MA 5: Focus Session: Magnetic Phenomena from Phonon Chirality and Angular Momentum I (joint session MA/TT)

The magnetic moment of the electron lies at the heart of magnetism and spintronics. However, recent research has unveiled the angular momentum and magnetic moment of chiral phonons as fundamental quantities in their own right. These chiral phonons give rise to a plethora of novel lattice phenomena analogous to electronic effects, such as the phonon Hall and phonon Zeeman effects. Moreover, they play a critical role in angular momentum transfer on ultrafast timescales, as seen in the Einstein-de Haas effect. Chiral phonons can also generate effective magnetic fields reaching the tesla scale, inducing magnetization in antiferromagnetic, paramagnetic, and even nonmagnetic materials - a phenomenon reminiscent of the Barnett effect. These advancements showcase phonon chirality and angular momentum as powerful emerging tools for generating and controlling magnetism. This focus session aims to highlight the latest breakthroughs in chiral-phonon magnetism and foster connections between the rapidly evolving field of chiral phononics and the broader magnetism research community.

Coordinators: Dominik M.Juraschek, Eindhoven University of Technology, d.m.juraschek@tue.nl; Martina Basini, ETH Zürich, m.basini@ethz.ch

Time: Monday 9:30–13:00 Location: H20

Invited Talk MA 5.1 Mon 9:30 H20

Driving Coherent Phonon-Phonon Angular Momentum Transfer via Lattice Anharmonicity — •Sebastian Maehrlein — Fritz Haber Institute of the Max Planck Society — Helmholtz Zentrum Dresden Rossendorf — TU Dresden

The discrete rotational symmetry of crystal structures leads to the conservation of quantized angular momentum in solids. Whereas the exchange of energy and linear momentum between lattice vibrations (phonons) via anharmonic coupling is a cornerstone of solid-state physics, conservation and transfer of angular momentum within the lattice remained a postulate, yet. Recently, phonon angular momentum, often in the form of chiral phonons, was linked to gigantic magnetic fields, dynamical ferroelectricity, ultrafast demagnetization, or magnetic switching. However, the fundamental process of phonon to phonon angular momentum transfer required for demagnetization and other spin-related relaxation phenomena remained elusive.

Here we drive coherent phonon-phonon angular momentum transfer by establishing helical nonlinear phononics. Thereby, we directly observe phonon helicity-switching dictated by (pseudo) angular momentum conservation and the discrete rotational symmetry of the lattice. Ab-initio modeling in conjunction with classical equations of motion confirm the experimentally observed anharmonic phonon-phonon coupling as the dominating lattice angular momentum transfer channel. Our results thus open the field of helical or chiral nonlinear phononics, turning lattice angular momentum into the long missing tuning knob for ultrafast material control.

Invited Talk MA 5.2 Mon 10:00 H20

Chiral phonons, phono-magnetism, and spin-rotation coupling — •Matthias Geilhufe — Department of Physics, Chalmers University of Technology, 412 96 Göteborg, Sweden

High-intensity THz lasers enable the coherent excitation of individual phonon modes. The ultrafast control of emergent magnetism through phonons and phonon angular momentum opens new avenues for tuning functional materials. Recent experiments suggest a substantial magnetization in various materials [1,2], presenting a challenge for theoretical modeling. I will provide an introduction to magnetization induced by phonon angular momentum via the phonon inverse Faraday effect [3]. Additionally, I will discuss a coupling mechanism based on inertial effects, which facilitates the interaction between rotational degrees of freedom and electron spin [4].

[1] Basini et al., Nature, 628, 534 (2024)
[2] Davies et al., Nature, 628, 540 (2024)
[3] Shabala, Geilhufe, Physical Review Letters, arXiv:2405.09538
[4] Geilhufe, Physical Review Research, 4, L012004 (2022)

Invited Talk MA 5.3 Mon 10:30 H20

Geometry of temporal chiral structures and photoinduced chirality-spin coupling — •Olga Smirnova[1,2,3], Philip Flores[1], Aycke Roos[1], David Ayuso[4], Piero Decleva[5], Stefanos Carlstroem[1], Serguei Patchkovskii[1], and Andres Ordonez[4] — [1]Max-Born Institute, Berlin — [2]Technische Universität Berin — [3]Technion - Israeli Institute of Technology, Haifa, Israel — [4]Imperial College London, UK — [5]CNR IOM and Dipartimento di Scienze Chimiche e Farmaceutiche, Universita degli Studi di Trieste, Italy

In non-relativistic physics the concepts of geometry and topology are usually applied to characterize spatial structures, or structures in momentum space. We introduce the concept of temporal geometry [1], which encompasses geometric and topological properties of temporal shapes, e.g. trajectories traced by a tip of a time-dependent vector on sub-cycle time scale, and apply it to light-driven ultrafast electron currents in chiral molecules. The geometric concepts: curvature and connection emerge as ubiquitous features of photoexcited chiral electron dynamics. To demonstrate the link between the geometric fields and spin, we extend the concept of curvature to spin-resolved photoionization, and show that it is responsible for enantio-sensitive locking of the cation orientation to the photoelectron spin. This translates into chirality induced spin selectivity in photoionization of oriented chiral molecules both in one photon and two-photon processes.

[1] Geometry of temporal chiral structures, A. F. Ordonez, A. Roos, P. Mayer, D.Ayuso, O. Smirnova, arXiv preprint arXiv:2409.02500, 2024

15 min. break

Invited Talk MA 5.4 Mon 11:15 H20

Phonon thermal Hall effect — •Kamran Behnia — Ecole Supérieure de Physique et de Chimie Industrielles, Paris, France

In insulating solids and liquids, heat is carried by phonons. The phonon scattering time is close to the so-called Planckian time near the melting temperature. It increases with cooling, as phonon-phonon Umklapp scattering events rarefy. A rigorous determination of thermal conductivity of insulators from first principles has been a major accomplishment of the quantum theory of solids. In contrast, our understanding of momentum and energy exchange between phonons at low temperatures is imperfect. In this context, the experimental detection of phonon thermal Hall effect in a growing number of insulators is a challenge to the condensed matter theory. The list now includes elemental insulators, such as black phosphorus, silicon and germanium, in which the spin degree of freedom is irrelevant and the atomic bonds are covalent. We will examine how magnetic field can influence anharmonicity.

Invited Talk MA 5.5 Mon 11:45 H20

Giant effective magnetic moment of chiral phonons — •Swati Chaudhary[1,3], Dominik Juraschek[2], Martin Rodriguez-Vega[3], and Gregory A Fiete[4] — [1]The Institute for Solid State Physics, The University of Tokyo, Japan — [2]Eindhoven University of Technology, Eindhoven, Netherlands — [3]The University of Texas at Austin, Austin, USA — [4]Northeastern University, Boston, USA

Chiral phonons carry angular momentum and lead to magnetic responses in applied magnetic fields or when resonantly driven with ultrashort laser pulses. On the basis of purely circular ionic motion, these phonons are expected to carry a magnetic moment of the order of a few nuclear magnetons. However, some recent experiments have demonstrated a phonon magnetic moment of the order of a few Bohr magnetons. This kind of giant magnetic response points towards the electronic contribution to the magnetic moment of phonons. Many diverse mechanisms have been discovered for this enhanced magnetic response of chiral phonons. The orbital-lattice coupling is one such mechanism where low-energy electronic excitations on a magnetic ion hybridize with phonons and endow a large magnetic moment to phonons. In this talk, I'll present a microscopic model for the effective magnetic moments of chiral phonons based on this mechanism. We apply our model to two types of materials: rare-earth halide paramagnets and transition-metal oxide magnets. In both cases, we find that chiral phonons can carry giant effective magnetic moments of the order of a Bohr magneton, orders of magnitude larger than previous predictions.

MA 5.6 Mon 12:15 H20

Extrinsic Phonon Thermal Hall Effect — •Dimos Chatzichrysafis[1], Robin Richard Neumann[1,2], and Alexander Mook[1] — [1]Johannes Gutenberg-Universität, Mainz, Germany — [2]Martin-Luther-Universität Halle-Wittenberg, Germany

The thermal Hall effect is a developing tool to investigate charge-neutral excitations, exposing the quantum many-body ground state of correlated materials. Since a sense of chirality for the energy carriers is necessary for the generation of a thermal Hall effect, it is natural to expect that quasiparticles of magnetic excitations are responsible for the Hall transport. This conventional wisdom has been recently challenged in experiments [1] which revealed a universal character of the thermal Hall effect independent on the magnetic texture and the lattice structure, even in systems where magnetism is completely absent. This finding asks for the re-investigation of the role of phonons in the thermal Hall effect.

Here, we develop a theory for a phononic thermal Hall effect where the source of chirality is given by the presence of the molecular Berry phase. As a toy model we study a non-magnetic system on a Bravais square lattice. We go beyond the intrinsic mechanism [2] usually studied in literature and consider the contribution of different possible extrinsic sources of phonon Hall transport. Our results demonstrate that phonon thermal Hall effects can be native to very generic systems.

[1] Xiaobo Jin et al, arXiv:2404.02863

[2] Takuma Saito et. al, Phys. Rev. Lett. 123, 255901, December 2019

MA 5.7 Mon 12:30 H20

Signatures of chiral phonons in $MnPS_3$ — •Banhi Chatterjee and Peter Kratzer — Faculty of Physics, University of Duisburg-Essen, Lotharstr. 1, 47057, Duisburg, Germany

Chiral phonons can exist in two-dimensional transition metal dichalcogenide (TMDC) monolayers without inversion symmetry. They can be observed in the non-equilibrium state triggered by optical excitations using circularly polarized light. In existing literature a detailed theoretical calculation of the circular phonons production rate has already been done for the TMDC MoS_2. We investigate the antiferromagnetic semiconductor $MnPS_3$ with a similar hexagonal crystal structure and band-structure like MoS_2 but a larger unit cell as a novel candidate material that may allow for excitation of circular phonons. In $MnPS_3$, although the total magnetic moment is zero in the ground state, exciting the system using circularly polarized light induces a net magnetic moment. The damping of the magnons observed experimentally points to the transfer of orbital angular moment to combined phonon-magnon excitations. Using DFT+U and density functional perturbation theory (DFPT) we obtain in-plane chiral phonon modes at the valley-points of a monolayer $MnPS_3$ and for these modes the S atoms make circular motions. We further study the electron-phonon coupling between these chiral phonon modes and the excited electronic states carrying orbital angular momentum, particularly the dominant d-electrons, in order to theoretically investigate the experimentally observed damping of magnons.

MA 5.8 Mon 12:45 H20

Elliptically polarized coherent phonons in a degenerate mode — Arne Ungeheuer, Mashood T. Mir, Ahmed Hassanien, Lukas Nöding, Thomas Baumert, and •Arne Senftleben — Institut für Physik, Universität Kassel

Controlled excitation of phonons in crystalline solids is an emerging way to alter the property of a material to create phenomena such as transient magnetic polarization [1,2]. Here, we want to focus on controlling the polarization properties of coherent optical phonons that can be launched by ultrashort laser pulses. we demonstrate the excitation of elliptically polarized coherent optical phonons of the E_{2g} shearing mode in graphite. This is achieved by exciting the superposition of two orthogonally polarized phonon modes using a tailored pair of time-delayed optical pulses with tilted polarization. The elliptically polarized coherent phonons are detected by ultrafast electron diffraction [3], where we determine the amount of ellipticity and the sense of rotation.

[1] D. M. Juraschek, et al. *Phys. Rev. Lett.* **118**, 054101 (2017).

[2] A. S. Disa, et al. *Nature Phys.* **16**, 937–941 (2018).

[3] C. Gerbig, et al. *New J. Phys.* **17**, 043050 (2015).