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FROM DYNAMIC STRUCTURES TO FUNCTIONAL MATERIALS

Acyl Transfer Drives Dynamic Reaction Droplets

K. Dai,[1] P. Pal,[2,3] J. Zhang,[4] T. Pramod,[2,4] D. Bhattacharjee,[2,3] and C. G. Pappas[2,3,4*]

[1]Freiburg Institute for Advanced Studies (FRIAS)
[2]Institute of Organic Chemistry
[3]FIT-Freiburg Center for Interactive Materials and Bioinspired Technologies
[4]DFG Cluster of Excellence livMatS, University of Freiburg, Germany

How chemical reactions become spatially organized and feed back to regulate chemistry is a central question in the design of life-like chemical systems. Dynamic phase-separated compartments[1,2] offer a powerful route to address this challenge by concentrating molecules, creating distinct microenvironments, and coupling chemical turnover to material formation and dissolution. However, a key challenge remains: how can synthetic non-equilibrium compartments participate in feedback loops that regulate chemical reactions, rather than merely representing passive outputs of a reaction cycle?

Here, we demonstrate a ‘‘structured-fuel’’ strategy[3,4] in which aminoacyl phosphate-driven acyl transfer generates transient peptide coacervates that actively shape their formation, composition, and lifetime. By selectively recruiting fuels, precursors, and transient products, these coacervates establish reciprocal feedback between chemical activation and phase separation. This reaction-phase separation coupling gives rise to collective behaviours inaccessible from the individual components alone: cross-activation of otherwise inefficient peptide precursors within a shared condensed phase, synchronization of apparent reaction kinetics across chemically distinct peptide systems, and dynamic reprogramming of molecular recruitment through reaction-driven changes in condensate composition. We further extend this concept to oil droplets that form a feedback loop with an acyl phosphate reaction network. Here, the droplet environment promotes ester hydrolysis, while the hydrolysis products reinforce droplet formation, creating an autocatalytic feedback loop. By controlling the assembly state in situ, the system can be switched over time between reaction-ON droplet states and reaction-OFF aggregation states.

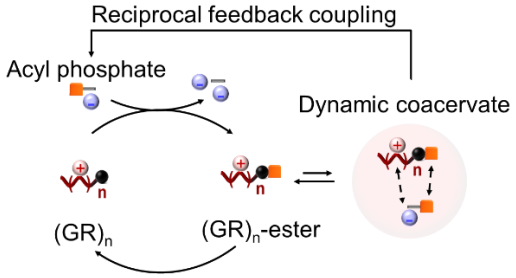

Fig.1 Acyl transfer drives transient peptide coacervates with reciprocal reaction–phase feedback

Together, these two systems demonstrate that non-equilibrium droplets can actively feed back into reaction networks, reshape reaction pathways, coordinate multicomponent chemistry, and encode temporal control through evolving phase states. This work provides a framework for designing reaction-active condensates and programmable life-like materials (Fig. 1).

References:

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