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Description of light scattering by arbitrarily shaped particles in terms of stochastic geometry

A. Malinka
Institute of Physics, Belarus (mal@light.basnet.by)

Stochastic geometry, also called geometrical statistics or stereology, is the most natural way to characterize an ensemble of randomly oriented non-spherical or irregularly shaped particles. The key concept in stochastic geometry is a random chord. Any random straight line, uniformly and isotropically distributed in space, produces a random chord when intersecting a particle. The chord length ξ is a random value, characterized by some distribution function $f(\xi)$, called the chord length distribution (CLD). The CLD functions or their moments are known for simple shapes, such as ellipsoid, cylinder, or parallelepiped. The exponential CLD function matches a stochastic mixture with Markov statistics.

This approach turns out to be very useful in the problem of light scattering by particles of irregular shape. Although it is not possible to solve this problem for any values of the refractive index m, two kinds of approximations, together with the stereology approach, allow one to get the analytical solutions for the light scattering characteristics. First one is the Wentzel-Kramers-Brillouin (WKB) approximation, valid for refractive indices close to 1; second one is the geometrical optics, valid for large refractive indices.

The WKB approximation supposes that the wave inside the particle does not change its direction and propagates with the phase corresponding to the refractive index of the substance. Following this approach it is easy to show that the integral characteristics (the extinction and absorption efficiencies) are expressed straightforwardly through the Fourier and Laplace transforms (F and L) of the CLD. Namely, $Q_{ext} = 2Re\left[1 - F\left(k(m-1)\right)\right]$ and $Q_{abs} = 1 - L(\alpha)$, where k is the wavenumber and α is the absorption coefficient.

The opposite approach, geometrical optics, allows one to consider scattering as a process of consequent refractions and reflections of a ray by the facets of the air-particle interface. Summing up a number of refraction and reflection events, one can also find the analytical expressions. Namely, $Q_{ext} = 1$ (the inherent relationship of the geometrical optics) and $Q_{abs} = T_{out}\left(1 - L(\alpha)\right) / \left(1 - R_{in}L(\alpha)\right)$, where T_{out} is the Fresnel transmittance of a border for diffuse incidence from outside and R_{in} is the internal Fresnel reflectance of a border for diffuse light.

Not only integral, but also angular characteristics of light scattering (the phase function and the polarization matrix) can be obtained analytically in this case. Also, as the geometrical optics operates with light rays, it does not require that the particles are in the far field zone and, therefore, includes the case of dense packing.

Therefore, the stochastic geometry may be extremely useful, as there are no strict analytical solutions for non-spherical particles and the strict numerical methods require huge computer resources.