Chiral Magnetic Effect of Noncentrosymmetric Weyl Semimetals

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Introduction

The Weyl semi-metal is a unique fermionic quantum critical system with non-trivial momentum space topology. In this gapless state, the linearly dispersing left and right handed Weyl fermions respectively appear as the unit charge monopole and anti-monopole of the Berry curvature. For the topological non-triviality, it is essential that the Weyl points are separated in the Brillouin zone by a momentum $\delta\mathbf{K}$. The Berry flux passing through a plane perpendicular to $\delta\mathbf{K}$ and located between the Weyl points is quantized to be 2π, and determines the topological stability and the existence of protected chiral surface states. The nontrivial Berry curvature leads to many anomalous transport and electrodynamic properties, which can be understood in terms of a space and time dependent magnetoelectric coefficient [1, 2]. In the absence of inversion symmetry, the right and the left handed Weyl points can also become separated in energy. This energy separation gives rise to a non-dissipative charge current along the direction of a uniform applied magnetic field, even in the absence of an external electric field. This effect is known as the chiral magnetic effect and is a hallmark of the underlying chiral anomaly of the Weyl fermions. According to the linearized continuum theory of Weyl fermions, the induced current is proportional to the magnetic field strength and the energy separation, with a universal coefficient e^2/h^2. This effect has potential technological applications for developing magnetic field sensor. Therefore, we need to establish the validity of this effect without the possible shortcomings of a linearized continuum theory, and it is also important to identify promising materials which can support this effect.

Results and Discussion

By considering a generic tight binding model for the cubic noncentrosymmetric metals, we show that such a system naturally supports a set of Weyl points, which are separated in energies. For cubic systems, due to the lack of inversion symmetry, the spin orbit coupling takes the form $t_{so}(\sin k_1\sigma_1+\sin k_2\sigma_2+\sin k_3\sigma_3)$, which in turn leads to the right handed Weyl fermions at (0, 0, 0), (0, π, π), (π, 0, π), (π, π, 0) and the left handed Weyl fermions at (π, 0, 0), (0, π, 0), (0, 0, π) and (π, π, π). However, conventional spin-independent first and third neighbor hopping terms create energy mismatch among the right and the left handed Weyl points. Therefore, field theoretic arguments of [1] suggest the possibility of realizing the chiral magnetic effect in noncentrosymmetric cubic metals such as Li_2Pd_3B, Li_2Pt_3B etc. By applying linear response theory, we have derived a very general formula for the chiral current induced by the magnetic field, in terms of the Berry curvatures of the spin orbit split bands. Remarkably, this formula does not rely on the linearized theory about the Weyl points and can also be applied to non-cubic noncentrosymmetric metals.

Conclusions

By choosing some representative tight-binding parameters for Li_2Pt_3B, we have found a large chiral magnetic conductivity $\sigma_{ch}= j/B \sim 1$ Amp/mm^2/Gauss, even at room temperature. The large size of this current comes from the presence of $1/h^2$. It will be important to consider the effects of impurities and interaction for a more realistic estimate of the chiral magnetic conductivity. However, the large size of the intrinsic contribution suggests that the current strength can remain significant even after a considerable degradation by scattering effects.

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References

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