Direct 3D observation of topological defect dynamics in liquid crystal

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Topological defects – topologically nontrivial structures that may exist in an order parameter field – are generic concepts that abound in a wide variety of fields, ranging from dislocations in crystal and disclinations in liquid crystal, to quantum vortices in superfluid and cosmic strings in cosmology. One may therefore ask what features of topological defects are common to different systems and what are unique to each. Liquid crystal is a particularly interesting system to address such questions, partly thanks to its amenability to direct optical observations, and also because of the recent surge of studies on active nematics [1] showing the presence and important roles of topological defects in microtubule bundles, bacterial colonies, and even in the body formation of a microorganism.

Here we aim at direct observations and characterization of 3D structures and dynamics of topological defects in nematic liquid crystal, namely disclination lines. Using confocal microscopy and fluorescent dyes, we successfully observed relaxation dynamics of disclination lines generated by a turbulent state [2]. In particular, we will report on reconnections of disclination lines, which are characteristic of such topological defect lines, and wish to argue what aspects of the results are common to different systems and what aspects are unique to liquid crystal. If time allows, we will also describe our interests from the statistical physics viewpoint, which concerns universal scaling laws governing a certain class of non-equilibrium systems, observed in a collection of disclination lines in a turbulent state [3].

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Observation of liquid crystal soliton: topology and kinetics

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Topological solitary waves, dubbed "solitons", represent nontrivial and distorted vector fields, which are distinct to the far-field background, exhibiting particle-like nature. Generating and switching solitons [1]-[6], resembling topologically-protected states such as magnetic skyrmions, have risen the tremendous interest in understanding solitonic behaviors at the microscopic scale. Observing and manipulating them is vital to understand the fundamental nonlinear processes of the localization of waves. The utmost challenge of this field is to understand the mechanism of the generation of the solitons and the resultant possible topological structures and the control of their kinetics towards active cargo transport and the like. Here, we present a novel example of generating a swarm of motile solitonic quasi-particles in micrometer-thick nematic liquid crystals [6]. The solitons are oscillating topological waves driven synchronized with the applied electric field. We show that reversible generation-extinction processes of the solitons and the subsequent motion control with variable angles can be achieved by simply tuning frequency and amplitude of the electric field. How they perform the kinetic motion is based on the electroconvection phenomena, primarily determined by the combinations of the anisotropies of the effective wave flux and elastic deformation. These results offer a playground for further development of soliton physics and applications like on-demand cargo transport.

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Lecture 3

Ferroelectric-antiferroelectric phase transition with large electromechanical response in a dipolar crystal

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Design and creation of functional materials are of great importance not only in technological applications but also in condensed matter physics to obtain physical principles how material function emerges. Soft materials such as polymer gels and liquid crystals have complex internal structure. In these substances, internal degrees of freedom with microscopic and mesoscopic length scale (e.g., liquid crystalline order) couples to macroscopic deformation of the substances, which leads to soft elasticity and cross-coupling effects. This concept is also applicable to crystalline solids because the order parameter characterizing phase transitions (e.g., dielectric polarization) couples with elastic strain [1]. However, simple physical principles to control soft mechanical response via phase transitions involving spontaneous crystal rearrangement remain elusive.

Here we present a simple physical mechanism of such controllability using a simple dipolar crystal model, which may capture an essence of phase transitions between ferroelectric and antiferroelectric phases [2]. Each particle is ellipsoidal shape possessing a permanent dipole moment at its centre, and they form crystalline state at low temperature spontaneously depending on dipolar ordering. By performing molecular dynamics simulation using this off-lattice model, we reveal that energetic frustration between the dipole-dipole interaction and interparticle steric interaction is a key to control ferroelectric-antiferroelectric phase transition accompanied with structural transformation. This phase competition with large lattice misfit is responsible for large electromechanical response under external electric field and mechanical stress.

We also present another mechanism to control dielectric and electromechanical properties with the addition of impurities, which disturb formation of macroscopic polar domain [3]. Finely divided polar domains surrounded by the impurities easily respond to external electric fields and mechanical stress with characteristic dielectric dispersion. The similarity between our system and the relaxor ferroelectrics is discussed.

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Lecture 4

Dynamic Assembly of Colloidal Nanosheets

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In living organisms, anisotropic colloids, such as proteins, self-assemble into well-organized hierarchical structures to realize spatiotemporally controlled advanced functions[1]. It is a major challenge in the field of materials science to mimic such sophisticated systems by using artificial building blocks. For this purpose, we have focused on titanate nanosheets (TiNSs)[2] as a promising building block. TiNS is a unilamellar nanosheet dispersed in water, featuring ultra-thin (0.75 nm) and extra-wide (several micrometers) dimensions. Owing to its dense negative charges on its surface, the strong electrostatic repulsion works between TiNSs in addition to the van der Waals attraction. These competitive repulsive and attractive forces allow for interlocking TiNSs in a cofacial manner at a fixed relative position, as described in the Derjaguin–Landau–Verwey–Overbeek (DLVO) theory.

Recently, we have established a rational strategy to precisely control the electrostatic repulsion between TiNSs, so that we can freely tune the distance between TiNSs[3]. As a result, we succeeded in constructing dynamic assemblies of TiNSs, leading to life-like soft materials, such as "a dynamic photonic crystal like tropical fish[3]", "an anisotropic hydrogel like articular cartilage[4]", "a mechanically adaptive hydrogel like sea cucumbers[5]", and "a propagating wave like ciliary waves[6]". In the presentation, a series of these studies will be discussed.

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Lecture 5

Self-organization of deformable colloidal particles at liquid interfaces

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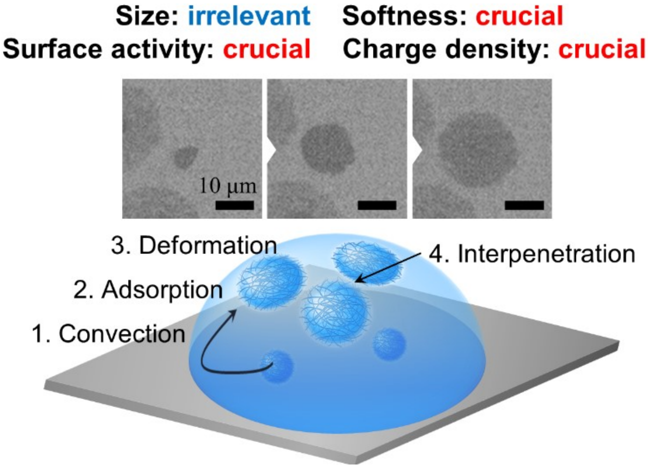
Interfacial behaviors of soft hydrogel microspheres (microgels), which are colloidal particles of cross-linked polymeric networks, will be presented. The author focuses on the drying behavior of aqueous dispersions containing poly(*N*-isopropyl acrylamide) (pNIPAm)-based microgels. Different from dispersions containing solid microspheres such as polystyrene and silica ones, we found that soft and deformable microgels did not exhibit "coffee-ring effect", which results in ring-like stain after dispersions evaporate. Our group has investigated that the self-organization of microgel dispersions during evaporation exhibit unique drying behaviors due to their selective adsorption at the air/water interface of sessile droplets. In the presentation, effects of size, crosslinking densities, types of chemical species, charge, shape for microgels, substrates and so forth on the phenomenon will be summarized. Our findings of this study would promote further development in many applications that understanding the interfacial behaviors of soft and deformable microgels is crucial, including emulsions, foams, coating and sensors.



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Nonequilibrium nature in meniscus splitting of aqueous polysaccharide suspensions

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The air-water interface is expected to play an important role in establishing a universal model of dissipative structures in nature. Viscous fingering, as an example of fluidic flow, is an unstable situation that is widely known as *tears of wine*. This has been explained through the Marangoni effect, coffee ring effect, Saffman-Taylor instability, etc. However, due to the transitional nature of these phenomena, there are few strategies for immobilizing such fluidically regulated interfaces. Recently, such phenomena have been applied successfully to an immobilized structure by controlling the evaporation of a mixture of biopolymer and water.[1-7]
In this study, we present a brief discussion of nonequilibrium phenomenon, “meniscus splitting”. More precisely, an air-liquid interface is divided into multiple interfaces to partition a space. In particular, by using a mixture of polysaccharides and water, a macroscopic pattern following a specific rule could be confirmed. When the mixture is dried from a top open cell, the polymer forms deposits at specific positions to split the meniscus by bridging a millimeter-scale gap. Because water irreversibly evaporates from the liquid phase to the air phase through a gap, the air-liquid interface is in a nonequilibrium state between polymer deposition and water evaporation. The interfacial instability is comparable to the mechanical instability of gels at the phase transition or to the skin layer of gel surfaces during shrinking. Furthermore, the deposited polymer film acts as vapor-sensitive materials. Here, the phenomenon and the material’s behavior would be discussed from physicochemical viewpoints.

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Emergent functions in a swarm of biomolecular motors

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Recent advancements in molecular robotics have been greatly contributed by the progress in various fields of science and technology, particularly in supramolecular chemistry, bio- and nanotechnology, and informatics. Yet one of the biggest challenges in molecular robotics has been controlling a large number of robots at a time and employing the robots for any specific task as flocks in order to harness emergent functions. Swarming of molecular robots has emerged as a new paradigm with potentials to overcome this hurdle in molecular robotics.

In this this talk, I will discuss the latest developments in swarm molecular robotics, particularly emphasizing the effective utilization of bio- and nanotechnology in swarming of molecular robots. Importance of tuning the mutual interaction among the molecular robots in regulation of their swarming is introduced. Successful utilization of DNA, photoresponsive molecules, and natural molecular machines in swarming of molecular robots to provide them with processing, sensing, and actuating ability is highlighted. The potentials of molecular swarm robots for practical applications by means of their ability to participate in logical operations and molecular computations are also discussed. Prospects of the molecular swarm robots in utilizing the emergent functions through swarming are also emphasized together with their future perspectives.

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