TT 18: Nanoelectronics I - Quantum Dots, Wires, Point Contacts

Time: Wednesday 14:00–17:15 Location: H19

TT 18.1 Wed 14:00 H19

Charge transfer statistics through multi-terminal Kondo and Anderson impurities — •Andrei Komnik[1], Thomas Schmidt[1], and Alexander Gogolin[2] — [1]Physikalisches Institut, Albert-Ludwigs-Universität Freiburg, Hermann-Herder-Str. 3, 79104 Freiburg — [2]Department of Mathematics, Imperial College London, 180 Queen's Gate, London SW7 2AZ, United Kingdom

We investigate the charge transfer statistics through a quantum dot in the Kondo regime coupled to an arbitrary number of terminals. Using the effective Hamiltonian valid at energies far below the Kondo temperature we calculate the generating function for the full counting statistics (FCS) perturbatively in the leading irrelevant operators. The transport seems to be mediated not only by single electron tunnelling but by correlated transport of electron pairs as well. We propose a measurement of cross correlations of Hanbury Brown and Twiss type in a multi-terminal geometry which is able to explicitly discern both processes in experiments. Furthermore we make predictions for generalised Fano factors to be universal and parameter-free. By comparison of perturbative expansions for weak and strong couplings we make predictions for the FCS of a more realistic multi-terminal Anderson impurity model, which are valid at all energy scales as long as the applied transport voltage is small.

TT 18.2 Wed 14:15 H19

Co-tunneling effects in transport through interacting quantum dots — •Jasmin Aghassi[1,2], Matthias Hettler[1], and Gerd Schön[1,2] — [1]Forschungszentrum Karlsruhe, INT, Postfach 3640, 76201 Karlsruhe — [2]Institut für theoretische Festkörperphysik, Universität Karlsruhe, 76128 Karlsruhe

We study charge transport in quantum dot systems within a diagrammatic technique. The current-voltage characteristics as well as the current noise are calculated within second-order perturbation expansion in the coupling parameter Γ. We allow for an intermediate coupling regime up to coupling constants of $\Gamma = k_B T$, where k_B is the Boltzmann constant and T the temperature. We explicitly account for intra- and inter-dot Coulomb interactions and the resulting many-body states of the quantum dots. For a single multilevel quantum dot we investigate the co-tunneling effects on the conductance and noise of the system in dependence of an applied gate voltage. In the Coulomb blockade region super-Poissonian noise is observed at the inelastic co-tunneling energy scale. This energy scale is also observable in the conductance in some cases. For non-local systems such as chains of coupled quantum dots ("artificial molecules") sequential tunneling results for transport under asymmetric conditions, i.e. non-resonant dots or asymmetric couplings are compared to second order results.

A. Thielmann *et.al.*, Phys. Rev. Lett., **95**, 146806 (2005)
J. Aghassi *et.al*, Appl. Phys. Lett. **89**, 052101 (2006), Phys. Rev.B **73**, 195323 (2006)

TT 18.3 Wed 14:30 H19

Frequency dependent quantum shot noise — •Jan C. Hammer and Wolfgang Belzig — University of Konstanz, Department of Physics, 78457 Konstanz, Germany

We study frequency-dependent quantum shot noise in the coherent charge transport through a double barrier quantum dot. In the framework of the scattering formalism we show how electron transport through such a Fabry-Perot-like setup reveals a super-Poissonian and an asymmetric noise spectrum for large frequencies. It depends on the applied bias voltage, the structure of the energy levels inside the scattering region and the coupling to the leads. For example, well separated energy levels lead to steps in the noise due to the emission and absorption of photons which get washed out as the width of the levels broadens. These can be shifted with respect to frequency by varying a gate voltage. At low frequency the Fano factor gets reduced and the spectrum is found to be symmetric.

TT 18.4 Wed 14:45 H19

Generation of Nonlocal Spin Entanglement in Nonequilibrium Quantum Dots — •Stefan Legel[1], Jürgen König[2], Guido Burkard[3], and Gerd Schön[1] — [1]Institut für Theoretische Festkörperphysik and DFG-Center for Functional Nanostructures (CFN), Universität Karlsruhe — [2]Institut für Theoretische Physik III, Ruhr-Universität Bochum — [3]Department of Physics and Astronomy, University of Basel

We propose schemes for generating nonlocal spin entanglement in systems of two quantum dots with onsite Coulomb repulsion weakly coupled to a joint electron reservoir. In nonequilibrium situations with one extra electron on each dot, we find the double-dot system in so-called Werner states with a fidelity exceeding 1/2, which indicates spin entanglement. We consider two specific setups. In the first setup we study the transient behavior of the system after rapidly pushing the dot levels from above to below the Fermi energy of the joint lead. We find the formation of an enhanced probability of the singlet state as compared to the triplet. In the second setup we analyze the stationary state with an applied bias voltage between the joint reservoir and two additional leads, which are weakly coupled to the dots. Depending on the polarity of the bias, we find an enhanced probability for either the singlet or the triplet states.

TT 18.5 Wed 15:00 H19

Non-equilibrium Josephson current through interacting quantum dots — •Marco G. Pala[1], Michele Governale[2], and Jürgen König[2] — [1]IMEP-MINATEC (UMR CNRS/INPG/UJF), F-38049 Grenoble, France — [2]Institut für Theoretische Physik III, Ruhr-Universität Bochum, D-44780 Bochum, Germany

We study transport through a quantum dot weakly coupled to both normal and superconducting leads. To this aim, we generalize a diagrammatic real-time transport theory[1] to account for superconductivity in the leads. In particular, we consider a system consisting of a quantum dot tunnel coupled to one normal and two superconducting leads. A finite voltage can be applied between the normal and the superconducting leads to drive the dot out of equilibrium. The dot is described by a single, spin-degenerate level, with arbitrary Coulomb repulsion U. The tunnel coupling to the superconducting leads induces a coherent superposition of the empty and doubly occupied dot states (proximity effect). In turn, this may mediate a Josephson current between the two superconductors. We find a situation in which the Josephson current is switched on due to the interplay of Coulomb interaction and non-equilibrium in the dot.

[1] J. König, H. Schoeller, and G. Schön, Phys. Rev. Lett. **76**, 1715 (1996)

TT 18.6 Wed 15:15 H19

Adiabatic pumping through interacting quantum dots: A perturbation expansion in the tunnel coupling — •Janine Splettstoesser[1,2], Michele Governale[2], Jürgen König[2], and Rosario Fazio[1,3] — [1]Scuola Normale Superiore, Pisa, Italy — [2]Theoretische Physik III, Ruhr-Universität Bochum, Germany — [3]SISSA, Trieste, Italy

We present a diagrammatic real-time approach [1,2] to adiabatic pumping of electrons through interacting quantum dots. Performing a systematic perturbation expansion in the tunnel-coupling strength, we compute the charge pumped through a single-level quantum dot per pumping cycle. The combination of Coulomb interaction and quantum fluctuations, accounted for in contributions of higher order in the tunnel coupling, modifies the pumping characteristics via an interaction-dependent renormalization of the quantum-dot level. The latter is even responsible for the *dominant* contribution to the pumped charge when pumping via time-dependent tunnel-coupling strengths.[3]

[1] J. König, H. Schoeller, and G. Schön, Phys. Rev. Lett.**76**, 1715 (1996). [2] J. König, J. Schmid, H. Schoeller, and G. Schön, Phys. Rev. B **54**, 16820 (1996). [3] J. Splettstoesser, M. Governale, J. König, R. Fazio, Phys. Rev. B **74**, 085305 (2006).

TT 18.7 Wed 15:30 H19

Adiabatic Pumping through Metallic Single-Electron Devices — •Nina Winkler, Michele Governale, and Jürgen König — Institut für Theoretische Physik III · Ruhr-Universität Bochum

In a mesoscopic system a DC current can be generated even at zero bias voltage by periodically changing some of its properties in time. This transport mechanism is called pumping. If the time dependence of the parameters is slow compared to the internal time scales of the system, pumping is adiabatic.

In analogy to Ref. [1], we develop a diagrammatic real-time approach to adiabatic pumping through a system of tunnel-coupled metallic islands, performing a systematic perturbative expansion in powers of the tunnel-coupling strengths. This method allows us to identify the different physical processes which contribute to the pumped charge.

We first apply our formalism to a single-electron transistor consisting of one metallic island with Coulomb interaction tunnel coupled to two non-interacting leads. We compute the pumped charge up to first order in the tunnel-coupling strength, finding that the contribution in first order is due to the renormalisation of the charging-energy gap. For the case of pumping with the two tunnel-coupling strengths, this term becomes the dominant one. Furthermore, we consider pumping with the charging-energy gaps in a system consisting of two tunnel-coupled metallic islands. We calculate the pumped charge through this system, and investigate the issue of pumped-charge quantisation.

[1] J. Splettstoesser, M. Governale, J. König, and R. Fazio, Phys. Rev. B **74**, 085305 (2006).

15 min. break

TT 18.8 Wed 16:00 H19

Nonadiabatic electron heat pump — •Sigmund Kohler[1], Michael Strass[1], Peter Hänggi[1], Miguel Rey[1,2], and Fernando Sols[3] — [1]Institut für Physik, Universität Augsburg — [2]Universidad Autónoma de Madrid, Spain — [3]Universidad Complutense de Madrid, Spain

When operating a quantum pump in the nonadiabatic regime, electrons can absorb photons and, thus, be scattered to states with a higher energy. Such processes may create thermal energy in the attached leads. At non-zero temperature, also the opposite is possible, namely substantial scattering to low-energy states. Thus the question arises whether in principle it is possible to achieve cooling in that way. We propose a setup in which the energy balance in one lead is indeed negative, which amounts to cooling the lead. This “quantum refrigerator” can operate at zero net electrical current as it replaces hot by cold electrons through two energetically symmetric inelastic channels. We present numerical results for a specific heterostructure and discuss general trends.

[1] M. Rey, M. Strass, S. Kohler, P. Hänggi, and F. Sols, cond-mat/0610155.

TT 18.9 Wed 16:15 H19

Linear and nonlinear transport across carbon nanotube quantum dots — •Leonhard Mayrhofer and Milena Grifoni — Theoretische Physik, Universität Regensburg, 93040 Regensburg, Germany

We present a low energy-theory for non-linear transport in finite-size interacting single-wall carbon nanotubes. It is based on a microscopic model for the interacting p_z electrons and successive bosonization. We consider weak coupling to the leads and derive equations of motion for the reduced density matrix. We focus on the case of large-diameter nanotubes where exchange effects can be neglected. In this situation the energy spectrum is highly degenerate. Due to the multiple degeneracy, diagonal as well as off-diagonal (coherences) elements of the density matrix contribute to the nonlinear transport. At low bias, a four-electron periodicity with a characteristic ratio between adjacent peaks is predicted. Our results are in quantitative agreement with recent experiments.

[1] L. Mayrhofer, M. Grifoni, Phys. Rev. B **74**, 121403(R) (2006).
[2] L. Mayrhofer, M. Grifoni, cond-mat/0612286 (2006).

TT 18.10 Wed 16:30 H19

Transport properties of double-wall nanotubes in parallel magnetic field — •Magdalena Marganska, Shidong Wang, and Milena Grifoni — Institut für Theoretische Physik, Universität Regensburg, 93040 Regensburg, Germany

We study the quantum transport in disorder-free double-wall carbon nanotubes in the presence of a parallel magnetic field. The diffusion exponent, both spectrum-averaged and as a function of energy is obtained by calculating the multi-fractal dimension of the energy spectrum in the corresponding energy range. In the absence of the magnetic field the spreading of a wave packet along the nanotube can be ballistic or anomalous diffusive depending on the degree of incommensurability between shells and on the considered energy range. The coupling between shells is modified by the magnetic field via the Peierls phase, which causes a change in the energy spectrum. This has a complex structure, periodic in B, which depends on the relative chiralities of the shells.

TT 18.11 Wed 16:45 H19

Commensurate-incommensurate transition in 1D Coulomb drag — •Markus Garst[1], Leonid Glazman[2], and Ady Stern[3] — [1]Institut für Theoretische Physik, Universität zu Köln, 50937 Köln — [2]Theoretical Physics Institute, University of Minnesota, Minneapolis, MN 55455, USA — [3]Department of Condensed Matter Physics, The Weizmann Institute of Science, Rehovot 76100, Israel

Coulomb interaction between electrons of two parallel conducting wires results in a drag effect which is able to reveal various strong interaction effects. When the electron densities in the two wires are commensurate the system is unstable with respect to the formation of an interwire charge density wave (CDW). If the difference of electron densities exceeds a critical value the system undergoes a commensurate-incommensurate quantum phase transition, which can be tuned for example by an external gate voltage. We identify the critical theory governing this transition. We calculate the critical Coulomb drag effect and find that the drag resistance is given by an universal function of temperature and commensurability.

TT 18.12 Wed 17:00 H19

The conductance of a multi-mode ballistic ring: Beyond Landauer and Kubo — •Swarnali Bandopadhyay[1], Yoav Etzioni[2], and Doron Cohen[2] — [1]MPIPKS Dresden, Nöthnitzer Str. 38, 01187 Dresden — [2]Department of Physics, Ben-Gurion University, Beer-Sheva 84105, Israel

The calculation of the conductance of ballistic rings requires a theory that goes well beyond the Kubo-Drude formula [S. Bandopadhyay, Y. Etzioni and D. Cohen, Europhys. Lett. 76, 739 (2006)]. Assuming mesoscopic circumstances of very weak environmental relaxation, the conductance is much smaller compared with the naive expectation. Namely, the electro-motive force induces an energy absorption with a rate that depends crucially on the possibility to make connected sequences of transitions. Thus the calculation of the mesoscopic conductance is similar to solving a percolation problem. The percolation is in energy space rather than in real space. Non-universal structures and sparsity of the perturbation matrix cannot be ignored. The latter are implied by lack of quantum-chaos ergodicity in ring shaped ballistic devices.