77

Field-induced hexagonal ordering in confined magnetic droplet assemblies

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We present an experimental study of the collective organization of confined magnetic droplets subjected to an external magnetic field. The droplets consist of an organic ferrofluid based on dodecane containing magnetic nanoparticles stabilized with oleic acid. They are generated by microfluidic flow-focusing in an aqueous phase with surfactant (SDS), allowing for controlled droplet size and dispersion (Fig.1a-b).

After deposition on a solid substrate, the droplets initially form a disordered assembly. Under increasing magnetic field, dipolar interactions induce a progressive structural reorganization (Fig.1c). The evolution of the system is quantified by tracking droplet positions over time and computing the hexagonal bond-orientational order parameter ψ_6, which probes the local angular symmetry of the arrangement.

We observe that the system evolves through successive transitions between quasi-stationary states, each characterized by a plateau in ψ_6 (Fig.1d). This stepwise behavior reflects collective rearrangements driven by the magnetic field.

To further characterize the structure, a Delaunay triangulation is applied to define nearest neighbors in a parameter-free manner. From this, the coordination fractions f_5, f_6, and f_7 are extracted. Although ψ_6 increases with the field, indicating enhanced orientational order, the fraction of sixfold-coordinated droplets remains significantly below unity, revealing persistent topological defects.

These results show that the system does not reach a perfect hexagonal crystal but rather a partially ordered state, where confinement and out-of-plane structures limit the relaxation toward the ground state. This work highlights the importance of combining orientational and topological metrics to describe ordering in confined magnetic droplet assemblies.

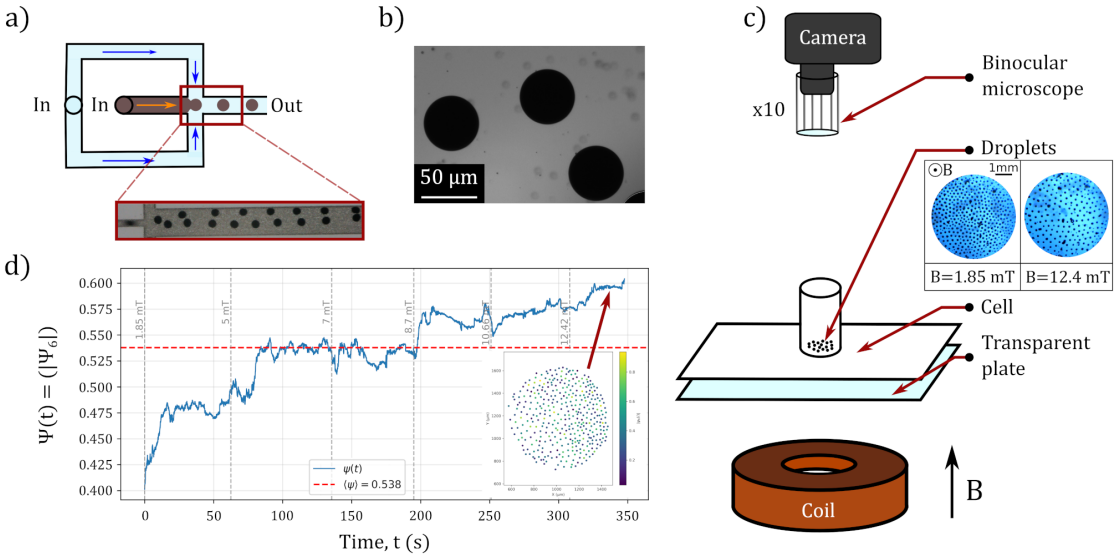

Figure 1: a) Microfluidic flow-focusing device used to generate monodisperse magnetic droplets. b) Optical image of droplets (scale bar: 50 µm). c) Experimental setup: droplets confined on a transparent substrate and subjected to a vertical magnetic field generated by a coil. Insets show typical configurations at low and high magnetic field. d) Temporal evolution of the hexagonal order parameter ψ_6, illustrating the progressive organization of the system through successive quasi-stationary states.

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