HL 9: Transport: Topological Insulators 1 (jointly with TT, MA)

Time: Monday 9:30–13:00 Location: H 3010

HL 9.1 Mon 9:30 H 3010

Quantum point contact as a probe of a topological superconductor — •Michael Wimmer, Anton Akhmerov, Jan Dahlhaus, and Carlo Beenakker — Instituut-Lorentz, Universiteit Leiden, The Netherlands

We calculate the conductance of a ballistic point contact to a superconducting wire, produced by the s-wave proximity effect in a semiconductor with spin-orbit coupling in a parallel magnetic field. The conductance G as a function of contact width or Fermi energy shows plateaus at half-integer multiples of $4e^2/h$ if the superconductor is in a topologically nontrivial phase, supporting Majorana fermions. In contrast, the plateaus are at the usual integer multiples in the topologically trivial phase (without Majorana fermions). Disorder destroys all plateaus except the first, which remains precisely quantized, consistent with previous results for a tunnel contact. The advantage of a ballistic contact over a tunnel contact as a probe of the topological phase is the strongly reduced sensitivity to

HL 9.2 Mon 9:45 H 3010

Interaction and trapping effects on a 2D topological insulator in an optical lattice. — •Daniel Cocks[1], Peter P. Orth[2], Michael Buchhold[1], Stephan Rachel[3], Karyn Le Hur[4,3], and Walter Hofstetter[1] — [1]Institut für Theoretische Physik, Goethe-Universität Frankfurt — [2]Institut für Theorie der Kondensierten Materie, Karlsruher Institut für Technologie — [3]Department of Physics, Yale University, New Haven — [4]Center for Theoretical Physics, École Polytechnique, Palaiseau

We investigate effects of interaction, disorder and trapping of a 2D system that exhibits topologically insulating phases in an optical square lattice using both real-space dynamical mean-field theory (R-DMFT) and analytical techniques. The tunability of this system allows for a large degree of freedom, and by adjusting the size of the magnetic unit cell, along with the strength of a spin-orbit coupling that does not preserve the S_z spin component and a staggered super-lattice potential, topologically non-trivial regions have been identified.

Using R-DMFT, we determine the interacting phase diagram as a function of Hubbard U. We observe interaction driven transitions between the topological and normal insulating phase, as well as dependence of transitions to magnetically ordered phases on the flux parameter. We also analyze trapping effects that are relevant to experimental conditions and identify ideal trapping potentials that preserve the topological phases. This system is realizable (Goldman et al. PRL 105, 255302, 2010) as an effective Hamiltonian by generating a synthetic non-Abelian gauge field on the surface of an atom chip.

HL 9.3 Mon 10:00 H 3010

Phonon induced backscattering in helical edge states — •Patrik Recher[1], Jan C. Budich[2], Fabrizio Dolcini[3], and Bjoern Trauzettel[2] — [1]Institute for Mathematical Physics, TU Braunschweig, 38106 Braunschweig, Germany — [2]Institute for Theoretical Physics and Astrophysics, University of Würzburg, 97074 Würzburg, Germany — [3]Dipartimento di Fisica del Politecnico di Torino, I-10129 Torino, Italy

A single pair of helical edge states as realized at the boundary of a quantum spin Hall insulator is known to be robust against elastic single particle backscattering as long as time reversal symmetry is preserved. However, there is no symmetry preventing inelastic backscattering as brought about by phonons in the presence of Rashba spin orbit coupling. In this talk, we show that the quantized conductivity of a single channel of helical Dirac electrons is protected even against this inelastic mechanism to leading order. We further demonstrate that this result remains valid even when Coulomb interaction is included in the framework of a helical Tomonaga Luttinger liquid.

HL 9.4 Mon 10:15 H 3010

Electromagnetically induced topological charge on the surface of a topological insulator due to magnetization dynamics — •Flavio Nogueira and Ilya Eremin — Institut für Theoretische Physik III, Ruhr-Universität Bochum, Universitätsstraße 150, 44801 Bochum, Germany

A topologically non-trivial solution of the Landau-Lifshitz-Gilbert equation is obtained. Such a solution induces electric and magnetic fields and implies a topological current at the surface of a topological insulator which is proportional to $\mathbf{E}\cdot\mathbf{B}$. The values of the topological charge in our solution are $Q = -1, 0, 1$. The spin current density plays in this scenario the role of a non-Abelian gauge field and the topological charge is reminiscent of the 't Hooft-Polyakov construction of the magnetic monopole. We discuss the physical consequences of our theory, including the role of topological spin transport on the surface of a topological insulator.

HL 9.5 Mon 10:30 H 3010

Interplay of bulk and edge states in transport of topological insulators — •Rolf W. Reinthaler and Ewelina M. Hankiewicz — Faculty of Physics and Astrophysics, University of Würzburg, Würzburg, Germany

We study ballistic transport in two-terminal metal/quantum spin-Hall insulator (QSHI)/metal junctions within the effective four band model (conduction/heavy hole bands) [1, 2]. We show that the conductance signals originating from the bulk and the edge contributions are not additive. While for a long junction the transport is determined by the edge states contribution, for a short junction, the conductance signal is built from both, bulk and edge states, in the ratio which depends on the width of the sample. Further, the conductance for short junctions shows a non-monotonic behavior as a function of the sample lenght in topological insulator regime [3]. Suprisingly this non-monotonic behavior of conductance can be traced to the formation of an effectively propagating solution which is robust against scalar disorder. Our predictions should be experimentally verifiable in HgTe QWs and BiSe thin films.

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[1] B. A. Bernevig et al., Science, 314(5806):1757, 2006.
[2] D G Rothe et al., New Journal of Physics, 12(6):065012, 2010.
[3] E. G. Novik et al., Phys. Rev. B, 81(24):241303, 2010.

HL 9.6 Mon 10:45 H 3010

Landau levels in a topological insulator — •Peter Schwab and Michael Dzierzawa — Institut für Physik, Universität Augsburg, 86135 Augsburg, Germany

Two recent experiments successfully observed Landau levels in the tunneling spectra of the topological insulator Bi_2Se_3. To mimic the influence of a scanning tunneling microscope tip on the Landau levels we solve the two-dimensional Dirac equation in the presence of a localized electrostatic potential. We find [1] that the STM tip not only shifts the Landau levels, but also suppresses for a realistic choice of parameters the negative branch of Landau levels.

[1] P. Schwab and M. Dzierzawa, arXiv:1107.0827

HL 9.7 Mon 11:00 H 3010

Surface flat bands in gapless topological phases — •Andreas Schnyder — Max-Planck-Institut für Festkörperforschung, Heisenbergstrasse 1, D-70569 Stuttgart, Germany

In this talk we discuss a classification of Fermi surfaces, Fermi lines and Fermi points, as well as nodal lines and nodal points in superconductors in terms of discrete symmetries and Fermi surface codimension. By use of a bulk-boundary correspondence, we determine the types of topologically protected zero-energy states that appear at the boundary of these gapless topological systems. As concrete examples we examine the polar state of 3He, the nodal non-centrosymmetric superconductor Li2Pt3B, and the ferromagnetic superconductor URhGe. For the latter two systems, we examine the signatures of the protected surface states in tunneling-conductance measurements and in Fourier transformed scanning tunneling spectra. Furthermore, we study the appearance of gapless modes located on topological defects in gapless topological phases.

15 min. break.

HL 9.8 Mon 11:30 H 3010

Weak antilocalization in HgTe quantum wells and topological surface states: Massive versus massless Dirac fermions — •Ewelina Hankiewicz and Grigory Tkachov — Wuerzburg University

HgTe quantum wells and surfaces of three-dimensional topological insulators support Dirac fermions with a single-valley band dispersion. In this work we conduct a comparative theoretical study of the weak antilocalization in HgTe quantum wells (QWs) and topological surface states. The difference between these two single-valley systems comes from a finite band gap (effective Dirac mass) in HgTe quantum wells in contrast to gapless (massless) surface states in topological insulators. The finite effective Dirac mass implies a broken internal symmetry, leading to suppression of the weak antilocalization in HgTe quantum wells and transition to the weak localization regime as a function of the gap or carrier density. Further we show how the difference in the behavior of the weak localization corrections for HgTe QWs allows to distinguish topological versus normal insulators. On the other hand, the topological surface states exhibit specific weak-antilocalization magnetoconductivity in a parallel magnetic field due to their exponential decay in the bulk. The relevant experiments will be discussed.

We acknowledge the financial support of the German DFG Grant HA5893/1-2 .

HL 9.9 Mon 11:45 H 3010

Coulomb blockade signatures of the topological phase transition in semiconductor-superconductor nanowires — •Björn Zocher[1,2], Mats Horsdal[1,3], and Bernd Rosenow[1] — [1]Institut für Theoretische Physik, Universität Leipzig, Germany — [2]Max Planck Institut für Mathematik in den Naturwissenschaften, Leipzig, Germany — [3]Max Planck Institut für Festkörperforschung, Stuttgart, Germany

In semiconductor-superconductor hybrid structures a topological phase transition is expected as a function of chemical potential or magnetic field strength. We show that signatures of this transition can be observed in nonlinear Coulomb blockaded transport through a ring shaped structure. In particular, for a fixed electron parity of the ring, the flux periodicity of the neutral excitation spectrum changes from the usual $h/2e$-periodicity to a characteristic h/e-periodicity when tuning the system from the topologically trivial to the nontrivial phase. We relate the h/e-periodicity to the recently predicted 4π-periodicity of the Josephson current across a junction formed by two topological superconductors.

HL 9.10 Mon 12:00 H 3010

Tuning the Fermi velocity of Dirac cones: Towards an anomalous quantum Hall effect on the surfaces of topological insulators? — •Lars Fritz, Matthias Sitte, and Achim Rosch — Universität zu Köln, Institut für theoretische Physik, Zülpicher Strasse 77, 50937 Köln

Long-range Coulomb interaction can trigger an instability of two-dimensional Dirac fermions, the so-called chiral symmetry breaking. Three-dimensional topological insulators host two-dimensional helical Dirac fermions on their surfaces. We investigate whether long-range Coulomb interaction, controlled by the dimensionless coupling constant $\alpha = e^2/(\hbar\epsilon_r\epsilon_0 v_F)$, can induce surface ferromagnetism thereby gapping the surface metal. This is accompanied by an anomalous quantum Hall effect *without* explicit breaking of time-reversal invariance by an external magnetic field. We find that the prerequisite for observing this effect is to reduce the Fermi velocity v_F of the surface Dirac fermions while keeping the bulk dielectric constant ϵ_r finite. We discuss under which conditions this can be achieved.

HL 9.11 Mon 12:15 H 3010

Supersymmetry and Ballistic Transport in Topological Insulators with Ferromagnetic Domain-walls — •Christian Wickles and Wolfgang Belzig — Universität Konstanz, Fachbereich Physik, 78457 Konstanz, Germany

We consider the surface Dirac Fermions of a topological insulator with a proximity induced ferromagnetic domain wall (DW). We present an exact analytical treatment to discuss the spectrum, bound states and the ballistic conductance of the system with a DW in the in-plane and out-of-plane configuration. In the latter case of the "mass" DW, we find oscillations in the conducatance as a function of the wall width and we find for certain widths the DW to be completely reflectionless. We will use the language of supersymmetry to reveal that the dispersion of the surface Dirac Fermions together with the specific DW profile gives rise to these interesting features.

HL 9.12 Mon 12:30 H 3010

Aspects of electron-electron interactions and spin-conservation in topological insulators — •Stephan Rachel — Department of Physics, Yale University, New Haven, CT 06520, USA

We consider topological insulators on the honeycomb lattice and investigate the effect of electron-electron interactions and breaking of S_z spin-symmetry. We compare (i) non-interacting bandstructures with and without conserved spin, (ii) the regime of moderate interactions as well as (iii) the corresponding spin models. We find in all interaction-regimes qualitative differences between conserved and broken S_z spin-symmetry. The origin of these differences is explained. Eventually we discuss which of the effects are generic and which are specific for the honeycomb lattice.

HL 9.13 Mon 12:45 H 3010

Luttinger Liquid Physics and Spin-Flip Scattering on Helical Edges — •Martin Hohenadler and Fakher Assaad — Institut für Theoretische Physik und Astrophysik, Universität Würzburg, Würzburg, Deutschland

We investigate electronic correlation effects on edge states of quantum spin Hall insulators within the Kane-Mele-Hubbard model by means of quantum Monte Carlo simulations. In accordance with Luttinger liquid theory, we find dominant transverse spin fluctuations with an interaction dependent power law and the expected doping dependence. For strong electronic correlations, bulk states become important, and high-energy spectral features beyond Luttinger liquid theory emerge. Inelastic spin-flip scattering leads to graphene-like edge state signatures, and transfers spectral weight from low to high energies causing a suppression of charge transport.