Symposium Curvilinear condensed matter (SYCL)

jointly organized by
the Magnetism Division (MA),
the Chemical and Polymer Physics Division (CPP), and
the Surface Science Division (O)

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Physical properties of living but also synthetic systems in condensed and soft matter are determined by the interplay between the physical order parameters, geometry and topology. Specifically to condensed matter, spin textures, static and dynamic responses become sensitive to bends and twists in physical space. In this respect, curvature effects emerged as a novel tool in various areas of physics to tailor electromagnetic properties and responses relying on geometrical deformations. Until recently, the impact of a curvature on electronic and magnetic properties of solids was mainly studied theoretically. The remarkable development in nanotechnology, e.g. preparation of high-quality extended thin films and nanowires as well as the potential to arbitrarily reshape those architectures after their fabrication, has enabled first experimental insights into the fundamental properties of 3D shaped semiconducting, superconducting, and magnetic nanoarchitectures. The investigation of physical effects governing the responses of curved nanoobjects to electric and magnetic fields has become a general trend in multiple disciplines, including electronics, photonics, plasmonics and magnetics. Considering the rapid development of the field, it is the purpose of this symposium to push the emergent topic of curvature-induced effects in condensed matter systems to a matured independent research direction in the modern condensed matter physics.

Overview of Invited Talks and Sessions

(Lecture hall HSZ 02)

Invited Talks

SYCL 1.1	Fri	9:30–10:00	HSZ 02	**Topology and transport in nanostructures with curved geometries** — •Carmine Ortix
SYCL 1.2	Fri	10:00–10:30	HSZ 02	**Properties of domain walls and skyrmions in curved ferromagnets.** — •Volodymyr Kravchuk
SYCL 1.3	Fri	10:30–11:00	HSZ 02	**3D Mesoscopic Magnetic Architectures: Fabrication, Actuation & Imaging** — •Laura Heyderman
SYCL 1.4	Fri	11:15–11:45	HSZ 02	**3D nanostructures for superconductivity and magnetism** — •Oleksandr Dobrovolskiy
SYCL 1.5	Fri	11:45–12:15	HSZ 02	**Effect of Curvature on Topological Defects in Chiral Condensed and Soft Matter** — •Avadh Saxena

Sessions

SYCL 1.1–1.5	Fri	9:30–12:15	HSZ 02	**Curvilinear Condensed Matter**

SYCL 1: Curvilinear Condensed Matter

Time: Friday 9:30–12:15 Location: HSZ 02

Invited Talk SYCL 1.1 Fri 9:30 HSZ 02
Topology and transport in nanostructures with curved geometries — •Carmine Ortix — Institute for Theoretical Physics, Utrecht University, Netherlands — Dipartimento di Fisica "E. R. Caianiello", Universita' di Salerno, Italy

Recent advances in nanostructuring techniques have enabled the synthesis of compact three-dimensional nanoarchitectures: constructs of one- or two-dimensional nanostructures assembled in curved geometries, such as nanotubes and nanohelices. In this talk, I will first show how the very fundamental quantum mechanical properties of the charge carriers in these nanomaterials are strongly affected by the curved background in which they live. Then I will discuss examples of unique curvature-induced topological and transport properties, including geometrical control of spin and charge transport properties [1], strongly directional dependent magnetoresistance [2,3], the generation of topological insulating phases in shape deformed nanowires with Rashba spin-orbit coupling [4], and non-linear Hall effect due Berry curvature dipoles in corrugated graphene [5,6].

[1] S. K. Das, D. Makarov, P. Gentile, M. Cuoco, B. J. van Wees, C. Ortix, I. J. Vera-Marun, Nano Letters 19, 6839 (2019); [2] C.-H. Chang, J. van den Brink, C. Ortix, Phys. Rev. Lett. 113, 227205 (2014); [3] C.-H. Chang, C. Ortix, Nano Letters 17, 3076 (2017); [4] P. Gentile, M. Cuoco, C. Ortix, Phys. Rev. Lett. 115, 256801 (2015); [5] R. Battilomo, N. Scopigno, C. Ortix, Phys. Rev. Lett. 123, 196403 (2019); [6] S.-C. Ho *et al.*, arXiv: 1910. 07509 (2019).

Invited Talk SYCL 1.2 Fri 10:00 HSZ 02
Properties of domain walls and skyrmions in curved ferromagnets. — •Volodymyr Kravchuk — Karlsruher Institut für Technologie, Karlsruhe, Germany — Bogolyubov Institute for Theoretical Physics, Kyiv, Ukraine

In the presence of the curvature, the topological magnetic solitons (domain walls, skyrmions, vortices) gain a number of new properties. A spatially localized curvature defect can generate the pinning as well as the repulsion potential for domain walls and skyrmions (depending on the signs of the curvature and topological charge of the soliton and also on its helicity). For a large amplitude defect, the pinned skyrmion demonstrates a multiplet of equilibrium states forming the ladder for the energy levels. The transitions between the layers can be controlled by pulses of the external magnetic field. Curvature drastically changes the dynamical properties of the topological solitons: the current-driven domain wall can demonstrate the negative mobility in three-dimensional curvilinear wire with torsion; the gradient of the mean curvature of the film results in the driving force acting on magnetic skyrmions; curvature enriches the spectrum of the spin eigenexitations of the skyrmion. Curvature generally couples the geometrical chirality of the magnet and spin chirality of the magnetic texture. This results in the chirality symmetry breaking effects, e.g. for the domain wall on the Moebius stripe, in the core switching process for a magnetic vortex on a spherical shell.

Invited Talk SYCL 1.3 Fri 10:30 HSZ 02
3D Mesoscopic Magnetic Architectures: Fabrication, Actuation & Imaging — •Laura Heyderman — Laboratory for Mesoscopic Systems, Department of Materials, ETH Zurich, Switzerland — Laboratory for Multiscale Materials Experiments, Paul Scherrer Institute, Switzerland

Advances in the manufacture of magnetic micro- and nanoscale systems in 3D are of great interest because of both the additional degrees of freedom [1] and the possibility to produce devices exploiting new topologies. We have manufactured 3D magnetic structures using two-photon laser lithography in combination with thin film deposition. One example is an artificial buckeyball consisting of a polymer scaffold coated with a cobalt layer that we have characterised with resonant ptychographic tomography to obtain a 3D map of the elemental composition with 25 nm spatial resolution [2]. Furthermore, we have established a method for tomographic imaging of the magnetization vector field, revealing the structure surrounding a Bloch point singularity [3]. We are also developing magneto-mechanical systems, for example a magneto-rheological fluid/polymer composite that displays shape memory [4], and have characterised the microstructure with hard x-ray tomography. In addition, we have created programmable origami micromachines incorporating arrays of nanomagnets such as a microscale bird that can flap, hover, turn and slide [5]. 1. S. Skjaervø et al. Nat Rev Phys 2019; 2. C. Donnelly et al. PRL 2015; 3. C. Donnelly et al. Nature 2017; 4. P. Testa et al. Adv. Mater. 2019; 5. J. Cui et al. Nature 2019.

15 min. break.

Invited Talk SYCL 1.4 Fri 11:15 HSZ 02
3D nanostructures for superconductivity and magnetism — •Oleksandr Dobrovolskiy — Superconductivity and Spintronics Lab, Nanomagnetism and Magnonics, University of Vienna, Austria

Patterned superconductors and nanomagnets are traditionally 2D planar structures, but recent work is expanding superconductivity and nanomagnetism into the third dimension. This expansion is triggered by advanced synthesis methods and the discovery of novel geometry- and topology-induced effects. In addition to self-assembled systems, a high level of maturity is now reached in direct-write nanofabrication by focused electron and focused ion beam induced deposition (FEBID and FIBID, respectively) [1, 2]. In this overview talk, a selection of shape- and curvature-induced effects in 3D superconducting and ferromagnetic structures will be outlined. A particular focus will be on the effects relevant for novel spintronic functionalities relying upon (i) the dynamics of Abrikosov vortices in superconductors [3], (ii) the dynamics of spin waves in ferromagnets [4], and (iii) the interplay of superconductivity and magnetism in heterostructures [5].

[1] M. Huth *et al.*, Microelectron. Engin. **185-186** (2018) 9.
[2] R. Winkler *et al.*, J. Appl. Phys. **125** (2019) 210901.
[3] O. Dobrovolskiy *et al.*, Nat. Commun. **9** (2018) 4927.
[4] O. Dobrovolskiy *et al.*, ACS Appl. Mater. Interf. **11** (2019) 17654.
[5] O. Dobrovolskiy *et al.*, Nat. Phys. **15** (2019) 477.

Invited Talk SYCL 1.5 Fri 11:45 HSZ 02
Effect of Curvature on Topological Defects in Chiral Condensed and Soft Matter — •Avadh Saxena — Los Alamos National Lab, USA

The interplay of geometry and topology underlies many novel and intriguing properties of a variety of hard and soft materials including chiral magnets, nematic liquid crystals, and biological vesicles. These materials harbor a gamut of topological defects ranging from domain walls, dislocations, disclinations, solitons, vortices, skyrmions and merons to monopoles, Dirac strings, hopfions and boojums among many others. I will illustrate this rich interplay with three distinct physical examples. (i) Either the change in the underlying curved manifold or the variation of the Dzyloshinskii-Moriya interaction (DMI) with curvature in magnetic systems. (ii) Controlled motion and confinement of liquid crystal skyrmions near curved boundaries using the Q-tensor (as opposed to director) based free energy where the twist acts as the analogue of DMI. (iii) Deformation of biological membranes and vesicles using Canham-Helfrich free energy and Bogomol*nyi decomposition technique to determine equilibrium shapes. Finally, I will briefly describe specific applications of these ideas in spintronics, memory devices, drug delivery systems as well as active matter and nonlinear relativistic systems.