02/05/2024

Heat Transport by Topological Excitations

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Abstract

Topological semimetals are materials with unique properties that hold great promise for use in high-speed electronics, next-generation spintronics, and quantum computing. Research to explore and understand the new quantum phenomena in these materials has recently become of considerable interest. The peculiar behavior of the semimetals is defined by their non-trivial linear band structure, where the relativistic nature of quasi-particles can be observed in low-energy excitations. The macroscopic consequences of the quantum phenomena are expected in charge and heat transport phenomena, such as the anomalous Hall effect and the chiral magnetic effect, which have been extensively studied. The latter effect is manifested as positive longitudinal magneto-electrical conductivity stemming from the chiral anomaly. However, the experimental study of this effect in electrical transport can be complicated by the occurrence of extrinsic effects such as the current jetting effect. On the other hand, the analogous form of chiral anomaly, the gravitational anomaly, is predicted to appear into heat transport, making its macroscopic consequences immune to such extrinsic effect as no external electric field is applied. Furthermore, thermal conductivity measurements are valuable in studying other topological excitations that are neither charge carriers nor phonons or magnons.

This dissertation presents the results of electrical and thermal transport studies of two Weyl semimetals, NbP and NdAlSi. In the former material, the results indicate the formation of a charge-neutral topological excitation called the chiral zero sound (CZS). Herein, huge quantum oscillations that appeared in thermal conductivity are ascribed as an additional heat channel due to CZS in the chiral limit. Consequently, these modes severely violate the Wiedemann-Franz (WF) law. In NdAlSi, a ferrimagnetic Weyl semimetal, the gravitational anomaly was the subject of study. This anomaly is postulated in quantum field theory describing the behavior of elementary particles and is

expected to be observable in Weyl semimetals. In our study, we observed an anomalous increase in magneto-electrical and -thermal conductivity in the semiclassical regime of NdAlSi. Remarkably, both anomalous changes in charge and thermal transport are related by the WF law.

This dissertation provides a better understanding of the topological properties and contributes to the search for a new type of non-trivial excitations in Weyl semimetals.