TT 102: Topology: Majorana Fermions

Time: Thursday 16:00–18:30 Location: A 053

TT 102.1 Thu 16:00 A 053

Structure and dynamics of Majorana states in hybrid superconducting nanowires — •Ivan Khaymovich[1,2], Alexander Kopasov[2], Jukka Pekola[3], and Alexander Mel'nikov[2,4] — [1]Max Planck Institute for the Physics of Complex Systems, D-01187 Dresden, Germany — [2]Institute for Physics of Microstructures, Russian Academy of Sciences, 603950 Nizhny Novgorod, GSP-105, Russia — [3]Low Temperature Laboratory, Department of Applied Physics, Aalto University School of Science, P.O. Box 13500, FI-00076 Aalto, Finland — [4]Lobachevsky State University of Nizhny Novgorod, 23 Gagarina, 603950 Nizhny Novgorod, Russia

We perform a microscopic analysis of the inverse proximity effect in superconducting hybrid structures hosting Majorana bound states (MBS) as well as of the dynamic response of MBS in such systems. the critical temperature of the semiconducting nanowires with large g-factor and spin-orbit interaction, covered by a superconducting film and placed in a magnetic field H, is shown to be significantly reduced due to the presence of van Hove singularities in the wire and have a non-monotonic H-dependence attributed to the topological regime. Nonlocal AC response of a pair of MBS in a system with effective p-wave gap parameter is studied using a time-dependent Bogolubov-de Gennes equations. The time-dependent perturbations of transport excite finite period beating of the wave function between the MBS. We propose an experimental test to measure the characteristic time scales of quasiparticle transport through the pair of MBS defining, thus, quantitative characteristics of nonlocality attributed to MBS.

TT 102.2 Thu 16:15 A 053

Charge-response of the Majorana toric code — •Fabian Hassler and Ananda Roy — JARA Institute for Quantum Information, RWTH Aachen University, 52056 Aachen, Germany

At zero temperature, a two dimensional lattice of Majorana zero modes on mesoscopic superconducting islands has a topologically ordered toric code phase. Recently, a Landau field theory has been proposed for the system that captures its different phases and the associated phase-transitions. It was shown that with the increase of Josephson tunneling between the islands, a continuous symmetry-breaking 3D-XY transition gets transformed into a discrete symmetry-breaking 3D-Ising transition through a couple of tricritical points and first order transitions. Using the proposed field theory, we analyze the charge-response of the system at the different continuous phase-transitions. We calculate the universal conductivity at the 3D-XY transitions and the change in the superconducting density at the Ising transition using 1/N expansion.

TT 102.3 Thu 16:30 A 053

Decaying spectral oscillations in a Majorana wire with finite coherence length — •Christoph Fleckenstein, Fernando Dominguez, Niccolo Traverso Ziani, and Björn Trauzettel — Institut für theoretische Physik, Universität Würzburg, Deutschland

Motivated by recent experiments, we investigate the excitation energy of a proximitized Rashba wire in the presence of a position dependent pairing. In particular, we focus on the spectroscopic pattern produced by the overlap between two Majorana bound states that appear for values of the Zeeman field smaller than the value necessary for reaching the bulk topological superconducting phase. The two Majorana bound states can arise because locally the wire is in the topological regime. We find three parameter ranges with different spectral properties: crossings, anticrossings and asymptotic reduction of the energy as a function of the applied Zeeman field. Interestingly, all these cases have already been observed experimentally. Moreover, since an increment of the magnetic field implies the increase of the distance between the Majorana bound states, the amplitude of the energy oscillations, when present, gets reduced. The existence of the different Majorana scenarios crucially relies on the fact that the two Majorana bound states have distinct k-space structures. We develop analytical models that clearly explain the microscopic origin of the predicted behavior.

TT 102.4 Thu 16:45 A 053

Majorana bound states in semiconducting carbon nanotubes - Part I (numerics) — •Magdalena Marganska[1], Lars Milz[1], Wataru Izumida[1,2], Christoph Strunk[3], and Milena Grifoni[1] — [1]Institute of Theoretical Physics, University of Regensburg, 93 053 Regensburg, Germany — [2]Department of Physics, Tohoku University, Sendai 980 8578, Japan — [3]Institute of Experimental and Applied Physics, University of Regensburg, 93 053 Regensburg, Germany

Considering the eminent usefulness which the Majorana states have for the field of quantum computing, their practical realization is eagerly awaited. The two best solid state candidates for Majorana hosts are the proximitized iron chains and proximitized semiconducting nanowires with spin-orbit coupling. The system which we investigate is a proximitized carbon nanotube, where the Majorana bound states arise through a physical mechanism similar as in the nanowire. The nanotube has however several advantages. First, it can be grown with minimal disorder. Second, due to its small size, it can be simulated numerically at the microscopic level. Finally, its tiny diameter reduces the number of relevant transverse modes to exactly one, with spin and valley degeneracy. We present here the results of numerical simulations of a proximitized nanotube, capturing the topological phase transition and the formation of Majorana states at the nanotube ends. We construct an effective analytical four-band model which allows us to analyze the system's symmetries and calculate a topological phase diagram, predicting the parameter ranges of chemical potential and magnetic field which hold the greatest promise for planned experiments.

TT 102.5 Thu 17:00 A 053

Majorana bound states in semiconducting carbon nanotubes - Part II (analytics) — •Lars Milz[1], Magdalena Marganska[1], Wataru Izumida[1,2], Christoph Strunk[3], and Milena Grifoni[1] — [1]Institut of Theoretical Physics, University of Regensburg, 93 035 Regensburg, Germany — [2]Department of Physics, Tohoku University, Sendai 980 8578, Japan — [3]Institute of Experimental and Applied Physics, University of Regensburg, 93 053 Regensburg, Germany

In this talk we present an effective two-band model Hamiltonian for superconducting carbon nanotubes, valid in the limit of small magnetic fields, which can be solved fully analytically. We will show the corresponding quasiparticle energy spectrum and the topological phase diagram for the bulk system. In the semi-infinite geometry we will demonstrate the presence of Majorana bound states in the topological non-trivial regions. The longitudinal component of the corresponding Majorana wave function has three contributions, one from the Γ-point and from each Fermi point. In order to obtain the full Majorana wave function we also include its transverse profile. Finally, we compare it with the wave function obtained by a numerical, real space tight-binding calculation.

15 min. break.

TT 102.6 Thu 17:30 A 053

Synthetic spin orbit interaction for Majorana devices — •Lauriane Contamin[1], Matthieu Desjardins[1], Matthieu Dartiailh[1], Laure Bruhat[1], Tino Cubaynes[1], Jeremie Viennot[2], François Mallet[1], Stanislas Rohart[3], André Thiaville[3], Audrey Cottet[1], and Takis Kontos[1] — [1]Laboratoire Pierre Aigrain, Ecole Normale Supérieure-PSL Research University, CNRS, Université Pierre et Marie Curie-Sorbonne Universités, Université Paris Diderot-Sorbonne Paris Cité, Paris, France — [2]JILA and Department of Physics, University of Colorado, Boulder, Colorado, USA — [3]3Laboratoire de Physique des Solides, Université Paris-Sud et CNRS, Orsay, France

The engineering of Majorana modes in condensed matter systems could allow one to study excitations with particle/antiparticle duality and non-abelian statistics. Most of the experimental setups with nanoscale circuits use nanowires with strong spin-orbit interaction connected to superconductors. Theoretical proposals have suggested inducing a spin-orbit coupling through a magnetic texture. In this work, we demonstrate experimentally such a platform using a single wall carbon nanotube as a conductor, which naturally exhibit few conduction channels. It is stamped over a magnetic gate and coupled to two superconducting electrodes. We observe subgap states in the conductance. A detailed study of their magnetic field evolution reveals a large synthetic spin-orbit energy. Furthermore, a robust zero energy state, the hallmark of localized Majorana modes, emerges at zero magnetic field.

TT 102.7 Thu 17:45 A 053

The influence of the non-locality of Majorana bound states on thesupercurrent — •Alexander Schuray[1], Alfredo Levy-Yeyati[2], and Patrik Recher[1,3] — [1]Institut für Mathematische Physik, TU Braunschweig, D-38106 Braunschweig, Germany — [2]Departamento de Física Teórica de la Materia Condensada C-V, Condensed Matter Physics Center and Instituto Nicolás Cabrera, UAM, E-28049 Madrid, Spain — [3]LENA Braunschweig, D-38106 Braunschweig, Germany

The transport signatures of Majorana bound states (MBS), which emerge at the boundaries of one dimensional p-wave superconductors, have been in the center of many research activities. One of these proposed signatures is that the supercurrent in an s-wave-p-wave Josephson junction is blocked [1], if the considered superconductors are semi-infinite. However, recent experiments [2] and theoretical works [3,4] suggest that finite size effects need to be taken into account and that the second MBS can not always be neglected. We show analytically that the second MBS lifts the blockade of the supercurrent and that the resulting current carries information about the spin canting angle of the two MBS. We verify our analytical effective model numerically by using a tight-binding approximation for a spin orbit coupled nanowire in a magnetic field with proximity induced superconductivity.

[1] A. Zazunov and R. Egger, Phys. Rev. B **85**, 104514 (2012)
[2] M.T. Deng et al., Science **354**, 1557 (2016)
[3] A. Schuray et al., Phys. Rev. B **96**, 085417 (2017)
[4] E. Prada et al., Phys. Rev. B **96**, 085418 (2017)

TT 102.8 Thu 18:00 A 053

Transport properties of Coulomb blockaded T-junctions hosting Majorana bound states — •Johan Ekström[1], Patrik Recher[2], and Thomas Schmidt[1] — [1]Physics and Materials Science Research Unit, University of Luxembourg, Luxembourg — [2]Institute for Mathematical Physics, TU Braunschweig, 38106 Braunschweig, Germany

We study electron transport through a T-shaped nanowire junction hosting Majorana bound states (MBS). When the T-junction is in the topologically nontrivial regime it hosts three MBS at the ends of the wires and one MBS localized at the crossing point of the junction. For finite wire length, the MBS localized at the ends overlap with the MBS at the crossing point. It was found previously that such a setup can give rise to exotic transport processes such as double crossed Andreev reflections. In this work, we investigate the effect of Coulomb blockade and study the different transport processes due to the coupling between the MBS using a master equation in the sequential tunneling regime.

TT 102.9 Thu 18:15 A 053

Friedel-oscillations in inhomogeneous topological superconductors — •Lars Lauke[1,2], Mathias Scheurer[1,3], Andreas Poenicke[1,4], and Jörg Schmalian[1,2] — [1]Institut für Theorie der Kondensierten Materie, Karlsruher Institut für Technologie (KIT), 76131 Karlsruhe, Deutschland — [2]Institut für Festkörperphysik, Karlsruher Institut für Technologie (KIT), 76131 Karlsruhe, Deutschland — [3]Department of Physics, Harvard University, Cambridge MA 02138, USA — [4]Institut für Theoretische Festkörperphysik, Karlsruher Institut für Technologie (KIT), 76131 Karlsruhe, Deutschland

In order to investigate Majorana bound states in p-wave superconductors and to reveal the precise influence of boundaries and inhomogeneities on the local structure of competing superconducting order parameters, we solve inhomogeneous Bogoliubov-de Gennes equations. Going beyond the quasi-classical approach we examine in particular the role of Friedel-oscillations due to inhomogeneities and the surface of the superconductor and analyse the distinct behaviour of the p-wave and the surface induced s-wave pairing amplitudes. We further discuss the observability of the local structure of the s-wave order parameter and the Majorana zero modes via scanning tunnelling microscopy.