TT 53: Topology: Majorana Physics

Time: Thursday 9:30–13:15 Location: HSZ 103

TT 53.1 Thu 9:30 HSZ 103

Finite-size effects in the in-gap bands of artificial spin chains on superconductors — •Lucas Schneider, Philip Beck, Levente Rózsa, Jens Wiebe, and Roland Wiesendanger — Department of Physics, Hamburg University, 20355 Hamburg, Germany

Magnetic chains on superconducting substrates are a promising system to realize topological superconductivity and Majorana bound states [1-5]. In this study, we use the tip of a scanning tunneling microscope to assemble magnetic chains atom-by-atom on the surface of an elemental superconductor and study the formation of multiple in-gap bands with increasing chain length. We observe different pronounced effects due to the finite length and an even or odd number of atoms in the chain. Furthermore, the symmetry of the underlying substrate offers multiple building directions with different inter-atomic spacings which enables to tune the electronic and magnetic interactions within the chain.

We acknowledge funding by the ERC via the Advanced Grant ADMIRE (No. 786020) and by the Cluster of Excellence 'Advanced Imaging of Matter' (EXC 2056 - project ID 390715994).

[1] Klinovaja *et al.*, PRL **111**, 186805 (2013)
[2] J. Li *et al.* PRB **90**, 235433 (2014)
[3] S. Nadj-Perge *et al.*, Science **346**, 6209 (2014)
[4] M. Ruby *et al.*, Nano Letters **17**, 4473, (2017)
[5] H. Kim *et al.*, Science Advances **4**, eaar5251 (2018).

TT 53.2 Thu 9:45 HSZ 103

High-Temperature Majorana Fermions in Magnet-Superconductor Hybrid Systems — Daniel Crawford[1], Eric Mascot[2], Dirk Morr[2], and •Stephan Rachel[1] — [1]School of Physics, University of Melbourne, Parkville, VIC 3010, Australia — [2]University of Illinois at Chicago, Chicago, IL 60607, USA

Magnet-superconductor hybrid structures represent one of the most promising platforms to realize, control and manipulate Majorana modes using scanning tunneling methods. By depositing either chains or islands of magnetic atoms on the surface of a conventional superconductor such as Pb or Re, topological superconducting phases can emerge. They feature either localised Majorana bound states at the chain ends or dispersing chiral Majorana modes at the island's boundary. Yet many of these experiments have not reached the spectral resolution to clearly distinguish between topological Majorana and trivial Shiba peaks due to tiny gap sizes in experiments performed at sub-Kelvin temperatures. Here we consider superconducting substrates with unconventional spin-singlet pairing, including high-temperature d-wave and extended s-wave superconductors. We derive topological phase diagrams and compute edge states for cylinder and island geometries and discuss their properties. Also various time-reversal invariant topological superconducting phases of the Zhang-Kane-Mele type are found and discussed. Quite generally, we find that unconventional superconducting substrates work as well as the conventional s-wave substrates to realize topological superconducting phases.

TT 53.3 Thu 10:00 HSZ 103

Topological superconductivity of adatom chains as probe for unconventional pairing — •Andreas Kreisel[1], Timo Hyart[2], and Bernd Rosenow[1] — [1]Institut für Theoretische Physik, Universität Leipzig — [2]International Research Centre MagTop, Institute of Physics, Polish Academy of Sciences

Chains of magnetic atoms on the surface of s-wave superconductors, have been established as a laboratory for the study of Majorana bound states. In such systems, the breaking of time reversal due to magnetic moments makes the system a one-dimensional topological superconductor. However, in unconventional superconductors even nonmagnetic impurities can induce in-gap states since scattering of Cooper pairs changes their momentum but not their phase. Here, we propose a novel paradigm for creating topological superconductivity, which is based on an unconventional superconductor with a chain of nonmagnetic impurities on its surface. The system can be driven into the topological phase by tuning magnitude and direction of an external Zeeman field. We show that the topological energy gap can approach the minimum of the bulk energy gap. We develop a general mapping of films with impurity chains in multiband superconductors to one-dimensional lattice Hamiltonians. This allows us to illustrate the feasibility of our proposal in the case of the material Sr_2RuO_4 , and to demonstrate that the study of impurity chains can be employed as a diagnostic tool for the nature of the pairing symmetry. This enables to distinguish competing proposals for the pairing symmetry in Sr_2RuO_4.

TT 53.4 Thu 10:15 HSZ 103

Linear and non-linear transport in a finite Kitaev chain — •Nico Leumer[1], Bhaskaran Muralidharan[2], Magdalena Marganska[1], and Milena Grifoni[1] — [1]University of Regensburg — [2]Indian Institute of Technology Bombay

The Kitaev chain is an archetypal model for one dimensional topological superconductivity and known for the emergence of so-called Majorana fermions [1, 2]. These states yield a $2e^2/h$ signature in the conductance of a transport set up.

We study in depth both linear and non-linear transport across a finite Kitaev chain. The simplicity of the Kitaev chain allows us an exact and analytical treatment for the spectrum [3], its eigenstates as well as of the Green's function matrix elements necessary for the transport calculations. Setting up the transport formulation of the finite Kitaev chain via the non-equilibrium Green's function approach, we identify the transport signatures arising from Majorana zero modes and generic ultra low-lying excitations. We show that the coupling to the contacts changes the signatures as well as modulates the topological phase diagram of the Majorana zero modes, when compared with that of a pristine wire. Further, precise quantization of conductance is only found along contact-broadened Majorana lines; the latter sustain exact MZMs in the finite, isolated Kitaev chain. In exploring the non-linear transport, we note clearly the contributions from the Andreev, the direct transfer and the crossed Andreev processes to the currents.

[1] A. Y. Kitaev, Phys. Usp. 44, 131 (2001)
[2] R. Aguado, Riv. Nuovo Cimento 40, 16 (2017)
[3] N. Leumer et al., arXiv:1909.10971

TT 53.5 Thu 10:30 HSZ 103

Time scales for charge-transfer based operations on Majorana systems — •Rubén Seoane Souto[1,2], Karsten Flensberg[2], and Martin Leijnse[1,2] — [1]Division of Solid State Physics and NanoLund, Lund University, Box 118, S-22100 Lund, Sweden — [2]Center for Quantum Devices and Station Q Copenhagen, Niels Bohr Institute, University of Copenhagen, DK-2100 Copenhagen, Denmark

By now, there has been a lot of evidence of the existence of Majorana fermions at the ends of topological superconductors (TSs) [1]. However, a definitive proof of their topological origin will rely on the demonstration of their non-abelian statistics, which emerge after the exchange of two or more Majorana fermions. As an alternative, they can be also demonstrated using charge-transfer based operations, where the charge of a quantum dot (QD) is transferred to two TSs [2].

In this presentation I will analyze the efficiency of charge-transfer based operations between a QD and to two TSs [3], setting bounds to the manipulation time scales. The lower bound depends on the phase difference, due to a partial decoupling of the different parity sectors. In contrast, the upper bound is determined by poisoning processes due to the tunneling of quasiparticles to the MBSs. Using realistic parameters, we find that operations can be performed with a fidelity close to unity in the ms to μs timescales, demonstrating the absence of dephasing and accumulated dynamical phases.

[1] R. Lutchyn et al., Nat. Rev. Mat. 3, 52 (2019)
[2] K. Flensberg, Phys. Rev. Lett. 106, 090503 (2011)
[3] R. Seoane Souto, K. Flensberg and M. Leijnse, arXiv:1910.08420

TT 53.6 Thu 10:45 HSZ 103

Transport signatures of topological superconductivity in HgTe-based quantum wells — •Elena G. Novik[1,2], Björn Trauzettel[3], and Patrik Recher[4,5] — [1]Dresden High Magnetic Field Laboratory, HZDR, Dresden — [2]Institute of Theoretical Physics, Technische Universität Dresden — [3]Institute of Theoretical Physics and Astrophysics, University of Würzburg — [4]Institute for Mathematical Physics, TU Braunschweig — [5]Laboratory for Emerging Nanometrology Braunschweig

We investigate transport through a normal-superconductor junction composed of a quantum spin Hall insulator with helical edge channels and a chiral topological superconductor (TSC) made of the same material in contact to an s-wave bulk superconductor and subjected to a magnetic field. Using the extended two-dimensional Bernevig-Hughes-Zhang model (including axial spin symmetry breaking terms, induced s-wave superconductivity and a Zeeman field) in a ribbon geometry we show that the emergence of the TSC is represented by regions of conductance quantization at zero energy being either $4e^2/h$ in a trivial phase of the TSC or $2e^2/h$ being the indication of a non-trivial phase for the TSC. The latter phase can be traced back to Majorana bound states appearing at the NS interface in this ribbon geometry. These features occur only inside the two-dimensional topological non-trivial phase with non-zero Chern number when the sample width largely exceeds the extent of the chiral Majorana edge channels which is on the order of the superconducting coherence length.

TT 53.7 Thu 11:00 HSZ 103

Long-lived Polaronic Majorana Edge Correlation via Non-Markovianity — •Oliver Kästle[1], Ying Hu[2], and Alexander Carmele[1] — [1]Institut für Theoretische Physik, Nichtlineare Optik und Quantenelektronik von Halbleitern, Technische Universität Berlin, 10623 Berlin, Germany — [2]State Key Laboratory of Quantum Optics and Quantum Optics Devices, Institute of Laser Spectroscopy, Shanxi University, Taiyuan, Shanxi 030006, China

Majorana fermions of 1D wires are a hot topic, which is motivated by the interest to use topology as a way to make quantum systems robust against microscopic imperfections. However, it has been shown that quantum correlations between Majorana states will rapidly decay when the system is coupled to a Markovian bath, even when it preserves parity [1, 2]. Here we go beyond the Markovian approximation and study the dynamics of Majorana edge correlation in the presence of dissipation. Taking the example of an ideal Kitaev chain coupled to a phonon bath, we derive a second-order perturbative polaron master equation. We find that the inclusion of a memory kernel can lead to significant suppression of the decoherence of Majorana edge correlations, thanks to the time-dependent system correlations counteracting the dissipation effect in the weak coupling regime. Moreover, we find that the presence of a next-to-nearest-neighbour interaction can provide an additional mechanism for stabilizing the edge correlations.

[1] Ying Hu, Zi Cai, M. A. Baranov, and P. Zoller, Phys. Rev. B 92, 165118 (2015)
[2] A. Carmele, M. Heyl, C. Kraus, and M. Dalmonte, Phys. Rev. B 92, 195107 (2015).

15 min. break.

TT 53.8 Thu 11:30 HSZ 103

Interacting Majorana modes at surfaces of noncentrosymmetric superconductors — •Janna Elisabeth Rückert, Gergö Roósz, and Carsten Timm — Institute of Theoretical Physics, Technische Universität Dresden, 01062 Dresden, Germany

Noncentrosymmetric superconductors with line nodes are expected to possess topologically protected flat zero-energy bands of surface states, which can be described as Majorana modes. We investigate their fate if residual interactions beyond BCS theory are included. For a minimal square-lattice model with a plaquette interaction, we find string-like integrals of motion that form Clifford algebras and lead to exact degeneracies. By mapping the Majorana model onto two decoupled spin compass models we can further analyse the gap above the ground state. Moreover, we compare the topological properties of the interacting Majorana model to those of the toric-code model. The Majorana model has long-range entangled ground states that differ by $\mathbb{Z}_2$ fluxes through the system on a torus. We find that the ground states exhibit string condensation similar to the toric code but that the topological order is not robust.

TT 53.9 Thu 11:45 HSZ 103

Minimal models of interacting Majorana modes — •Gergo Roosz, Carsten Timm, and Janna Rückert — TU Dresden

In this talk we investigate flat-band Majorana systems with plaquette interactions. At first the possible experimental realizations are briefly summarized. Then a mapping to quantum compass models is given. With the help of this mapping certain ladder systems can be solved exactly, we discuss here these integrable ladders. With the help of the integrable ladder systems, numerical exact diagonalization of small two dimensional systems and the representation theory of Clifford algebras we obtain the ground state degeneracy.

TT 53.10 Thu 12:00 HSZ 103

Majorana-Kondo interplay in T-shaped double quantum dots — •Piotr Majek[1], Krzysztof P. Wójcik[2,3], and Ireneusz Weymann[1] — [1]Faculty of Physics, Adam Mickiewicz University, ul. Uniwersytetu Poznańskiego 2, 61-614 Poznań, Poland — [2]Physikalisches Institut, Universität Bonn, Nussallee 12, D-53115 Bonn, Germany — [3]Institute of Molecular Physics, Polish Academy of Sciences, 60-179 Poznań, Poland

In this contribution, the electrical transport properties of a T-shaped double quantum dot side-coupled to a topological superconducting nanowire hosting Majorana zero-energy modes are considered theoretically by using the numerical renormalization group method. The corresponding spectral functions and linear response conductance are calculated as a function of model parameters and temperature. In the absence of coupling to Majorana wire, the double dot system exhibits the two-stage Kondo effect, where suppression of conductance at low temperatures is observed. It is shown that the coupling to Majorana wire gives rise to quantum interference, which suppresses the second stage of the Kondo screening in one of the spin channels. As a consequence, we find that the low-temperature conductance becomes equal to $e^2/2h$ in the case of long Majorana wires. On the other hand, for shorter wires, the overlap between Majorana quasiparticles develops, suppressing the quantum interference and restoring the two-stage Kondo effect. This work was supported by the National Science Centre in Poland through the Project No. DEC-2018/29/B/ST3/00937.

TT 53.11 Thu 12:15 HSZ 103

Majorana wires coupled to s-wave superconductors with vortices — •Alexander Nikolaenko[1,2] and Falko Pientka[2] — [1]Karazin Kharkiv National University, Kharkiv 61022, Ukraine — [2]Max Planck Institute for the Physics of Complex Systems,Nöthnitzer Str. 38, 01187 Dresden, Germany

One-dimensional systems proximity-coupled to a superconductor can be driven into a topological superconducting phase by an external magnetic field. Here, we investigate the effect of vortices created by the magnetic field in a type-II superconductor providing the proximity effect. We identify different ways in which the topological protection of Majorana modes can be compromised and discuss strategies to circumvent these detrimental effects. Our findings are also relevant to topological phases in proximitized quantum Hall edge states.

TT 53.12 Thu 12:30 HSZ 103

On-demand thermoelectric generation of equal-spin Cooper pairs — Felix Keidel[1], •Sun-Yong Hwang[2], Björn Trauzettel[1,3], Björn Sothmann[2], and Pablo Burset[4] — [1]Institute for Theoretical Physics and Astrophysics, University of Würzburg, D-97074 Würzburg, Germany — [2]Theoretische Physik, Universität Duisburg-Essen and CENIDE, D-47048 Duisburg, Germany — [3]Würzburg-Dresden Cluster of Excellence ct.qmat, Germany — [4]Department of Applied Physics, Aalto University, 00076 Aalto, Finland

Superconducting spintronics is based on the creation of spin-triplet Cooper pairs in ferromagnet-superconductor (F-S) hybrid junctions. Manipulation of spin-polarized supercurrents typically requires the ability to carefully control magnetic materials. We here propose a quantum heat engine that generates equal-spin Cooper pairs and drives supercurrents on-demand without manipulating magnetic components. Our proposal is based on a S-F-S junction, connecting two leads at different temperatures, on top of the helical edge of a two-dimensional topological insulator. Remarkably, only crossed Andreev reflections contribute to the charge current while electron cotunneling is responsible for the heat flow to the cold lead. Such a purely nonlocal Andreev thermoelectric effect injects spin-polarized Cooper pairs at the superconductors producing a supercurrent that can be switched on/off by tuning their relative phase.

TT 53.13 Thu 12:45 HSZ 103

Quantum phases of a one-dimensional Majorana-Bose-Hubbard model — •Ananda Roy[1], Johannes Hauschild[1,2], and Frank Pollmann[1] — [1]Department of Physics, Technical University Munich — [2]Department of Physics, University of California, Berkeley

Majorana zero modes (MZM-s) occurring at the edges of a 1D, p-wave, spinless superconductor, in absence of fluctuations of the phase of the superconducting order parameter, are quintessential examples of topologically-protected zero-energy modes occurring at the edges of 1D symmetry-protected topological phases. In this work, we numerically investigate the fate of the topological phase in the presence of phase-fluctuations using the density matrix renormalization group (DMRG) technique. To that end, we consider a one-dimensional array of MZM-s on mesoscopic superconducting islands at zero temperature. Cooper-pair and MZM-assisted single-electron tunneling, together with finite charging energy of the mesoscopic islands, give rise to a rich phase-diagram of this model. We show that the system can be in either a Mott-insulating phase, a Luttinger liquid (LL) phase of Cooper-pairs or a second gapless phase. In contrast to the LL of Cooper-pairs, this second phase is characterized by nonlocal string correlation functions which decay algebraically due to gapless charge-e excitations. The three phases are separated from each other by phase-transitions of either Kosterlitz-Thouless or Ising type. Using a Jordan-Wigner transformation, we map the system to a generalized Bose-Hubbard model with two types of hopping and use DMRG to analyze the different phases and the phase-transitions.

TT 53.14 Thu 13:00 HSZ 103

(Super)symmetry in the Sachdev-Ye-Kitaev model — •Jan Behrends[1] and Benjamin Béri[1,2] — [1]T.C.M. Group, Cavendish Laboratory, University of Cambridge, J.J. Thomson Avenue, Cambridge, CB3 0HE, United Kingdom — [2]DAMTP, University of Cambridge, Wilberforce Road, Cambridge, CB3 0WA, United Kingdom

Supersymmetry is a powerful concept in quantum many-body physics. It helps to illuminate ground state properties of complex quantum systems and gives relations between correlation functions. In this work, we show that the Sachdev-Ye-Kitaev model, in its simplest form of Majorana fermions with random four-body interactions, is supersymmetric. In contrast to existing explicitly supersymmetric extensions of the model, the supersymmetry we find requires no relations between couplings. The type of supersymmetry and the structure of the supercharges are entirely set by the number of interacting Majorana modes, and are thus fundamentally linked to the model's Altland-Zirnbauer classification. The supersymmetry we uncover has a natural interpretation in terms of a one-dimensional topological phase supporting Sachdev-Ye-Kitaev boundary physics, and has consequences away from the ground state, including in q-body dynamical correlation functions. This talk will not only illuminate the role of supersymmetry, but also the underlying Altland-Zirnbauer classes that have been previously overlooked.