Unconventional Superconductors

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The discovery of superconductivity by Kamerlingh Onnes over 100 years ago has offered physicists the opportunity to study this most intriguing macroscopically coherent state of electrons. For "conventional" superconductors the Cooper pairs are s-wave, while in "unconventional" materials the pair wavefunction may be an odd-parity spin-triplet.

Unconventional superconductivity can be found in number of different classes of materials. These include systems with noncentrosymmetric crystal structures, i.e. systems without inversion symmetry where parity is no longer a meaningful label, in materials with strong spin-orbit coupling, e.g. those containing 4d and 5d metals, and in systems with unusual crystallographic geometries, e.g. kagome lattice superconductors. It will be these three groups of superconductors that will be the focus of this work. In unconventional superconductors, a variety of physical effects that may previously have been forbidden are now allowed. Examples include exotic superconducting gap structures (lines or nodes in the superconducting gap), magnetoelectric effects such as a helical phase and upper critical fields exceeding the Pauli limiting fields, time reversal symmetry breaking, and even topological effects. For some of our recent work in this area please see Refs. 1-3.

In this experimental project, you will study the superconducting properties of some of these superconducting materials. You will learn how to prepare polycrystalline and single crystal samples. The structural properties of these samples will be studied using a suite of state-of-the-art x-ray diffractometers and electron microscopes. You will then examine the superconducting properties of these crystals in the laboratory at low temperatures and in high magnetic fields. A range of neutron scattering and muon spectroscopy techniques available at national and international central facilities will also be used to investigate the physics of these materials.

This experimental project will offer an excellent training in several important aspects of modern condensed matter physics.

[1] R. P. Singh, A. D. Hillier, B. Mazidian, J. Quintanilla, J. F. Annett, D. M. Paul, G. Balakrishnan, M. R. Lees, Physical Review Letters **112**, 107002 (2014).
[2] J. A. T. Barker, D. Singh, A. Thamizhavel, A. D. Hillier, M. R. Lees, G. Balakrishnan, D. M. Paul, R. P. Singh, Physical Review Letters **115**, 267001 (2015).
[3] D. A. Mayoh, A. D. Hillier, K. Götze, D. M. Paul, G. Balakrishnan, M. R. Lees, Physical Review B **98**, 014502 (2018).

DTG application form

Project title	Unconventional Superconductivity
Supervisor	Martin Lees
Co-supervisor / second supervisor	Geetha Balakrishnan
Group	Magnetism & Superconductivity
Cluster	Condensed Matter Physics

Student opportunity: the project should be good for the student *

The student will be given instruction in sample preparation and measurements at low-T and high magnetic fields using state-of-the-art apparatus in-house and at central facilities. They will be encouraged to take ownership of the project, moving the work forward in ways that suit their interests and talents. They will be given one-to-one tuition and guidance in all aspects of this work.

The project offers an excellent training opportunity allowing the student to follow a career in academic or industrial science, education, or to secure a job that requires a scientific training. All my previous PhD students have graduated on time. Fleck (3 papers 1 PRL), is a physics teacher who trained via the INSPIRE programme where a PhD is required. Wooldridge (5 papers 1 PRL), works at the NPL. Biswas- 8 papers-1 PRL is an instrument scientist at ISIS. Cook who completed a CASE award (sponsor JM) now holds an academic post in BCU. Dan Mayoh (9 papers) is now a Research Fellow in the Department.

Strategic need: why is the studentship needed now and why is it important?

Much of our Group's work is carried out at central facilities. Beam time is awarded via peer review and our success is a tribute to the quality of our science and a strong indicator of our international standing. These activities are fully funded incl. travel, subsistence, and in the case of UK facilities, consumables. Teaching commitments mean students are vital to complete this work.

The S+M Group currently has just 4 Ph.D. students including my current student David Jonas. David will graduate next year. Without a PhD student it is difficult to sustain a research programme using central facilities or to make the most of the capital investment in the Group. Over the last 30 years I have helped support the work of many of the students in our Group, but I have only supervised 6 students myself (only 4 of these were DTP awards). A student is vital for my personal research programme.

Funding opportunity: the DTG studentships should be leveraged against funding opportunities. *

I am currently co-investigator on two EPSRC funded projects, both led at Warwick by Prof. Geetha Balakrishnan. The first is a Programme Grant - Skyrmionics: From Magnetic Excitations to Functioning Low-Energy Devices (EP/N032128/1). We have recently submitted a Programme Grant proposal to continue working on topological materials - Topomagnetism: control of topological magnetic excitations through order-parameter engineering (EP/X036022/1). If successful this grant will focus on studying magnetic topological materials, some of which are related to the topological superconductors we propose to investigate here. The second grant is Crystal Growth at Warwick (EP/T005963/1), an activity that underpins all our work and will allow production of the samples needed for this project. I have begun writing a grant to support work on unconventional superconductors that I hope to submit to the EPSRC later this academic year.

Does this project have industrial support suitable to make it eligible for a CASE DTG? If so, please include the company name and state whether they have agreed to it. *

No

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In noncentrosymmetric crystal structures, i.e. systems without inversion symmetry, parity is no longer a meaningful label. The lack of inversion symmetry induces an antisymmetric spin-orbit coupling which can lift the degeneracy of the conduction band electrons and may cause the superconducting pair wavefunction to contain a mixture of singlet and triplet spin states. The breakdown of the usual classification of superconductors into even and odd-parity states means that a variety of physical effects that may previously have been forbidden are now allowed. Examples include exotic superconducting gap structures, magnetoelectric effects such as a helical phase and upper critical fields above the Pauli limit, time reversal symmetry breaking, and even topological effects.

You will study the superconducting properties of noncentrosymmetric materials. Single crystals will be grown. Their structural properties will be studied using state-of-the-art x-ray spectrometers and electron microscopes. The superconducting properties of these crystals will be examined in the laboratory at low temperatures and in high magnetic fields. A range of neutron scattering and muon spectroscopy techniques available at national and international central facilities will also be used to investigate the physics of these materials.

This experimental project offers an excellent training in modern condensed matter physics.