TT 14: Superconductivity: Tunnelling, Josephson Junctions, SQUIDs 1

Time: Monday 15:00–18:15 Location: HSZ 201

TT 14.1 Mon 15:00 HSZ 201

Correlation effects in two and three-terminal superconducting nanostructures — •Vladislav Pokorny[1] and Martin Žonda[2] — [1]Institute of Physics, Czech Academy of Sciences, Prague, Czech Republic — [2]Faculty of Mathematics and Physics, Charles University in Prague, Czech Republic

We study the effects of electron correlations on a system consisting of a single-level quantum dot attached to two superconducting and, optionally, a third metallic lead. We use the single-impurity Anderson model coupled to BCS superconducting leads to study this system and solve it using a self-consistent second-order perturbation theory method as well as the hybridization-expansion, continuous-time quantum Monte Carlo and the numerical renormalization group. We study the behavior of the Andreev subgap states, the Josephson current and the zero-pi quantum phase transition and set the limits of usability of the methods. We also show the agreement of various methods with the available experimental results.

TT 14.2 Mon 15:15 HSZ 201

Andreev spectrum of a Josephson junction with spin-split superconductors — Bogusz Bujnowski[1], •Dario Bercioux[1,2], François Konschelle[3], Jérôme Cayssol[4], and Sebastian Bergeret[1,3] — [1]Donostia International Physics Center (DIPC) - Manuel de Lardizabal 5, E-20018 San Sebastián, Spain — [2]IKERBASQUE, Basque Foundation for Science, Maria Diaz de Haro 3, 48013 Bilbao, Spain — [3]Centro de Física de Materiales (CFM-MPC) Centro Mixto CSIC-UPV/EHU E-20018 Donostia-San Sebastian, Basque Country, Spain — [4]LOMA (UMR-5798), CNRS and Université Bordeaux - F-33045 Talence, France

The Andreev bound states and charge transport in a Josephson junction between two superconductors with intrinsic exchange fields are studied. We find [3] that for a parallel configuration of the exchange fields in the superconductors the discrete spectrum consists of two pairs of spin-split states [1,2]. The Josephson current in this case is mainly carried by bound states. In contrast, for the antiparallel configuration we find that there is no spin-splitting of the bound states and that for phase differences smaller than a certain critical value there are no bound states at all. Hence the supercurrent is only carried by states in the continuous part of the spectrum. Our predictions can be tested by performing a tunneling spectroscopy of a weak link between two spin-split superconductors.

[1] P. M. Tedrow and R. Merservey, Phys. Rev. Lett., **26** 192 (1971).
[2] R. Merservey and P. M. Tedrow, Phys. Rep., **238** 173 (1994) .
[3] B. Bujnowski, *et. al*, EPL **115**, 67001 (2016).

TT 14.3 Mon 15:30 HSZ 201

Scanning tunneling spectroscopy to probe odd-triplet contributions to the long-ranged proximity effect in Al-EuS — •Simon Diesch[1], Christoph Sürgers[2], Detlef Beckmann[2], Peter Machon[1], Wolfgang Belzig[1], and Elke Scheer[1] — [1]Universität Konstanz, 78457 Konstanz, Germany — [2]Karlsruhe Institute of Technology, 76344 Karlsruhe, Germany

In conventional superconductors, electrons are bound in singlet Cooper pairs, i.e. with opposite spin. More recently, experiments on superconductor-ferromagnet systems have shown supercurrents tunneling through ferromagnetic layers, indicating Cooper pairs of equal spin, thus corresponding to a long-range triplet proximity effect [1]. Most experimental evidence for triplet superconductivity comes from observations of the thickness dependence of the Josephson current through a ferromagnetic barrier, and there is now an increasing amount of direct spectroscopic evidence [2] to test the existing theoretical models. In this talk we present scanning tunneling spectra of thin films of the ferromagnetic insulator europium sulfide on superconducting aluminum measured at 280 mK and in varying magnetic fields. We observe significant broadening of the superconducting energy gap and a variety of sub-gap structures induced by the presence of the ferromagnet. We interpret our findings based on the diffusive theory and a more advanced circuit theory model [3].

[1] F. S. Bergeret, Phys. Rev. Lett. 86, 4096 (2001)
[2] A. Di Bernardo, Nat. Comm. 6:8053 (2015)
[3] P. Machon, Phys. Rev. Lett. 110, 047002 (2013)

TT 14.4 Mon 15:45 HSZ 201

Thermoelectrical effects in hybrid superconducting Josephson junctions — •Alessandro Braggio[1,2,3], Riccardo Bosisio[1], Paolo Solinas[2], Sebastian Bergeret[4], and Francesco Giazotto[1] — [1]NEST, Istituto Nanoscienze-CNR, Piazza S. Silvestro 12, Pisa I-56127, Italy — [2]SPIN-CNR, Via Dodecaneso 33, 16146 Genova, Italy — [3]INFN, Sez. Genova, Via Dodecaneso 33, 16146 Genova, Italy — [4]Centro de Física de Materiales (CFM-MPC), Centro Mixto CSIC-UPV/EHU, Manuel de Lardizabal 4, E-20018 San Sebastián, Spain

We present an exhaustive theoretical analysis of charge and thermoelectric transport in a normal metal-ferromagnetic insulator-superconductor (NFIS) junction, and explore the possibility of its use as a sensitive thermometer. We evaluate the noise performance of open-circuit and closed-circuit setups. We show that temperature noise can be as low as 35nK $Hz^{-1/2}$[1]. In the second part we discuss the photon-mediated heat flow between two Josephson-coupled Bardeen-Cooper-Schrieffer (BCS) superconductors. We demonstrate that in standard low temperature experiments involving temperature-biased superconducting quantum interference devices (SQUIDs), this radiative contribution is negligible if compared to the direct galvanic one, but it largely exceeds the heat exchanged between electrons and the lattice phonons[2].

[1] F. Giazotto, P. Solinas, A. Braggio and F. S. Bergeret, Phys. Rev. Appl. 4, 044016 (2015)
[2] R. Bosisio, P. Solinas, A. Braggio and F. Giazotto, Phys. Rev. B 93, 144512 (2016)

TT 14.5 Mon 16:00 HSZ 201

Polarization dependence of the tunnel current in superconductor-ferroelectric-superconductor junctions — •Anke Sander, Victor Rouco, Laura Begon-Lours, Sophie Collin, Stephane Fusil, Jacobo Santamaría, Vincent Garcia, and Javier E. Villegas — Unité Mixte de Physique, CNRS, Thales, Univ. Paris-Sud, Université Paris Saclay, 91767 Palaiseau, France

In tunnel junctions with a ferroelectric barrier, a large resistance variation is observed upon ferroelectric switching, which can be induced by a short voltage pulse. Known as electroresistance, this phenomenon is connected to the interfacial screening of the electric field generated by the ferroelectric in the junction's electrodes.
Usually realized in junctions with normal-metal electrodes, here we experimentally investigate these effects in junctions that combine the ferroelectric $BiFeO_3$ and different types of superconducting electrodes. Using piezoresponse force microscopy and electrical measurements, we find an unusual temperature dependence of the electroresistance, which reaches up to 10^4% .The effects are discussed in terms of the interface charge-carrier depletion produced in the superconducting electrodes.

15 min. break.

Invited Talk TT 14.6 Mon 16:30 HSZ 201

Multi-Terminal Josephson Junctions as Topological Matter — •Julia S. Meyer — INAC/PHELIQS, Univ. Grenoble Alpes & CEA Grenoble, France

Topological phases of matter have attracted much interest in recent years. Starting with gapped phases such as topological insulators and superconductors, more recently gapless topological phases possessing topologically protected band crossings have been discovered.

We show that n-terminal Josephson junctions with conventional superconductors may provide a straightforward realization of tunable topological materials in n-1 dimensions [1], the independent superconducting phases playing the role of quasi-momenta. In particular, we find zero-energy Weyl singularities in the Andreev bound state spectrum of 4-terminal junctions.

Furthermore, we show that the presence of such Weyl singularities has important consequences on transport. Namely, it enables topological transitions that manifest themselves experimentally as changes of the quantized transconductance in units of $4e^2/h$ between two voltage-biased terminals.

[1] R.-P. Riwar, M. Houzet, J. S. Meyer, and Y. V. Nazarov, Nature Communications 7, 11167 (2016)

TT 14.7 Mon 17:00 HSZ 201

Multiple charge transport in a superconducting SET — •Thomas Lorenz, Susanne Sprenger, and Elke Scheer — University of Konstanz, 78467 Konstanz, Germany

A small island connected by two tunnel junctions forms a single electron transistor (SET) that shows Coulomb Blockade (CB) effects. The Orthodox Theory [1,2] quantitatively describes the behaviour in the weak-coupling regime, even in the case of superconducting transport. Despite much effort the transition from the weak- to the strong-coupling regime, in particular in the superconducting state, is not yet fully understood.

We are investigating transport through an all superconducting SET formed by an AlO_x tunnel barrier ($R_T \approx 120\mathrm{k}\Omega$) and a mechanically controlled break junction (MCBJ). The MCBJ can be adjusted to cover the whole range from the tunneling (weak coupling) regime to the point-contact (strong coupling) regime. We discuss the interplay between the CB and the appearance of superconducting multiple charge transport (multiple Andreev reflection, Josephson effect).

[1] R. J. Fitzgerald, Phys. Rev. B 57, R11073(R) (1997).
[2] K. K. Likharev, Proc. IEEE 87, 606 (1999).

TT 14.8 Mon 17:15 HSZ 201

Nonequilibrium effects in hybrid superconducting turnstiles — •Ivan Khaymovich — Max Planck Institute for Physics of Complex Systems, Dresden, Germany

Many superconducting micro- and nano-electronic devices operating at low temperatures suffer from the presence of non-equilibrium quasiparticles. The number of these quasiparticles increases rapidly with the increase in the operation frequencies above the threshold determined by the relaxation rate. Slowing down of the relaxation rate at low temperatures conflicts, thus, the performance of modern cryo-electronic devices such as qubit systems, superconducting resonators, turnstiles, and superconducting hybrid electron coolers.

In this project on the example of single-electron sources we present both new types of such devices immune to the quasiparticle poisoning and methods of effective control of excess quasiparticles in such single electronic systems, based on the quasiparticle trapping and untrapping by the magnetic field an its interplay with the inverse proximity effect. Most of theoretical predictions have been experimentally verified and the theory is in good agreement with experimental data.

[1] I. M. Khaymovich et al., Phys. Rev. B 92, 020501(R) (2015)
[2] M. Taupin, I. M. Khaymovich et al., Nat. Comm. 7: 10977 (2016)
[3] D. M. T. van Zanten et al., Phys. Rev. Lett. 116, 166801 (2016)
[4] I. M. Khaymovich, D. M. Basko, Phys. Rev. B 94, 165158 (2016)
[5] S. Nakamura et al., in preparation

TT 14.9 Mon 17:30 HSZ 201

Double quantum dot Cooper-pair splitter at finite couplings — •Robert Hussein[1,2], Lina Jaurigue[3], Michele Governale[3], and Alessandro Braggio[2,4] — [1]Fachbereich Physik, Universität Konstanz, D-78457 Konstanz, Germany — [2]SPIN-CNR, Via Dodecaneso 33, 16146 Genova, Italy — [3]School of Chemical and Physical Sciences and MacDiarmid Institute for Advanced Materials and Nanotechnology,Victoria University of Wellington, P.O. Box 600, Wellington 6140, New Zealand — [4]NEST, Istituto Nanoscienze-CNR, Piazza S. Silvestro 12, Pisa I-56127, Italy

We investigate the sub-gap physics of a Cooper-pair splitter based on a double quantum dot realized in a semiconducting nanowire. We study how the transport properties are determined by the interplay between local and nonlocal tunneling processes between the superconductor and the quantum dots. In the presence of interdot tunneling the system provides a simple mechanism to generate nonlocal entanglement even in the absence of nonlocal coupling with the superconducting lead. We show that spin-orbit interaction in combination with finite Coulomb energy opens the possibility to control the symmetry (singlet or triplet) of nonlocally entangled electron pairs.

[1] R. Hussein, L. Jaurigue, M. Governale, and A. Braggio, arXiv:1608.00504, accepted in Phys. Rev. B.

TT 14.10 Mon 17:45 HSZ 201

Theory of enhanced interlayer tunneling in optically driven high T_c superconductors — •Junichi Okamoto[1,2], Andrea Cavalleri[3,4], and Ludwig Mathey[1,2] — [1]Zentrum für Optische Quantentechnologien and Institut für Laserphysik, Universität Hamburg, 22761 Hamburg, Germany — [2]The Hamburg Centre for Ultrafast Imaging, Luruper Chaussee 149, 22761 Hamburg, Germany — [3]Max Planck Institute for the Structure and Dynamics of Matter, 22761 Hamburg, Germany — [4]Department of Physics, Clarendon Laboratory, University of Oxford, Oxford OX1 3PU, United Kingdom

Motivated by recent pump-probe experiments indicating enhanced coherent c-axis transport in underdoped YBCO [1], we investigate Josephson junctions periodically driven by optical pulses [2]. We propose a mechanism for this observation by showing that a parametrically driven Josephson junction exhibits an enhanced imaginary part of the low-frequency conductivity when the driving frequency is blue-detuned to the plasma frequency, implying an effectively enhanced Josephson coupling. We show that the emergent driven steady state is a genuine, non-equilibrium superconducting state, in which equilibrium relations between the Josephson coupling, current fluctuations, and the critical current no longer hold. Transient response under a short pump pulse is also discussed to fully compare our theory with the experimental results.

[1] W. Hu et al., Nature Materials 13, 705 (2014)
[2] J. Okamoto, A. Cavalleri, L. Mathey, Phys. Rev. Lett. 117, 227001 (2016)

TT 14.11 Mon 18:00 HSZ 201

Josephson currents induced by the Witten effect — •Flavio Nogueira[1], Jeroen van den Brink[2], and Zohar Nussinov[3] — [1]Institut für Theoretische Physik III, Ruhr-Universität Bochum — [2]Institute for Theoretical Solid State Physics, IFW Dresden — [3]Physics Department, CB 1105, Washington University

We reveal the existence of a new type of topological Josephson effect involving type II superconductors and three-dimensional topological insulators as tunnel junctions. We predict that vortex lines induce a variant of the Witten effect that is the consequence of the axion electromagnetic response of the topological insulator: at the interface of the junction each flux quantum attains a fractional electrical charge of $e/4$. As a consequence, if an external magnetic field is applied perpendicular to the junction, the Witten effect induces an AC Josephson effect in absence of any external voltage. We derive a number of further experimental consequences and propose potential setups where these quantized, flux induced, Witten effects may be observed.

[1] F. S. Nogueira, Z. Nussinov, and J. van den Brink, Phys. Rev. Lett. **117**, 167002 (2016)
[2] F. S. Nogueira, Z. Nussinov, and J. van den Brink, Phys. Rev. D **94**, 085003 (2016)