MA 3: Focus Session: Novel 3D magnetic spin textures

Theoretical modelling, synthesis and experimental characterization

Time: Monday 9:30–13:15 Location: H38

Invited Talk MA 3.1 Mon 9:30 H38
Three-dimensional solitons in magnetism, nuclei and particle physics — •Paul Sutcliffe — Durham University, Durham, UK.

Magnetic Skyrmions are two-dimensional topological solitons that are analogous to the three-dimensional Skyrmions introduced by Skyrme in the context of high energy particle physics. I shall discuss the similarities and differences between these two kinds of Skyrmions, together with recent progress on using three-dimensional Skyrmions to describe nuclei. Finally, I shall discuss the possibility of three-dimensional topological solitons in magnetism, called Hopfions, and explain their relation to both types of Skyrmion.

Invited Talk MA 3.2 Mon 10:00 H38
Simulations of particlelike states in three-dimensional magnets: chiral skyrmions, bobbers and hopfions — •Filipp N. Rybakov — KTH-Royal Institute of Technology, Stockholm, Sweden

Magnetization vector field of skyrmions in the crystals of chiral magnets look like vortex strings passing through the sample. Skyrmions exhibit particlelike properties and are free to move in the film plane and interact each other as ordinary particles [1]. As the size of the sample grows, skyrmion strings become longer as they are bounded by surfaces. Because of that, they cannot be considered wholly localized in three dimensions (3D). The situation is different for chiral bobbers which represent spin textures entirely localized in 3D and located on the surfaces of volumetric samples or films [2]. They behave like particles, but similar to skyrmions their mobility is restricted to two dimensions because the surface is two-dimensional. The progress in the theory of magnetic solitons, advanced computer simulations together with the development of various experimental techniques providing a full reconstruction of 3D spin textures in crystals allow one to hope for the discovery of truly 3D and intrinsically stable particles which can move in any spatial direction. Such 3D topological solitons are known as hopfions [3].

I will present an overview of recent progress in micromagnetic simulations of all the above solitons.

[1] H. Du et al., PRL 120, 197203 (2018).
[2] F. Zheng et al., Nat. Nanotechnol. 13, 451 (2018).
[3] http://hopfion.com

MA 3.3 Mon 10:30 H38
Interplay of chirality and spin-orbit coupling in the anomalous Hall effect of non-collinear magnets — •Fabian R. Lux[1], Matthias Redies[1], Frank Freimuth[1], Stefan Blügel[1], and Yuriy Mokrousov[1,2] — [1]Peter Grünberg Institut and Institute for Advanced Simulation, Forschungszentrum Jülich and JARA, 52425 Jülich, Germany — [2]Institute of Physics, Johannes Gutenberg University Mainz, 55099 Mainz, Germany

We discuss the emergence of a novel anomalous Hall effect, which is driven by the interplay of spin-orbit coupling and the presence of a non-collinear magnetic structure. The predicted effect is linear in the real-space gradients of the underlying magnetic texture and therefore chiral in nature. Within a semiclassical language, therefore, its origin is neither the emergent field which is responsible for the topological Hall effect, nor is it the pure momentum-space Berry curvature. Rather, it is the same effective magnetic field that is responsible for the emergence of a chiral contribution to the orbital magnetization [1]. This direction opens up new perspectives for the all-electrical detection of non-collinear magnetic structures such as skyrmions, hopfions and chiral bobbers [2].

[1] F. R. Lux *et al.*, Communications Physics **1**, 60 (2018)
[2] M. Redies *et al.*, arXiv:1811.01584 (2018)

Invited Talk MA 3.4 Mon 10:45 H38
Quantitative measurements of three dimensional magnetic textures using off-axis electron holography — •András Kovács[1], Nikolai Kiselev[2], Jan Caron[1], Thibaud Denneulin[1], Fengshan Zheng[1], Dongsheng Song[1], Stefan Blügel[2], and Rafal E Dunin-Borkowski[1] — [1]Ernst Ruska-Centre for Microscopy and Spectroscopy with Electrons, Peter Grünberg Institute, Forschungszentrum Jülich, Germany — [2]Peter Grünberg Institute and Institute for Advanced Simulation, Forschungszentrum Jülich, Germany

Nanoscale particle-like magnetization textures, such as skyrmion [1], chiral bobbers [2], and magnetic hopfions have generated considerable interest, both because of their fundamental physical properties and because they are candidates for future energy efficient recording and storage applications. However, measurements of their magnetic properties and magnetic imaging are challenging as a result of their small dimensions and three-dimensional magnetic field distributions. We use off-axis electron holography [3] in an aberration-corrected TEM to record electron optical phase images of chiral bobbers, Bloch- and Néel-type skyrmions. The phase images are analysed using a model-based iterative reconstruction algorithm to determine the magnetic moment distribution in each sample. Prospects for characterising more complex magnetic textures are discussed. [1] A. Kovacs et al, APL 111, 192410 (2017) [2] F. Zheng et al, Nat. Nanotech. 13, 451 (2018) [3] A. Kovacs and R.E. Dunin-Borkowski, Handbook of Magnetic Materials, vol. 27, p.59-153 (Ed. E.Brueck, Elsevier), 2018

15 min. break

Invited Talk MA 3.5 Mon 11:30 H38
Three-dimensional nanomagnetism: Present and future — •Amalio Fernandez-Pacheco — School of Physics and Astronomy, University of Glasgow, G12 8SU, Scotland, United Kingdom — Cavendish Laboratory, University of Cambridge, CB3 0HE, United Kingdom

Three-dimensional nanomagnetism is a new and exciting area of research focused on investigating nanomagnets that extend beyond the standard planar configuration. In these systems, with unconventional geometries and spin interactions, new physical effects emerge, with interlinked geometry, topology and chirality, paving the way to novel devices with functionalities beyond the substrate plane. However, the leap to 3D is complex, demanding for new fabrication and characterisation tools.

In this talk, I will review recent progress in this area, particularly on results of my group and collaborators. These include the development of "3D nano-printing" processes for advanced nanofabrication, which have allowed us to carry out pioneering experiments where magnetic information in the form of domain walls can be injected into 3D Permalloy nanowires. In these systems, the use of soft X-Ray magnetic microscopy techniques enables the reconstruction of their magnetic configuration in great detail. The extension to 3D also includes multilayered systems, where the interlayer Dzyaloshinskii-Moriya interaction opens a new route to create 3D spin chiral textures.

MA 3.6 Mon 12:00 H38
Magnetic ground states of perfect Py nanotubes and rings — •Elisabeth Josten[1], András Kovács[1], Felix Oertel[2], Artur Glavic[3], Thomas Jansen[1], Trevor P. Almeida[4], Attila Kákay[5], Teresa Wessels[1], Manuel Langer[3], Jörg Raabe[3], Daniel E. Bürgler[1], Katja Höflich[2], and Rafal E. Dunin-Borkowski[1] — [1]Forschungszentrum Jülich, Jülich, Germany — [2]Helmholtz-Zentrum Berlin for Materials and Energy, Berlin, Germany — [3]Paul Scherrer Institut, Villigen PSI, Switzerland. — [4]University of Glasgow, Glasgow, United Kingdom — [5]Helmholtz-Zentrum Dresden-Rossendorf, Dresden, Germany

Magnetic nanotubes (MNTs) have unique static and dynamic magnetic properties due to their size, aspect ratio, curvature and hollow structure. It is important to optimize the magnetic ground states of such 3D curved nano-objects for their successful implementation in novel devices. Recently, the synthesis of MNTs with perfectly circular cross-sections was achieved. The MNTs were fabricated by coating a carbon core template with a magnetron-sputtered permalloy (Py) shell. Here, we focus on the characterization of magnetic states in individual Py nanotubes and their cross-sections, which take the form of magnetic rings (MRs). The MRs were prepared by slicing individual MNTs using focused ion beam milling. For the investigation, we make use of scanning transmission X-ray microscopy and off-axis electron holography performed in a transmission electron microscope. The MRs are found to support novel magnetic states such as double vortices.

Invited Talk MA 3.7 Mon 12:15 H38

Revealing magnetic configurations with X-ray magnetic nanotomography — •Valerio Scagnoli — Laboratory for Mesoscopic Systems, Department of Materials, ETH Zurich, 8093 Zurich, Switzerland — Laboratory for Multiscale Materials Experiments, Paul Scherrer Institute, 5232 Villigen PSI, Switzerland

Three dimensional magnetic systems hold the promise to provide new functionality associated with greater degrees of freedom. Over the last years we have worked towards developing methods to fabricate and characterise three dimensional magnetic structures. Specifically, we have fabricated an artificial magnetic In order to determine the magnetic configuration in such three dimensional systems, we have combined X-ray magnetic imaging with a new iterative reconstruction algorithm to achieve X-ray magnetic tomography [1,2,3]. In a first demonstration, we determine the three dimensional magnetic nanostructure within the bulk of a soft GdCo2 magnetic micropillar, observing a complex magnetic configuration consisting of vortices and antivortices that form cross-tie and vortex walls. By determining the magnetic structure surrounding singularity points found at the intersections of these magnetic structures we have identified the presence of Bloch points of different types [3]. X-ray magnetic nanotomography will enable to unravel complex three dimensional magnetic structures for a range of magnetic systems with high spatial resolution [4].

[1] C. Donnelly et al., PRL 114, 115501 (2015) [2] C. Donnelly et al., PRB 94, 064421 (2016) [3] C. Donnelly et al., Nature 547, 328 (2017) [4] C. Donnelly et al., New J. Phys. 20, 083009 (2018).

MA 3.8 Mon 12:45 H38

Mesoscale Dzyaloshinskii-Moriya interaction: geometrical tailoring of the magnetochirality — •Oleksii Volkov[1], Denis Sheka[2], Yuri Gaididei[3], Volodymyr Kravchuk[3,4], Ulrich Rössler[4], Jürgen Fassbender[1], and Denys Makarov[1] — [1]Helmholtz-Zentrum Dresden-Rossendorf e.V., Dresden, Germany — [2]Taras Shevchenko National University of Kyiv, Kyiv, Ukraine — [3]Bogolyubov Institute for Theoretical Physics of the National Academy of Sciences of Ukraine, Kyiv, Ukraine — [4]Leibniz-Institut für Festkörper- und Werkstoffforschung (IFW Dresden), Dresden, Germany

Magnetic crystals with broken chiral symmetry possess intrinsic spin-orbit driven Dzyaloshinskii-Moriya interaction (DMI). Geometrically broken symmetry in curvilinear magnetic systems also leads to the appearance of extrinsic to the crystal exchange driven effective DMI [1,2]. The interplay between the intrinsic and geometrical-induced DMI paves the way to a mesoscale DMI, whose symmetry and strength depend on the geometrical and material parameters [3]. We demonstrate this approach on the example of a helix with intrinsic DMI. Adjusting the helical geometry allows to create new artificial chiral nanostructures with defined properties from standard magnetic materials. For instance, we propose a novel approach towards artificial magnetoelectric materials, whose state is controlled by means of the geometry.

[1] Y. Gaididei et. al, Phys. Rev. Lett. 112, 257203 (2014).
[2] R. Streubel et. al, J. Phys. D: Applied Physics 49, 363001 (2016).
[3] O. Volkov et. al, Scientific Reports 8, 866 (2018).

MA 3.9 Mon 13:00 H38

Prediction of a novel chiral magnetic interaction originating from the coupling of spin and topological orbital moment in B20 compounds — •S. Grytsiuk, M. Hoffmann, J.-P. Hanke, G. Bihlmayer, Y. Mokrousov, and S. Blügel — Peter Grünberg Institut and Institute for Advanced Simulation, Forschungszentrum Jülich and JARA, 52425 Jülich, Germany

It is believed that the complex magnetic structure of B20 materials, such as FeGe and MnGe, can be explained exclusively in terms of the Heisenberg exchange and antisymmetric Dzyaloshinskii-Moriya (DM) interaction. We demonstrate that this assumption is wrong. We discovered that the spin-spin interactions in MnGe are strongly influenced by the Berry phase effect of carriers hopping in a nontrivial spin background. We show that without SOI the non-coplanar magnetic structure in B20 materials gives rise to a topological orbital moment [1-2]. Moreover, we reveal that in case of MnGe the spin-orbit coupling between the local spins and topological orbital moment dominates over DMI in favoring a magnetic state of certain chirality even without external magnetic field. Together with the biquadratic coupling, that we found important in B20 compounds, we speculate that the corresponding novel chiral magnetic interaction can be a key element in resolving the puzzle of the complex 3D magnetic state of MnGe, and suggest that it can present a platform for realizing new classes of chiral magnetic materials and textures.

[1] M. Hoffmann, at. el., Phys. Rev. B 92, 020401(R) (2015).
[2] J.-P. Hanke, at. el., Sci. Rep. 7, 41078 (2017)