The significance of kagome

Iron (Fe) and tin (Sn) are common, unremarkable metals, but when their atoms are combined in certain patterns, unusual properties can emerge. The patterns, which resemble the kagome style of Japanese basket weaving, have important effects on electronic behavior. A well-known example of this is the emergence of Dirac fermions (i.e., electrons that behave as if they were massless) in the hexagonal lattice of graphene.

A kagome lattice is also a hexagonal network, with the addition of corner-sharing triangles around the hexagons. Electrons in kagome lattices have long been predicted to behave as if they were infinitely light (like Dirac fermions in graphene) or infinitely heavy (highly localized and confined). Materials with these properties plus the intrinsic magnetism of iron can exhibit topological and correlated electronic phenomena that could be useful in future device applications, including spintronic technologies.

In search of Dirac cones and flat bands

In band-structure diagrams, the presence of Dirac fermions is indicated by Dirac cones, and the signature of infinitely massive particles is a flat band. While both these features have been predicted by theoretical models of ideal kagome metals, their experimental realization has proven to be elusive. This is mainly due to the presence of complicating interactions, including those occurring between two-dimensional kagome layers stacked into three-dimensional materials.

Since 2016, a team of MIT researchers has focused on Fe$_m$Sn$_n$ compounds ($m:n = 3:1, 3:2, 1:1$) with different stacking structures. While a previous study on a 3:2 compound verified the presence of Dirac fermions, it did not find evidence of flat bands. A breakthrough came when they synthesized a 1:1 compound (FeSn) in which the kagome layers were well separated by a spacer layer of Sn.

MAESTRO probes individual layers

The researchers investigated the electronic structure of FeSn using two complementary techniques: angle-resolved photoemission spectroscopy (ARPES) at ALS Beamline 7.0.2 (MAESTRO, a light-based surface probe) and de Haas–van Alphen (dHvA) quantum oscillations (a bulk probe that uses high magnetic fields). One complexity in measuring the electronic structure of FeSn is that its surfaces expose two different layer terminations: one for the kagome layer and one for the spacer layer. These
two domains are microscopically mixed on a cleaved surface. MAESTRO overcomes this by microfocusing the light beam below the size of the surface domains, measuring the electronic structure of each termination independently.

**An ideal kagome metal**

The experiments unambiguously demonstrated the simultaneous emergence of both Dirac fermions and flat bands in FeSn, as predicted for an ideal kagome metal. The results also revealed the presence of unexpected surface Dirac fermions on the spacer-layer terminations. Theoretical work demonstrated that the surface Dirac states, when combined with the antiferromagnetic spin textures of FeSn, are a rare example of fully spin-polarized Dirac fermions.

Because the kinetic energy of flat-band electrons is extremely low, electron-electron interactions become important. Thus, flat-band systems are ideal for realizing correlation-driven phenomena, including high-temperature superconductivity and anomalous magnetism. In the future, the researchers hope to tune the flat-band position toward the Fermi level, to see what kind of correlated phases can be produced based on kagome-driven flat bands.

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