Electric and magnetic optical forces on submicron dielectric particles

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The understanding and control of particle transport and diffusion properties is a most relevant issue in fields ranging from biophysics to material science and chemical processing, with countless applications which include particle mixing, diffusive separation of particles, microrhelogy, intracellular transport or drug delivery, to mention a few[1-3].

The advances in sculpting optical wavefronts and light intensity profiles, make optical tools ideal for both imaging and manipulation of particles. Optical fields are easily tunable in general and affect any polarizable object, from atoms to microscopic colloidal particles [4, 5]. These fields can be used to arrange, guide or deflect particles in appropriate light pattern geometries [6-10].Intense optical waves can also induce significant forces between particles [11-14].

Light forces on small dielectric particles are traditionally described as the sum of two terms: the dipole or gradient force and the radiation pressure or scattering force proportional to the Poynting vector [15-17]. A non-conservative scattering curl force appears when the spatial distribution of the field polarization is not uniform [18]. For magnetodielectric particles [19-21], the force presents both electric and magnetic gradient and scattering contributions together with an additional term due to the electric-magnetic dipolar interaction, that contributes to both the scattering force and to the gradient force [20,22]. The main purpose of this work is to illustrate the relevance of this additional contribution.

In free space, the calculation of optical forces acting on small (Rayleigh) dipolar particles is relatively simple, allowing analytical treatment of the problem [15, 18, 23]. However, when the particle size is of the order of or larger than the internal wavelength, in the so-called “Mie" regime, it is difficult to obtain systematic predictions and most theoretical work in this regime is based on a numerical approach [24]. An analytical approach for the optical forces on particles far beyond the Rayleigh limit is still possible provide the scattering can be described by the first two electric and magnetic Mie coefficients [20-22, 25-26]. We will discuss the strong magnetic and electric optical forces on submicron dielectric particles with unusual scattering effects [20-22, 26]. As we will show, the electric-magnetic dipolar interaction plays an active role in spinning the particles either in or out of the whirls sites of the interference pattern, leading to trapping or diffusion [22]. This may permit the exploration of new forms of controlled atom motion in optical lattices [27, 28] and may be used to separate and sort small particles with slightly different optical characteristics [9, 10].

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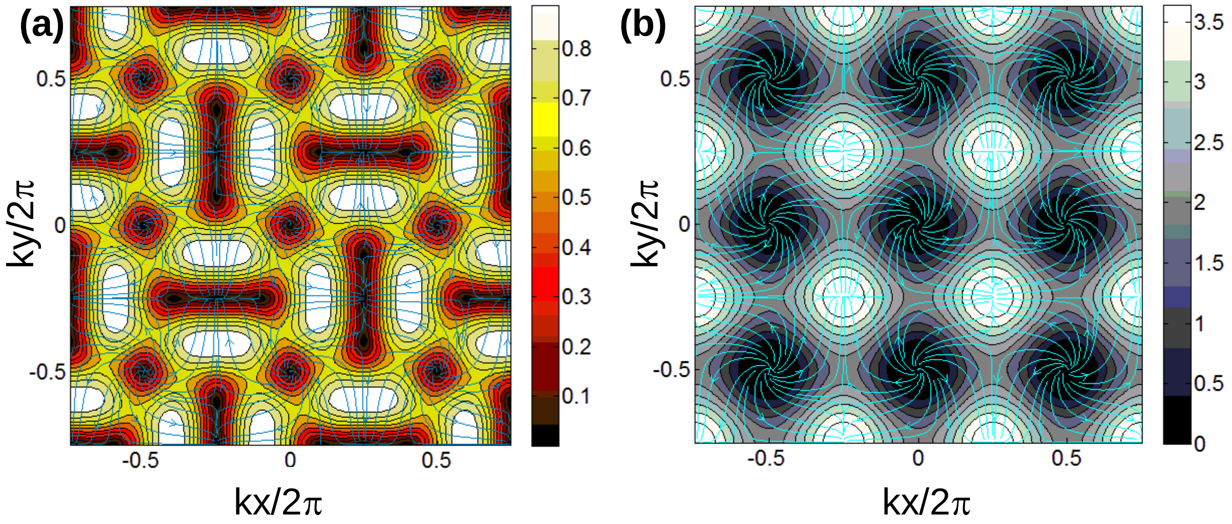
Figures



Nonconservative forces on a Si sphere of radius a = 230nm placed in the intersection region of two standing waves with a dephasing $\phi=1/2$ in a medium with $\epsilon=1$. (a) Contour intensity maps of the normalized total force, $<|\mathbf{F}|>/F_0$ with $F_0=|\mathbf{E}_0^2|/ka^3$, (b) Contour intensity maps of the normalized electric field intensity $|\mathbf{E}|/|\mathbf{E}_0|^2$. The light field wavelength, λ = 1600nm, slightly below (blue-shifted) the magnetic dipolar resonance. Equilibrium (zero force) positions correspond to electric field maxima.