Magnetic quantum oscillations in high-resistivity semiconductors and electrical insulators studied in fields of up to 75 T

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Magnetic quantum oscillations (for example, the Shubnikov-de Haas and de Haas-van Alphen effects) are a well-known high-magnetic-field property of degenerate semiconductor systems such as GaAs-(Ga,Al)As heterojunctions, and (of course) metals. Their observation is a consequence of the presence of a Fermi surface of electrons or holes; hence, they are not anticipated to occur in materials that are electrically insulating. However, over the past decade this expectation has been upset by the behaviour of several electrical insulators at high magnetic fields and low temperatures.

In this talk I shall describe a variety of experiments in magnetic fields of up to 75 T on a narrow-gap semiconductor, YbB_{12}, (E_g = 13 meV) [1] and a wide-gap Mott insulator, $YCu_3(OH)_6Br_2[Br_{1-y}(OH)_y]$ (YCOB- E_g = 3 eV) [2]. Though these materials are electrical insulators at low temperatures, they both exhibit quantum oscillations in magnetic field that are strong evidence for the presence of Fermi surfaces [1,2]. Equally striking is the low-temperature thermal conductivity of YbB_{12}, which looks as though it comes from a large concentration of free fermions. Somehow, mobile fermions are present and able to carry heat almost as well as in a conventional metal, but are unable to conduct electricity!

The most compelling models that explain the behaviours of these two materials invoke different types of neutral fermions. In YbB_{12}, the culprit may be a type of Majorana fermion that emerges from a failed condensate of electrons and holes [1,3]. In YCOB, the observed phenomena are consistent with a quantum spin liquid, whose excitations are fermionic spinons with a Dirac-like spectrum [2]. This talk is offered in the hope that similar phenomena can be looked for in other insulators, and perhaps even engineered in future semiconductor systems.

[1] Z. Xiang et al., Phys. Rev X 12 021050 (2022), and references therein.
[2] G. Zheng et al., arXiv:2310.07989 (2023).
[3] C.M. Varma, Phys. Rev. B 102, 155145 (2020), and to be published.

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