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Optical forces and multipolar decomposition

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Since the first experiments showing the possibility of trapping particles using light [1], optical tweezers have been added to the toolbox of several research fields. For instance, optical tweezers are used in biology [2] and have allowed the cooling of atoms to ultralow temperatures [3].

Along with the blooming of new applications, there has been a significant effort to understand, theoretically and experimentally, the mechanisms behind the optical forces. For a particle of a size much smaller than the wavelength of the incident field, the so-called Rayleigh regime, there is a simple and intuitive understanding of how the polarizability of such a particle is related to the optical forces it feels. In the other hand, if the size of the particle is considerably greater than the wavelength of the trapping beam, the optical force calculation through ray-optics model would be the best choice. This approximation obtains the total linear momentum transferred from the light beam to the particle by discretizing the incident light beam into a bundle of light rays. However, when the particle's size is close to the value of the incident light wavelength ($\lambda = r$), named 'Mie regime', both approximations fail, and an alternative description of the optical forces is needed. In this regard, Generalized Lorentz-Mie Theory (GLMT) [4] provides an exact solution to the scattering problem of spherical particles under general illumination conditions, making it the most reliable procedure for calculating the electromagnetic fields contributing to the optical forces.

In this talk, first, the basics of optical trapping will be introduced. Then, the different methods for calculating optical forces will be discussed, with special attention given to the method that uses the multipolar decomposition of the incident light beam. Finally, a typical Optical Tweezers setup will be analyzed (Fig. 1), explaining the functioning of the various devices contained in it, such as the trapping environment (Fig. 2), focusing elements (Fig. 3), Spatial Light Modulator (SLM) and the method for measuring trap stiffness constant.

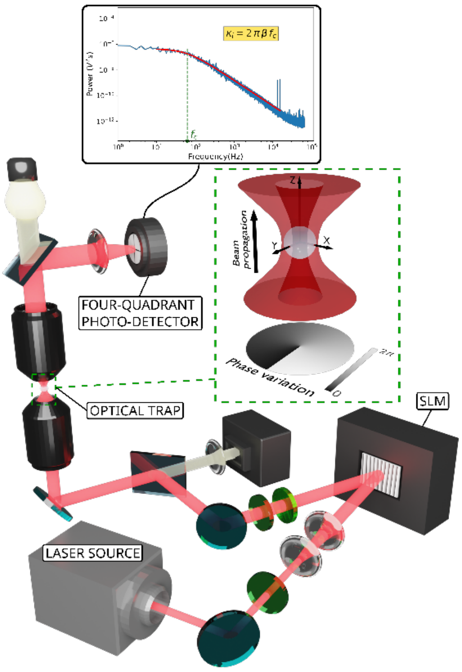

Figure 1. Optical trapping setup under study.

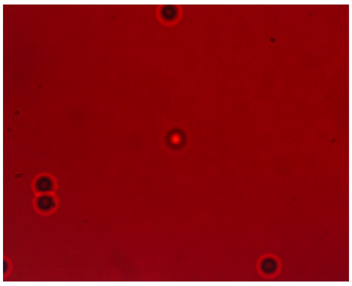

Figure 2. Imaging of an optically trapped particle.

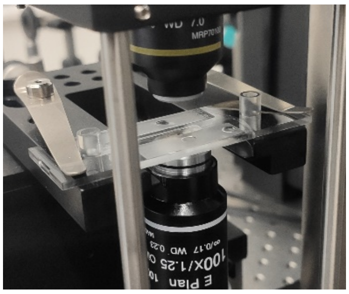

Figure 3. Optical trapping focusing elements.

References:
[1] A. Ashkin, J. M. Dziedzic, J. E. Bjorkholm, and S. Chu, “Observation of a single-beam gradient force optical trap for dielectric particles,” Opt. Lett., vol. 11, no. 5, pp. 288–290, 1986.
[2] A. Ashkin and J. M. Dziedzic, “Optical trapping and manipulation of viruses and bacteria,” Science, vol. 235, no. 4795, pp. 1517–1520, 1987.
[3] A. Ashkin and J. P. Gordon, “Cooling and trapping of atoms by resonance radiation pressure,” Opt. Lett., vol. 4, no. 6, pp. 161–163, 1979.
[4] G. Gouesbet and G. Gr´ehan, Generalized Lorenz-Mie theories, vol. 31. Springer, 2011.