Optical Ball Bearings: Good Things Come in Pairs

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We report on transformation of spin and orbital angular momenta (SAM/OAM) of light upon tight focusing of a circularly polarized (CP) vortex beam. In some regions of the focus the OAM changes by ±2, while CP handedness reverses in these spots resulting in adjacent rings of opposite CP direction. We show that while the whole pattern rotates at the rate of total AM, 3D SAM "balls" in a ring between adjacent rings (or between a core and a ring) rotate in an opposite sense as in an optical ball bearing. Applications include optical manipulation.

Most research on spin-orbit interaction (SOI) of light deals with SAM conversion to OAM [1,2]. Recently, the inverse process, OAM to SAM, was reported [3]. In order to study SOI we consider focusing of circular polarized light beam possessing a vortex/OAM of order m. The electric field **E** at the focus can be described by the Debye approximation [4] for cw/ccw, or «±» CP. For sharp focusing, in order to derive for the field at the focus analytical results that can be simple to interpret, we use a narrow ring aperture at the input. Then:

$$\mathbf{E}(\rho,\varphi,z) \approx -kf\,\frac{i^{m+1}}{2\sqrt{2}}A(\theta_0,z)\begin{bmatrix} e^{im\varphi}J_m(k\rho)+e^{i(m\pm 2)\varphi}J_{m\pm 2}(k\rho) \\ \pm i\left\{e^{im\varphi}J_m(k\rho)-e^{i(m\pm 2)\varphi}J_{m\pm 2}(k\rho)\right\} \\ \mp 2ie^{i(m\pm 1)\varphi}J_{m\pm 1}(k\rho)\end{bmatrix} \qquad (6)$$

The transformation of the longitudinal component is well known – the change of the vorticity by ± 1 corresponds to transformation SAM to OAM [1,2]. For transverse components E~ $\left\{\begin{pmatrix}1\\ \pm i\end{pmatrix}e^{im\varphi}J_m(k\rho)+\begin{pmatrix}1\\ \mp i\end{pmatrix}e^{i(m\pm 2)\varphi}J_{m\pm 2}(k\rho)\right\}$.

We observe that the transverse field consists of 2 parts, each weighted by a different Bessel function with max at different distance from z axis: one with original CP and OAM and a 2nd with a CP of opposite sign and OAM increased/decreased, depending on the sense «±» of the CP, by value of 2. The transverse intensity I distributions for cw CP, and m=-1, 1, -2, -3, correspondingly, is shown in Fig. 1:

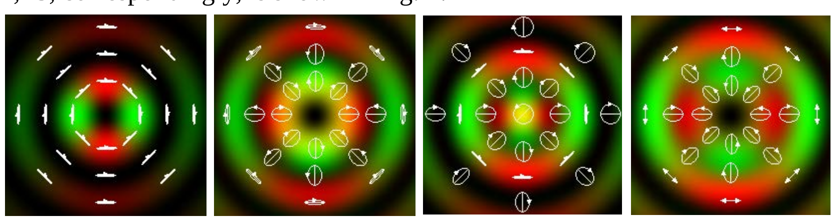

Fig. 1

a b c d

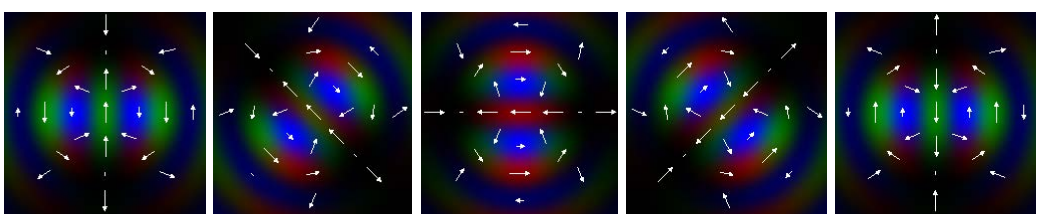

Fig. 2

t=0 t=T/8 t=T/4 t=3T/8 t=T/2

Here green, red and blue are x, y, z components. Except the case of cw CP and m=-1 where AM=0, all figures exhibit adjacent rings or ring/core with opposite CP directions. The time behavior of total I for the case of cw CP and m = -2 (Fig. 1c) s shown in Fig. 2. By observing a fixed spot between the center and the first lobe one discerns that the field arrow rotates cw –in opposite sense to the whole pattern rotation, reminiscent of a ball bearing action.

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