Gradient Particle Dispersions: A Versatile Platform for Polymeric Colloids, Photonic Materials, and Responsive Assemblies

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Continuous gradient particle dispersions offer access to colloidal systems with spatially and statistically varying properties that are not achievable with traditional discrete particle libraries. In this contribution, we present a versatile and general approach for synthesizing gradient dispersions, focusing on polymeric particles and microgels, and demonstrate how these systems enable new structure–property relationships and functions. The core idea uses time-dependent seeded growth in semi-batch processes to create dispersions with intentionally designed continuous particle size distributions, rather than uniform monodisperse populations. Using the Controlled Emulsion Extraction Process (CrEEP), gradient latex dispersions can be produced with precise control over particle size and compositional parameters such as glass transition temperature by adjusting the monomer feed. [1] This principle is also applicable to inorganic systems, as shown by the Controlled Extraction Stöber Process (CrESP), highlighting the broad versatility of this synthetic platform. [2]

We further demonstrate that such gradient dispersions can act as building blocks for functional materials. In hard-sphere-like colloidal systems, gradual size distributions produce photonic colloidal glasses with a continuous structural gradient, resulting in vivid, position-dependent coloration and increased light scattering. Extending this idea to soft polymeric core–shell microgels allows access to gradient assemblies, where swelling and deswelling can be monitored across an entire particle population. When incorporated into continuous materials through gradual filtration, these soft gradients show amplified thermoresponsive actuation, opening new prospects for self-actuating particle-based matter.

Taken together, these examples demonstrate that gradient particle dispersions are a versatile materials platform with applications in photonic scattering optimization, adaptive filtration media, and soft robotic or actuator systems. More broadly, they provide a general pathway to create mesoscopic gradients in colloidal matter and, as a result, enable emergent functionalities from controlled dispersity.

References:

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