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 Audimax 2)

Invited Talks

SYCL 1.1	Wed	10:00–10:30	Audimax 2	**Curvature Effects and Topological Defects in Chiral Condensed and Soft Matter** — •Avadh Saxena
SYCL 1.2	Wed	10:30–11:00	Audimax 2	**Topology and Transport in nanostructures with curved geometries** — •Carmine Ortix
SYCL 2.1	Wed	11:15–11:45	Audimax 2	**Superconductors and nanomagnets evolve into 3D** — •Oleksandr Dobrovolskiy
SYCL 2.2	Wed	11:45–12:15	Audimax 2	**Properties of domain walls and skyrmions in curved ferromagnets** — •Volodymyr Kravchuk
SYCL 2.3	Wed	12:15–12:45	Audimax 2	**X-ray three-dimensional magnetic imaging** — •Valerio Scagnoli

Sessions

SYCL 1.1–1.2	Wed	10:00–11:00	Audimax 2	**Curvilinear condensed matter 1**
SYCL 2.1–2.3	Wed	11:15–12:45	Audimax 2	**Curvilinear condensed matter 2**

SYCL 1: Curvilinear condensed matter 1

Time: Wednesday 10:00–11:00 Location: Audimax 2

Invited Talk SYCL 1.1 Wed 10:00 Audimax 2
Curvature Effects and Topological Defects in Chiral Condensed and Soft Matter — •Avadh Saxena — Theoretical Division, 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) Curvature induced quantum potential on minimal surfaces such as helicoids and catenoids (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 Dzyloshinskii-Moriya interaction in chiral magnets. (iii) Deformation of biological membranes and vesicles using Canham-Helfrich free energy and Bogomolnyi decomposition technique to determine equilibrium shapes. Finally, I will briefly describe specific applications of these ideas in memory devices, drug delivery systems as well as active matter and nonlinear relativistic systems.

Invited Talk SYCL 1.2 Wed 10:30 Audimax 2
Topology and Transport in nanostructures with curved geometries — •Carmine Ortix — Institute for Theoretical Physics, Utrecht University, Princetonplein 5, 3584 CC, Utrecht Netherlands — Dipartimento di Fisica "E. R. Caianiello", Universita' di Salerno, I-84084 Fisciano (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 discuss examples of unique geometry-driven topological and transport properties. These include the appearance of a non-linear Hall effect with time-reversal symmetry due to the Berry curvature dipole in corrugated bilayer graphene [1,2], the geometric control of spin transport properties in curved metallic nanochannels [3], the prediction of a strongly directional magnetotransport in carbon nanoscrolls [4], and the generation of topological insulating phases in shape-deformed semiconducting nanowires [5].

[1] R. Battilomo, N. Scopigno, C. Ortix, Physical Review Letters 123, 196403 (2019). [2] S.-C. Ho, C.-H. Chang, Y.-C. Hsieh, S.-T. Lo, B. Huang, T.-H.-Yen Vu, C. Ortix, T.-M. Chen, Nature Electronics 4, 116 (2021). [3] K. S. Das, D. Makarov, P. Gentile, M. Cuoco, B. J. van Wees, C. Ortix, I. J. Vera-Marun, Nano Letters 19, 6839 (2019). [4] C.-H. Chang, C. Ortix, Nano Letters 17, 3076 (2017). [5] P. Gentile, M. Cuoco, C. Ortix, Physical Review Letters 115, 256801 (2015).

SYCL 2: Curvilinear condensed matter 2

Time: Wednesday 11:15–12:45 Location: Audimax 2

Invited Talk SYCL 2.1 Wed 11:15 Audimax 2
Superconductors and nanomagnets evolve into 3D — •Oleksandr Dobrovolskiy — Superconductivity and Spintronics Laboratory, Nanomagnetism and Magnonics, Faculty of Physics, University of Vienna, Währinger Str. 17, 1090 Vienna, Austria

Patterned superconductors and nanomagnets are traditionally 2D planar structures. However, recent work is expanding superconductivity and nanomagnetism into the third dimension [1]. 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) [2, 3].

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 [4], (ii) the dynamics of spin waves in ferromagnets [5], and (iii) the interplay of superconductivity and magnetism in heterostructures [6].

[1] D. Makarov *et al.*, Adv. Mater. **33** (2021) 2101758.
[2] M. Huth *et al.*, Microelectron. Engin. **185-186** (2018) 9.
[3] A. Fernandez-Pacheco *et al.*, Mater. **13** (2020) 3774.
[4] O. Dobrovolskiy *et al.*, Appl. Phys. Lett. **118** (2021) 132405.
[5] O. Dobrovolskiy *et al.*, Nat. Commun. **11** (2020) 3291.
[6] O. Dobrovolskiy *et al.*, Nat. Phys. **15** (2019) 477.

Invited Talk SYCL 2.2 Wed 11:45 Audimax 2
Properties of domain walls and skyrmions in curved ferromagnets — •Volodymyr Kravchuk — Karlsruhe Institute of Technology, 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 levels 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 curvature gradients result in the driving force acting on domain walls and 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 2.3 Wed 12:15 Audimax 2
X-ray three-dimensional magnetic imaging — •Valerio Scagnoli — Laboratory for Mesoscopic Systems, Department of Materials, ETH Zurich, Zurich, Switzerland — Paul Scherrer Institute, Villigen, 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 characterize three dimensional magnetic structures. Specifically, we have combined X-ray magnetic imaging with new iterative reconstruction algorithms to achieve X-ray magnetic tomography and laminography [1-4]. In a first demonstration, we have determined the three-dimensional magnetic nanostructure within the bulk of a soft GdCo2 magnetic micropillar and we have identified the presence of Bloch points of different types [1] as well as three-dimensional structures forming closed vortex loops [3]. Subsequently, we have used the flexibility provided by the laminography geometry to perform time resolved measurements of the magnetization dynamics in a two-phase micrometer size GdCo disk. Therefore, X-ray magnetic three-dimensional imaging, with its recent extension to the soft X-ray regime [5], has now reached sufficient maturity that will enable to unravel complex three-dimensional magnetic structures for a range of magnetic systems.

[1] C. Donnelly et al., Nature 547, 328 (2017) [2] C. Donnelly et al., New J. Phys. 20, 083009 (2018) [3] C. Donnelly et al., Nat. Phys. 17, 316 (2021) [4] C. Donnelly et al., Nat. Nanotechnol. 15, 356 (2020) [5] K. Witte et al., Nano Letters 20, 1305 (2020)