Engineering topological superconductivity and Majorana states with defects in strong spin-orbit 2D superconductors

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Résumé

In recent years, a renewed interest in magnetic impurities in superconductors was driven by their potential as a new platform for topological superconductivity. Recent scanning tunneling spectroscopy measurements on a superconducting monolayer of lead(Pb) with nanoscale cobalt islands, have revealed puzzling quasiparticle in-gap states [1] which demand a better understanding of two-dimensional superconductivity in presence of spin-orbit coupling and magnetism. Tantalizingly, the quasiparticle states evoke general topologically protected states which haven't yet been explored in two-dimensional superconductors. Thus motivated, we theoretically study a model of two-dimensional s-wave superconductor with a fixed configuration of exchange field and spin-orbit coupling terms allowed by symmetry. Using analytics and exact diagonalization of tight-binding models, we find that a vortex-like defect in the Rashba spin-orbit coupling binds a single Majorana zero-energy (mid-gap) state. Importantly, in contrast to the case of a superconducting vortex [2], our spin-orbit defect does not create a tower of in-gap excitation states. Our findings match the puzzling features observed in the experiment, particularly: (1) preservation of superconducting gap, and (2) short localization length of the zero-energy state compared to the superconductor coherence length [3]. Additionally, these properties indicate that the system realizes the coveted well-protected Majorana states, which is a key requirement for a potential realization of a topological qubit. We also discuss how the quasiparticle states of the defect relate to the states of superconductors on top of magnetic textures, such as skyrmions.

Motivated by monolayer materials on a substrate, we also study superconducting vortex defects in mixed singlet-triplet pairing, in presence of spin-orbit coupling and Zeeman field. Throughout the phase diagram we find that a single defect can bind various numbers of zero-energy bound states despite time-reversal symmetry is broken. We discuss the phenomenon and implications of such multiple protected Majoranas. Especially, we focus on the role of discrete symmetries, such as magnetic mirror [4], in the protection of multiple Majoranas. The symmetries and protection of bound states are relevant also for general magnetic textures.

References

1. G. Ménard et al., Nature Comm 11, 1013 (2017).

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2. C. Caroli, P.G. de Gennes, and J. Matricon, Physics Letters 9, 307(1964).

4. G. Ménard, A. Mesaros et al., in preparation.
3. A. Mesaros and P. Simon, in preparation.