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Special Topic: Active Matter

Preface to the special topic on active matter

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Active matter refers to systems composed of individual units that consume locally stored energy to generate mechanical motion. Examples of active matter include biological entities such as schools of fish, flocks of birds, bacterial colonies, and synthetic systems such as self-propelled colloidal particles and engineered nanobots. The study of active matter seeks to provide understanding for complex behaviors and emergent phenomena arising from interactions of these energy-consuming units, with implications for fields ranging from physics and biology to materials science and robotics.

Here we organize a special topic on “active matter”, which includes three review articles and four research articles. These contributions cover a wide range of active matter systems, including active colloids, quorum sensing particles, chiral active matter and macroscopic artificial systems.

Traditional active matter research focuses primarily on linearly moving particles which have a symmetric body and self-propel along one of the symmetry axes. However, the building blocks of active systems, such as cytoskeleton filaments and molecular motors, often exhibit chiral asymmetry. The left-right symmetry breaking can give rise to chiral motility. Through particle interactions, this individual chiral motility can lead to many fascinating phenomena such as odd viscosity, odd diffusivity, dislocation dynamics in odd elasticity crystals, and hyperuniform states. In a review, Mecke *et al.* [1] summarized recent experimental and theoretical advances in chiral active matter system, such as the emergence of anti-symmetric odd stresses and topologically protected edge modes. In addition to the discussions on the fundamental mechanisms, the authors also provided insights into the potential of chiral active matter for various applications.

Newton’s third law establishes that the fundamental microscopic interactions between particles are reciprocal. However, this action-reaction symmetry can be broken when interactions are mediated through nonequilibrium environments. Such nonreciprocal interactions are prevalent in active matter systems where thermal equilibrium is broken at the individual level. In a research article, Zhou *et al.* [2] investigated the effect of the nonreciprocal interactions in a numerical model with a quorum sensing mechanism. In this model, individual particles change their diffusivity from high to low values, as the local concentration of their closest peers grows larger than a certain threshold. The authors demonstrated that the system exhibits a variety of two-phase (hot and cold) configurations with different interaction parameters.

Phase separation phenomenon widely exists in physical and biological systems. Understanding and controlling phase separation is of both fundamental and applied importance. In a research article, Peng *et al.* [3] investigated the spatiotemporal control of phase separation in chemically active immotile colloids, whose interactions are controlled by excitation light. The authors show that, by tuning the trigger frequency of light, they can control the lengths and growth kinetics of phase separation of silver colloids. In addition, the authors successfully used structured light to precisely control the shape, size, and contour of the phase-separated patterns.

Apart from exhibiting rich and exotic phenomena, active fluids can serve as an active bath that significantly influences the structure and dynamics of immersed passive objects, compared to an equilibrium bath. For instance, active environment can enhance effective temperature of passive particles, power a directed motion of asymmetric objects, and induce unexpected self-assemblies of passive colloids. Understanding the behavior of passive objects in the active bath is of importance in both fundamental study and practical applications. In a research article, Feng *et al.* [4] investigated the effective diffusion of a passive tracer in the active bath and derived a generalized Langevin equation for the tracer, with a memory kernel and two colored noises. Further, by using a path integral technique, the effective diffusion of the tracer was shown to decrease with the persistent time of active force and to depend nontrivially on the active particle concentration, which are well confirmed by simulations.

It is well known that the active bath can drive an asymmetric passive gear to rotate unidirectionally. However, in a research article, Wang *et al.* [5] demonstrated that a perfectly symmetric gear in a bath of spherical active Brownian particles may also rotate in one direction under certain conditions, due to spontaneous kinetic symmetry-breaking. Unexpectedly, the introduction of interparticle alignment would hinder it. Further investigation reveals that this spontaneous symmetry-breaking behavior shares similarities with the equilibrium phase transition of the Ising model, providing interesting insight into the spontaneous active ratchet phenomena.

Active matter exhibits non-equilibrium behaviors, presenting an appealing alternative pathway for revolutionizing disease diagnostics and therapy. A comprehensive understanding of how active matter interacts with cell membranes is essential for unraveling the underlying physical mechanisms and expanding potential biomedical applications. A review article by Jin *et al.* [6] establishes a conceptual framework elucidating the physiochemical mechanisms governing active matter-biomembrane interactions. They provide a brief overview of physical models concerning active matter and lipid membranes, outlining the typical phenomena arising from various active components, such as artificial active particles, cellular cytoskeletons, bacteria, and membrane proteins. Additionally, they address the ongoing challenges and future perspectives of non-equilibrium systems within living organisms. The insights and fundamental principles discussed herein illuminate the rational design of activity-mediated cellular interactions, potentially catalyzing the development of innovative functional systems and materials for advantageous biomedical applications.

Besides the active matter in the microscopic scale, artificial active matter at a macroscopic scale, comprising vibrating particles, robots, and camphor boats, has garnered increasing attention due to its uniform properties, rich and easily controllable parameters, convenient observation, and the detachment of biochemical processes from physical ones. These unique advantages are particularly beneficial for studying collective behaviors under conditions of strong confinement and crowded environments. A review article by Ning *et al.* [7] provides an overview of motion models, mechanisms, and dynamic characteristics of various active particles, both in unrestricted settings and within complex mediums. Furthermore, it explores the collective behaviors of "dry" active matter, encompassing structural and dynamic properties observed in experimental and theoretical contexts. The impact of hydrodynamic interactions on the dynamics and structure of these active particles within hydrodynamic environments is also summarized. Lastly, the review addresses emerging opportunities and challenges for advancing macroscopic artificial active matter in the future.

We extend our gratitude to all the authors, hoping their work will inspire and drive future advancements in active matter. Our thanks also go to the reviewers, editorial board members, and the production staff of *National Science Open* for their invaluable contributions in maintaining the high standards of these publications.

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