TT 9: Quantum Dots, Quantum Wires, Point Contacts

Time: Monday 9:30–13:00 Location: HFT-FT 101

Invited Talk TT 9.1 Mon 9:30 HFT-FT 101
Unconventional Superconductivity in Quantum-Dot Systems — •Stephan Weiss — Theoretische Physik, Universität Duisburg-Essen and CENIDE, 47048 Duisburg, Germany

The fermionic nature of electrons allows for four classes of superconducting correlations with definite symmetry in spin, space and frequency. Conventional (s-wave) superconductors accommodate even-frequency singlet Cooper pairs which are odd in spin and even in space and frequency. Odd-frequency triplet correlations generically arise in superconductor-ferromagnet heterostructures. Recently, we have suggested double quantum dots (DQDs) coupled to conventional superconductors in the presence of inhomogeneous magnetic fields as a model system exhibiting all four types of unconventional pairing. When reducing spatial degrees of freedom of the system further, i.e., to a single quantum dot, only odd-triplet and conventional superconducting correlations are allowed by symmetry. With the help of a diagrammatic real-time technique, the interplay of spin symmetry and superconductivity and its signatures in electronic transport, in particular current and zero frequency shot noise has been analyzed [2]. An applied magnetic field or attached ferromagnetic leads partially or fully reduce the spin symmetry, and odd-triplet superconducting correlations are generated.

[1] B. Sothmann, S. Weiss, M. Governale, J. König, Phys. Rev. B **90**, 220501 (2014).
[2] S. Weiss and J. König, Phys. Rev. B **96**, 064529 (2017).

TT 9.2 Mon 10:00 HFT-FT 101
Phase-dependent heat transport through superconductor-quantum dot hybrids — •Mathias Kamp and Björn Sothmann — Theoretische Physik, Universität Duisburg-Essen and CENIDE, D-47048 Duisburg, Germany

Phase-coherent charge transport in mesoscopic systems has received a lot of attention in past decades. Although phase-dependent heat currents through Josephson junctions have been predicted [1] and observed recently [2], phase-coherent heat transport has largely been neglected so far. Here, we consider a junction consisting of a quantum dot tunnel coupled to two superconducting leads. The system combines the interplay of superconducting correlations and strong Coulomb interaction on the dot in a nonequilibrium situation. We derive a generalized master equation using a real-time diagrammatic approach and calculate the phase-dependent heat and charge current in linear and nonlinear response.

[1] K. Maki and A. Griffin, Phys. Rev. Lett. **15**, 921 (1965).
[2] F. Giazotto and M. J. Martínez-Pérez, Nature **492**, 401 (2012).

TT 9.3 Mon 10:15 HFT-FT 101
Odd-frequency superconductivity revealed by thermopower — Sun-Yong Hwang[1], Pablo Burset[2], and •Björn Sothmann[1] — [1]Theoretische Physik, Universität Duisburg-Essen and CENIDE, D-47048 Duisburg, Germany — [2]Department of Applied Physics, Aalto University, FIN-00076 Aalto, Finland

Conventional superconductivity is well-explained in the framework of BCS theory by the formation of spin-singlet Cooper pairs. However, other exotic types of superconductivity involving, e.g., spin-triplet pairs exist as well. In general, superconducting correlations can be characterized by a nonvanishing pair amplitude which has a definite symmetry in spin, momentum and time or frequency. While the spin and momentum symmetry have been probed experimentally for different classes of superconductivity, the odd-frequency nature of certain superconducting correlations has so far been probed only indirectly. Here, we propose the thermopower as an unambiguous way to assess odd-frequency superconductivity. This is possible since the thermoelectric coefficient given by Andreev-like processes is only finite in the presence of odd-frequency superconductivity. We illustrate our general findings with a simple example of a superconductor-quantum dot-ferromagnet hybrid.

TT 9.4 Mon 10:30 HFT-FT 101
Electron transport and thermoelectricity in quantum dot Cooper-pair splitters — •Robert Hussein[1], Sigmund Kohler[2], Wolfgang Belzig[1], Francesco Giazotto[3], Michele Governale[4], and Alessandro Braggio[3] — [1]Fachbereich Physik, Universität Konstanz, Germany — [2]Instituto de Ciencia de Materiales de Madrid, CSIC, Spain — [3]NEST, Istituto Nanoscienze-CNR, Italy — [4]Victoria University of Wellington, New Zealand

We investigate electronic and thermoelectric transport in a Cooper-pair splitter based on a double quantum dot realized in a nanowire. We study how the interplay between local and nonlocal tunneling processes between the superconductor and the dots influences the transport properties. For finite Coulomb interaction and in the presence of interdot tunneling, the Cooper-pair splitter may develop spatial entanglement even in the absence of the cross Andreev reflection process. We show that the spin-orbit coupling of the nanowire can be used to control the symmetry (singlet or triplet) of the entangled electron pairs. We further analize under which conditions thermoelectric induced currents may lead to nonlocal cooling of one of the normal contacts, and when they may give rise to nonlocal power generation.

[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).

TT 9.5 Mon 10:45 HFT-FT 101
Charge-vibration interaction in normal-superconductor quantum dots — •Gianluca Rastelli[1], Pascal Stadler[2], and Wolfgang Belzig[2] — [1]Zukunftskolleg & Fachbereich Physik, Universität Konstanz, Konstanz, Germany — [2]Fachbereich Physik, Universität Konstanz, Konstanz, Germany

We study the quantum transport and the nonequilibrium vibrational states of a quantum dot embedded between a normal-conducting and a superconducting lead with the charge on the quantum dot linearly coupled to a harmonic oscillator of frequency ω [1,2]. We analyze the inelastic, vibration-assisted tunneling processes in the regime $\omega < \Delta$, with the superconducting energy gap Δ, and for sharp resonant transmission through the dot. Inelastic vibration-assisted Andreev reflections as well as quasiparticle tunneling induce a strong nonequilibrium state of the oscillator. In particular, we show that ground-state cooling of the oscillator - with phonon occupation n « 1 - can be achieved simultaneously for many of the oscillator's modes of different frequencies. We discuss how the nonequilibrium vibrational state can be readily detected by the asymmetric behavior of the inelastic current peaks with respect to the gate voltage.

[1] Phys. Rev. B. 96 , 045429 (2017);
[2] Phys. Rev. Lett. 117, 197202 (2016).

TT 9.6 Mon 11:00 HFT-FT 101
Temperature effects in superconducting quantum dots — •Vladislav Pokorný[1] and Martin Žonda[2] — [1]Institute of Physics, Na Slovance 2, 18221 Prague, Czech Republic — [2]Faculty of Mathematics and Physics, Charles University, Ke Karlovu 5, 12116 Prague, Czech Republic

We study the temperature effects in a system consisting of a single-level quantum dot with local Coulomb interaction attached to two superconducting leads and optionally a third, metallic lead. The system is described by the single-impurity Anderson model coupled to BCS superconducting baths and solved using the continuous-time, hybridization-expansion (CT-HYB) quantum Monte Carlo as well as the numerical renormalization group (NRG). We study the behavior of the subgap (Andreev-Shiba) states, the Josephson current and the fate of the zero-pi (singlet-doublet) quantum phase transition. We also show the limits of usability of the stochastic optimization method for obtaining the spectral functions from the imaginary-time CT-HYB results.

TT 9.7 Mon 11:15 HFT-FT 101
Simple transformation between symmetrically and asymmetrically coupled superconducting quantum dots — •Martin Žonda[1,2], Alžběta Kadlecová[2], and Tomáš Novotný[2] — [1]Institute of Physics, University of Freiburg, Hermann-Herder-Strasse 3, 79104 Freiburg, Germany — [2]Department of Condensed Matter Physics, Faculty of Mathematics and Physics, Charles University, Ke Karlovu 5, CZ-121 16 Prague 2, Czech Republic

We will present simple, yet very powerful correspondence between the characteristics of a single-level quantum dot coupled symmetrically to two phase-biased superconducting leads with its asymmetrically coupled equivalents. Counter-intuitively, it is the symmetric setup which is the most general one and its characterization enables full description of any equivalent asymmetrically coupled system. This discovery makes it possible to utilize known results for symmetric setups in general asymmetric cases via trivial analytical relations. We will present ready-to-use conversion formulas for the $0-\pi$ phase transition boundary, on-dot quantities, and the Josephson current and illustrate them on the numerical renormalization group results. The formulas also provide an efficient tool for estimating the coupling asymmetry directly from the experimental data, which is otherwise a demanding task. We will demonstrate this by analysing recent $0-\pi$ transition measurements [1].

[1] Delagrange et al., Phys. Rev. B **93**, 195437 (2016).

15 min. break.

TT 9.8 Mon 11:45 HFT-FT 101

Fermionic reaction coordinates and their application to an autonomous Maxwell demon in the strong coupling regime — •Philipp Strasberg[1], Gernot Schaller[2], Thomas L. Schmidt[1], and Massimiliano Esposito[1] — [1]Physics and Materials Science Research unit, University of Luxembourg, Luxembourg — [2]Institut für Theoretische Physik, Technische Universität Berlin, Germany

We establish a theoretical method which goes beyond the weak coupling and Markovian approximations while remaining intuitive, using a quantum master equation in a larger Hilbert space. The method is applicable to all impurity Hamiltonians tunnel-coupled to one (or multiple) baths of free fermions. The accuracy of the method is in principle not limited by the system-bath coupling strength, but rather by the shape of the spectral density and it is especially suited to study situations far away from the wide-band limit. In analogy to the bosonic case, we call it the fermionic reaction coordinate mapping. If time permits, we will discuss as an application a thermoelectric device made of two Coulomb-coupled quantum dots. We pay particular attention to the regime where this device operates as an autonomous Maxwell demon shoveling electrons against the voltage bias thanks to information. Contrary to previous studies we do not rely on a Markovian weak coupling description. Our numerical findings reveal that in the regime of strong coupling and non-Markovianity, the Maxwell demon is often doomed to disappear except in a narrow parameter regime of small power output.

TT 9.9 Mon 12:00 HFT-FT 101

Quantum thermodynamics in strongly coupled quantum dots — •Thomas Schmidt, Massimiliano Esposito, and Patrick Haughian — Physics and Materials Science Research Unit, University of Luxembourg, Luxembourg

It has emerged over the past years that it is not straightforward to find consistent definitions of thermodynamic quantities, such as heat and entropy, in driven quantum systems which are strongly coupled to reservoirs. In order to shed light on this question, we have investigated the simplest prototypical model, namely a noninteracting resonant level model coupled to fermionic reservoirs. Using an exact solution of the fully driven quantum mechanical model, we show how to define observable thermodynamical quantities which allow the derivation of a first and second law of thermodynamics.

TT 9.10 Mon 12:15 HFT-FT 101

Shot Noise and electron pairing in integer quantum Hall interferometers — •Giovanni Andrea Frigeri[1,3], Daniel D. Scherer[2], and Bernd Rosenow[3] — [1]MPI for Mathematics in the Sciences, Leipzig, Germany — [2]Niels Bohr Institute, Copenhagen, Denmark — [3]University of Leipzig, Germany

Recently, halving of the magnetic flux period was observed experimentally for a Fabry-Perot interferometer in the integer quantum Hall regime with bulk filling factor between 2.5 and 4.5 . In addition, shot noise measurements yielded a Fano factor of two, indicating that the halving of the flux period could be interpreted in terms of electron pairing [1].

While the flux period halving has been explained by a strong Coulomb interaction between the outermost interfering edge mode and an inner non-interfering edge mode [2], an extension of the model [2] is needed to compute shot noise produced by electron partitioning in the interferometer. Specifically, we consider a model in which the number of electrons in the inner edge mode can change stochastically, affecting in this way the tunnelling probability of an interfering electron, and giving rise to an enhanced Fano factor. In addition, we calculate the interference visibility in the presence of inner edge charge fluctuations, and derive a relation between Fano factor and interference visibility.

[1] H. Choi, I. Sivan, A. Rosenblatt, M. Heiblum, V. Umansky, and D. Mahalu, Nature Comm. 6 (2015)
[2] G. A. Frigeri, D. D. Scherer, B. Rosenow, arXiv:1709.04504 (2017)

TT 9.11 Mon 12:30 HFT-FT 101

Crystallization of Levitons in the fractional quantum Hall regime — •Flavio Ronetti[1,2], Luca Vannucci[1], Dario Ferraro[3], Jérôme Rech[2], Thibaut Jonckheere[2], Thierry Martin[2], and Maura Sassetti[1] — [1]Università di Genova and CNR-SPIN, Via Dodecaneso 33, 16146, Genova, Italy. — [2]Aix Marseille Univ, Université de Toulon, CNRS, CPT, Marseille, France. — [3]Istituto Italiano di Tecnologia, Graphene Labs, Via Morego 30, I-16163 Genova, Italy

The emergence of self-organized regular patterns in optical solitons has been recently subject of intense investigation, as they promise to be exceptionally useful in quantum communication [1]. In the framework of electron quantum optics, a train of Lorentzian voltage pulses emerges as the solid state counter-part of optical solitons, namely robust ballistically propagating wave-packets carrying an integer number q of electrons called Levitons [2,3]. Using a periodic train of Levitons, we investigate the charge density backscattered off a quantum point contact in the fractional quantum Hall regime, finding a self-organized and regular pattern of peaks and valleys[4]. We demonstrate that the predicted features manifest themselves as unexpected additional dips in the well-studied Hong-Ou-Mandel noise.

[1] D. C. Daniel, et al. Nature Photonics 11, 671 (2017).
[2] J. Keeling, et al., Phys. Rev. Lett. 97, 116403 (2006).
[3] J. Dubois, et al., Nature (London) 502, 659 (2013).
[4] F. Ronetti, et al., in preparation (2017).

TT 9.12 Mon 12:45 HFT-FT 101

Fractionalization of charge in incoherent, sequential electron transport — •Roman-Pascal Riwar — JARA Institute for Quantum Information (PGI-11), Forschungszentrum Jülich, 52425 Jülich, Germany

The notion of a fractional charge was up until now reserved for quasiparticle excitations emerging from strongly correlated, topological quantum systems, such as Laughlin quasiparticles in the fractional quantum Hall effect or, more recently, parafermions. Here, we argue that a topological braiding transition in the full counting statistics can lead to a fractionalisation of the charge - strikingly - in fully incoherent electron transport out of equilibrium. Importantly, this effect emerges already on the level of standard sequential tunneling through quantum dots and metallic islands, making its observation experimentally accessible to a large and easily controllable class of systems. We show that the fractional charge and the underlying topological invariants can be measured by means of the detector's waiting time distribution. Based on its topology, we find that this fractional charge effect can, in spite of its very different physical origin, be regarded as a quasiclassical analogy to the fractional transport of Cooper pairs in topological Josephson junctions.