A Magnetic Weyl Fermion State in Non-Collinear Antiferromagnet Mn₃Sn

Weyl fermions have been recently observed as gapless topological excitations in a number of inversion-breaking semimetals. However, their realization in spontaneously time-reversal-symmetry-breaking phases so far has evaded experimental detection. We present here an angle-resolved photoemission study of a noncollinear antiferromagnet Mn₃Sn that exhibits a large anomalous Hall effect even at room temperature, and reveals a magnetic Weyl fermion state in the quasiparticle electronic structures by a detailed comparison with our density functional theory calculation and transport measurements. This discovery lays the foundation for a new field of research and technology involving the Weyl excitations of the novel magnet, “Weyl magnet.”

When either inversion-symmetry or time-reversal-symmetry (TRS) is broken in solid states, two nondegenerate energy bands can touch at pairs of isolated points in the momentum (k) space, giving rise to Weyl quasiparticles. The touching points, the so-called Weyl points, act as the monopoles of Berry curvature [1], leading to exotic bulk properties represented by a large anomalous Hall effect (AHE).

In this work, by using synchrotron radiation ARPES, we observed the magnetic Weyl fermion state in a noncollinear antiferromagnet, Mn₃Sn. This compound is formed by a stacking of kagome lattice and the geometrical frustration leads to a 120° structure of Mn moments, whose symmetry allows a very small spin-momentum locking [2]. The experiment clearly captures the main elliptical-shaped contours centered at the M points, which have the same topology as the theoretical FSs (solid circle). This agreement is significant as it is this electron band that creates the Weyl points at its intersection with the other hole band.

Figure 1(b) shows ARPES images along the K–M–K high symmetry line obtained before (left) and after (right) dividing the intensities by the Fermi–Dirac distribution function to detect thermally populated bands above $E_F$. We observe intensity anomalies particularly in the middle and bottom distribution curve [Fig. 1(b)], arising from the crossings between the electron and hole bands. Comparing with theory, we note that the peak (red bar) at $k_x = 0.3 \AA^{-1}$ ($-0.3 \AA^{-1}$) between K and M points most likely comes from the dispersion in the intermediate vicinity of the Weyl point W⁺, W⁻ (Fig. 1(b)). The peak (red bar) at $k_z = 0.5 \AA^{-1}$ ($-0.5 \AA^{-1}$) between the K and M points corresponds to a large electron band, which crosses with another band and forms a Weyl point W⁺, W⁻ of different chirality. The single peak at $k_z = 0.1 \AA^{-1}$ [blue bar in Fig. 1(b)] is shifted from $k_z = 0$ by the intensity gradient and would arise from the flat hole band at $\pm 14\text{meV}$ above $E_F$. These results appear to be consistent with the theoretically predicted FSs and quasiparticle band structures.

Moreover, these results of the spectroscopic measurement of the Weyl points are consistent with our transport measurements that show topological transport properties such as AHE and chiral anomaly [7]. These facts constitute evidence for magnetic Weyl fermions realized in Mn₃Sn. Our experimental observations thus mark the start of basic research on magnetic Weyl fermions in the novel magnet, “Weyl magnet,” which may well lead to novel electronic and spintronic technology for future applications.

REFERENCES


Figure 1: (a) Magnetic texture in the kagome lattice. Arrows indicate Mn moments which have the local easy axis parallel to the in-plane direction along the x axis. (b) Distribution of the Weyl points in the bands on the $k_x$-$k_z$ plane at $E_F$ near E, for the magnetic texture shown in (a) and Bloch zone, showing the momentum sheet at $k_z = 0$. (c) ARPES intensity at $E_F$ in the $k_x$-$k_z$ plane using an energy $\theta_t = 130\text{meV}$ and the calculated Fermi surface (purple curves). (d) Left: $k_x$ dispersion along the H–K–H high-symmetry line [black arrows in (b)], and Right: corresponding energy dispersion curves (EDC). The ARPES maps are compared to the band calculations with strong band renormalization by a factor of five (solid lines). (e) ARPES E-$k_z$ cuts and the theoretical band structures along the K–H–K high-symmetry line. (f) Corresponding momentum distribution curve (MDC) at $E-F = 8\text{meV}$.
