Optical Rotation of Levitated Spheres in High Vacuum

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Abstract: A circularly polarized laser beam is used to levitate and control the rotation of microspheres in high vacuum via transfer of optical angular momentum. At low pressure, rotation frequencies as high as 6 MHz are observed for birefringent vaterite spheres, limited by centrifugal stresses. Due to the extremely low damping in high vacuum, the controlled optical rotation of amorphous SiO_2 spheres is also observed at rates above several MHz. At 10^{-7} mbar, a damping time of 6×10^4 sec is measured for a 10 μm diameter SiO_2 sphere. No additional damping mechanisms are observed above gas damping, indicating that even longer damping times may be possible with operation at lower pressure. The controlled optical rotation of microspheres at MHz frequencies with low damping, including for materials that are not intrinsically birefringent, provides a tool for performing precision measurements using optically levitated systems.

The control and measurement of angular degrees of freedom have been demonstrated for optically trapped particles in fluids, as well as in air and at moderate vacuum pressures for both torsional and rotational motion. In high vacuum, the levitation and rotation of electrically charged, micron-sized graphene flakes has been previously demonstrated. However, optical techniques for the levitation and rotation of electrically neutral masses have not been studied below $\sim 10^{-3}$ mbar, where feedback cooling of the center of mass degrees of freedom is necessary to maintain stable trapping.

Here, a system capable of fully optical levitation and rotation of both birefringent and amorphous dielectric spheres in high vacuum is demonstrated. The optical levitation of dielectric spheres offers advantages for certain classes of precision sensors since they can be electrically neutralized and their charge controlled at the single electron level; they have a highly uniform, spherical geometry; spheres with diameters ranging from $\sim$10 nm to $\sim$20 μm can be trapped; and long working distances (> several cm) between the focusing optics and trap location permit the use of a variety of excitation mechanisms and shielding electrodes.

In my talk, I will describe a recent observation of the optically driven rotational motion of levitated spheres at frequencies above several MHz. At 10^{-7} mbar, a damping time of 6×10^4 sec is measured for an amorphous SiO_2 sphere at a rotation frequency above 4 MHz. At these rotation frequencies and pressures, and in the absence of an externally applied torque, microspheres rotate for $\sim 10^{11}$ cycles in a single damping time due to the extremely low gaseous drag. No damping mechanisms above drag due to the residual gas are observed, indicating that even lower dissipation may be possible at pressures below 10^{-7} mbar.

I will further discuss ongoing work focusing on cooling the rotational degree of freedom of the sphere using a feedback system. Locking to zero velocity, the remaining motion in the rotational degree of freedom is termed “librational” motion and can be used as an extremely sensitive torque sensor.

F. Monteiro, *et al*, “Optical rotation of levitated spheres in high vacuum”, *Phys. Rev. A* **97**, 051802(R) (2018).