Direct measurement of osmotic pressure and a pair potential in colloidal dispersions

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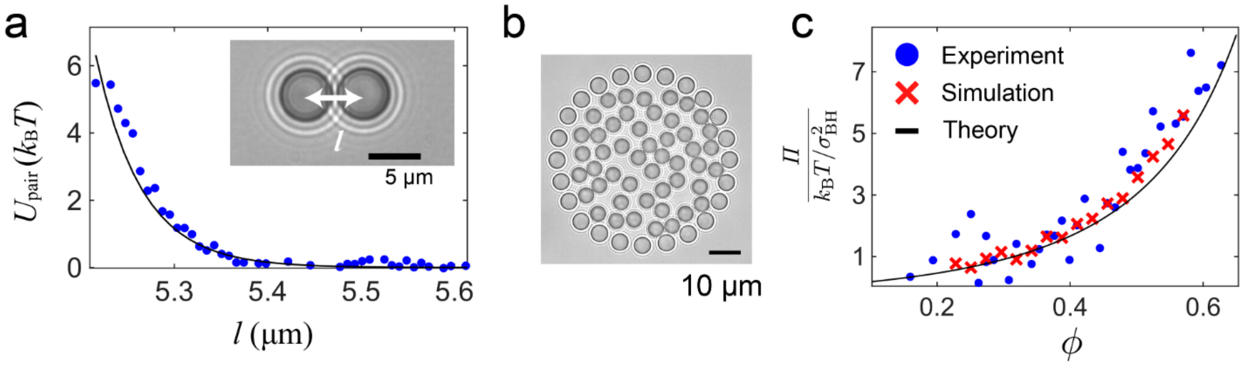
Osmotic pressure in colloidal dispersions is a key measure for their dispersibility, which characterizes the physical properties of colloidal dispersions [1]. Since osmotic pressure is very weak, available measurement methods are limited. In this context, a system that measures both osmotic pressure and interparticle interactions is highly desirable for understanding the relationship between macroscopic osmotic pressure and particle-level properties. In this study, we demonstrate measurement of both osmotic pressure and interparticle interactions within the same experimental system, an optical tweezer system.

For a pair potential U_{pair} measurement, two polystyrene particles were trapped by a Gaussian line trap formed by optical tweezers (inset of Fig. a). In thermal equilibrium, the probability $P(l)$ of finding a pair of particles at a distance is determined by the total potential U, which consists of U_{pair} and the harmonic potential U_{trap} of the optical trap [2]. Since U_{trap} can be estimated beforehand, U_{pair} is obtained from $U_{pair} = U - U_{trap}$ (Fig. a). For an osmotic pressure measurement, silica particles were trapped by the tweezers, forming the corral boundary (Fig. b). Polystyrene particles were dispersed inside the corral. Since both types of particles are heavier than the surrounding fluid, they settled at the bottom, and their motion was confined to a two-dimensional plane. Since the trapping force acting on a particle can be regarded as Hookean restoring force for small corral deformation, the force induced by the inside particles is measured by the displacement of the trapped particles, and osmotic pressure Π is calculated (osmotic pressure here is force per unit length).

Figure c shows the dependence of Π on area fraction Φ. The measured pressure agrees well with both the Brownian dynamics simulation and theoretical results based on the hard-sphere model, both calculated using the experimental measured U_{pair}. This agreement demonstrates the applicability of the proposed technique for investigating dispersive properties across multiple scales, linking microscopic particle-level interactions to macroscopic osmotic pressure within a single system. The proposed technique enables bottom-up design of colloidal materials through particle-level modifications.

Keywords:
Colloidal dispersions, Optical tweezers, Osmotic pressure



(a) Pair potential. The inset shows the two polystyrene particles trapped by a Gaussian line trap. (b) Our measurement system for osmotic pressure. (c) Nondimensionalized osmotic pressure in the colloidal dispersion.

References:

[1] W. B. Russel *et al*., Colloidal dispersions (Cambridge University Press, London, 1989).

[2] C. Zhang, *et al.*, *Nat. Commun.* **15**, 1020 (2024).