Pressure of radiation induced with a null average value of the electromagnetic flow

Manuel I. Marqués [a,b], Juan José Sáenz [b,c]

[a] Departamento de Física de Materiales, Universidad Autónoma de Madrid, 28049, Madrid, Spain
[b] Centro de Investigación en Física de la Materia Condensada (IFIMAC) and Instituto de Ciencia de Materiales “Nicolás Cabrera”, Universidad Autónoma de Madrid, 28049, Madrid, Spain
[c] Departamento de Física de la Materia Condensada, Universidad Autónoma de Madrid, 28049, Madrid, Spain

manuel.marques@uam.es

Abstract

The scattering force on small particles, which is proportional to the imaginary part of the polarizability of the particle and to the phase gradients of the fields [1-3] is traditionally considered to be proportional only to the Poynting vector but, for inhomogeneous waves, there is an additional contribution [4,5]. This additional contribution is proportional to the curl of the spin angular momentum of the light field [6].

The actual physical significance of this new contribution is subject of some controversy [7,8]. The contribution to the scattering force given by the full Poynting vector plus this spin curl contribution is equivalent to consider only the so-called orbital component of the Poynting vector [9].

To correctly analyze scattering processes, forces coming from the curl of light's spin must be considered. For example spin forces are important in the focal volume of microscope objectives [10-13] and in evanescent waves [14,15]. Also, spin forces may be fundamental to understand the dynamics of nanoparticles trapped in optical vortices generated by interfering laser beams [16] leading to complex dynamics [17,18].

In this work we explicitly show the importance of the non-conservative force coming from the curl of the spin density of the light field by describing some electromagnetic configurations with null average value of the Poynting vector but a non-zero scattering force coming purely from the spin density. In other words, we will show how it is possible to induce radiation pressure in a nanoparticle with a null average value of the electromagnetic energy flow. In particular we consider a configuration consisting in two perpendicular circularly polarized stationary waves [19,20] (Fig.1) and a configuration consisting in two perpendicularly polarized counter propagating evanescent waves [21] (Fig.2). These configurations may raise some fundamental questions about the meaning of an electromagnetic linear momentum density proportional to the Poynting vector [22].

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Figures

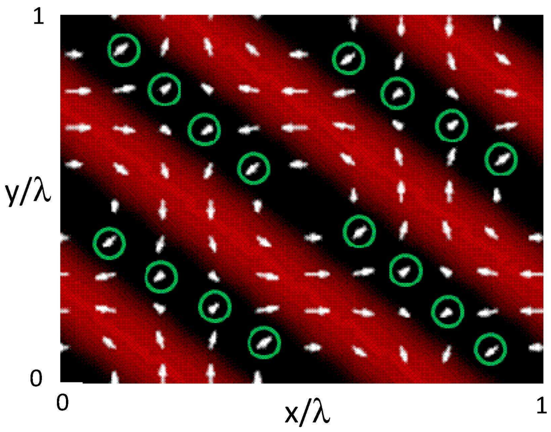

Fig.1 Scattering force on an electric dipole for the configuration consisting in two perpendicular, circularly polarized, stationary waves with wavelength λ propagating in the X-Y plane and with a difference of phase of $\pi/2$. The color map represents the magnitude of the average value of the Poynting vector (black for zero average and bright red for the maximum value). Green circles highlight the scattering forces which are different from zero in a region with a null value of the Poynting vector.

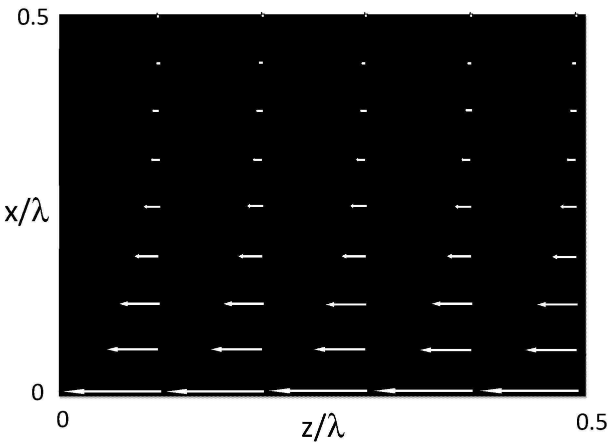

Fig.2 Scattering force on an electric dipole for the configuration consisting in two perpendicularly polarized, counter propagating, evanescent waves. The magnitude of the fields exponentially decreases in the X direction. The waves, both with wavelength λ, propagate in the Z direction (for the TE wave) and in the -Z direction (for the TM wave). The color map represents the magnitude of the average value of the Poynting vector (black for zero average and bright red for the maximum value). In this case all scattering forces are different from zero in a region with null average value of the Poynting vector.