DF 9: Focus Session: Skyrmions meet Multiferroicity

Bridging the gap between multiferroicity and skyrmions, which are themselves of high importance for new electronic building blocks, is an upcoming challenge. Recently, magnetoelectric effects and ferroelectric phases were demonstrated in insulating skyrmion crystals comprising novel mechanisms of complex magnetic and unconventional ferroelectric order. The focus session introduces the new field of skyrmion dielectric solids and aims at an inspiring interdisciplinary discussion.

Organized by Stephan Krohns

Time: Wednesday 9:30–12:50 Location: H25

Topical Talk DF 9.1 Wed 9:30 H25

Functional domain walls in multiferroics — •Dennis Meier — ETH Zürich, Switzerland

During the last decade a wide variety of novel and fascinating correlation phenomena has been discovered at domain walls in multiferroic bulk systems, ranging from unusual electronic conductance to inseparably entangled spin and charge degrees of freedom. The domain walls represent quasi-2D functional objects that can be induced, positioned, and erased on demand, bearing considerable technological potential for future nanoelectronics. Most of the challenges that remain to be solved before turning related device paradigms into reality, however, still fall in the field of fundamental condensed matter physics and materials science. In my talk I will provide an overview of seminal experimental findings gained on electric and magnetic domain walls in multiferroic bulk materials. A special focus is put on the physical properties that emerge at so-called charged domain walls and the added functionality that arises from coexisting magnetic order. The goal is to draw attention to the persistent challenges and identify future key directions for the research on functional domain walls in multiferroics.

DF 9.2 Wed 10:00 H25

Dielectric properties of the spin driven multiferroic linarite — •Alexander Ruff, Theresa Mack, Stephan Krohns, and Alois Loidl — Experimental Physics V, Center for Electronic Correlations and Magnetism, University of Augsburg, Germany

In the last decade various mechanisms for coupled polar and magnetic ordering, so called multiferroicity, were discovered. Among various multiferroic systems, spin-driven ferroelectrics are in the scientific focus due to a close coupling of spin and charge leading to cross-link control of magnetic and electric order. These systems have noncollinear spin structures, e.g., magnetic phases with spiral or helical order. Thus, two canted neighbouring spins S_i and S_j allow for inverse Dzychaloshinskii-Moriya interaction resulting in spin-driven ferroelectric polarization P via P = Q x (S_i x S_j), where Q denotes the propagation vector of the spin spiral. Those complex magnetic phases often reveal unconventional magnetic behaviour, which can be found in frustrated quantum spin systems, like $LiCuVO_4$ or the naturally grown single crystal linarite, $PbCuSO_4(OH)_2$.

Here we present the dielectric properties as well as the ferroelectric polarization obtained via pyro- and magnetocurrent measurements, both in applied magnetic fields up to 9 T. Their analysis allows validating the theoretical prediction of P = Q x (S_i x S_j). Compared to prototypical $LiCuVO_4$, linarite crystallizes monoclinic leading to a more complex relation of crystallographic direction, ferroelectric polarization and spin spiral axis. Finally, we provide (H,T)-diagrams for the multiferroic phase of linarite.

Topical Talk DF 9.3 Wed 10:20 H25

Neutron scattering study of the cycloidal and Néel-type skyrmion lattice phases of GaV_4S_8 — •Sándor Bordács[1], Jonathan S White[2], Nicole Reynolds[2,3], Charles D Dewhurst[4], Henrik M Rønnow[3], Vladimir Tsurkan[5], Alois Loidl[5], and István Kézsmárki[1] — [1]Department of Physics, Budapest University of Technology and Economics, Budapest, Hungary — [2]Laboratory for Neutron Scattering and Imaging, PSI, Villigen, Switzerland — [3]Laboratory for Quantum Magnetism, EPFL, Lausanne, Switzerland — [4]Institut Laue-Langevin, Grenoble, France — [5]Experimental Physics V, Center for Electronic Correlations and Magnetism, University of Augsburg, Augsburg, Germany

Recently, it was shown that not just whirlpool-like i.e. Bloch-type skyrmions but also Néel-type skyrmions formed by spin cycloids can exist in nature and the polar crystal symmetry of the Mott-insulator GaV_4S_8 can host this new kind of topological magnetic structures [1].

Here, we report the results of polarized small angle neutron scattering (SANS) experiments in the magnetically ordered phases of GaV_4S_8. We could experimentally demonstrate that the modulated magnetic states of GaV_4S_8 are formed by spin cycloids, thus, the helicity state of the skyrmions is compatible with the Néel type. Based on SANS experiments we also revealed that the orientation of the cycloidal wave vector is weakly pinned within the rhomboheral plane. Furthermore, the temperature vs. magnetic field phase diagram of GaV_4S_8 is systematically studied.

[1] I. Kézsmárki, et al., Nature Materials 14, 1116 (2015).

DF 9.4 Wed 10:50 H25

Real-space inspection of Skyrmion lattices with confined orientation in the multiferroic semiconductor GaV_4S_8 — •Erik Neuber[1], Peter Milde[1], Istvan Kézsmárki[2], and Lukas Eng[1] — [1]Institut für Angewandte Physik, TU Dresden, D-01069 Dresden, Germany — [2]Department of Physics, Budapest University of Technology and Economics and MTA-BME Lendület Magneto-optical Spectroscopy Research Group, 1111 Budapest, Hungary

Following early predictions, skyrmion lattices (SkL) constituting a periodic array of spin vortices have now been reported to exist in various magnetic crystals mostly with chiral structure. Although non-chiral but polar crystals with C_{nv} symmetry were identified as ideal SkL hosts, this archetype of SkL has remained experimentally unexplored. In this contribution, we report on the discovery and real-space exploitation of a SkL in the multiferroic polar magnetic semiconductor GaV_4S_8 (GVS) that possesses rhombohedral (C_{3v}) symmetry and easy axis anisotropy [1]. The SkL exists over an unusally broad temperature range compared to other bulk SkL crystals, while the orientation of vortices is pinned along the magnetic easy axis and can not be controlled via external magnetic fields. Our investigation focuses on the real-space inspection of SkL in GVS using various scanning probe techniques.

[1] Kézsmarki et al., Nature Materials **14**, 1116-1122 (2015)

20 min. break

Topical Talk DF 9.5 Wed 11:30 H25

Collective spin excitations at GHz frequencies in Skyrmion-hosting bulk materials — •Dirk Grundler — Laboratoire des Matériaux Magnétiques Nanostructurés and Magnoniques, Institut des Matériaux, Faculté Science et Technique de l'Ingénieur, Ecole Polytechnique Fédérale de Lausanne, 1015 Lausanne, Switzerland

Skyrmion-hosting materials have generated great research efforts in fundamental and applied sciences. Collective spin excitations in the GHz frequency regime are in particular interesting as they provide information about the system's free energy and define response times in possible applications, respectively. We report on GHz spectroscopy performed on different bulk materials. For cubic chiral helimagnets supporting Bloch-type Skyrmions, such as insulating Cu_2OSeO_3 and semiconducting $Fe_{0.8}Co_{0.2}Si$, we found a universal behavior when studying the GHz response throughout the magnetic phase diagram (T. Schwarze *et al.*, Nat. Mater. **14**, 478 (2015)). Comparing with data from the polar magnetic semiconductor GaV_4S_8 supporting Néel-type Skyrmions (D. Ehlers *et al.*, arXiv:1512.02391), characteristic changes in the spectra are encountered that we attribute to an additional uniaxial magnetic anisotropy. We acknowledge financial support by the DFG via TRR80. The reported works are performed in cooperations with A. Bauer, H. Berger, D. Ehlers, T. Fehér, M. Garst, I. Kézsmárki, H.-A. Krug von Nidda, A. Leonov, A. Loidl, C. Pfleiderer, T. Schwarze, I. Stasinopoulos, V. Tsurkan, J. Waizner, and S. Weichselbaumer.

DF 9.6 Wed 12:00 H25

Skyrmions carrying electric polarization in multiferroic GaV_4S_8 — •Eugen Ruff[1], Sebastian Widmann[1], Peter

Lunkenheimer[1], Vladimir Tsurkan[1,2], Sandor Bordács[3], István Kézsmárki[1,3], and Alois Loidl[1] — [1]Experimental Physics V, Center for Electronic Correlations and Magnetism, University of Augsburg, Augsburg 86135, Germany. — [2]Institute of Applied Physics, Academy of Sciences of Moldova, Chisinau 2028, Republic of Moldova. — [3]Department of Physics, Budapest University of Technology and Economics and MTA-BME Lendület Magneto-Optical Spectroscopy Research Group, Budapest 1111, Hungary.

As predicted by Bogdanov *et al.*[1], recently a skyrmion lattice (SkL) was found in the magnetic semiconductor GaV_4S_8. Skyrmions, topologically protected spin textures, have a big potential for future applications in data storage. A crucial question is whether the SkL causes a ferroelectric polarization, which can be controlled by an electric field. In this contribution we study the magnetic and polar properties in the lacunar spinel GaV_4S_8. The system shows a structural transition at 44 K, associated with orbital order, and is known to have a complex magnetic phase diagram below 13 K. We show that already below 44 K the system reveals a sizable polarization[3] of $1\ \mu C/cm^2$. Furthermore also the magnetically ordered phases show spin driven excess polarizations, so GaV_4S_8 is multiferroic below 13 K.

[1]A. N. Bogdanov and A. Hubert, J. Magn. Magn. Mater. **138**, 255 (1994). [2]I. Kézsmárki *et al.*, Nat. Mater. **14**, 1116 (2015). [3]E. Ruff *et al.*, Sci. Adv. **1**, e1500916 (2015).

Topical Talk DF 9.7 Wed 12:20 H25

Skyrmionic states in ferroelectric nanocomposites — Yousra Nahas[1], •Sergei Prokhorenko[1,2], Lydie Louis[3], Zhigang Gui[4], Igor Kornev[5], and Laurent Bellaiche[1] — [1]University of Arkansas, Fayetteville, Arkansas, USA — [2]University of Liege, Liege, Belgium — [3]University of Connecticut, Storrs, Connecticut, USA — [4]University of Delaware, Newark, Delaware,USA — [5]Ecole Centrale Paris, Chatenay-Malabry, France

Non-coplanar swirling field textures, or skyrmions, are now widely recognized as objects of both fundamental interest and technological relevance. So far, skyrmions were amply investigated in magnets, where due to the presence of chiral interactions, these topological objects were found to be intrinsically stabilized. Ferroelectrics on the other hand, lacking such chiral interactions, were somewhat left aside in this quest. Here we demonstrate, via the use of a first-principles-based framework, that skyrmionic configuration of polarization can be extrinsically stabilized in ferroelectric nanocomposites. The interplay between the considered confined geometry and the dipolar interaction underlying the ferroelectric phase instability induces skyrmionic configurations. The topological structure of the obtained electrical skyrmion can be mapped onto the topology of domain-wall junctions. Furthermore, the stabilized electrical skyrmion can be as small as a few nanometers, thus revealing prospective skyrmion-based applications of ferroelectric nanocomposites.