TT 68: Transport: Majorana Fermions

Time: Thursday 10:30–13:00 Location: H19

TT 68.1 Thu 10:30 H19

Edge instabilities of topological superconductors — •Johannes S. Hofmann[1,2], Fakher F. Assaad[1], and Andreas P. Schnyder[2] — [1]Institut für Theoretische Physik und Astrophysik, Universität Würzburg, Germany — [2]Max-Planck-Institut für Festkörperforschung, Stuttgart, Germany

Nodal topological superconductors display zero-energy Majorana flat bands at generic edges. The flatness of these edge bands, which is protected by time-reversal and translation symmetry, gives rise to an extensive ground state degeneracy and a diverging density of states. Therefore, even arbitrarily weak interactions lead to an instability of the flat-band edge states towards time-reversal and translation-symmetry broken phases, which lift the ground-state degeneracy. Here, we employ Monte Carlo simulations combined with mean-field considerations to examine the instabilities of the flat-band edge states of d_{xy}-wave superconductors. We find that attractive interactions induce a complex s-wave pairing instability together with a density wave instability. Repulsive interactions, on the other hand, lead to ferromagnetism mixed with spin-triplet pairing at the edge. We discuss the implications of our findings for experiments on cuprate high-temperature superconductors.

TT 68.2 Thu 10:45 H19

Gate-controlled preparation, manipulation, and readout of Majorana bound states in nanowire networks — •Michael Hell — Division of Solid State Physics and NanoLund, Lund University, Box. 118, S-22100, Lund, Sweden — Center for Quantum Devices and Station Q Copenhagen, Niels Bohr Institute, University of Copenhagen, Copenhagen, Denmark

We present a scheme for the preparation, manipulation, and readout of Majorana zero modes in mesoscopic islands in superconducting nanowires [1]. The key ingredient is to reversibly lock the fermion parity of the islands (stemming from the Majorana modes) to their charge state. This is achieved by gate control over Josephson junctions, complementing earlier proposals based on magnetic flux control, and allows experimental tools from quantum-dot experiments to be applied. Based on recent experimental progress, a sequence of milestones interpolating between zero-mode detection and quantum computing might be realized in the near future, including (1) detection of fusion rules for non-Abelian anyons using either proximal charge sensors or pumped current; (2) validation of a prototype Majorana qubit; and (3) demonstration of non-Abelian statistics. Experiments (1) and (2) can be performed already in a single-wire geometry, while experiment (3) requires branched nanowire structures.

[1] D. Aasen, M. Hell, R. V. Mishmash, A. Higginbotham, J. Danon, M. Leijnse, T. S. Jespersen, J. A. Folk, C. M. Marcus, K. Flensberg, and J. Alicea, arXiv:1511.05153]

TT 68.3 Thu 11:00 H19

Topological phases in superconductor-noncollinear magnet interfaces with strong spin-orbit coupling — •Menke H.[1], Toews A.[1,2], and Schnyder A. P.[1] — [1]Max-Planck-Institut für Festkörperforschung, Heisenbergstrasse 1, 70569 Stuttgart, Germany — [2]Quantum Matter Institute, University of British Columbia, Vancouver BC, Canada V6T 1Z4

Majorana fermions are predicted to emerge at interfaces between conventional s-wave superconductors and non-collinear magnets. In these heterostructures, the spin moments of the non-collinear magnet induce a low-energy band of Shiba bound states in the superconductor. Depending on the type of order of the magnet, the band structure of these bound states can be topologically nontrivial. Thus far, research has focused on systems where the influence of spin–orbit coupling can be neglected. Here, we explore the interplay between non-collinear (or non-coplanar) spin textures and Rashba-type spin-orbit interaction. This situation is realized, for example, in heterostructures between helical magnets and heavy elemental superconductors, such as Pb. Using a unitary transformation in spin space, we show that the effects of Rashba-type spin-orbit coupling are equivalent to the effects of the non-collinear spin texture of the helical magnet. We explore the topological phase diagram as a function of spin-orbit coupling, spin texture, and chemical potential, and find many interesting topological phases, such as p_x-, $(p_x + p_y)$-, and $(p_x + \mathrm{i}p_y)$-wave states. Conditions for the formation and the nature of Majorana edge channels are examined. Furthermore, we study the topological edge currents of these phases.

TT 68.4 Thu 11:15 H19

Real space mapping of Yu-Shiba-Rusinov states of an extended magnetic scatterer on a conventional superconductor — •Markus Etzkorn[1], Matthias Eltschka[1], Berthold Jäck[1], Andreas Topp[1], Christian R. Ast[1], and Klaus Kern[1,2] — [1]Max-Planck-Institute for Solid State Research, 70569 Stuttgart, Germany — [2]École Polytechnique Fédérale de Lausanne, 1015 Lausanne, Switzerland

The interaction of a local magnetic impurity with a superconductor causes the formation of Yu-Shiba-Rusinov (YSR)states in the vicinity of the impurity. These have recently received increasing attention in the context of Majorana Fermions and other exotic states that might be created from the mutual interplay. YSR states have been extensively studied by scanning tunneling microscopy and so far have been discussed mainly in the limit of point scattering impurities. Here we present our investigations of the local properties of single magnetic Copper-Phthalocynaine molecules on the (5x1) reconstructed, superconducting V(100) surface measured at 15 mK temperature. We find very intense YSR states with energies that depend on the precise absorbtion geometry of the molecule. At the same time we find no indication of a local suppression of the superconducting gap around the impurity. We follow the state evolution in real space for about 3 nm corresponding to about three orders of magnitude in spectral intensity. The spectra display rich structure with local variations in the electron-hole asymmetries. The observed intensity changes in the spectra can not be described on the basis of a single point like scattering potential.

TT 68.5 Thu 11:30 H19

Topological phase diagram of superconducting carbon nanotubes — •Lars Milz, Magdalena Marganska-Lyzniak, and Milena Grifoni — Institut I - Theoretische Physik Universität Regensburg, Germany

The topological superconducting phase diagram of superconducting carbon nanotubes is discussed. Under the assumption of a short-ranged pairing potential, there are two spin-singlet states: an s-wave and an exotic $p + ip$-wave that are possible because of the special structure of the honeycomb lattice. The consequences for the possible presence of Majorana edge states in carbon nanotubes are addressed. In particular, regions in the magnetic field-chemical potential plane possibly hosting localized Majorana modes are discussed.

15 min. break

TT 68.6 Thu 12:00 H19

Using Majorana spin-1/2 representation for the spin-boson model — •Pablo Schad[1], Alexander Shnirman[1], and Yuriy Makhlin[2,3] — [1]Institut für Theorie der Kondensierten Materie, Karlsruhe Institute of Technology, 76128 Karlsruhe, Germany — [2]L.D. Landau Institute for Theoretical Physics, acad. Semyonov av., 1a, 142432, Chernogolovka, Russia — [3]Moscow Institute of Physics and Technology, 141700, Dolgoprudny, Russia

The Majorana representation for spin operators enables efficient application of field-theoretical methods for the analysis of spin dynamics. Moreover, a wide class of spin correlation functions can be reduced to Majorana correlations of the same order, simplifying their calculation. For the spin-boson model, direct application of this method in the lowest order allows for a straightforward computation of the transverse-spin correlations, however, for the longitudinal-spin correlations it apparently fails in the long-time limit. Here we indicate the reason and discuss, how this method can be used as a convenient and accurate tool for generic spin correlations. Specifically, we demonstrate that accurate results are obtained by avoiding the use of the longitudinal Majorana fermion, and that correlations of the remaining transverse Majorana fermions can be easily evaluated using an effective Gaussian action.

TT 68.7 Thu 12:15 H19

Universal transport characteristics of multiple topological superconducting wires with large charging energy — •Oleksiy

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The system with multiple Majorana states coupled to the normal lead can potentially support the interaction between Majorana fermions and electrons. Such system can be implemented by several floating topological superconducting wires with large charging energy asymmetrically coupled to two normal leads. The analysis of the renormalization flow shows that there is a single fixed point — the strong coupling limit of isotropic antiferromagnetic Kondo model. The topological Kondo-like interaction leads also to the selective renormalization of the tunneling coefficients, strongly enhancing one component and suppressing others. Thus, charging energy crucially changes the transport properties of the system leading to the universal single-channel conductance independently from the values of the initial leads-wires coupling.

TT 68.8 Thu 12:30 H19

Transport signatures of rotating Majorana bound states —
•Luzie Weithofer, Sunghun Park, and Patrik Recher — TU Braunschweig, Germany

Recently, a transport scheme for the detection of the exchange phase of Majorana bound states (MBS) has been proposed in a Corbino-geometry topological Josephson junction, where a tunneling current from a single, static metallic tip to two rotating MBS is calculated in the weak tunneling limit [1]. Here, we systematically investigate the transport properties of this scheme for general temperature and tunneling strengths, and in addition discuss the transport signatures of a setup where two metallic tips are involved.

[1] S. Park and P. Recher, arXiv:1505.07124

TT 68.9 Thu 12:45 H19

Majorana tunneling entropy —
•Sergey Smirnov — University of Regensburg, D-93040 Regensburg, Germany

In thermodynamics a macroscopic state of a system results from a number of its microscopic states. This number is given by the exponent of the system's entropy. In non-interacting systems with discrete energy spectra, such as large scale quantum dots, the entropy as a function of the temperature has a plateau shape with integer values of the exponent of the entropy on these plateaus. Plateaus with non-integer values are fundamentally forbidden and would be thermodynamically infeasible.

Here we investigate the entropy of a non-interacting quantum dot coupled via tunneling to normal metals with continuum spectra as well as to topological superconductors. We show [1] that the entropy may have non-integer plateaus if the topological superconductors support weakly overlapping Majorana bound states. This brings a fundamental change in the thermodynamics of the quantum dot whose specific heat acquires low temperature Majorana peaks which should be absent according to the conventional thermodynamics. We also provide a fundamental thermodynamic understanding of the transport properties, such as the linear conductance. Thus, demonstrating thermodynamic signatures of Majorana fermions, we, on the other hand, connect them to other fields, such as transport, advancing their further understanding on a deep fundamental basis.

[1] S. Smirnov, PRB **92**, 195312 (2015).