# TT 46: Quantum Dots, Quantum Wires, Point Contacts

Time: Wednesday 15:00–18:30 Location: H22

TT 46.1 Wed 15:00 H22

**Spectral and transport properties of superconducting quantum dots** — •Vladislav Pokorný[1] and Martin Žonda[2] — [1]Institute of Physics, Czech Academy of Sciences, Na Slovance 2, 18221 Praha, Czech Republic — [2]Institute of Physics, Albert Ludwig University of Freiburg, Hermann-Herder-Strasse 3, 79104 Freiburg, Germany

We study the effects of electron correlations on a system consisting of one or two single-level quantum dots attached to superconducting leads. We use the superconducting Anderson impurity model to study the system and solve it using the self-consistent, second-order perturbation theory method as well as the hybridization-expansion, continuous-time quantum Monte Carlo (CT-HYB) and the numerical renormalization group (NRG). We study the behavior of the Andreev subgap states, the Josephson current and the fate of the zero-pi (singlet-doublet) quantum phase transition and compare the results of different methods, setting the limits of their reliability in various regimes.

TT 46.2 Wed 15:15 H22

**Enhancing entanglement by spin manipulation in Cooper pair splitters** — •Ciprian Padurariu[1], Jami Rönkkö[2], Michael V. Moskalets[3], and Christian Flindt[2] — [1]Institute for Complex Quantum Systems and IQST, Ulm University, 89069 Ulm, Germany — [2]Department of Applied Physics, Aalto University, 00076 Aalto, Finland — [3]Department of Metal and Semiconductor Physics, NTU Kharkiv Polytechnic Institute, 61002 Kharkiv, Ukraine

We study a Cooper pair splitter device consisting of two single level quantum dots fabricated in a strong spin-orbit coupling material (such as InAs or InSb) and coupled to a superconductor. The combined presence of spin-orbit coupling and Zeeman field gives rise to a finite probability of Cooper pair tunneling accompanied by spin flip, thereby involving the spin-triplet states of the doubly occupied dots.

We show that the population of triplet states leads to the spin blockade of Cooper pair tunneling. The blockade is advantageous for entanglement production if Cooper pair tunneling is resonant, when the blockaded electrons are in a fully entangled spin state. The entangled state is a superposition of singlet and triplet Bell states.

We propose two detection schemes, the first based on conventional transport spectroscopy and a second, based on charge detectors, [1] suitable for future devices capable of producing on-demand spin-entangled pairs.

[1] N. Walldorf, C. Padurariu, A.-P. Jauho, and C. Flindt, Phys. Rev. Lett. **120**, 087701 (2018).

TT 46.3 Wed 15:30 H22

**Phase-dependent heat and charge transport through superconductor-quantum dot hybrids.** — •Mathias Kamp and Björn Sothmann — Theoretische Physik, Universität Duisburg-Essen and CENIDE, D-47048 Duisburg, Germany

In the context of modern electronics, it becomes increasingly important to understand and control heat transport in nanostructures. So far, there has been a great activity on phase-coherent heat transport in superconducting tunnel junctions. Here, we consider heat transport through superconductor-quantum dot hybrids [1]. We evaluate heat and charge currents via a real-time diagrammatic technique which allows us to treat strong Coulomb interactions in a nonequilibrium system. We find a finite thermoelectric effect due to the proximity effect which surprisingly persist even at the particle-hole symmetric point. Furthermore the system can act as an efficient thermal diode.

[1] M. Kamp, B. Sothmann, arXiv 1809.09428 (2018)

TT 46.4 Wed 15:45 H22

**Nonlocal heat transfer between resonators by splitting Cooper pairs** — •Mattia Mantovani[1], Gianluca Rastelli[1,2], Wolfgang Belzig[1], and Robert Hussein[1] — [1]Fachbereich Physik, Universität Konstanz, D-78457 Konstanz, Germany — [2]Zukunftskolleg, Universität Konstanz, D-78457 Konstanz, Germany

Hybrid quantum dot-superconductor and quantum dot-oscillator systems have become attractive platforms to inspect quantum coherence effects and heat transport at the nanoscale [1,2]. Here, we investigate a Cooper-pair splitter setup [3] consisting of two quantum dots, each coupled capacitively to a local oscillator. The latter can be represented either by a microwave cavity or a nanomechanical resonator. Focusing on the subgap regime, we demonstrate that cross-Andreev reflection, through which Cooper pairs are split into both dots, generates nonlocal heat transfer between the two oscillators. The proposed scheme can then act as an efficient heat-pump device. Our findings have interesting potential applications for nanomechanical systems and energy harvesting with quantum dot systems [4].

[1] P. Stadler, *et al.*, Phys. Rev. Lett. **117**, 197202 (2016).
[2] R. Hussein, *et al.*, arXiv:1806.04569 (2018).
[3] R. Hussein, *et al.*, Phys. Rev. B **94**, 235134 (2016).
[4] B. Sothmann, *et al.*, Nanotechnology **26**, 032001 (2015).

TT 46.5 Wed 16:00 H22

**Phase-coherent heat circulator based on multiterminal Josephson junctions** — •Sun-Yong Hwang[1], Francesco Giazotto[2], and Björn Sothmann[1] — [1]Theoretische Physik, Universität Duisburg-Essen and CENIDE, D-47048 Duisburg, Germany — [2]NEST, Istituto Nanoscienze-CNR and Scuola Normale Superiore, Piazza San Silvestro 12, 56127 Pisa, Italy

We propose a phase-coherent thermal circulator based on ballistic multiterminal Josephson junctions. The breaking of time-reversal symmetry by either a magnetic flux or a superconducting phase bias allows heat to flow preferentially in one direction from one terminal to the next while heat flow in the opposite direction is suppressed. We find that our device can achieve a high circulation efficiency over a wide range of parameters and that its performance is robust with respect to the presence of disorder. We provide estimates for the expected heat currents for realistic samples.

TT 46.6 Wed 16:15 H22

**An integrable multi-channel sine-Gordon model with Josephson circuits** — •Ananda Roy[1,2] and Hubert Saleur[1] — [1]Institut de Physique Theorique, CEA-Saclay — [2]Institute for Quatum Information, RWTH Aachen University

Integrable field theories have always fascinated physicists. In particular, those which describe quantum impurity problems have been of much interest to both theorists and experimentalists. A prominent example is the boundary sine-Gordon (bSG) field theory. The latter describes a Luttinger liquid in the presence of an impurity. In this work, we propose an experimentally realizable, multi-channel generalization of the bSG model. We establish the classical and quantum integrability of the model by constructing a corresponding integrable bulk theory. We provide the first nontrivial conserved current of the bulk theory. Subsequently, we postulate the factorized scattering matrix describing the bulk theory and verify it using Bethe Ansatz computation of the ground state energy. Subsequently, we provide the factorized scattering matrix of the boundary field theory. Thermodynamic properties of both the bulk and boundary model are computed using the Thermodynamic Bethe Ansatz. Finally, we propose an experimental realization of the model with superconducting circuits, making use of the robust, tunable and dispersive Josephson nonlinearity. Our proposal can be realized with state-of-the-art system parameters.

TT 46.7 Wed 16:30 H22

**Manipulation of non-linear heat currents in the dissipative Anderson-Holstein model** — •Bitan De[1] and Bhaskaran Muralidharan[2] — [1]Indian Institute of Technology, Bombay — [2]Indian Institute of Technology, Bombay

The anomalous behavior of electron induced phonon transport is investigated using an *Anderson-Holstein* based dissipative quantum dot setup under two relevant bias situations: (a) a voltage bias in the absence of an electronic temperature gradient and (b) an electronic temperature gradient at zero voltage. It is shown that the direction of phonon transport in the non-linear regime is different in the two cases since the first case facilitates the accumulation of phonons in the dot and the second case leads to the absorption of phonons in the dot. In the linear regime, both the phonon and electronic transport get decoupled and Onsager's symmetry is verified. We explain the observed cumulative effects of voltage and electronic temperature gradients on the non-linear phonon currents by introducing a new transport coefficient that we term as the electron-induced phonon thermal conductivity. It is demonstrated that under suitable operating conditions in Case (a) the dot can pump in phonons into the hotter phonon reservoirs and in Case (b) the dot can extract phonons out of the colder phonon reservoirs. Finally, we elaborate on how the non-linear electronic heat current can be stimulated and controlled by engineering the temperature of the phonon reservoirs even under vanishing effective electron flow.

**15 min. break.**

TT 46.8 Wed 17:00 H22

**Resonant transport through interacting proximitized quantum dots** — •Stephan Weiss and Jürgen König — Theoretische Physik, Universität Duisburg-Essen and CENIDE, 47048 Duisburg, Germany

For a single level quantum dot that is resonantly coupled to a normal and a superconducting metal, we have calculated the current voltage characteristics. Numerically exact results are obtained within the iterative summation of path integrals (ISPI) [1] scheme. It builds upon the truncation of exponentially vanishing real-time correlations at finite temperature and/or bias voltage. Thereafter, the calculation of emerging partial spin traces along the Keldysh contour are performed in an iterative manner. Within the quantum regime, i.e. if there is no small parameter, ISPI calculations are performed to deduce the impact of Coulomb interactions, change of temperature, as well as gate voltage on the Andreev bound state spectrum for finite gap parameter $\Delta$ in a nonequilibrium situation.

[1] S. Weiss, et. al, Phys. Status Solidi B, **250** (11), 2298-2314 (2013).
[2] S. Weiss and J. König, in preparation (2018).

TT 46.9 Wed 17:15 H22

**Resonant tunneling through interacting quantum-dot spin valves - ISPI results** — •Simon Mundinar, Jürgen König, and Stephan Weiss — Theoretische Physik, Universität Duisburg-Essen and CENIDE, Lotharstr. 1, 47048 Duisburg

We study an interacting quantum dot coupled resonantly to ferromagnetic leads that induce spin-dependent tunneling. Starting with a real-time path integral approach expectation values of interest in the stationary limit are obtained from functional derivatives of the Keldysh partition function. Interactions are decoupled via a Hubbard-Stratonovich transformation which results in a discrete spin trace along the Keldysh contour. This trace is performed by means of iterative summation of path integrals (ISPI) [1], which is based on the truncation of lead-induced correlations after a characteristic memory time. Within this scheme we explore current-based observables and the density matrix for different system parameters, such as temperature, gate/bias voltage, polarization and Coulomb interaction strength. We tune parameters of interest beyond the perturbative regime. Especially in the low-temperature regime we find a strong impact of resonant tunneling processes on transport properties through quantum dot, leading to a rich structure in the tunnel magnetoresistance.

[1] S. Weiss, R. Hützen, D. Becker, J. Eckel, R. Egger, and M. Thorwart, Phys. Status Solidi B **250**, 2298-2314 (2013)
[2] S. Mundinar, J. König, S. Weiss *in preperation*

TT 46.10 Wed 17:30 H22

**Interference effects in the cotunnelling transport regime** — •Christoph Rohrmeier, Milena Grifoni, and Andrea Donarini — Institute of Theoretical Physics University of Regensburg, Regensburg, Germany

Interference, being intimately related to the superposition principle, plays a central role in quantum mechanics. I will report on interference effects in the transport characteristics of interacting systems in the cotunnelling regime. Particular emphasis will be given to quantum dot molecules exhibiting a quasi-degenerate spectrum. The method of choice for studying the transport characteristics is the Liouville approach. To this end, we systematically include coherences, essential to capture consistently interference effects and solve a generalized master equation for the reduced density matrix up to the fourth perturbative order in the coupling to the leads. Experimental fingerprints of such many-body quantum interference have been reported in semiconductor [1, 2] as well as in carbon nanotube based quantum dots [3]. These interacting systems certainly represents suitable candidates of experimental validation of our theory.

[1] C. Payette, et al., Phys. Rev. Lett. **102** , 026808 (2009);
[2] O. Karlström et al., Phys. Rev. B **83** , 205412 (2011);
[3] A. Donarini et al., arXiv:1804.02234, accepted for publication in Nat. Comm.

TT 46.11 Wed 17:45 H22

**Feynman-Vernon approach to transport in interacting quantum dots beyond the weak tunneling regime** — •Luca Magazzù and Milena Grifoni — Universität Regensburg, Regensburg, Germany

Quantum transport setups based on quantum dots display a rich variety of transport regimes, also involving exquisitely many-body phenomena (e.g. the Kondo effect), that arise by varying the relative magnitude of intra-dot interactions and tunnel coupling to the electronic reservoirs (leads). Despite the large variety of available approximation schemes, a unique framework enabling one to satisfactorily address this complexity is still missing.

In this work we discuss a path integral approach to transport where the trace over the leads degrees of freedom is performed exactly. As a result, formally exact expressions for the dot dynamics and the current are obtained, where the effect of the coupling to the leads is encapsulated in the Feynman-Vernon influence functional, a functional of the Grassmann-valued paths of the dot variables. In the presence of interactions, the path integral is not exactly solvable. Nevertheless, expansion of the influence functional in the number of tunneling events, in conjunction with a convenient parametrization of the paths allowed by properties of the Grassmann variables, provides a diagrammatic representation of the dynamics and offers an efficient means to systematically sum diagram classes. We propose a resummation which recovers results known from the nonperturbative resonant tunneling and second order von Neumann approximations and beyond.

TT 46.12 Wed 18:00 H22

**Coherent long-range transfer of two-electron states in ac driven triple quantum dots** — •Jordi Picó-Cortés[1,2], Fernando Gallego-Marcos[2], and Gloria Platero[2] — [1]Institute for Theoretical Physics, University of Regensburg, 93040 Regensburg, Germany — [2]Instituto de Ciencia de Materiales de Madrid (CSIC), E-28049, Madrid, Spain

Since the proposal by Cirac and Zoller to use photons for quantum state transfer between atoms located at spatially-separated nodes of a quantum network [1], different works have explored how to transfer quantum states. In our work [2] we propose a protocol to prepare a state in the left and center quantum dots of a triple dot array and transfer it directly to the center and right dots. Initially the state in the left and center dots is prepared combining the exchange interaction and magnetic field gradients. Once in the desired state, ac gate voltages in the outer dots are switched on, allowing to select a given photoassisted long-range path and to transfer the prepared state directly from one edge to the other with high fidelity. We investigate the effect of charge noise on the protocol and propose a configuration in which the transfer can be performed with high fidelity. Our proposal can be experimentally implemented and is a promising avenue for transferring quantum states between two spatially separated two-level systems.

[1] J. I. Cirac, P. Zoller, H. J. Kimble, H. Mabuchi, Phys. Rev. Lett. 78, 3221 (1997)
[2] J. Picó-Cortés, F. Gallego-Marcos, G. Platero, arXiv:1810.06517 (2018)

TT 46.13 Wed 18:15 H22

**Improved quantum transport calculations using the Numerical Renormalization Group** — •Emma L. Minarelli and Andrew K. Mitchell — School of Physics, University College Dublin, Belfield, Dublin 4, Dublin, Ireland

Generalized quantum transport calculations, involving a mesoscopic interacting region coupled two or more leads, are essential to understand the properties and potential applications of the new generation of complex nanoelectronic devices, including semiconductor quantum dot systems and single-molecule transistors. Within linear response, the Numerical Renormalization Group (NRG) is arguably the numerical method of choice, when combined with standard techniques for quantum transport such as Kubo and Meir-Wingreen. However, these methods have practical limitations, as discussed in this talk. We describe some alternative formulations for charge and heat transport calculations within NRG, and demonstrate dramatically improved numerical accuracy over standard methods.