MA 25: Focus Session: Chiral phonons and crystals coupled to magnetic order I

Conventional magnetism arises from electron spin and orbital angular momentum, forming the basis of spintronics and orbitronics. Recent advances, however, have revealed that magnetism is also intimately linked to the chirality and angular momentum of the crystal lattice itself, often mediated by circular lattice vibrations known as chiral or axial phonons. These discoveries have uncovered novel mechanisms of spin and phonon transport and enabled direct access to phonon chirality and angular momentum as fundamental physical quantities. These developments prompt a re-examination of angular momentum coupling in solids, including well-established phenomena such as the Einstein-de Haas and Barnett effects, as well as the role of phonon angular momentum in the equilibrium state of magnetic materials. Chiral and axial phonons emerge as a powerful new platform for controlling magnetic order and dynamics, bridging lattice, spin, and angular momentum physics. This focus session aims to highlight recent breakthroughs in phonon angular momentum and magnetism and to connect the rapidly expanding field of chiral phononics with the broader magnetism community, spanning both experimental and theoretical perspectives.

As part of this focus session, we offer an excursion to the high-field THz user facilities at HZDR with an introduction to the planned Dresden Advanced Light Infrastructure (DALI). See MA 32 for details.

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Time: Wednesday 9:30–12:45 Location: HSZ/0002

Invited Talk MA 25.1 Wed 9:30 HSZ/0002
Coherent phononic control of chirality — •Michael Först — Max Planck Institute for the Structure and Dynamics of Matter, Hamburg, Germany

Chirality is a pervasive property of matter that underpins many important phenomena across physics, chemistry and biology. Given its broad significance, the development of protocols for rational control of chirality in solid state systems is highly desirable, especially if this effect can be tuned continuously and in two directions.

I will show that coherent optical excitation of the crystal lattice at terahertz frequencies can induce chirality in the non-chiral solid BPO_4. By resonantly driving one of two orthogonal, doubly degenerate phonon modes and exploiting their nonlinear coupling to symmetry-lowering lattice distortions, chiral structures of either handedness can be selectively created. These findings offer new prospects for controlling of out-of-equilibrium phenomena in complex materials.

Invited Talk MA 25.2 Wed 10:00 HSZ/0002
Towards a modern theory of chiralization (and can chiral phonons help us get there?) — •Nicola Spaldin — Materials Theory, ETH Zürich, Switzerland

The goal of this talk is to answer the question: Given two chiral crystals, which one is the most chiral? In order to compare the amount of chirality, we propose the concept of “chiralization”, representing the amount of chiral moment per unit volume, as a bulk macroscopic thermodynamic quantity, analogous to magnetization or polarization. Such a quantity will allow us to identify the conjugate field for chirality, classify achiral to ferrochiral phase transitions in terms of an appropriate order parameter, determine the multipole(s) associated with chirality, and predict phenomena in chiral materials. We begin by analyzing ferroaxial materials, which are protochiral, in the sense that they have a symmetry-lowering structural phase transition that breaks mirrors but preserves inversion, and are often characterized by rotations of sub-units around an axis yielding domains of opposite handedness. We show that the electric toroidal dipole, calculated as the cross product of the spin and orbital angular momenta, is a suitable order parameter for ferroaxial phase transitions. We outline the difficulties in extending the physics of ferroaxial materials to ferrochiral materials, and indicate how our emerging understanding of chiral phonons might help.

MA 25.3 Wed 10:30 HSZ/0002
Coherent Transfer of Pseudo- and Real Angular Momentum via Lattice Anharmonicity — •Olga Minakova[1], Carolina Paiva[2], Maximilian Frenzel[1], Michael Spencer[1], Joanna Urban[1], Martin Wolf[1], Dominik Juraschek[2,3], and Sebastian Maehrlein[1,4,5] — [1]FHI Berlin — [2]Tel Aviv U. — [3]TU Eindhoven — [4]HZDR — [5]TU Dresden

Rotational symmetry in crystals enforces conservation of phonon pseudo-angular momentum. However, direct evidence for angular momentum transfer between phonon modes has been lacking. We demonstrate coherent angular momentum transfer between doubly degenerate phonons through a resonant three-phonon interaction [1]. Circularly polarized THz pulses drive an IR-active phonon in Bi2Se3, imprinting the helicity of the field and generating ionic loops possessing real angular momentum. Anharmonic coupling then upconverts two such IR phonons into a Raman-active phonon at twice the frequency, transferring energy, linear momentum, and angular momentum. The THz-driven Kerr effect directly resolves the Raman phonon trajectory, revealing a helicity reversal, which perfectly fulfills pseudo-angular momentum conservation in the discrete C3 rotational symmetry of the lattice. Group theory analysis and DFT confirm this helicity flip and simultaneously reveal transfer of real angular momentum as circular ionic motion. These results constitute the first direct experimental evidence of angular momentum conservation in phonon-phonon interactions.

[1] O. Minakova et. al., arXiv:2503.11626 (2025)

MA 25.4 Wed 10:45 HSZ/0002
Rotational Umklapp scattering in chiral nonlinear phononics — •Yu-Chi Huang[1], Carolina Paiva[2], and Dominik Juraschek[1] — [1]Eindhoven University of Technology, Eindhoven, Netherlands — [2]Tel Aviv University, Tel Aviv, Israel

Chiral phonons, circularly polarized lattice vibrations propagating perpendicular to their rotational plane, commonly arise in chiral materials and have attracted considerable attention in condensed matter physics lately. Due to n-fold rotational crystal symmetry, they enable rotational phonon-phonon Umklapp scattering through nonlinear phonon coupling. This process is the angular-momentum analog of the conventional Umklapp scattering conserving linear crystal momentum. Recent pump-probe experiments have measured the effect in Bi_2Se_3, and we here develop a general theory using α-quartz (α-SiO_2) as an example. Our results offer insight into the fundamentals of angular momentum conservation in solids.

15 min break

Invited Talk MA 25.5 Wed 11:15 HSZ/0002
Observation and control of chiral phonons in noncentrosymmetric materials — •Hiroki Ueda — Paul Scherrer Institute, Villigen, Switzerland

The field of chiral phonons has rapidly grown with the emergence of various intriguing phenomena, including magnetism, transport, and light-matter interactions. Chiral phonons are rotational phonon modes propagating out of the rotational plane, breaking improper rotational symmetry. I will present direct demonstrations of chiral phonons in chiral crystal α-SiO2 and polar crystals LiNbO3 and BaTiO3 using resonant inelastic X-ray scattering (RIXS) with circularly polarized X-rays. Angular momentum transfer between circularly polarized photons and chiral phonons imposes the selection rule in the RIXS process, enabling observation of chiral phonons through circular dichroism in phonon excitation peaks. Furthermore, in BaTiO3, we demonstrate in situ electrical switching of phonon chirality, opening pathways for dynamic control of chiral phononic properties.

MA 25.6 Wed 11:45 HSZ/0002

Associated magnetism of circular ionic motion probed with ultrafast x-ray pulses — •Clifford Allington[1], Matthew Lutz[2], E. Ho[2], F. Graf[3], M. Basini[3], H. Ueda[2], A. Elliot[2], M. Biggs[2], R. Finn[2], S-W Huang[1], M. Grimes[1], M. Henstridge[4], M. Hoffmann[4], R. Alonso-Mori[4], D. Zhu[4], Q. Nguyen[4], V. Esposito[4], T. Sato[4], E. Skoropota[1], E. Paris[1], A. Camps[1], E. Razzoli[1], R. Mankowsky[1], F. Capotondi[5], N. Jaouen[6], M. Radovic[1], M. Savoini[1,3], E. Abreu[3], S. Johnson[1,3], Jeremy Johnson[2], and Urs Staub[1] — [1]Paul Scherrer Institute — [2]Brigham Young University — [3]ETH Zurich — [4]SLAC National Accelerator Laboratory — [5]Elettra Sincrotrone Trieste — [6]Synchrotron SOLEIL

It has been proposed that the coherent circular motion of ions creates a magnetic field. This effect, termed dynamical multiferroicity (DM), has been evidenced experimentally in diamagnetic materials such as SrTiO3 using circular terahertz (THz)-pump optical-probe methodologies. However, the fields reported are much larger than predicted, raising questions on the exact nature of the transient state. Thus, we performed a suite of circular THz-pump experiments on the paramagnetic EuTiO3, a material directly analogous to SrTiO3 but with a S = 7/2 spin on the Eu2+ ion. We have measured the circular motion of ions by femtosecond x-ray diffraction as well as an optical-probe signal which changes sign upon changing the helicity of the THz-pump, consistent with DM. However, no induced Eu2+ moment was found within the resolution of time-resolved x-ray magnetic circular dichroism, providing a quantitative upper limit on the resulting field.

MA 25.7 Wed 12:00 HSZ/0002

Real-time laser-driven (chiral) phonon dynamics from atomistic simulations — •Mike Pols and Nicola A. Spaldin — Materials Theory, ETH Zürich, Zürich, CH-8093, Switzerland

I will present an approach to simulate the real-time dynamics of excited phonons in materials. Using machine-learning interatomic potentials (MLIPs) together with laser-driven molecular dynamics simulations, we can capture the response of materials to driven (chiral) phonon excitations and directly capture their nonlinear vibrational dynamics. Driving phonon modes into the nonlinear regime can induce a wide range of material properties, such as strain and magnetism [1]. While first-principles modeling has provided valuable insights into these dynamics, the commonly used coupled-oscillator method requires the computation of numerous higher-order coupling coefficients [2], limiting its scalability.

Our MLIP-based approach enables the direct simulation of the full anharmonic lattice response. It effectively models both IR- and Raman-active modes, with finite-temperature effects, and the nonlinear couplings to high orders. Using this method, we explore the vibrational dynamics of linear and chiral phonons in oxide perovskites, enabling predictive simulations of the behavior and coupling of phonons in functional materials.

[1] A. Disa et al., Nat. Phys. 17, 1087 (2021).
[2] A. Subedi et al., Phys. Rev. B 89, 220301 (2014).

MA 25.8 Wed 12:15 HSZ/0002

THz field-induced magnetic-like response in the quantum paraelectric diamagnet $KTaO_3$ — •Christelle Kadlec[1], Filip Kadlec[1], Dalibor Repček[1], Martina Basini[2], Petr Kužel[1], Jan-Christoph Deinert[3], Sergey Kovalev[3], Mattia Udina[4], Igor Ilyakov[3], Alexey Ponomaryov[3], and Stanislav Kamba[1] — [1]Institute of Physics, Prague, Czechia — [2]ETH Zurich, Switzerland — [3]HZDR, Dresden, Germany — [4]CESQ-ISIS, Strasbourg, France

The current efforts on developing new ways of data manipulation are aimed at ultrafast control of magnetization in magnetic materials, as well as at inducing magnetic moments in diamagnetics. We demonstrate that in the diamagnetic quantum paraelectric $KTaO_3$, the electric field of circularly polarized THz pulses with an amplitude of 300 kV/cm induces a transient magnetic-like response by resonantly pumping its degenerate soft phonon. The transient phonon-mediated magnetic-like response was measured via the rotation of the polarisation of a probe light. However, such response usually contains contributions from both the magneto-optic THz-field-induced Faraday effect and the electro-optic THz-field-induced Kerr effect (TKE). In order to distinguish between them, we separately measured the TKE by applying a linearly polarized THz pump beam. Moreover, we present a theoretical analysis of the TKE, showing that its contribution can be suppressed by subtracting the experimental data generated by opposite elliptically polarized THz radiation. Thus, we are able to unambiguously identify a magnetic-like behavior of the $KTaO_3$ crystal manifested by the extracted Faraday rotation.

MA 25.9 Wed 12:30 HSZ/0002

Phonon-induced chirality — •Dominik Juraschek — Eindhoven University of Technology, Eindhoven, Netherlands

Controlling and utilizing solid-state chirality is a central challenge in condensed matter physics, because it does not couple to applied magnetic or electric fields, in contrast to magnetism and ferroelectricity. In this talk I show that geometric chiral phonons, lattice vibrations whose instantaneous atomic displacements break inversion and mirror symmetries, can transiently drive an achiral crystal into a chiral state. Using group-theoretical analysis, we identified selection rules for phonon-induced geometric chirality across all 32 point groups and demonstrate that ultrashort mid-infrared and terahertz pulses can excite pairs of IR-active phonons whose nonlinear coupling rectifies a geometric chiral phonon. I further demonstrate that chiral order exhibits fundamental excitations which we term “chiralons,” similar to the recently discovered ferrons in ferroelectric order. Our results highlight an emerging functionality of chiral phononics beyond phonon angular momentum.