LOCALIZATION AND QUANTUM CHAOS

L-1 Energy excitations in localized electron systems and glasses

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Low energy excitations in a localized electron system are dipolar pares, involving neighboring occupied and unoccupied states. We consider the effect of the $1/r^3$ dipole coupling on these excitations. The problem at $T = 0$ has two equally important aspects: wavefunction delocalization and Efros-Shklovskii anomaly in the density of states at $E = 0$.

The $1/r^3$ coupling leads to wavefunction delocalization. However, since the coupling character is marginal, the resulting states are critical. Their scaling is characterized by fractal exponent of $P_4 \propto V^{-\alpha}$, with α smaller than the space dimension. Scaling of the states can be studied by a real space RG, leading to an RG flow of the distribution of coupling parameters characterized by a family of non-trivial fix points. Scaling of P_4 is sensitive to the nature of the RG fix point. For some fix points, the scaling is characterized by a distribution of exponents α, rather than by a single exponent.

The RG method can be generalized to treat the problem of interacting two-level systems. Besides couplings, in this problem the RG flow includes the density of states. The density of states is renormalized so that it develops a singularity near zero energy. Depending on the character of interaction the density of states is either suppressed in an Efros-Shklovskii fashion, or develops a peak.

Correspondingly, thermal conductivity exists at $T = 0$ due to a purely electron mechanism even at strong disorder, whereas charge excitations remain localized. In this regime, electron assisted hopping conductivity is possible at finite T. Estimates of these effects will be discussed.

L-2 Propagation of waves in disordered nonlinear media

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We show that the sensitivity of the wave speckle pattern in disordered non-linear media to changes of scattering potential increases with sample size. For large enough sample size this quantity diverges, which implies that at given coherent wave incident on a sample there are multiple solutions for the spacial distribution of the wave's density. The number of solutions increases exponentially with the sample size.

L-3 Chaotic Quantum Transport in Superlattices and Periodic Optical Potentials

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We report a new type of quantum chaotic system in which the classical Hamiltonian originates from the intrinsically quantum mechanical nature of the device. The system is a semiconductor superlattice in a magnetic field. The energy-momentum dispersion curves can be used to calculate semiclassical orbits for electrons confined to a single miniband. When a magnetic field is applied along the superlattice axis (x-direction), the electrons perform Bloch oscillations along the axis with cyclotron motion in the orthogonal plane. But when the magnetic field is tilted away from the x-direction, the orbits are chaotic, and have a spatial width along the superlattice axis, which is much larger than the amplitude of the Bloch oscillations. This is because the tilted field transfers momentum between the x- and z-directions, thereby delocalizing the electron path. This type of chaotic dynamics is *fundamentally different* to that identified in our previous studies of double-barrier resonant tunnelling diodes [1–3]. We investigate the relation between the orbits of the effective Hamiltonian, and the quantum states of the superlattice. In the regime of strong chaos, the wavefunctions have a highly diffuse structure which extends across many periods of the superlattice, just like the corresponding classical orbits. This chaos-induced delocalization increases the current flow through real devices. By contrast, in the stable domain the electron orbits remain localized along the paths of particular quasi-periodic orbits. We use theoretical and experimental current-voltage curves to show how the onset of chaos manifests itself in the transport properties of two and three-terminal superlattice structures, and identify current oscillations associated with classical resonances. We also consider analogies with ultra-cold atoms in an optical lattice with a tilted harmonic trap [4].

[1] P.B. Wilkinson *et al.*, Nature **380**, 608 (1996).
[2] T.M. Fromhold *et al.*, Phys. Rev. Lett. **75**, 1142 (1995).
[3] T.M. Fromhold *et al.*, Chaos, Solitons & Fractals **8**, 1381 (1997).
[4] T.M. Fromhold *et al.*, Journal of Optics B, to be published in October 2000.

L-4 Hot-electron effects in two-dimensional hopping with a large localization length

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We have studied nonlinear effects in the conductivity of a two-dimensional system with a large localization length (delta-doped GaAs structures) on both sides of the crossover from weak to strong localization. It is shown that nonlinearity in the hopping regime is due to electron overheating rather than the field effects. This qualitatively new behavior is a signature of a two-dimensional hopping transport with a large localization length. The hot-electron nonlinearity suggests that electron transport in the hopping regime is controlled by the electron temperature, and that the electron-electron interactions play an important role in hopping with a large localization length.

L-5 Shallow Coulomb Gap and Weak Level-Level Correlations in a Deeply Insulating Electron System with Interactions

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We consider [1] a system of two-dimensional electrons strongly localized by disorder. Interactions create a gap in the *average* tunneling density of states $\nu(E)$ at energies, E, close to the Fermi level. We derive a system of self-consistent equations for the correlators of *local* densities of occupied and empty states. When either the interactions are screened by the gate or the temperature, T, is high enough, so that the Coulomb gap is shallow, the perturbative solution of the system yields analytical expressions for the interaction-induced correction $\delta\nu(E)$ and the level-level correlator. We show that even with short-range interactions, $\delta\nu(E)$ exhibits a singular energy dependence at $T = 0$. We also demonstrate that at high T this energy dependence is a *universal* function of the the ratio E/T. Regarding the level correlations, we trace how the correlator falls off as a function of spatial and energy separation between the levels. We also trace how the correlations vanish with increasing T. Our most noticeable observation is that for two close energies the correlator changes sign from positive (attraction) at small distances to negative (repulsion) at large distances.

[1] Ya. M. Blanter and M. E. Raikh, cond-mat/0004327.

L-6 'Aging' in Anderson insulators – the role of interactions

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Field-effect measurements in Anderson insulating indium-oxide films exhibit a glassy behavior, such as 'aging' and other memory effects. For samples with small carrier concentration, the dynamics of the system becomes considerably faster, and the memory tends to disappear. This is interpreted as an indication for the importance of interactions to the relaxation process and to the memory effects.

L-7 Order, disorder and chaos in 2D lattice of coupled Sinai billiards

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Transport properties of a new kind of ballistic electron billiards – 2D lattice of Sinai billiards coupled through quantum point contacts – are experimentally studied. This lattice is peculiar by simultaneous existence of the effects inherent to single Sinai billiards or quantum dots, and the features reflecting lattice properties of system. Magnetotransport measurements give very pronounced commensurability peak even if the conductivity of the lattice $G \ll e^2/h$. Consequently it preserves the properties of ballistic regular structure at these conductivity states. On the other hand, the gate voltage dependencies of G show that the system behaves as percolation one. In weak magnetic fields negative magnetoresistance (NMR) is observed. It is described by theory of chaotic weak localization developed for case of single ballistic cavity. This NMR increases in going from $G > e^2/h$ to $G \ll e^2/h$. Thus, 2D lattice of coupled Sinai billiards is a unique system where coexistence of order, disorder and chaos are clearly demonstrated.

L-8 Multifractality and critical fluctuations at the Anderson transition

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Critical fluctuations of wave functions and energy levels at the Anderson transition are studied for the family of the critical power-law random banded matrix ensembles. It is shown that the distribution functions of the inverse participation ratios (IPR) P_q are scale-invariant at the critical point, with a power-law asymptotic tail. The IPR distribution, the multifractal spectrum and the level statistics are calculated analytically in the limits of weak and strong multifractality. The analytical results are supported and complemented by numerical simulations.

[1] F. Evers, A.D. Mirlin, Phys. Rev. Lett. **84**, 3690 (2000).
[2] A.D. Mirlin, F. Evers, cond-mat/0003332.

L-9 Spin, spin-orbit, and valley coupling in 2D electron system through the metal-insulator transition

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The existing data on the spin (and iso-spin) properties of 2D carriers will be reviewed and their relevance and irrelevance to the anomalous 'metallic' conduction will be analyzed. The data on the spin and spin-orbit properties include (i) strong magnetoresistance in parallel magnetic field, (ii) its weak anisotropy with respect to the current direction on the (100) plane, (iii) spin-splitting in strong perpendicular magnetic field, (iv) modulation of the Shubnikov-de Haas oscillations at high electron density, and (v) quantum interference suppression in a weak perpendicular field. For valley coupling, the data include valley splitting at high carrier density and in strong perpendicular magnetic field and valley splitting at low density and low field.

The data reveal the domains where quantum, semiclassical, and interaction effects dominate on the phase diagram of the 2D anomalous 'metallic' state.

L-10 Antilocalization in a 2D Electron Gas in a Random Magnetic Field

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We construct a supersymmetric field theory for the problem of a two-dimensional electron gas in a random, static magnetic field. We find a new term in the free energy, additional to those present in the conventional unitary σ-model, whose presence relies on the long-range nature of the disorder correlations. Under a perturbative renormalization group analysis of the free energy, the new term contributes to the scaling function at one-loop order and leads to antilocalization.

$\boxed{\text{L-11}}$ Density of states near the Anderson transition in $(4-\epsilon)$-dimensions

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The calculation of the density of states for the Schrödinger equation with a Gaussian random potential is equivalent to the problem of a second-order transition with a "wrong" sign of the coefficient of the quartic term in the Ginzburg–Landau Hamiltonian. The special role of the dimension $d = 4$ for such Hamiltonian can be seen from different viewpoints but fundamentally is determined by the renormalizability of the theory. Construction of ϵ-expansion in direct analogy with the phase transitions theory gives rise to a problem of a "spurious" pole. To solve this problem, the proper treatment of the factorial divergency of the perturbation series is necessary. In $(4-\epsilon)$- dimensional theory the terms of the leading order in $1/\epsilon$ should be retained for $N \sim 1$ (N is an order of the perturbation theory) while all degrees of $1/\epsilon$ are essential for large N in view of the fast growth of their coefficients. The latter are calculated in the leading order in N from the Callan–Symanzik equation with results of Lipatov method using as boundary conditions. The qualitative effect consists in shifting of the phase transition point to the complex plane. This results in elimination of the "spurious" pole and in regularity of the density of states for all energies.

QHE-1 Quantum Hall effect for interacting electrons

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We propose a unifying theory for both the integral and fractional quantum Hall regimes. This theory combines the Finkelstein approach to localization and interaction effects with the topological issues of an instanton vacuum and Chern-Simons gauge theory. We elaborate on the microscopic origin of the effective action and unravel a new symmetry in the problem with Coulomb interactions, the F-invariance.

We report the results of a detailed renormalization group analysis and establish the renormalizability of the Finkelstein action to two loop order. We show that the infrared behavior of the theory can be extracted from F-invariant quantities only. For these quantities (conductivity, specific heat) we derive explicite scaling functions.

We compute the responce of the theory to electromagnetic perturbations and Chern-Simons mapping of conductances to one loop order. We also discuss the consequences of the theory for the strong coupling, insulating regime.

QHE-2 Magnetooptics of Composite Fermions

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The Fermi energy and the Zeeman splitting of composite fermions (CFs) are measured from the temperature dependence of the electron spin polarization at $\nu = 1/2$. We demonstrate that the Zeeman splitting of CFs is enhanced by a factor of 2.5 due to the interaction between CFs. The latter is very sensitive on the finite width of the 2D-channel. In is demonstrated that the degree of electron spin polarization measured at $\nu = 1/3$ and $\nu = 2/3$ fractional states displays activated behavior. The observed behavior enables first direct measurement of the spin-wave energy gaps, which were compared with simultaneously measured transport values.

QHE-3 Magnetocapacitance study of 2DEG with long-range potential fluctuations

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We report on magnetocapacitance study of the quantum Hall effect (QHE) states. Capacitance minima width was found to be independent of magnetic field and to be the same for even, odd and fractional QHE states when measured as a function of the average electron density. This result indicates that the width of capacitance minima in the samples investigated are governed by long-range carrier density fluctuations. At low temperatures, amplitude of the minima decreases linearly with the temperature increase. Our experimental results for the integer QHE states are quantitatively explained by introducing unbroadened magnetic levels and dispersion of the electron density along the sample. The energy gaps at even filling factors obtained from fitting experimental data are found to be close to the known cyclotron gaps. At odd fillings $\nu = 1$, 3, and 5, the energy gaps appear to be enhanced in comparison with the Zeeman splitting, with the enhancement decreasing with magnetic level number.

The capacitance minima are argued to originate from the motion of incompressible regions along a sample caused by the gate voltage variation. We derive the condition for the appearance and motion of such regions for the case of gated samples with long-range fluctuations of charged donors.

The appearance of narrow magnetocapacitance peaks when a dc current is passed through the sample is reported. We hypothize that these peaks are due to the current percolation along incompressible strips.

QHE-4 Tunneling measurements of the Coulomb pseudogap in a two-dimensional electron system in a quantizing magnetic field

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We study the Coulomb pseudogap for tunneling into the two-dimensional electron system of high-mobility (Al,Ga)As/GaAs heterojunctions subjected to a quantizing magnetic field at filling factor $\nu \leq 1$. Tunnel current-voltage characteristics show that for the double maximum observed in the tunnel resistance at $\nu \approx 1$ the pseudogap is linear in energy with a slope that depends on filling factor, magnetic field, and temperature. We give a qualitative account of the filling factor dependence of the pseudogap slope and we confirm the recently reported appearance of another relaxation time for tunneling at $\nu \approx 1$. For the tunnel resistance peaks at $\nu = 1/3$ and $2/3$ a completely different behaviour of the current-voltage curves is found and interpreted as manifestation of the fractional gap.

QHE-5 Phase diagram and Skyrmion energy gap for bilayer heterostructures at integer filling factors

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Phase diagram of a bilayer heterostructure in the regime of the Quantum Hall effect at integer filling factors was established using the hidden symmetry method. Three phases: ferromagnetic, canted antiferromagnetic and spin-singlet, have been found. We confirm early results of Das. Sarma et al [1]. Each phase violates the $SU(4)$ hidden symmetry and is stabilized by the anisotropy interactions.

Our new results concern topological excitations in bilayers. We find that low-energy physics of the bilayer is governed by the $U(4)/U(\nu) \otimes U(4-\nu)$ coset non-linear Sigma Model. We identify charged excitations of the bilayer with skyrmions or topological excitations of this non-linear Sigma Model. We calculate the skyrmion energy gap to vary dramatically over the bilayer parameter space and we find a sharp dip of this gap in the canted antiferromagnetic phase of the bilayer. We compare the calculated skyrmion energy gap with the diagonal conductivity activation energy reported in recent experiment [2].

[1] S. Das Sarma, S. Sachdev and L. Zheng, Phys. Rev. Lett. **79**, 917 (1997).
[2] V. S. Khrapai et al., Phys. Rev. Lett. **84**, 729 (2000).

QHE-6 Quasiclassical memory effects: Anomalous transport properties of two-dimensional electrons and composite fermions subject to a long-range disorder

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We have studied the *ac* response and magnetoresistance of a two-dimensional electron gas in high-mobility samples in the presence of a smooth disorder. We have found that the low-ω behavior of the *ac* conductivity $\sigma(\omega)$ is governed by memory effects associated with return processes that are neglected in Boltzmann transport theory: the return-induced correction to $\mathrm{Re}\,\sigma$ exhibits a kink $\propto |\omega|$. This effect is of a quasiclassical origin and dominates (as compared to the quantum corrections $\propto \ln \omega$) in a wide frequency range, provided $k_F d \gg 1$, where k_F is the Fermi wave vector, d the correlation radius of disorder. The quasiclassical zero-ω anomaly is shown to be strongly enhanced in a strong magnetic field, within the framework of the composite-fermion (CF) theory of a half-filled Landau level. The prefactor of the $|\omega|$ term scales as d/l (l is the mean free path) for particles scattered by a random magnetic field and as $(d/l)^2$ in the case of scalar disorder. It is shown that the non-Markovian quasiclassical kinetics leads to a strong magnetoresistance $\Delta\rho_{xx}$. Again, the effect is more strongly pronounced for CFs. We argue that these memory effects account for the positive $\Delta\rho_{xx}$ observed at small deviations from half-filling. At a larger deviation, the positive magnetoresistance is followed by a sharp falloff of ρ_{xx}.

QHE-7 Shot Noise measurements of a fractional charge

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I'm going to briefly review the present understanding of the shot noise in mesoscopic systems. Than I will discuss the shot noise measurements in the Quantum Point Contact (QPC) imbeded into a Two Dimensional Electron Gas (2DEG) both in zero and in high magnetic field. I will discuss measurements of the quasiparticle charge in the high magnetic field when the 2DEG is under the conditions of the fractional quantum Hall (FQH). For the case when 1/3 (1/5) channel is weakly back scattered the charge happens to be $e/3$ [1,2] and $(e/5)$ [3] respectively. I will also discuss what happens in the transition region from the week to the strong back scattering.

[1] De Picciotto, R. et al., "Direct observation of a fractional charge", Phys. B 249-251, 395-400 (1998).
[2] Saminadayar, L., Glattli D. C., Jin, Y. and Etienne, B., "Observation of the e/3 fractionally charged Laughlin quasiparticles", Phys. Rev. Lett. 79, 2526-2529 (1997).
[3] Reznikov, M,. de Picciotto, Griffiths, R, T. G., Heiblum, M., and. Umansky, V., "Observation of a Fifth of the Electron Charge", Nature, v. 399, pp 238-240, 1999.

QHE-8 Imaging of localized states in the quantum Hall effect

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The concept of electron localization has long been accepted to be essential to the physics of the quantum Hall effect. The exact quantization of the Hall resistance and the zero of the diagonal resistance over a range of filling factors close to integral are attributed to the localization of electronic states at the Fermi level in the interior of a two-dimensional electron gas. As the electron density is changed, charging of the individual localized states may occur by single-electron jumps, causing associated oscillations in the local electrostatic potential. Here we search for such a manifestation of localized states in the QH regime, using a scanning single-electron transistor probe. We do observe localized potential signals, at numerous locations, that oscillate with changing density. Generally, the corresponding spatial patterns are complex, but often well-defined objects are seen which evidently arise from individual localized states. These objects interact, and at times form a lattice-like arrangement.

QHE-9 Electrons on Edge

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First, a simple theory of an electron state localized at the end of a one-dimensional system inside an energy gap is presented. Then, the results are applied to describe the following cases:

- Chiral edge states in the quantum Hall regime of the quasi-one-dimensional organic conductors $(TMTSF)_2X$
- Midgap Andreev bound states in the triplet superconducting state of $(TMTSF)_2X$
- Chiral edge states and spin quantum Hall effect in the triplet superconductor Sr_2RuO_4

Various experiments are proposed to detect the edge electron states. Relations to

- Solitons in polyacetylene
- Midgap Andreev bound states in *d*-wave cuprate superconductors
- Edge states in graphite and carbon nanotubes

are briefly discussed.

MINITALKS

M-1 Diffusive single and multiply connected SNS systems with high-transparent interfaces

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We present low-temperature transport measurements on single and multiply connected SNS systems fabricated on the basis of superconducting polycrystalline PtSi film. Zero bias anomaly (ZBA) and subharmonic energy gap structure (SGS) originating from the proximity effects and the multiple Andreev reflections were observed and carefully studied. It was found that the ZBA is not described by any theories developed for SNS junctions with high-transparent NS interface. The value of excess conductance and the width of ZBA for single SNS junction far exceed values predicted by up-to-date theories.

The NS interfaces of our SNS junctions are really high-transparent, for superconducting and normal metal parts are made of the same material. On the other hand, as we have to deal with long diffusive SNS junctions one might expect that impurities could provide the conditions for incoherent multiple Andreev reflections.

In comparison with single SNS junctions we observe significant narrowing of the ZBA in multiply connected SNS systems: one-dimensional (1D) and two-dimensional arrays (2D) of SNS junctions. In 2D arrays an appreciable SGS appears, with up to $n = 16$ ($eV = \pm 2\Delta/n$) and some numbers lost. One of the most interesting results obtained on 1D arrays consists in the appearance of symmetrical dips on the dependences $dV/dI - V$ at dc voltage corresponding to $6\Delta/e$. Unlike the PtSi films, where at $T > T_c$ the conductance is mainly determined by the contribution from superconducting fluctuations, in the two-dimensional arrays of SNS junctions the transition from 2D logarithmic weak localization behavior to metallic one has been observed.

M-2 Noise of entangled electrons: Bunching and antibunching

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Addressing the feasibility of quantum communication with entangled electrons in an interacting many-body environment, we propose an interference experiment using a scattering set-up with an entangler and a beam splitter. It is shown that, due to electron-electron interaction, the fidelity of the entangled singlet and triplet states is reduced by z_F^2 in a conductor described by Fermi liquid theory. We calculate the quasiparticle weight factor z_F for a two-dimensional electron system. The current noise for electronic singlet states turns out to be enhanced (bunching behavior), while it is reduced for triplet states (antibunching). Within standard scattering theory, we find that the Fano factor (noise-to-current ratio) for singlets is twice as large as for independent classical particles and is reduced to zero for triplets.

[1] cond-mat/9906071 (to appear in PRB Rapid Comm., June 2000).

M-3 Electron correlations and hopping in a quantum dot array

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We demonstrate a mapping between the problem of charge ordering on a triangular lattice and a frustrated Ising spin model. A temperature interval exists in which the system represents a correlated fluid with a particular short-range ordering. Long-range charge ordering in the fluid is characterized by topological defects (vortices) which freeze out in the correlated state. The transition from uncorrelated to correlated fluid state is of a Berezinskii-Kosterlitz-Thouless type. The correlations in the fluid state are characterized by an intrinsic height field order parameter similar to that of the solid-on-solid problem [1].

The system ground state at $T = 0$ depends on the electron density n. From numerical simulations, at simple rational n the ground state is a crystal. At generic values of n, however, the observed $T = 0$ state is sensitive to the cooling procedure, indicating presence of a manifold of nearly degenarate low energy states.

We study electron hopping transport in the system below and above the transition into the correlated fluid state. It is observed that, as the vortices freeze out at the transition, the hopping conductivity drops to a lower but manifestly finite value. This demonstrates the possibility of an intrinsic conductivity mechanism in the correlated state which does not involve vortex pairs. We propose a dynamical solid-on-solid model to describe charge transport in this state.

[1] L.S. Levitov, Boris Kozinsky, cond-mat/9912484

M-4 Electron Transport through Superconducting Quantum Point Contacts

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We study the quantization of the critical current I_c in a ballistic Superconducting Quantum Point Contact (SINIS junction) when the number of conducting channels in the constriction of 2DEG changes. We show that the quantization of the I_c is not universal, but depends on parameters of the contact, especially on the properties of 2DEG-S boundaries. Due to the effect of normal reflection the critical current has a resonance structure as a function of d_0 – the width of the constriction. At some values of d_0, E_f coincides with a quasi-stationary level of a quantum box made by the walls of the contact and I_c exhibits a local maximum (resonance). If only one channel is open in the constriction then the critical current is given by the ratio of an electron charge to the time of flight τ through the junction: $I_c = e/\tau$. This result for I_c is correct not only for the limiting case when the effect of normal scattering from the 2DEG-S boundaries is strong or weak [1], but also in intermediate situation. It is important to note that the critical current in a resonance can be calculated from the lowest positive Andreev level for the difference of phases between superconductors $\varphi = \pi$.

[1] N.M. Chtchelkatchev, G.B. Lesovik and G. Blatter, cond- mat 9907460

M-5 Density of States below the Thouless Gap in a Mesoscopic SNS Junction

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Semiclassical theory predicts an existence of a sharp energy gap $E_c \sim E_{Th} = D/L^2$ in the exitation spectrum of long, $L \gg \xi$, superconductor–normal-metal–superconductor (S-N-S) junction. We show that mesoscopic fluctuations smear this gap, in a way roughly similar to an appearence of a "Lifshitz tail" in the DoS for the usual Schrödinger equation with random potential. Technically, we use extension of Efetov's supermatrix σ-model for mixed S-N systems, in the form similar to the one developed in [1]. Saddle-point solutions of the σ-model action includes well-known semiclassical Usadel solution, as well as an additional "instanton-type" solution. We show that this instanton provides nonzero contribution to the DoS at energies $E < E_c$. In the range $G^{-2/3} \ll (E_c - E)/E_c \ll 1$ the DoS decreases with energy as $\rho(E) \sim \exp[-\mathrm{const}\, G\,(1 - E/E_c)^{3/2}]$, where $G \gg 1$ is the dimensionless conductance of the N region.

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QD-1 Collective Behavior of Interwell Excitons in GaAs/AlGaAs Double Quantum Wells

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Photoluminescence spectra of interwell excitons in double GaAs/AlGaAs quantum wells (n-i-n structures) have been investigated (an interwell exciton in these systems is an electron-hole pair spatially separated by a narrow AlAs barrier). Under resonance excitation by circularly polarized light, the luminescence line of interwell excitons exhibits a significant narrowing and a drastic increase in the degree of circular polarization of photoluminescence with increasing exciton concentration. It is found that the radiative recombination rate significantly increases under these conditions. This phenomenon is observed at temperatures lower than the critical point and can be interpreted in terms of the collective behavior of interwell excitons.

QD-2 Hyper Raman scattering of exciton polaritons in microcavities

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The interaction between quantum well excitons and cavity photons in semiconductor microcavities (MC) in the strong coupling regime results in mixed 2D exciton-photon states, called exciton polaritons. The behavior of a dense polariton system is of particular interest due to the fact that these particles have integer spin and, hence, obey Bose-Einstein statistics.

Drastic nonlinearities have been observed both in the LP emission intensity and polarization in the case of the resonant excitation into the LP branch under condition that $2\hbar\omega(k_{exc}) = \hbar\omega(k=0) + \hbar\omega(2k_{exc})$. The experiments have shown a very strong final state stimulation of a two polariton scattering due to the bosonic nature of the polaritons. The filling of $k = 0$ LP state significantly exceeding 1 has been realized under continuous excitation at $T = 1.8$ K The dependence of the effect on the polarization of photoexcited light and temperature is discussed.

QD-3 The role of disorder in the exciton photoluminescence from double quantum wells

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The results of recent experiments on the evolution of photoluminescence spectra of spatially indirect excitons with temperature T and concentration n are interpreted. The broad, low energy line, present at all T and n originates from "incoherent" excitons bound to individual impurities. However, due to screening effects, the local levels can accomodate only the concentration $n \leq n_c$; above the threshold (for $n > n_c$) the excess excitons remain delocalized (or localized only at large spatial scales). The spatial coherence of Kosterlitz-Thouless type may develop within this group of delocalized $2D$ excitons at low T, which results in the narrow, high-energy, peak in the luminescence spectrum, observed only at high concentrations and low temperatures.

QD-4 Tunnelling between strongly disordered two-dimensional electron systems in GaAs: suppression of the equilibrium tunnelling by magnetic field and evidence of interaction between Landau levels of different subbands

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Tunnelling current measurements between strongly disordered two-dimensional electron systems in a magnetic field parallel to the current are presented. Two-dimensional electron systems are formed by Si delta doping of GaAs on both sides of the AlGaAs barrier. At liquid helium temperatures, the high magnetic field creates a gap in the tunnelling density of states that depends linearly on magnetic field. The creation of the gap we relate with the Coulomb electron correlation in the layers. The temperature dependence of the magnetic field variation of the equilibrium tunnelling conductance reveals features which could be interpreted as a manifestation of the insulator-quantum Hall-insulator transition. Strong interaction between Landau levels of different two-dimensional subbands in GaAs have also been observed as anticrossing of related peak positions with magnetic field. The splitting of the interacted Landau levels is about 10 meV, which could not be explained by non-parabolicity of the conduction band in GaAs. The possible reasons of the observed interaction are discussed.

QD-5 Spectroscopy of Electron-Electron Scattering in a 2DEG

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The energy dependence of electron-electron scattering processes in a two-dimensional electron gas (2DEG) is studied experimentally. Decisive differences are expected in the momentum transfer compared with the three-dimensional case [1]. These differences are due to the conservation of energy and momentum and are controlled by a parameter $\max\{T,\varepsilon\}/\varepsilon_F$, which characterizes the degree of degeneracy. here, T is the temperature of 2DEG and ε is the non-equilibrium electron energy counted off from the Fermi energy ε_F. Differently from 3D, electron-electron collisions in 2DEG lead to scattering in small angles, $\varphi \sim \varepsilon/\varepsilon_F$. However, the probability of collisions of electrons with almost opposite momenta $\mathbf{p} \approx -\mathbf{p_1}$ is drastically increased compared with the three-dimensional case. The importance of these 2D scattering effects was first discussed by us in connection with numerical calculation the probability distribution $g(\varphi)$ of a non-equilibrium electron (hole) to appear at an angle φ after scattering [2].

Experimentally electron-beam injection and detection via quantum point-contacts (QPCs) is used to investigate the scattering of a non-equilibrium electron distribution in a 2DEG of a GaAs-(Ga,Al)As-heterostructure. The QPCs are defined electrostatically by applying a negative voltage to lithographically processed Schottky gates, a technique which allows for a good control of the electron-beam opening angle. The distance between injector and detector is typically of the order of 2 to 4 μm. The energy dependence of electron-electron scattering processes has been studied recently by investigating the detector signal associated with the non-deflected direct electron beam [3]. Assuming electron beams with a narrow opening angle, which is achieved experimentally by adjusting the QPCs to one conducting mode ($G_{QPC} = 2e^2/h$), a magnetic field B perpendicular to the 2DEG-plane causes only electrons which are scattered in a point O at an angle φ to reach the detector. Thus, using an ac + dc measurement technique it is possible to investigate directly the energy dependence of the angle distribution in a two-dimensional scattering process. The experimental data give a clear evidence for the importance of small angle scattering processes in two-dimensional systems.

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QD-6 Dilute electron gas in MOSFETS: role of valleys.

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Abstract is not supplied

QD-7 Electron-Electron Interactions in Zero Dimensions

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Abstract is not supplied

QD-8 The g-factors of discrete levels in nanoparticles

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Spin-orbit scattering suppresses Zeeman splitting of individual energy levels in small metal particles. This suppression becomes significant when the spin-orbit scattering rate $\tau_{\rm so}^{-1}$ is comparable to the quantum level spacing δ. At small $\delta\tau_{\rm so}$ the g-factor exhibits strong mesoscopic fluctuations. We find the shape of their distribution function using the random matrix theory, and express its parameters in terms of physical characteristics: $\tau_{\rm so}$, δ, the electron mean free path l, and the particle size L. At $\delta\tau_{\rm so} \to 0$ the average g-factor levels off at a small value $g \sim (l/L)^{1/2}$. On the contrary, in 2D quantum dots the g-factor is strongly enhanced by spin-orbit coupling.

QD-9 Microscopic aspects of charge-density wave dynamics

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Studies on charge-density-waves (CDWs) have merely been concentrated on bulk crystals, revealing its dynamics on macroscopic length scales. We have developed a technology to contact and pattern thin crystals of the CDW conductors $NbSe_3$ and TaS_3 on a submicron scale. Examples of devices for the study of mesoscopic CDWs will be given. Electrical transport measurements have been used to map out the local CDW dynamics. Our results show that transport on (sub)micron length scales differs substantially from that on macroscopic scales: strain-induced current conversion may be correlated in time [1] and I-V characteristic show negative resistances in the sliding regime [2]. These observations can not be explained by theories that only take the elasticity of the CDW into account (phase-only models). The negative- resistance measurement may involve charge-imbalence processes near phase-slip centers.

We have also fabricated a transistor-like device in which a transverse current modulates the CDW conduction [3]. Nonequilibrium conditions in this geometry lead to an exponential reduction of the depinning threshold, allowing the CDWs to slide for much lower bias fields. The results are in excellent agreement with a recently proposed dynamical model describing driven, elastic media.

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QD-10 Unified field theory of mesoscopic systems

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The main subject of mesoscopic physics is the electron propagation in disordered man-made systems and formation of electron states in there. It is still a rapidly developing field of physics and is characterized by an extreme diversity of theoretical approaches in use. Such phenomena as Coulomb blockade, electric noise, universal conductance fluctuations, weak localization, effects of electromagnetic environment, mesoscopic superconductivity and proximity effect, spin injection, counting statistics of the current are treated by formally different methods. However, the results show many similarities and analogies, so that one can hope that there is a unified theory of mesoscopic systems which underlies all the phenomena mentioned. One could, of course, start with microscopic Hamiltonian. However, this is rather symbolic than constructive.

We show that the most natural way to formulate such a theory results in a circuit one. We begin with a continious theory recently proposed in [1]. The authors introduce a field of of 8×8 matrices $\hat{G}(\mathbf{r}; t_1, t_2)$ depending on space coordinates and two times. Eight indices comprise spin, Nambu and Keldysh indices of underlying electrons. It is instructive to consider $t_{1,2}$ as extra matrix indices and operate with $\check{G}(\mathbf{r}) \equiv \hat{G}(\mathbf{r}; t_1, t_2)$ The field can be related to Green function of the electrons and satisties unitarity condition in each point: $\check{G}^2 = \check{1}$.

We formulate corresponding finite-element theory. A mesoscopic system is subdivided onto connectors, nodes, and terminals. The field $\hat{G}$ is defined in both terminals and nodes. It is fixed in terminals and fluctuates in nodes.

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QD-11 Mesoscopic Physics on Graphs

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I will consider properties of diffusive quasi-1D networks and of ballistic 1D networks.

The transport and thermodynamic properties of diffusive systems can be related to the spectral determinant of the diffusion equation (the product of its eigenvalues). I present a general formalism to calculate this spectral determinant on any network made of quasi-$1D$ diffusive wires. For a network with N nodes, it is simply written in terms of the determinant of a $N \times N$ matrix which describes the connectivity of the network [1]. An expansion of this determinant in terms of a walk on the network gives simply the field dependence of physical quantities, like the magnetization for example. I present a few developments on this problem, like the effect of boundary conditions [2].

Then I consider a network made of strictly $1D$ ballistic wires and I show how its transmission coefficient can be written in terms of the same $N \times N$ matrix as above. This formalism is used to calculate the transmission coefficient of regular networks, in particular of the so-called $\mathcal{T}_3$ network which exhibits the Aharonov-Bohm cage effect, i.e. the absence of transmission for half flux quantum per plaquette [3]. Comparison with recent experimental data are presented.

Finally I present a few considerations on the relation between the magnetism of non-interacting systems and the magnetism of interacting diffusive systems.

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COULOMB BLOCKADE

CB-1 Noise in SET transistors of different types

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We have fabricated and studied SET transistors made of different materials and having different geometries. The characteristics of the SET transistor as ultrasensitive electrometer were in the focus of our study.

We have found the optimum geometry of the SET transistor where the influence of the background charge fluctuations could be minimized. As a result, we have reached a very low value of the electrometer charge noise [1]: $\delta Q \approx 8 \times 10^{-6} e/\mathrm{Hz}^{1/2}$ (at $f = 10$ Hz, $T = 10$ mK).

The Al SET transistors with extremely small tunnel junctions (with charging energy of $E_c/k_B \approx 30$ K) have been fabricated and their noise figures were measured at T up to 13 K.

The new type of the SET transistor without traditional tunnel junctions has been developed and studied. It consists of two highly resistive Cr films directly attached to an Al island. This device demonstrated $IV-$ and modulation characteristics qualitatively similar to those of traditional tunnel junction transistors.

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CB-2 Al single-electron transistors: room-temperature operation and energy level quantization

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We have performed experiments [1] on Al-based single- electron transistors (SETs) incorporating ultrasmall islands with an aim to raise their operating temperature. The SETs were fabricated by angle evaporation through a Ge mask formed by electron beam lithography and dry etching. The island size was decreased to below the window size in the mask by changing the evaporation sequence. This enabled us to observe at 300 K modulation of an SET tunneling current by the gate voltage. Also, at temperatures below 30 K, we observed step-like features in the transport characteristics of the SET, indicating the existence of discrete energy levels in the tiny island. From the energy level separation, we estimated the island size about 4 nm and this is consistent with the measured charging energy of the device.

Our simulations based on the orthodox theory reproduce well the modulation curves in the whole temperature range 4.2 – 300 K.

We also measured temperature dependence of charge noise of the transistor and it was equal to $4 \times 10^{-2}\ e/\mathrm{Hz}^{1/2}$ at 1 Hz at 300 K.

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CB-3 Non-conventional Saddle Points and Instantons in Disordered Sigma Models

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We show that the detailed investigation of the interacting sigma-models (replica and Keldysh) reveals the rich structure of various saddle points. As a "warm-up" exercise one may compute electronic level statistics in the asymptotic regime in both of the above mentioned models. The simplest interacting problem of a quantum dot connected to a disordered wire (or disk) may be solved by considering spatially non-homogeneous saddle points (instantons) of the sigma-model.

CB-4 Strong compensation of the quantum fluctuation corrections in clean superconductors

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As it is well known, the first order fluctuation corrections to conductivity in the vicinity of superconducting transition are presented by the Aslamazov-Larkin (AL), Maki-Thompson (MT) and density of states (DOS) contributions. First one has the simple physical meaning of the direct charge transfer by the fluctuation pairs themselves and can be easily derived from the phenomenological time dependent Ginzburg-Landau equation. In this sense it is a result characteristic for the classical electron theory, while Maki-Thompson and DOS contributions have the purely quantum origin and can be calculated in the frameworks of the microscopic approach only. Dealing with the superconductor electrodynamics in fluctuation regime it is necessary to remember that in the vicinity of the critical temperature the role of fluctuation Cooper pair effective size plays the Ginzburg-Landau coherence length $\xi_{GL}(T) = \xi_0/\sqrt{\varepsilon}$ [where the reduced temperature $\varepsilon = (T - T_c)/T_c$]. So the case of dilute alloy ($\ell \gg \xi_0$) in the vicinity of the transition could be formally subdivided on clean, which is still local ($\xi_0 \ll \ell \ll \xi_{GL}(T)$) and ultra-clean, non-local ($\xi_{GL}(T) \ll \ell$) limits. The latter case becomes of the first importance already for metals of very modest purity, let us say, $T\tau \approx 10$. In practice one can speak about the dirty, intermediate or ultra-clean cases but not about the clean one. The classic 2D AL contribution turns out to be independent on the electron mean free path ℓ at all: $\delta\sigma_{AL}^{(2)} = \frac{e^2}{16}\frac{1}{\varepsilon}$. Anomalous Maki-Thompson contribution, being induced by the pairing on the Brownian diffusive trajectories, naturally depends on $T\tau$, but its form changes only when $\ell \sim \xi_{GL}(T)$ ($T\tau \sim 1/\sqrt{\varepsilon}$).

$$\sigma_{MT(an)}^{(2)} = \frac{e^2}{8}\begin{cases} \frac{1}{\varepsilon-\gamma_\varphi}\ln(\varepsilon/\gamma_\varphi), & \text{if } T_c\tau \ll 1/\sqrt{\varepsilon}; \\ \frac{8\pi^2 T\tau}{\sqrt{14\zeta(3)}}\frac{1}{\sqrt{\varepsilon}}\ln(T_c\tau\sqrt{\varepsilon}), & \text{if } 1/\sqrt{\varepsilon} \ll T_c\tau. \end{cases}$$

The analogous problem takes place in the DOS and regular part of MT contributions: their standard diagrammatic calculations lead to the negative correction

$$\sigma_{DOS+MT(reg)}^{(2)} = -\frac{e^2}{4s}\ln\left(\frac{1}{\varepsilon}\right)\begin{cases} \frac{56\zeta(3)}{\pi^4} \approx 0.691, & \text{if } T\tau \ll 1; \\ \frac{8\pi^2}{7\zeta(3)}(T\tau)^2, & \text{if } T\tau \gg 1; \end{cases}$$

evidently divergent when $T\tau \to \infty$. In the derivation of these results the local form of the fluctuation propagator and Cooperons were used. We reexamine the theory of fluctuation conductivity for an arbitrary impurity concentration including the ultra-clean limit. It is demonstrated that the formal divergency of the fluctuation DOS contribution, obtained previously for the clean case, is removed by the correct treatment of the non-local ballistic electron scattering, it is canceled by the Maki-Thompson term and only classical paraconductivity remains.

CB-5 In Search of Non-Newtonian Gravity in Sub-mm Distance Scales: Extra Dimensions

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Micro-mechanical systems machined from single crystals enable the detection of extremely small forces and displacements. We discuss our experimental effort towards the measurement of gravitational forces with micro-mechanical resonators in sub-millimeter distance scales, the subject of tremendous current interest. The possibility of a detectable effect from the proposed large extra dimensions as a correction to Newton's inverse square law is exciting in itself. This correction is significantly large in the physically accessible regime, since it is expected to be on the same order of magnitude as the inverse-square-law force in the sub-millimeter distance scales.

Important to the measurement of *mesoscopic gravity* is a narrow-band (high Q) sensitive detector integrated with a low noise detection technique. Contrary to the measurements in the large resonators where extrinsic dissipation mechanisms are detrimental, we find that intrinsic two-level systems dominate the dissipation (Q^{-1}) in our micron-sized resonators. We present extensive data on the intrinsic dissipation and frequency shift in various gallium arsenide and silicon resonators in the megahertz range at low temperatures. In our single-crystal resonators, we find a temperature independent dissipation reminiscent of the acoustic and dielectric anomalies observed in dipolar glasses at low temperatures, both of which are poorly understood. However, our micron-sized systems allow the measurement of extremely small forces well within the resolution limit required for *mesoscopic gravity*.

MS-1 Superconductive proximity effect in interacting disordered conductors

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We present a general theory of the superconductive proximity effect in disordered normal–superconducting (N-S) structures, based on the recently developed [1] Keldysh action approach. At an arbitrary transparency of the N-S interface, an effective low-frequency action contains an infinite number of terms accounting for multiple Andreev reflections. Andreev subgap conductance and shot noise in presence of interaction are calculated as functions of voltage and frequency for an arbitrary relation between interface resistance R_T and diffusive resistance R_D. Repulsion in the Cooper channel is shown to destroy coherence between electron and Andreev-reflected hole and can thus mimic the effect of finite electron dephasing time τ_ϕ. At sufficiently strong repulsion, charge transport through the whole structure can be described in terms of Cooper-pair transmission coefficients exactly in the same way as the normal electron transport in noninteracting system with a (renormalized) tunnel barrier.

[1] M. V. Feigel'man, A. I. Larkin, and M. A. Skvortsov, Phys. Rev. B **61**, 12361 (2000).

MS-2 Wavefunction Nodes and Dirty Superconductivity

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The Anderson theory on dirty superconductivity was established a few years after the discovery of the BCS wave function. Disregarding the rich properties in the one-particle energy spectrum in dirty limit, the theory claimed that the ground state condensate is translation invariant and free from Toulouse type of frustrations. This theory also set down the foundation of dirty superconductivity in the presence of external fields.

In this talk, I demonstrate the failure of the Anderson theory in amorphous superconducting films in general and its connection with Wigner-Dyson surmise. I will discuss the Chandraseka-Clogston limit in which the nodes in one-particle wave functions are shown to result in a novel superconducting glass phase. I will also discuss why nature has tolerated the failure.

MS-3 Excess Conductance in Normal Metal/Anderson Insulator/ Superconductor junctions

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The current-voltage characteristics of a normal-metal/Anderson insulator/ superconductor tunnel junctions exhibit peculiar zero-bias anomalies. At low temperatures the zero bias resistance attains saturation values that are smaller than the normal-state resistance by a factor that often exceeds 2. This zero-bias anomaly (ZBA) is characterized by a voltage scale much smaller than the superconducting energy gap. We also observe a non trivial effect of a microwave field on the ZBA features. We will discuss the possibility that these features arise from the nature of the barrier being an Anderson Insulator.

MS-4 Superconductivity in carbon nanotubes

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We show experimental evidence of induced and intrinsic superconductivity in carbon nanotubes. The supercurrent is observed in a single 1nm diameter SWNTs, in individual crystalline ropes containing about 100 nanotubes and also on multiwalled tubes. These samples are suspended as strings between two superconducting (double layer Au-Re, Au-Ta or Sn film) and normal (double layer Au-Pt film) electrodes. The critical current of samples, extensively studied as function of temperature and magnetic field, presents unusual features which are not observed in ordinary Superconducting-Normal-Superconducting junctions and can be related to the strong 1D character of these samples. We also show evidence of a huge sensitivity of dc transport properties of tubes to electromagnetic radiation in the radio-frequency range.

MS-5 Vortices in superconductors with triplet pairing: new symmetry classes and nonabelian statistics

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Superconductors with triplet pairing are predicted to exhibit many remarkable effects arising from the symmetries of odd pairing. One such effect is the appearance of zero-energy quasiparticle levels in vortex cores, which makes physics of such vortices very different from that in conventional superconductors.

First, the presence of a zero-energy level changes the symmetry class of vortex excitations. In the framework of random-matrix theory, a Hamiltonian of a disordered mesoscopic system may, under certain conditions, be described by a random matrix ensemble depending on its symmetries. In such a case the level statistics is universal and classified into one of the twelve symmetry classes. While quasiparticles in a disordered vortex in a conventional (s-wave) superconductor belong to the symmetry class C, in a triplet (p-wave) superconductor excitations inside the vortex belong to the symmetry class B if the time-reversal symmetry is broken or to the symmetry class DIII-odd if the time-reversal symmetry is preserved [for spin vortices in the order parameter without time-reversal symmetry breaking]. These are the first known mesoscopic realizations of the symmetry classes B and DIII-odd.

Second, the ground state of a system of several vortices is degenerate, and vortices may possess nonabelian braiding statistics when they move around each other. We consider a system of $2n$ isolated half-quantum vortices in the order parameter of the A phase of ^{3}He. Each such vortex has a zero-energy Majorana fermion level in its core, and the ground state of the system of vortices is 2^n-degenerate. From the general properties of Bogoliubov-deGenens equations, we explicitly derive the unitary transformations generated by vortex braiding. The vortex statistics is found to be identical to that for the Moore-Read (Pfaffian) quantum Hall state, which supports the conjecture by Read and Green about the topological equivalence between the Pfaffian and the BCS p-wave states.

MS-6 Coupling of two superconductors trough a ferromagnet. SFS π-junctions and inner frustrated networks

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Reentrant superconducting behavior of the critical supercurrent temperature dependencies has been observed for the Nb-Cu/Ni-Nb Josephson SFS (superconductor- ferromagnet-superconductor) junctions. The $I_c(T)$ oscillations detected are associated with a crossover of the SFS junctions from "0"- to "π"-state that is related to a special feature of superconducting pair flow through a ferromagnet (spatial oscillations of induced superconducting order parameter in presence of the exchange field). A triangular array of the junctions in the π-state shows evidence for a phase shift of π on the $I_c(H)$ dependence. We have argued advantages of the SFS π-junction use for the quantum bit implementation based on the superconducting loop with quantum Josephson junctions. While previously proposed designs are based on magnetically frustrated superconducting loops, we discuss the advantages offered by the pi-junctions in obtaining naturally degenerate two-level systems.

MS-7 Entangelement of Electrons and Drag Effect in the proximity of Superconductor

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Normal electrons near Fermi surface in the proximity of superconductor can be considered as a decayed Cooper pairs. These pairs have entangled spins and momenta, and thus the NS interface can serve in principle as an effective source for entangled electrons. We propose to probe this entanglement by measuring current-current cross correlator between two different normal leads, each lead containing a spin filter to avoid penetration of the whole pair. This proposed experiment constitutes a solid-state analog of the experiment with photons, proposed by Einstein, Podol'sky, Rosen (EPR) and allows to detect effectively correlations between electrons with different spin directions. In addition to the correlations, we describe a nonlocal effect, in which an e.m.f. is induced in one lead (unbiased with respect to the superconductor) in response to a bias in the other normal lead.

In other words, in a coherent wire which is part of a conductor where an NS boundary is inbedded, it is possible to induce a current in the absence of chemical potential difference between the wire and the superconductor. This remains true when a bias is imposed between the two in the direction opposite to that of the above induced current.

MS-8 Interplay between Andreev reflection and spin-relaxation in mesoscopic ferromagnet/superconductor junctions

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We analyze the change in the resistance of a junction between a diffusive ferromagnetic metal (F) and normal metal electrode, due to the onset of superconductivity (S) in the latter. A double Andreev scattering process leads to a complete internal reflection of a large fraction of the spin-polarized electrons back into the ferromagnet, so that the superconducting transition results in an additional contact resistance arising from the necessity to match the spin-polarized current in F-wire to the spin-less current in S-reservoir. This contact resistance is comparable to the resistance of a piece of a F-wire with the length equal to the spin-relaxation length. The analysis is extended onto giant magnetoresistance ferromagnetic/normal metal layered structures with superconducting contacts. Weak localisation correction to such a resistance is also analysed.

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MS-9 Transport and Noise Measurements in Mesoscopic Normal Metal – Superconductor Structures

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We report an experimental investigation of transport and noise properties of mesoscopic normal metal – superconductor (N-S) junctions. We recently observed doubling of the shot noise in a diffusive N-S junction as compared to a normal diffusive conductor [1], which is an indication that the effective charge of the current carriers is $2e$. In the presence of high-frequency radiation the photon-assisted tunneling features in the noise occur at bias voltages $V = h\nu/(2e)$, which constitutes another signature of an effective charge of $2e$ [2].

We also performed transport and non-equilibrium noise measurements in an Andreev interferometer. The conductance and noise are modulated by a magnetic field with a period corresponding to a magnetic flux quantum $h/(2e)$. In the presence of high-frequency RF irradiation we observe well-developed photon-assisted features in the conductance of an Andreev interferometer.

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MS-10 Probing Vortex Cores of High T_c Superconductors with Scanning Tunneling Spectroscopy

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Using scanning tunneling spectroscopy, the spatial variations of the electronic density of states due to the presence of vortex cores can be probed with a high energy and spatial resolution. This technique has been applied to the high T_c oxide superconductors YBCO and BSCCO, in order to map out the vortex lattice, and to probe the electronic structure of the cores. Contrary to the low T_c superconductor $NbSe_2$ where the core is found to contain a quasi continuous set of states, these materials show cores with only one (YBCO), or even zero (BSCCO) bound states. Strikingly, the spectra acquired in the cores of BSCCO show the pseudogap behaviour observed above T_c. Analysing the spatial dependence of the spectra around the cores, we find that the characteristics are not consistent with a BCS-like s or d-wave theory. Comparing the cores of $NbSe_2$, YBCO and BSCCO, we come to the conclusion that the coherence length for BSCCO is of the order of only a few lattice spacings. This extremely small coherence length has the consequence that the vortices are easily pinned at compositional defects, giving a strongly disordered lattice.

MS-11 Spatially resolved spectroscopy on a superconducting proximity nanostructure

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We investigated the local density of states (LDOS) of a normal metal (N) in good electrical contact with a superconductor (S) as a function of the distance x to the NS interface. The sample consists of a pattern of alternate L=1 μm wide stripes of Au and Nb made by UV-lithography. We used a low temperature scanning tunneling microscope and a lock-in detection technique to record simultaneously $dI/dV(V,x)$ curves and the topographic profile $z(x)$ at 1.5K. We scanned along lines perpendicular to the stripes. All the spectra show a dip near the Fermi energy which spectral extension decreases from the superconducting gap Δ at the NS interface to zero at distances $x \gg \xi_N$ where $\xi_N \simeq \sqrt{\hbar D_N/2\Delta} \simeq 53\,\mathrm{nm}$ is the coherence length in the normal metal. Our measurements are correctly described in the framework of the quasi-classical Green's function formalism [1,2]. We numerically solved the 1D Usadel equation [3] and extracted a decoherence time in gold of 20 ps. We also investigated the LDOS of small ridges of Au deposited on the top of the Nb lines. In this case, $L \leq \xi_N$ and the spatial variations of the spectra depend on the exact shape of the Au ridge. However our results are consistent with a predicted minigap related to the Thouless energy [2].

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QC-1 Unpaired Majorana fermions in quantum wires

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Any system of electrons can be formally described in terms of two Majorana operators per each electron mode, $c'_j = a_j + a_j^\dagger$ and $c''_j = -i(a_j - a_j^\dagger)$. For nonintaracting electrons, or in the mean-field approximation, the Majorana operators are effectively paired to form quasiparticle creation and annihilation operators. Under certain conditions, few Majorana fermions remain unpaired and spatially separated. In particular, an unpaired Majorana fermion occurs at a vortex core in a 2D p-wave superconductor [1,2]. We show that Majorana fermions can also occur at the ends of a one-dimensional conductor with an induced superconducting gap.

The simplest model is a one-dimensional tight-binding Hamiltonian with only one spin component and terms of the form $a_j a_{j+1}$. This system has two phases one of which exibits the Majorana fermions. We also find a general condition on a one-dimensional electron spectrum which determines whether the Majorana fermions exist. To satisfy this condition, one needs (i) an odd number of conducting channels (each spin component counts as a separate channel!) and (ii) the presence of a p-wave bulk superconductor to induce a gap.

A pair of Majorana fermions can be used as a qubit which is intrinsically immune to decoherence. We discuss possible implementations of quantum gates with such qubits.

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QC-2 Quantum measurement and statistics of current

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We study the quantum measurement process by a single-electron transistor or a quantum point contact coupled to a quantum bit. Analyzing the master equation for the time evolution of the reduced density matrix of the coupled system we find parameter regimes where a projective quantum measurement can be performed. The 'detector-dominated' regime with the fast dephasing is characterized by the Zeno effect and the projection onto the qubit's charge basis. In the 'qubit-dominated' limit the quantum state is projected onto the qubit's eigenbasis. We also discuss the continuous measurement in the stationary regime where the current develops the telegraph-noise behavior. To quantify the efficiency of the detector we estimate the relevant time scales: the qubit's dephasing times with detector turned on/off, the read-out time and the mixing time, after which the information about the initial state is lost.

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QC-3 Quantum Superposition of Macroscopic Persistent-Current States

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Superconducting circuits with Josephson tunnel junctions are interesting systems for research on quantum-mechanical behavior of macroscopic degrees of freedom. A particular realization is a small superconducting loop containing three Josephson junctions [1]. Close to magnetic frustration 1/2, the physics of this system corresponds to a double well, whose minima correspond to persistent currents of opposite sign. We present DC-measurements of the flux indicating a smooth transition close to the degeneracy point even at very low temperatures. Furthermore, microwave-spectroscopy experiments allow for the excitation to the next excited state. The dependence of the energy of the resonance on the applied flux clearly indicates the nature of these states as tunneling-splitted superposittions of flux states. We theoretically analyze the system using a generalized master-equation formulation of the spin-boson model. We address the nature of the measuring process by a switching DC-squid and the possible interpretation of the spectroscopy data in terms of quantum coherence. We discuss these aspects in the context of further applications as a quantum bit.

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QC-4 Spintronics for Quantum Computing

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We briefly review the spin-quantum dot architecture for a quantum computer [1]. Next we address the feasibility of quantum communication with electrons in a solid-state environment by investigating two examples in which mesoscopic transport and noise contain strong signatures of quantum entanglement. First, we consider a scattering set-up with an entangler and beam splitter where the current noise exhibits bunching behavior for electronic singlet states and antibunching behavior for triplet states [2]. The Fano factor (noise-to-current ratio) is calculated and shown to contain opposite signs for singlets and triplets. Second, we show that the entanglement of two electrons in a system of two coupled quantum dots can be detected in mesoscopic transport measurements [3]. In the cotunneling regime the singlet and triplet states lead to phase-coherent current contributions of opposite signs and to Aharonov-Bohm and Berry phase oscillations in response to magnetic fields. We analyze the Fermi liquid effects in the transport of entangled electrons [2]. Finally, we consider a quantum dot in the Coulomb blockade regime weakly coupled to current leads and show that in the presence of a magnetic field the dot acts as an efficient spin-filter (at the single-spin level) which produces a spin-polarized current. Conversely, if the leads are fully spin-polarized the up or down state of the spin on the dot results in a large sequential or small cotunneling current, and thus, together with ESR techniques, the setup can be operated as a single-spin memory and a read-out device for quantum computer [4].

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QC-5 Microwave activated quantum interferometer in an environment

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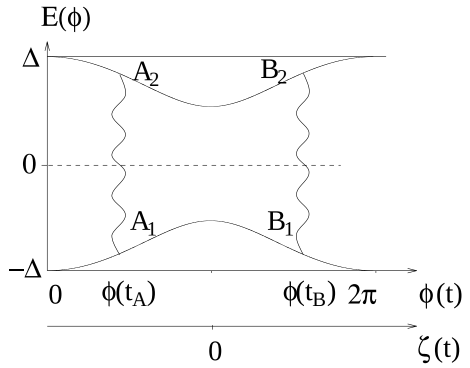
The so-called microwave-activated Andreev interferometer (AI) [1] is a device proposed as a tool to study the dynamics of Andreev levels (ALs), present in a superconducting quantum point contact (SQPC).



The Andreev level positions in a SQPC depend on the order parameter phase difference ϕ across the contact, as well as on its transparency D, the interlevel spacing being proportional to $\sqrt{1 - D\sin^2\phi/2}$. In a SQPC biased by voltage V the phase difference becomes time-dependent according to the Josephson relationship $\dot{\phi} = 2eV/\hbar$.

The principle of AI is clear from the picture where time dependences of adiabatic ALs are shown. The interference contribution to the current is a result of microwave-induced Landau-Zener transitions $A_1 \to A_2$ and $B_1 \to B_2$ between the Andreev levels and contains information about the positions of the latters.

In the previous work, it was assumed that Andreev states are coherent. However, in realistic systems these states interact with the environment and this leads to a decay of the interference pattern (dephasing).

A study of this dephasing is the aim of the present work. As concrete mechanisms of dephasing we study fluctuations in the bias voltage and in the transmission coefficient of SQPC. The latter can be due to e. g. fluctuations in the gate voltage in gated structures, etc. A fluctuation in the bias voltage V changes the ramping phase velocity $\dot{\phi}$, which in turn influences the phase accumulated between the subsequent Landau-Zener transitions.

The second source of decoherence changes the positions of the Andreev levels through variations in the transparency D, and in this way the accumulated phase is changed again.

It is shown that studies of the smearing allows one to obtain information on the properties of the electromagnetic environment and its coupling to the Andreev states in a SQPC.

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QC-6 Dissipative Landau–Zener Tunneling

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The Landau–Zener transition in a two level system can be suppressed or enhanced by coupling to an environment, depending on the temperature and the environment spectral function. We consider the marginal spectral function, when the dissipation effects are important for arbitrarily slow motion. Landau–Zener transition rate demonstrates a non-trivial dependence of the on the “bias”, i. e., on the rate of the two energy levels relative motion. The Landau–Zener transition is fully suppressed for the values of the bias below a threshold bias set by the coupling strength. Above the threshold, the transition rate for zero temperature is found using the instanton method. At finite temperature, the Landau–Zener transition rate has a non-monotonic dependence on the coupling strength, being suppressed at the strong coupling.

QC-7

Title is not received

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Abstract is not received

T-1 Manifestation of bosonic effects in different types of superconductors

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The aim of the talk is to examine experimental arguments which can be used as evidence of existence of bosonic superconductivity with preformed pairs. It is assumed that a bosonic superconductor needs strong coupling and low carrier density and that it can be realized under both, strong and weak disorder. Experimentally the search was performed in these two limits by examining the vicinity of the superconductor-insulator transition in amorphous In-O films (a disordered material) [1], and measuring the temperature dependence of the upper critical field B_{c2} in NdCeCuO single crystals (a material with regular lattice) [2].

For In-O films, crossing of the isotherms $R(B)$ at some critical value of $B = B_c$ is used as evidence of the existence of the transition and the high-field negative magnetoresistance indicates existence of localized bosons on its insulating side: when increased, the magnetic field breaks the pairs and thus enlarges the conductivity. The behaviours of the film resistance near B_c and at fields above the transition are similar for the parallel and normal magnetic field, indicating that neither orbital effects nor interactions between vortices are of the primary importance for the transition.

Properties which are discussed in connection with boson superconductivity are behaviors of the heat capacity and of the function $B_{c2}(T)$. In several high-T_c superconductors, they radically differ from the predictions of the BCS theory but follow those expected in a simplified picture of Bose condensation: not a jump, but a kink in heat capacity and zero derivative $\partial B_{c2}/\partial T = 0$ at T_c. In optimally doped NdCeCuO single crystals, the resistive superconducting transition shifts in magnetic field without broadening. This makes it possible to extract the function $B_{c2}(T)$. Careful experiments confirmed the law $B_{c2} \propto (T_c - T)^{3/2}$ which had been noticed before in several other high-T_c superconductors.

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T-2 Fluctuation Effects in High Sheet Resistance Superconducting Films

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As the normal state sheet resistance of a thin film superconductor increases, its superconducting properties degrade. Near a sheet resistance of 10 kΩ, superconductivity disappears. Questions about the processes responsible have intrigued experimentalists and theorists for some time. The answers can impact our understanding of the possible ground states of two dimensional electronic systems and the influence of disorder on quantum phase transitions.

I will review recent experimental progress on this problem and discuss how it relates to theories that model the disappearance with disorder or magnetic field as a superconductor to insulator quantum phase transition [1]. In particular, I will describe evidence from transport and tunneling experiments of fluctuation effects that can be associated with a quantum critical point in a disordered system [2,3]. I will discuss what these effects reveal about the phases near the critical point and I will highlight how recent low temperature scanning tunneling microscopy measurements lend new insight into how these fluctuation effects depend on film morphology [4]. In particular, I will present evidence that strong quantum or mesoscopic amplitude fluctuation effects in films with uniform morphology lead to a sheet resistance or magnetic field driven superconductor to metal-like phase transition rather than a superconducting to insulating transition. For the magnetic field driven case, the fluctuations become sufficiently strong near the critical point to melt the vortex solid phase [5,6].

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T-3 Vortex states at low temperature in disordered thin and thick films of a-$\mathbf{Mo}_x\mathbf{Si}_{1-x}$

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We have measured the ac complex resistivity in the linear regime, as well as dc resistivity, for thick (100, 300 nm) amorphous (a-)$\mathrm{Mo}_x\mathrm{Si}_{1-x}$ films at low temperatures ($T > 0.04$ K) in constant fields B. The critical behavior associated with the second-order transition has been observed for both dc and ac resistivities, which is similar to that observed for *granular* indium films [1]. This is the first convincing evidence for the vortex-glass transition (VGT) in the *homogeneously* disordered low-T_C superconductors containing microscopic pinning centers. We have found that the VGT persists down to $T \sim 0.1T_{C0}$ up to $B \sim 0.9B_{C2}(0)$, where T_{C0} and $B_{C2}(0)$ are the mean-field transition temperature and upper critical field at $T = 0$, respectively. At $T \to 0$ the VGT line $B_g(T)$ extrapolates to a value below $B_{C2}(0)$, indicative of the presence of a $T = 0$ quantum-vortex-liquid phase in the region $B_g(0) < B < B_{C2}(0)$. Upon cooling, breakdown of the critical behavior is visible below about $0.08T_{C0}$, which may suggest a crossover from a thermal to quantum liquid regime.

For thin (4 nm) films the ($T = 0$) field-driven superconductor-insulator transition takes place at B_C [2]. We have not obtained evidence of the metallic quantum liquid phase below B_C, while in $B > B_C$ an anomalous negative magnetoresistance (MR) suggesting the presence of the localized Cooper pairs has been observed. The negative MR is commonly observed for thin films; however, for thick films the MR is always positive. This means that the two dimensionality plays an important role in the appearance of the negative MR (or localized Copper pairs). The negative MR is no longer visible as the field is applied parallel to the film surface, consistent with the view that mobile vortices, as well as localized Cooper pairs, are present in $B > B_C$.

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T-4 Quantum superconductor-metal transition in a proximity array

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We construct a theory of quantum fluctuations in an array of small superconductive islands of size d in contact with dirty thin metal film with dimensionless conductance $g = \sigma_\square(\hbar/e^2) \gg 1$. Island's size is supposed to be large enough so that the proximity effect does not suppress superconductivity in the islands. Nevertheless, for the macroscopic superconductivity in the whole array to exist, the inter-island distance b should be short enough. The zero-temperature phase transition from the superconductive to normal-conductive state is shown to occur with the increase of distance between superconductive islands, at $\ln b_c/d \approx \pi\sqrt{g}$.

The critical distance b_c is much less than 2D localization length $L_{\mathrm{loc}} \sim e^{\pi^2 g}$, so the considered effect develops when the weak-localization corrections are still small. Our result contradicts to the expectations based upon A. Schmid's model of resistively shunted Josepshon junctions, since that model does not take into account an intrinsic nonlinearity of S-N transport due to the Andreev reflection. The method we used is a combination of the approach developed in the earlier paper [1] for a simplified version of the same model, and the recently proposed functional renormalization group method for the proximity action [2].

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