Multidimensional Quantum States of the Angular Momentum of Light

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Light carries energy as well as both linear and angular momenta. The total angular momentum can contain a spin contribution associated with polarization and an orbital contribution associated with the spatial profile of the light intensity and phase.[1] Such angular momentum can be transferred to trapped suitable material particles, causing them to rotate, a property with important applications in optical tweezers and spanners in fields as diverse as biosciences and micromechanics. The angular momentum of light can also be used to generate quantum entangled photon states. The spin contribution, described by a two-dimensional state, can be employed to generate *qubits*; the orbital contribution can generate multidimensional quantum entangled states, or *quNits*, with an arbitrarily large number of entanglement dimensions.[2]

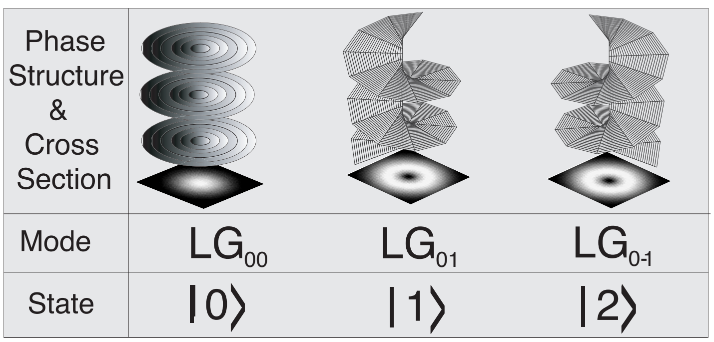

Figure 1. External angular momentum eigenstates of photons. The eigenstates LG_{00}, LG_{01} and LG_{0-1} carrying 0, $\hbar$, -$\hbar$ units of orbital angular momentum respectively per photon were chosen for the demonstration of qutrit entanglement and denoted as |0>, |1> and |2>, respectively. Their cross-section intensity distributions and their phase structure are shown.

We have recently put forward a general scheme, termed *L-managing*, to prepare photons in multidimensional vector states of orbital angular momentum, which allow the manipulation, including the addition and removal, of specific projections of the vector states.[3] The scheme is based on the generation of suitable superpositions of eigenmodes of the quantum mechanical angular momentum operator. The quantum angular momentum number carried by the photon in each eigenmode is represented by the topological charge, or winding number m, of the corresponding mode and each mode carries an orbital angular momentum of $m\hbar$ per photon. The scheme can be implemented in a variety of ways, including by use of suitable computer-generated holograms or vortex-pancake light distributions. One can elucidate distributions which carry prescribed states with either finite or infinite eigenmodes. The different orbital angular momentum eigenmodes can be sorted with interferometric methods, as demonstrated experimentally recently.[4]

L-managing has implications to the generation of quantum entangled photon states by parametric downconversion of the corresponding beams in quadratic nonlinear crystals. Simple superposition of a few modes has already been employed to experimentally observe the entanglement of the angular momentum of photons in downconversion of 351-nm photons in a crystal of β-barium borate.[2] What's more, in a recent experiment we experimentally demonstrated the entanglement of orbital angular momentum *qutrits*. This was done by demonstrating the violation of a generalized type of Bell's inequality in higher dimensions.[5] The ultimate goal is to generate multidimensional entangled states with modified probability amplitudes by using L-managed pump photons or L-managed detection set-ups. Such multidimensional entanglement should allow the experimental exploration of deeper quantum features only realizable in N-dimensional Hilbert spaces. Study of the degree of violation of Bell's inequalities generated by different L-managed vector states opens up fascinating horizons. Finally, we anticipate that multidimensional entanglement might guide the elucidation of capacity-increased quantum cryptography channels based on engineered quNits.

References

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