Phases with non-trivial topology in graphene and transition metal dichalcogenides

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Abstract

Topological phases of matter are new quantum states which do not fit into Landau's paradigm of spontaneous symmetry breaking. A topological insulator may have exactly the same symmetries of a non-topological insulator or semiconductor, yet we cannot adiabatically transform one into the other. While both have a finite energy gap in the bulk, only the topological insulator is metallic at the edge/surface due to the presence of a protected edge/surface states.

Two dimensional materials have many attributes, but experimental evidence for topological phases has not been reported yet. Curiously enough, one of the first proposals for a two-dimensional topological insulator was made for graphene. The key ingredient is the intrinsic spin-orbit coupling which, unfortunately, is extremely low in graphene, making this phase undetectable. It has been suggested that randomly depositing certain heavy adatoms can amplify the effect by many orders, and that a dilute concentration should be enough to open a detectable topological gap. Here we analyze this problem taken into account the random position of the adatoms, which makes the problem intrinsically disordered, using a realistic adatom parametrization. We show that: (i) for the widely used model where adatoms locally enhance graphene's intrinsic spin-orbit interaction, and additionally induce a local shift of the chemical potential, a low adatom density (coverage <<1%) makes the system topologically non-trivial; (ii) for a realistic model where, apart from intrinsic spin orbit, extra terms are also induced, the critical adatom density is larger by at least one order of magnitude (coverage >>1%). Using realistic parameter values we show that recent experiments are still deep in the topologically trivial side of the transition.

Fortunately, nature provides other two-dimensional materials where the subject of topology is pertinent. In particular, transition metal dichalcogenides are semiconducting materials which, contrary to graphene, have non-negligible spin-orbit coupling. Even though the system is topologically trivial, the sizable spin-orbit coupling induces an appreciable spin-splitting of the valence band, where a finite anomalous spin-valley-Hall response develops due to the non-trivial topology of the Fermi surface. Taking into account the moderate to high local electron-electron interactions due to the presence of transition metal atoms, we show that the system is unstable to an itinerant ferromagnetic phase where all charge carriers are spin and valley polarized. The spontaneous breaking of time reversal symmetry originates an anomalous charge Hall response which should be detected experimentally.