TT 6: Transport: Nanoelectronics I - Quantum Dots, Wires, Point Contacts 1

Time: Monday 9:30–13:00 Location: BH 334

TT 6.1 Mon 9:30 BH 334

Transport through multiple quantum dots coupled to superconducting leads — •Sebastian Pfaller and Milena Grifoni — Institut für Theoretische Physik, Universität Regensburg

We present a microscopic theory of transport through quantum dot set-ups coupled to superconducting leads. We derive a master equation for the reduced density matrix to lowest order in the tunneling Hamiltonian and focus on quasi-particle tunneling. In particular, we apply the theory to a quantum double dot with independently gated dots; considering the dots in series as well as in parallel configuration. Negative differential conductance, as well as the expected gap of the Coulomb diamonds proportional to the superconducting gap, are observed. Moreover, a current flows in the Coulomb blockade region due to thermally excited quasiparticles. These thermal excitations can be used to identify transitions through excited states in the "honeycomb" shaped stability diagrams.

TT 6.2 Mon 9:45 BH 334

Geometric phases in adiabatically driven, interacting quantum dots out of equilibrium — •Hernan L. Calvo[1,2], Janine Splettstoesser[1,2], and Maarten R. Wegewijs[1,2,3] — [1]Institut für Theorie der Statistischen Physik, RWTH Aachen University, 52056 Aachen, Germany — [2]JARA-Fundamentals of Future Information Technology — [3]Peter Grünberg Institut, Forschungszentrum Jülich, 52425 Jülich, Germany

Geometric phases arise in the quantum state of a system whose parameters are slowly varied along a closed contour, e.g. a quantum dot in a rotating magnetic field. In this work, we present a novel, generally applicable quantum transport theory for adiabatically driven, strongly interacting nanosystems characterized by non-trivial geometric phases in their dynamics. We account exactly for the local many-body interaction and applied non-linear voltages on a general type of quantum dot. We develop a perturbation theory in the tunnel coupling to the electrodes where the crucial ingredient is the time-dependent modulation of both the quantum energies (dynamical phases) as well as the wave functions (inducing geometric phases), both in the quantum dot and / or the reservoirs. We discuss the transport properties of such devices where the experimental signatures of geometric phases appear in the charge and spin pumping induced by the time-dependent parameters.

TT 6.3 Mon 10:00 BH 334

Influence of Coulomb interaction on the Aharonov-Bohm effect in an electronic Fabry-Pérot interferometer — •Stéphane Ngo Dinh[1] and Dmitry Bagrets[2,3] — [1]Institut für Theorie der Kondensierten Materie and DFG Center for Functional Nanostructures, Karlsruhe Institute of Technology, 76128 Karlsruhe, Germany — [2]Institut für Nanotechnologie, Karlsruhe Institute of Technology, 76021 Karlsruhe, Germany — [3]Institut für Theoretische Physik, Universität zu Köln, Zülpicher Str. 77, 50937 Köln, Germany

We study the role of Coulomb interaction in an electronic Fabry-Pérot interferometer (FPI) realized with chiral edge states in the integer quantum Hall regime in the limit of weak backscattering.

Assuming that a compressible Coulomb island in a bulk region of the FPI is formed, we develop a capacitance model which explains the plethora of experimental data on the flux and gate periodicity of conductance oscillations. It is also shown that a suppression of finite-bias visibility stems from a combination of weak Coulomb blockade and a nonequilibrium dephasing by the quantum shot noise.

TT 6.4 Mon 10:15 BH 334

Single-particle interference versus two-particle collisions — •Stefan Juergens[1], Janine Splettstoesser[1], and Michael Moskalets[1,2] — [1]Institut für Theorie der Statistischen Physik, RWTH Aachen University — [2]Department of Metal and Semic. Physics, NTU "Kharkiv Polytechnical Institute", Ukraine

In mesoscopics the particle- and wave-like nature of the electrons usually appears in separate setups. The discreteness of the charge leads e.g. to the well-known Coulomb blockade effect in quantum dots, while the wave-like behavior of an electron is manifested in the single-particle interference leading to Aharonov-Bohm (AB) oscillations of the current through a ring. Recently, tunable single-electron sources, supplying particles one by one, have been realized in the QHE regime [1]. Here we make use of these sources in order to propose and theoretically discuss a mesoscopic circuit in which the particle- and wave-like nature of electrons can be observed in the same setup. It comprises of two sources emitting particles into a Mach-Zehnder interferometer penetrated by a magnetic flux [2]. We show that when synchronizing the sources, on one hand the time-resolved current always shows an interference pattern, indicating the wave-like behavior of electrons. In contrast, whether the detected charge shows the AB effect depends on the occurrence of collisions between particles, emitted from the two different sources, at the interferometer's output. This ability to collide allows for an interpretation based on the particle nature of electrons.

[1] G. Fève et al, Science 316, 1169 (2007)
[2] S. Juergens, J. Splettstoesser, M. Moskalets, EPL 96, 37011(2011)

TT 6.5 Mon 10:30 BH 334

Finite size effects on transport coefficients for models of atomic wires coupled to phonons — •Christian Bartsch — Institute for Theoretical Physics, Technical University Braunschweig, D-38106 Braunschweig

We consider models of quasi-1-d, planar atomic wires consisting of several, laterally coupled rows of atoms, with mutually non-interacting electrons. This electronic wire system is coupled to phonons, corresponding, e.g., to some substrate. We aim at computing diffusion coefficients in dependence on the wire widths and the lateral coupling. To this end we firstly construct a numerically manageable linear collision term for the dynamics of the electronic occupation numbers by following a certain projection operator approach. By means of this collision term we set up a linear Boltzmann equation. A formula for extracting diffusion coefficients from such Boltzmann equations is given. We find in the regime of a few atomic rows and intermediate lateral coupling a significant and non-trivial dependence of the diffusion coefficient on both, the width and the lateral coupling. These results, in principle, suggest the possible applicability of such atomic wires as electronic devices, such as, e.g., switches.

TT 6.6 Mon 10:45 BH 334

Even-odd effect in the thermopower of superconducting single-electron transistors — •Jens Siewert[1,2] and Christopher Eltschka[3] — [1]Departamento de Química Física, Universidad del País Vasco, 48080 Bilbao, Spain — [2]Ikerbasque, Basque Foundation for Science, 48011 Bilbao, Spain — [3]Institut für Theoretische Physik, Universität Regensburg, 93040 Regensburg, Germany

We study charge and heat transport in single-electron transistors with a superconducting island and normal-conducting leads (NSN SET). Below a crossover temperature T^* the transport properties of this device depend on the parity of the island charge number, *i.e.*, whether *all* electrons are paired in Cooper pairs or whether there is a single unpaired electron [1]. While this effect has been described for the current-voltage characteristics of NSN SET, we show that even-odd effects manifest themselves also in the thermopower. Our results can be understood by applying an idea due to Matveev [2]. A particularly interesting finding is that the thermoelectric efficiency ZT may grow dramatically (up to 10^3 for realistic parameters) for such devices.

[1] M.T. Tuominen, J.M. Hergenrother, T.S. Tighe, and M. Tinkham, Phys. Rev. Lett. **69**, 1997 (1992).
[2] K.A. Matveev, Statistical and Dynamical Aspects of Mesoscopic Systems. Proceedings of the XVI Sitges Conference on Statistical Mechanics (2000).

15 min. break.

TT 6.7 Mon 11:15 BH 334

Zero-frequency noise in adiabatically driven quantum systems — •Roman-Pascal Riwar[1,2], Janine Splettstoesser[1,2], and Jürgen König[3] — [1]Institut für Theorie der Statistischen Physik, RWTH Aachen University, D-52056 Aachen, Germany — [2]JARA-Fundamentals of Future Information Technology — [3]Theoretische Physik, Duisburg-Essen and CeNIDE, D-47048 Duisburg, Germany

We investigate current-current correlations of adiabatic quantum pumps, taking into account Coulomb interaction. We make use of a real-time diagrammatic approach within a perturbative expansion in the tunnel coupling to the reservoirs and extend a treatment of

adiabatic time dependence (Splettstoesser et al., PRB 2006) to the calculation of current noise.

We consider the case of a single-level quantum dot coupled to two leads where charge pumping arises by applying two out-of-phase time-dependent parameters, such as the energy levels, the bias or the tunnel couplings. While the instantaneous contribution to the noise confirms the results of the stationary case (Thielmann et al., PRL 2005), new properties are found in the adiabatic correction, i.e., the pumping noise. If the leads are at equilibrium at any time, the adiabatic correction of the Fano factor has a stable shape independently of the choice of the pumping parameters, also beyond the sequential tunneling regime. It provides additional information on the tunnel-coupling and the electron-hole symmetric point. When including a time-dependent finite bias, we find that there can be pumping noise even if there is zero pumped charge, due to a finite tunnel coupling asymmetry.

TT 6.8 Mon 11:30 BH 334

Influence of interaction-induced dephasing on the ac-conductivity of disordered metals — •Martin Schäffer, Maximilian Treiber, Oleg Yevtushenko, and Jan von Delft — Physics Department, Arnold Sommerfeld Center for Theoretical Physics, and Center for NanoScience, Ludwig-Maximilians-Universität München, D-80333 München, Germany

We consider the influence of electron-interactions on the weak-localization (WL) correction to the ac-conductivity of disordered metals. It is well known that both an external ac-frequency and an interaction induced dephasing rate can govern the infrared behavior of the WL, but their interplay has never been studied in detail. One reason for this is that previous calculations had to employ a self-consistent regularization scheme which may lead to inaccurate results. Here, we adopt the diagrammatic approach developed in Ref.[1], which is free of both infrared and ultraviolet divergences since it includes so-called vertex diagrams. We analyze how this approach is modified at finite ac-frequencies and determine the leading cross- contributions for metals of arbitrary dimensionality. Furthermore, we discuss the effect of a finite system size (including the crossover to the so-called 0D regime of dephasing) on the interplay.

TT 6.9 Mon 11:45 BH 334

Bunching and anti-bunching in electronic transport — •Christina Pöltl, Clive Emary, Alexander Carmele, Julia Kabuss, Andreas Knorr, and Tobias Brandes — Institut für Theoretische Physik, Hardenbergstr. 36, TU Berlin, D-10623 Berlin, Germany

Current noise has long-since been established as an important tool for studying the physics of transport through mesoscopic and nano-scale conductors. The character of the current noise is typically assessed by considering the Fano factor, the ratio of the zero-frequency noise to the steady state current, and comparing with a Poisson process for which the Fano factor is equal to one. Systems with $F < 1$ are described as sub-Poissonian and systems which have $F > 1$ are called super-Poissonian. The standard physical interpretation of this comparison is that super-Poissonian Fano factors indicate a bunching of electrons which tunnel out of the conductor, whereas sub-Poissonian values indicates anti-bunching.

We directly investigate bunching and anti-bunching in electronic transport as a phenomenon in the time domain through the introduction of a second-order correlation function $g^{(2)}(\tau)$, analogous to that found in quantum optics. Our analysis shows that the simple picture relating super-Poissonian Fano factors to bunching and sub-Poissonian ones to anti-bunching is an oversimplification. Timescales can be found for which the electrons bunch, even though the Fano factor is sub-Poissonian and conversely.

TT 6.10 Mon 12:00 BH 334

Highly efficient Cooper pair splitting with carbon nanotube quantum dots — •Jens Schindele, Andreas Baumgartner, and Christian Schönenberger — Department of Physics, University of Basel, Klingelbergstrasse 82, CH-4056 Basel, Switzerland

An elegant idea for the creation of entangled electrons in a solid-state device is to split spin-singlet Cooper pairs by coupling a superconductor to two parallel quantum dots (QDs) in a Y-junction geometry [1]. Such Cooper pair splitting (CPS) was successfully detected in recent transport experiments on devices based on InAs nanowires [2,3] and Carbon nanotubes (CNTs) [4].

Here we present experiments on a CNT based Cooper pair splitter device with low inter-dot tunnel coupling. We find an unprecedented splitting efficiency, often much larger than 50

A high CPS efficiency is a prerequisite for Bell state measurements, a clear way of proving that Cooper pairs can be extracted coherently and lead to spatially separated entangled electron pairs.

[1] Recher et al., Phys. Rev. B 63, 165314 (2001)
[2] Hofstetter et al., Nature 461, 960-963 (2009)
[3] Hofstetter et al., Phys. Rev. Lett. 107, 136801 (2011)
[4] Herrmann et al., Phys. Rev. Lett. 104, 026801 (2010)
[5] Burset et al., Phys. Rev. B 84, 115448 (2011)

TT 6.11 Mon 12:15 BH 334

Carbon nanotubes with metallic contacts: energy and spin-orbit dependence of the tunneling rates — •Magdalena Marganska and Milena Grifoni — Institute for Theoretical Physics, University of Regensburg, 93053 Regensburg, Germany

A microscopic approach to evaluate tunneling rates between a carbon nanotube and a metallic lead is presented. We show that the magnitude of the tunneling rate not only depends on the energy of the tunneling electron, but also on specific carbon nanotube features, such as its chiral angle and size. The latter in turn determine its curvature and the strength of the spin-orbit coupling. As a consequence, we predict different tunneling rates when tunneling in or out of the spin-orbit-split doublet states.

TT 6.12 Mon 12:30 BH 334

Coherence of single-electron sources from Mach-Zehnder interferometry — •Geraldine Haack[1], Michael Moskalets[2], Janine Splettstoesser[3], and Markus Buettiker[1] — [1]University of Geneva, Geneva, Switzerland — [2]Kharkiv Polytechnic Institute, Kharkiv, Ukraine — [3]RWTH Aachen University, Aachen, Germany

A new type of single electron sources (SES) has emerged which permits to inject single particles in a controllable manner into an electronic circuit. Multiparticle exchange, two-particle interference effects and entanglement have already been proposed [1]. Here we determine the coherence length of the single-particle states analyzing the decay of Aharonov-Bohm oscillations as a function of the imbalance of a Mach-Zehnder interferometer connected to an SES [2]. This single-particle coherence length is of particular importance as it is an intrinsic property of the source in contrast to the dephasing length.

[1] J. Splettstoesser, M. Moskalets, M. Buettiker, PRL 103, 076804 (2009).
[2] G. Haack, M. Moskalets, J. Splettstoesser, M. Buettiker, PRB 84, 081303(R) (2011).

TT 6.13 Mon 12:45 BH 334

Inhomogeneous Spin Chains and Luttinger Liquids — •Nicholas Sedlmayr, Jan Ohst, Jesko Sirker, and Sebastian Eggert — University of Kaiserslautern, Germany

We consider a one-dimensional spin chain with inhomogeneous coupling, which can also be modeled as an inhomogeneous Luttinger liquid. The Luttinger liquid paradigm has proved a very successful theoretical tool for investigating one-dimensional wires. However, there remain open questions about what happens when such a system becomes inhomogeneous. The mapping between the spin chain and the Luttinger liquid allows us to use a variety of methods in analyzing the problem. Of particular interest is the case where the Luttinger liquid is attached to external leads, as is necessary for example when measuring the conductance of the wire. In this paper we use an abrupt shift in the parameters of the Luttinger liquid to model these connections and see how this affects its behavior. In particular we analyze the relevant back-scattering perturbations at the connections, and identify a case where this relevant operator can be tuned to zero within an otherwise still inhomogeneous system. This of course has consequences not only for transport in the Luttinger liquid system but also for the magnetic susceptibility of the spin chain.