LIGHT BEAMS WITH ANGULAR MOMENTUM

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Summary

During last decades, the ability of light beams to carry a certain mechanical angular momentum (AM) with respect to the propagation axis attracts a special attention. In this field, a lot of fundamental and impressive results have been established. Some of them are reviewed and discussed in this work.

In paraxial beams, the total AM of a beam can be represented as a sum of the spin (SAM) and orbital (OAM) angular momenta. SAM is an attribute of beams with elliptic (circular) polarization and is related to a non-zero spin of photons. It exists in an arbitrary small part of the cross section of a beam and is not obligatorily related to the macroscopic energy circulation. Its absolute value is limited by the beam intensity, so that it cannot exceed h per photon.

Another sort of AM is OAM which is conditioned by the macroscopic transverse energy circulation and does not depend on the beam polarization state. In its turn, OAM can be divided into two components which reflect different forms of this energy circulation. The "vortex" OAM indicates a "hidden" internal circulation that occurs, e.g., in the circular Laguerre-Gaussian mode with a screw wavefront dislocation. The "asymmetry" OAM characterizes the rotation of the beam as a whole (e.g., a rotating astigmatic Gaussian beam). In the transformations of the beam with symmetry breakdown, both forms can mutually convert, and the corresponding OAM components describe this process.

An important class of beams with OAM are vortex beams with helical geometric structure, which are eigenstates of the OAM operator, and whose OAM equals lh per photon (l is an integer). They compose a set of azimuthal harmonics so that an arbitrary paraxial beam can be represented as a superposition of helical beams with different l. Here, we discuss various models of helical beams and methods of their practical generation.

A helical beam shows some features assimilating it to a mechanical rotating body. This body cannot be rigid; its separate radial layers "glide" with respect to one another, and the radial distribution of their velocities exactly corresponds to the laws of the vortex behavior in other fields of physics (fluid dynamics, electricity). In addition, a helical beam can impart the rotational motion to other bodies. The corresponding experiments [the transmission of AM from a light beam to optical elements (e.g., a half-wave plate) and to suspended microparticles] have shown the mechanical equivalence of SAM and OAM and given a possibility to directly assess the beam AM.

Like all physical objects with helical structure, the vortex light beams demonstrate the equivalency between their rotation and longitudinal translation. Consequently, their observable frequency depends on the relative motion of the beam and an observer with respect to the beam axis — the so-called rotational Doppler effect. As a result, any rotation of an optical image appears to be equivalent to certain coordinated frequency shifts of its azimuthal harmonics. Reciprocally, an a.c. signal generated in a fixed photodetector upon the rotation of a spatially inhomogeneous beam is a beat signal caused by the interference between different azimuthal harmonics, and it can be used for the practical retrieval of the azimuthal harmonic spectrum of a beam.

The mechanical properties of non-vortex beams that are subjected to the forced rotation due to an external action are analyzed as well. Such beams always possess a complicated 3D configuration stipulated by differences in the propagation of their azimuthal harmonics. Their rotation is characterized by AM which is proportional but, surprisingly, is directed oppositely to the rotation angular velocity.

Possible perspectives of studies and ways of the practical utilization of the optical beams with AM are discussed.