Emerging properties in quantum materials studied using high magnetic fields.

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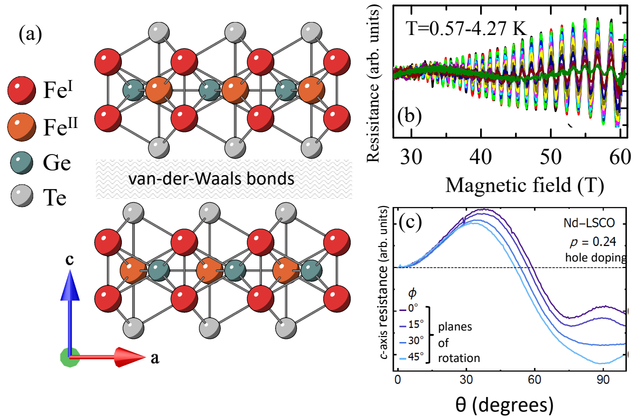
Are you interested in being at the forefront of understanding new electronic and magnetic properties?

High magnetic fields have long been used to characterise the behaviour of spins and electrons in magnets, metals, semiconductors and superconductors. However, in recent years new materials have emerged that challenge our existing understanding of magnetic and electronic behaviour. New theoretical models are required to explain the properties displayed by these so-called *quantum materials*, which are typically host to complex networks of many-body interactions between spins 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 novel electronic and magnetic properties. Promising avenues include:



(a) Crystal structure showing layers of Fe_3GeTe_2 coupled by weak vdW bonds [2]. (c) Quantum oscillations observed in $CeOs_4Sb_{12}$ [3]. (c) Angle-dependent magnetoresistance measurements of a high-temperature superconductor performed at 45 T and 20 K [4].

A new route to quantum spin liquids. Topological behaviour arises in many areas of research, from quantum-Hall physics to band structure, defects in crystalline lattices, and magnetism, and impacts many areas of technological relevance (e.g., spintronics, data storage and quantum technologies in general). While spin liquids arising from frustrated magnetism have shown to be been fertile ground for exploring topological effects, so far they emerge only within narrow regions of physical phase diagrams, limiting their robustness and practical applicability. It was recently shown that similar behaviour should be found in materials in which the hopping of itinerant electrons is frustrated [4]. This paves the way for a completely new route for the experimental realisation of quantum spin liquids based on kinetic rather than geometric frustration of interactions – a route that requires further theoretical and, importantly, experimental investigation. Measuring magnetic and electronic properties in candidate materials will be invaluable in understanding these new states.

Fermi surfaces of 2D quantum materials. These are materials whose layers are only weakly connected by van der Waals bonding (see Fig. 1a). Recently they have emerged as systems of considerable interest because of their fundamental properties as well as 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 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 in the bulk. For this we can use either quantum oscillations or angle-dependent magnetoresistance (AMR). In AMR, electronic transport is measured while the material is rotated in a large magnetic field. It is a powerful technique for characterising the FS of layered materials, but has not yet been applied to 2D quantum materials.

By exploring these new avenues, we hope to push our understanding 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] C. Glittum *et al.*, arXiv:2408.03372 (2024); [2] S. Vaidya *et al.*, Phys. Rev. Research 6, L032008 (2024); [3] K. Gotze *et al.*, Phys. Rev. B **101**, 075102 (2020); [4] G. Grissonnanche, *et al.*, Nature **595**, 667 (2021).