Polymer Microgels as Synthetic Mimics of Cellular Compartments and Nucleoprotein Condensates

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Polymer microgels are emerging as modular soft matter platforms that bridge materials science and synthetic biology by recreating essential structural and functional features of living systems. Their defined network architecture, tunable mechanics, and chemical responsiveness/adaptiveness enable the construction of synthetic microenvironments that mimic cellular confinement and dynamics as well as macromolecular crowding. Along these lines, hyaluronan-based microgels were engineered to immobilize functional proteins while preserving their activity, creating spatially confined reaction volumes capable of supporting cell-free gene expression.[1] These systems mimic intracellular organization by coupling matrix mechanics with localized biochemical functionality. In a complementary approach, polymer microgels equipped with DNA-binding motifs were developed as simplified model to study protein-DNA interactions of a bacterial cell division machinery.[2] By reproducing key aspects of nucleoid-associated protein–DNA interactions within a defined hydrogel network, these materials enable controlled investigation of biomolecular condensation and spatial protein synthesis in a bottom-up approach.
Stimuli-responsive microgels further expand this biomimetic concept. PNIPAAm-based networks with tailored crosslinking architectures translate molecular interactions into temperature-dependent swelling, providing adaptive and quantifiable readouts relevant for biosensing and cell heating during optical trapping.[3] Complementary micromechanical analyses of hydrogel viscoelasticity[4] contribute to understanding how local elasticity and relaxation behavior in microgels may influence a biological machinery therein.
Together, these studies showcase microgels as synthetic mimics of cellular compartments and nucleoprotein assemblies that integrate mechanical programmability with biochemical function. With these systems, we have a versatile tool at hand for constructing bottom-up cell models, studying confined biomolecular interactions, and designing programmable biomaterials for synthetic biology and bioinspired soft matter applications **.**

Keywords:
Synthetic biology, hydrogels, microgels, additive manufacturing, droplet microfluidics

References:

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