Neutral fermions and a new state of matter: experiments at fields of up to 75 T on YbB_{12}, a weird metal disguised as an electrical insulator*

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From infancy, we are taught that metals are good conductors of electricity and heat but that insulators are not. At High School we find out why; metals contain vast numbers of charged electrons that are free to move and carry heat and current, whereas insulators do not. At College, we learn that electrons are fermions, a metal is a solid with a Fermi surface and that the mapping of Fermi surfaces via magnetic quantum oscillations is one of the triumphs of quantum mechanics in condensed-matter physics.

The Kondo insulator YbB_{12} does not fit this comforting picture. Whilst its resistivity behaves like that of an insulator, becoming large at low temperatures (T), quantum oscillations (*i.e.,* a fundamental metallic property) are seen in the magnetic susceptibility and the resistivity. Further, the thermal conductivity at low T behaves like that of a metal. These observations point to a very unusual situation; the presence of neutral fermions that can act like regular electrons in some ways (thermal conductivity, magnetic quantum oscillations) but yet cannot conduct electrical charge. It is possible that the mixed valence of YbB_{12} may allow it to host a condensed-matter incarnation of Majorana fermions, and that these are our neutral quasiparticles.

To shed further light on this mystery, pulsed magnetic fields of up to 75 T are applied to convert YbB_{12} from a Kondo insulator to a strongly correlated Kondo metal whilst a raft of techniques – electrical transport, MHz skin depth, magnetization, magnetostriction – is used to track the fate of the neutral fermions. In the high-field Kondo-metal state, the neutral fermions still contribute quantum oscillations, despite the drastic increase in the density of conventional, charge-carrying heavy electrons at the insulator-to-metal transition.

Our data suggest a two-fluid model in both phases of YbB_{12}; a new state of matter comprising charge-neutral fermions cohabiting with canonical charged fermions. Scattering between these two populations gives rise to quantum oscillations of the resistivity. On the other hand, the heavy charged fermions that only appear in the Kondo metal state dominate its bad-metal-like electrical transport, albeit with properties modified by the neutral fermions. Moreover, with the availability of a fermion reservoir provided by the bad metal, the Fermi surface of neutral quasiparticles begins to die as the field grows.

The results also provide tests for models of neutral fermions: *e.g.*, (i) the amplitude of the neutral-fermion quantum oscillations in both the Kondo-insulator and Kondo-metal phases obeys the Lifshitz-Kosevich relationship to high accuracy (usually a smoking-gun fermion attribute); and (ii) apparent Zeeman splitting of the neutral-fermion quantum oscillations occurs in the Kondo-metal state, but not in the Kondo insulator.

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