Theoretical Investigations on Anomalous Transport in Topological Systems

Snehasish Nandy

Abstract

After the discovery of topological band insulators, Dirac and Weyl semimetals have led to an explosion of activity in recent years due to their intriguing topological properties and anomalous response functions. Recently, possible experimental realizations with real material candidates make these phases of matter even more interesting for their potential applications. Here, we study unusual transport properties such as anomalous Hall effect, planar Hall effect, and longitudinal magneto-conductivity in topological systems. Using quasi-classical Boltzmann transport equation with relaxation time approximation, we derive the general formalism for planar Hall effect in the presence of Berry curvature and orbital magnetic moment. In case of non-magnetic Weyl semimetal, we show that chiral anomaly is the origin of this novel phenomenon whereas it can appear from the bulk states of the topological insulator due to non-trivial Berry curvature even without chiral anomaly. In addition to the well known chiral anomaly, Dirac semimetals have been argued to exhibit mirror anomaly. We show that although mirror anomaly (step function-like behavior) seems to be valid in type-II Dirac semimetals (strictly speaking, in the linearized theory), type-I Dirac semimetals do not possess such an anomaly in anomalous Hall response even at the level of the linearized theory. Therefore, AHC may be used as a probe to identify two distinct types of Dirac semimetals. At the same time, the metallic interface between perovskite band insulators $LaAlO_3$ and $SrTiO_3$ has been the focus of considerable efforts for the last decade because of a wide variety of extraordinary properties such as superconductivity (below 200 mK), ferromagnetism (below 200 K), ferroelectricity and strong spin-orbit coupling (SOC) as well as their novel device applications. We have investigated the effect of Lifshitz transition on transport properties at $LaAlO_3/SrTiO_3$ interface. We have shown that the cusp in the Seebeck coefficient is a robust response of the change in the Fermi surface topology and can be used to examine Lifshitz transition in metallic systems. In addition, we have shown that multiple cusps appear in the Seebeck coefficient revealing multiple Lifshitz transitions beyond a sufficiently large field. Moreover, the repulsive electron-electron interaction reduces the critical density for the Lifshitz transition.

Key words: Planar Hall Effect; Chiral Anomaly; Mirror Anomaly; Anomalous Hall Effect, Lifshitz Transition.