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Superconductivity and quantized anomalous Hall effect in rhombohedral graphene

A central challenge for quantum computing is the realization of platforms that can store and manipulate quantum information in a way that is intrinsically protected from decoherence. Here, I lay the foundation for two approaches in graphene-based systems toward realizing decoherence-free quantum information, by proposing routes to create and manipulate non-Abelian anyons. The first relies on inducing superconducting correlations in chiral edge states, predicted to generate topologically protected zero-energy modes with non-abelian statistics. Experimental efforts so far have focused on engineering interfaces between superconducting materials—typically amorphous metals—and semiconducting quantum Hall or quantum anomalous Hall systems. However, the strong interfacial disorder inherent in this approach can prevent the formation of isolated topological modes. An appealing alternative is to use low-density flat band materials in which the ground state can be tuned between intrinsic superconducting and quantum anomalous Hall states using only the electric field effect. Here we show that rhombohedral tetralayer graphene aligned to a hexagonal boron nitride substrate hosts a quantized anomalous Hall state at superlattice filling $\nu = -1$ as well as a superconducting state at $\nu \approx -3.5$ at zero magnetic field. Gate voltage can also be used to actuate nonvolatile switching of the chirality in the quantum anomalous Hall state, allowing, in principle, arbitrarily reconfigurable networks of topological edge modes in locally gated devices. Thermodynamic compressibility measurements further show a topologically ordered fractional Chern insulator at $\nu = 2/3$ — also stable at zero magnetic field — enabling proximity coupling between superconductivity and fractionally charged edge modes [1]. The second approach focuses on trapping quasiparticles in the quantum Hall regime, which, in the case of even-denominator states, are predicted to host non-Abelian anyons. To this end, we fabricated a quantum point contact device with a central hole that serves as a confinement region. The structure is implemented in ultra-clean mesoscopic graphene devices by patterning graphite gates using local anodic oxidation with an atomic force microscope. This design enables backscattering through the quantum dot defined by the hole, as confirmed by bias spectroscopy, which reveals characteristic Coulomb diamonds indicative of single-electron charging. Furthermore, at high magnetic fields, edge reconstruction favors the emergence of a double quantum dot with tunable interdot coupling, providing a building block for charge qubits.

[1] Y.Choi*, Y. Choi,* M. Valentini* et al., “Superconductivity and quantized anomalous Hall effect in rhombohedral graphene” Nature (2025).