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Progress in Physics 2024

CONDENSED MATTER

9–10 October 2024, IOP London

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Reports on Progress in Physics™ has become a trusted resource for authoritative and cutting-edge review articles. We invite you to celebrate with us as the journal reaches its 90th anniversary. We'll look back at some of the advances in physics that have been reviewed by the journal, but also to look to the future as the journal evolves to publish primary research articles.

Members of the journal's international Editorial Board will be joined by invited researchers from the UK and Ireland across two days to discuss the latest in advances in their fields. For 2024, the focus of the **Progress in Physics 2024** is condensed-matter physics, in recognition of our Editor-in-Chief, Subir Sachdev.

Condensed matter sits at the exciting interface between quantum physics and materials science, where the intricate interplay between electrons and atoms gives rise to wide range of strange and exotic properties. These include superconductivity, topological insulators, superfluids, spintronics, but also so much more.

Progress in Physics 2024 present the latest in cutting edge condensed matter research, including the theoretical frameworks that help us understand and hopefully control these fascinating properties, through to those technologies looking to harness these properties in practical devices, and everything in between.

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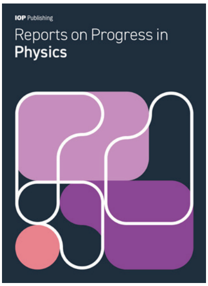

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Subir Sachdev, Harvard University
Editor-in-Chief, *Reports on Progress in Physics*

Programme

Wednesday 9 October

09:30-09:50	Welcome, coffee and pastries
09:50-10:00	**IOP/IOPP opening** **David Gevaux**, IOP Publishing
10:00-10:40	**Exploring spin-orbit coupling in quantum magnets and superconductors** **Hae-Young Kee**, University of Toronto
10:40-11:05	**Creating and exploring exotic physics in thin films and heterostructures** **Chris Bell**, University of Bristol
11:05-11:35	Coffee break
11:35-12:00	**Density functional theory for quantum thermodynamics** **Irene D'Amico**, University of York
12:00-12:25	**Skyrmions in chiral magnetic multilayers** **Christopher Marrows**, University of Leeds
12:25-12:50	**Title TBC** **Alan Dalton**, University of Sussex
12:50-14:00	Lunch
14:00-14:25	**Computational modelling of functionalized graphene: structures, properties and application in sensing.** **Natalia Martsinovich**, University of Sheffield
14:25-14:50	**Understanding delocalization & dissociation of excitons in heterogeneous semiconductors from first principles computational modelling** **Marina Filip**, University of Oxford
14:50-15:10	Coffee break
15:10-15:40	**Superconductivity in nickelates – comparison with high Tc cuprates** **Fu–Chun Zhang**, Kavli Institute for Theoretical Sciences, University of CAS
15:40-16:20	**From quantum entanglement to fractional Chern Insulator – the recent trend in quantum many-body computation.** **Zi Yang Meng**, University of Hong Kong
16:20-16:30	Close day followed by drinks reception

Thursday 10 October

09:30-10:00	Welcome
10:00-10:40	**Dark-matter challenges of the solid state** **Piers Coleman**, Rutgers University
10:40-11:05	**Gain-based computing with coupled light and matter** **Natalia Berloff**, University of Cambridge
11:05-11:35	Coffee break
11:35-12:00	**Symmetry and driven matter** **Paolo G Radaelli**, University of Oxford
12:00-12:25	**Using Ionic Liquids in Nanomanufacturing** **Carla Perez Martinez**, University College London
12:25-12:50	**Real space approaches to topological condensed matter systems** **Ryan Barnett**, Imperial College London
12:50-14:00	Lunch
14:00-14:25	**Atomically-thin materials: challenges and opportunities** **Amalia Patanè**, University of Nottingham
14:25-14:50	**Radiation damage of high temperature superconductors for fusion magnets** **Susie Speller**, University of Oxford
14:50-15:10	Coffee break
15:10-15:40	**Fractionalized excitations in quantum spin liquids and their detection** **Nandini Trivedi**, The Ohio State University
15:40-16:20	**From the Sachdev-Ye-Kitaev model to a universal theory of strange metals** **Subir Sachdev**, Harvard University
16:20-16:30	**IOP/IOPP closing** **David Gevaux**, IOP Publishing

Plenary speakers

Hae-Young Kee
University of Toronto, Canada
Reports on Progress in Physics Board Member

ABOUT THE SPEAKER

Hae-Young Kee is a Professor of Physics at the University of Toronto, holds a Canada Research Chair in the Theory of Quantum Materials, and is a Fellow of the Canadian Institute for Advanced Research in Quantum Materials.

Her research focuses on the condensed matter physics of quantum materials, such as quantum spin liquids, topological phases, high-temperature superconductors, and frustrated magnets. She has been recognized with numerous prestigious honours, including a Sloan Fellowship in 2003, election as an American Physical Society Fellow in 2018, the Canadian Association of Physicists Brockhouse Medal in 2023, and election as a Fellow of the Royal Society of Canada in 2024.

TALK TITLE

Exploring spin-orbit coupling in quantum magnets and superconductors
Spin-orbit coupling (SOC) plays a crucial role in shaping the electronic and magnetic properties of quantum materials, influencing their ground states and emergent behaviours. In this talk, I will examine the impact of SOC in two key areas: quantum magnets and superconductors, with a focus on how SOC can be incorporated into microscopic Hamiltonians to guide the search for candidate materials with tailored functionalities.

In quantum magnets, SOC drives diverse phenomena, ranging from anisotropic spin interactions in magnetic phases to exotic states such as Kitaev quantum spin liquids. These spin liquids, characterized by long-range entanglement and fractionalized excitations, emerge due to SOC's ability to alter magnetic interactions, giving rise to novel quantum phases.[1].
In superconductors, SOC facilitates unconventional pairing symmetries, such as inter-orbital antisymmetric and spin-triplet pairings in multi-orbital systems.[2]. I will also discuss recent theoretical developments that reveal the role of SOC in materials previously considered conventional magnets [3], highlighting its broader implications for understanding quantum materials.

[1] Beyond Kitaev physics in strong spin-orbit coupled magnets, Ioannis Rousochatzakis, Natalia Perkins, Qiang Luo, and Hae-Young Kee, Reports on Progress in Physics, 87, 026502 (2024).
[2] Identifying spin-triplet pairing in spin-orbit coupled multi-band superconductors, Christoph M. Puetter and Hae-Young Kee, Europhysics Letters, 98, 27010 (2012).

Chris Bell
University of Bristol,
United Kingdom

ABOUT THE SPEAKER

Chris Bell is currently an Associate Professor at the School of Physics, University of Bristol, having joined in 2013. Previously he held research positions at Stanford, Tokyo, Leiden and Cambridge. His research is focussed on the physics and materials science of quantum materials. Chris uses thin films, nanofabricated bulk crystals, and devices to tune the materials' structures and electronic properties. He studies superconductors and magnetic systems, as well as actinide materials, the latter using Bristol's Facility for Radioactive Materials Surfaces, unique in the UK.

TALK TITLE

Creating and exploring exotic physics in thin films and heterostructures

Thin films offer a myriad of ways of controlling and tuning states of matter. We can apply epitaxial strain, vary the dimensionality with thickness, and combine different order parameters together using proximity effects, to name but a few of the possibilities. In this talk I will briefly describe three case studies of engineering structural and electronic states with thin films. First, I will describe tuneable superconductivity in low density semiconducting single crystal thin film structures. Next, I will introduce using ferromagnetism and spin-orbit physics to generate novel superconducting order parameters in polycrystalline combinations. Finally, I will show an intriguing study of a topotactic phase transition in elemental uranium between an epitaxy-induced metastable hexagonal-close-packed phase, and the bulk ground-state orthorhombic structure.

Irene D’Amico
University of York,
United Kingdom

ABOUT THE SPEAKER

Professor Irene D’Amico is the head of the Semiconductor Spintronics and Quantum Information group and the lead of the Quantum Science and Technology Group of the Physics, Engineering and Technology School of the University of York. Irene D’Amico has been a professional researcher for over 20 years (PhD awarded in 2000), has written more than 140 publications as articles for international journals and book chapters, and given more than 120 invited talks, seminar, colloquia and public lectures worldwide. Her research interests include many-body interactions in solid state systems; dynamics of spin chains for quantum computing; metric space approach to quantum mechanics; density functional theory; and quantum thermodynamics.

TALK TITLE

Density functional theory for quantum thermodynamics

Density functional theory (DFT) is one of the most powerful methods to study properties of interacting many-body systems. It focuses on the local particle density (instead of the system’s state) as the key variable to derive the properties of interest. While DFT at zero-temperature is well established, the development of the finite-temperature formalism is comparatively in its infancy. Interest in this direction has been spurred by the recent advent of quantum technologies and quantum thermodynamics, and by the increasing ability to prepare and control quantum systems on a microscopic scale. However, from a theoretical point of view, addressing the study of interacting many-body quantum systems at finite temperature and out-of-equilibrium demands significant effort, usually requiring the use of approximations to tackle the complexity of problems beyond a handful of particles. In this context, we discuss the possibility of using DFT as a way to study the out-of-equilibrium thermodynamics of interacting many-body systems using two approaches. The first studies the dynamics of finite-temperature systems but building on zero-temperature DFT concepts; the second, develops thermal DFT to extrapolate information about the statistics of work and the irreversibility of a thermal quench.

Natalia Berloff
University of Cambridge, United Kingdom

ABOUT THE SPEAKER

Natalia Berloff is a Professor of Applied Mathematics, Department of Applied Mathematics and Theoretical Physics, University of Cambridge where she leads the quantum fluids and physics-inspired computing labs. She is also a Fellow of Jesus College, Cambridge. Prior to becoming a faculty member in Cambridge in 2002, she was an assistant professor at the Department of Mathematics, University of California in Los Angeles. While on leave from Cambridge from 2013-2016, Natalia was a Dean of Faculty and then the Director of the Photonics and Quantum Materials Program at Skolkovo Institute of Science and Technology. She was the visiting professor at Microsoft (2021-2023) and the Fellow of the Alan Turing Institute (2021-2023).

TALK TITLE

Gain-based computing with coupled light and matter

Gain-based computing based on light-matter interactions is a novel approach to physics-based hardware and physics-inspired algorithms, where the complex optimisation problems are encoded in the gain and loss rates of driven-dissipative systems. The system is driven through a symmetry-breaking transition on the changing loss landscape until a mode that minimises losses is selected, manifesting the optimal solution to the original problem. This process allows for solving important combinatorial optimisation problems via mapping to Ising, XY, and k-local Hamiltonians. Two primary directions have emerged for developing gain-based analogue hardware. The first approach exploits natural evolution principles of physical systems influenced and driven by external parameters, with the challenge of establishing controllable couplings between 'spins'. Polariton, atoms in QEDs and degenerate laser systems exemplify this. Conversely, the second approach, represented by technologies like analogue interactive machines and spatial photonic machines, focuses on establishing couplings through processes like light propagation, optical modulation, and signal detection, thereby managing system dynamics through feedback loops. Despite advancements in the physical realisation, critical questions remain about scalability, the influence of phase space structures on performance, and identifying problems best suited for these unconventional computing architectures. We need to understand the dynamic behaviour of the systems during symmetry-breaking transitions, trajectory optimisation towards global minima, error probabilities, and the potential for dissipation and nonlinearities to rectify these errors, highlighting the pivotal role of theory in addressing these challenges. By comparing various experimental platforms, including polaritons, lasers, and cold atoms, we should emphasise and exploit the universal nature of these questions. My talk outlines a strategic plan to tackle these outstanding questions while discussing and contrasting different approaches.

Christopher Marrows
University of Leeds,
United Kingdom

ABOUT THE SPEAKER

Christopher Marrows is Professor of Condensed Matter Physics at the University of Leeds, and was previously a Reader in the same subject, a lecturer, and before that an 1851 research fellow, funded by the Royal Commission for the Exhibition of 1851 following his PhD in 1997. His research programme concerns materials and devices for future information technology, in particular devices based on electron spin - so-called spintronics. This involves a wide-ranging investigation of nanoscale and thin film magnetic artificial structures, prepared largely by sputter deposition. Such materials are useful in the quest for ever more complex spin electronic devices - systems where the spin, as well as charge, of the electron is used in the storage and processing of information. Current areas of interest are chiral magnetism and magnetic skyrmions, spin torques in magnetic nanostructures, artificial frustrated systems, and the quantum spin Hall effect.

TALK TITLE

Skyrmions in chiral magnetic multilayers

Ionic K Zeissler[1], S Finizio[2], L Huang[1], C E A Barker[1], C Barton[3], K Fallon[4], K Shahbazi[1], E Haltz[1], T P Almeida[4], J R Massey[1], S Villa[4], C Kirkbride[4], F Al Ma'mari[1], A J Huxtable[1], D Bracher[2], A Kleibert[2], S Wintz[2,5], S Mayr[2,6], T Weßels[7], F Maccherozzi[8], B Sarpi[8], S S Dhesi[8], A Sadovnikov[9], M Rosamond[10], E H Linfield[10], D McGrouther[4], S McVitie[10], T A Moore[1], O Kazakova[3], J Raabe[2], G Burnell[1], and C H Marrows[1]

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[2]Swiss Light Source, Paul Scherrer Institute, 5232 Villigen, Switzerland
[3]National Physical Laboratory, Hampton Road, Teddington TW11 0LW, United Kingdom
[4]School of Physics and Astronomy, University of Glasgow, Glasgow G12 8QQ, United Kingdom
[5]Institute of Ion Beam Physics and Materials Research,Helmholtz-Zentrum Dresden-Rossendorf, 01328 Dresden, Germany
[6]Department of Materials, ETH Zürich, 8093 Zürich, Switzerland
[7]Ernst Ruska-Centre for Microscopy and Spectroscopy with Electronsand Peter Grünberg Institute, Forschungszentrum Jülich, 52425 Jülich, Germany
[8]Diamond Light Source, Didcot, Oxfordshire OX11 0DE, United Kingdom
[9]Laboratory "Metamaterials", Saratov State University, Saratov, 410012, Russia
[10]School of Electronic and Electrical Engineering, University of Leeds,Leeds LS2 9JT, United Kingdom

Magnetic skyrmions are topologically-nontrivial spin textures with particle-like properties [1]. Their size, topological stability, and mobility suggest their use in future generations of spintronic devices [2], the prototype of which is the skyrmion racetrack [3]. To realise a racetrack requires three basic operations: the nucleation (writing), propagation (manipulation), and detection (reading) of a skyrmion, all by electrical means.

Here we show that all three are experimental feasible at room temperature in Pt/Co/Ir or Pt/CoB/Ir multilayers in which the different heavy metals above and below the magnetic layer break inversion symmetry and induce chirality by means of the Dzyaloshinskii-Moriya interaction, defining the structure of Néel skyrmion spin textures [4]. We show deterministic nucleation on nanosecond timescales using an electrical point contact on top of the multilayer [5] (Figure 1), current-driven propagation along a wire in which the skyrmions are channelled by defects in the multilayer [6], and their detection by means of the Hall effect (Figure 2) that reveals an unexpectedly large contribution to the Hall signal that correlates with the topological winding number [7].

New directions in skyrmion research include spin wave-driven motion [8] and synthetic antiferromagnetic skyrmions [9].

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Alan Dalton
University of Sussex,
United Kingdom

TALK TITLE

To be confirmed

Natalia Martsinovich
University of Sheffield,
United Kingdom

ABOUT THE SPEAKER

Dr Natalia Martsinovich is a Senior Lecturer in Theoretical Chemistry at the University of Sheffield, UK. She obtained her undergraduate degree from the Belarusian State University, followed by a PhD in Theoretical Chemistry from the University of Sussex. She was a postdoctoral researcher in the Department of Physics at King's College London and the Department of Chemistry at the University of Warwick. Natalia was appointed Lecturer in the Department of Chemistry at the University of Sheffield in 2013 and promoted to Senior Lecturer in 2023. She is a member of the Royal Society of Chemistry and the Institute of Physics, and a Fellow of the Higher Education Academy. Natalia's research uses computational methods to study the properties of materials for applications in photocatalysis, sensors and nanotechnology. She works in close collaboration with experimentalists, using modelling to explain experimentally observed trends and predict properties of new materials.

TALK TITLE

Computational modelling of functionalized graphene: structures, properties and application in sensing

Graphene's excellent electronic and optical properties enable its use in a variety of applications. In particular, graphene is used as a sensor material to detect volatile gas molecules and as an electrode material in electrochemical sensors. While graphene's high electrical conductivity enables high-sensitivity measurements, selectivity is a challenge, which may be addressed by functionalizing graphene with various functional groups. We collaborated with experimental partners to investigate the structure-property relationship of oxygen-functionalized graphene-based materials and to design graphene-based sensors to detect phosphate, an essential plant nutrient.

We used theoretical modelling to investigate how chemical functionalization and changes in morphology affect electronic properties of graphene. Density-functional theory (DFT) calculations were used to model flat and curved graphene sheets containing epoxide and hydroxyl groups and substitutional oxygen. Curvature was found to have little effect on the electronic properties of graphene. However, oxygenation had significant effect on graphene's properties, with band gap opening in functionalised graphene's with oxygen content above 6%. This tuning of graphene's properties by chemical functionalization can lead to new applications in electronics and sensors.

Furthermore, we investigated chemical modification of graphene quantum dots by exploring the effects of sp3 carbons in graphene dots on these materials' optoelectronic properties. Our calculations showed that sp3 carbons prefer to form dimers or chains along the edge of the graphene dots, and they result in tuning of these materials optical absorption spectra, in some cases extending the absorption into the red region of the solar spectrum.

Finally, we investigated adsorption of phosphate species on pristine and oxygenated graphene. Adsorption of phosphate was found to affect graphene's band structure and resulted in significant and distinct changes in pristine and oxygen-functionalized graphene sheets' electrical conductivities. In particular, our calculations predicted an increase in resistivity upon adsorption of phosphate on pristine graphene, which was experimentally verified by our collaborators. These results suggest pristine and oxygen-functionalized graphene as promising materials for electrical sensors.

Marina Filip
University of Oxford,
United Kingdom

ABOUT THE SPEAKER

Marina Filip is an Associate Professor of Condensed Matter Physics at the University of Oxford and a Tutorial Fellow in Physics at University College, Oxford. Before joining the Oxford Physics faculty in February 2020, Marina was a postdoctoral scholar in the Physics Department at UC Berkeley and Lawrence Berkeley National Laboratory (2018-2020) and the Materials Department at the University of Oxford (2015-2018). Marina received her doctorate in Materials Science from the University of Oxford in 2016 (having defended 2015). Before this, Marina completed her undergraduate studies in Physics, at the University of Bucharest, Romania. Marina was recently awarded the 2024 IUPAP Early Career Scientist Prize in Semiconductor Physics, and a Somorjai Miller Visiting Professorship at UC Berkeley for Fall 2024. She was previously selected as part of the 2019 class of "Rising Stars in Physics", and between 2015 and 2018 she was awarded a Junior Research Fellowship from Wolfson College Oxford.

TALK TITLE

Understanding delocalization & dissociation of excitons in heterogeneous semiconductors from first principles computational modelling

In this talk, I will present an overview of my research group's recent first principles studies of optical excitations in a series of organic-inorganic layered lead-halide perovskites [1-4] using the state-of-the-art GW+BSE computational framework [5,6]. I will show how the exciton binding energy and spatial delocalization of excitons can be readily tuned by controlling structural and chemical properties of the organic and inorganic layers of these systems. If time permits, I will also briefly introduce a new first principles approach we have been developing, based on GW+BSE, which allows us to understand the impact ionic vibrations on the dielectric screening of excitons from first principles [7,8]. Using this approach, we are able to compute for the first time the temperature dependent exciton binding energies and dissociation rates in standard semiconductors and insulators [8,9].

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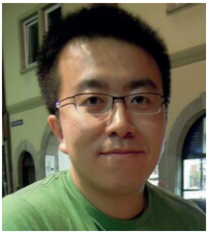


Zi Yang Meng
University of Hong Kong, China
Reports on Progress in Physics Board Member

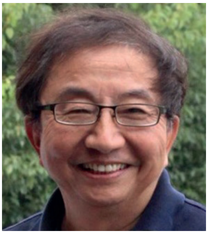
ABOUT THE SPEAKER

Prof. Zi Yang Meng is a computational condensed matter physicist, and his research focuses on developing and employing large-scale numerical simulation techniques to investigate quantum many-body systems and materials. He obtained Ph.D. from University of Stuttgart in Germany in 2011, and was postdoctoral fellow at Louisiana State University and University of Toronto from 2011–2014. In 2014, he became an Associate Professor with tenure at Institute of Physics, Chinese Academy of Sciences in Beijing and promoted to Full Professor in 2018. He became affiliated with Department of Physics, The University of Hong Kong (HKU) as an Associate Professor in 2019 and a Full Professor from 2023. He works on model design and algorithmic development for quantum many-body physics research and made contributions to topological quantum matter, frustrated magnetism, quantum phase transitions and critical phenomena.

More details can be found in his webpage https://quantummc.xyz/.

TALK TITLE

From quantum entanglement to fractional Chern Insulator – the recent trend in quantum many-body computation



Fu-Chun Zhang
Kavli Institute for Theoretical Sciences, China
Reports on Progress in Physics Board Member

ABOUT THE SPEAKER

Fu-Chun Zhang is Director of Kavli Institute for Theoretical Sciences, University of Chinese Academy of Sciences. He received Ph.D. at Virginia Tech. in 1983. He was a postdoctoral fellow at University of Minnesota, University of Maryland and ETH-Zurich, before he took a professorship position in University of Cincinnati 1988. He moved to the University of Hong Kong (HKU) as Chair Professor in 2003, and to Zhejiang University in 2014. He has been in the present position since 2017.

Zhang is elected APS Fellow, and received Distinguished Research Professorship in University of Cincinnati, and Distinguished Achievement Award in Research and endowed Zhou Guangzhao Professorship in HKU. Zhang is a condensed matter theorist, and has been interested in unconventional superconductivity including cuprates and nickelates, and possible Majorana zero modes in condensed matter systems among various topics.

TALK TITLE

Superconductivity in nickelates – comparison with high Tc cuprates

Since the discovery of high Tc superconducting cuprate in late 1980's, there have been great efforts to search possible superconductivity in nickelates because of the similarity of nickel and copper atoms. Nickelate superconductor had not been found till 2018 by Harold Hwang group in Stanford in infinite layer NdNiO2 with transition temperature Tc below 20K. More recently, La3Ni2O7 was discovered to have Tc around 80K under high pressure. In this talk, I shall review the recent development of superconductivity in nickelates and discuss possible theories for superconductivity, in comparison with superconductivity in cuprates.

Piers Coleman
Rutgers University,
United States
Reports on Progress in Physics Board Member

ABOUT THE SPEAKER

Piers Coleman completed his undergraduate education at Trinity College, Cambridge; he later studied theoretical condensed matter physics at Princeton University with Philip Warren Anderson. He was awarded a Junior Research Fellowship at Trinity College, Cambridge, and was a postdoctoral Fellow at the Kavli Institute for Theoretical Physics Santa Barbara. He joined the faculty at Rutgers University in 1987. Since 2010 he has also held the position of University of London Chair of Theoretical Condensed Matter Physics at Royal Holloway, University of London. In 2011, Piers Coleman replaced David Pines as a co-director of the Institute for Complex Adaptive Matter.

Coleman is known for his work related to strongly correlated electron systems, and in particular, the study of magnetism, superconductivity and topological insulators. He is the author of the popular text Introduction to Many-Body Physics.

TALK TITLE

Dark-matter challenges of the solid state

At the turn of the 20th century, physicists faced an uncanny range of unsolved problems: simple questions, such as why hot objects change colour, why matter is hard and why the sun keeps on shining, went unanswered. These problems heralded a new era of quantum physics. One of the truly remarkable lessons of discovery in this heroic era, was the intertwined nature of research: in the lab and in the cosmos, for solving superconductivity really did help answer why the sun keeps on shining, while looking at the stars provided clues as to why matter is hard.

The challenges facing us today, epitomized by our failure to quantize gravity, the mysteries of dark matter, energy and quantum information, challenge physics to its core. I will discuss some less well-known “dark matter challenges of the solid state”, epitomized by the discovery strange metals with linear resistivity and strange insulators and superconductors which appear to exhibit neutral Fermi surfaces. I will argue that laboratory-scale problems of this ilk challenge our fundamental understanding of matter in new and intriguing ways.

Paolo G Radaelli
University of Oxford,
United Kingdom

ABOUT THE SPEAKER

Paolo G Radaelli obtained a Laurea degree Summa cum Laude in 1986 from University of Milan. Between 1988 and 1989, he worked as a research associate at the ITM institute of the National Research Council (Italy) in the field of High-temperature superconductivity. In 1989, he was awarded a travel scholarship by Pirelli Cavi e Sistemi and moved to the Illinois Institute of Technology (Chicago) where he later completed a PhD under the academic supervision of Carlo Segre, and working in close collaboration with James D. Jorgensen and David Hinks at Argonne National Laboratory. After a post-doc in Jorgensen's group between 1992 and 1993, he moved to Grenoble, first as a post-doc with Massimo Marezio at the Laboratories de Cristallographie of the Centre national de la recherche scientifique, then as a scientist at the Institut Laue–Langevin. In 1998, he became Instrument Scientists and later Crystallography Group Leader at the ISIS neutron source at the Rutherford Appleton Laboratory in Didcot, England. Since 2008, he is the Dr Lee's Professor of Experimental Philosophy (Physics) at the University of Oxford, and he is also a Professorial Fellow of Wadham College, Oxford. Radaelli was appointed a Knight of the Order of the Star of Italy (2017) and received the Occhialini Medal and Prize (2023), jointly awarded by the Institute of Physics (UK) and the Società Italiana Fisica.

Throughout his career, Radaelli authored 250 publications. His main interest has been the study of compounds displaying novel physical phenomena, such as high-temperature superconductivity, "colossal" magnetoresistance or multiferroics behaviour, with the potential of device applications. He has made leading contributions to the physics of transition metal oxides and related compounds, using neutron and X-ray scattering and spectroscopy as primary tools. In recent years, Professor Radaelli has established a new field of research in photo-induced magnetism and real-space antiferromagnetic topology.

TALK TITLE

Symmetry and driven matter

Recent developments in lasers and optical sources, and specifically the ability to generate frequency-tuneable, large-amplitude pulses of controllable duration in the 10-30 THz regime, have allowed for experiments in which specific collective modes are addressed resonantly and can be coupled non-linearly to other modes – so-called non-linear phononics. In turn, these modes also couple with electronic degrees of freedom, so that pumping in the ultra-fast regime can induce properties (e.g. ferroelectricity, ferromagnetism or superconductivity) that are generally expected to appear on cooling through phase transitions. There is hope that this technique will eventually stabilise 'phases of matter' that do not occur in equilibrium. In the absence of a comprehensive theoretical interpretation and modelling of these experiments, symmetry considerations are of paramount importance and have been successfully used both to predict the 'emergence' of these properties [1] and to select specific linear/non-linear optical probes to identify them unambiguously. I will discuss examples from our recent work where symmetry played a key role in predicting the emergence of light-induced ferrimagnetism [2] and structural chirality [3] and helped to design the experimental protocols to detect them in the ultra-fast regime.

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Ryan Barnett
Imperial College London, United Kingdom

ABOUT THE SPEAKER

Ryan Barnett is Reader in Condensed Matter Theory in the Department of Mathematics at Imperial College London. Before moving across the pond, Ryan received his PhD from Harvard Physics followed by postdoctoral positions at Caltech and the Joint Quantum Institute (University of Maryland/NIST). Ryan is the present Chair of the IOP special interest group: Theory of Condensed Matter (TCM), which promotes the TCM field and serves the TCM community in the UK. Ryan has carried out research on a broad range of topics in quantum TCM. His current interests focus primarily on dynamics of ultracold atomic gases and topological condensed matter systems.

TALK TITLE

Real space approaches to topological condensed matter systems

The fields of Topology and Condensed Matter Physics have experienced a fruitful overlap which has led to a deep understanding of certain physical properties. For instance, topological invariants expressed in terms of "bulk" quantities (i.e. deep in the material), predict the existence of robust states living on the surface. In this talk, I will focus on a real-space picture of such topological systems. In particular, I will discuss how so-called topological markers are useful to describe topological properties of materials lacking translational invariance. I will also discuss how Wannier functions (a key concept bridging solid-state physics and chemistry) can be understood in topological systems.

Amalia Patanè
University of Nottingham, United Kingdom

ABOUT THE SPEAKER

Amalia Patanè studied at the University of Rome "La Sapienza" where she received her MSc in Physics (1994) and PhD (1998). She then moved to the School of Physics and Astronomy at Nottingham where she has been Professor of Physics (since 2011) and Director of Research (2019-23). Her research achievements in semiconductor physics were recognized by the Sir Charles Vernon Boys Medal and Prize of the Institute of Physics (2007), an EPSRC Advanced Research Fellowship (2004-09), a Leverhulme Trust Research Fellowship (2017-19), a Chinese Academy of Science (CAS) President's International Fellowship Award (2018-19), and an honorary professorship at the Institute of Semiconductors, CAS, Beijing (since 2019). Since 2015, Patanè is the UK Director and Council member of the European Magnetic Field Laboratory, a national facility of the EPSRC for development and use of magnetic fields. Also, she leads at Nottingham the EPI2SEM facility, a now a hub for development of next generation atomically-thin semiconductors for science and technologies.

TALK TITLE

Atomically-thin materials: challenges and opportunities

Atomically-thin materials can revolutionize modern science and technologies. However, future advances require advanced manufacturing and analytical techniques. Here, I will present my research on atomically-thin semiconductors, also referred to as two-dimensional materials, and a new facility at Nottingham for creating and studying these quantum systems [1-2]. By integration of growth, scanning probe microscopy and electron spectroscopy in ultra-high vacuum, we can create artificial materials with physical properties engineered at the atomic scale for a myriad of new applications.

[1] https://bit.ly/3zNOOdx
[2] https://www.youtube.com/watch?v=GHCxEDMh3RO

Susie Speller
University of Oxford,
United Kingdom

ABOUT THE SPEAKER

Susie Speller is a Professor of Materials Science at the University of Oxford where she leads the Superconducting Materials research group and co-directs the Oxford Centre for Applied Superconductivity. Over the last 20 years, she has worked on a wide variety of superconducting materials, ranging from superconducting solders for persistent mode joints to high temperature superconducting cuprates and iron-based materials. Her research focuses on correlating processing with microstructure and superconducting properties using advanced microscopy and spectroscopy techniques. She is currently undertaking a 5 year EPSRC Fellowship to study irradiation damage of coated conductors for compact fusion applications. Her group has carried out pioneering in situ experiments to measure the effects of cryogenic irradiation on superconducting properties, as well as investigating the nature of irradiation-induced defects using the combination of atomic-resolution electron microscopy, synchrotron x-ray absorption spectroscopy and density functional theory. She enjoys working closely with industrial collaborators and national laboratories, including Tokamak Energy, United Kingdom Atomic Energy Authority (UKAEA), Oxford Instruments and Siemens Healthineers, on industrially-relevant projects. Susie is currently the Letters Editor for Superconductor Science and Technology and has recently published a book for the general audience: “A materials science guide to superconductors: and how to make them super”.

TALK TITLE

Radiation damage of high temperature superconductors for fusion magnets

High temperature superconductors (HTS) in the form of coated conductors are an enabling technology for the next generation of compact nuclear fusion reactors. However, the superconducting magnet windings are exposed to a flux of fast neutrons which introduce structural damage. Previous studies using both fission spectrum neutrons and ions at room temperature (or slightly elevated temperatures) have shown that an initial increase in the superconducting current carrying performance upon irradiation is followed at higher fluences by a severe degradation of the properties and eventually complete loss of superconductivity. The superconducting transition temperature decreases monotonically with fluence, strongly suggesting that radiation-induced defects occur throughout the entire crystal lattice. This talk will outline the research being carried out by the Oxford Superconducting Materials group to improve understanding of radiation damage in HTS materials. This includes innovative in situ ion irradiation experiments to assess radiation damage of HTS at cryogenic temperatures, superconducting property measurements at ultra-high magnetic fields, and studies aimed at elucidating the nature of irradiation induced lattice defects using state-of-the-art microscopy and spectroscopy techniques.

Carla Perez Martinez
University College London, United Kingdom

ABOUT THE SPEAKER

Carla Perez Martinez is a UKRI Future Leaders Fellow at the London Centre for Nanotechnology at University College London. Carla obtained her BS, MS and PhD degrees from MIT in 2011, 2013 and 2016, respectively. For her undergraduate and graduate research, Carla worked with Prof Paulo Lozano in the MIT Space Propulsion Lab, developing ionic liquid ion sources. After her PhD, she moved to the UK to take up a postdoctoral position in the group of Prof Susan Perkin in the Physical and Theoretical Chemistry Laboratory at the University of Oxford, where she was also appointed Junior Research Fellow at Trinity College. At Oxford, Carla studied ionic liquids and electrolytes under nanoconfinement, in particular, the response of these substances when subjected to electric fields. In January 2020, Carla moved to the London Centre for Nanotechnology with funding from UKRI to set up her own group, to develop new nanomanufacturing technologies based on ionic liquid ion sources. Current research interests include charged particle optics, focused ion beams, material irradiation, and device engineering.

TALK TITLE

Using Ionic Liquids in Nanomanufacturing

Ionic liquids are room temperature molten salts (Figure 1(a)). These substances can be used in nanomanufacturing by using a device known as an Ionic Liquid Ion Source (ILIS). In ILIS, a micro-tip emitter is covered with ionic liquid and subjected to an electric field to trigger ion emission (Figure 1(b)). The resulting beam can be used treat materials. For instance, ILIS have been used to erode silicon, a common microelectronics substrate [1]. The talk will summarise recent efforts in filtering the polydisperse ion beam for tailored treatment [2]. It will also cover the development of optimisation methods for charged particle optics [3], aimed at applying ILIS in Focused Ion Beams (FIB), a technique crucial for nanoscale fabrication and characterisation.

[1] C. Perez-Martinez, et al., J. Vac. Sci. Technol. B 28, L25 (2010).
[2] A. Storey et al., J. Vac. Sci. Technol. B, under review
[3] A. Sabouri and C. Perez-Martinez, Ultramicroscopy, 266, 114024 (2024)

Nandini Trivedi
Ohio State University, United States
Reports on Progress in Physics Board Member

ABOUT THE SPEAKER

Carla Nandini Trivedi is a Professor of Physics and a Distinguished Professor of the College of Arts and Sciences at the Ohio State University. Trivedi got her undergraduate degree from the Indian Institute of Technology, Delhi and a PhD in physics in 1987 from Cornell University. After post-doctoral research at University of Illinois at Urbana-Champaign and State University of New York, Stony Brook, she joined Argonne National Laboratory as a staff scientist. In 1995 she joined the faculty of the Tata Institute of Fundamental Research, Mumbai. Since 2004 she has been a professor of physics at the Ohio State University. Trivedi's research is in understanding emergent phases in quantum matter due to strong correlations and topology.

TALK TITLE

Fractionalized excitations in quantum spin liquids and their detection

The 2022 Nobel prize celebrates the detection of entanglement between two photons. Quantum spin liquids (QSLs) are long-range entangled states of matter of billions of interacting qubits or spins that develop in a Mott insulator. The fate of the interacting spins can progress along two paths as the temperature is lowered: the spins can undergo long range ordering, spontaneously breaking the continuous symmetries, leading to a magnetic phase; or the spins can remain disordered but get quantum mechanically entangled with long range patterns of many-body entanglement in the resultant QSL. The possibility of obtaining QSL phases is enhanced by having a low spin and enhanced quantum fluctuations, and frustration arising from the lattice geometry and/or competing spin-spin interactions. Remarkably QSLs harbour fractionalized excitations rather than the conventional spin waves of ordered magnets that carry integer units of angular momentum. In my talk I will identify detectable signatures of these fractionalized excitations that can potentially be seen in experiments using light and neutrons. I will also discuss the possibility of detecting braiding statistics of fractionalized excitations using pump-probe non-linear time-dependent response.

In collaboration with Shi Feng, Adhip Agarwala, Subhro Bhattacharjee, Kang Wang, Penghao Zhu, Tao Xiang, Xu Yang, Ryan Buechele

[1] Anyon dynamics in field-driven phases of the anisotropic Kitaev model, S. Feng, A. Agarwala, S. Bhattacharjee, N. Trivedi, Phys. Rev. B 108, 035149 (2023)
[2] Fractionalization Signatures in the Dynamics of Quantum Spin Liquids, Kang Wang, Shi Feng, Penghao Zhu, Runze Chi, Hai-Jun Liao, N. Trivedi, and Tao Xiang, arXiv 2403.12141
[3] Emergent Majorana Metal in a Chiral Quantum Spin Liquid, Penghao Zhu, Shi Feng, Kang Wang, Tao Xiang, and N. Trivedi, arXiv:2405.12278

Subir Sachdev
Harvard University,
United States
Reports on Progress in Physics Editor-in-Chief

ABOUT THE SPEAKER

Subir Sachdev is Herchel Smith Professor of Physics at Harvard University. He has been elected to national academies of science in India and the United States, and the Royal Society in the U.K. He is a recipient of several awards, including the Dirac Medal from the International Centre for Theoretical Physics, and the Lars Onsager Prize from the American Physical Society. Sachdev has made extensive contributions to the theory of the diverse varieties of states of quantum matter, and of their behaviour near quantum phase transitions. Many of these contributions have been linked to experiments, especially to the rich phase diagrams of the copper-oxide high temperature superconductors. Sachdev's research has also exposed remarkable connections between the nature of multi-particle quantum entanglement in certain laboratory materials, and the quantum entanglement in astrophysical black holes, and these connections have led to new insights on the entropy and radiation of black holes proposed by Stephen Hawking.

TALK TITLE

From the Sachdev-Ye-Kitaev model to a universal theory of strange metals

The Sachdev-Ye-Kitaev model provides a solvable theory of entangled many-particle quantum states without quasiparticle excitations in zero spatial dimensions. Insights from the SYK model have to led a universal theory of quantum phase transitions in metals in two spatial dimensions in the presence of impurity-induced disorder. This theory successfully describes the strange metal state observed in numerous correlated electron compounds, including the copper-oxide based high temperature superconductors.

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