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The geometry and topology of soft materials

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Soft materials can undergo dramatic deformations in response to external perturbations, such as applied fields or thermal fluctuations. This high mechanical and chemical susceptibility has earned these materials the epithet *fragile objects* and is the key to their wide industrial applications ranging from liquid crystal displays to polymer based devices.[1]

Aside from applied fields, geometric and topological constraints provide an additional and less explored route to harness the extreme responsiveness of soft materials (Shim *et al.*, DOI: 10.1039/c3sm51148k). It is this unique feature that allows control of the self-assembly of relatively simple building blocks into complex hierarchical structures with emergent macroscopic properties (Sacanna *et al.*, DOI: 10.1039/c3sm50500f; Zakhary *et al.*, DOI: 10.1039/c3sm50797a; Kaplan *et al.*, DOI: 10.1039/c3sm50488c). Of particular interest are structures that are stable and, at the same time, tailor-made. An open challenge of this field is to understand the properties and design principles of functional materials, made stable and tunable by their non-trivial topology or geometry.

Furthermore, elastic theories that describe soft materials undergoing large deformations are naturally cast in the language of modern differential geometry and topology[2,3] (Santangelo, DOI: 10.1039/c3sm50476j). A key physical concept that permeates the field is the notion of geometric frustration. When soft materials assemble in the presence of geometrical and topological constraints, the regular order favored by local interactions is frustrated and cannot be extended throughout space.

For example, elongated liquid crystal molecules that would normally align their orientation in the bulk cannot do so when constrained on the surface of a spherical particle[3,4] (Nguyen *et al.*, DOI: 10.1039/c3sm50489a). Similarly, hexagonal-crystal-forming colloids run into trouble when ordering on a curved surface.[5,6] In both cases, the different rules of non-euclidean geometry that exist on a curved surface, such as the convergence of parallel lines, frustrate the formation of long-range order. This frustration is typically soothed by spontaneously formed topological

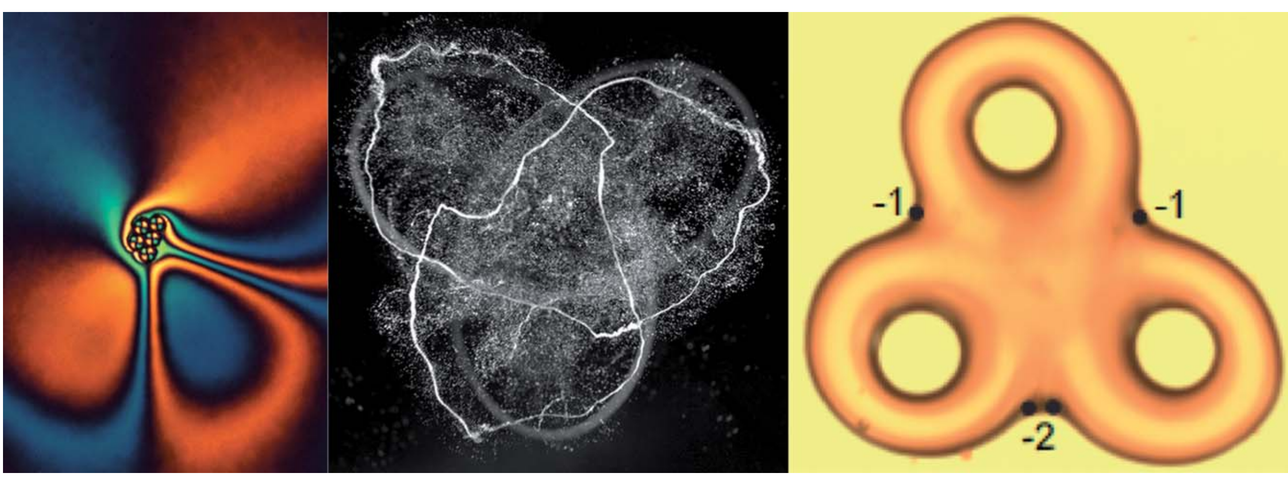

Fig. 1 (left) Handlebody colloidal particles in liquid crystals. Courtesy of I. Smalyukh. (centre) A vortex knot in water. Courtesy of W. Irvine. (right) Stable droplets filled with nematic liquid crystals. Courtesy of A. Fernandez-Nieves.

defects on the surface that can be later functionalized chemically. Colloidal or nano-particles can thereby be turned into macroscopic atoms with a valence.[4,7,8]

Similarly, disclinations and vortices in three-dimensional complex and normal fluids minimize their elastic energy when they are straight lines. Nonetheless, they can be coaxed into knotted and linked field configurations by geometrical and topological constraints, see Fig. 1. The constraints can arise statically from the presence of curved boundaries to which the molecules align[9–11] (Araki *et al.*, DOI: 10.1039/c3sm50468a; Copar *et al.*, DOI: 10.1039/c3sm50475a; Tkalec and Muševič, DOI: 10.1039/c3sm50713k) or dynamically by suitably designed obstacles to flow.[12]

This handful of examples illustrates how geometric and topological frustration, far from being a hindrance, provides an opportunity for the design of novel materials. In this special issue, we bring together experimental and theoretical physicists, mathematicians, mechanical engineers, material scientists and chemists who are active in this burgeoning field. Browsing through the following pages, you will find several examples that illustrate vividly the geometrical and topological paradigm to the physics of soft materials.

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