TT 22: Quantum Dots, Quantum Wires, Point Contacts

Time: Tuesday 9:30–13:15 Location: HSZ 201

TT 22.1 Tue 9:30 HSZ 201

Cross-correlation spin-noise spectra of interacting quantum dot ensembles — •Andreas Fischer and Frithjof Anders — Theoretische Physik 2, Technische Universität Dortmund, 44227 Dortmund

Two-color pump-probe experiments indicate interactions between the electron spins in ensembles of singly charged InGaAs quantum dot. The interaction strength is comparable to the strength of hyperfine fluctuations but the microscopic origin of the interaction is still unknown. Previously these inter-dot interactions where studied far from thermal equilibrium via periodic optical excitations. We propose the investigation of inter-dot interactions by spin cross-correlation functions accessible in non-invasive two-color spin-noise spectroscopy. For our calculations we use a semiclassical central spin model extended by a Heisenberg interaction between the electron spins. We demonstrate that the cross-correlation function is sensitive to inter-dot interactions and robust in a broad range of frequencies against disorder caused by nuclear quadrupolar interactions, spin-phonon interactions and ensemble inhomogeneities of the electron g-factor.

TT 22.2 Tue 9:45 HSZ 201

Asymmetry effects and spin dynamics in resonant transport through quantum-dot spin valves — •Simon Mundinar, Alfred Hucht, Jürgen König, and Stephan Weiss — Theoretische Physik, Universität Duisburg-Essen and CENIDE, Lotharstr. 1, 47048 Duisburg, Germany

We present results of a theoretical investigation of spin effects in resonant transport through an interacting quantum-dot spin valve. The system is built from a quantum dot tunnel-coupled to two ferromagnetic leads, that induce spin-dependent tunneling. In the regime of small to intermediate interaction strengths we study the current through the system as well as occupation number and spin components of the dot, using the method of iterative summation of path integrals (ISPI) to achieve numerical exact data. We find an asymmetry in the current with respect to the gate voltage, that manifests once a local Zeeman field is applied to the quantum dot. The asymmetry can be traced back to the spin-dependent hybridization between dot and leads, together with higher order exchange field effects. Additionaly, we report on the strong impact of resonant tunneling processes on the tunnel magnetoresistance (TMR) at low temperatures [1]. We find a strong response of the TMR to an externally applied Zeeman field, resulting in a change in the sign of the TMR.
[1] S. Mundinar, P. Stegmann, J. König, S. Weiss, Phys. Rev. B **99**, 195457 (2019)

TT 22.3 Tue 10:00 HSZ 201

Charge-Photon statistics and short-time correlation in a single quantum dot-resonator system — •Tineke L. van den Berg[1] and Peter Samuelsson[2] — [1]Donostia International Physics Center (DIPC), Paseo Manuel de Lardizabal 4, E-20018 San Sebastián, Spain — [2]Physics Department, Lund University, Sweden

Electrical quantum conductors coupled to microwave resonators have in the last decade emerged as a versatile testbed for controllable light-matter interaction on the nanometer scale. Recent experimental progress with high impedance resonators has resulted in conductor-resonator systems with a large, dimensionless coupling parameter $\lambda \gtrsim 0.1$, well beyond the small coupling regime $\lambda \ll 1$. Motivated by this progress, we here analyse theoretically the joint statistics of transported electrons and emitted photons in a single level quantum dot coupled to a microwave resonator, for arbitrarily large λ. Describing the electron-photon dynamics via a number-resolved master equation, we evaluate the joint long-time probability distribution as well as joint short-time, $g^{(2)}(t)$, correlation functions.
[1] T. L. van den Berg and P. Samuelsson PRB **100**, 035408 (2019).

TT 22.4 Tue 10:15 HSZ 201

Transport geometric phases: breaking gauge symmetries — •Roman-Pascal Riwar[1] and Janine Splettstoesser[2] — [1]PGI-2, Forschungszentrum Jülich, Germany — [2]MC2, Chalmers University of Technology, Sweden

Geometric phases and their relation to topological phase transitions are by now well-established notions in closed quantum systems. The generalization to open quantum systems on the other hand is an actively considered problem. We here review some of our recent works on geometric phases defined in the charge transport statistics of small quantum systems, and explore possible relations. Namely, the geometric phase can either be defined along the time axis (time-dependently driven systems) or along the detector momentum (time-dependent measurements). We find that there are two important gauge degrees of freedom: one related to energy displacement currents, and the other to charge displacement currents. We show for driven quantum systems, that violation of energy conservation renders the geometric phase highly sensitive to whether or not many-body interactions are present in the system. We contrast these findings to time-dependent measurements schemes, where geometric phases along the detector momentum are important. Here, the presence of non-zero displacement currents allows to probe and analyse dynamical phase transitions, and the resulting fractional charges.

TT 22.5 Tue 10:30 HSZ 201

Interference and shot noise in a degenerate Anderson-Holstein model — Michael Niklas, •Andrea Donarini, and MIlena Grifoni — Institut für Theoretische Physik, Universität Regensburg, Germany

Mechanical degrees of freedom can leave clear signatures in the transport characteristics of a nanojunction. We study an Anderson-Holstein model with orbital degeneracies [1] and tunnelling phases that allow for the formation of dark states [2]. The resulting destructive interference yields a characteristic pattern of positive and negative differential conductance features with enhanced shot noise, without further asymmetry requirements in the coupling to the leads. Measurements on suspended carbon nanotubes showed analogous effects [3,4], which acquire in this framework a new interpretation, free of ad-hoc matching of vibrational and electronic energies. The Lamb-shift renormalization introduced by charge fluctuations is the key ingredient for the understanding of such transport characteristics.
[1] M. G. Schultz, Phys. Rev. B 82, 155408 (2010)
[2] A. Donarini et al., Nature Comm. 10, 381 (2019)
[3] S. Sapmaz et al., Phys. Rev. Lett. 96, 026801 (2006)
[4] R. Leturcq et al., Nat. Phys. 5, 327 (2009)

TT 22.6 Tue 10:45 HSZ 201

Spin interference effects in quantum rings in the presence of SU(2) fields — Alberto Hijano[1,2,3] and •Dario Bercioux[3,4] — [1]University of the Basque Country, UPV/EHU, Bilbao, Spain — [2]Centro de Física de Materiales (CFM-MPC) Centro Mixto CSIC-UPV/EHU, E-20018 Donostia-San Sebastián, Spain — [3]Donostia International Physics Center, Paseo Manuel de Lardizbal 4, E-20018 San Sebastián, Spain — [4]IKERBASQUE, Basque Foundation of Science, 48011 Bilbao, Spain

We present a theory for quantum transport in quantum networks that accounts for Rashba spin-orbit coupling (SOC) and an in-plane magnetic field, the theory is based on a generalization of previous works with only Rashba SOC [1,2]. We investigate the conductance of polygonal structures as square and rings with symmetric contacts so as studied experimentally in the group of Nitta at Tohoku University. For the case of rings our approach is in agreement with the experimental finding [3]. Additionally, for the case of the square [4], we find interesting results when the in-plane magnetic field is parallel to two of the links for the network. Specifically, along this direction, the magnetic field erases the spin-precession effect due to the Rashba spin-orbit coupling, similarly to the case of systems where the Rashba and the Dresselhaus SOCs have the same strengths.
[1] Bercioux *et al.*, Phys. Rev. Lett. **93**, 056802 (2004).
[2] Bercioux *et al.*, Phys. Rev. B **72**, 113310 (2005).
[3] Nagasawa *et al.*, Nat. Comm. **4**, 2526 (2013).
[4] Wang *et al.*, arXiv:1908:01825 (2019).

TT 22.7 Tue 11:00 HSZ 201

Spin-dependent scattering in a nanowire with spin-orbit coupling and an impurity — Alba Pascual[1], •Tineke L. van den Berg[1,2], Vitaly N. Golovach[1,2,3], Dario Bercioux[2,3], Juan José Sáenz[2,3], and Sebastián Bergeret[1,2] — [1]Centro de Física de Materiales (CFM-MPC) Centro Mixto CSIC-UPV/EHU,E-20018 Donostia-San Sebastián, Spain — [2]Donostia International Physics Center

(DIPC), E-20018 Donostia-San Sebastián, Spain — [3]IKERBASQUE, Basque Foundation of Science, E-48011 Bilbao, Spain

We study a quasi-one-dimensional quantum wire with spin-orbit coupling (SOC), and containing a spinless impurity. We use a perturbative approach to leading order in SOC to obtain an effective Hamiltonian with decoupled sub-bands of size quantization. We calculate the scattering matrix using the Lippmann-Schwinger approach, accounting for the SU(2) gauge field generated by the SOC in the nanowire. The well-known dip in the conductance due to Fano interference is lifted from zero as a result of the spin scattering at the impurity. Going beyond the perturbative approach, we discuss numerical results of a tight-binding calculation in the continuous limit of fine discretization. We analyse the conductance dip behaviour as a function of the impurity and the SOC strength. We relate the numerical results to our toy-model calculation using an asymptotic-freedom approach.

15 min. break.

TT 22.8 Tue 11:30 HSZ 201

Pair-amplitude dynamics in superconductor-quantum dot hybrids — •Mathias Kamp and Björn Sothmann — Theoretische Physik, Universität Duisburg-Essen and CENIDE, D-47048 Duisburg, Germany

Electromagnetic pulses in the THz regime have recently been used to excite oscillations of the order parameter in bulk superconductors [1]. These oscillations can be understood as a collective precession of the Anderson pseudospin and are linked to the Higgs amplitude mode of the order parameter.
Here, we consider a superconductor-quantum dot hybrid driven out of equilibrium by a temperature and phase bias. We investigate the dynamics of the proximity-induced pair amplitude on the dot after both a quench and under periodic driving of system parameters. We find that the system can exhibit coherent oscillations of the pair amplitude and link them to the time- dependent charge and heat currents through the system.
[1] Matsunaga et al., Science **345**, 1145 (2014).

TT 22.9 Tue 11:45 HSZ 201

Single-photon pump by Cooper-pair splitting — Mattia Mantovani, Wolfgang Belzig, Gianluca Rastelli, and •Robert Hussein — Fachbereich Physik, Universität Konstanz, Germany

Cooper-pairs are a source of correlated electrons and their nonlocal breaking can be used in entanglement generation [1,2], thermoelectric transport [3], and spin-current-control [4]. Here, we consider a hybrid superconductor-double-quantum-dot system as a Cooper-pair splitter. By coupling each quantum dot to an electromagnetic or mechanical resonator, one can simultaneously cool down both resonators into their ground state [5]. We demonstrate that the process of cross-Andreev reflection can additionally be employed to coherently transfer single photons, and therewith heat, between these two distant resonators, realizing an efficient photon bus. The proposed scheme has further potential applications in quantum heat engines and refrigerators
[1] R. Hussein, L. Jaurigue, M. Governale, and A. Braggio, Phys. Rev. B 94, 235134 (2016).
[2] R. Hussein, A. Braggio, and M. Governale, Phys. Status Solidi B 254, 1600603 (2017).
[3] R. Hussein, M. Governale, S. Kohler, W. Belzig, F. Giazotto, and A. Braggio, Phys. Rev. B 99, 075429 (2019).
[4] A. Rezaei, R. Hussein, A. Kamra, and W. Belzig, arXiv:1908.09610.
[5] M. Mantovani, W. Belzig, G. Rastelli, and R. Hussein, Phys. Rev. Research 1, 033098 (2019).

TT 22.10 Tue 12:00 HSZ 201

Waiting time distribution and current cross-correlations in triple quantum dot-based Cooper pair splitters — •Kacper Wrześniewski and Ireneusz Weymann — Faculty of Physics, Adam Mickiewicz University in Poznań, Poland

We study the spin-resolved subgap transport in a triple quantum-dot system coupled to one superconducting and two ferromagnetic leads. The Andreev processes are examined in the parallel and antiparallel alignments of ferromagnets' magnetic moments in both linear and nonlinear response regimes. The emphasis is put on the analysis of the electron waiting time distributions and cross-correlations between the currents flowing through the left and right arms of the device. In particular, we consider various detuning schemes of the quantum dots' energy levels and find the optimal parameters for the efficient splitting and maximized Andreev current. We predict short waiting times for electrons tunneling through the distinct ferromagnetic contacts indicating fast splitting of emitted Cooper pairs and strong positive cross-correlations associated with the presence of tunneling processes enhancing the Cooper pair splitting efficiency.

TT 22.11 Tue 12:15 HSZ 201

Perturbation theory for superconducting double quantum dot systems — •Vladislav Pokorný[1] and Martin Žonda[2] — [1]Institute of Physics, Czech Academy of Sciences, Na Slovance 2, Praha 8 CZ-182 21, Czech Republic — [2]Institute of Physics, Albert Ludwig University of Freiburg, Hermann-Herder-Strasse 3, Freiburg DE-791 04, Germany

We present an approach based on the second order perturbation theory in the Coulomb interaction to calculate properties of double quantum dots coupled to superconducting BCS leads. We map the system on a generalized two-impurity Anderson model and using this perturbative method we evaluate several single-particle quantities such as the on-dot induced gap and generalized occupation numbers together with the Andreev in-gap spectra and compare them with numerically exact results from the Numerical Renormalization Group and Quantum Monte Carlo finding a good correspondence for not too strongly correlated regimes. This method can offer an efficient and reliable alternative to the heavy numerical tools in a wide parameter range.

TT 22.12 Tue 12:30 HSZ 201

Pseudospin resonances in a double quantum dot — •Christoph Rohrmeier and Andrea Donarini — Institute of Theoretical Physics University of Regensburg, Regensburg, Germany

The interplay between interference and interaction produces several effects in degenerate quantum systems, including spin torques [1], all electrical spin control [2] and dark states formation [3]. In this context, a spin resonance without spin splitting has been first predicted for a single quantum dot spin valve [4]. We consider a spin-full double quantum dot with the orbital degree of freedom described by a pseudospin and predict a rich variety of pseudospin resonances. The latter are modulated with the system parameters, can be split up and even turned into a Fano-like resonance in the presence of ferromagnetic leads. This interplay of spin and pseudospin is understood in terms of spin dependent pseudo-exchange fields. The numerical results are obtained in the framework of a generalized master equation, calculated up to next to leading order in the tunnelling coupling.
[1] M. Braun et al., Phys. Rev. B 70, 195345 (2004)
[2] A. Donarini et al., Nano Lett. 9, 2897 (2009)
[3] A. Donarini et al., Nature Comm. 10, 381 (2019)
[4] M. Hell et al., Phys. Rev. B 91, 195404 (2015)

TT 22.13 Tue 12:45 HSZ 201

Colortronics in Triple Quantum Dots — •Martin Maurer[1], Jürgen König[2], and Herbert Schoeller[1] — [1]Institut für Theorie der Statistischen Physik, RWTH Aachen and JARA - Fundamentals of Future Information Technology — [2]Theoretische Physik, Universität Duisburg-Essen and CENIDE

We study coherence effects in a three-level spinless quantum dot with strong local Coulomb interaction coupled weakly to metallic reservoirs. Employing the generators of the SU(3), we decompose the reduced density matrix in the subspace of single occupation. It is then characterized by an eight-dimensional real vector that is the analogue to the vector of average (iso-)spin in a two-level setup. We call this vector the dot color. In the high-temperature limit we derive a kinetic equation for the dot color to first order in the dot-lead coupling. This equation can be decomposed into an accumulation, a relaxation, and a rotation component, providing intuitive insight into the dot dynamics. We discuss the inclusion of spin and a generalization to an arbitrary number of dot levels.

Regarding the three-level case, we propose an experimental setup that produces a complete current blockade in nonlinear response for degenerate levels. This blockade is based on the formation of a coherent superposition of dot levels and is broken when dot energies are detuned. The resulting current-detuning curve highlights the role of coherence between all three dot levels in the blockade.

TT 22.14 Tue 13:00 HSZ 201

Extended quasiparticle picture for quantum wires in the high-density limit — •Klaus Morawetz[1,2], Vinod Ashokan[3], Renu Bala[4], and Kare Narain Pathak[5] — [1]Münster University of Applied Sciences,Stegerwaldstrasse 39, 48565 Steinfurt, Germany

— [2]International Institute of Physics- UFRN,Campus Universitário Lagoa nova,59078-970 Natal, Brazil — [3]Department of Physics, Dr. B.R. Ambedkar NationalInstitute of Technology, Jalandhar (Punjab) - 144 011, India — [4]Centre for Advanced Study in Physics, Panjab University, 160014 Chandigarh, India — [5]Department of Physics, MCM DAV College for Women, 160036 Chandigarh, India

The high-density limit of quantum wires are considered and an extended quasiparticle picture is developed. This allows to calculate the reduced density, the pair correlation function and the effective mass. A non-universal behaviour of the Tan constant is reported for the Coulomb limit. The structure factor is obtained analytically which provides the exact correlation energy. [Eur. Phys. J. B 91 (2018) 29, Phys. Rev. B 97 (2018) 155147, arXiv:1909.09331]