MA 13: Altermagnets II

Time: Tuesday 9:30–13:00 Location: H20

MA 13.1 Tue 9:30 H20

Dynamics of the altermagnetic candidate compound UCr_2Si_2C — Nikolaos Biniskos[1], •Manuel dos Santos Dias[2], Karin Schmalzl[3], Andrea Piovano[4], Ursula Bengaard Hansen[4], Michal Vališka[1], and Petr Čermák[1] — [1]Department of Condensed Matter Physics, Charles University, Praha, Czech Republic — [2]Scientific Computing Department, STFC Daresbury Laboratory, United Kingdom — [3]Jülich Centre for Neutron Science at ILL, Forschungszentrum Jülich, Grenoble, France — [4]Institut Laue-Langevin, Grenoble, France

Altermagnets are collinear antiferromagnets where spin degeneracy of the electronic bands or degeneracy of the magnon bands is not enforced by symmetry, potentially enabling diverse physical phenomena. However, it remains challenging to find materials that experimentally exhibit the hallmarks of altermagnetism. UCr_2Si_2C has been recently reported as a high-temperature antiferromagnet with a rare crystal structure that is compatible with altermagnetism [1]. This talk will report on our combined experimental and theoretical investigation of this compound. A large single crystal was successfully grown and experimentally investigated with bulk specific heat and magnetic susceptibility measurements, and through unpolarized and polarized inelastic neutron scattering. These experimental results have been interpreted with density functional theory calculations, providing a unified picture of UCr_2Si_2C and of its prospects as an altermagnet.

[1] Lemoine et al., Inorg. Chem. **57**, 2546-2557 (2018)

MA 13.2 Tue 9:45 H20

Theory of circular dichroism in resonant photoelectron diffraction of altermagnets — •Peter Krüger — Materials Science Dpt, Chiba University, Chiba 263-8522 Japan

Recently we have developed a computational method for resonant photoelectron diffraction (RPED) and its circular dichroism (CD) of magnetic surfaces, by combining ligand field multiplet and multiple scattering theory. The method was successfully tested for ferromagnetic Ni(111) [Phys. Rev. B 107, 075407 (2023)]. Here I apply the new method to the altermagnet MnTe. For a photon energy at the Mn L3-edge resonance and light incidence parallel to the magnetization axis, I show that there is a large, purely magnetic CD signal at the forward focusing peaks of the RPED pattern. This CD signal provides a direct probe of the staggered magnetization in altermagnets, which is closely related to the X-ray magnetic circular dichroism observed in ferromagnets.

MA 13.3 Tue 10:00 H20

New altermagnetic material candidates showing 4*f*-magnetism — •Franziska Walther[1], Johannes Fey[1], Michelle Ocker[1], Libor Šmejkal[2,3], Cornelius Krellner[1], and Kristin Kliemt[1] — [1]Physikalisches Institut, Goethe-Universität 60438 Frankfurt/Main — [2]Max Planck Institut für Physik komplexer Systeme, Nöthnitzer Str. 38, 01187 Dresden — [3]Institut für Physik, Johannes Gutenberg Universität Mainz, 55099 Mainz

Altermagnets are a novel class of collinear magnetic materials, which are characterised by a vanishing net magnetization while breaking the time-reversal symmetry in the electronic band structure with a unique alternating spin-momentum locking [1]. So far, altermagnetism has been proven for magnetic 3*d*-systems such as CrSb [2], MnTe [3] and Mn_5Si_3 [4] by the time-reversal breaking signature in the band structure or the observation of the anomalous Hall effect. In order to study the altermagnetism arising from local 4*f* moments, we have grown single crystals of lanthanoid-based intermetallic compounds and characterised their physical and chemical properties. We report on the crystal growth and measurements of magnetism, heat capacity and resistivity of the altermagnetic candidates.

[1] L. Šmejkal et al., Phys. Rev. X 12, 031042 (2022)
[2] S. Reimers et al., Nat. Commun. 15, 2116 (2024)
[3] J. Krempaský et al., Nature 626, 517 (2024)
[4] H. Reichlova et al., Nat. Commun. 15, 4961 (2024)

MA 13.4 Tue 10:15 H20

Altermagnetic properties of hematite. — •Edgar Galindez-Ruales[1], Rafael Gonzales-Hernandez[1,2], Gerhard Jakob[1], and Mathias Kläui[1] — [1]Institute of Physics, Johannes Gutenberg University Mainz, Staudingerweg 7, 55128 Mainz, Germany. — [2]Grupo de Investigacíon en Física Aplicada, Departamento de Física,Universidad del Norte, Barranquilla, Colombia.

Hematite, a prototypical antiferromagnet, has emerged as a promising altermagnet due to its unique magnetic and electronic properties[1]. Unlike conventional antiferromagnets, altermagnets exhibit a nonzero anomalous Hall effect (AHE) due to symmetry-breaking electronic structures despite having no net magnetization. In hematite, we observe anisotropic magnetotransport with a strong crystal orientation dependence, including a striking sign inversion in the Hall effect[2]. Using advanced XMCD and XMLD imaging, we directly visualize and distinguish 180° domains, confirming the interplay between collinear antiferromagnetism and non-centrosymmetric atomic arrangements that drive the altermagnetic behavior. These findings provide robust experimental evidence of hematite*s altermagnetic nature, offering new mechanisms for identifying altermagnetic candidates and establishing hematite as a model system for exploring altermagnetic phenomena. This work paves the way for utilizing altermagnetic materials in spintronic applications, revolutionizing our understanding of magnetic material classification and transport phenomena. [1] L. Šmejkal et al., PRX 12, 040501 (2022). [2] E. Galindez-Ruales et al., ArXiv:2310.16907 (2023).

MA 13.5 Tue 10:30 H20

Ferro-spinetic altermagnetic insulators from electronic correlations — •Toshihiro Sato[1,2], Ion Cosma Fulga[1,2], Fakher F. Assaad[3,2], and Jeroen van den Brink[1,2] — [1]Institute for Theoretical Solid State Physics, IFW Dresden, Germany — [2]Würzburg-Dresden Cluster of Excellence ct.qmat, Germany — [3]Institut für Theoretische Physik und Astrophysik, Universität Würzburg, Germany

While altermagnets are a class of fully compensated antiferromagnets lacking combined time-reversal and translational symmetry, their symmetry allows for unique polarization phenomena when inversion symmetry is broken. In this talk, we introduce an interacting fermion model with emergent ferro-spinetic polarizations in altermagnetic insulators - a spin analog to ferroelectricity. This model is grounded in a two-dimensional Hubbard framework incorporating inversion symmetry-breaking elements. Quantum Monte Carlo simulations demonstrate an altermagnetically ordered state with broken inversion symmetry driven by electron correlations, where spin-up and spin-down polarizations accumulate on opposite edges, with their directions reversibly controlled by the inversion symmetry-breaking factor. While the system retains electron-hole symmetry, resulting in zero ferroelectric charge polarization, breaking this symmetry induces the charge polarization orthogonal to the spin polarization.

MA 13.6 Tue 10:45 H20

Interplay of composition and magnetic properties in VxNbS2: An Altermagnetic candidate — •Sunil Wilfred Dsouza and Jan Minár — New Technologies Research Centre, University of West Bohemia, Univerzitní 8, CZ-306 14 Pilsen, Czech Republic

We investigate the interplay of chemical composition and electronic structure with respect to V atoms in an altermagnetic candidate VxNbS2 in the magnetically ordered state. The results from the first-principles calculations employing coherent potential approximation demonstrate that the electronic band structure exhibits valley-spin splitting induced by bulk magnetic order, which is only slightly affected by disorder and deficiency of V atoms, but an impact on the magnetic exchange coupling can be inferred. The results are interesting for the research on 3d-metal inserted transition-metal dichalcogenides and in a broader context for the understanding and design of Altermagnet-based spintronic materials.

MA 13.7 Tue 11:00 H20

Spin-transfer and topological Hall physics in d-wave altermagnets — •Ricardo Zarzuela — Johannes Gutenberg Universität Mainz, Mainz, Germany

Altermagnets, a novel magnetic phase of matter exhibiting zero net magnetization, anisotropic spin-split isoenergy surfaces and time reversal-symmetry-broken momentum-dependent spin splittings in the

electronic band structure, have gained enormous momentum in the recent years due to their potential usage as active elements in Terahertz spintronic-based technologies [1]. In this talk, I will introduce an effective long-wavelength theory for charge carriers flowing within a d-wave altermagnet, from which the spin-splitter effect can be inferred as well as an unconventional spin-transfer response of the electron fluid. Reciprocally, the presence of altermagnetic textures induces the deflection of the electron trajectories. In this regard, I will also discuss how the d-wave nature of the altermagnet yields unconventional features to the topological Hall conductivity, which can be observed experimentally.

[1] L. Šmejkal, J. Sinova and T. Jungwirth, Phys. Rev. X 12, 031042 (2022); ibid. 040501 (2022).

15 min. break

MA 13.8 Tue 11:30 H20

Crystal structure and absence of magnetic order in single crystalline RuO_2 — •Lara Kiefer[1], Felix Wirth[1], Alexandre Bertin[1], Petra Becker[2], Ladislav Bohatý[2], Karin Schmalzl[3], Anne Stunault[4], José Alberto Rodríguez-Velemazan[4], Oscar Fabelo[4], and Markus Braden[1] — [1]II. Physic. Inst., Univ. Cologne, Germany — [2]Inst. Geology a. Mineralogie, Univ. Cologne, Germany — [3]Fz Jülich, Grenoble, France — [4]ILL, Grenoble, France

The recent report of antiferromagnetic order above room temperature in RuO_2 and its identification as an altermagnetic state boosted research on the material [1,2]. However, muon and neutron experiments, along with DFT calculations, recently questioned the existence of magnetic order in RuO_2 and suggested that it only occurs in the presence of vacancies [3-4]. We conducted polarized and unpolarized neutron diffraction experiments on RuO_2 crystals, which were characterized by magnetization, EDX, electrical conductance, and XRD measurements [5]. We did not confirm the proposed structural distortion in our crystals down to 2K. Ruthenium vacancies were below a few percent in our crystals. Polarized neutron experiments did not show magnetic Bragg reflections for the proposed $\vec{k}$=(0,0,0) [2]. Even a smaller ordered moment would have yielded significant intensities. Thus, this antiferromagnetic order is ruled out in our stoichiometric crystals [5].
[1] L. Ŝmejkal *et al.*, 2022, Phys. Rev. X **12(3)**, 031042.[2] T. Berjilin *et al.*, 2017, Phys. Rev. Lett. **118**, 077201.[3] A. Smolyanyuk *et al.*, 2024, Phys. Rev. B. **109**, 134424. [4] P. Keßler *et al.*, 2024, npj Spintronics **2**, 50. [5] L. Kiefer *et al.*, 2024, arXiv, 2410.05850.

MA 13.9 Tue 11:45 H20

Ferroelectric Switchable Altermagnetism — Mingqiang Gu[1], Yuntian Liu[1], Haiyuan Zhu[1], Kunihiro Yananose[2], Xiaobing Chen[1], Yongkang Hu[1], •Alessandro Stroppa[3], and Qihang Liu[1] — [1]Department of Physics and Guangdong Basic Research Center of Excellence for Quantum Science, Southern University of Science and Technology, Shenzhen 518055, China — [2]Korea Institute for Advanced Study, Seoul 02455, Republic of Korea — [3]CNR-SPIN - Via Vetoio - 67100 - Coppito (AQ), Italy.

We propose a novel ferroelectric switchable altermagnetism effect, by synergistically correlating the switching of ferroelectric polarization and the altermagnetic spin splitting. We demonstrate the design principles for the ferroelectric altermagnets and the further symmetry constraints for switching the altermagnetic spin splitting through flipping the electric polarization based on the state-of-the-art spin-group symmetry techniques. 22 ferroelectric altermagnets are found by screening through the 2001 experimental reported magnetic structures in the MAGNDATA database and 2 of them are identified as ferroelectric switchable altermagnets. Using the hybrid improper ferroelectric material [C(NH2)3]Cr(HCOO)3 as an example, we show how the altermagnetic spin splitting is tightly coupled to the ferroelectric polarization, providing an ideal platform for designing electric-field-controllable multiferroic devices. Finally, we find that such manipulation of altermagnetism can be detected by monitoring the physical quantities that are related to the non-vanishing Berry curvature dipole, such as the linearly polarized photogalvanic spin current.

MA 13.10 Tue 12:00 H20

Growth and properties of sputter-deposited altermagnetic RuO_2 thin films — •Maik Gaerner, Martin Wortmann, Judith Bünte, Inga Ennen, Andreas Hütten, Jan Schmalhorst, Timo Kuschel, and Günter Reiss — Bielefeld University, Germany

Altermagnetic materials exhibit time-reversal symmetry breaking and non-relativistic, anisotropic spin splitting in their bandstructure. RuO_2 is widely regarded as such an altermagnetic material, since e.g. spin-torque generation in RuO_2 has been observed [1]. However, muon spin rotation experiments [2] and density functional theory calculations [3] hint at the fragility of the magnetic order in RuO_2.

Here, we report on the growth and characterisation of RuO_2 thin films, deposited on MgF_2-, TiO_2- and MgO-substrates using reactive magnetron sputtering. In contrast to MgF_2-substrates, the lattice mismatch between the commonly used TiO_2-substrates and RuO_2 induces a significant strain on the RuO_2 which can enhance the density of states near the Fermi level [4]. We compare the crystallographic and electronic transport properties of the RuO_2 films, deposited at varying growth conditions and on the different substrates, with regard to the detection of the altermagnetic phase.

[1] Bose et al., Nat. Electron. 5, 267 (2022)
[2] Keßler et al., npj Spintronics 2, 50 (2024)
[3] Smolyanyuk et al., Phys. Rev. B 109, 134424 (2024)
[4] Ruf et al., Nat Commun 12, 59 (2021)

MA 13.11 Tue 12:15 H20

Thermo-electric magnetotransport studies on altermagnetic CrSb — •Sajal Naduvile Thadathil[1,2], T. Kotte[1], C. Müller[3], D. Kriegner[4], J. Pospíšil[4], R. Firouzmandi[5], M. Uhlarz[1], M. C. Rahn[2], T. Speliotis[6], V. Kocsis[5], J. Wosnitza[1,2], H. Reichlova[3], and T. Helm[1] — [1]High Magnetic Field Laboratory Dresden, (HLD-EMFL), HZDR, Germany — [2]Institute of Solid State and Materials Physics, TU Dresden, Germany — [3]Institute of Physics, Academy of Science of the Czech Republic — [4]Charles University, Czech Republic — [5]Leibniz Institute for Solid State and Materials Research, Dresden, Germany — [6]Institute of Nanoscience and Nanotechnology, NCSR Demokritos

Recent observations of materials exhibiting properties of both ferromagnets and antiferromagnets, characterized by antiparallel magnetic ordering, have led to the classification of a third distinct magnetic phase known as "altermagnetism". In this study, we investigate the thermo-electric and magnetotransport properties of the altermagnetic candidate material CrSb, using bulk and micron-sized structures fabricated from single crystals. We performed measurements of thermal-transport, magnetoresistance (MR) and the Hall effect between 1.8 and 300 K under magnetic fields up to 14 T. Our results reveal a significant nonlinear field dependence of the Hall resistance, confirmed by similar nonlinear behavior in the thermal Hall effect, providing evidence for multiband physics in CrSb. Additionally, we observe a non-saturating MR up to 14 T. These findings provide new insights into the multiband electronic structure of CrSb.

MA 13.12 Tue 12:30 H20

SU(N) altermagnetism: Lattice models, magnon modes, and flavor-split bands — •Pedro Monteiro Cônsoli and Matthias Vojta — Institut für Theoretische Physik, TU Dresden

Altermagnets are magnetically ordered states which, much like antiferromagnets, have zero net magnetization, and yet resemble ferromagnets in that their band structure shows signs of broken time-reversal symmetry. They have stirred great interest lately not only due to their potential for spintronics applications, but also as gateways to unconventional phases of matter. In this talk, we will demonstrate that a generalized form of altermagnetism can occur in SU(N) magnets with $N > 2$. Guided by symmetry principles, we will present a recipe to construct simple Heisenberg models for such generalized altermagnets and apply it explicitly to two-dimensional examples with $N = 2$ and 3. We will then report a comparative analysis based on spin- and flavor-wave calculations which proves that both systems share the same characteristic behavior of insulating altermagnets, namely that their magnon bands are nondegenerate and carry different sets of magnetic quantum numbers. Finally, we will show that the analogy between the models persists when they are supplemented with charge carriers to become metallic.

MA 13.13 Tue 12:45 H20

Quasi-symmetry Constrained Spin Ferromagnetism in Altermagnets — Mercè Roig[1,2], Yue Yu[2], Rune C. Ekman[1], •Andreas Kreisel[1], Brian M. Andersen[1], and Daniel F. Agterberg[2] — [1]Niels Bohr Institute, University of Copenhagen, DK-2100 Copenhagen, Denmark — [2]Department of Physics, University of Wisconsin Milwaukee, Milwaukee, Wisconsin 53201, USA

Altermagnets break time-reversal symmetry and their spin-orbit cou-

pling (SOC) allow for an anomalous Hall effect (AHE) that depends on the direction of the Néel ordering vector. AHE and ferromagnetic spin moment share the same symmetry and hence are usually proportional. However, density functional theory (DFT) calculations find that the AHE exists with negligible ferromagnetic spin moment for some compounds, whereas it reaches sizable values for other altermagnets. By examining realistic minimal models for altermagnetism in which the DFT phenomenology is captured, we uncover a general SOC-enabled quasi-symmetry that provides a natural explanation for the amplitude of the ferromagnetic spin moment across the vast range of different altermagnetic materials. Additionally, we derive analytic expressions for the magnetic anisotropy energy, providing a simple means to identify the preferred altermagnetic Néel vector orientation for altermagnets.