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TOPOLOGICAL MATERIALS

Dynamical anomaly

Using the coupling between electrons and phonons in a Weyl semimetal allows the detection of the dynamical chiral magnetic effect.

Xi Dai

The chiral anomaly is one of the measurable properties of materials with Weyl nodes in their band structure. In the past, various experiments have claimed to show the static version of this effect, but so far, no consensus has developed around whether alternative explanations can account for the data. Now, writing in *Nature Communications*, Xiang Yuan and collaborators have demonstrated a dynamical anomaly[1]. This gives substantial evidence that Weyl semimetals do show these anomalies, and can couple to electromagnetic fields in unusual ways.

When the mass term in the Dirac equation vanishes, two independent solutions appear. They are chiral fermions with opposite handedness called Weyl fermions. Although they have not been discovered as a type of fundamental particle within the Standard Model, quasiparticles with these properties were discovered about five years ago in condensed matter systems called Weyl semimetals. The chirality of the Weyl fermion comes from the fact that the direction of its pseudospin is always locked to the direction of the translational motion and is either parallel (positive chirality) or anti-parallel (negative chirality) to it.

The chiral electronic structure leads to particular charge dynamics: the chiral anomaly and chiral magnetic effect. The chiral anomaly refers to the charge pumping effect from one Weyl point to the other when electric and magnetic fields are applied parallel to each other. The corresponding pumping rate is proportional to the product of the magnitudes of the two fields. On the other hand, the chiral magnetic effect refers to the appearance of additional charge current along the magnetic field when the two Weyl nodes have different chemical potential from each other.

In solid state materials, the first evidence of the chiral anomaly and chiral magnetic effect came from the negative longitudinal magnetoresistance, where the charge pumping from one Weyl point to another caused by the chiral anomaly results in a steady state with imbalanced chemical potential between the two Weyl points. This induces an additional current along the magnetic field leading to negative magnetoresistance. Although the chiral anomaly and chiral magnetic effect provide a natural explanation for the longitudinal negative magnetoresistance discovered in these materials, there are still many features that remain unclear, for example the angle dependence of the field.

In their paper, Yuan and collaborators from Fudan University in Shanghai observe a dynamical version of the chiral magnetic effect and chiral anomaly for the first time through a phenomenon called field-induced optical activity. The authors used light with its polarisation parallel to the surface to excite a particular phonon mode in a typical Weyl semimetal material, NbAs. Such a mode usually cannot be seen by the particular setup in their experiment, but it became 'visible' when the sample was placed in a static external magnetic field. This effect has been theoretically proposed[2,3] based on the chiral magnetic effect and it is caused by electron–phonon coupling, through which a particular phonon mode can couple to the energy levels of the different Weyl points.

When oscillating, the phonon mode will push down the energy of the Weyl points of one chirality and lift up those with the opposite chirality, leading to an oscillating chemical potential difference between them. When an additional static magnetic field is applied, the chiral magnetic effect will generate an oscillating current along the field, which can couple to the incoming light and make such a phonon mode visible.

The field induced optical activity observed in NbAs is the first evidence in Weyl semimetals for the dynamical chiral magnetic effect. After this, many follow-up studies can be carried out along this direction. Compared to the chiral magnetic effect in the DC limit, the dynamical effect is less sensitive to the relaxation processes — which are anisotropic in the crystal environment — and in principle the effect could be more isotropic. Therefore, experimental studies on the dependence of field direction should be explored. And similar effects should also appear in many other Weyl semimetals, which are yet to be revealed. Another important aspect is that the dynamical effect does not suffer from the potential issues with current jetting that disrupts transport measurements of the static effect[4], making it much more certain that materials such as NbAs do indeed host topological Weyl fermions. ❐

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