Direct Measurement of Colloidal Interaction Forces

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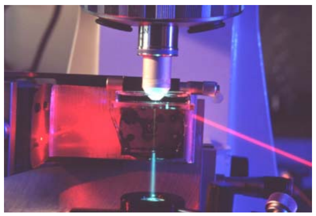
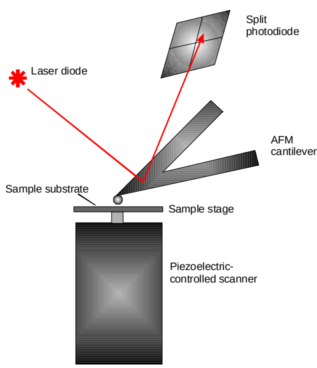
Understanding the forces between colloidal particles in solution is of primary importance in a variety of industrial and natural processes. We utilize two relatively new experimental tools that allow directly measuring these forces between a single colloidal particle and a planar substrate in water.

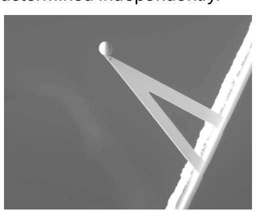


The picture above shows graduate student Martin Piech using the atomic force microscope (AFM), while at left is a close-up picture of the sample stage in total internal reflection microscopy (TIRM). The green laser beam from below is being used to exert radiation pressure on the particle.

Atomic Force Microscope (AFM)

In the atomic force microscope, a single colloidal particle is glued to the tip of an AFM cantilever and brought near the substrate by a piezoelectric scanner. The deflection of the cantilever is measured via the position of a laser beam reflected from the surface. The particle-substrate force can then be determined using the known spring constant of the cantilever, which can be determined independently.

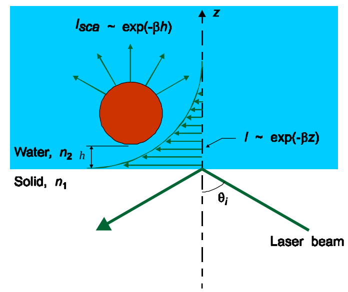


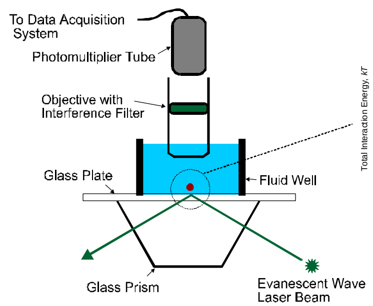


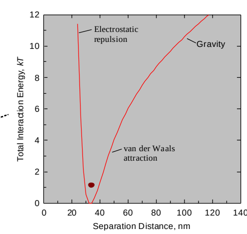
The picture at left is an SEM image of a 20 μm diameter TiO_2 particle glued to an AFM cantilever tip.

Total Internal Reflection Microscopy (TIRM)

In TIRM, an evanescent wave is formed at a solid/fluid interface via the total internal reflection of a continuous wave laser beam. A particle located sufficiently close to the interface scatters the evanescent wave with a scattering intensity that varies exponentially with the dimensionless gap width, βh, where β is a known constant. Measuring this intensity allows rapid and accurate determination of the separation distance.

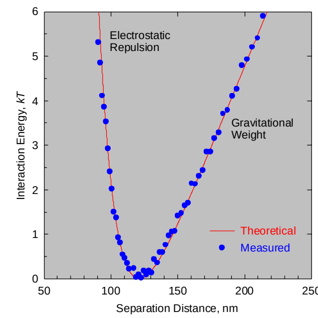






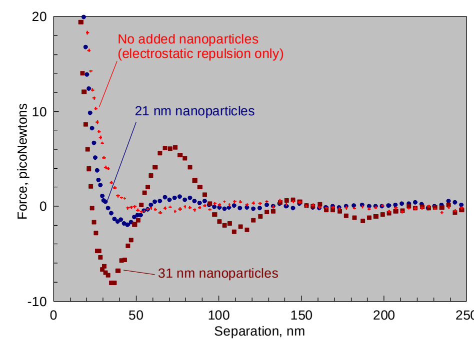
If a Brownian particle is trapped in a local energy well, such as that shown on the right, the probability distribution of displacements, $p(h)$, will follow a Boltzmann distribution of the form $p(h) \sim \exp[-E(h)/kT]$, where $E(h)$ is the potential energy of the particle-plate interaction and kT is thermal energy. Measuring the displacements over a statistically long period of time thus allows determining the determining the distribution of separation distances, from which the interaction energy profile can be calculated.

TIRM-Measured Energy Profile



Shown here is a typical potential energy profile measured with TIRM. The system was a 15 μm diameter polystyrene sphere interacting with a glass plate in a 0.5 mM NaCl aqueous solution. The red curve is the profile calculated as the sum of the known gravitational potential plus a screened Coulombic potential (DLVO interaction). A major advantage of TIRM is its extreme sensitivity for detecting small forces.

Depletion Forces Measured with AFM



This graph shows the impact of a nonadsorbing polyelectrolyte material on the force profile between a 2.6 μm diameter silica sphere and a silica plate in a low ionic strength aqueous solution. The polyelectrolytes used here were small silica nanospheres (two different sizes at equal number concentrations), and the gravitational force has been subtracted. The oscillations are due to the ordering of the nanospheres in the particle-plate gap region.