Meta-trapping: optical forces on meta-materials

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In recent years there has been a lot of interest in the field of meta-materials. Progress in this field has been aided by advances in fabrication technologies that led to the realization of both microwave and optical meta-materials [1]. These materials offer the ability to create perfect lenses, invisibility cloaks and control the directionality of scattering [2]. They also allow the creation of new types of optically trapped particles which could be useful for microscopic force probes or use in fundamental science. The possibility to engineer how these particles scatter light could be useful for improving optical trap depth or improving the measurement sensitivity by maximizing light scattered in a particular direction. Full understanding of how these particles scatter light is necessary for intelligently engineering particles or the light fields that manipulate these particles for particular applications.

For spherical particles, the solutions for the scattered field are exact. We can simulate the scattering of these particles by calculating the Mie coefficients with arbitrary values for the permittivity and permeability [3]. The forces acting on the particle can be found by calculating the change in momentum of the scattered light. In order to understand the optical forces on these exotic particles, we consider a vector spherical mode expansion of the scattering in order to look at the different contributions to the force from different modes.

In this presentation we will provide a visual guide for the types of particles which can be optically trapped. We will consider absorbing and emitting materials, particles with non-unity relative permeability and special cases such as zero back scattering particles and trapping of refractive-index matched particles. Beginning with particles which only scatter into the dipole mode, we will then extend the work to the quadrupole mode and higher order modes. We will discuss how these modes can be engineered to enhance optical trapping, either by engineering the beam or the particle. And finally, we will discuss what the results mean for optical trapping of spherical particles in a simple focused Gaussian beam.

References

[1] Tanaka, T., and A. Ishikawa, 2017: Towards three-dimensional optical metamaterials. *Nano Convergence* **4**, 34.

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