HL 8: Transport: Quantum dots, wires, point contacts 1 (TT, jointly with HL, O)

Time: Monday 9:30–13:00 Location: H20

HL 8.1 Mon 9:30 H20

Tunneling-induced renormalization in interacting quantum dots — •Janine Splettstoesser[1], Michele Governale[2], and Jürgen König[3] — [1]Institut für Theorie der Statistischen Physik, RWTH Aachen University — [2]School of Physical and Chemical Sciences, Victoria University of Wellington, New Zealand — [3]Theoretische Physik, Universität Duisburg-Essen, Germany

A single-level quantum dot with arbitrarily strong onsite Coulomb interaction weakly coupled to electronic reservoirs is studied. We here present an analysis of tunneling-induced quantum fluctuations, generating cotunneling processes and renormalizing system parameters. For a perturbative treatment of these quantum fluctuations in the limit of weak tunnel coupling, we remove off-shell parts of the Hamiltonian via a canonical transformation. We find that the tunnel couplings for the transitions connecting empty and single occupation respectively single and double occupation of the dot renormalize with the same magnitude but with *opposite* signs [1]. This has an important impact on the shape of the renormalization extracted for example from the conductance. Finally, we verify the compatibility of our results with a systematic second-order perturbation expansion of the linear conductance performed within a diagrammatic real-time approach.

[1] J. Splettstoesser, M. Governale, J. König, Phys. Rev. B **86**, 035432 (2012).

HL 8.2 Mon 9:45 H20

Interaction-induced charge and spin pumping through a quantum dot at finite bias — Hernan L. Calvo[1], •Laura Classen[1], Janine Splettstoesser[1], and Maarten R. Wegewijs[1,2] — [1]Institut für Theorie der Statistischen Physik, RWTH Aachen University, Germany and JARA - Fundamentals of Future Information Technology — [2]Peter Grünberg Institut, Forschungszentrum Jülich, Germany

We discuss charge and spin transport through an adiabatically driven, strongly interacting quantum dot weakly coupled to two metallic contacts with finite bias voltage. We identify coefficients of response to the time-dependent external driving and relate these to the concept of emissivity [1]. These coefficients allow for a straightforward analysis of the predicted interaction-induced pumping under periodic modulation of the gate and bias voltage [2]. We extend this adiabatic Coulomb blockade spectroscopy to spin pumping. In the absence of a magnetic field, we show a striking, simple relation between the pumped charge at zero bias and at bias equal to the Coulomb charging energy. At finite magnetic field, we discuss the possibility to have interaction-induced pure spin pumping. For large-amplitude driving, the magnitude of both the pumped charge and spin saturates at values which are independent of the specific shape of the pumping cycle. Each of these values provides an independent, quantitative measurement of the junction asymmetry.

[1] M. Büttiker, H. Thomas, and A. Prêtre, Z. Phys. B 94, 133 (1994).
[2] F. Reckermann, J. Splettstoesser, and M. R. Wegewijs, Phys. Rev. Lett. 104, 226803 (2010).

HL 8.3 Mon 10:00 H20

Structure and conductance analysis of atomic-sized contacts — •Manuel Matt[1], Fabian Pauly[1], Juan Carlos Cuevas[2], and Peter Nielaba[1] — [1]University of Konstanz, Department of Physics, 78457 Konstanz, Germany — [2]Departamento de Física Teórica de la Materia Condensada, Universidad Autónoma de Madrid, E-28049 Madrid, Spain

We study the conductance histograms of different metals such as Au and Al. Our theoretical approach combines molecular dynamics simulations of the stretching of atomic-sized wires with the non-equilibrium Green's function formalism based on the tight-binding modelling of the electronic system. As compared to pervious work [1,2], we consider substantially larger wires and explore different lattice orientations. The results show good agreement with experiments.

[1] M. Dreher, F. Pauly, J. Heurich, J. C. Cuevas, E. Scheer, and P. Nielaba, Phys. Rev. B 72, 075435 (2005)
[2] F. Pauly, M. Dreher, J. K. Viljas, M. Häfner, J. C. Cuevas, and P. Nielaba Phys. Rev. B 74, 235106 (2006)

HL 8.4 Mon 10:15 H20

Transport through two interacting resonant levels connected by a Fermi sea — •Elena Canovi, Alexander Moreno, and Alejandro Muramatsu — Institut für Theoretische Physik III, Universität Stuttgart

We study transport at finite bias, i.e. beyond the linear regime, through two interacting resonant levels connected by a Fermi sea. Our results are obtained by means of time-dependent density matrix renormalization group. We find that at finite size both the current and the occupations of the interacting levels oscillate as a function of time. We determine the amplitude and period of such oscillations as a function of bias and extension of the Fermi sea. In particular, the occupations on the two dots oscillate with a relative phase which depends on the distance between the impurities and on the Fermi momentum of the Fermi sea, as expected for RKKY interactions. The approximant to the steady-state current displays oscillations as a function of the distance between the impurities. In the free case we find that it is affected by resonances. The latter can be understood by considering the transmission coefficient of one particle propagating freely in the system. We discuss finally the incidence of interaction on such a behavior.

HL 8.5 Mon 10:30 H20

Magnon-driven quantum-dot heat engine — •Björn Sothmann and Markus Büttiker — Département de Physique Théorique, Université de Genève, CH-1211 Genève 4, Switzerland

Recently, thermoelectric effects have generated a lot of interest. In Ref. [1], transport through two capacitively coupled quantum dots in a three-terminal setup was investigated in the Coulomb-blockade regime. It was shown how such a device can convert a heat current into a directed charge current. This converter is optimal in the sense that it transfers one electron for every quantum of energy delivered by the hot dot and thus allows to reach Carnot efficiency. A generalization to systems with many transport channels was analyzed in Ref. [2].

Here, we discuss a new class of devices where a single-level quantum dot is coupled to two ferromagnetic electrodes as well as to a ferromagnetic insulator at different temperatures [3]. We demonstrate that the system can convert a magnon current into a pure electron spin current or a spin-polarized electron current depending on the magnetic configuration. We analyze the maximal output power as well as the efficiency and show that the tight-coupling limit where heat and charge currents are proportional to each other can be reached.

[1] R. Sánchez and M. Büttiker, Phys. Rev. B **83**, 085428 (2011).
[2] B. Sothmann, R. Sánchez, A. N. Jordan and M. Büttiker, Phys. Rev. B **85**, 205301 (2012).
[3] B. Sothmann and M. Büttiker, EPL **99**, 27001 (2012).

HL 8.6 Mon 10:45 H20

Iterative summation of path integrals for nonequilibrium molecular quantum transport — Roland Huetzen[1], •Stephan Weiss[1,2], Michael Thorwart[3], and Reinhold Egger[1] — [1]Heinrich-Heine Universität Düsseldorf, Universitätsstr.1, 40225 Düsseldorf — [2]Universität Duisburg-Essen and CENIDE, 47048 Duisburg — [3]Universität Hamburg, Jungiusstr. 9, 20355 Hamburg

We formulate and apply a nonperturbative numerical approach to the nonequilibrium current, $I(V)$, through a voltage-biased molecular conductor. We focus on a single electronic level coupled to an unequilibrated vibration mode (Anderson-Holstein model), which can be mapped to an effective three-state problem. Performing an iterative summation of real-time path integral (ISPI) expressions, we accurately reproduce known analytical results in three different limits. We then study the crossover regime between those limits and show that the Franck-Condon blockade persists in the quantum-coherent low-temperature limit, with a nonequilibrium smearing of step features in the IV curve.

[1] S. Weiss, J. Eckel, M. Thorwart, and R. Egger, Phys. Rev. B **77**, 195316 (2008).
[2] R. Hützen, S. Weiss, M. Thorwart, and R. Egger, Phys. Rev. B **85**, 121408 (2012).

15 min. break

HL 8.7 Mon 11:15 H20

Spin dynamics in nanoparticles near Stoner instability — •Philipp Stegmann[1], Björn Sothmann[2], Jürgen König[1], and Yuval Gefen[3] — [1]Theoretische Physik, Universität Duisburg-Essen and CENIDE, 47048 Duisburg, Germany — [2]Départment de Physique Théorique, Université de Genève, CH-1211 Genève 4, Switzerland — [3]Dept. of Condensed Matter Physics, Weizmann Institute of Science, Rehovot 76100, Israel

We analyse the spin dynamics of a nanoparticle close to the Stoner instability. The nanoparticle is weakly tunnel coupled to two ferromagnetic leads. By mapping to an effective Fokker-Planck description we identify two different types of dynamic behaviour (diffusion vs. drift), which are revealed by characteristic relaxation times and a Fano factor that oscillates as a function of an applied bias voltage. Finally, we propose biasing schemes to generate states with magnetic quadrupole moments that dominate over a negligible dipole moment.

HL 8.8 Mon 11:30 H20

Nonlinear transport through interacting quantum dots with superconducting leads in the weak coupling regime — •Sascha Ratz and Milena Grifoni — Institut für Theoretische Physik, Universität Regensburg, 93040 Regensburg, Germany

We present a nonequilibrium real-time diagrammatic transport theory for the systematic investigation of the quasiparticle and Josephson currents through a hybrid superconductor-quantum dot system in the weak coupling regime. In details, our device consists of an interacting quantum dot coupled to two biased spin-singlet superconducting leads. To describe the transport dynamics, we derive a completely general equation of motion for the reduced density matrix including all the contributions of a perturbation expansion in the tunneling Hamiltonian. Within these investigations, already in fourth order we can identify the contributions of the nonlocal time evolution kernel to the quasiparticle and DC Josephson transport. To clarify the difference between quasiparticle cotunneling and phase-coherent two-particle Andreev tunneling in fourth order, we first choose a single-level Anderson impurity model for the interacting quantum dot. In particular, one can give a clear explanation for subgap features due to proximity effects, which are also important when we finally compare our theoretical results for a carbon nanotube quantum dot with experimental observations.

HL 8.9 Mon 11:45 H20

Spindephasing and Coherent Control of an Ensemble of Quantum Dots — •Andre Jovchev and Frithjof B. Anders — Technische Universität Dortmund, Lehrstuhl für Theoretische Physik II, 44221 Dortmund, Germany

We present a numerical treatment of pump-and-probe experiments with an ensemble of singly charged quantum dots in a magnetic field. We examine the excitation of trions, which is part of an effective polarization mechanism for the spin of the residual electrons, precessing around the magnetic field vector. Inhomogeneities in the magnetic g-factor of different electrons lead to dephasing. The effect of the short pump pulses is described by a unitary operator in the subspace of a spin degenerated electron and trion. For the dynamics between the pulses we apply a Lindblad theory to describe the decoherence due to environmental effects and the hyperfine interaction of the electrons with surrounding nuclei. We study the polarization of the whole ensemble after the application of different pulse protocols, and give an explanation for the polarization of the nuclear spins, which can lead to a remarkably increase of dephasing times which were already seen in experiments.

HL 8.10 Mon 12:00 H20

Adiabatic pumping in the quasi-one-dimensional triangle lattice — Michael Schulze[1], •Dario Bercioux[1], and Daniel F. Urban[2,3] — [1]Freiburg Institute for Advanced Studies, Albert-Ludwigs-Universität, 79104 Freiburg, Germany — [2]Physikalisches Institut, Albert-Ludwigs-Universität, 79104 Freiburg, Germany — [3]Fraunhofer Institute for Mechanics of Materials IWM, Wöhlerstraße 11, 79108 Freiburg, Germany

We analyze the properties of the quasi-one-dimensional triangle lattice emphasizing the occurrence of flat bands and band touching via the tuning of the lattice hopping parameters and on-site energies [1]. The spectral properties of the infinite system will be compared with the transmission through a finite piece of the lattice with attached semi-infinite leads. Furthermore, we investigate the adiabatic pumping [2] properties of such a system: depending on the transmission through the lattice, this results in nonzero integer charge transfers or transfers that increase linearly with the lattice size.

[1] M. Schulze, D. Bercioux, D. F. Urban, arXiv:1208.6113.
[2] P. W. Brouwer, Phys. Rev. B **58**, 10135(R) (1998).

HL 8.11 Mon 12:15 H20

Thermoelectric efficiency of a driven double quantum dot — •Federica Haupt[1], Stefan Juergens[1], Michael Moskalets[2], and Janine Splettstoesser[1] — [1]RWTH Aachen University, Aachen, Germany — [2]Kharkiv Polytechnical Institute, Kharkiv, Ukraine

By applying phase-shifted AC signals to the gates of two quantum dots connected in series, it is possible to transfer charge from one lead to another in a quantized way [1,2], even in the presence of an applied bias voltage or a temperature gradient. In this work we investigate the thermoelectric properties of such a double quantum dot device. We show that not only charge but also heat can be pumped in a quantized way. If the modulation frequency Ω is sufficiently small, we find regimes in which the unit of heat $2\pi k_B T \ln 2$ is transported during each period, where T is the temperature of the considered lead and the factor $\ln 2$ stems from spin degeneracy. This would open the possibility of using the pumping cycle to transfer heat against a temperature gradient or to extract work from a hot reservoir with Carnot efficiency. However, the performance of a real device is limited by dissipative effects due to leakage currents and finite time operation, which we rigorously take into account by means of a real-time diagrammatic approach in the regime of weak coupling to the leads. We show that despite these dissipative effects, efficiencies up to 70% of the maximal theoretical value can be reached.

[1] H. Pothier, *et al.*, Europhys. Lett **17**, 249 (1992)
[2] S. J. Chorley, *et al.* App. Phys. Lett. **100**, 143104 (2012).

HL 8.12 Mon 12:30 H20

Controlling entanglement and spin-correlations in double quantum dots in the non-equilibrium regime — •Carlos Alberto Büsser[1] and Fabian Heidrich-Meisner[2] — [1]Ludwig-Maximilians-Universität, München, München — [2]FAU Erlangen-Nuremberg and LMU München

We study the non-equilibrium dynamics in a parallel double-quantum dot structure induced by a large bias voltage. By applying both a magnetic flux and a voltage, it is possible to generate spin-spin-correlations between the two quantum dots. The sign and absolute value of these correlations can be controlled by changing the bias voltage. Using a canonical transformation we argue that the mechanism that drives the spin-spin correlations can be understood in terms of an effective Ruderman-Kittel-Kasuya-Yosida (RKKY) interaction that is mediated by the current. Our study is based on the Anderson-impurity model and we use time-dependent density matrix renormalization group (tDMRG) simulations to obtain currents and spin-correlations in the steady state of the non-equilibrium regime. We also perform quench in the Hamiltonian to prove the stability of the entangled state.

HL 8.13 Mon 12:45 H20

Role of coherent state superpositions in the bipolar spin blockade of a triple quantum dot — Maria Busl[1], Ghislain Granger[2], Louis Gaudreau[2], •Rafael Sánchez[1], Alicia Kam[2], Michel Pioro-Ladrière[3], Sergei Studenikin[2], Piotr Zawadzki[2], Zbigniew Wasilewski[2], Andrew Sachrajda[2], and Gloria Platero[1] — [1]Instituto de Ciencia de Materiales de Madrid (ICMM-CSIC), Madrid, Spain — [2]National Research Council Canada, Ottawa, Canada — [3]Université de Sherbrooke, Sherbrooke, Canada

In double quantum dots, Pauli spin blockade manifests as a rectified current: charge flows or is blocked depending on the sign of the applied voltage[1]. We present experimental and theoretical investigations of the equivalent process in triple quantum dots in series. We focus on a configuration where (2,0,2) (2,1,1), (1,1,2) and (2,1,2) states are degenerate. When a bias is applied in a magnetic field beyond 10mT, bipolar spin blockade is observed where current is suppressed independent of the applied bias direction. As the field is reduced to zero, leakage resonances are observed. Of special interest are two very sharp resonances which correspond to triple dot conditions when states in the left and right dot but not the center dot align. One of these resonances is found itself to involve bipolar spin blockade and is found to result from a purely quantum coherent effect: electrons occupy states that involve their transference from one extreme to the other of the triple quantum dot without ever visiting the center[2].

[1] K. Ono et al., Science 297, 1313 (2002).

[2] M. Busl et al., unpublished.