New Twist on Light Beams for Quantum Information Science

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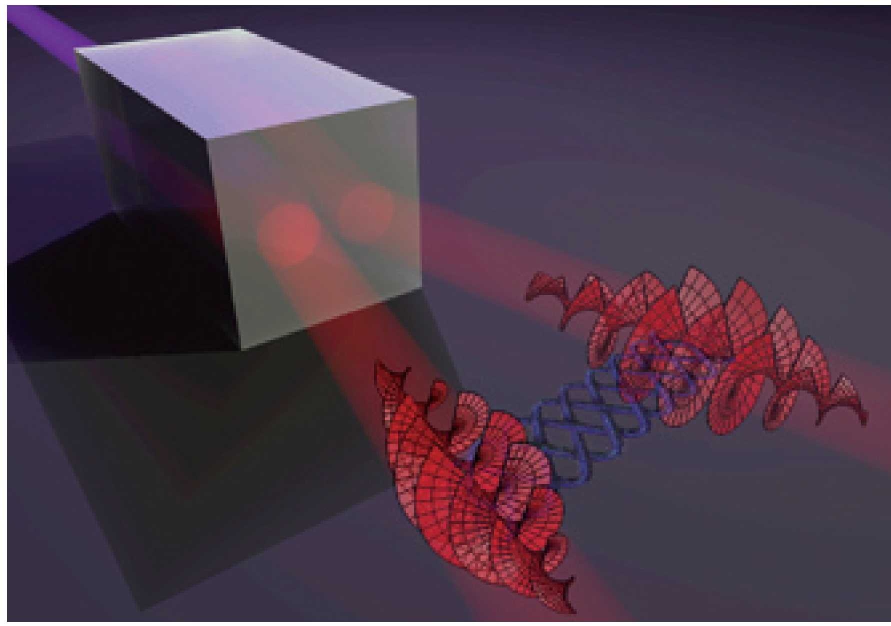
Recent research has opened pathways for new protocols in quantum information science based on the orbital angular momentum states of photons. Light beams can carry angular momentum via two mechanisms. Spin angular momentum is associated with the circular polarization of light. A light beam can also carry angular momentum by means of any helicity associated with the phase fronts.[1] For example, a light field possessing an azimuthal phase structure of the sort $\exp(il\varphi)$, where l is an integer, carries an angular momentum of $l\hbar$ per photon. The Laguerre-Gauss modes familiar from laser physics provide an example of a field distribution that carries orbital angular momentum (OAM).

These OAM states have important implications for quantum information science because they reside in infinite-dimensional state space. Photons can be prepared in any one of these modes or in fact in any linear combination of them. It is thereby possible to impress large amounts of information onto a single photon. An application that has attracted much attention recently is new protocols for quantum key distribution, in which more than one bit of information is carried by each photon.[2] In this application, the data transfer rate is increased in proportion to the number of bits of information carried by each photon; moreover, the security of the protocol is increased.

Because these applications rely on the quantum properties of the OAM states,[3] much effort has been invested in quantifying these properties. We recently performed a quantitative study of the degree of entanglement between two photons created by parametric downconversion.[4] Entanglement of the properties of two separated particles constitutes a fundamental signature of quantum mechanics and is a key resource for quantum information science. We quantified entanglement by measuring the degree of correlation of both the OAM and the azimuthal position of the birthplaces of the two photons. These correlations demonstrate the Einstein-Podolsky-Rosen effect for angle and angular momentum and were found to be an order of magnitude stronger than those allowed by the uncertainty principle for independent (nonentangled) particles.



An intense laser beam excites a nonlinear crystal, and two new photons are created by the nonlinear process. They are strongly correlated in both birthplace and OAM. Specifically, even though the OAM of either is undetermined, the two OAMs always add up to zero. In addition, the angular position of the birthplace of one photon is highly correlated to that of the other. Since the photons are strongly correlated in both angular position and OAM, they are entangled.

In a separate experiment,[5] we studied angular two-photon interference in a scheme in which entangled photons are made to pass through apertures in the form of double angular slits. Using this scheme, we demonstrated an entangled two-qubit state that is based on the angular-position correlations of entangled photons. A high degree of entanglement, as quantified by a property known as the concurrence, was measured for these states. This technique provides a means for preparing entangled two-qubit states for use in quantum information protocols. ◭

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