Optical Spin and Orbital Angular Momentum and a Higher Order Poincare Sphere: Implications and Applications

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The well known optical vortex (OV) beams have received considerable interest in recent years because of their unique helical phase structure and resulting ability to carry a well-defined optical orbital angular momentum (OAM) per photon that is in addition to a spin angular momentum (SAM) associated with polarization. Less well known are cylindrical vector (CV) beams, beams of light with a helical polarization structure such as radial and azimuthally polarized beams. These beams have also received recent interest in part due to their unique ability to produce strong longitudinal field components and smaller spot sizes upon focusing by high numerical aperture objective lenses. There is a rich connection between OV beams and CV beams. A CV beam can be expressed as the linear superposition of orthogonal circular polarized OV beams of opposite topological charge, and therefore the constituent components of CV beams are eigen-states of total optical angular momentum (AM). In this work the connection between OV beams and CV beams and the SAM and OAM of light is illustrated through a higher order Poincare sphere (PS) representation that includes *two* spheres describing higher order states of polarization of a light beam, built up from a basis of orthogonal circular polarized OV states of opposite topological charge in terms of higher order Stokes parameters. The resulting sphere has a number of interesting implications. The higher order PS is the direct product between the spaces of the conventional PS (that can be considered a zeroth order representation) and the orbital PS devised by Miles Padgett. Sir Michael Berry's topological argument that the Pancharatnam's phase is the flux through a closed loop on the PS surface of a magnetic monopole situated at the origin implies the flux of the magnetic monopole of the higher order PS is proportional to the total optical angular momentum including both SAM and OAM. As the higher order PS description entails two spheres a topological picture is envisaged where each sphere of opposite monopole flux is connected by a Dirac string. The higher order PS is proposed to have a number of practical applications including the description of higher order TE, TM, and HE modes in an optical fiber, hybrid quantum entanglement of the SAM and OAM degrees of freedom of single photons, and a higher order Pancharatnam-Berry geometric phase involving both optical SAM and OAM which may offer an alternate description of the rotational frequency shift of a light beam.