Design of Asymmetric Soft Actuators Based on Functional Colloidal Gradients in Magnetic Hydrogels

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We report the fabrication of a pH-sensitive polyacrylamide hydrogel [1] loaded with high-remanence neodymium-iron-boron (NdFeB) micro-particles, leveraging the controlled spatial distribution of the colloidal phase to program macroscopic deformation.
A key aspect of this study is the exploitation of sedimentation kinetics and magnetic field alignment during the polymerization process. This allows for the generation of a colloidal density gradient, resulting in a functionally graded material with a bilayer-like architecture. We analyze how this structural asymmetry, combined with the pH-dependent swelling of the hydrogel network, dictates the interfacial mechanics and the subsequent bending macroscopic response.
Furthermore, the magnetic moments of the NdFeB particles are pre-aligned to create preferential axes of magnetization. Under low-frequency alternating magnetic fields, the interplay between interfacial elastic forces and magnetic torque induces a large-amplitude, asymmetric oscillatory motion. We demonstrate that this non-reciprocal movement enables directional fluid transport. These results highlight the potential of colloid-filled hydrogels as programmable platforms for microfluidics and biomimetic interfacial engineering.

Keywords:
Magnetic Colloids, Soft Matter Composites, Colloidal Gradients, Stimuli-Responsive Hydrogels, Soft Actuators

References:

[1] A. Leon-Cecilla et al., *Int. J. Biol. Macromol.* **2024** , *260* , 129368.

Acknowledgements:
This study was supported by the grant PID2023-151913NB-I00 funded by MICIU/AEI/10.13039/501100011033, Spain, and by ERDF, EU