MA 17: PhD Focus Session: The Hitchhiker's Guide to Spin Phenomena at the Space and Time Limit

The growing hunger of society for fast data storage and processing, together with the end of Moore's law, demand the development of new technologies to implement smaller, faster and more power-efficient devices. Research in magnetic materials has shown the potential of spin-based devices in this regard. Pushing for 'More than Moore' devices, space and time limits need to be tackled. At the heart of this research are three fundamental operations: Control of magnetic order, spin transport and efficient monitoring of spin angular momentum in space and time. Topical clusters ranging from ferro- to antiferromagnets up to 2D materials, magnetic-organic interfaces and heterostructures are extensively studied. New materials and concepts are being developed rapidly which can appear very complex to someone new to the field. Young researchers often manage to get an overview of their own specific field but lack the big picture. For this reason, this PhD symposium will focus on talks in mostly tutorial-like style, yet will also include recent highlights. In addition, the symposium aims to exchange ideas and foster discussions on a broad range of spin phenomena. Organizers: Yannic Behovits (Physics, Freie Universität Berlin and Fritz Haber Institute of the MPS), Mona Bhukta (Physics, Johannes Gutenberg University Mainz), Bikash Das Mohapatra (Physik, Martin-Luther-Universität Halle-Wittenberg), Oliver Gueckstock (Physics, Freie Universität Berlin and Fritz Haber Institute of the MPS), Hendrik Meer (Physics, Johannes Gutenberg University Mainz), Maximilian Paleschke (Physik, Martin-Luther-Universität Halle-Wittenberg), Eva S. Walther (Physics, Technische Universität Kaiserslautern).

Time: Tuesday 15:00–17:00 Location: H43

Invited Talk MA 17.1 Tue 15:00 H43

Ultimately fast, small and energy-efficient magnetism: fundamentals and prospects — •Johan Mentink — Radboud University, Nijmegen, The Netherlands

Findings ways to switch between magnetically ordered states at the smallest possible length and time scale, while simultaneously dissipating the least amount of energy is a major challenge in magnetism. One of the most appealing routes to achieve this goal is by bringing a magnetic system strongly out of equilibrium, after which the dynamics is driven by exchange interaction, the strongest force in magnetism. Although this has been extensively discussed in ferrimagnetic systems, harnessing such exchange-driven dynamics in ferromagnets is fundamentally limited by angular momentum conservation. We will discuss basic models of magnetism that can be solved even under strongly nonequilibrium conditions and have been key to identify the mechanisms for ultrafast switching. We will exemplify this for chiral ferromagnets as studied by recent XFEL experiments. For this case, the nonequilibrium dynamics is driven by an additional antisymmetric exchange interaction, resulting in ultrafast nucleation of nanoscale magnetic skyrmions. This opens a new path for switching that is not only fast, but also can operate at the nanoscale. By comparing with the fundamental energy-speed limits for switching between physically distinct states, we will argue that such exchange-driven dynamics can be key to achieve even faster, smaller and much more energy-efficient switching than demonstrated so far.

Invited Talk MA 17.2 Tue 15:30 H43

From spintronics at limiting temporal and spatial scales in antiferromagnets to an emerging altermagnetic phase — •Tomas Jungwirth — Institute of Physics, Czech Academy of Sciences and University of Nottingham, UK

Magnetically ordered crystals are traditionally divided into two basic phases – ferromagnetism and antiferromagnetism. In the first part of the talk, we will recall that the ferromagnetic order offers a range of phenomena and existing device applications, while the vanishing net magnetization in antiferromagnets is potentially favorable for temporal and spatial scalability of spintronic devices. In the second part of the talk we will move on to the recent predictions of instances of strong time-reversal symmetry breaking and spin splitting in electronic bands, typical of ferromagnetism, in crystals with antiparallel compensated magnetic order, typical of antiferromagnetism. This apparent fundamental conflict in magnetism is resolved by symmetry considerations that allow us to classify and describe a third basic magnetic phase. Its alternating spin polarizations in both crystal-structure real space and electronic-structure momentum space suggest a term altermagnetism. We will demonstrate that altermagnets combine merits of ferromagnets and antiferromagnets, that were regarded as principally incompatible, and have merits unparalleled in either of the two traditional basic magnetic phases. We will show that they underpin a development of a new avenue in spintronics based on strong non-relativistic spin-conserving phenomena, without magnetization imposed scalability limitations, and with complex logic-in-memory functionalities.

Invited Talk MA 17.3 Tue 16:00 H43

An electronic structure viewpoint on candidate van der Waals ferromagnets — •Phil King[1], Matt Watson[1], Brendan Edwards[1], Akhil Rajan[1], Jiagui Feng[1], Deep Biswas[1], Monica Ciomaga Hatnean[2], Amelia Hall[2], Geetha Balakrishnan[2], Giovani Vinai[3], David Burn[4], Thorsten Hesjedal[5], Gerrit van der Laan[4], Oliver Dowinton[6], and Saeed Bahramy[6] — [1]Univ. St Andrews — [2]Univ. Warwick — [3]Elettra synchrotron — [4]Diamond Light Source — [5]Univ. Oxford — [6]Univ. Manchester

Control over materials thickness down to the single-atom scale has emerged as a powerful tuning parameter for manipulating both single-particle band structures and collective states of solids. Magnetism is a new frontier in the study of 2d materials. Here, I will show how direct measurement of the electronic structure using angle- resolved photoemission (ARPES) can lead to valuable insight not only into whether a 2d material exhibits long-range magnetic order, but also on its microscopic mechanisms. I will consider monolayer VSe_2, where a putative magnetic order is destabilised by the formation of a robust charge density wave,[1,2] but can be re-established via proximity coupling;[3] $V_{1/3}NbS_2$, where proximity coupling to the surface layer can lead to a modulation of spin-valley locking, and $CrGeTe_3$, an established van der Waals ferromagnet, where band structure measurements provide important microscopic insights even in a local moment system.[4] [1]Rajan et al., Phys. Rev. Materials 4 (2020) 014003; [2]Feng et al., Nano Lett. 18 (2018) 4493; [3]Vinai et al., Phys. Rev. B 101 (2020) 035404 ; [4]Watson et al., Phys. Rev. B 101 (2020) 205125.

Invited Talk MA 17.4 Tue 16:30 H43

Nano-scale skyrmions and atomic-scale spin textures studied with STM — •Kirsten von Bergmann — Department of Physics, University of Hamburg, Germany

Non-collinear magnetic order arises due to the competition of different magnetic interactions. Often the dominant interaction is the isotropic pair-wise exchange between neighboring atomic magnetic moments. An additional sizable contribution from anisotropic exchange (Dzyaloshinskii-Moriya-Interaction) typically leads to spin spiral ground states in the absence of magnetic fields. In applied magnetic fields such systems can transition into skyrmion lattices or isolated skyrmions with diameters down to a few nanometers.

In zero magnetic field single skyrmions can arise as metastable states, stabilized by frustrated exchange interactions, which originate from competing non-negligible exchange interaction to more distant magnetic moments [1]. Periodic two-dimensionally modulated magnetic states on the atomic scale can arise due to higher-order magnetic interactions. Such higher-order interactions can favor superpositions of

spin spirals, so called multi-q states. Depending on the sample system atomic scale non-collinear magnetic lattices of different symmetry and size can form [2]. Higher-order interactions can also determine the type and width of domain walls in antiferromagnets [3].

[1] S. Meyer et al., Nature Commun. 10, 3823 (2019).
[2] M. Gutzeit et al., arXiv:2204.01358.
[3] J. Spethmann et al., Nature Commun. 12, 3488 (2021).