TT 40: Topological Josephson Junctions

Time: Wednesday 15:00–17:00 Location: HSZ 103

TT 40.1 Wed 15:00 HSZ 103

Second Chern number and non-Abelian Berry phase in topological Josephson matter — •Hannes Weisbrich, Raffael L. Klees, Gianluca Rastelli, and Wolfgang Belzig — Universität Konstanz

Topology and related quantized numbers play an important role in condensed matter physics in various topics. For instance, it has been theoretically proposed that the first Chern number is related to a quantized transconductance in topological Josephson matter [1]. Higher dimensional topological phases characterized by the second Chern number can describe even more complex quantum states, e.g. the four dimensional quantum Hall effect [2]. Hereby we present a first theoretical proposal for topological Josephson matter with a non-trivial second Chern number. We show that a double quantum dot in contact with several superconducting leads can implement such exotic topological state. Moreover the lowest pair of Andreev states shows a non-Abelian Berry phase which can be used to perform arbitrary rotations within the twofold degenerate subspace by adiabatic changes of the superconducting phases. Finally, we discuss a measurement protocol for the second Chern number by means of a combination of non-Abelian Berry rotations and polarized microwave spectroscopy [3].

[1] R.-P. Riwar et al., Nat. Commun. 7, 11167 (2016).
[2] S. C. Zhang and J. Hu, Science, 294(5543), 823-828 (2001).
[3] R. L. Klees et al., arXiv:1810.11277 (2018).

TT 40.2 Wed 15:15 HSZ 103

Detection of Majorana modes via supercurrents through quantum dots — •Jens Schulenborg and Karsten Flensberg — Center for Quantum Devices, Niels Bohr Institute, University of Copenhagen, 2100 Copenhagen, Denmark

Experimental techniques to verify Majorana fermions are of current interest. A prominent test is the effect of Majoranas on the Josephson current between two wires linked via a normal junction.

This talk presents the case of a quantum dot connecting the two superconductors and the sign of the supercurrent in the trivial and topological regimes under grand-canonical equilibrium conditions, explicitly allowing for parity changes due to, e.g., quasi-particle poisoning. We find that the well-known supercurrent reversal for odd quantum dot occupancy (π-junction) in the trivial case[1] does not occur in the presence of Majoranas in the wires. However, we also find this to be a mere consequence of Majoranas being zero energy states, and therefore one cannot conclude that the lack of supercurrent sign reversal is a discriminating signature of Majoranas.

[1] B. I. Spivak et al., Phys. Rev. B **43**, 4 (1991)

TT 40.3 Wed 15:30 HSZ 103

Transverse Josephson current in magnetic TI junction — •Oleksii Maistrenko[1], Benedikt Scharf[2], Dirk Manske[1], and Ewelina Hankiewicz[2] — [1]Max Planck Institute for Solid State Research, D-70569 Stuttgart, Germany — [2]Institut für theoretische Physik (TP4), Universität Würzburg, Am Hubland, D-97074 Würzburg, Germany

Josephson junctions based on 3D topological insulators offer intriguing possibilities to realize unconventional p-wave pairing and Majorana modes. In particular, such junctions exhibit non-chiral, counterpropagating Majorana modes for a superconducting phase bias $\phi = \pi$ [1]. We show how by applying an appropriately oriented in-plane magnetic field in the junction, we can switch these Majorana modes to a regime in which they become unidirectional. One can understand this switching behavior from the interplay between the magnetic field and the spin-momentum locking of the topological insulator. Interestingly, the application of the in-plane magnetic field is also accompanied by a net transverse supercurrent that can be a sizable fraction of the longitudinal supercurrent. This current might be spin polarized. Magnetic Josephson junctions based on 3D topological insulators thus present a versatile platform for manipulating Majorana modes and controlling transverse supercurrents.

[1] L. Fu and C. L. Kane, Phys. Rev. Lett. **100**, 96407 (2008)

TT 40.4 Wed 15:45 HSZ 103

Topologically nontrivial Andreev bound states — •Pasquale Marra[1,2] and Muneto Nitta[2] — [1]Graduate School of Mathematical Sciences, The University of Tokyo — [2]Department of Physics, Keio University

Andreev bound states are low energy excitations appearing below the particle-hole gap of superconductors, and are expected to be topologically trivial. Here, we report the theoretical prediction of topologically *nontrivial* Andreev bound states in one-dimensional superconductors. These states correspond to another topological invariant defined in a synthetic two-dimensional space, the particle-hole Chern number, which we construct in analogy to the spin Chern number in quantum spin Hall systems. Nontrivial Andreev bound states have distinct features and are topologically nonequivalent to Majorana bound states. Yet, they can coexist in the same system, have similar spectral signatures, and materialize with the concomitant opening of the particle-hole gap. The coexistence of Majorana and nontrivial Andreev bound state is the direct consequence of "double dimensionality", i.e., the dimensional embedding of the one-dimensional system in a synthetic two-dimensional space, which allows the definition of two distinct topological invariants ($\mathbb{Z}_2$ and $\mathbb{Z}$) in different dimensionalities.

TT 40.5 Wed 16:00 HSZ 103

Current–phase relation in a long topological Josephson junction — •Stefan Backens[1] and Alexander Shnirman[1,2] — [1]Institute for Theoretical Condensed Matter Physics (TKM), KIT, Karlsruhe, Germany — [2]Institute of Nanotechnology, KIT, Karlsruhe, Germany

The surface of a 3D topological insulator (TI) can be gapped out, e. g., by a proximity-induced superconducting order parameter. We consider a Josephson junction formed by two s-wave superconductors on a TI surface. In this geometry, the surface spectrum comprises electronic modes localised around the junction in addition to scattering modes. Taking into account the contributions of both scattering states and bound states, we analyse the phase dependence of the Josephson current mediated by the TI surface modes. The impact of their spectrum combining spin–orbit coupling and (induced) s-wave superconductivity is of particular interest.

TT 40.6 Wed 16:15 HSZ 103

Improving topological superconductivity in two-dimensional Josephson junctions — •Aidan Wastiaux and Falko Pientka — Max-Planck Institut für Physik komplexer Systeme, Noethnitzer Straße 38 01187 Dresden

Two-dimensional Josephson junctions in a magnetic field are a new platform to host localized Majorana bound states (MBS) [1]. While recent experiments [2,3] have confirmed the possibility of engineering such a topological phase, improvements are needed to stabilize it. It is therefore important to predict suitable values of the microscopic parameters in order to realize a robust topological phase in Josephson junctions (see [4,5]).

In this talk, we extend previous work to the case of large Zeeman energies and identify optimal regimes (i.e., with a large spectral gap protecting the MBS), based on a combination of analytical and numerical results. Moreover, we compare the planar Josephson junction to a nanowire proximitized by two superconductors with a phase difference.

[1] Pientka et al., PRX 7, 021032 (2017)
[2] Fornieri et al., Nature 569, 89-92 (2019)
[3] Ren et al., Nature 569, 93-98 (2019)
[4] Setiawan et al., PRB 99, 220506 (2019); Setiawan et al., PRB 99, 174511 (2019)
[5] Scharf et al., PRB 99, 214503 (2019)

TT 40.7 Wed 16:30 HSZ 103

Manipulation of Majorana qubits in the Josephson junction on helical edges — •Sang-Jun Choi, Calzona Alessio, and Trauzettel Bjoern — Institute of Theoretical Physics and Astrophysics, University of Würzburg, Würzburg, Germany

Topological Josephson junctions constitute a promising platform to observe the exotic properties of Majorana fermions (MFs). Hosting MFs – especially in a Josephson junction setup – enables us (i) to manipulate the coupling between MFs via the phase difference of the superconductors and (ii) measure the fermion parity of two MFs by the sign of the supercurrent. First experimental hints for the existence of MFs in Josephson junctions have recently been established by a measurement of the fractional Josephson effect.

We theoretically study the Josephson effect on a U-shaped quantum spin Hall edge channel which hosts four MFs and hence describes a single Majorana qubit. Two distinct knobs – chemical potential and superconducting phase difference – are used to tune the various couplings among the MFs. As a result, we find two kinds of finite rotations of the Majorana qubit around x- and z-axis. We identify signatures of Lamor precession and Rabi oscillations in this setup. Additionally, we show that the rotated (Majorana qubit) state can be read-out by measuring the supercurrent. Finally, we propose an experimental protocol that is able to detect the non-Abelian nature of the MFs.

TT 40.8 Wed 16:45 HSZ 103

Quantized phase-coherent heat transport of helical Majorana modes — •Alexander G. Bauer[1], Benedikt Scharf[2], Ewelina M. Hankiewicz[2], Laurens W. Molenkamp[3], and Björn Sothmann[1] — [1]Theoretische Physik, Universität Duisburg-Essen and CENIDE, D-47048 Duisburg, Germany — [2]Institute of Theoretical Physics and Astrophysics and Würzburg-Dresden Cluster of Excellence ct.qmat,University of Würzburg, Am Hubland,97074 Würzburg, Germany — [3]Physikalisches Institut, EP3, Universität Würzburg, Würzburg, Germany

Recently, phase-coherent heat transport in superconducting tunnel junctions has received great interest. On the one hand, it allows for the realization of caloritronic circuits [1]. On the other hand, it can serve as a probe of fundamental properties of topological quantum matter [2]. Here, we investigate heat transport in superconductor-topological insulator-superconductor (S-TI-S) hybrid junctions perpendicular to the direction of phase bias. We demonstrate that the thermal conductance is quantized for a phase difference $\phi = \pi$. This arises directly from the existence of gapless Majorana modes which propagate along the S-TI interfaces. In contrast, we find a strong suppression of thermal conductance for $\phi \neq \pi$ due to the opening of a gap in the Andreev bound state spectrum.

[1] F. Giazotto and M. J. Martinez-Perez, Nature 492, 401 (2012)
[2] B. Sothmann and E. M. Hankiewicz, Phys. Rev. B 94, 081407 (2016)