Research news

Transformation between elastic dipoles, quadrupoles, octupoles, and hexadecapoles driven by surfactant self-assembly in nematic emulsion

B. Senyuk, A. Mozaffari, K. Crust, R. Zhang, J. J. de Pablo, and I. I. Smalyukh, Science Advances, 7, eabg0377, 2021.

From foods and drinks to health and personal care products, emulsions are common but import to our daily life. Nematic emulsions composed of nematic liquid crystals and other liquids have attracted great attention due to their potential applications in many areas ranging from bio-detection to smart windows, which mainly rely on changes of molecular alignment structures around the drops in response to chemical, thermal, electric, and other stimuli. In this work, the authors show that absorption or desorption of trace amounts of common surfactants can drive continuous transformations of elastic multipoles induced by the droplets within the uniformly aligned nematic host. Out-of-equilibrium dynamics of director structures emerge from a controlled self-assembly or desorption of different surfactants at the drop-nematic interfaces, with ensuing forward and reverse transformations between elastic dipoles, quadrupoles, octupoles, and hexadecapoles. The authors also characterise inter-transformations of droplet-induced surface and bulk defects, probe elastic pair interactions, and discuss emergent prospects for fundamental science and applications of the reconfigurable nematic emulsions.

A self-healing ferroelectric liquid crystal electro-optic shutter based on vertical surface-relief grating alignment

P. J. M. Wyatt, J. Bailey, M. Nagaraj, and J. C. Jones, Nature Communications, 12, 4717, 2021.

Ferroelectric liquid crystals exhibit significantly faster optical response times compared to nematics and are of great interest to applications such as displays and spatial light modulators. However, smectic layers are sensitive to shock-induced flow and are usually permanently displaced once a well-aligned sample is disrupted, rendering such devices inoperable. In this work, the authors introduce a vertical alignment geometry combined with a surface-relief grating to control both the smectic layer and director orientations. This mode undergoes ‘self-healing’ of the smectic layers after disruption by shock-induced flow. Sub-millisecond switching between optically distinct states is demonstrated using in-plane electric fields. Self-healing occurs within a second after being disrupted by shock, wherein both the layer and director realign without additional external stimulus. This technique shows promising potential for various applications such as fast spatial light modulators for high-speed adaptive optics, micro-displays for virtual/augmented reality and telecommunications with inherent shock stability.

Electrically driven formation and dynamics of swallow-tail solitons in smectic A liquid crystals

Y. Shen and I. Dierking, Materials Advances, 2, 4752–4761, 2021. DOI: 10.1039/D1MA00356A

Solitons are self-sustained spatially localised waves that propagate with constant speeds and shapes in nonlinear matter. They have been observed in many branches of physics, such as nonlinear photonics, superfluids, plasma, superconductors, magnetic materials, and liquid crystals. However, solitons in liquid crystals have mainly been observed in nematics so far. In this publication, Shen and Dierking report the generation of dynamic three-dimensional particle-like solitons in a smectic A liquid crystal. The soliton is a localised ‘swallow-tail’-like deformation of smectic layers with a singular defect line located at its focus. They can move through a slab of uniformly aligned smectic bulk in a direction perpendicular to the smectic layers with a constant speed and do not spread while moving over macroscopic distances hundreds times larger than their size. Both the speed and the direction of the solitons can be controlled by the frequency and amplitude of the electric field. During the motion, the solitons survive collisions with each other, restoring shape and speed. The solitons can also form linear chains that move with constant speeds and can even interact with colloidal particles. The authors provide a facile method for generating and manipulating multi-dimensional solitons in
smectic liquid crystals which is attractive to not only physical and material scientists due to their rich non-linear dynamic behaviours, but also engineers due to their potential applications such as targeted delivery of optical information and micro-cargo.

**Active liquid crystals powered by force-sensing DNA-motor clusters**

M. Tayar, M. F. Hagan, and Z. Dogic, PNAS, 118(30), e2102873118, 2021

Cytoskeletal active nematics exhibit striking nonequilibrium dynamic behaviours that are powered by energy-consuming molecular motors. To understand the structure and mechanics of these materials, the authors design programmable clusters in which kinesin motors are linked by a double-stranded DNA linker. These clusters have a programmable binding strength, rupturing above critical applied stress and thereafter ceasing to generate microtubule sliding and associated active stresses. Monitoring the fraction of bound clusters within an active nematic uncovers the average load experienced by the motors, an essential yet previously inaccessible parameter. Such programmable DNA-based force-sensing motor clusters provide insights into both the molecular structure, mechanics, and active stress generation of microtubule-based active nematics.

**Active phase separation by tuning towards regions of higher density**

J. Zhang, R. Alert, J. Yan, N. S. Wingreen, and S. Granick, Nature Physics, 17, 961–967, 2021.

From molecular assemblies to animal groups, studies of active matter have revealed two broad classes of behaviour: a tendency to align yields orientational order and collective motion, whereas particle repulsion leads to self-trapping and motility-induced phase separation. In this work, a third class of behaviour: orientational interactions that produce active phase separation is reported. By combining theory and experiments on self-propelled Janus colloids, the authors show that stronger repulsion on the rear than on the front of these particles produces non-reciprocal torques that reorient particle motion towards high-density regions. Particles thus self-propel towards crowded areas, which leads to phase separation. Clusters remain fluid and exhibit fast particle turnover, in contrast to the jammed clusters that typically arise from self-trapping, and interfaces are sufficiently wide that they span entire clusters. This work identifies a torque-based mechanism for phase separation in active fluids, and predicts that these orientational interactions yield coexisting phases that lack internal orientational order.

**Transmembrane transport in inorganic colloidal cell-mimics**

Z. Xu, T. Hueckel, W. T. M. Irvine, and S. Sacanna, Nature, 597, 220–224, 2021.

Living cells are able to harvest energy from environment and use it to pump specific atomic and molecular species in and out of their system. Active transport allows cells to store metabolic energy, extract waste and supply organelles with basic building blocks at the sub-micrometre scale. In this work, the authors report the generation of microcapsules which can be brought out of equilibrium by simple global variables (illumination and pH), to capture, concentrate, store and deliver generic microscopic payloads. They use hollow colloids serving as spherical cell-membrane mimics, with a well-defined single micropore. Precisely tunable monodisperse capsules are the result of a synthetic self-inflation mechanism and can be produced in bulk quantities. Inside the hollow unit, a photo-switchable catalyst produces a chemical gradient that propagates to the exterior through the membrane’s micropore and pumps target objects into the cell, acting as a phoretic tractor beam. An entropic energy barrier brought about by the micropore’s geometry retains the cargo even when the catalyst is switched off. Delivery is accomplished on demand by reversing the sign of the phoretic interaction. Their findings provide a blueprint for developing the next generation of smart materials, autonomous micromachinery and artificial cell-mimics.

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