Realizing a Quantum Spin Hall State in Monolayer Graphene

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Introduction

In monolayer graphene under a perpendicular magnetic field a quantum spin Hall state is predicted at charge neutrality for sufficiently large values of the Zeeman splitting [1]. However, in normal graphene devices, short ranged electron-electron interactions drive the system to an antiferromagnetic order instead. We've engineered devices in which disorder is very low, and electron interactions are partially screened, to make observation of this state possible by driving the system to a ferromagnetic state using large in-plane magnetic fields.

Experimental

We studied electronic transport in our graphene devices in magnet cell 12. This consisted of measuring the 2-terminal resistance of the graphene devices as a function of gate voltage near charge neutrality. These measurements were repeated at increasing values of the in-plane component of the magnetic field while keeping the perpendicular component of the field constant.

Results and Discussion

The primary dataset (Figure 1)[2] displays a clear transition with in-plane magnetic field from an insulator to a conductor with conductance ~ $2e^2/h$. Additional capacitance and nonlocal resistance measurements confirm that the state at large in-plane field is a quantum spin Hall state. At intermediate values of the field we also observe a double peak structure which we interpret as the conduction through gapped canted anti-ferromagnet edge states. These results are consistently described by a transition from an anti-ferromagnetic ground state to a ferromagnetic ground state with in-plane field [3].

Conclusions

This magnet time conclusively demonstrated the realization of a quantum spin Hall state in monolayer graphene, a long sought after goal. These results were a culmination of multiple past trips to the NHMFL and were supported by the amazing staff at the magnet lab. The results are currently awaiting publication.

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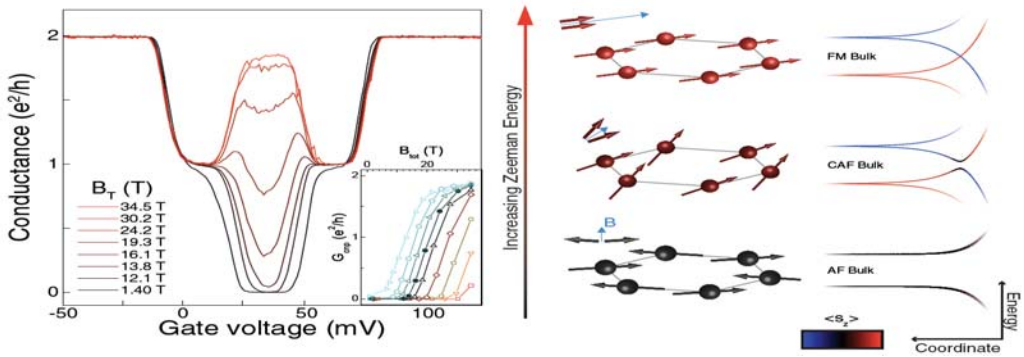

Figure 1. **Left,** Graphene conductance measurements at a fixed perpendicular magnetic field of 1.4T. With increasing in-plane magnetic field a transition from an insulating state to a conductive state is observed (black to red lines). **Right**, Schematic of transition with increasing Zeeman energy showing spin structure of ground state and edge state band dispersion.