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Chiral modes of topological semimetals under magnetic field

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Abstract

Topological Dirac/Weyl semimetals, two new quantum phases of matter, attract broad interests from both condensed matter and particle physicists [1-3]. A Dirac (Weyl) semimetal with degenerate (nondegenerate) linear touchings, dubbed as Dirac (Weyl) points, in the electronic band structure is protected by various crystal symmetries (topology) [4-12]. While a Weyl point bears a topological charge in terms of the momentum-space Berry gauge flux, a Dirac point is neutral since it consists of two Weyl points of the opposite topological charge [13]. In addition, the Dirac (Weyl) semimetal exhibits cusps (Fermi arcs) instead of the conventional Fermi ring at the boundary of the Brillouin zone. On the other hand, because of the Landau level formation under an external magnetic field, these band touchings gain to hold massless chiral one-dimensional channels rarely seen outside the discussion of fundamental particles. As a result of the famous chiral anomaly [14-21], the chiral magnetic effect [22-24] is realized in such systems and is observed as the negative magnetoresistance [25-28].

Here, we try to provide a natural but yet missing analysis of the chiral matter, Weyl semimetal, in terms of the powerful framework of Tomonaga-Luttinger liquid, which enables us to examine the correlation and localization effects largely enhanced in this system under a strong magnetic field. We found new features unique to the 1D channels such as the independent critical exponents for the Greens function and the resistivity, which can be directly compared with experiments of realistic materials. The ubiquitous presence of a large number of Weyl points is also taken into account.

Besides, we consider the Dirac semimetal in the form of a nanowire, i.e., new ingredient of confinement geometry is added to this conventional gapless topological semimetal. Once a magnetic field along the nanowire direction is further applied, there will occur a competition between the effects of the confinement and the magnetic field, which strongly affects how the band gap is opened in the system. Expectedly, the system at finite temperature will show distinct transport features as one turns on and gradually increases the external magnetic field.

There has been an increase of interest recently by the micro- or nano-technology community in considering topological materials emerged in the last decade, whose novel topological properties may bring about new possibilities in various applications. Based on these findings, we hope to clarify a few aspects from the viewpoint of either fundamental science or nano-micro engineering.

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