Student Research Connection:

Condensed Matter and Material Physics

The Book of Abstracts

Day 1: Tuesday, 14th February 2023

1.30pm - Paolo Radaelli: *Large-scale user facilities: a very short introduction*

In this brief presentation, I want to give a sense of the history of large-scale facilities (LSF) for neutron and X-ray research and highlight some of their major contributions over the past 60 years. I will describe the evolution of LSF and what the landscape looks like in 2023 for neutron, synchrotron and free-electron sources. Finally, I will discuss the opportunity provided by LSF as places to do research and build careers as physicists. I provide three references for background reading: [1] describes the current landscape of neutron sources and their applications, with a focus on Europe; [2] contains a lecture by Giorgio Margaritondo, one of the pioneers of synchrotron radiation and free electron lasers, describing the history and most significant developments in the field up to circa 2013; [3] is an early history of free electron lasers, their principle of operation and principal applications, which are now being realised at different sources around the world.

[1]https://www.esfri.eu/sites/default/files/NGL_CombinedReport_230816_Complete%20document_0209-1.pdf

[2] https://indico.ictp.it/event/a12174/session/6/contribution/4/material/0/0.pdf

[3] https://www.slac.stanford.edu/pubs/slacpubs/15000/slac-pub-15120.pdf

2pm - Prof. Sarnjeet Dhesi, Dr. Alessandro Bombardi, Dr. Cephise Cacho, Dr. Larissa Ishibe Veiga, and Dr. Mirian Garcia-Fernandez: *Virtual tour of Diamond Light Source*

In this tour we will briefly review the history of synchrotron sources, and see the inner workings of Diamond light source, from the generation of electrons through to their storage at relativistic energies where they are used the production of synchrotron X-ray light.

- Alessandro Bombardi: *I16: A world of research opportunities*

I will provide during my talk a brief introduction to I16[1], the material and magnetism beamline at Diamond. I16 is a medium hard x-ray beamline based on a linear undulator. The beamline offers the possibility to fully control the incident photon polarization and linearly analyse the final photon polarization. This is coupled with the possibility of tuning the energy to probe specific elements in a material. The large reciprocal space cover and the possibility of installing large sample environment makes I16 ideal to investigate subtle ordering processes in quantum, functional and magnetic materials via a variety of experimental techniques including non-resonant and resonant magnetic scattering [2], Bragg Coherent diffraction imaging [3], diffuse multiple scattering [4]. Some selected examples will be presented [5].

[1] S.P. Collins et al, AIP Conference Proceedings 1234, 303 (2010); https://doi.org/10.1063/1.3463196
[2] Resonant X-Ray Scattering and Absorption S. P. Collins & A. Bombardi
[3] Robinson, I., Harder, R. Coherent X-ray diffraction imaging of strain at the nanoscale. *Nature Mater* **8**, 291–298 (2009). https://doi.org/10.1038/nmat2400
[4] Nisbet, A. G. A., Beutier, G., Fabrizi, F., Moser, B. & Collins, S. P. (2015). Acta Cryst. A71, 20-25.
[5] https://www.diamond.ac.uk/Instruments/Magnetic-Materials/I16/publications.html

- Mirian Garcia-Fernandez: *Probing electronic excitations with Resonant Soft X-ray Scattering: Possibilities at Diamond's I21 RIXS beamline*

The I21 beamline at Diamond Light Source is a next-generation soft x-ray Resonant Inelastic X-ray Scattering (RIXS) beamline at Diamond Light Source in the UK. The beamline covers an energy range from 250 to 1500 eV with a planned upgrade up to 3000 eV currently under commissioning. First users were welcomed in September 2017 and the beamline is currently fully operational between 250 to 1500 eV.

The scientific program of the beamline focusses on the study of low-energy (< 0.5 eV) electronic and lattice excitations in solid state magnetic materials. Through the early X-ray commissioning and user operations, we obtained the energy resolution of about 35 meV at Cu L-edge (930 eV) and about 15 meV at Oxygen K-edge (532 eV) with high photon flux.

In this talk, I will introduce briefly soft x-ray resonant inelastic scattering followed by a discussion of the possibilities at I21 for the study of electronic, magnetic and lattice dynamics, particularly in strongly correlated electron systems.

- Cephise Cacho: *Science highlights from beamline I05*
- Larissa Ishibe Veiga: *Science highlights from beamline I06*

From sensors based on magnetoresistance materials to electric cars, magnetic materials are the fundamental building blocks of technology nowadays. But to study such materials and their potential functionalities, a probe sensitive to the magnetic elements, the spin-orbit coupling, allied to depth sensitivity as well as nanoscale spatial resolution, is required. In this talk, I will present how X-ray absorption spectroscopy combined with the different polarisation of x-rays is a powerful tool for studying magnetic materials. Such technique can be found in the I06 Nanoscience beamline, a soft X-ray beamline with full polarisation control hosting a range of advanced instrumentation able to probe magnetic properties on length scales of micrometres using the superconducting magnet (SCM) to tenths of nanometres using the photoemission electron microscope (PEEM).

16.15pm – Dr. Pascal Manuel, Dr. Haroon Rafique, and Dr. Aleks Krajewska *Virtual tour of ISIS, UK Neutron and Muon Source*

In this virtual tour of the ISIS facility, we will briefly review how ISIS produces neutrons from its ion source through to the synchrotron, target and moderator assembly. These moderated neutrons have the right energy/wavelength to study the structure and dynamics of an enormous range of materials helping scientists around the world to tackle challenges in a huge variety of science themes such as chemistry, energy, biology, environment, physics, electronics, manufacturing, geology, cultural heritage…

As an illustrative example, the tour will then focus on the components of one of ISIS 30 beamlines and an experiment being run on a particular day.

- Haroon Rafique: *ISIS accelerator talk*

Big science was instigated by the particle accelerator, and accelerators remain amongst homo sapiens greatest technical accomplishments. Accompanying a video tour, we will journey though the ISIS accelerator chain from source to target, endeavouring to understand the key features of these complex machines.

- Aleks Krajewska: *ISIS science talk*

Quantum materials are a platform for rich variety of phases and functions such as superconductivity, colossal magnetoresistance, or thermoelectricity, and are of interest for technological applications as well as fundamental research in physics and chemistry. X-ray and Neutron facilities such as Diamond and ISIS are key for investigation and understanding of Quantum Materials for future targeted design. In this talk, I will present Kitaev Materials which are candidates for novel Kitaev Quantum Spin Liquid (KQSL) state with long-range entanglement and topological order.

Day 2: Wednesday, 15th February 2023

1.30pm - Chris Howard: Applied materials research (Keynote)

In this talk, I will discuss the topic of 'applied research' in condensed matter and materials physics, starting with an historical overview of the field and some current challenges. I will then discuss some examples from my own research [1,2] before finally giving some thoughts on the challenges and opportunities of translating academic research into real-world technological applications.

[1] Production of phosphorene nanoribbons, Watts *et al.* Nature (2019), 586, 216

[2] Phosphorene Nanoribbon-Augmented Optoelectronics for Enhanced Hole Extraction, Macdonald *et al.* J. Am. Chem. Soc. (2021), 123(51), 21549

[3] Room Temperature Optically and Magnetically Active Edges in Phosphorene Nanoribbons, Ashoka *et al.* https://arxiv.org/abs/2211.11374

2pm - Konstantin Novoselov: *Materials in the Flatland*

When one writes by a pencil, thin flakes of graphite are left on a surface. Some of them are only one angstrom thick and can be viewed as individual atomic planes cleaved away from the bulk. This strictly two dimensional material called graphene was presumed not to exist in the free state and remained undiscovered until a few years ago. In fact, there exists a whole class of such two-dimensional crystals. The most amazing things about graphene probably is that its electrons move with little scattering over huge (submicron) distances as if they were completely insensitive to the environment only a couple of angstroms away. Moreover, whereas electronic properties of other materials are commonly described by quasiparticles that obey the Schrödinger equation, electron transport in graphene is different: It is governed by the Dirac equation so that charge carriers in graphene mimic relativistic particles with zero rest mass. The very unusual electronic properties of this material as well as the possibility for it's chemical modification make graphene a promising candidate for future electronic applications.

Probably the most important "property" of graphene is that it has opened a floodgate of experiments on many other 2D atomic crystals: BN, $NbSe_2$, TaS_2, MoS_2, *etc*. One can use similar strategies to those applied to graphene and obtain new materials by mechanical or liquid phase exfoliation of layered materials or CVD growth. An alternative strategy to create new 2D crystals is to start with an existing one (like graphene) and use it as an atomic scaffolding to modify it by chemical means (graphane and fluorographene are good examples). The resulting pool of 2D crystals is huge, and they cover a massive range of properties: from the most insulating to the most conductive, from the strongest to the softest.

If 2D materials provide a large range of different properties, sandwich structures made up of 2, 3, 4 … different layers of such materials can offer even greater scope. Since these 2D-based heterostructures can be tailored with atomic precision and individual layers of very different character can be combined together, - the properties of these structures can be tuned to study novel physical phenomena (Coulomb drag, Hostadter butterfly, metal-insulator transition, etc) or to fit an enormous range of possible applications, with the functionality of heterostructure stacks is "embedded" in their design (tunnelling or hot-electron transistors, photovoltaic devices).

2.30pm - Margherita Sepioni: *SmartIR*

I am Margherita Sepioni, CEO and Co-founder of SmartIR. We are a spin-out company from the University of Manchester developing graphene based thermal management solutions for Space.

As a scientist who has moved gradually into business, I will try to explain the challenges of becoming an entrepreneur in a very exciting and high-risk company!

3pm - Dawid Bowler: *The importance of materials modelling and close collaboration*

We have a wide variety of increasingly sophisticated experimental techniques available to characterise materials, in many cases giving atomic resolution of complex structures. However, there are often limits to the information that can be extracted from experiment, which modelling techniques can supplement. At the same time, modelling and theory without experimental input is not connected to reality. I will discuss a number of approaches to materials modelling, concentrating on atomistic modelling, and illustrate the importance of close collaboration between experiment and modelling.

[1] Atomistic Computer Simulations, V. Brazdova and D. R. Bowler, Wiley-VCH Berlin (2013) DOI:10.1002/9783527671816

[2] Building bridges: matching density functional theory with experiment, D. R. Bowler, Contemporary Physics 1--14 (2019) DOI: 10.48550/arXiv.1902.07553

3.30pm - Chris Stock: Orbitally tuned magnetism in two dimensions

Spatially long range order in two dimensions is possible only under specific energetic constraints. I will discuss and outline the conditions for this in my talk and provide examples from both liquid crystals and magnetic materials, focusing on scattering results. I will then discuss the role that orbital ordering plays in aiding spatial magnetic order.

4.15pm - Dr. Akshay Rao: *Opto-electronics*

There is a pressing need to reshape the world energy economy and shift to a sustainable, zero-carbon economy within the next 20-30 years. This sets huge scientific challenges but also offers enormous opportunities. To achieve a zero-carbon future we need both incremental improvements of existing technologies, but also new science and new materials to make use of the significant headroom that remains for improving the performance, cost, reliability, and sustainability of our energy technologies.

The Optoelectronics Group of the Cavendish Laboratory brings together several research groups interested in the fundamental materials and device physics of novel classes of organic semiconductors, hybrid organic-inorganic perovskite semiconductors as well as other functional materials, that could help addressing these challenges. These materials typically contain weakly van-der Waals bonded molecular units, that can be tuned by chemical design and give rise to unique physical properties and phenomena, including molecular quantum effects as well as strong coupling between electronic excitations and vibrational dynamics. Our focus is on understanding these phenomena in their full depth using a broad range of experimental approaches supported by theoretical simulations and to exploit them for applications in large-area electronics, optoelectronics, bioelectronics and renewable energy technologies.

4.45pm – Virtual tour of Cavendish Optoelectronis laboratories at the University of Cambridge