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Emergent Supersymmetry from Strongly Interacting Majorana Zero Modes

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Phys. Rev. Lett. 115, 166401 (2015)

Abstact: We show that a strongly interacting chain of Majorana zero modes exhibits a supersymmetric quantum critical point corresponding to the c=7/10 tricritical Ising model, which separates a critical phase in the Ising universality class from a supersymmetric massive phase. We verify our predictions with numerical density-matrix-renormalization-group computations and determine the consequences for tunneling experiments.

Phase Diagram of the Interacting Majorana Chain Model

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arXiv:1505.03966 (2015)

Abstact: The Hubbard chain and spinless fermion chain are paradigms of strongly correlated systems, very well understood using Bethe ansatz, Density Matrix Renormalization Group (DMRG) and field theory/renormalization group (RG) methods. They have been applied to one-dimensional materials and have provided important insights for understanding higher dimensional cases. Recently, a new interacting fermion model has been introduced, with possible applications to topological materials. It has a single Majorana fermion operator on each lattice site and interactions with the shortest possible range that involve 4 sites. We present a thorough analysis of the phase diagram of this model in one dimension using field theory/RG and DMRG methods. It includes a gapped supersymmetric region and a novel gapless phase with coexisting Luttinger liquid and Ising degrees of freedom. In addition to a first order transition, three critical points occur: tricritical Ising, Lifshitz and a novel generalization of the commensurate-incommensurate transition. We also survey various gapped phases of the system that arise when the translation symmetry is broken by dimerization and find both trivial and topological phases with 0, 1 and 2 Majorana zero modes bound to the edges of the chain with open boundary conditions.

Strongly interacting Majorana fermions
Ching-Kai Chiu, D. I. Pikulin, and M. Franz
Phys. Rev. B 91, 165402 (2015)

Abstract: Interesting phases of quantum matter often arise when the constituent particles —electrons in solids—interact strongly. Such strongly interacting systems are, however, quite rare and occur only in extreme environments of low spatial dimension, low temperatures or intense magnetic fields. Here we introduce a system in which the fundamental electrons interact only weakly but the low energy effective theory is described by strongly interacting Majorana fermions. The system consists of an Abrikosov vortex lattice in the surface of a strong topological insulator and is accessible experimentally using presently available technology. The simplest interactions between the Majorana degrees of freedom exhibit an unusual nonlocal structure that involves four distinct Majorana sites. We formulate simple lattice models with this type of interaction and find exact solutions in certain physically relevant one- and two-dimensional geometries. In other cases we show how our construction allows for the experimental realization of interesting spin models previously only theoretically contemplated.

Statistical translation invariance protects a topological insulator from interactions
A. Milsted, L. Seabra, I. C. Fulga, C. W. J. Beenakker, and E. Cobanera
Phys. Rev. B 92, 085139 (2015)

Abstract: We investigate the effect of interactions on the stability of a disordered, two-dimensional topological insulator realized as an array of nanowires or chains of magnetic atoms on a superconducting substrate. The Majorana zero-energy modes present at the ends of the wires overlap, forming a dispersive edge mode with thermal conductance determined by the central charge c of the low-energy effective field theory of the edge. We show numerically that, in the presence of disorder, the c=1/2 Majorana edge mode remains delocalised up to extremely strong attractive interactions, while repulsive interactions drive a transition to a c=3/2 edge phase localized by disorder. The absence of localization for strong attractive interactions is explained by a self-duality symmetry of the statistical ensemble of disorder configurations and of the edge interactions, originating from translation invariance on the length scale of the underlying mesoscopic array.