Fingerprints of Majorana Bound States in Aharonov-Bohm Geometry

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We study a ring geometry, coupled to two normal metallic leads, which has a Majorana bound state (MBS) embedded in one of its arms and is threaded by Aharonov-Bohm ($\mathcal{AB}$) flux ϕ. We show that by varying the $\mathcal{AB}$ flux, the two leads go through resonance in an anticorrelated fashion while the resonance conductance is quantized to $2e^2/h$. We further show that such anticorrelation is completely absent when the MBS is replaced by an Andreev bound state (ABS). Hence this anti-correlation in conductance when studied as a function of ϕ provides a unique signature of the MBS which cannot be faked by an ABS. We contrast the phase sensitivity of the MBS and ABS in terms of tunneling conductances. We argue that the relative phase between the tunneling amplitude of the electrons and holes from either lead to the level (MBS or ABS), which is constrained to $0, \pi$ for the MBS and unconstrained for the ABS, is responsible for this interesting contrast in the $\mathcal{AB}$ effect between the MBS and ABS.

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Introduction.—Zero energy Majorana bound states (MBS), which appear as end states of a 1D p-wave superconductor have been attracting a lot of interest recently [1,2], mainly due to their topological nature and relevance [3] in topological quantum computation. Although serious attempts for confirming the existence of the MBS have been made experimentally [4,5], their outcome remains controversial, and it is perhaps fair to say that there still has not been a definitive experiment to verify their existence. The primary reason for this is that it is not easy to distinguish Majorana modes from other spurious zero energy modes. This has also led to considerable theoretical effort [6] to look for clearly distinguishable robust signals of Majorana modes.

Many earlier theoretical studies have focused on promising physical systems that support Majorana modes [7,8]. Another focus [9,10] has been understanding and extending the prototypical model that hosts Majorana modes, which is the Kitaev model [11]. There have also been generalizations that yield more than one Majorana mode at each of the edges [12,13], Floquet generation of Majorana modes [14,15], etc.

In this Letter, we show that the Aharonov-Bohm ($\mathcal{AB}$) effect in a ring geometry with a MBS embedded in one of its arms can provide a distinct signature which cannot be faked by an Andreev bound state (ABS). Earlier attempts to use $\mathcal{AB}$ flux interferometers have been in the context of teleportation [16,17] or nonlocal conductance or persistent currents [18], but they involve the MBS at both ends of a wire. Many other recent proposals that discuss distinguishing signatures of the MBS rely on quantum noise measurements [19], which are in general difficult to implement. In contrast, we propose conductance measurements which can clearly distinguish the Majorana from a spurious zero mode. Our proposed setup comprises of a two terminal ring geometry as shown in Fig. 1, with direct coupling between the leads as well as coupling via a MBS (ABS) hosted by a superconductor, which is the third lead and which remains grounded for our proposal. We show that when both the normal leads are equally biased with respect to the grounded superconductor, constructive resonance for one of the normal leads is always accompanied by a destructive antiresonance on the other normal lead. As the conductance on each lead has flux periodicity of a flux quantum ($\phi_0 = hc/e$), each normal lead goes through a resonance and an antiresonance as the phase of the direct tunneling term, which is tunable by the $\mathcal{AB}$ flux, changes by ϕ_0. On the contrary, when we replace the MBS by an ABS in the above-described setup, we find that the current flowing through both the leads remains equal, irrespective of the variation of the $\mathcal{AB}$ flux. Hence, the anticorrelation in current obtained as a function of the flux can be considered as a robust and direct signature of the MBS.

Tunneling into the MBS.—To begin with, we consider a model where a MBS is tunnel coupled to two normal leads.

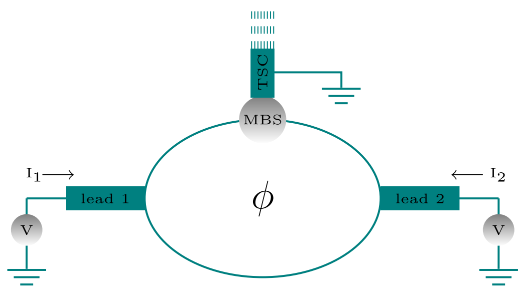

FIG. 1. Schematic illustration of the $\mathcal{AB}$ ring setup with two normal leads, at voltage V, directly coupled to each other as well as via a MBS (ABS) hosted at the edge of a grounded topological (nontopological) superconductor.

