Interference between electric and magnetic dipoles in dielecric spheres: Scattering anisotropy and optical forces.

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Electromagnetic scattering from nanometer-scale objects has long been a topic of large interest and relevance to fields from astrophysics or meteorology to biophysics, medicine and material science [1-5]. In the last few years, small particles with resonant magnetic properties are being explored as constitutive elements of new metamaterials and devices. Magnetic effects, however, cannot be easily exploited in the visible or infrared regions due to intrinsic natural limitations of optical materials and the quest for magnetic plasmons and magnetic resonant structures at optical frequencies [6] has then been mainly focused on metallic structures. The unavoidable problems of losses and saturation effects inherent to these metamaterials in the optical and near infrared regimes have stimulated the study of high-permittivity particles as their constitutive elements [7-9]: For very large permittivities, small spherical particles present well defined sharp resonances [1]; either electric or magnetic resonant responses can then be tuned by choosing the appropriate sphere radius.

In the presence of both electric and magnetic properties, the scattering characteristics of a small object present markedly differences with respect to pure electric or magnetic responses. Even in the simplest case of small or of dipolar scatterers, remarkable scattering effects of magnetodielectric particles were theoretically established by Kerker et al. [10] concerning suppression or minimization of either forward or backward scattering. Intriguing applications in scattering cancellation and cloaking [11] and magneto-optical systems [12-14] together with the unusual properties of the optical forces on magnetodielectric particles [15-17] have renewed interest in the field.

The striking characteristics of the scattering diagram of small (Rayleigh) magnetodielectric particles [10,18] were obtained assuming arbitrary values of electric permittivity and magnetic permeability. Nevertheless, no concrete example of such particles that might present those interesting properties in the visible or infrared regions had been proposed.

Very recently, it has been shown [19] that submicron silicon spheres present dipolar magnetic and electric responses, characterized by their respective first-order Mie coefficient, in the near infrared, in such a way that either of them can be selected by choosing the illumination wavelength. We will show that Si spheres constitute such a previously quested real example of dipolar particle with either electric and/or magnetic response, of consequences both for their emitted intensity and behavior under electromagnetic forces [16,17]. These properties should not be restricted to Si particles but should also apply to other dielectric materials with relatively moderate refraction index. Furthermore, we will discuss the effects associated to the interference between electric and magnetic dipoles in germanium spheres [20]. As we will demonstrate the extinction cross section and the scattering diagrams of these submicron dielectric particles in the infrared region can be well described by dipolar electric and magnetic fields, being quadrupolar and higher order contributions negligible in this frequency range. Specifically, the scattering diagrams calculated at the generalized Kerker's conditions are shown to be equivalent to those previously reported [10,18] for hypothetical ($\varepsilon \neq 1$, $\mu \neq 1$) magnetodielectric particles. Finally we will analyze the consequences of the strong scattering anisotropy on the radiation pressure on these particles showing 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[17].

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