Extended geometrical optics approximation and Monte Carlo ray tracing for light scattering by an irregular object

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The study of light-particle interaction is essential for optical metrology of particles in multiphase flows. The theoretical and numerical tools have been widely developed for light scattering by macroscopic objects:
- Rigorous theories of light scattering of a laser beam of any shape by a particle of simple shape (sphere, cylinder…).
- Extended geometrical optics approximation (EGOA) of light scattering of a plane wave or a Gaussian beam by an axisymmetric particle: the model takes into account not only the deviation of each light ray, but also interferences, the diffraction and absorption effects and the intensity variation of incident beam. It is shown that considering all the effects mentioned, the EGOA can accurately predict the scattering patterns with comparison to the rigorous theory.
- Numerical method of Monte Carlo ray tracing (MCRT) to treat the light scattering by objects of any shape illuminated by a plane wave in 3D.

The first method is applicable only to regular particles. The second method may be extended to irregular particles, but currently limited to 2D axisymmetric case. The MCRT method can be used to objects of complex shape. However the calculation is time consuming and the effects of polarization, absorption, interference and diffraction as well as incident beam shape are not taken into consideration.

Objects encountered in the two-phase medium are often irregular and complex, for example, liquid ligaments formed by a spray. In order to meet our specific needs to spray optical metrology, the EGOA method should be extended to more complex particles in 3D. And the different scattering effects (polarization, diffraction, interference…) in the MCRT model should be included.

Therefore, the purpose of our work is to improve these two methods to describe accurately the light scattering by objects of any shape in 3D. Furthermore, when we want to extend the EGOA to particles of relatively complex shape (a spheroid, for example), no rigorous theory is available to compare, the two methods can be verified each other.

New advances concerning both methods have been obtained. In one hand, the EGOA method has been applied to predict the scattering patterns of a spheroidal droplet or bubble with an arbitrary ellipticity. Furthermore, to meet experimental requirement of arbitrary angle incidence, the EGOA model has also been extended to non-axisymmetric case: scattering of a spheroidal particle illuminated by an inclined plane wave. On the other hand, the MCRT has been improved by adding the effects of absorption, polarization, incident beam shape and interference. The basic scattering case of a sphere illuminated by a plane wave has been used for validating the MCRT. Each element added in the MCRT has been verified by comparison with the EGOA results. Fig. 1 shows the comparisons of scattering intensities with interference simulated by two methods for a spheroidal bubble illuminated by a polarized plane wave. From these figures, good agreement between two methods can be found.

**Fig. 1** Comparisons of the scattering intensities for the perpendicular and parallel polarizations calculated by EGOA and by MCRT for a spheroid of transversal radius \(b = 50\,\mu m\), symmetric radius \(a = 25\,\mu m\) and of refractive index \(n = 0.75\) illuminated by a plane wave of wavelength \(\lambda = 0.6328\,\mu m\).

Finally, the improvement of these two models will allow us to predict accurately the light scattering by an irregular object in 3D which is supposed to serve for spray imaging and other optical metrology techniques. It will lead to a better understanding of present optical diagnosis and innovation in spray metrology.