Materials Science and Engineering Department

# Fall Seminar Series

## Non-equilibrium Dynamics of Vesicles in Precisely Controlled Flows

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Vesicles are membrane-bound containers that play an integral role in biological processes. In this work, we study the non-equilibrium dynamics of giant unilamellar vesicles in precisely defined steady and time-dependent flows using a Stokes trap, which is a new method to manipulate particles using feedback control. In this way, we directly observe non-equilibrium vesicle shapes as a function of reduced volume, viscosity contrast, and capillary number using fluorescence microscopy. Remarkably, vesicles are found to be highly deformable objects that undergo reversible deformation in the bending-dominated regime with deformed aspect ratios >20 in repeated stretch-relax cycles. Vesicles deform through a wide range of conformations in flow, including asymmetric and symmetric dumbbells, in addition to pearling, wrinkling, and buckling instabilities depending on membrane properties. We precisely determine the flow-phase diagram for vesicles in capillary number-reduced volume space. We further study the non-equilibrium stretching dynamics of vesicles, including transient and steady-state stretching dynamics in extensional flow. Our results show that vesicle stretching dynamics are a strong function of reduced volume, such that the steady-state deformation of vesicles exhibits a second critical capillary number and shows power-law behavior as a function of reduced capillary number. We further identify two distinct relaxation processes for vesicles stretched to high deformation, revealing two characteristic time scales: a short time scale corresponding to bending relaxation and a long-time scale dictated by the relaxation of membrane tension. Finally, we study vesicle shape dynamics in large-amplitude oscillatory extensional (LAOE) flow, including both numerical simulations and experiments. Our results show three distinct dynamical regimes - pulsating, reorienting, and symmetrical deformations - based on the competition between flow frequency, flow time scale, and membrane deformation timescale. Overall, our results provide new insights into the flow-driven shape instabilities for vesicles using new experimental methods based on the Stokes trap.


Dr. Charles Schroeder is the James Economy Professor of Materials Science and Engineering and Professor of Chemical & Biomolecular Engineering at the University of Illinois at Urbana-Champaign. He is Co-Chair of the Molecular Science and Engineering Theme in the Beckman Institute for Advanced Science and Technology. Professor Schroeder is a faculty member in the Center for Biophysics and Quantitative Biology and holds affiliate status in the Department of Chemistry, the Department of Bioengineering, the Carl R. Woese Institute for Genomic Biology, and the Materials Research Lab (MRL). He previously served as Associate Head in the Department of Chemical & Biomolecular Engineering at Illinois. Dr. Schroeder received his B.S. in Chemical Engineering from Carnegie Mellon University in 1999, followed by an M.S. in 2001 and Ph.D. in 2005 in Chemical Engineering from Stanford University under the supervision of Professors Eric Shaqfeh and Steve Chu. Before joining the University of Illinois in 2008, he was a postdoctoral fellow in the Department of Chemistry and Chemical Biology at Harvard University and the Department of Chemical Engineering at the University of California, Berkeley. Professor Schroeder has been the recipient of several awards, including a Packard Fellowship for Science and Engineering, a Camille Dreyfus Teacher-Scholar Award, an NSF CAREER Award, the Publication Award from the Society of Rheology, the Arthur B. Metzner Award from the Society of Rheology, an NIH Pathway to Independence Award (K99/R00), and the Dean's Award for Excellence in Research at Illinois.

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