Light Depolarization in Nanosphere-Dimers by Incoherent Mixing of Mueller Matrices

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Abstract

In this work, we report on the influence that mixing basic configurations has on the depolarization of the light scattered by two coupled nanospheres. Both the Discrete Dipole Approximation (DDA) and The T-Matrix method have been used as intermediate tools to calculate the scattering matrices of coupling metallic nanospheres. When the polar decomposition (PD) is applied to the mixed Mueller matrix (MM), the principal decomposition parameters can be obtained and depolarization turns up. Principal depolarization parameters are sensitive to the gap between nanospheres. This study can be of interest in applications where depolarization has to be avoided. Gas sensing or colloid analysis techniques are two examples of such applications.

System Geometry and Numerical Method

The scattering system we analyze consists on two silver spheres (n=0,135+3,988i, λ=633nm) of radius r=0.1λ, and with gap distances ranging from 0.1λ to 0.8λ. We have considered three different geometries (X, Y and Z geometry, corresponding to Figs.1a, 1b and 1c, respectively), all illuminated by a monochromatic plane wave of λ=633nm. We numerically obtain the elements of the MM by using DDA [1] and T-Matrix [2]. These computational procedures are suitable for studying scattering and absorption of EM radiation in this kind of electromagnetic systems [3, 4].

The MMs obtained from these procedures have been post-processed in all cases with an algorithm that performs the PD [5]. After testing the purity of the matrices [6], it was found that in the cases analyzed, the MMs obtained for single states were pure. This means that the system does not produce any depolarization. However, depolarization -as incoherent process- could be expressed as a linear combination of pure contributions [6]. In a first approach, we suppose that identically contribution of each pure state (pondered sum of the MMs obtained for X, Y and Z geometries) could lead to depolarization. This procedure can be understood in terms of a randomly contribution from two spherical nanoparticles places along X, Y or Z axis.

The system matrix can be decomposed as $M_{4x4}= M_{\Delta}\cdot M_R\cdot M_D$, where M_{Δ}, the depolarization matrix, is the Identity 4x4 in pure states case, M_R is the retardance matrix and M_D is the diattenuation matrix. Due to the symmetry properties, and as a result of the PD, we can decompose our problem in an equivalent system composed by an ideal diattenuator aligned with the scattering plane, $M_D(t)$, with the fast axis of a lineal retarder, $M_R(\delta)$, and with the principal axis of a linear depolarizer, M_{Δ} (d_1,d_2,d_3).

Examining in detail the polarimetric properties of our system and making use of the PD, we can describe the behavior of our system by just considering from three to six independent parameters: the total system transmittance (M_{11}), the transmission along one of the diattenuator axes (t), the phase shift introduced by the retarder (δ) and, in the case of non-pure systems, the principal depolarization parameters (d_1,d_2 and d_3). Once the meaning of the PD parameters is well understood, this polarimetric method provides us with a handy tool to approach the analysis of the system [7].

Results and Conclusions

Principal PD parameters of pure geometries are shown in Fig. 2 a), b) and c), while diattenuation and retardance parameters of a MMs mixing are shown in Fig. 2 d). It is observed that in mixed (non-pure) cases interaction-dominant contributions are smoothed and, although qualitatively the interaction effects remain, quantitatively changes occur. These changes could be analyzed from the depolarization point of view. In fact, we can observe depolarization contribution in Fig. 3: When principal depolarization parameters (d_i) decrease, depolarization increases. Furthermore, depolarization by mixing pure states contribution increases when gap decreases.

We are now working in increasing the number of random states (not only X, Y, and Z geometries), so this theoretical approach could be involved with real experimental situations by associating both mean free path in a nanoparticles sample with the gap distance between nanospheres and depolarization with incoherent addition of states due to any type of movement (Brownian, convection flow, etc.). Polarimetric measures in gas sensing, aerosols or colloidal solutions are issues that could be sensitive to depolarization in the terms outlined in this paper.

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References

[1] B. T. Draine, P. J. Flatau, User Guide for the Discrete Dipole Approximation Code DDSCAT 6.1, 2004. URL http://arxiv.org/abs/astro-ph/0409262v2
[2] M. I. Mishchenko, L. D. Travis and D. W. Mackowski, JQSRT, **55** (1996) 535-575.
[3] P. Albella, F. Moreno, J. M. Saiz, F. González, Optics Express **15 (11)** (2007) 6857-6867.
[4] B. Setién, P. Albella, J. M. Saiz, F. González and F. Moreno, New J. Phys. **12** (2010) 103031.
[5] J.M. Sanz, P. Albella, F. Moreno, J. M. Saiz and F. González, JQSRT **110** (2009) 1369–1374.
[6] J. J. Gil, Eur. Phys. J. of Appl. Phys. **40** (2007) 1-47.
[7] J.M. Sanz, J. M. Saiz, F. González, and F. Moreno, Appl. Opt. **50 (21)** (2011) 3781–3788.

Figure 1: Dimer Scattering Geometries

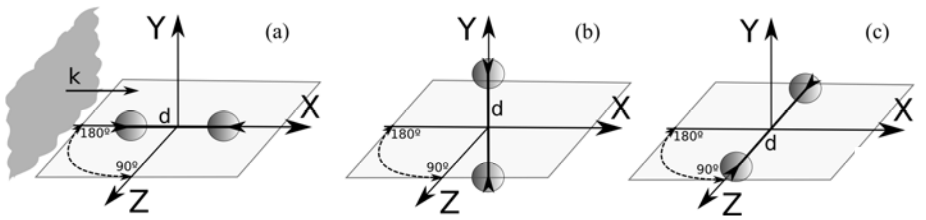

Figure 2: PD Principal Parameters vs. Scatt. Angle for Gap=0,1λ: a), b) and c) Pure Geometries, d) Pondered Mixing Geometries.

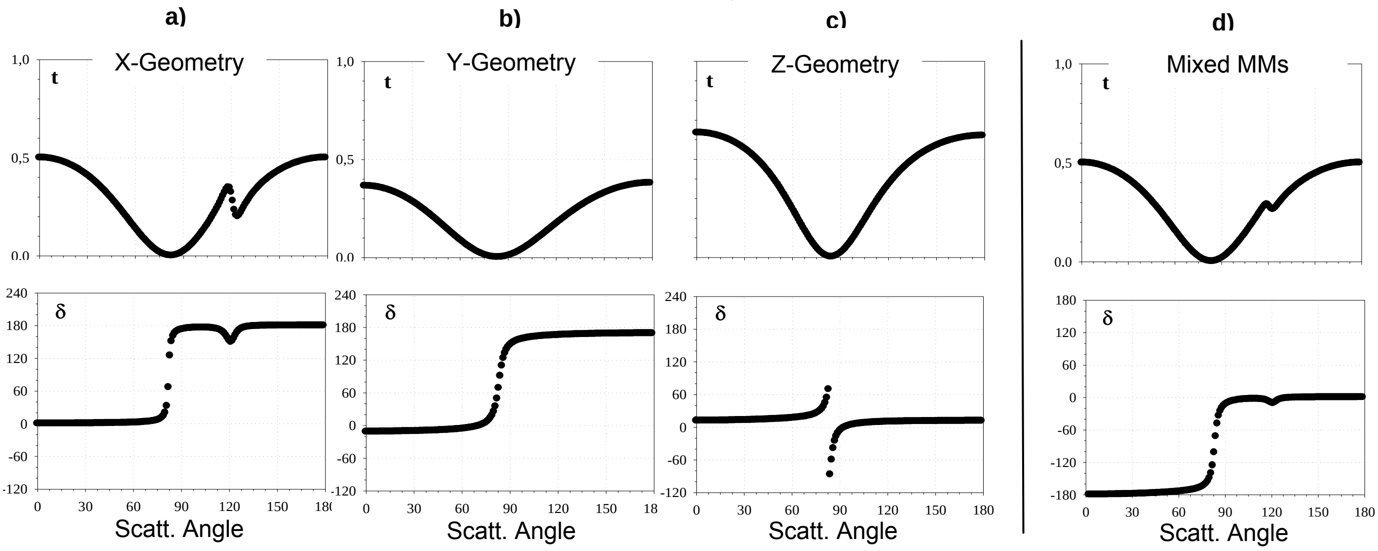

Figure 3: Mixing MMs Principal Depolarization Parameters vs. Scatt. Angle: a) Gap=0,1λ, b) Gap=0,2λ c) Gap=0,8λ.