Quantum charge pumping through Majorana bound states

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We study adiabatic charge pumping through a Majorana bound state tunnel coupled to multiple normal leads. We show that, for most of the parameters, such a pump does not lead to any net pumped charge between the various leads unless a multiply connected geometry is implemented. We introduce an Aharonov–Bohm ring geometry at the junction to implement such a multiply connected geometry. We further show that the Fourier transform of the pumped charge with respect to the flux inserted through the ring shows a clear distinction between the case of an Andreev bound state and the Majorana bound state. Hence such a Fourier analysis can serve as a diagnostic for the detection of Majorana bound states in the proposed geometry.

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I. INTRODUCTION

One of the first steps that is required for the application of Majorana modes [1–3] in quantum computation is its unambiguous identification. This has proved difficult in experiments [4,5], since the usual diagnostic of Majorana bound states (MBSs), a zero-bias peak in the conductance, can have many other origins besides signaling the presence of a Majorana mode. This fact has led to considerable work [6] in recent years, encompassing the study of various toy models [7] and promising physical systems [8,9] and their electrical transport signatures [10].

However, there has been no definitive experimental confirmation so far which has proved the existence of Majorana modes in any system and hence it is still of interest to look for different ways to confirm the existence of Majorana modes. In this context, it is worth exploring the question of charge pumping through a Majorana mode and examining whether there are unique signals which can identify it and differentiate it from pumping through other resonant levels or Andreev bound states. Charge pumping or the phenomenon of obtaining current in the absence of bias by local variations of parameters of the quantum system has been studied in many contexts, beginning with Thouless [11] who considered the effect of a traveling periodic potential that could drag the electrons along. The analysis performed by Thouless was in the spirit of a closed quantum system.

Later the idea of pumping was extended to open quantum system in Refs. [12,13], where the pumping of charge is induced between different electron reservoirs by periodically varying the independent parameters of the scattering matrix that describes the scattering of electrons between the different electron reservoirs. When the variation of the parameters is much slower than the transport time, then the pumping is adiabatic and the Brouwer formula [13] can be applied. Adiabatic charge pumping has attracted a great deal of interest in the last several years, and different aspects of it have been studied in great detail [14–37]. There has also been some work [38–49] on normal-metal–superconductor interfaces including Majorana [50–52] mediated charge pumps.

There has also been recent interest in cases when the pumped charge is quantized, and in particular for topological reasons [50], so that it is stable to disorder and could be used for metrological applications. As mentioned above, this was first studied by Thouless [11] who showed that the quantized adiabatic charge transport was related to the Chern number of the band, which also counts the number of monopoles or equivalently gapless points enclosed by the pumping contour. In recent work [50], it has been shown that the presence of a single transmitting channel at the interface between a normal wire and a superconductor enables quantization of the pumped charge by tuning the system through topological phase transitions so that isolated topologically trivial regions are surrounded by topological regions. Thus pumping paths can be chosen to make noncontractible loops in the parameter space which could lead to quantized charge pumping.

In an earlier paper [53], we studied the conductance through a Majorana bound state (MBS) embedded in an Aharonov–Bohm ring geometry and showed that the currents at the two leads tunnel coupled to the Aharonov–Bohm ring were anticorrelated and the degree of anticorrelation could be tuned by the Aharonov–Bohm ($\mathcal{AB}$) flux threading the ring. In this paper, we explore charge pumping through the MBS in the same geometry and study the role of the $\mathcal{AB}$ ring geometry, which exhibits nontrivial topology. Unlike Ref. [50], where the pumping of charge required going through topological phase transitions as one traverses along the pumping contour, here we show show that it is possible to obtain quantized pumped charge even when the superconductor hosting the MBS does not undergo phase transitions.

The ring geometry plays a crucial role here since we will show that there is no pumped charge when the two leads are just connected to the MBS (normal-MBS-normal or simple two-lead geometry without the ring). This is unlike the earlier study of conductance [53] where the anticorrelation existed even in the two-lead geometry and the $\mathcal{AB}$ geometry

