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Collective dynamics in suspensions of anisotropic and deformable particles[1]

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Dispersions of small particles in a viscous fluid are ubiquitous in both natural and industrial processes. A major difficulty in understanding these systems arises from the slow decay of hydrodynamic disturbances at low Reynolds number, which leads to long-ranged interactions and results in strong velocity fluctuations and large-scale correlated motions. In this work, I will address two problems in which hydrodynamic interactions result in collective dynamics, with emphasis on the effects of particle shape and deformability. I will first address the behavior of suspensions of anisotropic particles such as rigid spheroids under sedimentation. Hydrodynamic interactions in these systems result in a concentration instability, by which the particles aggregate into dense clusters surrounded by clear fluid. Using newly developed algorithms, large-scale simulations were performed with the aim of understanding the mechanism for the instability and of elucidating the wavenumber selection process reported in experiments. Simulations in finite containers indeed exhibit a wavenumber selection, and theoretical arguments suggest that the size of the concentration fluctuations is controlled by vertical density gradients that form during the sedimentation process. The case of deformable particles such as viscous droplets is also addressed, and theory and simulations both demonstrate that a similar instability also occurs in these systems. I will then discuss the dynamics in dispersions of polarizable Brownian rods in an electric field, a situation of practical relevance in microfluidic applications involving nano-barcodes. The polarization of a rod results in the formation of a dipolar charge cloud around its surface, leading to a non-linear fluid slip: this phenomenon, termed induced-charge electrophoresis, causes particle alignment with the applied field and creates a disturbance flow in the surrounding fluid. A theoretical model and numerical simulations are developed to describe interactions in such suspensions, and both demonstrate that induced-charge electrophoresis results in particle pairings, in good agreement with experimental observations.

[1]This work was done in collaboration with Eric S. G. Shaqfeh and Eric Darve (Stanford University)