HL 35: Transport: Quantum Coherence and Quantum Information Systems 3 (jointly with TT, MA)

Time: Tuesday 9:30–12:15 Location: BH 243

Invited Talk HL 35.1 Tue 9:30 BH 243

Making and manipulating Majorana fermions for topological quantum computation — •Felix von Oppen — Dahlem Center for Complex Quantum Systems and Fachbereich Physik, Freie Univversitaet Berlin, 14195 Berlin

Known theoretically for decades, Majorana fermions have never been observed as fundamental particles. But there is growing excitement among condensed matter physicists that Majorana fermions could be observed as quasiparticles in the solid state. This excitement is fueled by their remarkable properties: They are their own antiparticle and obey an exotic (and yet unobserved) form of quantum statistics called non-Abelian statistics. These properties make Majorana fermions the simplest candidate for realizing topological quantum information processing which could go a long way towards alleviating the problem of decoherence in conventional quantum computation.

Among the systems predicted to support Majorana fermions are exotic fractional quantum Hall states as well as hybrid structures of topological insulators, semimentals, or semiconductors with conventional superconductors. Realizations based on semiconductor quantum wires in proximity to conventional superconductors are perhaps particularly promising since they allow for relatively detailed scenarios of how to manipulate the Majorana fermions. In this talk, I will discuss this proposal to realize Majorana fermions.

HL 35.2 Tue 10:00 BH 243

Engineering and manipulating Majorana bound states in 1D quantum wires — •Panagiotis Kotetes[1], Alexander Shnirman[2], and Gerd Schön[1] — [1]Institut für Theoretische Festkörperphysik, Karlsruhe Institute of Technology, 76128 Karlsruhe, Germany — [2]Institut für Theorie der Kondensierten Materie, Karlsruhe Institute of Technology, D-76128 Karlsruhe, Germany

Recently, the interest in topological quantum computing has grown due to the appearance of promising platforms for realizing the long sought Majorana bound states. Among the proposals that appear suitable for engineering the Majorana bound states, the most prominent involves a 1D semiconducting quantum wire in proximity to a bulk s-wave superconductor, where in addition a Zeeman magnetic field is applied. In this work, we investigate the possibility of performing qubit operations via the adiabatic variation of certain internal parameters without using any external gates or network of wires. The crucial feature of our model is the combination and interplay of phases for the magnetic field and the superconducting order parameter. In an appropriate junction setup, we explore the possible phase configurations that could lead to a Majorana bound state exchange.

HL 35.3 Tue 10:15 BH 243

Coulomb-assisted braiding of Majorana fermions in a Josephson junction array — •Fabian Hassler[1], Bernard Van Heck[2], Anton Akhmerov[2], Michele Burrello[2], and Carlo Beenakker[2] — [1]Institute for Quantum Information, RWTH Aachen University, D-52056 Aachen, Germany — [2]Instituut-Lorentz, Universiteit Leiden, P.O. Box 9506, 2300 RA Leiden, The Netherlands

We show how to exchange (braid) Majorana fermions in a network of superconducting nanowires by control over Coulomb interactions rather than tunneling. Even though Majorana fermions are charge-neutral quasiparticles (equal to their own antiparticle), they have an effective long-range interaction through the even-odd electron number dependence of the superconducting ground state. The flux through a split Josephson junction controls this interaction via the ratio of Josephson and charging energies, with exponential sensitivity. By switching the interaction on and off in neighboring segments of a Josephson junction array, the non-Abelian braiding statistics can be realized without the need to control tunnel couplings by gate electrodes. This is a solution to the problem how to operate on topological qubits when gate voltages are screened by the superconductor.

HL 35.4 Tue 10:30 BH 243

Quantum information transfer between topological and spin qubit systems — •Martin Leijnse and Karsten Flensberg — Nano-Science Center and Niels Bohr Institute, University of Copenhagen, Denmark

In this talk I will introduce a method to coherently transfer quantum information, and to create entanglement, between topological qubits and conventional spin qubits. The transfer method uses gated control to transfer an electron (spin qubit) between a quantum dot and edge Majorana modes in adjacent topological superconductors. Because of the spin polarization of the Majorana modes, the electron transfer translates spin superposition states into superposition states of the Majorana system, and vice versa. Furthermore, I will discuss how a topological superconductor can be used to facilitate long-distance quantum information transfer and entanglement between spatially separated spin qubits [1,2].
[1] M. Leijnse, K. Flensberg, PRB **84**, 140501(R) (2011)
[1] M. Leijnse, K. Flensberg, PRL **107**, 210502 (2011)

15 min. break.

Invited Talk HL 35.5 Tue 11:00 BH 243

Distinguishing quantum and classical transport through nanostructures — •Clive Emary[1], Neill Lambert[2], Franco Nori[2,3], and Yueh-Nan Chen[4] — [1]TU Berlin, Germany — [2]RIKEN, Japan — [3]University of Michigan, USA — [4]National Cheng-Kung University, Tainan, Taiwan

I will discuss the question of how to distinguish quantum from classical transport through nanostructures using fundamental quantum-mechanical inequalities. I will briefly discuss how Bell's inequalities can be employed to investigate entanglement in the solid-state, before focusing on a less well-known inequality, the Leggett-Garg inequality. This latter probes the 'macroscopic realism' of a system, i.e. whether or not the system has a well-defined state independent of the observer. I will describe how the Leggett-Garg inequality can be realised in transport context, and how it can be violated by quantum coherent transport.

HL 35.6 Tue 11:30 BH 243

Spin-orbit-induced strong coupling of a single spin to a nanomechanical resonator — •Andras Palyi[1,2], Philipp R. Struck[1], Mark Rudner[3], Karsten Flensberg[3,4], and Guido Burkard[1] — [1]University of Konstanz, Germany — [2]Eotvos University, Budapest, Hungary — [3]Harvard University, Cambridge, Massachusetts, United States — [4]Niels Bohr Institute, Copenhagen, Denmark

We theoretically investigate the coupling of electron spin to vibrational motion due to curvature-induced spin-orbit coupling in suspended carbon nanotube quantum dots. Our estimates indicate that, with current capabilities, a quantum dot with an odd number of electrons can serve as a realization of the Jaynes-Cummings model of quantum electrodynamics in the strong-coupling regime. A quantized flexural mode of the suspended tube plays the role of the optical mode and we identify two distinct two-level subspaces, at small and large magnetic field, which can be used as qubits in this setup. The strong intrinsic spin-mechanical coupling allows for detection, as well as manipulation of the spin qubit, and may yield enhanced performance of nanotubes in sensing applications [1].
[1] arXiv:1110.4893)

HL 35.7 Tue 11:45 BH 243

Emission spectrum of a driven nonlinear resonator — •Stephan André[1,2], Lingzhen Guo[1,3], Michael Marthaler[1,2], and Gerd Schön[1,2] — [1]Institut für Theoretische Festkörperphysik, Karlsruhe Institute of Technology, 76128 Karlsruhe, Germany — [2]DFG Center for Functional Nanostructures (CFN), Karlsruhe Institute of Technology, 76128 Karlsruhe, Germany — [3]Department of Physics, Beijing Normal University, Beijing 100875, China

Motivated by recent "circuit QED" experiments [1,2] we investigate the properties of coherently driven nonlinear resonators. By using Josephson junctions in superconducting circuits, strong nonlinearities can be engineered, which lead to the appearance of pronounced quantum effects with a low number of photons in the resonator.

Based on a master equation approach we determine the emission spectrum and observe for typical circuit QED parameters, in addition to the primary side-peaks, second-order peaks which are not predicted

by a linearized theory. These peaks result from transitions between next-to-nearest levels in the rotating frame and from fluctuations of the oscillation amplitude. We show that an effective Planck constant provides a measure for the importance of the quantum effects.
[1] I. Siddiqi *et al.*, Phys. Rev. B **73**, 054510 (2006).
[2] F.R. Ong *et al.*, Phys. Rev. Lett. **106**, 167002 (2011).

HL 35.8 Tue 12:00 BH 243

Noise-induced transition in an electronic Mach-Zehnder interferometer — •Andreas Helzel[1], Leonid Litvin[1], Werner Wegscheider[2], and Christoph Strunk[1] — [1]Institute of exp. and applied physics, University of Regensburg, Germany — [2]Solid State Physics Laboratory, ETH Zurich, 8093 Zurich, Switzerland

The visibility of Aharonov-Bohm interference of an electronic Mach-Zehnder interferometer (MZI) shows a lobe structure when changing the applied DC bias. Multiple side lobes are present at filling factors from 1.5 to 2. By varying the transmission of a quantum point contact set in series at a distance D before the MZI (QPC0) we can suppress the multiple side lobes to a single side lobe. This occurs at a transmission probability of $T_{QPC0} = 0.5$. Above this transmission the lobe structure is robust and does not change qualitatively. For $T_{QPC0} < 0.5$ the multiple side lobes disappear and the central lobe width increases drastically with decreasing transmission. We see these properties both in the visibility and in the AB-phase. This behavior coincides with a recently proposed noise-induced phase transition [1].
[1] Ivan P. Levkivskyi, Eugene V. Sukhorukov, Phys. Rev. Lett. **103**, 036801 (2009)