# ELECTRIC AND MAGNETIC DIPOLAR RESPONSE OF SMALL DIELECTRIC PARTICLES: ANGLE-SUPPRESSED SCATTERING AND OPTICAL FORCES

**R. Gómez-Medina[1]**, B. García-Cámara[2], I. Suárez-Lacalle[1], L. S. Froufe-Pérez[1], F. González[2], F. Moreno[2], M. Nieto-Vesperinas[3], and J. J. Sáenz[1]

[1]Departamento de Física de la Materia Condensada and Instituto Nicolás Cabrera, Universidad Autónoma de Madrid, 28049 Madrid, Spain.
[2]Grupo de Óptica, Departamento de Física Aplicada, Universidad Cantabria, 39005 Santander, Spain.
[3]Instituto de Ciencia de Materiales de Madrid, C.S.I.C.,Campus de Cantoblanco, 28049 Madrid, Spain.

r.gomezmedina@uam.es

## Abstract

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. [1] concerning suppression or minimization of either forward or backward scattering. Intriguing applications in scattering cancellation and cloaking together with the unusual properties of the optical forces on magnetodielectric particles [2] have renewed interest in the field. The striking characteristics of the scattering diagram of small (Rayleigh) magnetodielectric particles [1, 3] 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.

Here, we show [4] that submicron dielectric spheres present dipolar magnetic and electric responses (see Fig. 1), 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. Moreover, we will see that Si or Ge 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 [5, 6] and behavior under electromagnetic forces [2, 5, 7]. Specifically the exact scattering diagram, computed from the full Mie expansion, of submicron Si and Ge particles in the infrared will be shown to be consistent with the expected result for dipolar electric and magnetic scattering (see Fig. 2). Finally, we will show that the force is a simple combination of conservative and non-conservative steady forces that can rectify the flow of magnetodielectric particles. In a vortex lattice the electric-magnetic dipolar interaction can spin the particles either in or out of the whirls sites leading to trapping or diffusion (see Fig. 3).

## References

[1] M. Kerker, D. S. Wang, and C. L. Giles, “Electromagnetic scattering by magnetic spheres”, J. Opt. Soc. Am. 73, (1983) 765-767.

[2] M. Nieto-Vesperinas, J. J. Sáenz, R. Gómez-Medina and L. Chantada, “Time-averaged total force on a dipolar sphere in an electromagnetic field”, Opt. Express 18, 11428-11443 (2910).

[3] B. García-Camara, F. Moreno, F. Gonzalez and J. M. Saiz, “Exception for the zero-forward-scattering theory”, J. Opt. Soc. Am. A 25, (2008) 2875-2878.

[4] A. García-Etxarri, et al. , “Strong magnetic response of Silicon nanoparticles in the infrared”, Opt. Express 19, 4815-4826 (2011).

[5] M. Nieto-Vesperinas, R. Gómez-Medina, and J. J. Sáenz, “Angle-Suppressed Scattering and Optical Forces on Submicron Dielectric Particles”, J. Opt. Soc. Am. A 28, 54-60 (2011).

[6] R. Gómez-Medina, et al. , “Electric and magnetic dipolar response of Germanium spheres: Interference effects, scattering anisotropy and optical forces”, J. Nanophoton. 5, (2011) 053512.

[7] R. Gómez-Medina, M. Nieto-Vesperinas and J. J. Sáenz, “Nonconservative electric and magnetic optical forces on submicron dielectric particles”, Phys. Rev. A, 83, 033825 (2011).

## Figures

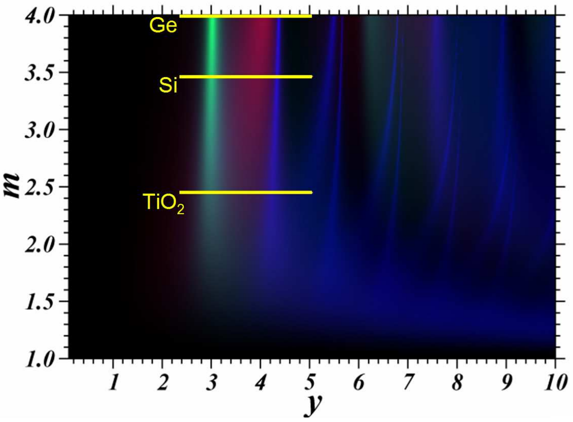

**Figure 1.** Scattering cross section map of a non-absorbing Mie sphere as a function of the refractive index *m* and the *y* parameter, *y* = *mka*. Green areas correspond to parameter ranges where the magnetic dipole contribution dominates the total scattering cross section, while red areas represent regions where the electric dipole contribution is dominating. The remaining blue saturated areas are dominated by higher order multipoles. (Adapted from Ref.[4]).

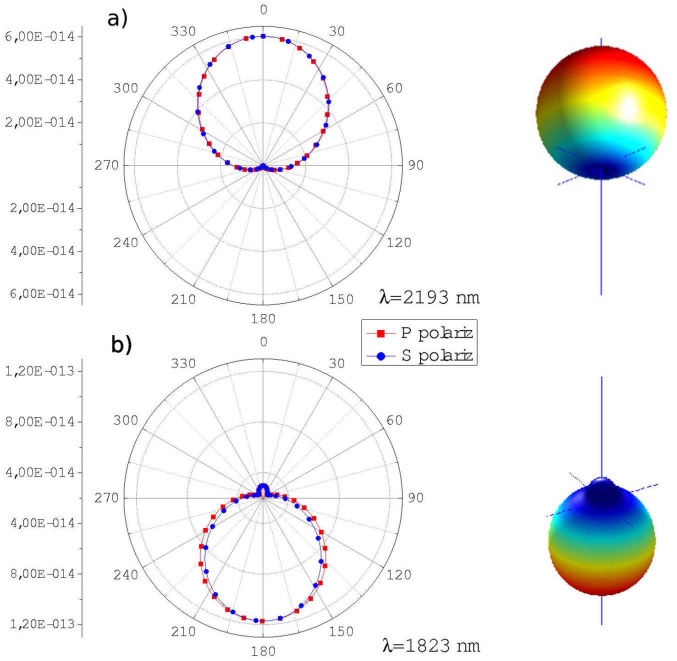

**Figure 2.** Scattering diagrams for the 240nm Ge nanoparticle ($\varepsilon_p$ =16 and $\mu_p$ =1) at $\lambda$=2193 and $\lambda$=1823 nm, (first and second GK conditions, respectively). Both polarizations, with the incident electric field parallel (P polarization) or normal (S polarization) to the scattering plane are considered. Notice that while the backward intensity drops to zero at the first GK condition wavelength, at the second condition, although the most of the intensity goes backward, the scattering diagram presents a very small peak in the forward direction. (Adapted from Ref. [6]).

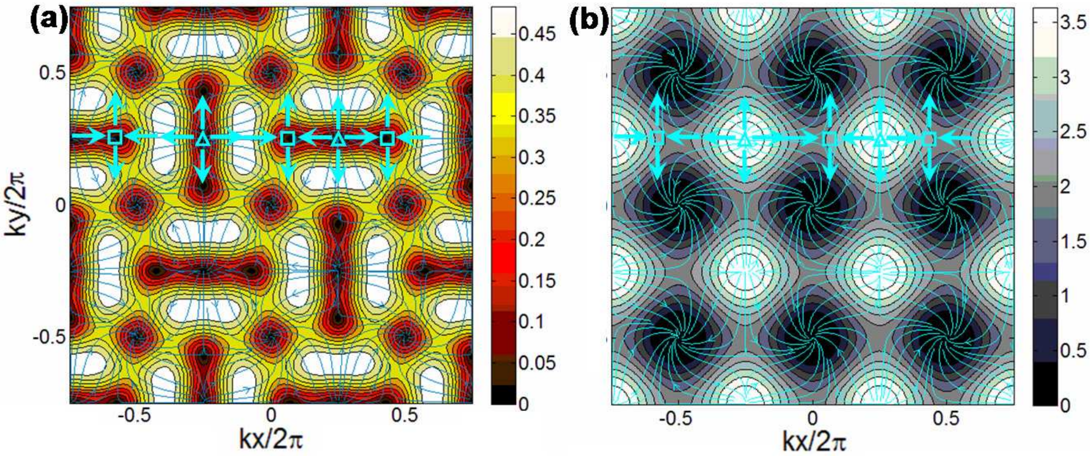

**Figure 3**. Nonconservative forces on a Si sphere of radius a=230nm placed at the intersection region of two standing waves for a wavelength λ=1725nm slightly above (red-shifted) the magnetic dipolar resonance. Arrows in (a) and (b) point along the total force lines. (a) Contour maps of the modulus of the normalized total force. (b) Contour maps of the normalized electric field intensity. The symbols sketch the force fields at several positions: □ corresponds to saddle points and Δ corresponds to unstable equilibrium (zero-force) positions, respectively. (Adapted from Ref.[7]).