MA 41: Focus Session: Altermagnetism: Transport, Optics, Excitations

While antiferromagnetic spintronics is an established research field, key spintronic functionalities such as giant/tunneling magnetoresistance (GMR/TMR), have remained elusive in compensated magnetic systems. This paradigm could change in the light of the recent theoretical discovery of a new class of magnetic materials so called altermagnets which feature alternating spin polarizations in both crystal-structure real space and electronic-structure momentum space. Despite the vanishing net magnetization and antiparallel spin arrangement, altermagnets were predicted to exhibit a robust anomalous Hall effect and GMR and spin transfer torque phenomena. The predictions have been already supported by initial experiments. The goal of this focus session is to introduce the concept of altermagnetism to the broad research community, to present the first experimental works and stimulate future research directions. Here, altermagnets are predicted to have a broad impact beyond spin-electronics in fields ranging from magneto-transport, ultra-fast photo-magnetism to superconductivity and magnetic topological matter. The Focus Session is organized by Dr. Matthias Althammer (Walther-Meißner-Institut, Garching), Prof. Sebastian Goennenwein (Uni Konstanz) and Dr. Andy Thomas (IFW Dresden).

Time: Thursday 15:00–18:00 Location: HSZ 02

Invited Talk MA 41.1 Thu 15:00 HSZ 02

Altermagnetism and spin symmetries — •Libor Šmejkal — Johannes Gutenberg Universitat Mainz, Germany — Institute of Physics, Czech Academy of Sciences, Prague, Czech Republic

Different phases of matter can be distinguished by symmetries and order parameters. In this talk, we will discuss the classification of magnetically ordered crystals according to recently studied spin symmetries [1]. Spin symmetries consider pairs of operations in spin and crystal space and remarkably reveal an unconventional magnetic class. This unconventional class, called altermagnetism, is sharply distinct from ferromagnets and antiferromagnets. It is characterized by an unconventional alternating spin order in electronic momentum space that breaks time-reversal symmetry and is spin compensated and anisotropic [1,2]. We show that these properties can arise from ordered and anisotropic spin densities and crystal fields, as described for a typical Ruthenium Dioxide altermagnet [1-4]. Finally, we show that altermagnetism provides a unifying explanation for the recently predicted and experimentally observed unconventional anomalous Hall effects in collinear systems without magnetisation [2,3,5 and references therein].

[1] Šmejkal, L., Sinova, J., and Jungwirth, T., Phys. Rev. X 12, 031042 (2022), [2] Šmejkal, L. et al., Science Advances 6, eaaz8809 (2020) [3] Feng, Z., et al. Nature Electron. 5, 735-743 (2022) [4] Šmejkal, L. et al., Phys. Rev. X 12, 011028 (2022) [5] Mazin, I.I et al., PNAS 118 (42) e2108924118 (2021)

Invited Talk MA 41.2 Thu 15:30 HSZ 02

Spontaneous Hall effect in Mn5Si3 altermagnet — •H. Reichlova[1,2], R. Lopes Seeger[3], R. González-Hernández[4], I. Kouta[6], R. Schlitz[1], D. Kriegner[2], P. Ritzinger[2], M. Lammel[9], M. Leiviska[3], V. Petricek[2], E. Schmoranzerova[7], A. Badura[2], A. Thomas[1,8], V. Baltz[3], L. Michez[6], J. Sinova[5,2], S.T.B. Goennenwein[9], T. Jungwirth[2,10], and L. Smejkal[5,2] — [1]IFMP, Technische Universität Dresden — [2]Institute of Physics CAS, Czech Republic — [3]CNRS, CEA, Grenoble, France — [4]Universidad del Norte, Barranquilla, Colombia — [5]Johannes Gutenberg Universität Mainz — [6]CINaM, Marseille, France — [7]MFF Charles University, Praha, Czech Republic — [8]IFW Dresden — [9]Universität Konstanz — [10]University of Nottingham, United Kingdom

The family of materials that can exhibit spontaneous Hall effect has been significantly expanded by discovery of altermagnets with opposite spin sublattices coupled by crystallographic rotations [1]

I present our observations of the spontaneous Hall effect in an altermagnetic candidate - Mn5Si3 epilayers [2]. Epitaxial constraints stabilize a hexagonal unit cell in the magnetic state distinct from previously described phases in bulk crystals and we observe a sizable spontaneous Hall conductivity. The signal can be explained by an unprecedented altermagnetic band structure with time-reversal symmetry breaking spin-polarized valleys.

[1] Smejkal et al. Science Advances 6, 23 (2020) [2] Reichlova H. et al., arXiv:2012.15651

MA 41.3 Thu 16:00 HSZ 02

Spin-split collinear antiferromagnets: a large-scale ab-initio study — •Yaqian Guo[1], Hui Liu[1,2], Oleg Janson[1], Ion Cosma Fulga[1,2], Jeroen van den Brink[1,2], and Jorge I. Facio[1,3,4] — [1]Leibniz Institute for Solid State and Materials Research, Germany — [2]Würzburg-Dresden Cluster of Excellence ct.qmat, Technische Universität Dresden, Germany — [3]Centro Atómico Bariloche and Instituto Balseiro, Argentina — [4]Instituto de Nanociencia y Nanotecnología CNEA-CONICET, Argentina

It was recently discovered that, depending on their symmetries, collinear antiferromagnets can break the spin degeneracy in momentum space, even in the absence of spin-orbit coupling. Such systems are signalled by the emergence of a spin-momentum texture set mainly by the crystal and magnetic structure, relativistic effects playing a secondary role. Here we consider all collinear q=0 antiferromagnetic compounds in the MAGNDATA database allowing for spin-split bands. Based on density-functional calculations for the experimentally reported crystal and magnetic structures, we study more than sixty compounds and introduce numerical measures for the average momentum-space spin splitting. We highlight some compounds that are of particular interest, either due to a relatively large spin splitting, such as CoF_2 and $FeSO_4F$, or because of their low-energy electronic structure. The latter include $LiFe_2F_6$, which hosts nearly flat spin-split bands next to the Fermi energy, as well as RuO_2, $CrNb_4S_8$, and CrSb, which are metals.

MA 41.4 Thu 16:15 HSZ 02

Giant magnetoresistance effects in altermagnets — •Anna Birk Hellenes[1], Rafael González-Hernández[2], Jairo Sinova[1,3], Tomas Jungwirth[3,4], and Libor Šmejkal[1,3] — [1]Johannes Gutenberg Universität Mainz, Germany — [2]Universidad del Norte, Barranquilla, Colombia — [3]Czech Academy of Sciences, Prague, Czech Republic — [4]University of Nottingham, United Kingdom

Commercial spintronics devices using magnetoresistance effects rely on spin currents in ferromagnets, generated by a time-reversal symmetry broken band structure. To realise a counterpart effect with all-antiferromagnetic electrodes has remained experimentally elusive, as the combined time-reversal symmetry with translation or inversion in antiferromagnets prohibits nonrelativistic spin polarisation. Recently, a third fundamental magnetic order was discovered, which exhibits exclusively different spin symmetries from ferromagnets and antiferromagnets[1]. In these altermagnets, the spin polarisation forms d,g, or i-wave compensated spin order in momentum space which breaks time-reversal symmetry. Hence, altermagnetism provides a unifying explanation for our recently predicted giant TMR and GMR effects[2,3]. In the present contribution, we describe the symmetry requirements that lead to distinct spin polarisations such as the d-wave type, and illustrate the GMR and TMR mechanism with tight-binding models and in the candidate materials RuO_2 and Mn_5Si_3. [1] L. Šmejkal et al., Phys. Rev. X 12, 031042, 2022. [2] L. Šmejkal, A. B. Hellenes et al., Phys. Rev. X 12, 011028, 2022. [3] H. Reichlova et al., arXiv:2012.15651v2.

Invited Talk MA 41.5 Thu 16:30 HSZ 02

Generation of tilted spin-current by the collinear antiferromagnet RuO2 — •Arnab Bose — Johannes Gutenberg Universität, Mainz, Germany

Recently a new type of magnetic material is theoretically proposed, referred to as *altermagnet* which is a collinear antiferromagnet in real space although hosting the spin-split bands in the momentum space that allows it to exhibit the properties of ferromagnet depending upon the direction of the current flow with respect to the crystal axis [1,2]. We report the first experimental evidence of strongly crystal axis-dependent unconventional transverse spin-current generation by the altermagnet RuO2 [3] arising from the novel spin-split bands as theoretically predicted [1]. This unconventional tilted spin-current is the key to the implementation of high-density nonvolatile magnetic memories.

[1] R. González-Hernández et. al. Phys. Rev. Lett. 126, 127701 (2021) [2] L. Šmejkal et. al. arXiv: 2204.10844 (2022) [3] A. Bose et. al. Nature Electronics 5, 267 (2022).

Invited Talk MA 41.6 Thu 17:00 HSZ 02

First-principles studies on the anomalous transport properties of ferromagnets, antiferromagnets, and altermagnets — •Wanxiang Feng — School of Physics, Beijing Institute of Technology, Beijing 100081, China

Magnetic topological semimetals bring new vitality to the ideas evolving around the next generation of dissipationless spintronic devices benefiting from their exotic anomalous and spin transport properties. I shall first show that ferromagnetic $M\mathrm{F}_3$ (M = Pd, Mn) are high-quality nodal chain spin-gapless topological semimetals with 100% spin-polarized transport properties. The dominant intrinsic origin is found to originate entirely from the gapped nodal chains without the entanglement of any other trivial bands. The side-jump mechanism is predicted to be negligibly small, but the skew scattering enhances the intrinsic Hall and Nernst signals significantly. Second, I shall present the spin-chirality-dependent anomalous Hall and Nernst effects in coplanar noncollinear antiferromagnets $\mathrm{Mn}_3X\mathrm{N}$ (X = Ga, Zn, Ag, and Ni) as well as the topological magneto-optical effects and their quantization in noncoplanar antiferromagnets γ-$\mathrm{Fe}_x\mathrm{Mn}_{1-x}$ and $\mathrm{K}_{0.5}\mathrm{RhO}_2$. Beyond ferromagnetism and antiferromagnetism, altermagnetism is recently discovered to be the third essential magnetic phase. Room-temperature metallic RuO_2 is a typical altermagnet, in which the rearrangement of nonmagnetic atoms induces crystal chirality playing a critical role in anomalous transport properties. Finally, I will discuss the crystal-chirality-dependent anomalous Nernst, anomalous thermal Hall, and magneto-optical effects in RuO_2.

Invited Talk MA 41.7 Thu 17:30 HSZ 02

Insight into chemical and magnetotransport properties of epitaxial α-Fe2O3/Pt bilayers — •Anna Kozioł-Rachwał[1], Natalia Kwiatek[2], Witold Skowroński[3], Krzysztof Grochot[3], Jarosław Kanak[3], Ewa Madej[2], Kinga Freindl[2], Józef Korecki[2], and Nika Spiridis[2] — [1]Faculty of Physics and Applied Computer Science, AGH University of Science and Technology, Mickiewicza 30, 30-059 Kraków, Poland — [2]Jerzy Haber Institute of Catalysis and Surface Chemistry, Polish Academy of Sciences, 30-239 Kraków, Poland — [3]Institute of Electronics, AGH University of Science and Technology, Mickiewicza 30, 30-059 Kraków, Poland

Recently a spin Hall magnetoresistance (SMR) was presented for Pt/α-Fe2O3(hematite) bilayer.[1],[2] In our studies we investigated the chemical structure and SMR in epitaxial α-Fe2O3(0001)/Pt(111) bilayers with hematite layers grown by molecular beam epitaxy on a MgO(111) substrate.[3] We observed a sign change of the SMR from positive to negative when the thickness of the hematite increased from 6 to 15 nm. For α-Fe2O3(15 nm)/Pt, we demonstrated room-temperature switching of the Néel order with rectangular, nondecaying switching characteristics. Such structures open the way to extending magnetotransport studies to more complex systems with double asymmetric metal/hematite/Pt interfaces. [1] J. Fischer et al. Phys. Rev. Applied 13, 014019 (2020). [2] Y. Cheng et al. Phys. Rev. Lett. 124, 027202 (2020). [3] A. Kozioł-Rachwał et al., Phys. Rev. B 106, 104419 (2022).