Using optical eigenmodes for single photon description

Michael Mazilu
SUPA, School of Physics and Astronomy, University of St Andrews, St Andrews, KY169SS, United Kingdom
e-mail: mm17@st-andrews.ac.uk

Abstract: Photon states can be represented using many families of orthogonal fields, such as plane waves, Laguerre-Gaussian beams, Bessel beams, etc... Here, we show that optical eigenmodes offer a particular useful description of single photon quantum state in a light-matter interaction.

In general, linear light-matter interaction is proportional to the intensity of the incident light field. These linear interactions can be described by a quadratic function of the incident fields. For example, the momentum imparted by a scattering beam onto an object is determined by integrating the flux of Maxwell's stress tensor on a closed surface surrounding this scattering object. The quadratic and, more precisely, Hermitian nature of Maxwell's stress tensor leads to a linear dependence onto the intensity of the field. However, due to the quadratic nature, we observe, at the same time, interference effects. Indeed, the momentum transfer resulting from the superposition of two beams is not the same as the sum of the momenta from each of the beams incident separately. This interference effect disappears when the two fields constituting the superposition are orthogonal with respect to the quadratic momentum measure. In general, this is the case when the fields are optical eigenmodes of the momentum measure [1-3].

The field orthogonality of the optical eigenmodes makes them a suitable representation of the fields associated with photon creation/annihilation operators. This representation allows for a simplification of the description of light-matter interaction when considering quantum mechanical observable operators. For example, observing and measuring the momentum transfer of a photon to a scattering object collapses the quantum state of the photon onto one of the optical eigenmodes. Therefore, optical eigenmodes provide a natural framework to consider the interaction of quantum light states with macroscopic matter [4]. More generally, this property is applicable to all Hermitian quadratic measures of the field linked to quantum photon observables, such as energy, momentum and angular momentum.

References

[1] M. Mazilu, "Optical eigenmodes; spin and angular momentum," *J. Opt*., **13**, 064009 (2011).
[2] M. Mazilu, J. Baumgartl, S. Kosmeier, and K. Dholakia, "Optical Eigenmodes; exploiting the quadratic nature of the energy flux and of scattering interactions," *Opt. Express*, **19**, 933 (2011).
[3] M. Mazilu, "Spin and angular momentum operators and their conservation," *J. Opt. A*, **11**, 094005 (2009).
[4] K. Ballantine, and M. Mazilu "Optical eigenmode description of single-photon light-matter interactions." *SPIE Proceedings, Complex Light and Optical Forces XIII*, **10935**, 1B (2019).