Lifshitz transitions and Weyl semimetals from a topological superconductor with a current flow

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Abstract: We demonstrate that the non-equilibrium state of a topological superconductor crossed by a current flow can be mapped into the ground state of a half-filled two-dimensional Weyl semimetal, whose Fermi surface exhibits Lifshitz transitions.

A current flowing through a superconductor induces a spatial modulation in its superconducting pairing, characterized by a wavevector Q related to the total momentum of a Cooper pair. We investigate this phenomenon in a p-wave topological superconductor, described by a one-dimensional Kitaev model. We demonstrate that, by treating Q as an extra synthetic dimension, the current carrying non-equilibrium steady state can be mapped into the ground state of a half-filled two-dimensional Weyl semimetal, whose Fermi surface exhibits Lifshitz transitions when varying the model parameters. Specifically, the transition from Type-I to Type-II Weyl phases corresponds to the emergence of a gapless p-wave superconductor, where Cooper pairs coexist with unpaired electrons and holes. Such a transition is signalled by the appearance of a sharp cusp in the Q-dependence of the supercurrent, at a critical value Q* that is robust to variations of the chemical potential μ. We determine the maximal current that the system can sustain in the topological phase, discuss possible implementations, and compare to the case of a conventional s-wave superconductor [1]. Furthermore, for the cases $\mu = 0$ or $Q = \pm\pi/2$ the model turns out to exhibit special symmetries, which are proven to induce an even/odd effect in the correlations as a function of the distance l between two lattice sites, as they are nonvanishing or strictly vanishing depending on the parity of l, measured in the lattice spacing unit [2].

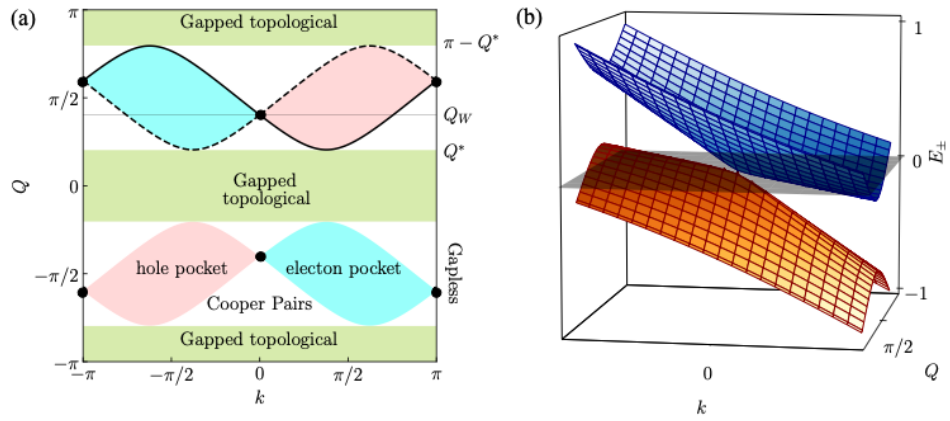

Fig. 1 (a) The Fermi surface of the 2D fermionic model associated to the Kitaev chain, where the superconducting phase modulation Q *is* treated as a synthetic dimension, consists of four Weyl nodes (black bullets), and of electron and hole pockets. Green areas denote the gapped topological phases of the 1D Kitaev chain, while in the other areas the Kitaev model exhibits a gapless superconducting state. (b) energy band in the vicinity of a Weyl node, showing that the associated 2D fermionic model is a Type-II Weyl Semimetal.

References

[1] F. G. Medina Cuy, F. Buccheri, and F. Dolcini, *Lifshitz transitions and Weyl semimetals from a topological superconductor with supercurrent flow*, Phys. Rev. Research. **6**, 033060 (2024)

[2] F. G. Medina Cuy, F. Buccheri, and F. Dolcini, *Correlation functions of the Kitaev model with a spatially modulated phase in the superconducting order parameter,* Phys. Rev. B. **110,** 214512 (2024).