

From Proteins to Peas: Diffusion Across Scales

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Abstract

Diffusion is one of the most basic and elemental transport processes and is responsible for the molecular mixing of different chemical species. For a protein molecule, the diffusivity is given by the Stokes-Einstein-Sutherland formula relating the diffusivity to the thermal energy times the hydrodynamic mobility. The self-diffusivity decreases as the concentration of protein molecules increases owing to the crowding effect of near neighbors. As the diffusing species increases in size from a protein to a several micron-sized colloidal particle, the stirring of the background fluid can give rise to another mechanism of transport – ‘shear-induced’ diffusion. Here, hydrodynamic interactions among particles promote mixing and the self-diffusivity now scales as the particle size squared times the shear rate. In this regime, the self-diffusivity is an increasing function of concentration since particle-particle ‘collisions’ are responsible for the diffusive motion. At still large particle size (millimeter or larger), the inertia of the particles becomes important, direct particle-particle collisions dominate, and the self-diffusivity now behaves like that in a dense gas with the diffusivity proportional to the particle size times the square root of the ‘granular temperature’, which is set by the stirring motion and the energy dissipated upon collision. As in a dense gas, the self-diffusivity now decreases with increasing particle concentration. The physical origin of these various behaviors and their implications for mixing and concentration distributions in multiphase flows will be discussed.