MA 52: Altermagnets

Time: Friday 9:30–13:30 Location: EB 202

MA 52.1 Fri 9:30 EB 202

Strain induced antiferromagnetic to altermagnetic transition — •Atasi Chakraborty — Institut für Physik, Johannes Gutenberg Universität Mainz, D-55099 Mainz, Germany

Altermagnets, unconventional collinear compensated magnetic systems, offer advantages of spin polarized current akin to ferromagnets, and THz functionalities similar to antiferromagnets, while introducing new novel effects like spin-splitter currents. A key challenge for future applications and functionalization of altermagnets, is to demonstrate controlled transitioning to the altermagnetic phase from other conventional phases in a single material. Here we prove a viable path towards overcoming this challenge through a strain-induced transition from an antiferromagnetic to an altermagnetic phase in ReO2. Combining spin group symmetry analysis and ab initio calculations, we demonstrate that under compressive strain ReO2 undergoes such transition, lifting the Kramer*s degeneracy of the band structure of the antiferromagnetic phase in the non-relativistic regime. In addition, we show that this magnetic transition is accompanied by a change in the non-trivial surface state topology from one phase to the other. We calculate the distinct signature of spin polarized spectral functions of the two phases, which can be detected in angle resolved photo-emission spectroscopy experiments.

MA 52.2 Fri 9:45 EB 202

Electronic and transport properties of Rh-doped altermagnetic RuO_2 — •Lishu Zhang[1], Stefan Blügel[1], and Yuriy Mokrousov[1,2] — [1]Peter Grünberg Institute and Institute for Advanced Simulation, Forschungszentrum Jülich, 52425 Jülich, Germany — [2]Institute of Physics, Johannes Gutenberg-University Mainz, 55099 Mainz,Germany

In the past years RuO_2 has emerged as a central material for understanding the basic properties of altermagnetic materials [1]. In our work, we study the effects of Rh-doping on the properties of altermagnetic RuO_2. We use first-principles methods to simulate the effect of replacing Ru atoms with Rh and study the corresponding changes in the characteristic spin-splitting with the wave vector (k) and changes in the spin-resolved Fermi surface topology. We demonstrate that the latter has a profound impact on various transport characteristics of RuO_2 [2]. We thus promote Rh-doped RuO_2 as a promising platform for tuning the electronic properties and transport effects in altermagnetic materials.

[1] Smejkal et al., Physical Review X 12(2022): 040501.
[2] Zhou et al., arXiv:2305.01410 (2023).
L.Z. is supported by the Alexander von Humboldt foundation

MA 52.3 Fri 10:00 EB 202

Growth and properties of altermagnetic RuO_2/MgO/ferromagnet tunnel junctions — •Maik Gaerner, Martin Wortmann, Laila Bondzio, Inga Ennen, Karsten Rott, Timo Kuschel, Jan Schmalhorst, and Günter Reiss — Bielefeld University, Germany

Altermagnetic materials, such as RuO_2, exhibit time-reversal symmetry breaking and non-relativistic, anisotropic spin splitting in their bandstructure. Meanwhile, they also posses zero net magnetization. Therefore, these materials are promising candidates for the use in fast and robust spinelectronic devices, such as magnetic tunnel junctions (MTJs) [1,2,3].

Here, we report on the fabrication and characterization of MTJs with one altermagnetic RuO_2 and one ferromagnetic electrode. The thin films have been grown using (reactive) magnetron sputtering. Their crystallographic structure has been investigated using specular and off-specular X-ray diffraction as well as transmission electron microscopy. Afterwards, the MTJs have been patterned by electron beam lithography. In low temperature resistivity measurements, we observe a tunneling magnetoresistance which is controlled by the orientation of the magnetization of the ferromagnetic electrode. Within this contribution, we present first experimental results and give insights into MTJs with one altermagnetic electrode.

[1] L. Šmejkal et al., Phys. Rev. X 12, 031042 (2022)
[2] B. Chi et al., arXiv:2309.09561
[3] K. Samanta et al., arXiv:2310.02139

MA 52.4 Fri 10:15 EB 202

Fragility of the magnetic order in the prototypical altermagnet RuO_2 — •Laura Garcia-Gassull[1], Andriy Smolyanyuk[2], Igor Mazin[3], and Roser Valenti[1] — [1]Goethe University, Frankfurt am Main, Germany — [2]Institute of Solid State Physics, Vienna, Austria — [3]George Mason University, Fairfax, USA

The search for a material that fulfills the requirements needed to be an altermagnet has been only increasing in recent years. A proposed material, RuO_2, has been at the center of this search. However, its magnetic properties are still controversial, with some experiments pointing towards it being an altermagnet and others a paramagnet. We present first principles electronic structure calculations that show that pristine RuO_2 is not magnetic and that altermagnetism is realized only in the presence of (Ru) vacancies. Moreover, we corroborate NMR experiments that argue for its altermagnetic nature under the effects of vacancies.

MA 52.5 Fri 10:30 EB 202

Ultrafast electron dynamics in altermagnetic KRu4O8 — •Marius Weber[1,2], Kai Leckron[1], Luca Haag[1], Rodrigo Jaeschke[2], Libor Šmejkal[2], Jairo Sinova[2], and Hans Christian Schneider[1] — [1]Department of Physics and Research Center OPTIMAS, University of Kaiserslautern-Landau ,67633 Kaiserslautern, Germany — [2]Institut für Physik, Johannes Gutenberg University Mainz, 55099 Mainz, Germany

Altermagnetic materials [1] exhibit various intriguing properties, including a distinctive anisotropic band-structure landscape with an alternating spin arrangement. We present here a numerical investigation of optically-induced electronic dynamics in altermagnetic KRu4O8. Ab-initio band structure and the corresponding dipole matrix elements are used as input to determine optically excited carrier distributions from a Fermi's Golden Rule approach. To investigate the characteristics of electronic dynamics in altermagnets, it is crucial to compute the microscopic momentum-dependent scattering dynamics throughout the whole Brillouin zone. We utilize a tight-binding model and calibrate the model parameters to the DFT band structure, which captures the essential momentum-space characteristics of KRu4O8. We numerically determined the electron dynamics resulting from electron-phonon [2] and electron-electron interactions. We characterize the influence on charge and spin dynamics dynamics throughout the entire Brillouin zone, and highlight the importance Elliot-Yafet spin flips.

[1] L. Šmejkal et al.; Phys. Rev. X 12, 031042 (2022)
[2] M. Weber et. al.; arXiv:2305.00775

MA 52.6 Fri 10:45 EB 202

Strain induced anomalous Hall effect in the altermagnet ruthenium-dioxide — •Bennet Karetta[1], V.K. Bharadwaj[1], R. Jaeschke-Ubiergo[1], Libor Šmejkal[1,2], and Jairo Sinova[1,3] — [1]Insitut fur Physik, Johannes Gutenberg Universität Mainz, D-55099 — [2]Inst. of Physics Academy of Sciences of the Czech Republic, Cukrovarnicka 10, Praha 6, Czech Republic — [3]Department of Physics, Texas A\&M University, College Station, Texas 77843-4242, USA

We explore the influence of strain on the magnetic and anomalous Hall transport properties of altermagnetic RuO2. We illustrate a shift from an out-of-plane to an in-plane magnetic moment configuration under a sufficient shear strain. This strain-induced symmetry breaking presents in RuO2, resulting in a measurable anomalous Hall effect response. This effect involves a two-step switch in the Hall conductivity. For minor strains, the out-of-plane component of the Hall vector becomes non-zero. After reorientation of magnetic moments, an in-plane component can be generated. We demonstrate that the Berry's curvature-mediated anomalous Hall effect exhibits a substantial magnitude, on the order of hundreds of S/cm. The non-zero components undergo a change when the Néel order reorients from out-of-plane to in-plane. Our findings point towards possible application of strain-controlled magneto-transport based devices based on light common elements, paving the way to sustainable environmentally friendly sensory systems.

MA 52.7 Fri 11:00 EB 202

Anomalous Nernst effect in the altermagnet Mn5Si3 —

•Warlley Hudson Campos[1], Venkata Krishna Bharadwaj[1], Rodrigo Jaeschke-Ubiergo[1], Antonin Bad'ura[2], Helena Reichlova[2], Libor Šmejkal[1,2], and Jairo Sinova[1] — [1]Institut für Physik, Johannes Gutenberg Universität Mainz, 55099 Mainz, Germany — [2]Institute of Physics, Czech Academy of Sciences, Cukrovarnická 10, 162 00 Praha 6, Czech Republic

Altermagnets (AMs), a recently discovered class of magnetic materials, exhibit compensated magnetic ordering and alternating spin-polarization in both direct and reciprocal spaces [1]. AM belong to a different symmetry class from ferromagnets (FMs) and antiferromagnets (AFs) and can host unique properties (spin splitter currents) as well as combine properties of ferromagnets (spin polarized currents) and antiferromagnets (ultrafast spin dynamics). Here, we employ symmetry analysis and first-principle calculations to investigate the anomalous Nernst effect (ANE), the transverse electric response to an applied longitudinal temperature gradient, in the AM phase of Mn5Si3 [2]. We investigate the dependence of the ANE tensor with respect to the orientation of the spin quantization axes. In our calculations, we also demonstrate the controllability of Nernst conductivity through manipulation of chemical potential and temperature. Finally, we discuss possible experimental geometries for observation of ANE.

[1] L. Šmejkal, et al., Phys. Rev. X 12, 031042 (2022). [2] I. Kounta, et al., Phys. Rev. Mat. 7, 024416 (2023).

MA 52.8 Fri 11:15 EB 202

Magnetooptical effects in altermagnetic MnTe — •Venkata Krishna Bharadwaj[1], Warlley Hudson Campos[1], Rodrigo Jaeschke-Ubiergo[1], Libor Šmeijkal[1,2], and Jairo Sinova[1,2] — [1]Institut für Physik, Johannes Gutenberg-Universität Mainz, Staudingerweg 7, D-55099 Mainz, Germany — [2]Inst. of Physics Academy of Sciences of the Czech Republic, Cukrovarnická 10, Praha 6, Czech Republic

A recent breakthrough in the field of magnetism unveiled a novel category of magnetic materials known as altermagnets [1]. Altermagnets represent a unique class of magnetic compounds characterized by magnetic compensation, breaking time-reversal symmetry and resulting in a spin-split band structure. This band structure exhibits alternating spin polarization both in real and reciprocal spaces. The underlying origin of this spin splitting can be traced to variations in local crystal field anisotropies across different magnetic sublattices.

In this study, we explore the magneto-optical response in altermagnets using first principles. Specifically, we focus on MnTe, which is predicted to bean altermagnetic insulator [1] where the altermagnetism can be examined through the magneto-optical Kerr effect. Our findings provide a foundation for exploring optical responses in other altermagnetic materials.

[1] L. Šmejkal, et al., Phys. Rev. X 12, 031042 (2022).

15 min. break

MA 52.9 Fri 11:45 EB 202

Mechanisms for stabilizing altermagnetism in minimal models — Mercè Roig[1], •Andreas Kreisel[1], Brian M. Andersen[1], Yue Yu[2], and Daniel F. Agterberg[2] — [1]Niels Bohr Institute, University of Copenhagen, DK-2200 Copenhagen, Denmark — [2]Department of Physics, University of Wisconsin-Milwaukee, Milwaukee, Wisconsin 53201, USA

Altermagnetism has been proposed as a new magnetic phase that shares properties of antiferromagnets and ferromagnets like no net magnetization but finite anomalous Hall effect. In this work, we use minimal models to study the 2D and 3D mechanisms giving rise to altermagnetism by examining the altermagnetic susceptibility and comparing it to the usual spin susceptibility. In particular, in the 2D case we study the interplay between interband and intraband susceptibility and the effect of Van Hove singularities to stabilize altermagnetism. Finally, we discuss relevant tight-binding models for altermagnetic materials candidates, including the rutile metal RuO_2. We demonstrate that the minimal tight-binding models are sufficient to capture a leading altermagnetic instability.

MA 52.10 Fri 12:00 EB 202

Anomalous Nernst effect of altermagnetic Mn_5Si_3 — •Antonin Badura[1], Warlley Campos[2], Javier Rial[3], Ismaïla Kounta[4], Lisa Michez[4], Jan Zemen[5], Filip Křížek[1], Kamil Olejník[1], Dominik Kriegner[1], Sebastian Sailer[6], Jairo Sinova[2], Vincent Baltz[3], Tomas Jungwirth[1], Libor Šmejkal[2], Sebastian T. B. Goennenwein[6], and Helena Reichlova[1] — [1]Institute of Physics, Czech Academy of Sciences, Prague, Czechia — [2]Institut für Physik, Johannes Gutenberg Universität Mainz, Germany — [3]Univ. Grenoble Alpes, CNRS, CEA, Grenoble INP, Spintec, Grenoble, France — [4]Aix-Marseille University, CNRS, CINaM, Marseille, France — [5]Faculty of Electrical Engineering, Czech Technical University in Prague, Czechia — [6]Universität Konstanz, Fachbereich Physik, Konstanz, Germany

The spin-split electronic band structure of altermagnetic materials gives rise to various spintronic phenomena, many of which were already confirmed experimentally. However, an experimental investigation of thermoelectric phenomena in altermagnets, such as the anomalous Nernst effect, is still missing. Here, we demonstrate the presence of the anomalous Nernst effect in a particular altermagnetic candidate, thin epitaxial layers of Mn_5Si_3. The transverse Nernst voltage is generated by a temperature gradient in the sample (0001) plane. We carefully analyze the dependence of the Nernst signal on the applied magnetic field and identify multiple contributions to the signal, demonstrating the complex transport response of our layers. Furthermore, our experimental study is supported by *ab initio* calculations of the anomalous Nernst coefficient in Mn_5Si_3.

MA 52.11 Fri 12:15 EB 202

Impacts of Crystallographic Domain Boundaries on the Electronic Properties of RuO2 — •Gina Pantano[1], Eklavya Thareja[1], Libor Šmejkal[2,3], Jairo Sinova[2], and Jacob Gayles[1] — [1]Department of Physics, University of South Florida, Tampa, FL USA — [2]Institut für Physik, Johannes Gutenberg Universität Mainz, Mainz, Germany — [3]Institute of Physics, Czech Academy of Sciences, Prague, Czech Republic

Research on interfacial phenomena in condensed matter physics has garnered significant interest due to the discovery of new properties and phases distinct from the bulk. Our work investigates novel effects that arise from crystallographic domain boundaries in the altermagnet ruthenium dioxide (RuO2). Altermagnets are characterized by having a non-relativistic momentum-dependent spin splitting comparable to ferromagnetic materials but with compensated magnetic ordering. This offers a new mechanism for controlling spin-dependent transport phenomena, such as the spin and anomalous Hall effects, based on the configuration of the crystal. We use first principle calculations to determine the orbital, atomic, and spin contributions to the electronic states at the interface. We expect the emergence of a transverse voltage parallel to the interface without spin-orbital coupling due to spin scattering and novel spin currents to develop when spin-orbit coupling is considered. Our findings will further our understanding of how altermagnetic properties evolve toward interfaces with the reduction in dimensionality and symmetry and contribute to advancements toward the design of sustainable, energy-efficient low-power devices.

MA 52.12 Fri 12:30 EB 202

Altermagnetic band splitting in CrSb thin films investigated by photoemission spectroscopy — •Lukas Odenbreit[1], Sonka Reimers[1], Libor Smejkal[1], Vladimir Strocov[2], Procopios Constantinou[2], Anna Hellenes[1], Rodrigo Jaeschke Ubiergo[1], Warlley Campos[1], Venkata Bharadwaj[1], Atasi Chakraborty[1], Mathias Kläui[1], Jairo Sinova[1], and Martin Jourdan[1] — [1]Institut für Physik, Johannes Gutenberg-Universität Mainz, 55099Mainz, Germany — [2]Paul Scherrer Institut, CH-5232 Villigen PSI, Switzerland

Altermagnets are characterized by a collinear magnetic phase with compensated order in real space and alternating spin polarization in reciprocal space.

Using spin-integrated soft X-ray angular resolved photoemission spectroscopy (SX-ARPES), we observe directly the associated band splitting near the Fermi energy. The SX-ARPES data obtained from epitaxial thin films of the anticipated antiferromagnetic material CrSb enable a comprehensive comparison with band structure calculations. Our analysis reveals a robust agreement between the experimental results and the theoretical predictions, thereby providing strong evidence for the characterization of CrSb as an altermagnet [Rei23].

The observed maximum altermagnetic band splitting of approximately 0.6 eV in proximity to the Fermi energy underscores the promising potential of altermagnets in advancing applications within the realm of spintronics.

[Rei23] S. Reimers et al., arXiv:2310.17280v1 (2023).

MA 52.13 Fri 12:45 EB 202

Inverse Faraday Effect in altermagnets from first-principles

— •Theodoros Adamantopoulos[1,2], Maximilian Merte[1,2,3], Frank Freimuth[1,3], Dongwook Go[1,3], Stefan Blügel[1], and Yuriy Mokrousov[1,3] — [1]Peter Grünberg Institut and Institute for Advanced Simulation, Forschungszentrum Jülich and JARA, 52425 Jülich, Germany — [2]Department of Physics, RWTH Aachen University, 52056 Aachen, Germany — [3]Institute of Physics, Johannes Gutenberg University Mainz, 55099 Mainz, Germany

While the understanding of altermagnetism is still at a very early stage, it is expected to play a role in various fields of condensed matter research, for example spintronics, caloritronics and superconductivity [1]. In the field of optical magnetism, it is still unclear whether altermagnets can exhibit magnetisation dynamics effects distinct from ferromagnets and antiferromagnets. Here we choose RuO_2, a prototype metallic altermagnet with a giant spin splitting, and CoF_2, an experimentally known insulating altermagnet, to study the inverse Faraday effect (IFE) in altermagnets from first-principles. We predict large and canted induced spin and orbital moments after the optical excitation which are distinct on each magnetic sublattice. By resorting to microscopic tools we interpret our results in terms of the altermagnetic spin splittings and of their reciprocal space distribution. Overall, in accordance with our symmetry analysis, we demonstrate that the behavior of altermagnets when exposed to optical pulses incorporates both ferromagnetic and antiferromagnetic features.

[1] L. Smejkal et al. PRX**12**, 040501 (2022).

MA 52.14 Fri 13:00 EB 202

Altermagnetic signatures in the ultrafast photoconductivity of RuO2 — •Stephan Wust[1], Marius Weber[1], Akashdeep Akashdeep[2], Luca Haag[1], Kai Leckron[1], Christin Schmitt[2], Rafael Ramos[3], Takashi Kikkawa[4], Eiji Saitoh[4], Mathias Kläui[2], Libor Šmejkal[2], Jairo Sinova[2], Martin Aeschlimann[1], Gerhard Jakob[2], Hans Christian Schneider[1], and Benjamin Stadtmüller[1] — [1]Department of Physics and Research Center OPTIMAS, University of Kaiserslautern-Landau, 67663 Kaiserslautern, Germany — [2]Institut für Physik, Johannes Gutenberg University Mainz, 55099 Mainz, Germany — [3]CIQUS, Departamento de Química-Física, Universidade de Santiago de Compostela, Santiago de Compostela, Spain — [4]Department of Applied Physics, The University of Tokyo, Tokyo 113-8656, Japan

The discovery of altermagnets as a new class of magnets opens new avenues to exploit spin-polarized electron conductivity in materials with compensated spin structures. This is possible due to the spin-split band structure of altermagnets and the corresponding non-relativistic spin polarization, leading to novel effects such as spin-splitter currents. Here, we demonstrate the existence of characteristic altermagnetic signatures in the photoconductivity of the prototypical altermagnet RuO2 after optical excitation using fs light pulses. This is achieved by combining all-optical pump-probe methods with ab-initio calculations, which together provide insight into the spin polarization of the optically excited carriers in RuO2 for different excitation geometries.

MA 52.15 Fri 13:15 EB 202

Zero-Field Crystal Thermal Hall Effect in Insulating Altermagnets — •Rhea Hoyer, Libor Šmejkal, and Alexander Mook — Johannes Gutenberg Universität Mainz, Mainz, Deutschland

The thermal Hall effect is an emerging probe of charge-neutral collective excitations in insulating quantum matter. Here we address the question of whether thermal Hall effects can occur in compensated collinear magnets at zero magnetic field. Following the recently developed concept of altermagnetism [1,2,3], we provide an affirmative answer by developing a minimal model that exhibits a crystal thermal Hall effect. Specifically, we present a Heisenberg-type spin model on the rutile lattice. The presence of nonmagnetic atoms causes altermagnetic spin-splitting of magnons [4,5] and gives rise to Dzyaloshinskii-Moriya interaction. As microscopic heat carriers, we consider magnons, whose Berry curvature causes an intrinsic contribution to the thermal Hall conductivity [6]. We show how the Hall conductivity changes as a function of the Néel vector direction, highlighting the influence of magnetic point group symmetries. The role of symmetry is further emphasized by studying fluctuation induced piezomagnetism and strain engineering of the Hall conductivity. Finally, the thermal Hall response is contrasted with a spin-Nernst response to explore the potential for heat-to-spin conversion in altermagnetic insulators.

[1] L.Š. et al., PRX 12, 031042 (2022). [2] L.Š. et al., PRX 12, 040501 (2022). [3] L.Š. et al., Sci. Adv.6, eaaz8809 (2020). [4] L.Š. et al., arXiv:2211.13806 (PRL, accepted). [5] M.G. et al., PRL 126, 127701 (2023). [6] R.M. et al., PRL 106, 197202 (2011).