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Near-field optical forces: magnetic levitation and angular decomposition

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Abstract: When a dipole radiates near a surface, many interesting optical forces can arise: from attraction and repulsion, to lateral forces caused by directional evanescent coupling. Here we propose a formalism, the force angular spectrum, which provides much intuition. We relate this directly to the coupling efficiency of surface or guided modes, via Fermi’s golden rule, and Huygens dipole is placed near a metallic waveguide to demonstrate how the new formalism explains surface recoll forces. We also present new results which theoretically predict levitation of vertical magnetic dipoles placed suitably close to a planar surface of relative permittivity $\epsilon_r < 1$, due to a near-field optical force. We analyse the physical origins of this phenomena and study the implications of rotating the dipole and show that this behaviour is robust under given conditions.

Near-Field Directionalities

The below example demonstrates a general principle behind near-field optical forces and can be applied to a wide range of systems. This framework lends itself to intuitive understandings and diagnoses of more complicated problems.

Near-field angular force spectrum

The angular force spectrum splits contributions of the force into distinct parts. Below shows how the mode coupling (only dependant on the dipole moments) can be represented alongside the corresponding reflection coefficient (only dependant on the surface). The product forms the Fourier plane of the force component in question.

Angular decomposition

The angular force spectrum splits contributions of the force into distinct parts. Below shows how the mode coupling (only dependant on the dipole moments) can be represented alongside the corresponding reflection coefficient (only dependant on the surface). The product forms the Fourier plane of the force component in question.

Magnetic dipole levitation over an $\epsilon_r < 1$ surface

We have recently uncovered a surprising repulsive near-field optical force that acts upon a magnetic dipole. The below figure shows that if the surface has a permittivity less than vacuum, the magnetic dipole will be repelled by the surface. This force is driven by the reflected near fields of the dipole [2].

Effect of rotation

The force on the vertical magnetic dipole can be described fully by the angular force spectrum and all surface properties are represented in the radiation reflection coefficient. When very near the surface, we can invoke the quasi-static approximation where large transverse wavevectors dominate the force integral. By Taylor expanding around $h=0$, for $\epsilon_r$ and retrieve similar results to that of the exact case. We therefore describe this interaction as the quasistatic limit of an $s$-polarized particle.

$$r_s(k_t) = k_0^2 \frac{\epsilon_r - 1}{4k_t^2} + \ldots$$

References: