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Active Thermodynamics in Bacterial Swarms

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ABSTRACT

The diffusion of molecules and particles in a fluid is an important process ubiquitous in the physical and natural sciences. At equilibrium, the diffusion of colloidal particles in a simple, homogeneous fluid is driven by thermal (Brownian) motion and damped by viscous resistance. As elegantly encapsulated in the Stokes-Einstein relationship built on Perrin's studies, the diffusivity is connected to the temperature of the fluid and the size of the particle with larger particles diffusing slower than smaller particles. In externally driven, non-equilibrium systems, fluctuations are not thermal; linking fluctuations to particles dynamics becomes a difficult endeavor. Biologically complex fluids such as bacterial swarms and algal suspensions are not just non-equilibrium systems, they are also active systems comprised of self-propelling, force-free organisms. These micron-sized entities inject energy, generate mechanical stresses, and create flows with or without external forcing. A natural question to then ask is if these systems can be characterized by extending classical thermodynamics concepts such as diffusivity and temperature.

In my talk I will present experiments and theory on the motion and diffusion of passive colloids in suspensions of the flagellated bacterium Escherichia coli. Using polystyrene spheres with a range of sizes (from 0.6 to 39 microns) as probes, we analyze particle dynamics and relaxation at both short and long time scales. As in equilibrium constant-temperature systems, the probes exhibit super-diffusive ballistic behavior at short times before eventually transitioning to diffusive behavior. Surprisingly however, we find a regime in which larger particles can diffuse faster than smaller particles: the particle long-time effective diffusivity exhibits a peak in particle size, a non-intuitive deviation from classical thermal diffusion. I will present a minimal theory that accounts for the competition between bacterial correlation times and particle relaxation times and qualitatively explains the existence of the peak and its dependence on bacterial concentration and probe size.