ABSphere - Software for calculation of all physical properties of Any shaped Beam by a Spherical particle

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Abstract

Based on the rigorous solution of the Maxwell equation – the Generalized Lorenz-Mie Theory (GLMT), software ABSphere has been developed for the calculation of different physical properties concerning the interaction of a spherical particle and a shaped beam. The particle can be homogeneous or stratified. Five kinds of shaped beam are considered: circular Gaussian beam, elliptical Gaussian beam, Doughnut beam and Bessel beam. It is also possible for user to provide the beam shaped coefficients for any shaped beam. Five quantities can be calculated: 1). Scattering diagram, 2). Internal/near field intensity, 3). Efficient coefficients (sections), 4). Radiation forces 5). Radiation torques. The test on a conventional personal computer shows that the particle size can be as large as some millimetres (for visible light) and the number of layers can be some ten thousands.

1 Context of the development

In the field of light-particles interaction, the scattering of a spherical particle is the simplest and the most important since it is the only model that we can calculate rigorously all the physical properties for particles of almost any size illuminated by any shaped beam. Particularly, when the spherical particle is illuminated by different shaped beam we can reveal many physical phenomena and serves as reference to validate the models for other shaped particles.

In the framework of Generalized Lorenz-Mie Theory, the incident beam and the particle property are described respectively and independently by two series of the beam shaped coefficients (BSC) $g^m_{n,TM}$, $g^m_{n,TE}$ and four series of the Mie coefficients: a_n , b_n for the scattered fields and c_n , d_n for the internal fields. Once we know the beam shaped coefficients and the Mie coefficients we can calculates all physical quantities [1, 2].

2 Description of the software

The calculation of the Mie coefficients and the beam shape coefficients are essential. A brief description of the calculation of these coefficients is given in this section.

2.1 Mie Coefficents

The calculation of Mie coefficients is for a homogeneous particle is well documented [1] and without special problem even for large particle. However, the numerical evaluation of these coefficients for a stratified sphere is not an easy task [3]. Based on the work of Wu et al [4] the author has developed an algorithm which is more stable and efficient.

2.2 Shaped beams in ABSphere

The beam shape coefficients are at the core for the numerical prediction of the scattering of a shaped beam by a sphere. They are also essential for the scattering of a spheroid or other shape particle since the beam shaped coefficients in that coordinate system can be expressed as function of the beam shape coefficients in spherical coordinate system. Many authors have contributed to the numerical evaluation of these BSC (see [4] and the references therein).

In ABSphere, the Integral Localized Application (ILA) [5] is adopted since for commonly used shaped beams, the integral can be evaluated to the standard Bessel function (see Table 1). Therefore, there is no problem of numerical instability. By comparison with the rigorous quadrature methods it is proved that the precision of ILA is usually very satisfactory.

Shaped beams	Parameters	Beam shape coefficients
Circular Gaussian beam	Beam waist radius w_0	All beam shape coefficients are calculated by using Bessel function derived from ILA.
Elliptical Gaussian beam	Beam waist radii w_{0x} , w_{0y}	
Doughnut beam	Beam waist radius w_{0dn} Polarization: 4 states	
Bessel Beam	Any order υ with given angle of axicon α_0	
Any beam with known g^m_n	ABSpher reads the beam shape coefficients to calculate the physical quantities.	

Table 1 *Shaped beams considered in ABSphere*

Theoretically, any given double series of BSC $g^m_{n,TM}$, $g^m_{n,TE}$ describe a beam whose electromagnetic fields satisfy perfectly the Maxwell equations. The evaluation of the beam shape coefficients from given electromagnetic field is just to find the coefficients which describe a beam the most "faithful" to the given one. To reply the needs of calculation for any shaped beams, ABSphere provides the possibility for the user to give the double series of BSC in order to calculate the quantities listed in the following section. For example, if the user wants to calculate the radiation pressure on a sphere in the evanescent wave, he can calculates its BSC independently by integral methods and then ABSphere reads the coefficients from a file to calculate the quantities at his will.

2.3 Quantities calculated by ABSphere

The actual version of ABSphere calculates the following quantities:

1). Scattering diagram $I(\theta)$ for given an azimuth angle φ (to define the observation plane).
2). Internal/near field $I(x,y,z)$
3). Efficient coefficients (sections) Q_{ext}, Q_{sca}, Q_{abs} as function of particle size.
4). Radiation forces section $C_{pr,x}, C_{pr,y}, C_{pr,z}$ as function of particle size or its position.
5). Radiation torques T_x, T_y, T_z as function of particle size or its position.

2.4 Some results

Some typical results are given in this section.

Figure 1 is a graph of ABSphere showing the scattering diagram of a particle of glass (m=1.5) of radius a=7.5 µm, illuminated by a circular Gaussian beam ($\lambda = 0.5\ \mu m$, $w_0 = 5\ \mu m$). The blue and the red curves are the total scattering intensities for the azimuth angle $\varphi = 0$ and $90°$, while the black and the green curves are the intensities of the Debye series for diffraction plus reflection for the two observation planes at $\varphi = 0$ and $90°$.

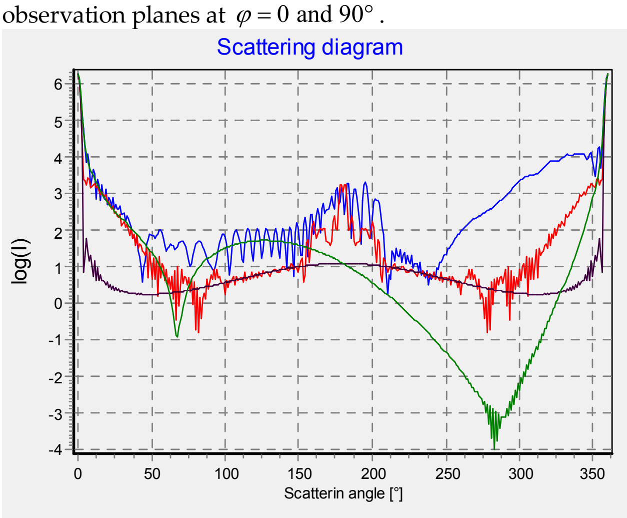
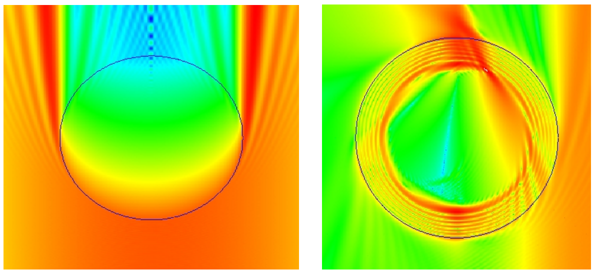


Figure 1 *. Scattering diagrams of a particle of glass located at* $x_0 = 5\ \mu m$ *in a Gaussian beam.*

The second example is to show the calculation of the internal and near fields when a particle is illuminated by a shaped beam. Figure 2(a) shows the internal and near fields of a nano-sphere in SiO_2 (a=92.5nm) illuminated by Synchrotron ray of 248 eV and Figure 2(b) the internal and near fields of a glass sphere (a=7.5 µm) illuminated by a Gaussian Beam (w_0=5µm) at 10 µm off-axis.



(a) (b)

Figure 2 *. Internal and near fields of a particle: (a) a nano-sphere in SiO2 (a=92.5nm) illuminated by Synchrotron ray of 248 eV, (b) a glass sphere (a=7.5 µm) illuminated by a Gaussian Beam (w0=5µm) at 10µm off-axis.*

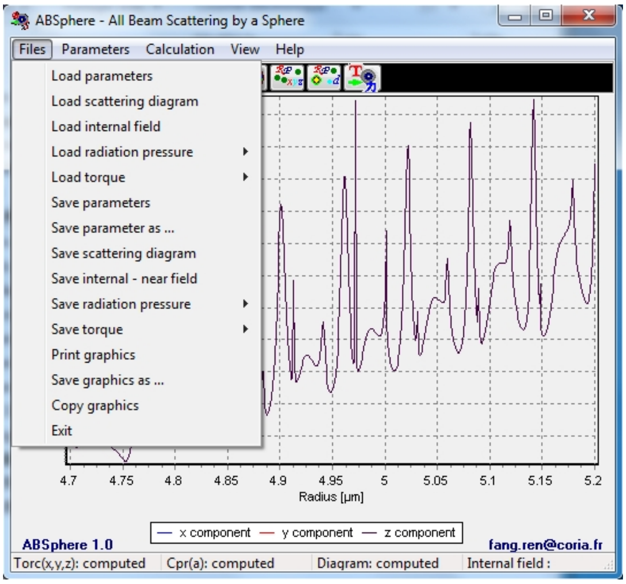


Figure 3. *Screen Shot of ABSPHERE - Software*

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4 References

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