Field-Induced Microstructural Reorganization in Colloidal Gels with Magnetic Particles

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Magnetic gels are a broad class of soft materials that have attracted considerable attention in recent years because they can change their shape and properties in situ when an external magnetic field is applied. The field promotes aggregation of the embedded magnetic particles, leading to a restructuring of the gel network. In this work we study colloidal gels in which only a fraction of the particles is magnetic—as a model for micro-magnetic gels—using Brownian dynamics simulations that include long-range hydrodynamic interactions. We focus on how the network evolves after a constant magnetic field is applied and compute several structural and dynamic properties to elucidate the restructuring mechanism. The presence of non-magnetic particles suppresses chain formation and produces a more complex spatial distribution of magnetic particles. At intermediate field strengths the magnetic interactions tend to misalign neighboring dipoles, so saturation occurs only at much higher fields than in purely magnetic suspensions. Magnetic particles migrate toward energetically favorable regions and drag non-magnetic particles with them. This migration has a characteristic length scale—the size of the aggregates that move together with the magnetic particles—which we analyze as a function of field strength. Finally, we assess the role of hydrodynamic interactions by comparing the full-hydrodynamics case with freely draining dynamics. A detailed understanding of the interplay between magnetic particles and the gel network will be crucial for designing magnetic gels with tailored properties for a wide range of applications.

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His theoretical research in soft matter and colloidal-scale fluid mechanics emphasizes transport phenomena, phoretic mechanisms, and hydrodynamic interactions in active colloidal systems, with significant contributions on osmotic propulsion, self-powered enzyme micropumps, and catalytic colloidal behavior. He has led major collaborative research initiatives, including those integrating soft materials science and artificial intelligence, and has established programs to enhance research capacity and STEM training across disciplines. Administratively, he served as Executive Vice President for Academic Affairs and Research for the University of Puerto Rico System and plays a strategic role at the Puerto Rico Science, Technology and Research Trust. He is also founder and CEO of Acerola Strategies LLC, a Puerto Rico–based firm that advances adaptive, data-driven innovation, systems thinking, and agile strategic action in research ecosystems and organizational capacity building.