TT 71: Transport: Majorana Fermions (organized by TT)

Time: Wednesday 15:00–18:00 Location: HSZ 03

TT 71.1 Wed 15:00 HSZ 03

Majorana spin liquid and dimensional reduction in Cs_2CuCl_4 — •Tim Herfurth, Simon Streib, and Peter Kopietz — Institut für Theoretische Physik, Universität Frankfurt, Max-von-Laue Strasse 1, 60438 Frankfurt, Germany

The low-temperature behavior of the magnetic insulator Cs_2CuCl_4 can be modeled by an anisotropic triangular lattice spin 1/2 Heisenberg antiferromagnet with two different exchange couplings J and $J' \approx J/3$. We show that in a wide range of magnetic fields the experimentally observed field dependence of the crossover temperature T_c for spin-liquid behavior can be explained within a mean-field theory based on the representation of spin operators in terms of Majorana fermions. We also show that for small magnetic fields the specific heat and the spin susceptibility both exhibit a maximum as a function of temperature at $T_c = J/2$. In the spin-liquid regime, the Majorana fermions can only propagate along the direction of the strongest bond, in agreement with the dimensional reduction scenario advanced by Balents[1].

[1] Nature **464**, 199 (2010)

TT 71.2 Wed 15:15 HSZ 03

Supersymmetry in the Majorana Cooper pair box — •Jascha Ulrich and Fabian Hassler — Institut für Quanteninformation, RWTH Aachen

Over the years, supersymmetric quantum mechanics (SUSY QM) has evolved from a toy model of high energy physics to a research direction of its own. Although many examples of SUSY QM systems have been found, systems that can be naturally realized are generally scarce. In this work, we argue that the interaction of fermionic subgap Majorana bound states with the underlying Cooper pair condensate provides a natural setting for SUSY QM. We show that the extension of the conventional Cooper pair box by an anomalous Majorana-Josephson coupling realizes SUSY QM for certain values of gate voltage and Josephon/Majorana-Josephson coupling ratio. We show that the resulting degeneracy of all subgap energy levels can be probed directly in a tunneling experiment and discuss the various transport signatures. An observation of the predicted level degeneracy would provide evidence for the presence of a Majorana-induced anomalous Josephson coupling.

TT 71.3 Wed 15:30 HSZ 03

Robustness of exchange protocols of Majorana fermions in quantum wire networks — •Rolf W. Reinthaler[1], Chao Lei[2], Allan H. MacDonald[2], and Ewelina M. Hankiewicz[1] — [1]Faculty of Physics and Astrophysics, University of Würzburg, Würzburg, Germany — [2]Department of Physics, University of Texas at Austin, USA

The ends of one-dimensional spinless p-wave superconductors support Majorana bound states [1], whose non-trivial exchange statistics makes them promising candidates for topological quantum computation [2]. The huge advantage of using networks of 1D nano wires is that the Majorana fermions can be manipulated and exchanged by purely electrical means [3]. By applying a tight binding approach we solve the time dependent Bogoliubov-de Gennes equations for the Kitaev chain model [1]. We analyze how the robustness of the exchange protocols is affected by non-adiabatic effects as well as by a finite overlap of the Majorana bound states.

We acknowledge financial support by the DFG grant HA 5893/3-1.

[1] A. Y. Kitaev, Physics-Uspekhi **44** (2001) 131
[2] D. A. Ivanov, PRL **86** (2001) 268
[3] J. Alicea et al., Nature Physics **7** (2011) 412

TT 71.4 Wed 15:45 HSZ 03

Absence of Aharonov-Bohm effect of chiral Majorana fermion edge states — •Sunghun Park[1,4], Joel Moore[2,3], and Heung-Sun Sim[1] — [1]Department of Physics, Korea Advanced Institute of Science and Technology, Daejeon 305-701, Korea — [2]Department of Physics, University of California, Berkeley, California 94720, USA — [3]Materials Sciences Division, Lawrence Berkeley National Laboratory, Berkeley, California 94720, USA — [4]Institute for Mathematical Physics, TU Braunschweig, 38106 Braunschweig, Germany

Majorana fermions in a superconductor hybrid system are charge neutral zero-energy states. For the detection of this unique feature, we propose an interferometry of a chiral Majorana edge channel, formed along the interface between a superconductor and a topological insulator under an external magnetic field perpendicular to the surface of the topological insulator. The superconductor is of a ring shape and has a Josephson junction that allows the Majorana state to enclose continuously tunable magnetic flux. Zero-bias differential electron conductance between the Majorana state and a normal lead is found to be independent of the flux at zero temperature, manifesting the Majorana feature of a charge neutral zero-energy state. To compare with a non-Majorana case, we consider the same setup on graphene. In this case, the setup has no Majorana states and shows Aharonov-Bohm effects.

TT 71.5 Wed 16:00 HSZ 03

Fractional Josephson effect in a quadruple quantum dot — •Björn Sothmann, Jian Li, and Markus Büttiker — Département de Physique Théorique, Université de Genève, CH-1211 Genève 4, Switzerland

A double quantum dot coupled to an s-wave superconductor and subject to an inhomogenous magnetic field can host a pair of zero-energy Majorana fermions when the dot properties are tuned appropriately [1]. Here, we demonstrate the possibility to generate a fractional 4π Josephson effect in two such double dots tunnel-coupled to each other. We discuss the robustness of this effect with respect to perturbations away from the special point in parameter space where the uncoupled doube dots host Majorana fermions. We point out the possibility to generate Josephson effects with a period of 8π and 12π in strongly-coupled double dots.

[1] M. Leijnse and K. Flensberg, Phys. Rev. B **86**, 134528 (2012)
[2] B. Sothmann, J. Li, M. Büttiker, New J. Phys. **15**, 085018 (2013)

15 min. break.

Invited Talk TT 71.6 Wed 16:30 HSZ 03

Majorana Fermions in Chains of Magnetic Atoms on the Surface of a Superconductor — •Ali Yazdani — Princeton University

In this talk, I will describe a proposal and related experiments for realization of Majorana fermions in chains of magnetic atoms on the surface of a conventional superconductors. I will describe model calculations that motivate the experimental studies, which show that a spiral spin textured chain of atoms give rise to a topological superconducting phase when place in contact with a s-wave superconductor. Remarkably, only chains of as long as few tens of atoms is required to realize this phase in the calculations. I will also describe experiments in which we use in situ assembly of magnetic atoms on the surface of an s-wave superconductor and spectroscopic mapping with a scanning tunneling microscope (STM) to search for signatures of Majorana fermions at the end of such chains. Spin-polarized STM experiments in which we probe the spin texture of such chains will also be described.

[1] S. Nadj-Perge, I.K. Drozdov, B.A. Bernevig, and A. Yazdani, Phys. Rev. B 88, 020407 (2013)
[2]J. Klinovaja, P. Stano, A. Yazdani, and D. Loss, Phys. Rev. Lett. 111, 186805 (2013)

TT 71.7 Wed 17:00 HSZ 03

Disordered one-dimensional topological superconductors — •Michael Wimmer[1,2], Inanc Adagideli[3], and Aykut Teker[3] — [1]Universiteit Leiden, The Netherlands — [2]TU Delft, The Netherlands — [3]Sabanci University, Istanbul, Turkey

It is well-established that disorder is harmful to a topological phase in p-wave superconductors [1]. Recently, it has been proposed to engineer ap-wave superconductor using conventional materials: a nanowire with strong spin-obrit coupling in proximity to a s-wave superconductor and in a magnetic field ("s-wave Rashba wires"), and first experimental results have been obtained [2].

We present a simple and intuitive method to link topological properties of superconducting wires to their normal state properties. This allows to describe ensemble-averaged topological properties as well as individual systems. In particular, we show that the effect of disorder is quite different in p-wave superconductors and s-wave Rahsba wires: While disorder is always harmful for the former, topology can be created by disorder in the latter [3].

[1] P. Brouwer *et al.* Phys. Rev. B **84**, 144526 (2011)
[2] V. Mourik *et al.* Science **336**, 1003 (2012)

[3] I. Adagideli, M. Wimmer, A. Teker. arXiv:1302.2612 (2013)

TT 71.8 Wed 17:15 HSZ 03

Majorana Fermions in Antiferromagnetically doped Superconductors — •Andreas Heimes, Panagiotis Kotetes, and Gerd Schön — Institut für Theoretische Festkörperphysik and DFG-Center for Functional Nanostructures, Karlsruhe Institute of Technology, D-76128 Karlsruhe, Germany

Recently the field of Majorana fermions (MFs) in solid state physics has attracted great attention. Among the many existing proposals for their experimental realization and detection, one can distinguish a class of self-tuned MF systems, consisting of spiral spin chains on s-wave superconductors. We propose an alternative MF platform based on a chain of antiferromagnetically (AFM) ordered magnetic impurities on top of a conventional superconductor, which has the advantage that it allows for an external tunability by experimental parameters: The transition to the MF regime is achieved and controlled by the combination of a supercurrent flow and a Zeeman field. In fact, the latter can be considerably weak since the presence of the AFM order relaxes the requirement of a large Zeeman energy. Evenmore, the currently existing STM technology renders our proposal directly experimentally accessible.

TT 71.9 Wed 17:30 HSZ 03

Majorana fermions in quasi-1d Rashba semiconductor/superconductor heterostructures without the requirement of a Zeeman field — •Panagiotis Kotetes, Alexander Shnirman, and Gerd Schön — Karlsruhe Institute of Technology

Recent experiments have provided the first promising indications of Majorana fermions (MFs) in heterostructures consisting of Rashba semiconducting wires and superconductors in the presence of a Zeeman field. By performing a complete classification of engineered topological superconductors (TSCs) [1] we predict that MFs are accessible in quasi-1d Rashba semiconductors with proximity induced superconductivity, even in the absence of magnetism. The only requirement is the presence of a Josephson current, flowing transversely to the principal axis of the quasi-1d structure. Here, we demonstrate how MFs emerge within our proposal when multi-wire or multi-channnel semiconductors are involved. The crucial effect of the supercurrent flow is to convert the inter-wire/channel spin-orbit coupling into an effective Zeeman term. Our results can motivate a new set of experiments using the already developed devices but in different configurations, providing in this way an accessible and irrefutable method for confirming the emergence of MFs.

[1] P. Kotetes, New J. Phys. 15, 105027 (2013)

TT 71.10 Wed 17:45 HSZ 03

Quantum spin liquid with a Majorana Fermi surface on the three-dimensional hyperoctagon lattice — •Maria Hermanns and Simon Trebst — Institut für Theoretische Physik, Universität zu Köln

Motivated by the recent synthesis of β-Li_2IrO_3 – a spin-orbit entangled $j = 1/2$ Mott insulator with a three-dimensional lattice structure of the Ir^{4+} ions – we consider generalizations of the Kitaev model, believed to capture some of the microscopic interactions between the Iridium moments, on various trivalent lattice structures in three spatial dimensions. Of particular interest is the so-called hyperoctagon lattice – a cubic non-Bravais lattice, which is probably best described as the premedial lattice of the hyperkagome lattice – for which the ground state is a gapless quantum spin liquid where the gapless Majorana modes form an extended Majorana Fermi surface. We demonstrate that this Majorana Fermi surface is inherently protected by lattice symmetries and discuss possible instabilities when allowing for a reduction in lattice symmetries. We discuss these findings also in light of recent results obtained for the hyperhoneycomb lattice.