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Signatures of Majorana and Weyl Fermions in confined phases of superfluid ^{3}He[1]

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The B-phase of superfluid ^{3}He exhibits symmetry breaking in which separate invariance under gauge-, spin- and orbital rotations is reduced to the maximal sub-group, $SO(3)_{L+S} \times T$. Parity is broken, but time-reversal is preserved. Broken relative spin-orbit rotational symmetry implies emergent spin-orbit coupling and non-trivial topology of the ground state, both of which are encoded in the Bogoliubov-Nambu Hamiltonian: $\mathcal{H} = \xi(\mathbf{p})\tau_3 + c\,\mathbf{p}\cdot\vec{\sigma}\,\tau_1$, where $c = \Delta/p_f$ is several orders of magnitude slower than the Fermi velocity. The topology of the B-phase is expressed in terms of a non-trivial winding number for the mapping between momentum space and Nambu space, $N_{\text{3D}} = \int \frac{d^3p}{24\pi^2}\,\epsilon_{ijk}\,\text{Tr}\Big\{T\,C\,(\mathcal{H}^{-1}\partial_{p_i}\mathcal{H}) \times (\mathcal{H}^{-1}\partial_{p_j}\mathcal{H})(\mathcal{H}^{-1}\partial_{p_k}\mathcal{H})\Big\} = 2$, where C is the particle-hole transformation. The physical consequence of $N_{\text{3D}} \neq 0$ is the emergence of a spectrum of Majorana fermions confined on any surface of ^{3}He-B whose effective Hamiltonian is described $H = \sum_{\mathbf{p}_{||}} \psi^T_{-\mathbf{p}_{||}}\mathbf{p}_{||} \times \vec{\sigma}\cdot\hat{\mathbf{s}}\,\psi_{\mathbf{p}_{||}}$. The surface excitations are self-conjugate Majorana fermions with a gapless relativistic dispersion relation $\varepsilon(\mathbf{p}) = c|\mathbf{p}_{||}|$, and their spins locked normal to the in-plane momentum and the surface normal, $\hat{\mathbf{s}}$. In this talk I describe theoretical predictions for experimental signatures based on NMR, mass flow, local ion probes and ultra-sound spectroscopy of these unique quanta that reflect the topological nature of the ground state of superfluid ^{3}He.

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