey $t = -i\,{\rm sgn}(t_0)[2\rho(1-\rho)]^{1/2}$, where $\rho = 2|t_0|^2/(vv_{\rm e} + 2|t_0|^2)$ and v, v_e are the Fermi velocities in the contact and the wire, respectively. Importantly, the tunneling transparency $G_{\rm t} = 2|t|^2 = 4\rho(1-\rho)$ can be expressed in terms of single parameter ρ. Our main result for this model is the interaction-induced renormalization of ρ and, as a consequence, of $G_{\rm t}$. We show that interaction leads to decrease of ρ (thus suppressing tunneling) only if bare value of ρ is sufficiently small. Otherwise, ρ monotonically *increases* in the course of renormalization. Two different fixed points (FP) ($\rho = 0$ and $\rho = 1$) correspond to different states of the wire: although the tunnel contact is decoupled from the wire at both FPs, the wire at $\rho = 0$ is homogeneous, while at $\rho = 1$ it is broken up into two disconnected pieces. There exists an intermediate point $\rho = \rho_c$, which corresponds to the *phase transition* separating two phases with $\rho = 0$ and $\rho = 1$

We also discuss more general types of the tunneling contacts and demonstrate that a homogeneous LL is actually generically *unstable* at low energies to arbitrarily weak tunneling and the breakup into two independent semi-infinite wires. The ZBA at the true (stable) fixed point (FP) is strongly enhanced. For sufficiently weak interaction or sufficiently strong tunnel coupling, the tunnel conductance actually *grows* with decreasing energy scale (temperature, bias voltage) before it reaches maximum and starts to renormalize toward zero.

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Effects under conditions of the microwave-induced 'zero-resistance' state

S. I. Dorozhkin
Institute of Solid State Physics RAS, Chernogolovka, Moscow district, 142432 Russia

Under microwave radiation, high mobility two-dimensional electron systems (2DES) demonstrate spectacular effect of magnetoresistance oscillations with periodicity determined by the ratio of the circular microwave frequency ω to the cyclotron frequency ω_c. In the main oscillation minima, both the magnetoresistivity and magnetoconductivity tend to zero giving rise to the so-named zero-resistance state (ZRS). The time-averaged photo-voltage signals oscillating synchronously with the magnetoresistance are detected on the internal potential probes surrounded by 2DES. We found that, in the zero-resistance state, the photovoltage can spontaneously switch between two different values [1] giving rise to the random telegraph signal. This switching occurs synchronously for a set of different contacts indicating redistribution of the microwave induced Hall currents in a macroscopic region of a sample. Such bistability may be brought about by the spontaneous symmetry breaking under conditions of negative conductivity as has been predicted for ZRS explanation [2].

It was well established that microwave radiation strongly affects the 2DES magnetoconductivity and can even drive it negative in a homogeneous system. We showed that it practically does not change the diffusion coefficient, so that the Einstein relation does not hold in the non-equilibrium state [3]. In the linear response regime, we have derived stability condition for a finite two-dimensional system of length L: $\sigma + \frac{\epsilon D}{2L} \geq 0$ [4]. Here σ and D are the conductivity and the diffusion coefficient, respectively, and ϵ is the dielectric constant. This equation shows that positive diffusion coefficient can stabilize the state with the negative conductivity. Such a state is shown to have a set of unusual properties.

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Metal-Insulator Transition in 2D Systems with Chiral Symmetry

P. M. Ostrovsky,[1,2] E. J. König,[3] I. V. Protopopov,[3,2] and A. D. Mirlin[3,4]
[1]*Max Planck Institute for Solid State Research, D-70569, Stuttgart, Germany*
[2]*L. D. Landau Institute for Theoretical Physics RAS, 119334 Moscow, Russia*
[3]*Karlsruhe Institute of Technology, 76128 Karlsruhe, Germany*
[4]*Petersburg Nuclear Physics Institute, 188300 St. Petersburg, Russia*

Field-theoretical approach to Anderson localization in 2D disordered fermionic systems of chiral symmetry classes (BDI, AIII, CII) is developed. Important representatives of these symmetry classes are random hopping models on bipartite lattices at the band center. As was found by Gade and Wegner two decades ago within the sigma-model formalism, quantum interference effects in these classes are absent to all orders of perturbation theory. We demonstrate that the quantum localization effects emerge when the theory is treated non-perturbatively. Specifically, they are controlled by topological vortex-like excitations of the sigma models. We derive renormalization-group equations including these non-perturbative contributions. Analyzing them, we find that the 2D disordered systems of chiral classes undergo a metal-insulator transition driven by topologically induced Anderson localization. We also show that the Wess-Zumino and Z_2 theta terms on surfaces of 3D topological insulators (in classes AIII and CII, respectively) overpower the vortex-induced localization.

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June 23, Saturday, Morning

Weak and strong insulators: evidence from level statistics

L. Ioffe
Rutgers University, USA

A Universal Critical Density Underlying the Physics of Electrons at the $LaAlO_3/SrTiO_3$ Interface

Shahal Ilani
Department of Condensed Matter Physics, Weizmann Institute of Science, Rehovot, Israel

The two-dimensional electron system formed at the interface between the insulating oxides $LaAlO_3$ and $SrTiO_3$ exhibits ferromagnetism, superconductivity, and a wide range of unique magnetotransport properties. A key challenge is to find a unified microscopic mechanism that underlies these emergent phenomena. In this talk I will show that a universal Lifshitz transition between d-orbitals lies at the core of the observed transport phenomena in this system. Our measurements find a critical electronic density at which the transport switches from single to multiple carriers. This density has a universal value, independent of the $LaAlO_3$ thickness and electron mobility. The characteristics of the transition, its universality, its compatibility with spectroscopic measurements, and its accompanied electronic anisotropies establish it as a transition between d-orbitals of different symmetries. A simple band model, allowing for spin-orbit coupling at the atomic level, connects the observed universal transition to a range of reported magnetotransport properties. Interestingly, we also find that the maximum of the superconducting transition temperature occurs at the same critical density, indicating a possible connection between the two phenomena. Our observations demonstrate that orbital degeneracies play an important role in the fascinating behavior observed so far in these oxides.

Superconductivity and Ferromagnetism in Oxide Interface Structures: Possibility of Finite Momentum Pairing

Karen Michaeli, Andrew C. Potter, and Patrick A Lee
Department of Physics, Massachusetts Institute of Technology,
77 Massachusetts Avenue, Cambridge, MA 02139

Separately, $LaAlO_3$ (LAO) and $SrTiO_3$ (STO) are both electronically boring insulators. However, when these materials are combined, their interface has surprising electronic properties: it is highly conducting, ferromagnetic, and becomes a superconductor when cooled down to low temperature. The strong magnetism of the LAO/STO interface and its easily tunable electronic properties make this system a promising candidate for novel electronic and spintronic devices. This has led to an extensive experimental investigation; nevertheless, the material's properties are still not well understood.

In the talk I will present a model that captures the physical properties of the LAO/STO interface. In particular, we address one of the most intriguing phenomena observed in these system: the coexistence of ferromagnetism and superconductivity. Ordinarily this ferromagnetism would destroy superconductivity, but due to strong spin-orbit coupling near the interface, the magnetism and superconductivity can coexist by forming an FFLO-type condensate of Cooper pairs at finite momentum. Surprisingly, this unconventional superconducting state survives even at strong disorder. In the talk, I will describe the origin of this phenomenon and discuss experimental consequences.

Poster session

A Fano resonance in transport characteristics of 1D atomic spin structures

S.V. Aksenov,[1] V.V. Val'kov,[2,3] and E.A. Ulanov[3]
[1] *L.V. Kirensky Institute of Physics, Krasnoyarsk 660036, Russia*
[2] *L.V. Kirensky Institute of Physics, Krasnoyarsk 660036*
[3] *Siberian State Aerospace University, Krasnoyarsk 660014, Russia*

Miniaturization of data storage devices implies control of magnetism on the atomic scale. Recently, fundamental opportunity of changing of the magnetic state both single atoms, molecules and chains by the inelastic interaction with the transported electrons was demonstrated [1, 2].

In present work, the results of theoretical study of the single-electron transport through the single magnetic impurity and spin dimer are presented. It is supposed that the electron scatters inelastically at the expense of the exchange interaction with the spin structure. As a result, the transport is implemented by channels which correspond the ground and excited states of the system. Specifically, it leads to realization of the Fano effect in transport characteristics of the spin structures. The Fano resonances appear only when energy of the incoming electron is less than a value of the exchange interaction between the dimer spin moments or than the anisotropy parameter of the magnetic impurity. In such cases, there are two types of interacting states in the system. The first one is the continuum state which correspond to the ground state and the others (or only one) are the localized excited states. Substantially, the effect of the gate voltage on the spin structure plays an important role in observation of the Fano effect under the tunnel transport regime. It is shown that the response of the Fano resonances to the external magnetic field is appeared to be the reason of the anomalously high magnetoresistance of the systems under consideration.

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Poster session

Spin entanglement and nonlocality of multifermion systems

Marsel R. Arifullin and Vitaly L. Berdinskiy
Orenburg University, Pobedy av., 13, Orenburg, Russia

The fundamental property of electron spin S = 1/2 is very perspective for usage as the information carrier in spintronics, quantum computing and quantum cryptography. However, to be used any electron spin should be extracted from the ensemble of undistinguished particles, and spin properties of such ensemble should be known. Spin states of odd number N of undistinguished fermions and their properties have been studied in details. Spin states are proved to be determined by the Pauli's principle unequivocally and should be described by spin density matrices (SDM). The initial step for calculation of SDM is the antisymmetric fermion wavefunction chosen as the Slater determinant. The effective algorithm for calculation of multispin SDM has been developed. Such SDM are shown can be presented as the normalized sum of nonorthogonal projector operators onto all possible multifermion singlet states

$$\rho_N = 2^{N/2}(N/2)!(N!)^{-1}\sum_P P(\mid S_{ij}S_{kl}S_{mn}... >< S_{ij}S_{kl}S_{mn}... \mid), \quad (1)$$

here P means all possible permutations of the indexes i,j,k,l,m,n..., and S are the singlet spin state of the fermion pair. The Sylvester criterion of nonnegativity together with the Peres-Horodecki one were used to prove that the SDM (1) describes entangled spin states of any multifermion subsystems. The important case is the twospin subsystem. Taking the trace over spin states of all the extra fermions the SDM

$$\rho_2 = 4^{-1}(N+2)(N-1)^{-1} \mid S >< S \mid + 4^{-1}(N-2)(N-1)^{-1}(\mid T_+ >< T_+ \mid + \mid T_0 >< T_0 \mid + \mid T_- >< T_- \mid) \quad (2)$$

Usage of the Peres-Horodecki criterion proves that the twospin subsystem is not entangled in spite of the fact that spin state of any separate fermion is entangled with the rest of the multifermion system. This result illustrates the violation of transitivity of spin entanglements: the entanglement of system A and C does not follows from the fact that the system A is entangled with the system B, and the system B is entangled with the system C. Violation of the Bell's inequalities was proved for the case if the initial fermion system decays and produces one fermion.

Josephson φ-device concept based on complex nanostructures with normal metal/ferromagnet bilayer

S. V. Bakurskiy,[1] N. V. Klenov,[1] A. A. Golubov,[2] and M. Yu. Kupriyanov[3]
[1]*Faculty of Physics, Moscow State University, 119992, Leninskie Gory, Moscow, Russia*
[2]*Faculty of Science and Technology, University of Twente, 7500 AE Enschede, The Netherlands*
[3]*Skobeltsyn Institute of Nuclear Physics, Moscow State University, Moscow, 119992, Russia*

The φ-junction is the Josephson device with nontrivial ground state phase ($0 < \varphi < \pi$) created by non-sinusoidal ($I_S(\varphi) = A\sin(\varphi) + B\sin(2\varphi) + ...$) current phase relation (CPR) with a relatively large and negative amplitude of the second harmonic B. This junction has applicability in superconductive quantum circuits, e.g. qubits or quantum detectors. The competition of its creation associated with the fact, that required CPR can't be fulfilled on the base of single-layer devices. The previously proposed concepts use the arrays of 0- and π- ferromagnet SFS junctions [1, 2] featured by the large scale.

In this work we have demonstrated that the structures composed from longitudinally oriented normal and ferromagnet films in the weak link region can be used as reliable φ-device. In this case F-layer opens a window of the relative smallness of the first harmonics amplitude A and N-layer provides the negative sign of the second one. To prove it, in the frame of Usadel equations we solved two dimensional boundary problem for different geometries of S-NF-S structures and found analytical criteria of φ-state existence. Finally we numerically estimated those concepts and showed the structure with scale in order of 100 nm and critical current equal to 3 μA in the φ-state.

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Calculation of the normal and the superconducting current in heterostructures with superconducting pnictide

A. V. Burmistrova and I. A. Devyatov
M. V. Lomonosov Moscow State University Skobeltsyn Institute of Nuclear Physics, Leninskie gory, GSP-1, Moscow 119991, Russian Federation

At present time there is a clear inconsistency of the obtained experimental data [1–3] about transport of the quasiparticle and Josephson current in heterostructures with superconducting pnictides with their theoretical interpretation.

By present time some theories of electron transport in the S-N junctions [4–7] and Josephson junctions with pnictides [6, 8, 9] were proposed. However, theories of electron transport in S-N junctions [5–7] and theories of Josephson transport in superconducting junctions containing pnictides [8, 9] do not take into account the essentially non parabolic and anisotropic form of the excitation spectrum of pnictides or all important types of superconducting pairing [4]. Moreover, in the theories [8, 9] some types of the tunnel Hamiltonian approach have used. It is well known [10] that the tunnel Hamiltonian approach is not applied for adequate description of coherent transport in superconducting junctions with sign-changing order parameter in configuration space, that certainly happens in the case of superconductivity in pnictides.

We present the theory of the coherent electron transport of both normal and Josephson current in structures containing pnictides, that takes into account the specific form of the excitation spectrum of pnictide and all important types of superconducting pairing. Within the framework of this theory the conductances of S-N junctions for different models of superconducting pairing in pnictides and the phase dependencies of Josephson current across a superconducting junctions contained usual isotropic BCS type superconductor and high-temperature iron-containing superconductor for different orientations of the boundary with respect to the crystallographic axes of pnictides were calculated. The temperature dependencies of critical current were also calculated taking into account the temperature dependence of the order parameter of superconductors.

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Single-shot measurements simulation in Josephson qubits coupled to a bosonic bath

M.V. Denisenko and A.M. Satanin
Nizhny Novgorod State University, 23 Gagarin Ave., 603950, Nizhny Novgorod, Russia

It is known that closed quantum systems can indefinitely stay in steady states. At the same time, the transitions between steady states can occur stochastically in an open quantum system (so-called quantum jumps). Recently such quantum jumps have been observed in single-shot measurements of nuclear spin [1], electron spin in the quantum dots [2] and microscopic defects in a Josephson junction [3].

Such quantum system play an important role in quantum information, because this objects allow realize the two-level systems or qubits [4] (the quantum analog of bits). In the present work we are going to investigate the relaxation processes in qubit coupled with a nonlinear bifurcation oscillator by using the quantum trajectories approach (quantum Monte Carlo method)[5]. This method gives two main advantages in the investigation of open systems: i) To illuminate the behavior of a single system (including of noise) for each realization, and ii) The effective fast parallel simulation tool for the realization on CPU. The quantum trajectories approach allows us to simulate directly the processes of single-shot measurements [1–3]. We have simulated the dissipative dynamics of the qubit excited states, interrupted by quantum jumps. It is demonstrated that after the averaging the levels population by the number of the realization it can reach the saturation. Whereas, the level population for an individual realization of a single quantum system can be traced back several types of quantum jumps as a consequence the interaction with the bosonic bath. The transition to the averaged behavior, which characterizes by the time of longitudinal and transverse relaxation, was studied. We have investigated the process of projective measurements and back action effects in the coupled system the meter (nonlinear bifurcation oscillator) and the qubit. The results of numerical calculation qualitatively agree with the data of recent experiments [3].

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Cooper pair fluctuations in the system of spatially separated electrons and holes

D.K. Efimkin[1] and Yu.E. Lozovik[1,2]
[1]*Institute of Spectroscopy RAS, 142190, Troitsk, Moscow region, Russia*
[2]*Moscow Institute of Physics and Technology, 141700, Moscow, Russia*

Recently it was shown [1] that thin film of topological insulator with independently gated opposite surfaces is rather favorable system for electron-hole pairing [2]. Electron-hole pairing leads to superfluidity, anomalies in transport and internal Josephson effect. Pronounced internal Josephson effect manifests itself as strong enhancement of tunneling conductivity between the layers. It was observed in the system of spatially separated composite electrons and composite holes [3]. Here we considered influence of Coulomb interaction on tunnel conductivity between opposite surfaces of the topological insulator thin film in the normal state. We used diagrammatic perturbation theory and linear response scheme for calculation of tunneling conductivity. Dependence of tunnel conductivity on external voltage contains peak that appears due to restrictions from momentum and energy conservations laws. In absence of Coulomb interaction dependence of width and height of the peak on quasiparticle decay rate is strong and their dependence on temperature is rather weak. Coulomb interaction between electrons and holes leads to considerable enhancement of tunneling. In vicinity of phase transition temperature T_0 dependence of peak height on temperature is critical one. Its height and width depends only on temperature and height of the peak diverges $(T - T_0)^{-\nu}$ with critical index $\nu = 2$. This enhancement can be interpreted as manifestation of Cooper pair fluctuation in normal state in vicinity of critical temperature. The work was supported by Grant of the President of Russian Federation MK-5288.2011.2. D.K.E acknowledges support from Dynasty Foundation.

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Disorder-tuned Transition from Bulk through Filamentary Superconductivity to AF insulator in Q1D metal

Ya. A. Gerasimenko, V. A. Prudkoglyad, A. V. Kornilov, and V. M. Pudalov
P. N. Lebedev Physical Institute of the RAS, 119991, Moscow, Leninskiy pr., 53, Russia

Coexistence of superconductivity (SC) and spin-density wave (SDW) in a narrow pressure region is known for a long time for quasi one-dimensional (Q1D) organic superconductor $(TMTSF)_2PF_6$ [1]. The coexistence proved to be spatially inhomogeneous [1] and SC slabs were suggested to explain an unusual critical field increase [2]. Recent experimental observation [3] of anisotropic onset of superconductivity along different crystal axes suggests the emergence of soliton phase in the coexistence region. This raises the crucial question about the parameters, such as Fermi surface (FS) peculiarities [3], strain or disorder [4], responsible for the formation of superconducting texture.

Ambient-pressure Q1D organic superconductor $(TMTSF)_2ClO_4$ allows to study the effects of both FS transformation and disorder on the SC/SDW competition thanks to order-disorder transition in ClO_4 anion orientations controlled with cooling rate [5].

Here we present our experimental study of the coexistence of superconductivity and spin-density wave tuned by anion disorder in $(TMTSF)_2ClO_4$. By varying the degree of anion disorder we observed fast degradation of superconductivity inside the layers and transition to SDW insulator, as cleary seen in the intralayer transport. On the contrary, interlayer transport demonstrates full superconducting transition for all disorders, even for those where SDW is stabilized. This evidences for the transformation of bulk superconductivity into filamentary SC with increasing disorder. We observe narrow superconducting filaments aligned along the c^* axis (normal to layers) in the coexistence region. We also find that critical field $H_{c2}||c^*$ increase dramatically when the system is driven deeper into the SDW phase with increasing disorder. We discuss the role of disorder and energy gap (due to anion ordering) on bulk-to-filamentary transformation of superconductivity.

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Hybrid planar S-N-S Josephson junctions with spin polarized injection

T. E. Golikova,[1] M. Wolf,[2] D. Beckmann,[2] S. A. Nikonov,[1] and V. V. Ryazanov[1]
[1]*Institute of Solid State Physics RAS, 142432 Chernogolovka, Moscow district, Russia*
[2]*Institute of Nanotechnology, Karlsruhe Institute of Technology, 76021 Karlsruhe, Germany*

We have investigated the current-voltage characteristics of the hybrid planar Al-Cu-Al Josephson junctions with injection of the spin-polarized current from a ferromagnet at low temperatures. We report the observation of resonance peaks in transport characteristics even at zero external magnetic field. This effect enlarges dramatically in magnetic field. We suppose that this behavior can probably be explained by an electron spin resonance due to Josephson generation at finite voltage on S-N-S junction.

Poster session

A new superconducting interferometer as a detector of quantum states

V.L. Gurtovoi,[1] A.V. Nikulov,[1] V.A. Tulin,[1] V.N. Antonov,[2] and R. Shaikhaidarov[2]

[1] *Institute of Microelectronics Technology, Russian Academy of Sciences, 142432 Chernogolovka, Moscow District, Russia*

[2] *Physics Department, Royal Holloway University of London, Egham, Surrey TW20 0EX, UK*

It is about 50 years since the analysis of Josephson junction (JJ) operation and first measurements of SQUID - the most sensitive detector of magnetic field, which is often used for detection of superconducting qubit quantum states. There were recent attempts to improve SQUID sensitivity by about an order of magnitude [1], but advancement in development of the quantum devices puts pressure on the SQUIDs since more sensitive detectors of magnetic filed with a reduced back action on the quantum devices themselves are needed.

We suggest a new universal superconducting differential double contour interferometer (DDCI) which could be used as both a phase detector of quantum states and precision magnetic field measurement device with unique sensitivity. The structure consists of two independent superconducting contours connected by two JJs (1,2) in a such way that phase difference of wave functions on segments of the contours results in jump changes of the structure critical current from zero to maximum value in process of sequential changes of contour quantum numbers. The DDCI operation is defined by the following expression

$$I = I_{c1} \sin \Delta\varphi_1 + I_{c2} \sin(\Delta\varphi_1 + \pi(n_1 + n_2)) \tag{1}$$

where n_1 and n_2 are quantum numbers of the contours and $\Delta\varphi_1$ is the phase difference on one of the JJs. Thus, the current depends only on parity of quantum number sum and do not depend on contour areas and magnetic field, which results in ideal detector of quantum states. The maximum current through DDCI, $I_{max} = I_{c1} + I_{c2}$, when $n_1 + n_2$ is even and $I_{max} = |I_{c1} - I_{c2}|$, when $n_1 + n_2$ is odd. In case of $I_{c1} = I_{c2}$, there will be current jumps from zero to $2I_0$ and back to zero for sequential changes of main contour quantum numbers n_1 and n_2.

In this work, we have investigated DDCI behavior from 0.4 K to1.25 K. At all temperatures, for quantum number changes voltage jumps with an amplitude equals to superconducting gap (reaching 200 μV at 0.4 K) were observed.

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Concept of tunable qubit based on a molecule of two fractional Josephson vortices

D. M. Heim,[1] K. Vogel,[1] W. P. Schleich,[1] E. Goldobin,[2] D. Koelle,[2] and R. Kleiner[2]

[1] *Institut für Quantenphysik and Center for Integrated Quantum Science and Technology (IQ^{ST}), Universität Ulm, D-89069 Ulm, Germany*

[2] *Physikalisches Institut and Center for Collective Quantum Phenomena, Universität Tübingen, D-72076 Tübingen, Germany*

We propose a concept of a qubit based on two coupled fractional vortices pinned at two artificially created κ discontinuities of the Josephson phase in a long Josephson junction. Each discontinuity can be created by a pair of tiny current injectors with the current $I_{\text{inj}} \propto \kappa$ applied. Similar to the previous proposal based on a 0-π-0 junction [1] we map the dynamics of the system to the dynamics of a single particle in a double-well potential and calculate the effective parameters of this potential. By tuning the discontinuities $\kappa \propto I_{\text{inj}}$ during experiment one is able to control the parameters of the effective double-well potential. The system can be used to study macroscopic quantum phenomena involving tailored vortex matter.

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Thermodynamics of enhanced heat transfer: a model study

Karen V. Hovhannisyan and Armen E. Allahverdyan
Yerevan Physics Institute, Alikhanian Brothers Str. 2, Yerevan 0036, Armenia

Situations where a spontaneous process of energy or matter transfer is enhanced by an external device are widespread in nature (human sweating system, enzyme catalysis, facilitated diffusion across bio-membranes, industrial heat exchangers). The thermodynamics of such processes remains however open. Here we study enhanced heat transfer by a model junction immersed between two thermal baths at different temperatures T_h and T_c ($T_h > T_c$). The transferred heat power is enhanced via controlling the junction by means of external time-dependent fields. Provided that the spontaneous heat flow process is optimized over the junction Hamiltonian, any enhancement of this spontaneous process does demand consumption and subsequent dissipation of work. The efficiency of enhancement is defined via the increment in the heat power divided over the amount of consumed work. We show that this efficiency is bounded from above by $T_c/(T_h - Tc)$. Formally this is identical to the Carnot bound for the efficiency of ordinary refrigerators which transfer heat from cold to hot. It also shares some (but not all) physical features of the Carnot bound.

Search for hyper-activation in the insulating side of the superconductor-insulator transition in Indium Oxide

David Kalok, Maoz Ovadia, and Dan Shahar
Department of Condensed Matter Physics, Weizmann Institute of Science, Rehovot 76100, Israel

We present data obtained from high resolution, low temperature, transport study in the vicinity of the magnetic-field driven superconductor-insulator transition in amorphous Indium Oxide (a:InO). Previous measurements on amorphous Indium Oxide [1] and polycrystalline Titanium Nitride [2] have shown an activated behavior of the resistance in the insulating state. Our earlier measurements were limited by the current resolution, defining the highest measurable resistance. Additionally, the current-voltage characteristics are highly non-linear at low temperatures, leaving only a small voltage window for measuring the Ohmic resistance. In our improved setup, the current resolution is brought down to 1-2 femto Amperes, which enables the measurement of much higher resistances. We observe deviations from the activated behavior at temperatures below 125 mK in the highly insulating state for a wide range of magnetic fields. We investigate whether the extended temperature dependence of the resistance can be explained by hyper-activation due to a collective Coulomb blockade or by hoping scenarios.

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Poster session

Vortex core states in 2D electron system with proximity induced superconductivity

I.M. Khaymovich,[1] N.B. Kopnin,[2,3] and A.S. Melnikov[1]

[1] *Institute for Physics of Microstructures, Russian Academy of Sciences, 603950 Nizhny Novgorod, GSP-105, Russia*
[2] *Low Temperature Laboratory, Aalto University, P.O. Box 15100, 00076 Aalto, Finland*
[3] *L. D. Landau Institute for Theoretical Physics, 117940 Moscow, Russia*

We study the proximity induced superconducting states in a layer of normal two-dimensional (2D) ballistic electron gas coupled to a bulk type II superconductor (SC) assuming the conservation of the in-plane quasiparticle momentum, i.e. on the basis of coherent tunneling model. The entire structure is placed into a transverse magnetic field which leads to the formation of a vortex in the bulk SC that in turn induces a vortex-like structure in the 2D layer due to the proximity effect. We consider electronic states in the core of such proximity induced 2D vortex and focus on the peculiarities of the local density of states (LDOS) which can be observed by scanning tunnel microscope (STM).

We demonstrate that the spectrum consists of *two* anomalous branches as functions of the impact parameter. One of these branches qualitatively follows the usual Caroli-deGennes-Matricon (CdGM) anomalous branch [1] of the vortex in bulk SC and extends above the induced gap where it turns into the scattering-state resonances. This branch approaches the bulk superconducting gap at the bulk coherence length ξ_S. The other branch lies below the induced superconducting gap and resembles the CdGM anomalous branch for a vortex with much larger core diameter ($\xi_{2D} \gg \xi_S$). It has much slower dependence on the impact parameter and reaches energies of the order of the induced gap for trajectories that go far from the induced vortex core.

LDOS vs energy close to the vortices' centre $\rho \le \xi_S^2/\xi_{2D}$ demonstrate two peak-like anomalies, caused by the different anomalous branches. The coordinate dependence of the LDOS profile reveals two-scale behavior: the larger core size ξ_{2D} essentially exceeds the coherence length of the bulk SC ξ_S. This behavior favors the interpretation of large coherence length values obtained in STM experiments [2] on the surface of MgB_2 in terms of a proximity induced gap.

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Interaction and disorder effects in 3D topological insulator thin films

Elio König,[1,2] P. M. Ostrovsky,[3,4] I. V. Protopopov,[5,4] I. V. Gornyi,[5,6] I. S. Burmistrov,[4] and A. D. Mirlin[5,1,7,2]

[1] *Inst. für Theorie der kondensierten Materie, Karlsruhe Institute of Technology, 76128 Karlsruhe, Germany*
[2] *DFG Center for Functional Nanostructures, Karlsruhe Institute of Technology, 76128 Karlsruhe, Germany*
[3] *Max-Planck-Institute for Solid State Research, D-70569 Stuttgart, Germany*
[4] *L. D. Landau Institute for Theoretical Physics RAS, 119334 Moscow, Russia*
[5] *Institut für Nanotechnologie, Karlsruhe Institute of Technology, 76021 Karlsruhe, Germany*
[6] *A. F. Ioffe Physico-Technical Institute, 194021 St. Petersburg, Russia*
[7] *Petersburg Nuclear Physics Institute, 188300 St. Petersburg, Russia.*

It has been recently predicted that Coulomb interaction drives a surface of a 3D topological insulator into a critical state [1]. We employ the sigma-model formalism [2] to investigate the effect of electron-electron interaction on the transport by surface states in topological insulator thin films. We take into account the interaction of electrons on different surfaces and also the top-bottom asymmetry of the film (different densities of states and strength of disorder on top/bottom surface). This asymmetry is naturally present in experiments where the electronic densities on the surfaces are controlled independently by means of electrostatic gates. The lack of symmetry between top and bottom surfaces is shown to have strong effect on the film conductivity. The interplay of weak antilocalization, Coulomb interaction within and between surfaces and topological protection leads to a rich flow diagram representing the low temperature behavior of the system. In particular, the intersurface interaction is found to evoke a non-monotonic temperature dependence of the conductuctivity and eventually drives the film into a metallic state. The connection with recent experiments [3] on Bi_2Se_3 films is discussed.

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Electromagnetic waves in graphene at the interface between two dielectric media

O.V. Kotov[1,2] and Yu.E. Lozovik[1,2]

[1] *Institute of Spectroscopy RAS, 142190, Troitsk, Moscow region, Russia*
[2] *Moscow Institute of Physics and Technology, 141700, Moscow, Russia*

The influence of the optical contrast between the two media, located on the opposite sides of graphene on the behavior of electromagnetic waves with TE and TM polarization was studied. It was found that TE-polarized waves, predicted to exist only in graphene [1], become leaky due to the increase of the optical contrast. In the considered case TE-mode frequency lies only in the window determined by the contrast. Analytical expressions describing the frequency range and extent of leakage depending on the contrast were deduced. The different characteristics of leaky modes: the wave vector, phase and group velocities, the characteristic length of leakage were studied in detail. The sensitivity of TE-modes to changes in contrast was estimated. Near the frequency where the imaginary part of the conductivity of graphene vanishes, the very high sensitivity and very low detection limit were observed. The considered effect can be used for design of highly sensitive optical sensors based on graphene. We expect that they can outperform modern plasmon resonance sensors [2] by several orders. The work was supported by Russian Foundation for Basic Research and by the Grant of President of Russian Federation MK-5288.2011.2.

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Poster session

Linear temperature dependence of quantum contact conductance as a consequence of electron scattering by the Friedel oscillations

Krishtop T. V. and Nagaev K. E.
Kotel'nikov Institute for Radioengineering and Electronics of RAS

We calculate the conductance of two-dimensional ballistic contacts on an assumption that the contact size a is much smaller than the Fermi wavelength λ_F. Such a quantum point contact can be realized on high mobility GaAs/AlGaAs heterostructure if the applied gate voltage is sufficiently large.

Previously, we calculated the conductance of wide ballistic microcontacts with size $a \gg \lambda_F$. The electron-electron scattering in such contacts leads to an anomalously large positive correction to the conductance, linear in temperature in zero magnetic field [1]. The theory [1] is in a good agreement with the experimentally obtained dependencies of the conductance on temperature and magnetic field [2], [3]. But when a large gate voltage reduces the contact size to a few λ_F, the experimental dependence [3] of the conductance on the contact size in zero magnetic field is much stronger than the theoretical dependence $\delta G \propto (k_F a)^2 \ln \frac{l_c}{a}$. Therefore we decided to calculate the conductance in a narrow contact.

As a contact model we use two 2D electron gases separated by a thin impenetrable barrier with a gap of width a.

First, we consider the contact without electron-electron interaction and calculate the conductance with the help of Landauer method [4] as a sum of transmission coefficients. The obtained conductance is proportional to the fourth power of the size of the contact $\delta G \propto (k_F a)^4$. It is in a physical analogy with the Rayleigh scattering of light, since the intensity of light scattering by a particle much smaller than the wavelength is proportional to the square of the particle volume.

Now let's take into account the electron-electron interaction, that is the electron scattering by the Friedel oscillations due to the barrier. This results in a cusp of the total transmission coefficient at the Fermi surface. This cusp leads to a linear dependence of conductance on temperature after integration over the energy.

We calculate the correction to the conductance due to electron-electron scattering for the arbitrary weak interaction potential $U_{ee}(\mathbf{p})$. The main contribution is due to scattering of electrons by the Friedel oscillations far from the contact, at the distances of the order v_F/T. The correction is proportional to the fourth power of the contact size. This dependence on contact size is stronger than the theoretical dependence for the case of wide contacts [1] and apparently in better agreement with the experiment [3] in the case of narrow contacts. The relative correction does not depend on the size of the contact. The conductance correction consists of a constant term and a term that linearly dependent on temperature. The first one provides a small change of the Fermi level. We are mainly interested in the second one $\delta G = \delta G_H - \delta G_F$ which is a sum of the direct (Hartree) term $\delta G \propto -(k_F a)^4 \frac{T}{E_F} 2U_{ee}(2k_F)$ and exchange (Fock) term $\delta G \propto (k_F a)^4 \frac{T}{E_F} U_{ee}(0)$. The sign of the correction is determined by the competition between them. It is negative in the case of short-range interaction, when the direct interaction dominates, and positive in the case of long-range interaction, when the exchange term dominates.

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Anisotropy of fluctuation conductivity near the onset of localized superconductivity

S.V. Mironov and A.S. Mel'nikov
Institute for Physics of Microstructures Russian Academy of Science, Nizhniy Novgorod, Russia

We study the fluctuation Aslamazov-Larkin conductivity of planar hybrid superconductor/ferromagnet (S/F) systems. Domain structure of the ferromagnet can produce a variety of anisotropic superconducting states in the S film near the critical temperature T_c. Depending on the parameters of domain structure (namely the amplitude of the stray magnetic field H_0 perpendicular to the S film and the width of magnetic domains d) the superconductivity appears in the whole superconducting layer or in separate low-dimensional regions localized near domain walls.

We demonstrate that the similar kind of anisotropy appears even above the critical temperature due to anisotropy of the energy spectrum of fluctuating Cooper pairs. In case $H_0 = 0$ the dependence of the energy E on the momentum $\mathbf{k}$ in the plane of the S film has the standard form ($E = \hbar^2\mathbf{k}^2/4m$), and the corresponding Aslamazov-Larkin correction to the conductivity $\Delta\sigma$ is isotropic and has standard $(T - T_c)^{-1}$ singularity at the superconducting transition temperature. In case of finite but small amplitude of the stray field ($H_0 d^2 \ll \Phi_0$) the spectrum stays parabolic for low energies but the effective mass tensor becomes anisotropic, which results in the anisotropy of $\Delta\sigma$ in the plane of superconducting film: the fluctuation conductivity along domain walls exceeds the one across domain walls.

With the increasing of H_0 the magnitude of $\Delta\sigma$ anisotropy also increases and at $H_0 d^2 \approx \Phi_0$ the energy spectrum changes qualitatively: the effective mass corresponding to the momentum $k_\parallel$ along the domain walls change its sign and two minima of the energy spectrum at non-zero $k_\parallel$ appear. This results in peculiar non-monotonic dependencies of $\Delta\sigma$ components on $H_0 d^2$ at fixed temperature.

Finally for $H_0 d^2 \gg \Phi_0$ the effective mass corresponding to the momentum across domain walls tends to infinity. The corresponding fluctuation conductivity tensor becomes essentially anisotropic. In particular, the dependence of the component $\Delta\sigma_\parallel$ along domain walls on temperature reveals a crossover from standard two-dimensional $(T - T_c)^{-1}$ behavior to the one-dimensional $(T - T_c)^{-3/2}$ one, which corresponds to the formation of quasi-one-dimensional channels with enhanced fluctuations localized near domain walls. At the same time, the transversal component $\Delta\sigma_\perp \propto (T - T_c)^{-1/2}$ near the critical temperature.

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Electron States in Graphene with One-dimensional Potential Barriers and Wells: Exact and Approximate Results.

D.S. Miserev[1, 2] and M.V. Entin[1]

[1]*Institute of Semiconductor Physics, Siberian Division, Russian Academy of Sciences, Novosibirsk, 630090 Russia*
[2]*Novosibirsk State University, Novosibirsk, 630090 Russia*

Electron states in graphene with one-dimensional potential $U(x)$ are studied in the envelope approximation. Near the conic points the Hamiltonian

$$H = \sigma_x p_x + \sigma_y p_y + U(x) \tag{3}$$

is utilized. The problem is reduced to one-dimensional case of massive relativistic particles with mass p_y. The analytical solutions are found for potentials

$$U(x) = -\frac{U}{|x| + d}, \tag{4}$$

$$U(x) = F \cdot x, \tag{5}$$

$$U(x) = U \tanh\left(\frac{x}{a}\right). \tag{6}$$

The potential (4) is applicable to the problem of electronic states with a Coulomb impurity in a carbon nanotube. The rest potentials correspond to the plane graphene with p-n junction. All considered potentials are applicable as model smooth potential walls. In addition to analytically solvable problems we have studied different approximate methods for arbitrary potentials, such as the quasiclassics and the series expansion by small y-component of electron momentum p_y. It was found that the reflection probability vanishes proportionally to p_y^2. We have found wave functions, 1D subband energies, transmission and reflection probabilities and phases. Transmission probabilities give us the conductance and I-V characteristics of graphene with p-n or n-p-n junctions. In particular case of the model potential (6) the exact solution for conductance of p-n junction is

$$G = e^2 U \frac{\pi L_{-1}(2\pi a U) - 2}{8\pi^2 \sinh^2(\pi a U)}, \tag{7}$$

where $L_{-1}(x)$ - the Struve function.

Scattering phases are used for approximate determination of quantum states of a graphene strip with smooth potential walls. The potential (4) gives the Coulomb-like electron states. If d tends to zero, the ground state is

$$E_0 = p_y \left(1 - 2U^2 \log^2(p_y U d)\right), \tag{8}$$

and the rest states have double degeneracy. These results are valid for $U \ll 1$. The discrete spectrum condenses to the energy $E = p_y$. The transmission coefficient for energies $p_y - U/d < E < -p_y$ strongly oscillates, has weak energy dependence when $E > p_y$ and has no finite limit when d vanishes.

Anomaly in temperature dependence of magnetoresistance for dilute 2DEG in high mobility Si-MOSFET

Morgun L. A., Omel'yanovskiy O. E., Kuntsevich A. Yu., and Pudalov V. M.
P. N. Lebedev Physical Institute of the Russian Academy of Sciences, Moscow, Leninskiy prospekt, 53

The quantum correction to conductivity of a 2D electron gas (2DEG) due to electron-electron interaction in low parallel magnetic field is commonly considered to be $\Delta\sigma = \sigma(B,T) - \sigma(0,T) = f(F_0^\sigma)B^2/T$ in ballistic regime ($T\tau \gg 1$) and $\Delta\sigma = g(F_0^\sigma)B^2/T^2$ in diffusive regime ($T\tau \ll 1$) [1]. Here τ is elastic mean free path, f and g are some functions depending on F_0^σ where F_0^σ is the Fermi-liquid constant. The task was to investigate the behaviour of correction to conductivity of 2DEG in Si-MOSFET in parallel magnetic field in broad range of temperatures and electron concentrations and to compare the results with the theoretical predictions [1, 2].

We measured parallel field magnetoresistance $\rho(B_\parallel)$ of dilute 2D electron gas in Si-MOSFET. All the samples were fabricated in Hall-bar geometry. Resistance was measured by standard lock-in technique. Four Si samples with different electron mobilities ($\mu = 2000, 9500, 25000, 32000\, cm^2/V/s$) were investigated in temperature range $0.4 \div 20\,K$. The measurements were carried on in low-density regime with electron concentrations $0.9 \div 10 \cdot 10^{11}\, cm^{-2}$ (with critical concentration $n_c \sim 0.8 \cdot 10^{11}\, cm^{-2}$ for high-mobility samples). In low magnetic field the correction to conductivity is proportional to B^2: $\sigma(B) = \sigma(0) - a_\sigma(T,n)B^2$ (here B is in-plane magnetic field, T is temperature and n is carrier density). In our measurements $a_\sigma(T,n)$ demonstrated a kink in temperature dependence (FIG. 1), that cannot be explained by the existing theory of interaction corrections. The effect was observed for all studied high and moderate mobility samples, and is missing for low mobility ones.

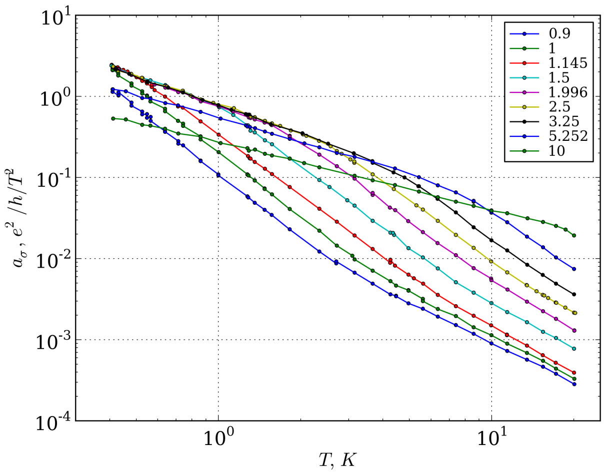

FIG. 1: Temperature dependences of $a_\sigma(T,n)$ for different carrier densities (labeled in $10^{11}\, cm^{-2}$).

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Poster session

"Probabilistic" approach to Richardson equations

W. V. Pogosov
Institute for Theoretical and Applied Electrodynamics,
Russian Academy of Sciences, Izhorskaya 13, 125412 Moscow, Russia

Bardeen-Cooper-Schrieffer theory of superconductivity is based on the reduced interaction potential, which couples only electrons with opposite spins and zero total momentum. Hamiltonians of this kind are exactly solvable [1, 2]. Namely, they lead to the Richardson equations, which are nonlinear algebraic equations for the set of complex energy-like quantities. These equations can be recovered through an algebraic Bethe-ansatz approach [3].

It is known that solutions of Richardson equations can be represented as stationary points of the "energy" of classical free charges on the plane. We suggest to consider "probabilities" of the system of charges to occupy certain states in the configurational space at the effective temperature given by the interaction constant, which goes to zero in the thermodynamical limit. It is quite remarkable that the expression of "probability" has similarities with the square of Laughlin wave function. Next, we introduce the "partition function", from which the ground state energy of the initial quantum-mechanical system can be determined. The "partition function" is given by a multidimensional integral, which is similar to Selberg integrals appearing in conformal field theory and random-matrix models. As a first application of this approach, we consider a system with the constant density of energy states at arbitrary filling of the energy interval, where potential acts. In this case, the "partition function" is rather easily evaluated using properties of the Vandermonde matrix. Our approach thus yields quite simple and short way to find the ground state energy, which is shown to be described by a single expression all over from the dilute to the dense regime of pairs. In addition, we discuss how the gap changes along such a crossover. Our method also provides new insights into the physics of Cooper-paired states. We believe that it can be extended to other Gaudin-like models.

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Superconducting fluctuations and the Berezinskii-Kosterlitz-Thouless transition in ultrathin TiN films

S. V. Postolova,[1] A. Yu. Mironov,[1] A. Glatz,[2] M. R. Baklanov,[3] V. M. Vinokur,[2] and T. I. Baturina[1,2]

[1] *A. V. Rzhanov Institute of Semiconductor Physics SB RAS, 13 Lavrentjev Avenue,630090, Novosibirsk, Russia*

[2] *Materials Science Division, Argonne National Laboratory 60439, Argonne, Illinois, USA*

[3] *IMEC Kapeldreef 75, B-3001 Leuven, Belgium*

It has long been known that in thin films the transition into a superconducting state occurs in two stages: first, with the decreasing temperature, the finite amplitude of the order parameter forms at the superconducting critical temperature T_c, second, a global phase coherent state establishes at lower temperature T_{BKT} [the temperature of the Berezinskii-Kosterlitz-Thouless (BKT) transition]. Neither of these two temperatures results in singularities in the temperature dependences of the linear resistivity $R(T)$ and determination of T_c and therefore T_{BKT} from the experimental data is a challenge. To accomplish this task we develop the approach based on the complete account of quantum contribution to conductivity using the up-to-date theory of superconducting fluctuations [1]. Juxtaposing $R(T)$ measured on TiN films with the results of the theory of quantum contributions to conductivity, we find that it describes completely all the details of $R(T)$ behavior, including its non-monotonic behavior and the significant broadening of the transition. We show that appreciable decrease in the resistance at temperatures well exceeding the superconducting transition temperature, T_c, is dominated by the Maki-Thompson process. We demonstrate that account of *all* contributions enables the precise determination of T_c which appears to lie at the very foot of the resistive curves [2].

We show that the transition to a global phase-coherent superconducting state occurs via the Berezinskii-Kosterlitz-Thouless (BKT) transition. The BKT transition is detected by the change of the shape of the I-V characteristics [3], which at the transition switches from the Ohmic behavior ($V \propto I$ at low currents) at $T > T_{BKT}$, to the low-current power-law, $V \propto I^{\alpha}$, $\alpha = 3$, behavior, accompanied by an abrupt voltage jump terminating the power-law behavior at some threshold current. The exponent α increases further upon decrease the temperature below T_{BKT} and the $I-V$ curve retains its threshold switching character. We observe The Berezinskii-Kosterlitz-Thouless (BKT) transition also by analysis of the flux flow transport in the magnetic field [4]. With increase of temperature the $R(B)$ dependences progress from positive curvature (below T_{BKT}) through linear dependence, which corresponds to the BKT transition to negative curvature (above T_{BKT}). These two techniques give a very close values of T_{BKT}. The ratio T_{BKT}/T_c follows the universal BMO-relation [5].

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Energy relaxation between the electrons of counter propagating edge channels in quantum Hall effect regime

Maria Prokudina and Vadim S. Khrapai
Institute of Solid State Physics, Russian Academy of Sciences, 142432 Chernogolovka, Russian Federation

This work represents the experimental and calculation results of nonequilibrium energy transfer between the electrons in quasi one dimensional counter propagating edge channels [1] in the integer quantum Hall effect. The pairwise electron processes are exactly prohibited for counter-propagating electrons. There are two possibilities to overcome the 1D phase-space constraints. The first one is based on three-particle interaction, combined with a non-linear dispersion[2, 3]. The other assumes some fail of momentum conservation in a small range Q of momenta [4]. We made a calculation in the frame of perturbation theory for the latter scenario. The expressions of transfer power for both Coulomb and nonequilibrium acoustic phonons scattering were obtained. The transfer energy per unit time has a threshold dependence on degree of hot channel nonequilibrium. The evaluation of transfer power for electrons in GaAs indicates Coulomb scattering domination [5]. Also we experimentally investigated the interaction between electrically isolated counter-propagating edge channels and compared calculation with the experiment.

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Spectral and power properties of long Josephson junctions as a source of broadband noise radiation

L.S. Revin,[1,2] E.A. Matrozova,[2] and A.L. Pankratov[1,2]

[1] *Institute for Physics of Microstructures of RAS, GSP-105, Nizhny Novgorod, 603950, Russia*
[2] *Laboratory of Cryogenic Nanoelectronics, Nizhny Novgorod State Technical University, Nizhny Novgorod, Russia*

At the present time for many applications including ecology and atmosphere monitoring, hi-tech and safety systems, medicine and biology, the problem of the precise analysis of multicomponent gas composites is important. For a wide variety of problems, it is necessary to perform the detection of microconcentrations of several gases simultaneously that imposes the strong requirement of sensitivity and speed of a spectrometer operation. New method of nonstationary microwave spectroscopy based on noise sources of radiation allows to realize high sensitivity, high resolution and possibility of wide range measurements simultaneously[1]. The Josephson flux flow oscillator (FFO) based on a long Nb-AlOx-Nb Josephson junction, generating the broadband signal, is a good candidate to be a radiation source for creation of a noisy spectrometer. Besides this, it is very important to have a good noisy source for calibration of mixers, such as based on SIS Josephson junctions, and for calibration of superconductive integrated receiver (SIR).

Spectral and power properties of the inline long Josephson junction operating in a flux flow regime are investigated using direct computer simulation of the sine-Gordon equation with a noise source [2]. Good agreement of simulation results with the formula for the linewidth [3] is achieved. The comparison with long Josephson junction of overlap geometry is performed. It is demonstrated that the inline junction has the linewidth which is by a factor of two larger than the overlap junction, while the oscillation power is only 1.5 times smaller. With discussion of the fundamental differences in the dynamics of the inline and overlap junctions the various behavior depending on the junction length and noise intensity has been shown [4].

The effect of various bias current profiles on the spectral linewidth of long overlap Josephson junction are investigated. It has been demonstrated that the spectral linewidth can be increased by a factor of three with the moderate reduction of emitted power [5].

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Poster session

Superconducting Heterostructure with Hybrid Magnetic Interlayer

A.E. Sheyerman, Yu.V. Kislinskii, A.V. Shadrin, G.A. Ovsyannikov, K.Y. Constantinian.
Kotelnikov Institute of Radio Engineering and Electronics Russian Academy of Sciences, Mokhovaya st., 11-7, 125009, Moscow, Russia

We present experimental data on multilayer superconducting heterostructure with hybrid interlayer exhibiting Josephson effect at mm wave frequencies. The base electrode of heterostructure was oxide d-wave superconductor $YBa_2Cu_3O_{7-\delta}$ with thickness 190 nm grown epitaxially on $NdGaO_3$ substrate by means of laser ablation. Then 8-9 nm $SrRuO_3$ and 6 nm thick $La_{0.7}Sr_{0.3}MnO_3$ layers were in situ deposited over the base electrode. The top electrode was Nb/Au bilayer (Au - 20 nm). The hybrid interlayer consists of $La_{0.7}Sr_{0.3}MnO_3$ and $SrRuO_3$ ferromagnetic films that have different directions of magnetization. The I-V curve measured at $T = 4.2$ K showed no hysteresis for a heterostructure with in-plane size 10×10 μm^2; critical current $I_C = 88\,\mu A$ and normal resistance R_N=0.16 Ω results in critical frequency $f_C = (2e/h)I_C R_N = 6.8$ GHz. Oscillating critical current and Shapiro steps with power of applied microwaves were registered. At $f_e = 41$ GHz (ratio $f_e/f_C = 6$ very well corresponds to high frequency limit) maximum of the first Shapiro step was as large as $I_1 = 94\,\mu A$. Half-integer Shapiro step was observed as well, and the maximal amplitude was $I_{1/2} = 15\,\mu A$. Taking into account the negligible small impact of heterostructure capacitance on high frequency dynamics this apparently hints at non-sinusoidal current-phase relation. Obtained results are discussed in terms of possible generation of longrange spin triplet superconducting current component at the interfaces of singlet superconductors in contacts with ferromagnetic bi-layer consisting of ferromagnetic materials with different spatial directions of magnetization.

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Electron-hole Cooper pairing in thin film of topological insulator

D.K. Efimkin,[1] Yu.E. Lozovik,[1,2] and A.A. Sokolik[1]
[1] *Institute for Spectroscopy RAS, Fizicheskaya 5, 142190, Troitsk, Moscow region, Russia*
[2] *Moscow Institute of Physics and Technology, Institutskii per. 9, 141700, Dolgoprudny, Moscow region, Russia*

Theoretical and experimental studies of topological insulators increasingly grow in recent years [1]. Strong three-dimensional topological insulators are insulating in the bulk, but have topologically protected surface electron states, described by two-dimensional Dirac equation for massless particles (similar to that for electrons in graphene).

Recent advances in fabrication of arbitrarily thin films of topological insulators (such as Bi_2Se_3) [2] suggest to use electron states on opposite surfaces of these films as realization of strongly-interacting electron-electron or electron-hole bilayers. We consider Cooper pairing of Dirac electrons and holes in a topological insulator thin film under conditions of antisymmetrical doping of its opposite surfaces (similar to electron-hole pairing in graphene bilayer [3]).

Exotic properties of superfluid condensate and vortices in such system were noticed [4], but quantitative estimates of the critical temperature of the pairing in realistic conditions have not been yet presented. We perform such estimations, going beyond simple BCS model. We take into account appearance of the gap due to hybridization of electron states on opposite surfaces of thin films and influence of this intrinsic gap on the pairing. We also consider self-consistent suppression of the screening of electron-hole Coulomb interaction due to appearance of the gap, leading to formation of exotic strongly-correlated state.

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Shot noise measurement in a GaAs transistor

E.S. Tikhonov,[1,2] V.S. Khrapai,[1] and D.V. Shovkun[1]

[1] *Institute of Solid State Physics, Russian Academy of Sciences, 142432 Chernogolovka, Russian Federation*
[2] *Moscow Institute of Physics and Technology, Dolgoprudny, 141700, Russian Federation*

Shot noise is thoroughly studied in ballistic and metallic transport regimes and experimental results are in good agreement with theoretical predictions [1]. However, in the majority of experiments concerning electron transport in insulating state, the values of Fano-factor different from a naively expected Poissonian value were observed [2, 3].

We study shot noise in a wide channel $100\mu m \times 0.2\mu m$ GaAs transistor at temperature of 0.5K.

The temperature dependance of conductance is measured for 0.5-4.2K and is close to being proportional with temperature for a range of gate voltages. The I-V curves are strongly nonlinear with $I \sim V^a$, $a \approx 2$ and close to a prediction [4] for two-impurity hops.

The shot noise spectral density S_I is measured in the range 10-20 MHz and is free from 1/f-like contribution at least above 2 MHz. The Fano-factor is found to depend on current. We measure $F = 1$ at small currents $I \sim 30nA$, where the nonlinearity is most pronounced, and observe a decrease to $F \approx 0.6$ with increasing current. To our best knowledge, this is the first experimental demonstration for Poissonian shot noise in an insulator with hoping conduction.

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Current rectification in the artificial multilayer structure containing three magnetic layers with non-coplanar magnetization distribution

O.G. Udalov

Institute for Physics of Microstructures RAS, GSP-105, Nizhny Novgorod, 603950, Russia

At now transport properties of artificial multilayer magnetic nanostructures are of great interest. One of the most known phenomena is tunnel magnetoresistance. It appears in the three layer system ferromagnet/ insulator/ferromagnet. Such structures are well investigated. At the present time systems with three magnetic layers separated by insulators are actively explored. Resonant-tunneling, Coulomb blockade, spin accumulation in the middle layer can appear in such a system. One more interesting peculiarity of the systems with three magnetic layers is possibility of realization of non-coplanar magnetization distribution. It has been recently theoretically predicted that current rectification effect appears in continuous media with non-coplanar magnetization. In the present work the rectification effect is theoretically investigated for layered magnetic structure containing three magnetic layers.

Poster session

Coexistence of superconductivity and antiferromagnetism in strong electron correlation systems with heavy fermions

Valery V. Val'kov[1, 2] and Anton O. Zlotnikov[1]

[1]*L.V. Kirensky Institute of Physics, Krasnoyarsk 660036, Russia*
[2]*Siberian State Aerospace University, Krasnoyarsk 660014, Russia*

A phase diagram of strong electron correlation systems where superconductivity competes and coexists with antiferromagnetism has been studied in the framework of the periodic Anderson model (PAM). Taking into account high-energy hybridization processes in the PAM leads to forming effective superexchange interaction in the localized electron subsystem [1]. This interaction is responsible for antiferromagnetic ordering and Cooper instability in the model. Phase transitions under pressure develop in such way that a strong competition is suggested between antiferromagnetism and superconductivity. It has been proposed that pressure increases the energy of the localized states in the PAM. Such a mechanism in the case of Ce-based heavy-fermion systems is explained by increasing Coulomb repulsion between a 4f electron of Ce ion and nearest-neighbor ions having an effective negative charge.

In spite of the competition mentioned above, conditions have been found for inducing superconductivity which coexists with antiferromagnetism up to a critical pressure where magnetic ordering is suppressed. Theoretical results of the pressure effects on the phase transitions of the heavy-fermion systems are in good agreement with experimental data for the rare-earth intermetallic compound $CeRhIn_5$ [2–4]. In the coexistence phase there occur two types of Cooper pairing due to the antiferromagnetic exchange field. It worth noting that considering quasi-bidimensional real structure of $CeRhIn_5$ is important to accurately describe the phase diagram. The divergence of the effective electron mass produced by suppressing long-range antiferromagnetic order has also been analyzed in the same framework. Further it has been shown that at the quantum critical point there occurs the transition from small to large Fermi surface. Such features have been found in different experiments for $CeRhIn_5$ [5, 6].

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EPR lanthanum manganite $(La_{0,5}Eu_{0,5})_{0,7}Pb_{0,3}MnO_3$

S.B. Zikirin,[1] D.V. Stass,[1] O.N. Martyanov,[2] and S.N. Trukhan[2]

[1]*Institute of Chemical Kinetics and Combustion,*
Siberian Branch of Russian Academy of Sciences, Novosibirsk, Rusia
[2]*Boreskov Institute of Catalysis, Siberian Branch of Russian Academy of Sciences, Novosibirsk, Rusia*

Substituted manganites of $R_xA_{1-x}MnO_3$ (where "R" is a trivalent rare-earth ion, for example, La^{3+}, Eu^{3+}, “A” is a divalent ion, for example, Ca^{2+}, Pb^{2+}) are the object of intensive research because of their complex phase diagram and physical properties, sensitive to external influences, such as magnetic and electric fields, heating or cooling. Colossal magnetoresistance observed in these materials makes them promising materials for applications.

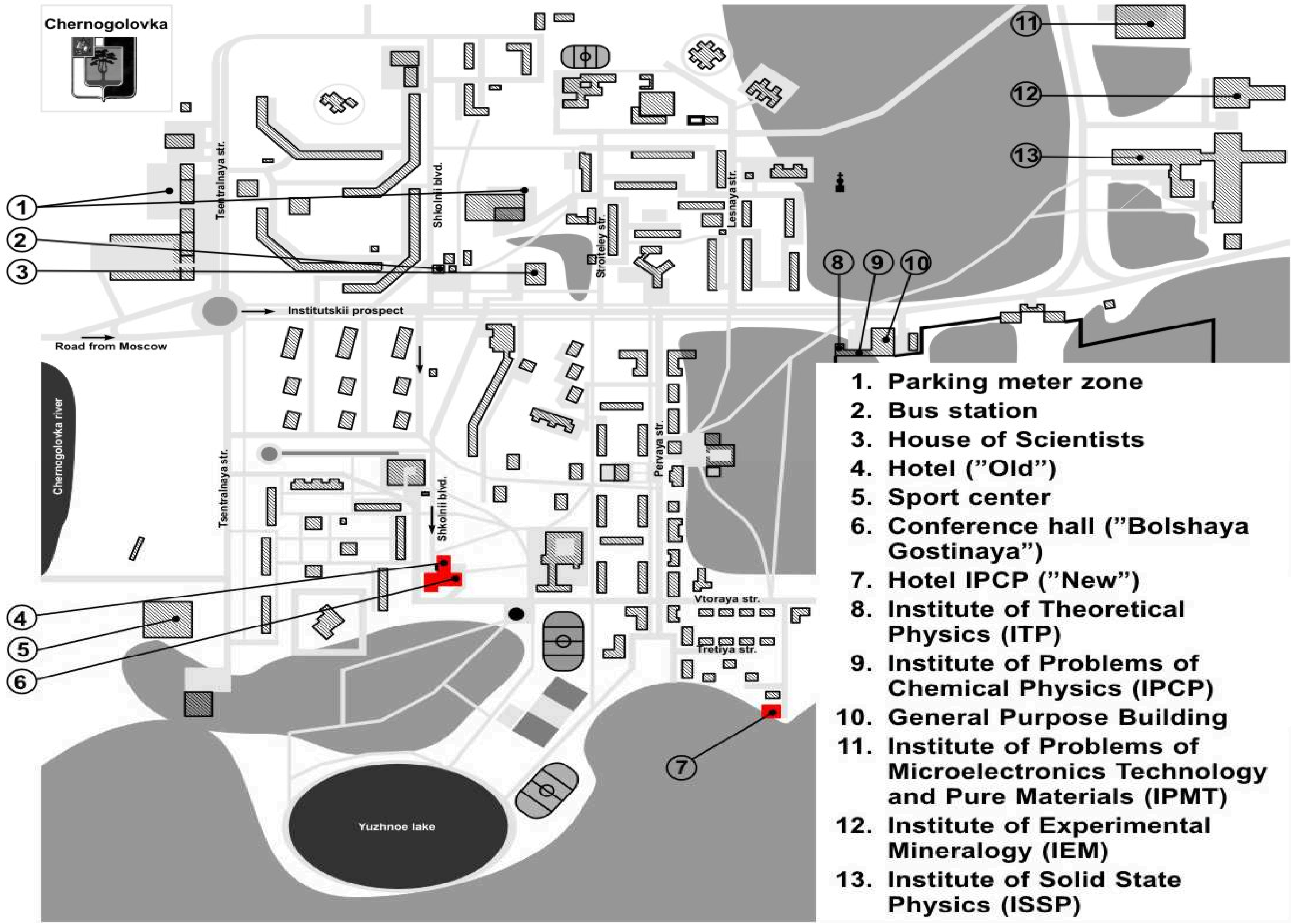
We have studied lanthanum manganite composition $(La_{0,5}Eu_{0,5})_{0,7}Pb_{0,3}MnO_3$. Dependences on temperature of electron paramagnetic resonance spectra were registered. Analyzing the dependence of the form of the EPR spectra on temperature, shows that double integral and the line width of the EPR spectrum in the form of the first derivative of the absorption line changed on heating or cooling. Because the form of the EPR spectrum and its temperature transformation, we can conclude that the magnetic system is a mix of two magnetic subsystems - ferromagnetic and paramagnetic. At temperatures above the phase transition point (above the Curie point - in the paramagnetic region), the line width increases with increasing temperature. This behavior of the linewidth can serve as proof that the conductivity of the sample can be explained in the framework of the polaron hopping transport.

List of participants

p. 12	Dmitry Abanin	Harvard Univ., USA	dabanin@princeton.edu
p. 37	Sergey Aksenov	Kirensky IP, Krasnoyarsk, Russia	asv86@iph.krasn.ru
p. 8	Yoichi Ando	Osaka Univ., Japan	y_ando@sanken.osaka-u.ac.jp
p. 29	Anne Anthore	Univ. Paris Diderot, France	anne.anthore@lpn.cnrs.fr
p. 38	Marsel Arifullin	Orenburg Univ., Russia	arifullinm@mail.ru
p. 15	Peter Armitage	Johns Hopkins Univ., USA	npa@pha.jhu.edu
p. 25	Oleg Astafiev	NEC, Tsukuba, Japan	astf@zb.jp.nec.com
p. 38	Sergey Bakurskiy	Moscow State Univ., Russia	r3zz@mail.ru
p. 11	Helene Bouchiat	Univ. Paris-Sud, Orsay, France	helene.bouchiat@u-psud.fr
p. 14	Vincent Bouchiat	Neel Inst., Grenoble, France	vincent.bouchiat@grenoble.cnrs.fr
p. 6	Hartmut Buhmann	Univ. of Würzburg, Germany	hartmut.buhmann@physik.uni-wuerzburg.de
p. 13	Igor Burmistrov	Landau ITP, Russia	burmi@itp.ac.ru
p. 39	Angelina Burmistrova	Moscow State Univ., Russia	burangelina@yandex.ru
p. 13	Claude Chapelier	CEA, Grenoble, France	claude.chapelier@cea.fr
p. 7	Joseph Checkelsky	RIKEN, Wako, Japan	joe.checkelsky@gmail.com
p. 15	Tristan Cren	Univ. P. et M. Curie, Paris, France	tristan.cren@insp.jussieu.fr
p. 26	Richard Deblock	Univ. Paris-Sud, Orsay, France	deblock@lps.u-psud.fr
p. 28	Matthieu Delbecq	ENS, Paris, France	matthieu.delbecq@lpa.ens.fr
p. 18	Eugene Demler	Harvard Univ., USA	demler@physics.harvard.edu
p. 40	Marina Denisenko	N. Novgorod State Univ., Russia	mar.denisenko@gmail.com
	Igor Devyatov	Moscow State Univ., Russia	igor-devyatov@yandex.ru
	Mathias Diez	Leiden Univ., The Netherlands	diez@lorentz.leidenuniv.nl
p. 35	Sergey Dorozhkin	ISSP, Chernogolovka, Russia	dorozh@issp.ac.ru
p. 40	Dmitry Efimkin	I of Spectroscopy, Troitsk, Russia	mitruga@yandex.ru
p. 32	Lara Faoro	Univ. Paris 6 et 7, France	faoro@physics.rutgers.edu
	Kirill Fedorov	KIT, Karlsruhe, Germany	kirill.fedorov@kit.edu
p. 19	Alexander Finkelstein	Weizmann Inst., Israel	Lwalfn@wisemail.weizmann.ac.il
p. 31	Yuri Galperin	Oslo Univ., Norway	iouri.galperine@fys.uio.no
	Oleksandr Gamayun	Bogolubov ITP, Kiev, Ukraine	oleksandr.ludimagister@gmail.com
p. 41	Yaroslav Gerasimenko	Lebedev PI, Moscow, Russia	gyaroslav@sci.lebedev.ru
p. 25	M. Gershenson	Rutgers Univ., USA	gersh@physics.rutgers.edu
p. 41	Tatiana Golikova	ISSP, Chernogolovka, Russia	golt2@list.ru
p. 42	Vladimir Gurtovoi	IMT, Chernogolovka, Russia	gurtovoi@iptm.ru
p. 42	Dennis Heim	Ulm Univ., Germany	dennis.heim@uni-ulm.de
p. 43	Karen Hovhannisyan	Yerevan Phys. Inst., Armenia	kavahox@gmail.com
p. 36	Shahal Ilani	Weizmann Inst., Israel	shahal.ilani@weizmann.ac.il
p. 27	Evgeni Il'ichev	I of Phot. Tech., Jena, Germany	evgeni.ilichev@ipht-jena.de
p. 36	Lev Ioffe	Rutgers Univ., USA	ioffe@physics.rutgers.edu
p. 23	Pavel Ioselevich	Landau ITP, Russia	piossel@gmail.com
p. 14	Dmitri Ivanov	ETH Zurich, Switzerland	ivanov@alum.mit.edu
p. 34	Valentin Kachorovskii	Ioffe Inst., St.-Petersburg, Russia	kachor.valentin@gmail.com
	Sergey Kafanov	RIKEN, Tsukuba, Japan	sergey.kafanov@gmail.com
p. 43	David Kalok	Weizmann Inst., Israel	David.Kalok@weizmann.ac.il
	Peter Karpov	MISIS, Moscow, Russia	kar-pi@mail.ru

	Andrey Katanin	IMP, Ekaterinburg, Russia	katanin@mail.ru
p. 44	Ivan Khaymovich	IPM, N. Novgorod, Russia	ivan.khaymovich@gmail.com
p. 30	Alexei Kitaev	Caltech, USA	kitaev@cs.caltech.edu
p. 45	Elio König	KIT, Karlsruhe, Germany	elio.koenig@kit.edu
p. 45	Oleg Kotov	I of Spectroscopy, Troitsk, Russia	kotov-o-v@mail.ru
p. 46	Tatiana Krishtop	Kotel'nikov IRE, Moscow, Russia	tatiana.krishtop@gmail.com
	Alexander Kuntsevich	Lebedev PI, Moscow, Russia	alexkun@lebedev.ru
p. 7	Dmitry Kvon	Rzhanov ISP, Novosibirsk, Russia	kvon@thermo.isp.nsc.ru
p. 9	Yuri Latyshev	Kotel'nikov IRE, Moscow, Russia	yurilatyshev@yahoo.com
p. 9	Michael Levin	Univ. of Maryland, USA	malevin@umd.edu
p. 9	Leonid Levitov	MIT, USA	levitov@mit.edu
	Mahmood Mahmoodian	Rzhanov ISP, Novosibirsk, Russia	mahmood@isp.nsc.ru
	Pavel Maksimov	MIPT, Dolgoprudny, Russia	pavelmax@mail.ru
p. 11	Vladimir Manucharyan	Harvard Univ., USA	manuchar@fas.harvard.edu
p. 26	Robert McDermott	Univ. of Wisconsin, USA	rfmcdermott@wisc.edu
p. 24	Alexander Mel'nikov	IPM, N. Novgorod, Russia	melnikov@ipm.sci-nnov.ru
p. 36	Karen Michaeli	MIT, USA	karenmic@mit.edu
p. 47	Sergey Mironov	IPM, N. Novgorod, Russia	sermironov@rambler.ru
p. 48	Dmitry Miserev	Rzhanov ISP, Novosibirsk, Russia	erazorheader@gmail.com
	Roman Morari	IEEN, Chisinau, Moldova	morari.roman@gmail.com
p. 49	Leonid Morgun	Lebedev PI, Moscow, Russia	morgunl@gmail.com
	Andrey Mostovov	SEA Saclay, Paris, France	andrey.mostovov@cea.fr
p. 35	Pavel Ostrovsky	MPI FKF, Stuttgart, Germany	ostrov@tkm.uni-karlsruhe.de
	Andrey Pankratov	IPM, N. Novgorod, Russia	alp@ipm.sci-nnov.ru
p. 16	Yuri Pashkin	NEC, Tsukuba, Japan	pashkin@zp.jp.nec.com
p. 16	Jukka Pekola	Aalto Univ., Finland	jukka.pekola@aalto.fi
p. 50	Walter Pogosov	ITAE, Moscow, Russia	walter.pogosov@gmail.com
p. 51	Svetlana Postolova	Rzhanov ISP, Novosibirsk, Russia	svet.postolova@gmail.com
p. 52	Maria Prokudina	ISSP, Chernogolovka, Russia	musek@yandex.ru
p. 20	Charis Quay	Univ. Paris-Sud, Orsay, France	quay@lps.u-psud.fr
p. 53	Leonid Revin	IPM, N. Novgorod, Russia	rls@ipm.sci-nnov.ru
p. 34	Michael Reznikov	Technion, Haifa, Israel	misha.reznikov@gmail.com
	Yaroslav Rodionov	ITAE, Moscow, Russia	yaroslav.rodionov@gmail.com
p. 28	Clemens Rössler	ETH Zurich, Switzerland	roessler@phys.ethz.ch
p. 17	Mark Rudner	Ohio State Univ., USA	mark.s.rudner@gmail.com
p. 22	Valery Ryazanov	ISSP, Chernogolovka, Russia	ryazanov@issp.ac.ru
p. 8	Benjamin Sacépé	Neel Inst., Grenoble, France	benjamin.sacepe@grenoble.cnrs.fr
	Denis Savinov	IPM, N. Novgorod, Russia	savinovda@ipm.sci-nnov.ru
p. 31	Maksym Serbyn	MIT, USA	serbyn@mit.edu
p. 30	Dan Shahar	Weizmann Inst., Israel	dan.shahar@gmail.com
p. 54	Alexander Sheyerman	Kotel'nikov IRE, Moscow, Russia	s_shdsdh@mail.ru
	Anastasia Shcherbakowa	KIT, Karlsruhe, Germany	anastasia.shcherbakowa@kit.edu
p. 17	Alexander Shtyk	Landau ITP, Russia	shtyk@itp.ac.ru
	Kirill Shulga	MIPT, Dolgoprudny, Russia	zanzius@mail.ru
p. 11	Vitaly Shumeiko	Chalmers Univ., Sweden	vitaly.shumeiko@chalmers.se
p. 25	Alessandro Silva	ICTP, Trieste, Italy	asilva@ictp.it
	Olga Skryabina	ISSP, Chernogolovka, Russia	ropundel@mail.ru

p. 22	Mikhail Skvortsov	Landau ITP, Russia	skvor@itp.ac.ru
p. 33	Jurgen Smet	MPI FKF, Stuttgart, Germany	j.smet@fkf.mpg.de
p. 10	Marieke Snelder	Univ. of Twente, The Netherlands	M.Snelder@utwente.nl
p. 54	Alexey Sokolik	I of Spectroscopy, Troitsk, Russia	aasokolik@yandex.ru
	Vasiliy Stolyarov	ISSP, Chernogolovka, Russia	vasiliy@travel.ru
p. 21	Lenar Tagirov	Kazan Univ., Russia	ltagirov@mail.ru
p. 10	Yukio Tanaka	Nagoya Univ., Japan	ytanaka@nuap.nagoya-u.ac.jp
p. 55	Evgeniy Tikhonov	ISSP, Chernogolovka, Russia	jenek.t@mail.ru
p. 19	Konstantin Tikhonov	Landau ITP, Russia	tikhonov.konstantin@gmail.com
p. 55	Oleg Udalov	IPM, N. Novgorod, Russia	udalov@ipmras.ru
p. 27	Alexey Ustinov	KIT, Karlsruhe, Germany	ustinov@physik.uni-karlsruhe.de
p. 56	Valery Val'kov	Kirensky IP, Krasnoyarsk, Russia	vvv@iph.krasn.ru
	Vladimir Vanovsky	MIPT, Dolgoprudny, Russia	vovici@gmail.com
	Denis Vodolazov	IPM, N. Novgorod, Russia	vodolazov@ipm.sci-nnov.ru
p. 23	Hong Yao	Stanford Univ., USA	hyao@stanford.edu
p. 33	Andrea Young	MIT, USA	afy@mit.edu
p. 56	Samat Zikirin	ICKC, Novosibirsk, Russia	zikirin@gmail.com
p. 12	Maciej Zgirski	Inst. of Phys., Warsaw, Poland	zgirski@ifpan.edu.pl



1. Parking meter zone
2. Bus station
3. House of Scientists
4. Hotel ("Old")
5. Sport center
6. Conference hall ("Bolshaya Gostinaya")
7. Hotel IPCP ("New")
8. Institute of Theoretical Physics (ITP)
9. Institute of Problems of Chemical Physics (IPCP)
10. General Purpose Building
11. Institute of Problems of Microelectronics Technology and Pure Materials (IPMT)
12. Institute of Experimental Mineralogy (IEM)
13. Institute of Solid State Physics (ISSP)