A. Quantum oscillations probing the Fermi surface of Iron-based Superconductors and Dirac Materials

Quantum oscillations is a well-established and powerful technique for the experimental characterisation of the Fermi surface at low temperatures. Due to the Landau quantisation of electronic states in an applied magnetic field, oscillations of various physical properties, periodic in inverse magnetic field, are observed. The frequency of oscillations relates directly to extremal areas of the Fermi surface, and the temperature-dependence of the amplitude of oscillations reveals the orbitally-averaged quasiparticle masses. The quasiparticle masses compared with band structure mass quantify the extend of electronic correlations inside different quantum materials and they provide clue on how to enhance superconductivity.

This project aims to establish the Fermi surface of novel quantum materials using high magnetic fields and low temperatures. A suitable candidate should have a strong background in condensed matter physics and advanced computational skills, such as using Matlab and Python. The student will compare existing experimental data with band structure calculations using Wien2k and make proposals of Fermi surface to describe the experimental data and estimate relevant parameters.

We are looking for candidates interested to pursue an MPhys project and a PhD project in condensed matter physics. To apply for this project please send your CV and a cover letter to justify your interest in the proposed topic to amalia.coldea@physics.ox.ac.uk.

Further reading:

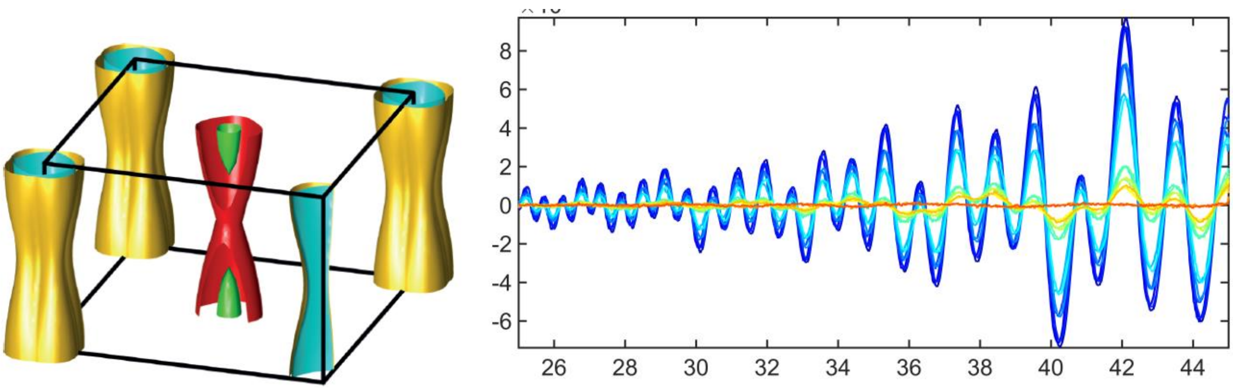
The key ingredients of the electronic structure of FeSe
Amalia I. Coldea, Matthew D. Watson
Annual Review of Condensed Matter Physics, Vol 9 (2018)
https://arxiv.org/abs/1706.00338

Quantum oscillations probe the Fermi surface topology of the nodal-line semimetal CaAgAs
Y. H. Kwan, P. Reiss, Y. Han, M. Bristow, D. Prabhakaran, D. Graf, A. McCollam, S. A. Parameswaran, A. I. Coldea
https://arxiv.org/abs/2001.02434

Linear magnetoresistance caused by mobility fluctuations in the n-doped Cd3As2
Phys. Rev. Lett. 114, 117201 (2015)
https://arxiv.org/abs/1412.4105

Quantum oscillation studies of the Fermi surface of iron-pnictide superconductors,
Reports on Progress in Physics, 74 124507, 2011
http://iopscience.iop.org/article/10.1088/0034-4885/74/12/124507

Wien2k; http://susi.theochem.tuwien.ac.at/



Fermi surface of an iron-based superconductor and an example of quantum oscillations in magnetic fields up to 45T and temperatures below 1.5K.

B. Instrument control using Python to control sample rotation in magnetic fields

An electronic nematic ordered state can occur in a strongly interacting electronic system in which a Fermi surface undergoes a spontaneous distortion to a shape with lower symmetry compared to the underlying crystal lattice. The observation of electronic nematic order in different families of high-temperature superconductors suggests that the same interactions may be involved in stabilizing both the nematic and superconducting states. Establishing the phase boundaries of nematic and other anisotropic phase transitions require complete experimental investigation along different crystallographic axes, beyond the single-axis rotation currently available. A full angular dependence is necessary for complete understanding competing electronic phases of correlated matter and superconductivity.

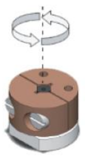
We have recently acquired Attocube rotators made from Titanium and CuBe which allow rotation of very small samples at low temperature and high magnetic fields. Two rotators can be coupled together to allow physical properties measurements as a function of orientation in magnetic field. A positioning controller permits the integration of different stepping module to finely control each rotator separately.

We are looking for an enthusiastic student with good computational and electronics skills to implement this rotator in an existing Python software that control most of our low temperature experiments. This project will be performed in the new Oxford Centre for Applied Superconductivity (CfAS). The aim is to control accurately sample position in magnetic field using two-axis rotator and calibrate the instruments for different temperatures and magnetic fields.

A suitable candidate should have strong computational and electronics skills. To apply for this project please send your CV and a cover letter to justify your interest in the proposed topic to amalia.coldea@physics.ox.ac.uk.

For further reading please visit

https://www.attocube.com/en and https://www.python.org/

 **Miniature piezo-rotator (10-15 mm)**	 **Motion Controller**	 **Stepping modules for controller**

Different components of the Attocube system which enables sample rotation in magnetic fields and at low temperatures.

C. Enhancing superconductivity by applied pressure in iron-based superconductors

Applied hydrostatic pressure is an important tuning parameter that can induce and significantly enhance superconductivity as well as it can change the size of the unit cell, the electronic bandwidth as well as the strength of electronic interactions. FeSe is a unique high temperature superconductor in a monolayer form close to 100K. On the other hand, pressure applied to single crystals of FeSe strongly enhances its superconductivity from 9K towards 40K.

This is an experimental project to perform pressure experiments under pressure using either transport or tunnel diode oscillator technique to probe the skin depth and penetration depth of novel materials. Tunnel diode oscillator based-technique is known to be sensitive to the London magnetic penetration depth in superconducting materials and can probe the transition temperature and the upper critical field. These experiments will be performed on high quality single crystals of FeSe-based superconductors and the superconducting phase diagrams under pressure will be constructed.

A suitable candidate should have a strong background in condensed matter physics and basic knowledge of electronics. Computational skills, such as using Matlab and Python would be useful. We are looking for candidates interested to pursue a MPhys project and a PhD project in condensed matter physics. To apply for this project please send your CV and a cover letter to justify your interest in the proposed topic to amalia.coldea@physics.ox.ac.uk.

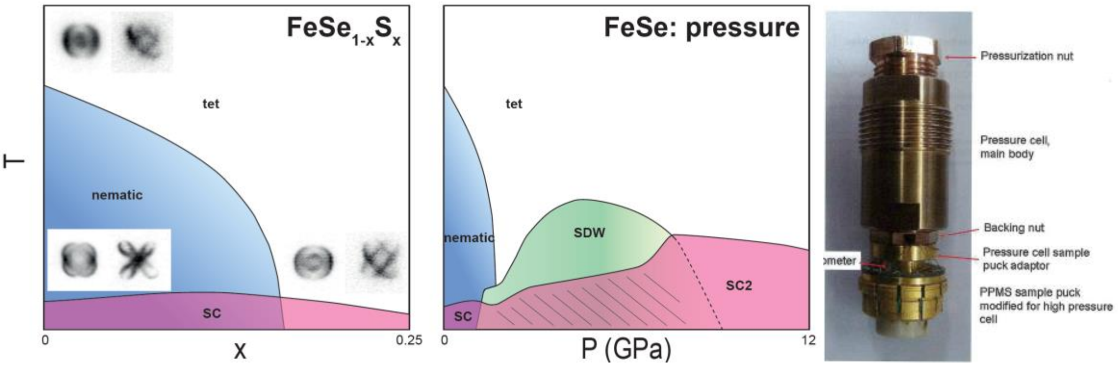
For further questions please email amalia.coldea@physics.ox.ac.uk

For further reading consult:

The key ingredients of the electronic structure of FeSe
Amalia I. Coldea, Matthew D. Watson
Annual Review of Condensed Matter Physics, Vol 9 (2018)
https://arxiv.org/abs/1706.00338

Quenched nematic criticality separating two superconducting domes in an iron-based superconductor under pressure P. Reiss, D. Graf, A. A. Haghighirad, W. Knafo, L. Drigo, M. Bristow, A. J. Schofield, A. I. Coldea, Nature Physics (2019); https://arxiv.org/abs/1902.11276;
https://www.nature.com/articles/s41567-019-0694-2

Maximizing T c by tuning nematicity and magnetism in FeSe1−xSx superconductors,
K. Matsuura, Y. Mizukami, Y. Arai, Y. Sugimura, N. Maejima, A. Machida, T. Watanuki,
https://arxiv.org/abs/1704.02057
https://www.nature.com/articles/s41467-017-01277-x



Phase diagrams of FeSe tuned by chemical (using chemical substitution) and applied hydrostatic pressure. The components of a pressure cell are shown on the right.

D. Modelling vortex dynamics inside novel superconductors in magnetic fields

This project aims to understand the complex vortex dynamics inside two-dimensional superconductors in the presence of different defects and impurities. This is crucial for the implementation of high-temperature superconductors in applications as the vortex pinning on defects help to maintain very large critical currents. Simulations will rely on time-dependent Ginzburg Landau theory, which is already implemented in the commercial software package COMSOL Multiphysics. In this project, simulations of vortex lattice and relevant superconducting parameters will be perform using realistic parameters in order to understand the presence of large critical currents in novel iron-based superconductors. This project will be performed in the new Oxford Centre for Applied Superconductivity (CfAS).

A suitable candidate should have a strong background in condensed matter physics and strong computational skills, such as COMSOL, Matlab or Python. We are looking for candidates interested to pursue further projects in condensed matter physics.

To apply for this project please send your CV and a cover letter to justify your interest in the proposed topic to amalia.coldea@physics.ox.ac.uk.

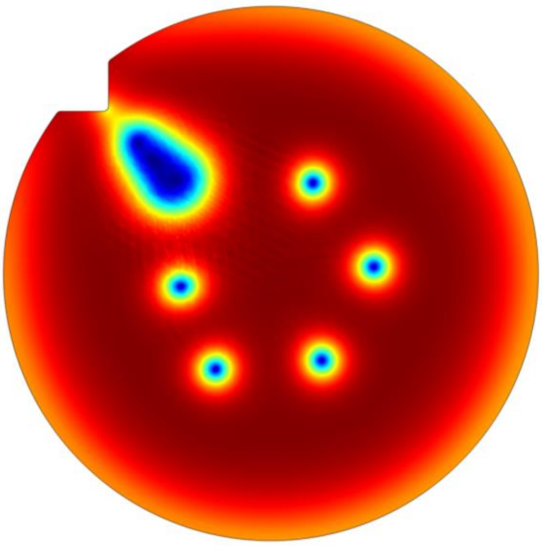
For further reading see:

1. COMSOL Multiphysics https://www.comsol.com/comsol-multiphysics

2. https://www.comsol.com/blogs/modeling-superconductivity-ybco-wire/

3. Time-Dependent Ginzburg — Landau Simulations of the Critical Current in Superconducting Films and Junctions in Magnetic Fields

4. See also the video of simulations on http://www.cfas.ox.ac.uk/discover



Simulation of the vortex state formation in the presence of an external magnetic field for a type II superconductor.