Majorana Fermions Bound at Vortices and Surface of Superfluid ^{3}He

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A Majorana fermion is a relativistic particle equivalent to its anti-particle, which was originally proposed by Ettore Majorana in 1937. Recently, it has been predicted that it hides in various materials, such as vortices and surface of superfluid ^{3}He. The remarkable fact that the creation operators of Majorana zero modes are self-Hermitian implies that their host vortices obey the non-abelian statistics.
Here, we investigate the Majorana fermions bound at (i) half-quantum vortices (HQV's) and (ii) surface Andreev bound states (SABS's) in superfluid ^{3}He A- and B-phases, which are expected to involve Majorana fermions. Here, it is demonstrated that although the HQV is expected to appear in rotating ^{3}He A-phase confined to a slab, the strong coupling effect which becomes crucial in high pressure regime makes the HQV unstable.[1] Then, we reveal the nontrivial structure of low-lying quasiparticles in phase vortex and coreless vortex which are energetically competitive to the HQV in A-phase.[2] We also discuss the SABS in A- and B-phases, where the former (later) gives rise to spontaneous mass (spin) current along the surface. In particular, based on the quasiclassical Eilenberger and full-quantum Bogoliubov-de Gennes theories, we demonstrate that the Majorana nature of the SABS in B-phase is sensitive to the dipole interaction and the orientation of magnetic field.

[1] T. Kawakami *et al.*, Phys. Rev. B **79**, 092506 (2009); J. Phys. Soc. Jpn. **80**, 044603 (2011).
[2] M. Ichioka, T. Mizushima, and K. Machida, Phys. Rev. B **82**, 094516 (2010).

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