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Editorial: Topological Soft Matter

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Editorial on the Research Topic

Topological Soft Matter

In recent years, topology has acquired more and more importance in hard-condensed matter systems such as superconductors or photonic materials [1, 2]. Yet it also plays a central role in soft, non-crystalline materials. The behavior of many soft materials relies on vector fields, such as the nematic director in liquid crystals, velocity in fluids or in active particles, deformation in soft solids, or the orientation of fibers. All these fields can host singularities, or topological defects [3], which are crucial in determining the properties and behavior of soft systems [4]. The goal of this Special Topic is to bring together perspective from soft matter scientists on the role of topological defects in soft materials, focusing especially on metamaterials, liquid crystals, and active matter.

When thinking about topological materials, topological insulators immediately come to mind [5]. Soft analogs of such materials are provided by topological mechanical networks, or phononic metamaterials, where the propagation of mechanical deformations is suppressed in the bulk material but allowed at the boundaries, thus creating edge modes similar to those found in topological insulators. An example of such a material is described in the work by Ronellenfitsch and Dunkel, which shows the emergence of chiral edge modes in mechanical networks. These systems open new perspectives for the design of phononic metamaterials with exotic properties such as negative Poisson's ratio, negative effective mass, or gapped vibrational spectra.

Liquid crystals also offer fascinating perspectives in the design of photonic metamaterials, where matter and light can interact in unusual ways. Liquid crystal defects are characterized by strong elastic interactions and can therefore be used to direct the self-assembly of colloidal particles into complex 3D-architectures, with an optical index that is modulated at the scale of the light wavelength. Do et al. study defects in smectic-A liquid crystals, called oily streaks, to understand how nanoparticles are trapped and assembled within the defect.

Topological defects exist in all vectorial fields, but can defects from different fields crosstalk and interact? This crucial question has recently been addressed in different ways. Piccirillo et al. present an example of crosstalk between singularities in liquid crystals and phase singularities in optics, showing that the manipulation of liquid crystal defects can be a powerful tool to control optical beams.

Beyond applications, liquid crystals also constitute real laboratories to test predictions on topological defects and understand their behavior and interactions, since liquid crystal defects are observable and controllable [6]. This collection shows two important examples of this fine control. On the one hand, Pieranski and Godinho show a “defect collider” to study the annihilation between “dowsons,” special topological defects in nematic liquid crystals whose dynamics resemble that of vortices in superconductors. On the other hand, the work by Harth and Stannarius presents a detailed study of the dynamics of defect interaction in smectic-C liquid crystal films, thus focusing on a nearly 2-dimensional system.

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The ability to control liquid crystal defects comes from the existence of experimental tools to manipulate defects and from the development of predictive tools resulting from the understanding of the liquid crystal free energy. The work by Sussmann and Beller provides a detailed characterization of a new simulation tool to minimize the Landau-deGennes free energy, especially suited for capturing defects in confined nematic liquid crystals and in liquid crystals with imposed surface alignment.

A new open question in soft matter is to understand the role that topological defects have in the organization of active systems and living matter [7]. Defects in living systems appear at several length-scales, from lipid domains to cells, and at all length-scales there is evidence that they drive self-organization. Sengupta offers a perspective focusing on the micro-scale, highlighting the role that defects have in the interaction between microbes and their microenvironment.

Liquid crystal organization of biological material is also the subject of the work by Khadem and Rey, which focuses on the liquid crystalline behavior of tropocollagen, a polymer present in cells' extracellular matrix. This polymer forms rigid structures that create liquid crystal assemblies and drive the orientation of collagen fibers. The role of condensed liquid crystalline phases both in the cell cytoskeleton and in the extracellular matrix is still debated, and this paper sheds light on the energy of condensation of tropocollagen in various micro-environments.

Although the organization of biofibers in the cell cytoskeleton is responsible for the cell mechanical properties, complex cell functions, such as motility or replication, require the presence of force-generators, which bring the system out-of-equilibrium. A bioinspired "active nematic" has recently been developed by

mixing microtubules with kinesin motors [8]. Here topological defects behave as self-propelled particles that control the flows in the material. In this out-of-equilibrium system, questions such as defect-mediated self-assembly of colloidal particles need to be reformulated. The work by Hardoüin et al. focuses on the formation and the dynamics of a line defect around a colloidal particle, paving the way for future research in the field.

Through examples of the behavior of topological defects in mechanical metamaterials, liquid crystals, and active matter, we hope to raise more questions and interest in the role that soft matter systems can play in understanding both the mechanism of formation of topological defects and their practical importance for materials technology and biology.

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