On the feasibility of measuring extinction of single particles

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The extinction of a single particle is often considered as a total power extracted from the beam as a result of the scattering and absorption, which is the essence of the optical theorem. On the one hand, when a collection of particles (e.g., a cloud or suspension) is involved the extinction is reliably measured by the detector in the forward direction, subtracting the results with and without the sample present. On the other hand, the extinction is described by the interference of the scattered and incident fields in the far-field zone, which happens not only in the forward direction but for a wide range of scattering angles. This interference was described in details by Berg *et al.* [1], who suggested that a detector covering up to 60° may be required for single-particle extinction measurement. Inspired by this alarming suggestion, Mishchenko *et al.* [2] explicitly calculated the reading of a circular and square detectors placed around the forward direction (for a simplified case of isotropic scalar scattering). The reading of a perfectly centered circular detector indeed oscillate with a detector size and have no limit. However, for a square detector these oscillations decrease with detector size, converging to the expected result proportional to the extinction cross section. Still, a relatively large detector size R is required ($R^2 \gg \lambda z$, z is the distance to the detector and λ is the wavelength), which has already been mentioned in classical textbooks [3,4]. It has also been recently discussed in [5], which showed that use of collimated beam improves convergence of measured power with increasing detector size.

In this work I analyze the extinction measurements for a single particle illuminated by a plane wave using a detector of arbitrary shape, described by a function $\rho(\theta)$ in polar coordinates. Using the stationary-phase arguments, it is shown that the error scales as $\sqrt{\lambda z/\Delta(\rho^2)}$, where $\Delta(\dots)$ denotes the difference between the maximum and minimum values of a function (or its variation). This general result is further applied to a non-centered circular detector and, next, extended to a random movement of a particle during the measurement time (which was previously analyzed only qualitatively). The latter decreases (averages out) the error, but the diffusion shifts should be smaller than the size of the detector, so that the geometrical shadow of the particle always falls inside the detector. Finally, the feasibility of the extinction measurement is analyzed in terms of the dynamic range of the detector (since the reference signal increases proportionally to the detector area). Measuring extinction of a fixed particle with 1% accuracy requires the dynamic range of 10^8, while 10^4 can be sufficient for a randomly moving one.

References

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