Abstract Book

4th Superconductivity Summer School 2016

20–22 July 2016

Wolfson College, Oxford, UK

Organised by the IOP Superconductivity Group in collaboration with
The European Society for Applied Superconductivity (ESAS)

IOP | Institute of Physics
Superconductivity Group

ESAS
The European Society for Applied Superconductivity

http://super2016.iopconfs.org

4th Superconductivity Summer School 2016

Wednesday 20 July 2016

07:30 **Breakfast** – *Hall (For residential delegates only)*

Registration - *Wolfson Auditorium Foyer*

08:20 **Introduction**
Ziad Melhem, Oxford Instruments, UK

08:30 **Memories of Harry Jones in Oxford**
Chris Grovenor, Oxford University, UK

Superconductivity Basics

08:45 **Superconducting fundamentals and theory**
Stephen Blundell, Oxford University, UK

09:45 **The synthesis and chemistry of iron-based superconductors**
Simon Clarke, Oxford University, UK

10:30 **Tea & coffee break**
Haldane Room

11:00 **Superconducting materials**
Susannah Speller, Oxford University, UK

11:45 **Superconducting materials in conductor forms**
David Larbalestier, Florida State University, USA

12:45 **Lunch** - *Haldane Room*

13:45 **Bulk superconducting materials**
John Durrell, Cambridge University, UK

Superconducting Conductors and Technology Basics

14:30 **Measurement techniques for superconducting materials and applications**
Damian Hampshire, Durham University, UK

15:30 **Tea & coffee break** - *Haldane Room*

16:00 **Applications of superconductivity**
Martin Wilson, Consultant, Oxford, UK

17:00 **Superconducting applications – cables**
Joe Minervini, Massachusetts Institute of Technology, USA

18:15 **Welcome reception** – *Harbour Terrace & Harbour Lawn*

4th Superconductivity Summer School 2016

Thursday 21 July 2016

07:30 **Breakfast** – *Hall (For residential delegates only)*

<u>Superconducting Electronics</u>

08:30 **Superconducting circuits for quantum information processing**
Yuri Pashkin, Lancaster University, UK

09:30 **Superconducting hybrid devices for quantum metrology**
Jukka Pekola, Aalto University, Finland

10:30 **Tea & coffee break** - *Haldane Room*

<u>Superconducting Magnet Basics</u>

11:00 **Design principles of superconducting magnets – Part I: Magnet configurations and quenching**
Martin Wilson, Consultant, Oxford, UK

12:00 **Computer aided engineering and design in applications of superconducting coils**
Chris Riley, Cobham Technical Services, UK

13:00 **Lunch** - *Haldane Room*

<u>Summer School Visit to Oxford Instruments</u>

13:45 **Depart for Oxford Instruments visit**
Wolfson Auditorium Foyer

14:15 **Visit to Oxford Instruments Tubney Woods Site and Introduction to Products Manufacture**
Ziad Melhem, Oxford Instruments, UK

16:40 **Return to Wolfson College**

19:00 **Summer School Reception & Dinner** – *Harbour Terrace & Haldane Roon*

4th Superconductivity Summer School 2016

Friday 22 July 2016

07:30 **Breakfast –** *Hall (For residential delegates only)*

08:30 **Design principles of superconducting magnets – Part 2: Stabilisation, filamentary wires and AC losses**
Martin Wilson, Consultant, Oxford, UK

Superconducting magnet applications

09:30 **Superconducting technology for high energy physics and accelerators**
Luca Bottura, CERN, Switzerland

10:30 **Tea & coffee break -** *Buttery*

11:00 **Superconducting technology for fusion**
Joe Minervini, Massachusetts Institute of Technology, USA

12:00 **Cryogenics for superconducting applications**
Charles Monroe, Monroe Brothers Ltd, UK

12:45 **Lunch** - *Buttery*

13:30 **Fundamentals of superconductivity in iron-based superconductors**
Amalia Coldea, Oxford University, UK

14:15 **Superconducting applications – MRI**
M'hamed Lakrimi, Siemens Magnet Technology, UK

15:00 **Tea & coffee break -** *Buttery*

15:30 **Superconducting electrical machines**
Mark Ainslie, Cambridge University, UK

16:15 **Closing remarks**
Ziad Melhem, Oxford Instruments, UK

16:30 **Close**

4th Superconductivity Summer School 2016

Wednesday 20 July 2016

Superconducting fundamentals and theory

S Blundell

Oxford University, UK

Some of the theoretical ideas underlying superconductivity are reviewed at a level which should be comprehensible for experimentalists. I will discuss aspects of Fritz London's notion of a macroscopic quantum object and the BCS theory, as well as reviewing some of the models used to describe superconductors described in the last couple of decades.

The synthesis and chemistry of iron-based superconductors

S J Clarke

University of Oxford, UK

The chemistry of a range of systems displaying superconductivity will be surveyed briefly. The main focus will be on the factors controlling superconductivity in the relatively new class of iron-based superconductors. Synthetic methods for realising members of the class of iron based superconductors will be described. In particular the focus will be on compounds containing iron selenide layers with electropositive metals and small molecules such as ammonia in the interlamellar space, which have been characterised using neutron diffraction investigations [1,2] and *in-situ* X-ray powder diffraction investigations carried out during synthesis [2]. The control of the physical properties through chemical transformations including absorption of small molecules [2] will be described, and the interplay of magnetism and superconductivity as a function of composition will be compared with that of the iron arsenide members of the class [3]. New results will be described [4] which show that further synthetic routes enable new members of the class of iron-based superconductor to be synthesised and manipulated by chemical transformation.

[1] M. Burrard-Lucas et al., Nature Materials 12, 15 (2013)
[2] S. J. Sedlmaier et al., J. Am. Chem. Soc. 136, 630 (2014)
[3] D. R. Parker, et al., Phys. Rev. Lett. 104, 057007 (2010)
[4] H. Sun et al., Inorg. Chem., 54 1958 (2015)

Superconducting materials

S Speller

Oxford University, UK

Superconductors are a diverse class of materials, ranging from simple metals and alloys to complex ceramic materials. This lecture will give a brief introduction to the most important classes of materials, focussing on the structural and chemical factors that influence their performance. Case studies will be used to illustrate how the properties of materials are optimised for specific applications, including superconducting solders for joints in magnets and thin film superconductors for device applications. Further examples will be the topic of subsequent lectures by Prof Larbalestier (conductors) and Dr Durrell (bulk superconductors).

Superconducting materials in conductor forms

D C Larbalestier

Florida State University, USA

Of many hundreds, perhaps thousands of materials known to be superconducting, only 6 are available industrially. By far the largest production is of Nb47wt.%Ti followed by Nb_3Sn, both in multifilamentary form. Together they account for well over 90% of all superconductor made because they can supply high critical current density Jc(4.2K), well over 1000 A/mm^2, in fields of up to about 8 T for Nb-Ti and up to ~16 T for Nb_3Sn. Thus well over 95% of all superconducting magnets have been made from these materials. Three cuprate superconductors have been made in conductor forms, first $Bi_2Sr_2CaCu_2O_{8+x}$ (Bi-2212), later $(Bi,Pb)_2Sr_2Ca_2Cu_3O_x$ (Bi-2223), then coated conductors of $REBa_2Cu_3O_{7-x}$ (REBCO). For any superconductor to become viable, it must be available in an affordable, protectable and strong enough conductor form be to suitable for magnet construction, a task well fulfilled by Nb-Ti and Nb_3Sn in magnets with fields up to 23 T. HTS materials, notably Bi-2212 and REBCO have allowed demonstration magnets above 30 T. Most recently a REBCO insert coil has achieved 9 T in a 31 T background field. Many believe in REBCO coated conductors as the future commodity superconductor because of its capability to operate at temperatures well above 30 K, perhaps even as high as 65-77 K but its present high cost, limited conductor architecture and difficulty of protection mean that it is still only slowly emerging into the market. Bi-2212 offers some intriguing options since it is the only HTS conductor available with high Jc in round, multifilament form, while Bi-2223, also multifilament though in strongly coupled and high aspect ratio tape format, has found wide use in prototype electric utility devices. All three cuprate conductors are expensive which has allowed MgB2 conductors to enter small-scale production as a low field (~0-3 T), medium temperature (~10-30 K), potentially cheaper alternative uses not served by Nb-Ti. I will discuss ways of achieving high Jc in these various superconductors, their upper critical field limitations and some aspects of their architectural, strength and production cost constraints.

Bulk superconducting materials

J Durrell

Cambridge University, UK

In 2003 Tomita and Murakami set the record for the trapped field in a bulk superconductor of a shade over 17.2 T. In 2014, not without significant effort, this record was raised to 17.6 T. This apparently slow progress may suggest that the pace of progress in Bulk Superconductors has been very slow. In fact nothing could be further from the truth. The growth of bulk materials from (RE)BCO has seen innovations which have permitted a wider range of materials to be successfully grown, engineered pinning enhancement to provide improved critical currents, progressively larger samples and significant progress towards batch processing. In the meantime MgB_2 has emerged, in spite of its relatively low critical temperature, as a cheap, easy to make and rare earth free competitor. In this presentation I will discuss the significant advances that have taken place over the last ten or so years in the materials science of (RE)BCO and MgB_2 bulk superconductors. I will address the challenges to practical application, in particular that of charging, and discuss the approaches being taken around the world to solve them. In parallel with rapid materials development a range of innovative applications for Bulk Superconductors have appeared. I will outline some of these applications which are in domains as diverse as non- destructive testing, energy storage and medicine.

Measurement techniques for superconducting materials and applications

D Hampshire

Durham University, UK

To make world-class high-field measurements on superconductors in high magnetic fields you need a combination of a good scientific environment, experience of in-house design of instruments, access to international high-field facilities, world-class research students and post-docs, funding, hard work, intuition and some luck. Durham has housed the European Reference Laboratory in which we have made thousands of different transport and magnetic measurements on Nb3Sn wires in high fields for the TF coils of the ITER program.

This talk will review the most important types of measurements in applied superconductivity. It will include visualisation of the flux-line-lattice in high fields superconductors, some comments about the experience gained making the reference laboratory measurements and detailed considerations of how to make both room temperature measurements and cryogenic measurements on both low temperature and high temperature superconductors at high-field International facilities and in-house.

Figure 1: The (16) Nb3Sn toroidal field coils) - each coil weighs 290 tonnes.
Each starts with 1100 wires ~ 0.81 mm diameter that are twisted into a 40 mm tube to form a conductor 820 m long.

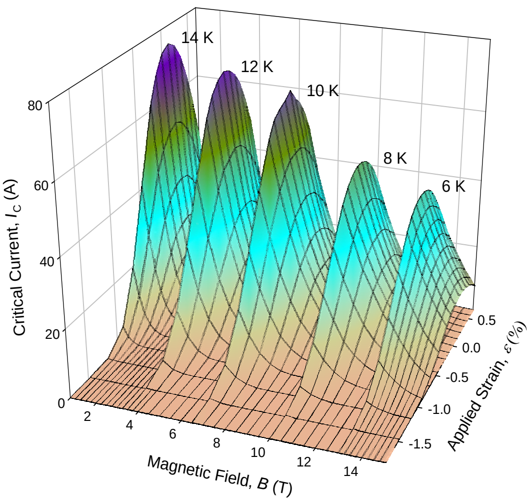

Figure 2: The critical current of Nb3Sn as a function of magnetic field, temperature and applied strain.

Applications of superconductivity

M Wilson

(Consultant) Oxford, UK

Market surveys show that commercial activity in superconductivity worldwide is dominated by magnets and high current applications, with superconducting electronic devices claiming only a small share of the market. Big science was the first application area to use superconductivity on a large scale, but scanner magnets for MRI now dominate the magnet sector with ~ 75% of the total worldwide business in superconducting products.

A quarter century after their discovery, high temperature superconductors HTS have yet to make a large impact, but their use is now growing rapidly. This review will describe the application of superconductors in research magnets, NMR spectrometers, MRI scanners, medical applications including cancer therapy, particle accelerators, fusion, magnetic separation, electric power engineering and high sensitivity electronics. Prospects for the adoption of HTS in these areas will be discussed.

Superconducting applications – cables

J Minervini

Massachusetts Institute of Technology, USA

Both low and high temperature superconductors are usually produced as small round wires or flat tapes with dimensions on the order of 1-12 mm. Although these wires can carry very high currents relative to their cross-sectional area, i.e., very high current density, the absolute value of current they carry may be in the range of some tens to hundreds of amperes, depending on the local magnetic field and temperature. There are many large-scale applications that would be infeasible if conductors were limited to these relatively low value of currents. For example, in the cases of power transmission and power conditioning, high energy and nuclear physics accelerator magnets, or magnets for magnetic confinement fusion, currents in the range of a few kiloamperes to tens of kiloamperes are required. For these applications, the single wires or tapes must be bundled into larger cables to operate at these higher currents. The manufacturing and electrical behaviors of these large cables are much more complex to understand because they introduce issues such as non-uniform current distribution among the wires, and different types of ac losses during magnet ramping or during pulsed or ac operation. The construction of these cables is also usually very different for each type of application and operating conditions. This lecture will introduce you to superconducting cables for these various applications and describe, why they look the way they do, how they perform, and how to manufacture them.

4th Superconductivity Summer School 2016

Thursday 21 July 2016

Superconducting circuits for quantum information processing

Y Pashkin

Lancaster University, UK

Starting from motivation and a brief introduction to the field of quantum computing, I will describe the physics of the Josephson effect and explain how and what type of qubits can be built using Josephson junction devices. Besides discussing application of superconducting circuits for quantum information processing, I will briefly mention other applications, such as displacement sensing of nanomechanical resonators and single microwave photon generation.

Superconducting hybrid devices for quantum metrology

J Pekola

Aalto University, Finland

I will discuss single-electron control in hybrid superconducting circuits. A key element is a tunnel junction formed between a normal metal and a superconducting electrode. The principle and operation of a single-electron turnstile to produce a quantized current $I = ef$ at the operation frequency f will be presented, together with physics governing its performance. Control of Andreev processes, co-tunneling and non-equilibrium quasiparticles in a superconductor will be discussed. In the second part of the presentation, I show how hybrid tunnel junctions can be used for ultrasensitive thermometry and eventually for single microwave photon calorimetry.

Design principles of superconducting magnets – Part I: Magnet configurations and quenching

M Wilson

(Consultant) Oxford, UK

Because they have no Ohmic dissipation, superconducting magnets are able to reach much higher fields than conventional electromagnets without the need for an iron yoke. In the absence of iron, the resulting field shape will be determined solely by the winding configuration. The different windings needed to produce solenoid, dipole and toroidal field shapes will be described, together with the electromagnetic forces and resulting stresses produced in the winding materials.

Quenching occurs when a point within the magnet windings goes from superconducting to resistive state. Intense Ohmic heating ensues, the resistive zone grows by thermal conduction so that the magnet current decays via the growing internal resistance. If the current does not decay quickly enough, the temperature at the point where the quench started may be high enough to destroy the magnet. Methods of calculating quench behaviour and of protecting against damage by quenching will be described. The resistive zone in an HTS winding grows much more slowly than in an LTS winding, which makes the quench protection problem more difficult.

Computer aided engineering and design in applications of superconducting coils

C Riley

Cobham Technical Services, UK

The lecture will introduce modelling of the main commercial and research applications of superconducting materials in magnets and other devices, where the superconducting capability is used to carry large currents to produce magnetic fields. In the latter part of the lecture, models where the superconducting nature of the material is significant will also be addressed

In most electromagnetic field modelling, the superconducting properties of the material do not have to be captured and superconducting coils can be treated identically to resistive coils. The Biot-Savart expressions to calculate magnetic field in free space from a current carrying source will be introduced. An example where design optimization software is used to obtain a homogeneous field volume from a set solenoid coils will illustrate this.

In practical magnetic systems, other materials also exist (shields, cryostats, vacuum vessels, magnetic cores, structural steel etc.) and the Biot-Savart expression alone is not sufficient to calculate the field. Finite element solutions of magnetic field equations will be briefly explained and the benefits of combining Biot-Savart and finite element results for very accurate field evaluation demonstrated. A range of examples, including MRI, accelerator magnets and electrical machines will illustrate some of these points and some of the design issues associated with using superconducting coils in these applications highlighted.

The structural integrity of superconducting coils is also of importance and the use of multiphysics simulations combining electromagnetic and small displacement stress analysis will be discussed.

The final part of the lecture will cover application modelling where the superconducting properties of the coil or material must be included. This will cover modelling of the Meissner effect, hysteretic behaviour, superconducting quench and induced effects in HTS.

Visit to Oxford Instruments Tubney Woods Site and Introduction to Products Manufacture

Z Melhem

Oxford Instruments, UK

The visit to Oxford Instruments Tubney Woods site will be in two parts. Part I will be a 30 min overview talk on OI products with special focus on superconducting and cryogenics environments. Part II will be a factory tour to see things being manufactured and processes at work. This will cover stages from design, manufacture, acceptance testing and finally packaging and shipment. The visit will also provide an opportunity to talk to various people at OI involved with the engineering and production activities.

4th Superconductivity Summer School 2016

Friday 22 July 2016

Design principles of superconducting magnets – Part 2: Stabilization, filamentary wires and AC losses

M Wilson

(Consultant) Oxford, UK

A common experience in using superconducting magnets is that they fail to achieve the current and field expected from the critical properties as measured on a short sample of wire. Furthermore, the magnet performance will generally improve after repeated energization, an effect known as 'training'. It is thought to be caused by a sudden small release of energy within the winding coming from mechanical motion or magnetic flux change. Different approaches to curing the problem, with the general name of 'stabilization', will be described.

The magnetic instability, known as 'flux jumping', is cured by making the superconductor in the form of fine filaments. This technique also brings the benefit of reduced ac loss and improved field uniformity. For convenient handling, many fine filaments are embedded in a resistive matrix and made into a composite wire. If high currents are needed, many filamentary wires are made into a cable. In both these situations, the filaments are coupled together magnetically, which causes undesirable behaviour. The steps needed to minimize coupling in filamentary composite wires and cables will be described.

Superconducting technology for high energy physics and accelerators

L Bottura

CERN, Switzerland

Superconductivity has played a key role throughout the past century in expanding the frontiers of human knowledge. Superconducting materials and superconducting magnet technology offer important new tools to expand our understanding of the world and the potential to foster new energy technologies. This talk will review the main applications of superconductivity for large scale science projects, and more specifically HEP accelerators and detectors. The working principle of a modern accelerator will be reviewed, developing on the need of superconducting magnets and RF. Details of superconducting magnet and superconducting RF design will be discussed, and the talk will conclude with state of the art and perspectives for future developments.

Superconducting technology for fusion

J Minervini

Massachusetts Institute of Technology, USA

Magnet systems are the ultimate enabling technology for magnetic confinement fusion devices. Powerful magnetic fields are required for confinement of the plasma, and, depending on the magnetic configuration, dc and/or pulsed magnetic fields are required for plasma initiation, ohmic heating, inductive current drive, plasma shaping, equilibrium, and stability control. Almost all design concepts for power producing commercial fusion reactors rely on superconducting magnets for efficient and reliable production of these magnetic fields. Future superconducting magnets for fusion applications require improvements in materials and components to significantly enhance the feasibility and practicality of fusion reactors as an energy source. This lecture presents the different magnetic configurations for fusion devices, explains the roles of the magnetic systems, and gives an overview of the superconductor and magnet design aspects.

Examples are drawn from present operating fusion tokamak, helical and stellarator machines that use low temperature superconductors, and introduces the use of high temperature superconductors for future fusion devices.

Cryogenics for superconducting applications

C Monroe

Monroe Brothers Ltd, UK

Cryogenic applications for superconductivity can have cooling requirements ranging from a few milliwatts or up to kilowatts. The designer has to address the question: what is the best way to deliver this cooling power? The lecture will provide an overview of the typical methods of delivering the necessary cooling for a range of cryogenic applications.

The first part of the talk will review the principles of refrigeration, draw conclusions about the cost of refrigeration and present the options of cooling either from cryogens delivered by an external supplier, from cryocoolers or from a large scale helium liquefier.

The second part will look at a number of example applications for superconductivity. These will include superconducting RF cavities for accelerators, low loss NMR magnets (low cryogen loss), and superconducting magnets with cryocoolers which can be either zero cryogen loss or dry systems. In each case a study of the application, the resources available, the cooling requirements, the need for stability and the economics will all contribute to identifying the most appropriate cooling method.

Fundamentals of superconductivity in iron-based superconductors

A Coldea

Oxford University, UK

Iron-based superconductors are a new class of materials that display superconductivity in a variety of forms with transition temperatures up to 75K.

In this talk I will review the recent advances in this field focusing on efforts to understand the superconductivity of FeSe and related systems by using high magnetic fields and angle resolved photoemission spectroscopy.

Superconducting applications – MRI

M Lakrimi

Siemens Magnet Technology, UK

The presentation will start with a general reminder of superconductivity as an enabler of technology. This will be followed with an introduction to MRI. This will cover some facts about MRI, to include world market value, installed base and scan modality. The MRI hardware will be described.

At the heart of every MRI scanner is a magnet. The presentation will explain how discrete coils are used to produce a uniform and homogeneous field. It will then focus on important engineering aspects. A typical construction of a magnet will be given.

Superconducting electrical machines

M Ainslie

Cambridge University, UK

This lecture will give an overview of some of the design principles and considerations necessary for the design of superconducting electrical machines. Starting with the basic operating principles and uses of some commonly used electrical machines, the use of different forms and types of superconducting materials in electrical machines will be discussed, including superconducting material requirements and some of the technical challenges faced. There have been a number of projects around the world that have demonstrated the technical feasibility of superconducting machines in various forms and a number of these will be used as case studies. Finally, some of the cryogenic cooling system options – a crucial enabling technology for any superconducting application – for superconducting machines will be discussed.

Sponsors

Institute of Physics
76 Portland Place, London W1B 1NT, UK
Telephone: +44 (0)20 7470 4800
www.iop.org/conferences

Registered Charity Number: 293851