TT 5 Transport: Nanoelectronics I - Quantum Dots, Wires, Point Contacts - Part 1

Time: Monday 09:30–13:00 Room: HSZ 304

Invited Talk

TT 5.1 Mon 09:30 HSZ 304

Correlation effects on electronic transport through dots and wires — •Volker Meden — Institut für Theoretische Physik, Universität Göttingen

We investigate how two-particle interactions affect the electronic transport trough several meso- and nanoscopic systems made of two building blocks: quasi one-dimensional quantum wires of interacting electrons and quantum dots with local Coulomb correlations. A recently developed functional renormalization group scheme is used that includes the essential aspects of Tomonaga-Luttinger liquid physics (one-dimensional wires) as well as of the physics of local correlations, with the Kondo effect being an important example. We describe the appearance of a variety of surprising correlation effects. (1) For a Y-junction of wires pierced by a magnetic flux we find a regime in which correlations restore time-reversal symmetry. (2) We investigate the interplay of Tomonaga-Luttinger physics and the Kondo effect in transport through a single site dot with interacting leads. Studied separately, the first leads to a sharp Lorentz-like resonance in the gate voltage dependence of the linear conductance while the latter implies a broad plateau-like resonance. (3) We find a pair of novel correlation induced resonances in the gate voltage dependence of the linear conductance through a parallel double-dot systems that results from the interplay of correlations and quantum interference. It should be observable in experiments on the basis of presently existing double-dot setups. An outlook on future application of the functional renormalization group scheme in mesoscopic physics is given.

TT 5.2 Mon 10:00 HSZ 304

Two-electron entanglement in double quantum dots with Coulomb and spin-orbit interaction — •S. Weiss, M. Thorwart, and R. Egger — Heinrich-Heine Universität Düsseldorf

We investigate the entanglement of two-particle electronic charge states in vertical double quantum dots in presence of the Coulomb and spin-orbit interaction. Upon using exact diagonalization, the spectrum and the eigenvectors of the Hamiltonian are obtained as a function of all the model parameters. The entanglement is quantified in terms of the Peres-Horodecki measure which follows immediately from the density operator of the system. Interestingly enough, we find a non-monotonous dependence of the entanglement on the Coulomb interaction strength. Depending on the tunneling amplitude between the two dots, we even find a suppression of the entanglement for large Coulomb interaction and for intermediate tunneling couplings. This counterintuitive behavior can be explained by the confinement of the electrons in the dots.

[1] S.Weiss, M. Thorwart and R. Egger, submitted.

TT 5.3 Mon 10:15 HSZ 304

Cotunneling and renormalization effects in the thermopower of a single-electron transistor — •Björn Kubala and Jürgen König — Institut für Theoretische Physik III, Ruhr-Universität Bochum, D-44780 Bochum, Germany

We study thermal conductance and thermopower of a metallic single-electron transistor (SET) within a perturbative real-time theory. Like the conductance, the thermal conductance of an SET is governed by Coulomb blockade physics at low temperatures. The (Coulomb-) oscillations of thermopower with varying gate voltage have been studied, considering sequential [1] and cotunneling [2] processes.

We investigate thermopower by performing a systematic perturbative calculation of the (thermal) conductance including sequential tunneling and cotunneling as well as terms capturing the renormalization of system parameters by quantum fluctuations. As thermopower constitutes a direct measure of the average energy of transported particles, we predict, that the logarithmic reduction of the Coulomb blockade gap due to a multi-channel Kondo-effect can be accessed in thermopower measurements.

[1] A. A. M. Staring, L. W. Molenkamp, B. W. Alphenhaar, H. van Houten, O. J. A. Buyk, M. A. A. Mabesoone, C. W. J. Beenakker, and C. T. Foxon, Europhys. Lett. 22, **57** (1993).
[2] M. Turek and K. A. Matveev, Phys. Rev. B **65**, 115332 (2002).

TT 5.4 Mon 10:30 HSZ 304

Aharonov-Bohm Interferometry with Quantum Dots — •Stefan Legel[1], Jürgen König[2], and Gerd Schön[1,3] — [1]Universität Karlsruhe — [2]Ruhr-Universität Bochum — [3]Forschungszentrum Karlsruhe, Institut für Nanotechnologie

We study electron transport through a closed Aharonov-Bohm interferometer containing two single-level quantum dots. We address the question how Coulomb interaction on the dots affects the coherence of the transport. The method of real-time transport theory enables us to treat these systems both in equilibrium as well as in non-equilibrium. A perturbation expansion in the coupling strength of the quantum dots to the leads allows us to make predictions for the signatures of quantum interference in the conductance of the considered systems in first and second order (so-called cotunneling) in the coupling strength.

TT 5.5 Mon 10:45 HSZ 304

Non-local effects in transport through coupled quantum dots — •Jasmin Aghassi[1,2], Axel Thielmann[1,2], Matthias Hettler[1], and Gerd Schön[1,2] — [1]Forschungszentrum Karlsruhe, INT, Postfach 3640, 76021 Karlsruhe — [2]Institut für Theoretische Festkörperphysik, Universität Karlsruhe, 76128 Karlsruhe

We study current and shot noise in sequential tunneling through non-local systems such as two and three coupled quantum dots ("artificial molecules"). The dots are fully coherent among each other and weakly coupled to the electrodes via the interfacial dots. In the case of two coupled quantum dots various sources of asymmetry, i.e. non-resonant dots or asymmetric couplings lead eventually to super-Poissonian noise and negative differential counductance above the sequential tunneling threshold. In contrast, the three dot system displays interesting super-Poissonian behavior even in fully symmetric situations due to a complex spin-related mechanism. Fano factors may thus be largely enhanced up to values of 100. Such strong enhancement should allow direct experimental detection of shot noise in lateral quantum dot experiments. Within our diagrammatic approach we further discuss the influence of cotunneling processes on the transport characteristics in these non-local systems.

[1] J. Aghassi, A. Thielmann, M.H. Hettler, and G. Schön, cond-mat/0505345

TT 5.6 Mon 11:00 HSZ 304

Electron pumping in periodic fields — •Stefan Kurth[1], Angel Rubio[2], and E.K.U. Gross[1] — [1]Institute for Theoretical Physics, Free University Berlin, Berlin, Germany — [2]Donostia International Physics Center, San Sebastian/Donostia, Spain

Using our recently developed algorithm for the time-dependent description of transport(Phys. Rev. B **72**,035308 (2005)) we study pumping of electrons between two reservoirs at the same chemical potential. Pumping is achieved by applying a spatially inhomogeneous perturbation which is periodic in time. The flexibility of the algorithm, which is based on the time evolution of the Schrödinger equation, allows us to study pumping in the linear and nonlinear, adiabatic and non-adiabatic regimes. For perturbations with the shape of a travelling wave, electrons are transferred in packets moving with the minima of the wave.

— 15 min. break —

TT 5.7 Mon 11:30 HSZ 304

Adiabatic Pumping through Interacting Quantum Dots — •Janine Splettstoesser[1,2], Michele Governale[1,2], Jürgen König[2], and Rosario Fazio[1] — [1]Scuola Normale Superiore, Piazza dei Cavalieri, I-56126 Pisa — [2]Institut für Theoretische Physik, Ruhr-Universität Bochum, D-44780 Bochum

By periodically changing in time some parameters of a conductor a DC current can be produced without applying a bias voltage. This effect is known as *pumping*. In case of non-interacting electrons Brouwer's formula provides a general framework for the computation of the pumped charge [1]. The situation is profoundly different for pumping through interacting systems. In fact, there are only few works that address this problem with methods suited to tackle specific systems/regimes. We present a general formalism to study adiabatic pumping through interacting quantum dots. We derive a formula that relates the pumped charge to the local, instantaneous Green's function of the dot. This formula is then applied to the infinite-U Anderson model both for weak and strong tunnel-coupling strengths [2].

[1] P. W. Brouwer, Phys. Rev. B **58**, R10135 (1998).
[2] J. Splettstoesser, M. Governale, J. König, R.Fazio, cond-mat/0506080 (2005), to be published in PRL.

TT 5.8 Mon 11:45 HSZ 304

Non-adiabatic electron pumping: Maximal current with minimal noise — •Sigmund Kohler, Michael Strass, and Peter Hänggi — Institut für Physik, Universität Augsburg, 89135 Augsburg

The noise properties of pump currents through an open double quantum dot setup with non-adiabatic ac driving are investigated. Driving frequencies close to the internal resonances of the double-dot system mark the optimal working points at which the pump current assumes a maximum while its noise power exhibits a remarkably low minimum. Within a rotating-wave approximation, we derive for the current and its noise power analytical expressions, which allow to optimize the pump. For an inter-dot tunneling larger than the coupling between the dots and the electrodes, we find that the current noise is significantly below the shot noise level [1]. The analytical results are compared against numerically exact results from a Floquet transport theory [2]. The role of electron-electron interactions is studied within a master equation formalism.

[1] M. Strass, P. Hänggi, S. Kohler, Phys. Rev. Lett. **95**, 130601 (2005).
[2] S. Kohler, J. Lehmann, P. Hänggi, Phys. Rep. **406**, 379 (2005).

TT 5.9 Mon 12:00 HSZ 304

Coulomb blockade (CB) and Andreev reflection (AR) in a series of two quantum-point contacts (QPCs) — •Ursula Schröter, Olivier Schecker, and Elke Scheer — FB Physik, Universität Konstanz, 78457 Konstanz

Merging a Green's functions method and a rate equation technique we developed a model to calculate current-voltage characteristics (IVs) of a series of two QPCs in the normal and the superconducting state. Between the two junctions is a bulk-like metallic island of, however, such small capacitance that the potential shifts considerably with each single excess charge. Our method is valid for arbitrary transmissions of the transport channels in both contacts and multiple AR are included. Interaction between transport processes in both junctions is assumed via the island charging only, but our approach allows extension to maintaining coherence over the whole system.

Based on wave-function overlaps our calculations for QPCs predict qualitatively different behavior from models relying purely on energy conservation and typically used to describe tunnel diodes, even in the low transmission regime. Different conditions have to be fulfilled for particular transport processes to occur. These multiple conditions involve the island charging energy and, in the superconducting state, the gap of the material. Steps in the IVs can be explained in an intuitive energy-level picture. Furthermore we find that multiple AR in the first junction are not necessarily suppressed due to CB by the presence of a second junction of low transmission.

TT 5.10 Mon 12:15 HSZ 304

Transport of interacting electrons through quantum point contacts — •Andreas Lassl, Peter Schlagheck, and Klaus Richter — Institut für Theoretische Physik, Universität Regensburg

We investigate the influence of interaction effects on the electronic transport properties of two-dimensional nanostructures. For our numerical studies we use a self-consistent iteration scheme based on the nonequilibrium Green function formalism. This allows us to include electron-electron interactions on the level of a mean-field description for the spin-dependent conductance. For transport through point contacts we show how short-range interactions can cause an asymmetry in the transmission of different spin directions leading to anomalous conductance steps which resemble the so-called "0.7 anomaly"[1].

[1] K.J. Thomas, J.T. Nicholls, M.Y. Simmons, M. Pepper, D.R. Mace, D.A. Ritchie, Phys. Rev. Lett. **77**, 135 (1996)

TT 5.11 Mon 12:30 HSZ 304

Transport through Interacting Quantum Wires with Impurities: Influence of Tunneling Barriers on Power Laws. — •Severin Jakobs[1], Tilman Enss[2], Volker Meden[3], and Herbert Schoeller[1] — [1]Institut für Theoretische Physik A, RWTH Aachen, D-52056 Aachen, Germany — [2]Max-Planck-Institut für Festkörperforschung, D-70569 Stuttgart, Germany — [3]Institut für Theoretische Physik, Universität Göttingen, D-37077 Göttingen, Germany

We theoretically analyze the conductance through an interacting quantum wire with impurities, and its dependence on temperature and voltage. The wire is modelled by a tight-binding-chain including nearest neighbour interaction. For calculating the transport properties, we use a functional renormalization group method recently developed for the analysis of linear transport through quantum wires [1], and a generalization of this technique to nonlinear transport. We find that the power laws predicted by bosonization for the current vs. temperature or the current vs. voltage [2] are eliminated if tunneling barriers separate the wire from the leads. This behaviour can be traced back to the scaling of the height and width of the single peaks of transmission.

[1] V.Meden et al., Phys.Rev.B **65**, 045318 (2002)
[2] C.L.Kane, M.P.A.Fisher, Phys.Rev.B **46**, 15233 (1992)

TT 5.12 Mon 12:45 HSZ 304

Photo-assisted transport in the Luttinger Liquid with weak disorder — •Dmitry Bagrets — Institut für Theoretische Festkörperphysik, Universität Karlsruhe, D-76128, Karlsruhe, Germany

We consider a photo-assisted transport through a one-dimensional interacting wire (Luttinger Liquid) with a weak disorder. The photo-assisted conductance, current shot noise and generally the full counting statistics (FCS) of charge transfer are evaluated under the presence of alternating bias voltage of the form $V(t) = V_{dc} + V_{ac}\cos(\Omega t)$, Ω being a driven frequency. The Coulomb interaction is treated exactly, while the backscattering due to impurities is considered in the second order Born approximation. The FCS of backscattering current is a bidirectional Poissonian process. In the limit of large Ω and dc applied voltage V_{dc} as compared to the Thouless energy of the wire the differential conductance and photo-assisted shot noise exhibit a series of power low singularities of the form $\sim |n\Omega - eV_{dc}|^{g-1}$ as a function of dc voltage, where $g < 1$ is the interaction constant in the wire. The experimental verification of this phenomenon is feasible in the 10-20 GHz range of Ω with the use of V-groove and cleaved edge overgrowth GaAs nanowires.