Emerging electronic properties in quantum materials studied using high magnetic fields.

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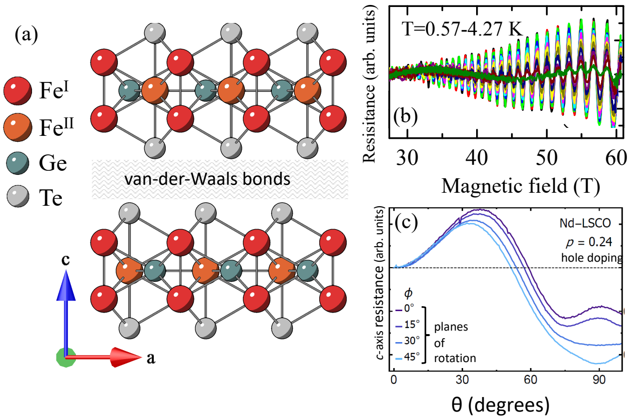
Are you interested in being at the forefront of understanding new electronic properties?

High magnetic fields have long been used to characterise the nature of the charge carriers in semiconductors, metals and superconductors. However, in recent years new materials have emerged that challenge our existing understanding of electronic behaviour. New theoretical models are required to explain the properties displayed by these so-called *quantum materials*, which are typically host to a complex network of many-body interactions between magnetic moments and electrons, and are exquisitely sensitive to aspects such as dimensionality, fluctuations and topology.

In this project we will collect experimental data that will be used to develop and test evolving theories of exotic electronic properties. Promising avenues we will pursue include:



(a) Crystal structure showing layers of Fe_3GeTe_2 coupled by weak vdW bonds [1]. (c) Quantum oscillations observed in $CeOs_4Sb_{12}$ [2]. (c) Angle-dependent magnetoresistance measurements of a high-temperature superconductor performed at 45 T and 20 K [3].

Angle-dependent magnetoresistance in 2D quantum materials. These are materials whose layers are only weakly connected by van-der-Waals (vdW) bonding (see Fig. 1a). Recently they have emerged as systems of considerable interest both from the point of view of their fundamental properties and their ability to be pulled apart layer-by-layer until only one or two sheets of atoms remain. They lie in the extreme 2D limit and provide for the first time the exciting possibility of studying quantum materials all the way from a bulk sample down to a single atomic layer. However, in the vast majority of cases, the fine details of their electronic properties, including their Fermi surfaces (FSs), have yet to be experimentally verified. Angle-dependent magnetoresistance, in which electronic transport is measured while the material is rotated in a large magnetic field, is a powerful technique for characterising the FS of layered materials, but has not yet been applied to 2D quantum materials. We will attempt these measurements for the first time.

Anomalous quantum oscillations. Oscillations in the physical properties of materials subject to a changing magnetic field are known to be a hallmark of metallic materials. Recently, however, these quantum oscillations have been observed in a number of apparently insulating materials. A host of theories have emerged to account for these results, but no clear picture has so far emerged likely due to to a lack of systematic, high-quality experimental data. We will investigate a number of different materials to attempt to resolve this fast-developing mystery.

By investigating these emerging phenomena, we hope to push our understanding of electronic transport beyond the current limits and open a route for exploiting the untapped potential of new quantum materials to underpin future technology. High magnetic fields will be accessed using in-house apparatus and by travelling to facilities that provide the world's highest available fields, such as the European Magnetic Field Laboratory and the National High Magnetic Field Laboratory in the US.

Prof Goddard joined Warwick University in 2013 and is expert in the use of high magnetic fields to elucidate the properties of new materials of fundamental and technological significance. In 2023, he was awarded the Pippard Prize by the Superconductivity Group of the Institute of Physics for his developmental work on the technique of angle-dependent magnetoresistance. For further information about the project do not hesitate to contact Prof Goddard directly at p.goddard@warwick.ac.uk

For information on how to apply please see https://warwick.ac.uk/go/physicspgadmissions

[1] S. Vaidya *et al.*, in preparation (2023); [2] K. Gotze *et al.*, Phys. Rev. B **101**, 075102 (2020); [3] G. Grissonnanche, *et al.*, Nature **595**, 667 (2021).