

Topology and energy dependence of Majorana bound states in a photonic cavity

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Light–matter interaction plays a crucial role in modifying the properties of quantum materials. We investigate the effect of cavity induced photon fields on a topological superconductor hosting Majorana bound states (MBS). We model the system using a Peierls substitution of the photonic operator in the kinetic and spin-orbit terms, and utilize an exact diagonalization of Hamiltonian for a finite number of photons to probe the coupled system.

We find that the MBS persist even in the presence of a cavity field and notably appear at finite and tunable energy, in contrast to a usual 1D topological superconductor. The MBS energy is shifted by two processes: the cavity photon energy adds a constant energy shift, while the light-matter interaction induces additional parameter dependencies, such that the MBS experience a pseudo-dispersion as a function of both light-matter interaction and magnetic field. Additionally, we find that the MBS energy oscillations are suppressed with increasing light–matter interaction and that disorder stability is not impacted by the light-matter interaction. Combined, these offer additional tunability and stability of the MBS.

As a second result, we establish a modified spectral localizer formalism as an essential tool for topological characterization of quantum matter in a cavity. The spectral localizer allows characterization at arbitrary energies, which is needed for probing different photon sectors. However, hybridization between different photon sectors in the low-frequency regime limits a straightforward application of a standard spectral localizer. We fully resolve this issue by judiciously applying an energy shift to the spectral localizer.

Our work thus introduces a new avenue for controlling MBS via light–matter coupling and provides a framework for exploring cavity-modified topologies.