Remote Actuation of Bioinspired Micro-Compartments Using External Forcefields

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Compartmentalization is a key feature of living systems, enabling spatial organization of biochemical processes and efficient regulation of energy and matter fluxes. In this work, we exploit liquid–liquid phase separation (LLPS) as a strategy to engineer internal organization within protocell models based on water-in-oil droplets. By combining polyethylene glycol (PEG) and dextran, we generate biphasic droplets with well-defined subcompartments that allow selective localization of functional cargoes.

We demonstrate that dextran-functionalized magnetic nanoparticles are preferentially sequestered within the dextran-rich phase, where they act as energy transducers capable of converting external alternating magnetic fields (AMFs) into localized heat. This enables remote actuation of the droplets without direct physical interaction. Meanwhile, the PEG-rich phase remains available for the encapsulation of complementary components, such as enzymes.

The spatial segregation of these elements allows decoupling of energy transduction and biochemical activity. In particular, we show that heat generated in the dextran phase can be used to enhance enzymatic reactions occurring in the PEG phase, demonstrating controlled energy transfer between subcompartments.

These results establish LLPS as a powerful tool for hierarchical organization and modular design in protocell systems, enabling the integration of multiple functionalities within a single microenvironment. This approach opens new avenues for the development of stimuli-responsive microreactors and advanced synthetic cell models.

Keywords:
liquid-liquid phase separation, magnetic nanoparticles, plasmonics, biphasic droplets, microreactors

References:

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