“Evolution and age-coarsening in colloidal gels: Micro-mechanics and rheology”

Roseanna N. Zia, Ph.D

Assistant Professor
Department of Chemical and Biomolecular Engineering
Cornell University

Tuesday, March 4th, 2014, 4:00 pm | B11 Kimball Hall
Refreshments at 3:30, Upson Hall Lounge

Abstract
We study via theoretical and computational modeling the evolving structure and time-dependent rheological properties of an aging colloidal gel, with a focus on understanding the non-equilibrium forces that drive late-age coarsening. Colloidal suspensions span a rich range of states—from dispersed to arrested, and from liquid-like to solid-like behavior. In a colloidal suspension where particles experience attractive forces, the particle attractions can lead to phase separation—analogous to the phase transition of steam to liquid water—into particle-rich and particle-poor regions separated by a single interface. But this separation is sometimes interrupted before full separation occurs: at certain particle concentrations and interparticle potentials, the same attractions between particles that promote phase separation also inhibit it, leading to kinetic arrest of the phase separation and the subsequent formation of a space-spanning network—a gel. When attractions between particles are on the order of just a few $kT$, e.g. as arises in the presence of a polymer depletant, the kinetic arrest of the phase separation can lead to a non-fractal bi-continuous morphology, a so-called ‘reversible’ colloidal gel. In such gels, thermal kicks from the solvent are strong enough to dislodge particle bonds, which then reform, allowing aging and restructuring of the gel over long times. Because particle diffusion is dramatically slowed by inter-particle attractions, however, such have difficulty reaching equilibrium, because the thermal rearrangements required to do so are weak and difficult. Prior studies left open the question of how the particle-rich regions are structured—liquid-like, glassy, or crystalline—whether restructuring takes place via bulk diffusion, surface migration, or coalescence of large structures, and what underlying mechanisms provide the driving force for coarsening. We show that the strands are disordered and nominally glassy, that macroscopic gel coarsening is driven by migration of particles along the network surface, and we connect macroscopic rheology to the underlying driving force.

Biographical sketch
Dr. Zia is an Assistant Professor of Chemical and Biomolecular Engineering and a James C. & Rebecca Q. Morgan Sesquicentennial Faculty Fellow at Cornell University. She received her Ph.D. from the California Institute of Technology in Mechanical Engineering in 2011, specializing in the theory of colloidal hydrodynamics and suspension mechanics under the guidance of Dr. John F. Brady. Dr. Zia subsequently conducted post-doctoral research in the study of colloidal gels and kinetically arrested systems at Princeton University, in conjunction with Dr. William B. Russel. Prior to her studies at Caltech she worked as a mechanical engineer in the automotive industry in Detroit, specializing in the design of precision mechanisms and pyrotechnically actuated devices for occupant restraint; during this time she earned an M-Eng degree at the University of Michigan. Her undergraduate degree, a B.S. in Mechanical Engineering, was obtained at the University of Missouri.

Dr. Zia’s work in colloidal systems focuses on the development of predictive theory to elucidate the micro-mechanical underpinnings of macroscopic material behaviors in complex fluids and other soft matter, with a focus on non-equilibrium systems. Such systems span a rich range of states, from dispersed to condensed, dilute to concentrated, kinetically mobile to kinetically arrested, and fluid to networked to glassy. Problems of interest include the storage of the microstructural entropy that underlies mechanical stress, the imbalance between fluctuation and dissipation driven by stress gradients, and the structural coarsening that enables sudden collapse of dynamically arrested gels, to name a few. From this understanding we work out new theories to predict macroscopic behaviors from the detailed evolution of particle microstructure.