Beyond the conventional Dirac-Weyl-Majorana classification-Observation of three-component fermions in the topological semimetal molybdenum phosphide

Subject Code：A04

With the support by the National Natural Science Foundation of China, a collaborative research team led by Prof. Ding Hong (丁洪), Prof. Qian Tian (钱天), and Prof. Shi Youguo (石友国) from the Institute of Physics, Chinese Academy of Sciences (IOP, CAS) has made a major breakthrough in the study of fermions in solids. They give the first observation of the fermions that are beyond the conventional Dirac-Weyl-Majorana classification, which was published in *Nature* (2017, 546: 627—631).

In quantum field theory, the Standard Model has predicted three types of fermions in the universe—Dirac, Weyl and Majorana fermions, which are constrained by Lorentz invariance. In high-energy physics, the Dirac fermions have been identified, whereas the existence of Weyl and Majorana fermions has not been confirmed experimentally. On the other hand, significant advances in band theory have provided an alternative way to realize these fermions as quasiparticle excitations in condensed-matter systems. The existence of Dirac and Weyl fermions in condensed-matter systems has been confirmed experimentally, and that of Majorana fermions is supported by various experiments. However, in condensed-matter systems, fermions in crystals are constrained by the crystal symmetries of the 230 space groups rather than by Lorentz invariance, giving rise to the possibility of finding other types of fermionic excitation that have no counterparts in high-energy physics.

Recently, a theoretical research group at IOP, CAS made up of Prof. Weng Hongming (翁红明), Prof. Fang Chen (方辰), Prof. Dai Xi (戴希), and Prof. Fang Zhong (方忠) predicted that the electronic structures of several materials with tungsten carbide structure host triply degenerate points. Quasiparticle excitations near a triply degenerate point are three-component fermions, beyond the conventional Dirac-Weyl-Majorana classification. The three-component fermions can be viewed as an "intermediate species" between the four-component Dirac fermions and the two-component Weyl fermions. Soon after, Mr. Feng Zili (冯子力) with the guidance of Prof. Shi Youguo fabricated single crystals of one such material—molybdenum phosphide (MoP). By investigating the electronic structure of MoP with angle-resolved photoemission spectroscopy (ARPES), Mr. Lv Baiqing (吕佰晴) with the guidance of Prof. Ding Hong and Prof. Qian Tian observed the triply degenerate nodal points in MoP directly. The experimental results are excellently consistent with the theoretical calculations made by Mrs. Xu Qiunan (许秋楠) with the guidance of Prof. Weng Hongming, which provides the first experimental evidence of the existence of three-component fermions.

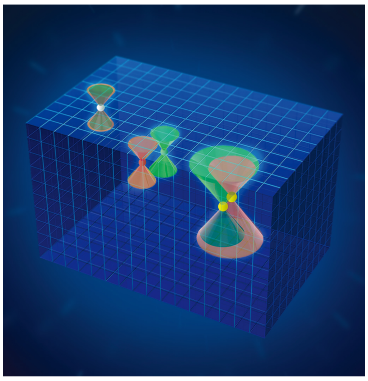

Figure Schematics of Dirac and Weyl fermions, and the newly discovered three-component fermions in condensed-matter systems.

The exploration of unconventional fermions in condensed-matter systems has just begun. The discovery of three-component fermions opens up a way of exploring the new physics of unconventional fermions in condensed-matter systems. The study of novel quantum phenomena in unconventional fermion systems could pave the way for new applications.