TT 84: Focus Session: Emerging Magnetic Phenomena from Chiral Phonons II (joint session MA/TT)

Contemporary efforts in spintronics focus on utilizing and controlling electronic angular momentum for possible applications in data storage and processing. Only recently, an alternative has arisen in the form of angular momentum generated by circularly polarized (chiral) phonons. Chiral phonons have been shown to lead to a variety of novel magnetic phenomena, including a phonon Hall, phonon Einstein-de Haas, phonon Barnett, and phonon Zeeman effect. Phonon angular momentum can be utilized to control the magnetic state of solids and even to induce magnetization in nonmagnetic materials. These discoveries make the angular momentum of chiral phonons a promising tool for the control of magnetic materials and an emerging quantity of interest for spintronic applications. The goal of this focus session is to highlight topical research on novel magnetic phenomena arising from chiral phonons and to connect this rapidly developing field to the broader audience working in magnetism and spintronics.

Coordinators: Sebastian T. B. Goennenwein, Universität Konstanz, sebastian.goennenwein@uni-konstanz.de Ulrich Nowak, Universität Konstanz, ulrich.nowak@uni-konstanz.de

Time: Friday 9:30–11:30 Location: H 1058

TT 84.1 Fri 9:30 H 1058

Born effective charges in insulators and metals — •Paolo Fachin, Francesco Macheda, and Francesco Mauri — Sapienza, Università di Roma, Italia

The Born effective charges quantify the coupling of phonons with light, allowing to describe experimental spectra of crystals in infrared spectra. While in insulators the electrical polarization is well defined and the Born Effective charges are described in a Berry phase formulation in the context of the modern theory of polarization[1], in metals this quantity is more challenging to deal with. There are two different limits, the static [2] and the dynamical [1][3] one, concurring in the determination of the vibrational features in a combination depending on the phonon frequency and linewidth ratio [4]. The nature of these two limits is clarified using a low energy model for graphene compared with ab initio simulations. The effect of the recently predicted [5][6] intrinsic chiral phonons in crystals can be detected in infrared experiments in a way that is described by the Born effective charges.

[1] Bistoni,Mauri et al., 2D Materials, 6, 045015 (2019)
[2] Macheda, Barone and Mauri, Phys.Rev.Lett.,129(18),185902(2022)
[3] Dreyer,Coh, and Stengel, Phys. Rev. Lett., 128, 095901 (2022)
[4] Marchese, Macheda, Mauri and al., Nat. Phys. (2023)
[5] Bistoni, Mauri, and Calandra, Phys.Rev.Lett. 126,225703 (2019)
[6] Saparov, Niu et al., Phys. Rev. B 105, 064303 (2022)

TT 84.2 Fri 9:45 H 1058

Magnon-phonon coupling in $Co_{25}Fe_{75}$ thin film/crystalline substrate heterostructures — •J. Weber[1,2], M. Müller[1,2], F. Engelhardt[3,4,5], V. Bittencourt[6], T. Luschmann[1,2,7], M. Cherkasskii[5], S.T.B. Goennenwein[8], S.V. Kusminskiy[5,3], S. Geprägs[1], R. Gross[1,2,7], M. Althammer[1,2], and H. Huebl[1,2,7] — [1]Walther-Meißner-Institut, Bayerische Akademie der Wissenschaften, Garching, Germany — [2]School of Natural Sciences, Technical University of Munich, Garching, Germany — [3]Max Planck Institute for the Science of Light, Erlangen, Germany — [4]Department of Physics, University Erlangen-Nuremberg, Erlangen, Germany — [5]Institute for Theoretical Solid State Physics, RWTH Aachen University, Aachen, Germany — [6]ISIS (UMR 7006), Université de Strasbourg, Strasbourg, France — [7]Munich Center for Quantum Science and Technology (MCQST), Munich, Germany — [8]Department of Physics, University of Konstanz, Konstanz, Germany

The coupling between the quantized excitations of the spin system (magnons) and the lattice (phonons) regained interest due to potential applications in quantum devices. Here, we report the coherent excitation of elastic waves in a metallic ferromagnetic $Co_{25}Fe_{75}$ thin film by driving its Kittel modes, leading to the excitation of transverse acoustic phonons in the substrate forming a bulk acoustic wave resonator. Our results agree well with model calculations based on the magnetic and acoustic properties of the magnetic and elastic subsystems and allow to determine the effective magnetoelastic coupling strength.

TT 84.3 Fri 10:00 H 1058

Light induced magnetization in $SrTiO_3$ — •Natalia Shabala and R. Matthias Geilhufe — Department of Physics, Chalmers University of Technology, 412 96 Göteborg, Sweden

Dynamical multiferroicity refers to magnetization of a material caused by a temporally varying polarization [1]. Such phenomena can be light-induced. For example, Kerr-effect measurements on THz-pumped $SrTiO_3$ (STO) reveal significant magnetic moments in the sample of about 0.1 Bohr magneton per unit cell, while $SrTiO_3$ itself is non-magnetic [2]. Moreover, this value is significantly larger than the one expected from a circularly moving charge argument. We attempt to understand this discrepancy by finding a connection between magnetization resulting from optically driven chiral phonons and Berry connection. By extending the formalism of inverse Faraday effect to phonons and applying modern theory of polarization, we hope to develop a better understanding of the large difference between theoretical and experimental values of light induced magnetization. In the prospect of "phonon-enabled technology", we apply our formalism to investigate a Hall effect in graphene/STO, mediated by light-induced chiral phonons in the STO substrate. We find that a laser field strength of 0.1 MV/m and a current of 1 mA will cause a transverse electric field of about 40 nV, which can be measured in state-of-the-art experiments.

[1] D. M. Juraschek et al., "Dynamical multiferroicity", *Phys. Rev. Mater.*, 1.1 (2017): 014401
[2] M. Basini et al., "Terahertz electric-field driven dynamical multiferroicity in $SrTiO_3$", *arXiv preprint arXiv:2210.01690* (2022)

TT 84.4 Fri 10:15 H 1058

Creating and observing elliptically polarized coherent optical shear phonons in graphite — Arne Ungeheuer, Mashood T. Mir, Ahmed S. Hassanien, Lukas Nöding, Thomas Baumert, and •Arne Senftleben — Institut für Physik, Universität Kassel

We present a scheme to create circularly or elliptically polarized coherent phonons of the degenerate inter-layer shear mode in graphite. The approach utilizes the time-delayed excitation of two coherent phonons linearly polarized in perpendicular directions by femtosecond laser pulses. We observe the resulting elliptically polarized coherent phonon using ultrafast electron diffraction [1], where they create a unique signature that allows us to determine the phonon's ellipticity and sense of rotation. Analyzing the atomic motion in the crystal, we find that the atoms in adjacent layers circulate in the same direction in a Hula hoop fashion. In magnetic materials, such elliptically polarized phonons can create a transient magnetization in an atomistic version of the Barnett effect [2].

[1] C. Gerbig, et al. *New J. Phys.* **17**, 043050 (2015).
[2] T. F. Nova, et al. *Nature Phys.* **13**, 132–136 (2017).

TT 84.5 Fri 10:30 H 1058

Chirality of spin and orbital dynamics in laser-induced demagnetization — •Junjie He — Charles University, Prague, Czech Republic

Despite spin (SAM) and orbital (OAM) angular momentum dynamics are well-studied in demagnetization processes, their components receive less focus. Here, we utilize the real-time ab initio theory to unveil significant x and y components of SAM and OAM induced by circularly left (σ+) and right (σ-) polarized laser pulse in Ferromagnetic metals. Our results show that the magnitude of OAM is an order of magnitude larger than that of SAM, highlighting a stronger optical response from the orbital degrees of freedom of electrons compared to spin. Additionally, we observe a marked dependency of the oscillations of the x and y components on the optical helicity. Intriguingly, $\sigma+$ and σ- pulses induce chirality in the precession of SAM and OAM, respectively, with clear associations with laser frequency and duration. Our results could be important to understand the polarized phonon in the demagnetization process.

TT 84.6 Fri 10:45 H 1058

Ultrafast symmetry breaking with multicolor chiral phonons
— •Omer Yaniv and Dominik Juraschek — Tel Aviv University, Tel Aviv, Israel

In the field of ultrafast dynamics, terahertz pulses stand out as powerful tools capable of initiating coherent vibrational motions in crystal lattices. Circularly or elliptically polarized pulses can excite chiral phonons, which are the collective vibrational patterns of circular or elliptical orbital motions of atoms around their equilibrium lattice positions. Such phonons carry angular momentum and are able to generate magnetic fields leading to a varying range of phenomena. Our study explores the coherent driving of chiral phonons using multicolor laser pulses. Such driving allows us to generate different types of magnetic patterns. We focus on IR-active optical degenerate phonons in CsPbF3 with frequencies at 1.8 THz and 3.6 THz and look at three different features of this multicolor phonon driving. We dynamically induce inversion symmetry breaking in the centrosymmetric lattice structure. This can give rise to nonlinear phenomena, such as second harmonic generation (SHG). Additionally, we show the generation of atomic eight-curve motion, which leads to the generation of spatially distinct alternating phononic angular momentum. This gives rise to an antiferromagnetic pattern of the dynamical phonon magnetic moment. Furthermore, our findings indicate that coherent excitation can lead to the formation of new symmetries, such as a 3-fold rotation, arising from atomic cloverleaf motion. We expect our predictions to be realizable with state-of-the-art pulse shaping techniques.

TT 84.7 Fri 11:00 H 1058

Chiral phonons as dark matter detectors
— •Carl Romao[1], Riccardo Catena[2], Nicola Spaldin[1], and Marek Matas[1] — [1]Department of Materials, ETH Zurich, CH-8093 Zurich, Switzerland — [2]Department of Physics, Chalmers University of Technology, SE-412 96 Goteborg, Sweden

We have proposed a method for detecting single chiral phonons using magnetometers. This would allow chiral phonons to be used as dark-matter detectors capable of exploring a multitude of unprobed dark-matter candidates. Metal*organic frameworks are potential candidate detector materials, as their flexibility yields low-energy chiral phonons with measurable magnetic moments, and their anisotropy leads to directional sensitivity, which mitigates background contamination. InF3(4,4'-bipyridine) has been identified as a candidate material; sensing of its phonon magnetic moments would extend detector reach by orders of magnitude below current limits.

TT 84.8 Fri 11:15 H 1058

Nuclear boost to pseudomagnetic fields from quantum geometry
— •Lennart Klebl[1], Arne Schobert[1], Giorgio Sangiovanni[2], Alexander V. Balatsky[3,4], and Tim O. Wehling[1,5] — [1]Universität Hamburg, Germany — [2]Universität Würzburg, Germany — [3]University of Connecticut, Storrs, USA — [4]Nordita, Stockholm University and KTH Royal Institute of Technology, Stockholm, Sweden — [5]The Hamburg Centre for Ultrafast Imaging, Germany

Recent experiments demonstrate precise control over coherently excited phonon modes using high-intensity terahertz lasers, opening new pathways towards dynamical, ultrafast design of magnetism in functional materials. While in qualitative agreement with the observed dynamics in experiments, the theoretically predicted magnetic field strengths of circularly polarized phonon modes lack three orders of magnitude. In this work, we put forward a coupling mechanism based on electron-nuclear quantum geometry. This effect is rooted in the adiabatic evolution of the electronic wavefunction under a circular evolution of nuclear coordinates. The excitation pulse then induces a transient level splitting between electron orbitals that carry angular momentum. When converted to effective magnetic fields, values on the order of tens of Teslas are easily reached. We give criteria under which the evolution of nuclear degrees of freedom can be described adiabatically in the electronic sector and find that in the perovskite $SrTiO_3$, the adiabatic regime is in experimental reach.