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JOURNAL OF PHYSICS B: ATOMIC, MOLECULAR AND OPTICAL PHYSICS

J. Phys. B: At. Mol. Opt. Phys. **41** (2008) 101001 (7pp)

doi:10.1088/0953-4075/41/10/101001

FAST TRACK COMMUNICATION

Angular momentum of photons and phase conjugation

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Received 27 December 2007, in final form 19 March 2008
Published 6 May 2008
Online at stacks.iop.org/JPhysB/41/101001

Abstract

Using the concept of an *ideal* phase-conjugating mirror we demonstrate that regardless of internal physical mechanism the phase-conjugation of a singular laser beam is accompanied by excitation within the mirror of internal waves which carry doubled angular momentum in order to match angular momentum conservation. For a Brillouin hypersound wavefront-reversal mirror this means that each elementary optical vortex belonging to a speckle pattern emits an acoustical vortex wave with doubled topological charge. The exact spatial profiles of light intensity and the intensity of hypersound in the vicinity of the phase singularity are obtained. These *spiral* profiles have a form of double helix which rotates with the frequency of sound. An optoacoustic experiment is proposed for visualization of the wavefront reversal of twisted optical beams and tunable twisted sound generation.

The conservation of angular momentum (AM) $\vec{J}$ stems from the isotropy of space [1]. In contrast to particles with nonzero rest mass m_o, the decomposition of $\vec{J}$ into 'spin' $\vec{S}$ and 'orbital' $\vec{L}$ parts of a photon's AM is referred to as an ambiguous procedure [1, 2]. The spin part $\vec{S}$ is related to polarization, i.e. time-dependent layout of electrical $\vec{E}$ and magnetic $\vec{B}$ fields of the 'transverse' light wave. The orbital part (OAM) $\vec{L}$ is associated with a helical staircase wavefront [2–5]. As a matter of fact purely transverse light waves are an abstraction because of small but inevitable projections of $\vec{E}$ and $\vec{B}$ in the direction of propagation, say the z-axis (figure 1). Indeed, the spin-orbital coupling of light occurs [6] due to a vectorial interplay between longitudinal and transversal components of the fields $\vec{E}$ and $\vec{B}$. The vectorial solutions of Maxwell's equations for propagation of light spatially localized by a waveguide or emitted through a finite aperture to free space give a strict relationship between the longitudinal and transversal field components [7, 8]. Nevertheless the approximate decomposition in the form $\vec{J} = \vec{S} + \vec{L}$ has proven to be very fruitful for small curvatures of the light wavefront, i.e. in the paraxial wave approximation [2].

The propagation of light in an anisotropic medium changes the polarization, and historically the spin of photon was observed for the first time in Bethe's experiment where a birefringent $\lambda/2$ plate induced a change of photon polarization from circular ($S_z = +\hbar$) to counter-rotating ($S_z = -\hbar$) [9]. The elementary event of the photon's spin change is accompanied by a back action and a stepwise change in the angular momentum of a plate. The quantum–classical correspondence is fulfilled by the origin of a macroscopically observable classical torque $\vec{T} = \frac{\mathrm{d}}{\mathrm{d}t}\vec{J} = [\vec{D} \times \vec{E}]$ [2], where $|\vec{J}| \approx \frac{I}{\omega}$, ω is angular frequency and I the intensity of light.

The reflection of a circularly polarized photon from an ideal conventional mirror (metal of multilayer dielectric) does not change the direction of both the spin $\vec{S}$ and orbital momentum $\vec{L}$ in the laboratory frame, and the mechanical torque $\vec{T}$ on such a mirror is absent (figure 1). This follows from both the boundary conditions for Maxwell's equations [8] and rotational symmetry of the setup with respect to the z-axis [1, 10].

The current communication pays particular attention to conservation laws for reflection of a photon carrying OAM $L_z = \ell\hbar$ from a phase-conjugating mirror (PCM). The discussion is centered mainly around a Brillouin wavefront-reversal mirror [10]. We will demonstrate the hidden anisotropy of an SBS-mirror which arises due to excitation of internal helical waves, i.e. acoustical vortices, whose existence

0953-4075/08/101001+07$30.00

Self-pumped phase conjugation of light beams carrying orbital angular momentum

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Abstract: We investigate the properties of angular momentum carrying vortex beams, reflected by a phase-conjugating mirror. It is shown that a self-pumped photorefractive phase-conjugating mirror is suitable to produce stable, high-fidelity phase conjugation of vortex beams. We prove that the topological charge of the vortex beam is maintained, and thus the angular momentum in the laboratory frame of reference is reversed, as it is expected by the time reversal property of the phase-conjugating mirror. The three dimensional interference pattern in front of the phase-conjugating mirror is studied and applications in optical traps are suggested.

OCIS codes: (190.5040) Phase conjugation; (190.5330) Photorefractive optics; (260.6042) Singular optics; (050.4865) Optical vortices; (140.7010) Laser trapping.

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#116646 - $15.00 USD Received 3 Sep 2009; revised 5 Oct 2009; accepted 22 Oct 2009; published 30 Nov 2009