Symposium United Kingdom as a Guest of Honor (SYUK)

organised by the DPG Condensed Matter Section (SKM)

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The "Guest of Honor" symposia celebrates the European physics community in general and the links in science across Europe. Thereby, the German Physical Society aims to foster collaborations between individual scientists, research groups and institutions.

This year's "Guest of Honor" symposium honors the numerous ties between United Kingdom and Germany (beyond Brexit) by highlighting five fields of common interest. Each is represented by a pair of Invited Talks from distinguished scientist from UK and Germany.

Overview of Invited Talks and Sessions

(Lecture hall H2)

Invited Talks

SYUK 1.1	Wed	9:30–10:00	H2	**Structure and Dynamics of Interfacial Water** — •Angelos Michaelides
SYUK 1.2	Wed	10:00–10:30	H2	**A molecular view of the water interface** — •Mischa Bonn
SYUK 1.3	Wed	10:30–11:00	H2	**Motile cilia waves: creating and responding to flow** — •Pietro Cicuta
SYUK 1.4	Wed	11:00–11:30	H2	**Cilia and flagella: Building blocks of life and a physicist's playground** — •Oliver Bäumchen
SYUK 1.5	Wed	11:45–12:15	H2	**Computational modelling of the physics of rare earth - transition metal permanent magnets from $SmCo_5$ to $Nd_2Fe_{14}B$** — •Julie Staunton
SYUK 2.1	Wed	15:00–15:30	H2	**Hysteresis Design of Magnetic Materials for Efficient Energy Conversion** — •Oliver Gutfleisch
SYUK 2.2	Wed	15:30–16:00	H2	**Non-equilibrium dynamics of many-body quantum systems versus quantum technologies** — •Irene D'Amico
SYUK 2.3	Wed	16:00–16:30	H2	**Quantum computing with trapped ions** — •Ferdinand Schmidt-Kaler
SYUK 2.4	Wed	16:45–17:15	H2	**Breaking the millikelvin barrier in cooling nanoelectronic devices** — •Richard Haley
SYUK 2.5	Wed	17:15–17:45	H2	**Superconducting Quantum Interference Devices for applications at mK temperatures** — •Sebastian Kempf

Sessions

SYUK 1.1–1.5	Wed	9:30–12:15	H2	**United Kingdom as Guest of Honor I**
SYUK 2.1–2.5	Wed	15:00–17:45	H2	**United Kingdom as Guest of Honor II**

SYUK 1: United Kingdom as Guest of Honor I

Time: Wednesday 9:30–12:15 Location: H2

Invited Talk SYUK 1.1 Wed 9:30 H2
Structure and Dynamics of Interfacial Water — •Angelos Michaelides — University of Cambridge, Cambridge, UK

There are few molecules, if any, more important than water. However, remarkably little is known about how it interacts with surfaces, particularly at the molecular level. In this talk I will discuss some of our recent work on the application and development of a variety of state of the art computer simulation methods to better understand the structure and dynamics of water at surfaces and under confinement. Specific topics discussed will include work carried out in collaboration with experimentalists to understand the growth and diffusion of ice clusters at metal surfaces, heterogenous ice nucleation, and water confined within 1- and 2-dimensional membranes. Methodological developments aimed at providing more accurate treatments of adsorption on and bonding within solids will also be covered, as well as an efficient machine learning strategy for simulating complex aqueous interfaces.

Invited Talk SYUK 1.2 Wed 10:00 H2
A molecular view of the water interface — •Mischa Bonn — Max Planck, Mainz, Germany

Water surfaces and interfaces are ubiquitous, not just in nature, but also in many technological applications. Water is a rather unique liquid, owing to its strong intermolecular interactions: strong hydrogen bonds hold water molecules together. At the surface of water, the water hydrogen-bonded network is abruptly interrupted, conferring distinct properties on the interface, compared to bulk. I will present some challenges and progress in the study of interfacial water. Specifically, I will address how to study the ~1 monolayer of water molecules that is in direct contact with the other phase, and distinguish this ~Angstrom-thin layer from the bulk. The question rises how large the interface is. And can we describe the interfacial region as a modified dielectric continuum, or do we need to consider molecular structure?

Invited Talk SYUK 1.3 Wed 10:30 H2
Motile cilia waves: creating and responding to flow — •Pietro Cicuta — University of Cambridge, Cambridge, UK

Motile cilia are active filaments present on the surface of various human organs, where they perform crucial functions by driving surface flows. Structurally, they are conserved across the eukaryotes. Cilia can affect each other, for example leading to phase locking of their beating, by the forces they exert on each other through the fluid and in some cases through the cell cytoskeleton.

Some beautiful physics has been developed by various teams in the last decade to understand how the details of beating on each cilium can lead to specific phase locking, and to the emergence of collective waves. In recent work we have explored the role of external flows, both oscillatory and constant. Analogies can be drawn between these flows and the effect of external magnetic fields in magnetic systems.

We present both experimental results, and numerical explorations of a simple class of "rower" models of motile cilia.

Invited Talk SYUK 1.4 Wed 11:00 H2
Cilia and flagella: Building blocks of life and a physicist's playground — •Oliver Bäumchen — Chair of Experimental Physics V, University of Bayreuth, Bayreuth, Germany

Flagella and cilia are actively beating, hair-like cellular appendages that represent universal building blocks of life. They inherit various essential functions that range from driving fluid flows in the mammalian brain and transporting mucus in the respiratory tract to realizing microbial motility and navigation through complex environments. While large-scale flows are achieved through the coordination of dense ciliary carpets, only a few isolated flagella are needed in order to propel a single-celled microorganism. These flagella displace the surrounding fluid by means of periodic motions, while precisely timed modulations of their beating enable the cell to steer towards or away from specific locations. In this presentation I will focus on the interactions of flagella with interfaces and elucidate how physical principles advance our understanding of microbial motility and emergent phenomena in microbial suspensions. Microorganisms that are equipped with photoreceptors may adapt their flagella beating and also actively switch their flagella-surface interactions in response to light cues. These skills allow photoactive microorganisms to effectively adapt to variable light conditions in their natural habitats and make flagellated microbes a fascinating playground for physicists.

15 min. break

Invited Talk SYUK 1.5 Wed 11:45 H2
Computational modelling of the physics of rare earth - transition metal permanent magnets from $SmCo_5$ to $Nd_2Fe_{14}B$ — •Julie Staunton — University of Warwick, Coventry CV4 7AL, U.K.

Magnetic materials are ubiquitous, technologically indispensable and a deeper understanding of the physics is needed for the design of new permanent magnets. Most strong magnets contain both rare earths (RE) and transition metals (TM) and this talk will describe recently developed *ab initio* modelling of intrinsic properties. Each RE atom has a magnetic moment, set up by its nearly localised f-electrons, immersed in a glue of septillions of valence electrons coming from all the RE and TM atoms. Local magnetic moments associated with the TM atoms also emerge from this complex electron fluid. The magnetic properties stem from the behaviour of the RE and TM local moments, the atomic arrangements and on the overall response to applied fields. *Ab initio* Density Functional Theory-based Disordered Local Moment (DLM-DFT) theory provides a parameter-free, accurate account of the electrons and incorporates the effects of the fluctuating local moments by averaging over them to describe temperature dependent effects. After demonstrating the computational modelling with calculations of the light RE-Co_5 permanent magnet class, the rich and complex behaviour associated with the Fe atoms in $Nd_2Fe_{14}B$ will be described together with its role in determining the hard magnetic properties of this champion magnet.

SYUK 2: United Kingdom as Guest of Honor II

Time: Wednesday 15:00–17:45 Location: H2

Invited Talk SYUK 2.1 Wed 15:00 H2
Hysteresis Design of Magnetic Materials for Efficient Energy Conversion — •Oliver Gutfleisch — TU Darmstadt, Material Science

High performance permanent magnets are key components of energy-related technologies, such as direct drive wind turbines and e-mobility. They are also important in robotics and automatization, sensors, actuators, and information technology. The magnetocaloric effect is the key for new and disruptive solid state-based refrigeration. Magnetic hysteresis and its inherent energy product - characterises the performance of all magnetic materials. Despite considerable progress in the modelling, characterisation and synthesis of magnetic materials, hysteresis is a long-studied phenomenon that is still far from being completely understood. Discrepancies between intrinsic and extrinsic magnetic properties remain an open challenge and magnets do not operate yet at their physical limits. Basic material requirements, figure of merits, demand and supply, criticality of strategic elements are explained for both permanent magnets and magnetocalorics referring to the benchmark materials NdFeB and LaFeSi. The search for perfect defects is driving the material design strategy.

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Invited Talk SYUK 2.2 Wed 15:30 H2
Non-equilibrium dynamics of many-body quantum systems

versus quantum technologies — •Irene D'Amico — University of York, York, UK

Quantum technologies take advantage of properties developed by quantum systems when driven out of equilibrium. For example, quantum computation is based on an accurate, controlled driving of these systems to perform specific dynamics which produce entanglement, compute basic gates, and eventually leads to the completion of a numerical algorithm. Thermal fluctuations are often an enemy which spoils the controlled out-of-equilibrium dynamics. On the other side, quantum thermodynamics takes advantage of thermal - and quantum - fluctuations to create engines and refrigerators of sizes well below the thermodynamic limit and properties still under discussion. In this talk we will first focus on engineering robust properties for distributed quantum computing using spin-networks [1]: here the twist is *not* to drive the out-of-equilibrium dynamics, but let the system Hamiltonian do the job. We will then turn up the temperature, and consider a less-explored aspect of quantum thermodynamics, that is the effects and signatures of many-body interactions on few-electrons' quantum machines [2].

[1] L. Mortimer et al., Adv. Quantum Technologies 4, 2100013 (2021); A. H. Alsulami et al., arXiv:2202.02632

[2] K. Zawadzki et al., Phys. Rev. Research 2,033167 (2020); M. Herrera et al. Phys. Rev. Lett. 127, 030602 (2021); G. A. Canella et al., preprint (2022)

Invited Talk SYUK 2.3 Wed 16:00 H2

Quantum computing with trapped ions — •Ferdinand Schmidt-Kaler — QUANTUM, Uni Mainz

Quantum technologies allow for fully novel schemes of hybrid computing. We employ modern segmented ion traps. I will sketch architectures, the required trap technologies and fabrication methods, control electronics for quantum register reconfigurations, and recent improvements of qubit coherence and gate performance. Currently gate fidelities of 99.995% (single bit) and 99.8% (two bit) are reached. We are implementing a reconfigurable qubit register and have realized multi-qubit entanglement [1] and fault-tolerant syndrome readout [2] in view for topological quantum error correction [3], since current aim is to leave the noisy area of quantum computing. Complementary to gate tomography, we employ thermodynamically-inspired methods within the frameworks of global passivity and passivity deformation where system qubits undergoing unitary evolution but may optionally be coupled also to an unobserved environment qubit, resulting in a heat leak [4].

[1] Kaufmann er al, Phys. Rev. Lett. 119, 150503 (2017) [2] J. Hilder, et al., Phys. Rev. X.12.011032 (2022) [3] Bermudez, et al, Phys. Rev. X 7, 041061 (2017) [4] D. Pijn, et al., Phys. Rev. Lett. 128 110601 (2022)

15 min. break

Invited Talk SYUK 2.4 Wed 16:45 H2

Breaking the millikelvin barrier in cooling nanoelectronic devices — •Richard Haley — Physics Department, University of Lancaster, Lancaster LA1 4YB, UK

Over the last several years a number of groups across Europe have been developing techniques to cool the electrons in nano-fabricated devices to sub-mK temperatures. Cooling device electrons into the microkelvin regime, below the canonical limit of around 10 millikelvin, enhances sensitivity for observing known and new physical phenomena, and improves the performance of quantum technologies, sensors and metrological standards.

There are two main challenges. First, one must provide a technique which will deliver electron temperatures colder than a dilution refrigerator and which is relatively easy to implement. Currently the microkelvin regime is really only accessible in specially dedicated labs. Second, one must understand the thermal links between the microkelvin cooling platform and the electrons in the device of interest, bearing in mind that nanoscale systems are typically also more susceptible to nuisance heating than bulk materials. Progress has been made with three methods and combinations thereof: immersion cooling in liquid helium; demagnetisation cooling of electrical leads and contacts; and the demagnetisation of material deposited directly onto device chips.

Here we review the current state-of-the-art in cooling nanoelectronic devices, and ways to make the techniques easier to adapt and adopt.

Invited Talk SYUK 2.5 Wed 17:15 H2

Superconducting Quantum Interference Devices for applications at mK temperatures — •Sebastian Kempf — Institute of Micro- and Nanoelectronic Systems, Karlsruhe Institute of Technology, Hertzstraße 16, 76187 Karlsruhe, Germany.

Superconducting quantum interference devices (SQUIDs) are among the most sensitive wideband devices for measuring any quantity that can be naturally converted into magnetic flux. They are intrinsically compatible with Kelvin and sub-Kelvin operation temperatures, offer great sensitivity to even tiniest signals and often show a noise level close to the quantum limit. For this reason, SQUIDs are routinely used for various applications such as investigating magnetic nanoparticles, diagnostics in health care, "non-invasive" mineral deposit exploration, low-field magnetic resonance imaging, quantum information processing or the readout of low-impedance cryogenic particle detectors. However, SQUID based measurements are susceptible to suffer from parasitic Joule heating, often preventing to reach very low sub-K temperatures.

Using the example of cryogenic low-impedance detectors, we discuss strategies to minimize parasitic SQUID Joule heating to ultimately operate single-channel detectors as well as mid- and large-scale detector arrays at lowest mK temperatures. We particularly show that on-chip thermal decoupling of shunt resistors and sample environment or dispersive SQUID readout allow for performing SQUID based measurements down to very low temperatures. Moreover, we discuss a SQUID based multiplexer allowing for simultaneous readout of hundreds and thousands of signal sources with only several nW of power.