Emergent dynamics of active magnetic colloids

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Strongly interacting colloids driven out-of-equilibrium by an external periodic forcing often develop nontrivial collective dynamics. Active magnetic colloids proved to be excellent model experimental systems to explore emergent behavior and active (out-of-equilibrium) self-assembly phenomena. While colloidal systems are relatively simple, understanding their collective response, especially in out of equilibrium conditions, remains elusive.Dispersions of magnetic particles suspended at a liquid-air or liquid-liquid interface and driven far-from-equilibrium by a transversal alternating magnetic field develop nontrivial dynamic self-assembled structures [1-3]. Experiments revealed new types of nontrivially ordered phases emerging in such systems in a certain range of excitation parameters. These remarkable magnetic non-equilibrium structures emerge as a result of the competition between magnetic and hydrodynamic forces.

Ferromagnetic micro-particles immersed in water and sedimented on the bottom surface turn into colloidal rollers when energized by a single-axis homogeneous alternating magnetic field applied perpendicular to the surface supporting the particles. The activity in this system originates only from spinning degrees of freedom and self-propulsion emerges due to the presence of a solid interface. The rolling motion emerges as a result of spontaneous symmetry breaking of the particle rotations in external field in a certain range of excitation parameters. Experiments reveal a rich collective dynamics of magnetic rollers including a formation of chiral (polar) states – roller vortices [4]. Self-organized roller vortices have an ability to spontaneously switch the direction of rotation and move across the surface. We reveal the capability of certain non-active particles to pin the vortex and manipulate its dynamics [5]. Complex multi-vortex states are revealed.

In a related system ferromagnetic microparticles, suspended at a liquid interface and energized by a uniaxial in-plane alternating magnetic field, spontaneously form arrays of self-assembled spinners rotating in either direction. The spinners, emerging as a result of spontaneous symmetry breaking of clock/counterclockwise rotation of self-assembled particle chains generate vigorous vortical flows at the interface. An ensemble of spinners exhibits chaotic dynamics due to self-generated advection flows. The same-chirality spinners (clockwise or counterclockwise) show a tendency to aggregate and form dynamic clusters. Erratic motion of spinners at the interface generates chaotic fluid flow reminiscent of two-dimensional turbulence [6].

The research was supported by the U.S. Department of Energy, Office of Science, Materials Sciences and Engineering Division.

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