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Optical force exerted on a Rayleigh particle by a vector arbitrary-order Bessel beam

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Optical trapping by highly a focused beam has been widely studied and employed for the manipulation of micro- and nano-particles, and has found more and more applications in various fields including physics, biology, and optofluidics. Polarization is one important property of light. Utilization of vectorial nature of laser beam has attracted great interest to manipulate small particles. In this report, we will derive the optical force exerted on a Rayleigh particle by a vector Bessel beam.

According to angular spectrum representation, an arbitrary beam can be written in Cartesian vector components as

$$E(r,\theta,\phi)=\int_{\alpha=0}^{\alpha_{max}}\int_{\beta=0}^{2\pi}QP(\alpha,\beta)e^{ik\cdot r}|\sin\alpha\cos\alpha|d\alpha d\beta \tag{1}$$

where k is the wavenumber, α and β denote, respectively, the polar and azimuthal angles of the wave vector, and $P(\alpha,\beta)$ describes the incident beam's profile and

$$Q=\begin{bmatrix} p_x(\cos\alpha\cos^2\beta+\sin^2\beta)-p_y(1-\cos\alpha)\sin\beta\cos\beta \\ -p_x(1-\cos\alpha)\sin\beta\cos\beta+p_y(\cos\alpha\sin^2\beta+\cos^2\beta) \\ -p_x\sin\alpha\cos\beta-p_y\sin\alpha\sin\beta \end{bmatrix} \tag{2}$$

For an l-order Bessel beam(BB), the angular spectrum is

$$QP(\alpha,\beta)=E_{pw0}Q\frac{\delta(\alpha-\alpha_0)}{\sin\alpha_0}e^{il\beta} \tag{3}$$

which describes the plane waves with wave vectors on the conical surface. A Bessel beam can then be represented as

$$E(r,\theta,\phi)=\int_{\beta=0}^{2\pi}E_{pw0}Qe^{il\beta}e^{ik\cdot}d\beta \tag{4}$$

where (p_x,p_y) is the complex polarization vector of plane-wave component. By the change of (p_x,p_y), we can obtain high-order Bessel beams of various polarization.

The radiation pressure force, as a sum of the scattering force and the gradient force, has been investigated by many people. This paper is devoted to the radiation forces of the vector high-order Bessel beams (VHOBBs) on a dielectric sphere in the Rayleigh scattering regime, which can be expressed as:

$$\frac{2F_\rho}{\varepsilon_0\varepsilon_m}=\Re\left\{\sum_{\gamma=1}^{3}\ell E_\gamma\frac{\partial}{\partial\rho}E_\gamma^*\right\},\quad \frac{2F_\varphi}{\varepsilon_0\varepsilon_m}=\Re\left\{\sum_{\gamma=1}^{3}\ell E_\gamma\frac{\partial}{\rho\partial\varphi}E_\gamma^*\right\},\quad \frac{2F_z}{\varepsilon_0\varepsilon_m}=\Re\left\{\sum_{\gamma=1}^{3}\ell E_\gamma\frac{\partial}{\partial z}E_\gamma^*\right\} \tag{5}$$

where F_ρ, F_φ and F_z are respectively ρ, φ and $z$components of optical force. $\Re$denotes the real part, and * represents conjugate.

In this report, we will first derive the analytical formulas of EM fields for a vector high-order Bessel beam and their optical force based on Eqs.(4) and (5). Then optical force exerted on a Rayleigh particle is analyzed in detail. The effect of various parameters including order of beam, polarization, location, etc to optical force will be discussed. Such work is of great significance to the improvement of optical tweezers system.

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