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Harnessing Equilibrium and non-Equilibrium Phenomena of Liquid-Liquid Phases and Interfaces for the Design of Functional Materials

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The coexistence of two liquid phases, namely liquid-liquid phase (LLPS) separation is relevant to a range of biological and materials-related processes. Liquid crystals (LCs) are fluids with orientational order, which arise when the molecules of the fluids phase have sufficiently large anisotropy in their shape and interaction energies. Here, we report on surprising phase behavior of lyotropic chromonic liquid crystals (LCLC) that display a liquid-liquid crystal phase coexistence/separation when DNA is present at concentrations that are typical for DNA post an amplification event (such as PCR). The depletion-driven phase separation of LCLCs occurs at surprisingly low concentrations of DNA (~ pM). In contrast, polyethylene glycol, a common depletant, causes a phase transition of the LCLC only at micromolar concentrations. We explain these striking results using simple arguments showing that rods are extremely strong depletants when compared to spheres of similar volume. Further, we tune the starting concentration of the LCLC such that it selectively responds to a chosen length and therefore a particular base pair of the DNA thereby enabling a facile optical reporting platform on the presence of DNA/completion of DNA amplification (~ 100 billion copies). The second part of the talk looks at fluid-fluid interfaces wherein we seek to explore the role of non-equilibrium phenomena such as the presence of an interfacial instability in influencing liquid-liquid extractions. We find that at specific ion concentrations in the aqueous and oil phases, there is an onset of interfacial instability resulting in Marangoni flows. While the Marangoni flow occurs, transport of dissolved ionic species such as lithium follows a non-diffusive behavior thereby leading to higher extraction rates. Additionally, via this out of equilibrium extraction process, we find that the volume of the oil phase can be an order of magnitude lower than at equilibrium extractions and therefore lead to efficient up-concentration of the metal ions including lithium. Overall, this work presents foundational knowledge of a model active-matter system which can potentially be utilized as a novel extraction technique or deployed as a “loop to an existing technology” in the design of advanced separation techniques.

Karthik Nayani is an Assistant Professor in the Department of Chemical Engineering at the University of Arkansas. The research in his group involves the design of a range of biologically and technologically relevant soft materials to address societal challenges in the realm of health, environment, and materials. He is the recipient of the ACS-PRF and the USDA New Investigator awards. Previously, he was a postdoctoral scholar at Cornell University where he worked on discovering new principles for the development of passive sensors. He received a PhD in 2017 from Georgia Institute of Technology. His doctoral research explored the spontaneous emergence of macroscopic chirality in confined mesophases.