TT 9: Transport: Quantum Dots, Quantum Wires, Point Contacts I (organized by TT)

Time: Monday 9:30–13:15 Location: BEY 81

TT 9.1 Mon 9:30 BEY 81

Transport through nanostructures: Finite time vs. finite size — •Peter Schmitteckert[1], Sam Carr[2], and Hubert Saleur[3,4] — [1]Institute of Nanotechnology, Karlsruhe Institute of Technology, 76344 Eggenstein-Leopoldshafen, Germany — [2]School of Physical Sciences, University of Kent, Canterbury CT2 7NH, UK — [3]Institut de Physique Théorique, CEA, IPhT and CNRS, URA2306, 91191 Gif Sur Yvette, France — [4]Department of Physics, University of Southern California, Los Angeles, CA 90089-0484

Numerical simulations and experiments on nanostructures out of equilibrium usually exhibit strong finite size and finite measuring time t_m effects. We discuss how these affect the determination of the full counting statistics for a general quantum impurity problem [1]. We find that, while there are many methods available to improve upon finite-size effects, any real-time simulation or experiment will still be subject to finite time effects: in short **size matters**, but **time is limiting**. We show that the leading correction to the cumulant generating function (CGF) at zero temperature for single-channel quantum impurity problems goes as $\ln t_m$ and is universally related to the steady state CGF itself for non-interacting systems. We then give detailed numerical evidence for the case of the self-dual interacting resonant level model that this relation survives the addition of interactions. This allows the extrapolation of finite measuring time in our numerics to the long-time limit, to excellent agreement with Bethe-ansatz results.

[1] P. Schmitteckert, S. C. Carr, H. Saleur, arXiv:1307.7506

TT 9.2 Mon 9:45 BEY 81

Towards steady state currents on finite systems — •Tim Collet[1] and Peter Schmitteckert[2] — [1]Theoretical Condensed Matter physics, KIT — [2]Institute for Nanotechnology, KIT

The determination of transport properties of strongly correlated quantum systems by quenches in the charge imbalance is a well established technique. However, the achievable time scales are limited by the system size inducing a finite transit time. Here we present a technique in the spirit of absorbing boundary conditions. This allows to obtain steady states on a finite system and to overcome said limitation from finite transit times. We discuss the application of this concept in the context of transport through quantum impurities.

TT 9.3 Mon 10:00 BEY 81

Kwant - a software package for quantum transport — •Michael Wimmer[1], Christoph Groth[2], Anton Akhmerov[1], and Xavier Waintal[2] — [1]TU Delft, The Netherlands — [2]CEA Grenoble, France

Computing transport properties numerically is a problem that appears in many different areas of physics. I will present a wave-function based approach to computing transport properties in non-interacting tight-binding systems that scales more favourably than standard algorithms such as the recursive Green's function algorithm.

We have implemented this method in an open-source software package Kwant based on the python language. It allows for an easy definition of arbitrary tight-binding problems using intuitive concepts ("like writing the problem on the blackboard"), and allows to compute transport properties such as the conductance, but also local properties such as electron densities. The software package itself together with extensive documentation, tutorials and examples of research where Kwant has already been used can be found at www.kwant-project.org.

[1] C. W. Groth, M. Wimmer, A. R. Akhmerov, X. Waintal. arXiv:1309.2926 (2013)

TT 9.4 Mon 10:15 BEY 81

Non perturbative approach to transport through Anderson quantum dot: the influence of charge fluctuations — •Davide Mantelli and Milena Grifoni — Institut für Theoretische Physik, Universität Regensburg, D-93040 Regensburg, Deutschland

Transport through a strongly interacting Anderson quantum dot is analyzed for tunneling couplings Γ comparable or larger than the thermal energy $k_B T$. In this regime the commonly used sequential tunneling approximation, where tunneling rates are calculated to the lowest order in Γ, breaks down. By accounting for charge fluctuations accompanying the transfer of one electron onto the dot, "dressed" tunneling rates and the associated current across the dot can be calculated [1]. The difference between the standard lowest order theory and the "dressed" one is carefully analyzed in the weak ($\Gamma \ll k_B T$), intermediate ($\Gamma \simeq k_B T$) and strong ($\Gamma \gg k_B T$) coupling regimes. At low temperatures features typical of the Kondo resonance are recovered.

[1] J. Kern and M. Grifoni, Eur. Phys. J. B **86**, (2013) 384

TT 9.5 Mon 10:30 BEY 81

Energy current cotunnelling features for the Anderson quantum dot — •Niklas M. Gergs[1], Christoph B. M. Hörig[1], Dirk Schuricht[1], and Maarten R. Wegewijs[2,3,4] — [1]Institute for Theoretical Physics, Utrecht University, Netherlands — [2]Institute for Theory of Statistical Physics, RWTH Aachen University, Germany — [3]JARA–Fundamentals of Future Information Technology — [4]Peter Grünberg Institut, Forschungszentrum Jülich, Germany

We discuss the particle and energy current through an Anderson quantum dot with a strong Coulomb interaction U subject to both voltage and temperature bias. A diagrammatic perturbation theory up to second order in the tunnel rates Γ is set up in Liouville space. We find that pair tunnelling features show up in the particle and energy current, while pure inelastic cotunnelling spinflip features are absent in the energy current. The latter cotunnelling processes do appear however when assisted by sequential tunnelling (COSET). Therefore, the energy current contains more distinctive features than the particle current. Thus one can use the energy current for enhanced spectroscopy of quantum dot systems.

TT 9.6 Mon 10:45 BEY 81

Non-equilibrium transport through a Josephson quantum dot — •Jan Frederik Rentrop[1,2], Severin Jakobs[1,2], and Volker Meden[1,2] — [1]Institut für Theorie der Statistischen Physik, RWTH Aachen University, Germany — [2]JARA Fundamentals of Future Information Technology, 52056 Aachen, Germany

We investigate a quantum dot featuring Hubbard interaction coupled to superconducting leads. Applying a bias voltage across the system leads to a time-dependent periodic Hamiltonian. This implies that the observable, namely the current through the system, aquires a periodic time-dependence (AC Josephson effect). The non-equilibrium feature of so called Multiple Andreev Reflections (MAR), known from the non-interacting case, is observed in the static component of the current.

The self-energy on the dot is calculated with the functional renormalization group method. The derived first and second order truncation schemes allow for a "quasi-static" (i.e. allowing for the periodic time-dependence but not more) approximation of the self-energy. Model and method allow for asymmetric choices of the super-conducting gaps, the lead temperatures, the lead-dot couplings, tuning of the Hubbard interaction, shifting of on-site energy and applying a magnetic field. Numerical results are presented for symmetric choices at zero magnetic field and zero temperature, while lead-dot coupling, on-site energy and Hubbard interaction are tuned. Also, first order self-consistent perturbation theory results are presented as a benchmark.

We discuss limitations that the MAR physics impose on any perturbative scheme that expands in small orders of the interaction.

TT 9.7 Mon 11:00 BEY 81

Magneto-electric spectroscopy of Andreev bound states in Josephson quantum dots — •Nils Wentzell[1], Tobias Meng[2], Volker Meden[3], Sabine Andergassen[1], and Serge Florens[4] — [1]University of Vienna — [2]University of Basel — [3]RWTH Aachen University — [4]CNRS Grenoble

We theoretically investigate the behavior of Andreev levels in a single-orbital interacting quantum dot in contact to superconducting leads, focusing on the effect of electrostatic gating and applied magnetic field, as relevant for recent experimental spectroscopic studies. In order to account reliably for spin-polarization effects in presence of strong correlations, we further extend here two simple and complementary approaches that are tailored to capture effective Andreev levels: the static functional renormalization group and the self-consistent Andreev bound states theory. We provide a systematic analysis of the Andreev level spectroscopy for the full electric and magnetic tuning available in quantum dot devices.

15 min. break.

TT 9.8 Mon 11:30 BEY 81

In gap and out of gap features in the cotunneling spectroscopy of a superconductor coupled quantum dot — •Sascha Ratz and Milena Grifoni — Institute for Theoretical Physics, University of Regensburg, D-93040 Regensburg, Germany

We present a nonequilibrium real-time diagrammatic theory for the systematic investigation of low temperature quantum transport properties of a superconductor contacted quantum dot in an individual single wall carbon nanotube. In the low temperature regime particle transport is dominated by cotunneling and Andreev reflection processes. As recent experiments show, elastic/inelastic cotunneling features are clearly visible inside the Coulomb blockade regime, sharpened by the superconducting leads. The proximity induced higher order Andreev reflection processes result in subgap features, however. Temperature dependent measurements show in addition rich features inside the superconducting gap which can be attribute to thermally excited quasiparticles. More detailed experimental investigations and theoretical calculations are in progress to understand the experimental findings.

TT 9.9 Mon 11:45 BEY 81

Unconventional superconductivity in quantum dot systems — Björn Sothmann[1], •Stephan Weiss[2], Michele Governale[3], and Jürgen König[1] — [1]Departement de Physique Theorique, Universite de Geneve, Switzerland — [2]Theoretische Physik, Universität Duisburg-Essen and CENIDE, Germany — [3]School of Chemical and Physical Sciences, Victoria University of Wellington, New Zealand

Conventional superconductivity of electrons is well described in terms of the BCS theory. Fermi statistics dictates the overall symmetry of e.g. the order parameter. The single ingredients could take either symmetric or antisymmetric properties, hence spin as well as spatial degrees of freedom and time might independently change sign and unconventional pairing amplitudes emerge [1]. We show how quantum dot setups may be used to create unconventional pairing between electrons. Brought into proximity to a conventional SC, Cooper pairs tunnel into the double (quadrupel)-quantum dot (DQD/QDD) system [2,3]. Locally, manipulations of the electronic state is possible by tuning electric and/or magnetic fields. An inhomogeneous magnetic field between the dots breaks the SU(2) symmetry of the spin. This results in nonzero unconventional order parameters. We study the emergence and decay of even/odd singlet and triplet order parameters in different geometries. For DQD and QDD setups spectroscopic properties and signatures of unconventional correlations in the Andreev current are studied.

[1] F. S. Bergeret, et al., Rev. Mod. Phys. 77, 1321 (2005).
[2] M. Governale, et al., Phys. Rev. B 77, 134513 (2008).
[3] J. Eldridge, et al., Phys. Rev. B 82, 184507 (2010).

TT 9.10 Mon 12:00 BEY 81

The interplay of the proximity and Kondo effects in spin-resolved transport through quantum dots — •Krzysztof P. Wójcik and Ireneusz Weymann — Faculty of Physics, Adam Mickiewicz University, Umultowska 85, 61-614 Poznań, Poland

Transport properties of hybrid quantum dots coupled to ferromagnetic (FM) and superconducting (SC) leads are studied by means of the numerical renormalization group method [1,2]. By constructing the full density matrix of the system [3], the linear conductance and respective spectral functions are calculated. Aiming to emphasize the role of Andreev processes in transport, we model the quantum dot coupled to the superconductor by an effective Hamiltonian in the limit of large superconducting gap [4]. First, a three-terminal setup is considered, for which we study the proximity effect on the spin-dependent current flowing between the two FM leads. Then, the transport properties in a two-terminal setup, with one FM and one SC lead, are analyzed. In this case we focus on the interplay of the exchange field induced by FM lead, the Kondo effect and the Andreev processes. We show that the conductance generally depends on the ratio of these three quantities, leading to nontrivial transport behavior.

[1] K. G. Wilson, Rev. Mod. Phys. **47**, 773 (1975).
[2] We use the open-access Budapest NRG code, O. Legeza, C. P. Moca, A. I. Toth, I. Weymann, G. Zarand, arXiv:0809.3143 (2008).
[3] A. Weichselbaum, J. von Delft, Phys. Rev. Lett. **99**, 076402 (2007).
[4] Y. Tanaka, N. Kawakami, A. Oguri, J. Phys. Soc. Jap. **76**, 074701 (2007).

TT 9.11 Mon 12:15 BEY 81

The electroluminescence of the transmission line driven by a biased quantum point contact — •Jinshuang Jin[1,2,3], Michael Marthaler[2,4], Andreas Heimes[2,4], and Gerd Schön[2,4] — [1]Karlsruhe Institute of Technology (KIT), Institute of Nanotechnology, Karlsruhe, Germany — [2]Institut für Theoretische Festkörperphysik, Karlsruhe Institute of Technology(KIT), Karlsruhe, Germany — [3]Department of Physics, Hangzhou Normal University, Hangzhou, China — [4]DFG-Center for Functional Nanostructures (CFN), Karlsruhe Institute of Technology, Karlsruhe, Germany

A transmission line resonator driven by a biased quantum point contact is investigated. The quantum point contact (QPC) is not only an efficient detector but also a light emission device. We find that the excited photon number in the resonator is monotonically increased with the bias voltage for $eV > \hbar\omega_r$ with V the applied bias voltage and $\hbar\omega_r$ the frequency of the resonator. The linewidth and the height of the emission spectrum are sensitive to the parameters of the QPC, such as the tunneling rate, the applied bias voltage, and the coupling strength between the QPC and resonator. Moreover, we demonstrate that the noise spectrum of the current through QPC has characteristic features showing peak and dip, which is closely related to the excited photon dynamics of the resonator.

TT 9.12 Mon 12:30 BEY 81

Accumulation of spin anisotropy in a nanoparticle in the mesoscopic Stoner regime — •Philipp Stegmann[1], Björn Sothmann[2], and Jürgen König[1] — [1]Theoretische Physik, Universität Duisburg-Essen and CENIDE, 47048 Duisburg, Germany — [2]Départment de Physique Théorique, Université de Genève, CH-1211 Genève 4, Switzerland

We theoretically discuss the accumulation of spin-quadrupole moment [1, 2] in an isotropic system giving rise to a large spin anisotropy although the spin-dipole moment remains strongly suppressed. Our system is a nanoparticle weakly tunnel coupled to two ferromagnetic leads. For such system, it has been demonstrated that the spin fluctuations give rise to enhanced shot noise [3]. Here, large positive spin-quadrupole moments are generated by abruptly switching off the bias voltage for parallel leads‘ polarizations. Moreover, applying an oscillating bias voltage results in large negative spin-quadrupole moments for parallel or antiparallel polarizations.

[1] B. Sothmann, and J. König, Phys. Rev. B **82**, 245319 (2010).
[2] M. M. E. Baumgärtel, M. Hell, S. Das, and M. R. Wegewijs, Phys. Rev. Lett **107**, 087202 (2011).
[3] B. Sothmann, J. König, and Y. Gefen, Phys. Rev. Lett. **108**, 166603 (2012).

TT 9.13 Mon 12:45 BEY 81

Overhauser effect in spin blockaded double quantum dots-the case of dual hysteresis — •Bhaskaran Muralidharan and Siddharth Buddhiraju — Electrical Engineering Department, Indian Institute of Technology Bombay, Mumbai, India

In the spin blockade transport regime through GaAs double quantum dots (DQD), experiments [1] revealed that the hyperfine interaction with host nuclei can have profound consequences on the electron-spin dynamics. One of which, is the observation of bistablity and flat-topped behavior in the current versus applied DC magnetic-field characteristics. In this talk, we will first explain the essence of this flat-topped hysteretic behavior using a simple six-state model that captures the multiple-feedback mechanisms that are involved. We will then consider a more detailed model that elucidates the role of the physical parameter space of the DQD set up and a feedback mechanism involving the difference Overhauser field caused by the two separate nuclear spin baths of the DQD set up.

[1] K. Ono and S. Tarucha, Phys Rev Lett., 92, 256803 (2004).

TT 9.14 Mon 13:00 BEY 81

Fixing the Energy Scale in Scanning Tunneling Microscopy on Semiconductor Surfaces — Gerhard Münnich[1], •Andrea Donarini[2], Jascha Repp[1], and Martin Wenderoth[3] — [1]Institute of Experimental and Applied Physics, University of Regensburg, 93053 Regensburg, Germany — [2]Institute of Theoretical Physics, University of Regensburg, 93053 Regensburg, Germany — [3]IV. Physikalisches Institut der Georg-August-Universität Göttingen, Friedrich-Hund-Platz 1, 37077 Göttingen, Germany

In scanning tunneling experiments on semiconductor surfaces, the energy scale within the tunneling junction is usually unknown due to tip-induced band bending. Here, we experimentally recover the zero point of the energy scale by combining scanning tunneling microscopy with Kelvin probe force spectroscopy. With this technique, we revisit shallow acceptors buried in GaAs [1]. Enhanced acceptor-related conductance is observed in negative, zero, and positive band-bending regimes. An Anderson-Hubbard model is used to rationalize our findings, capturing the crossover between the acceptor state being part of an impurity band for zero band bending and the acceptor state being split off and localized for strong negative or positive band bending, respectively.

[1] G. Münnich, A. Donarini, J. Repp, and M. Wenderoth, Phys. Rev. Lett. 111, 216802 (2013)