Topological Braiding in Acoustic Metamaterials

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Abstract

Topological quantum computing relies on the robust manipulation of exotic quantum states, yet experimental platforms for testing theoretical frameworks remain limited. Classical metamaterials offer a promising avenue for emulating quantum phenomena, but full implementation of key models has proven challenging. Here we present the first experimental realization of the complete Kitaev Hamiltonian with complex superconducting order parameter $\Delta = \Delta + i\Delta$ using acoustic metamaterials. Our modular platform employs tube-coupled acoustic resonators that preserve all fundamental symmetries-time-reversal, particle-hole, and chiral-enabling faithful reproduction of topological phase diagrams and interface-bound Majorana-like modes. We demonstrate two critical operations for topological braiding: smooth spatial translation of degenerate mid-gap modes and adiabatic rotation of Δ in the complex plane, both maintaining spectral isolation throughout. Experimental measurements show excellent agreement with finite element simulations, with topological edge and interface modes localized as predicted. We validate our approach using a modular assembly, demonstrating scalability from laboratory prototypes to integrated devices. These results establish acoustic metamaterials as a robust experimental platform for exploring non-abelian physics and provide the essential building blocks for implementing topological quantum computing protocols through braiding of Majorana modes.

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