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Complete experimental toolbox for alignment-free quantum communication[1]

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Quantum communication employs the counter-intuitive features of quantum physics for tasks that are impossible in the classical world. It is crucial for testing the foundations of quantum theory and promises to revolutionize information and communication technologies. However, to execute even the simplest quantum transmission, one must establish, and maintain, a shared reference frame. This introduces a considerable overhead in resources, particularly if the parties are in motion or rotating relative to each other. We experimentally show how to circumvent this problem with the transmission of quantum information encoded in rotationally invariant states of single photons. Our approach exploits multiple degrees of freedom of single photons. In particular, the polarization and transverse spatial modes stand out for this purpose. Just as the circular polarization states are eigenstates of the spin angular momentum of light, the helical-wavefront Laguerre-Gaussian modes are eigenmodes of its orbital angular momentum (OAM). We implement photonic qubit invariant under rotation around the optical axis by combining the polarization with OAM properties. By developing a complete toolbox for the efficient encoding and decoding of quantum information in such photonic qubits, we demonstrate the feasibility of alignment-free quantum key-distribution, and perform proof-of-principle demonstrations of alignment-free entanglement distribution and Bell-inequality violation. The core of our toolbox is a liquid crystal device, named "q-plate," that maps polarization-encoded qubits into qubits encoded in hybrid polarization-OAM states of the same photon that are invariant under arbitrary rotations around the propagation direction, and vice versa. The scheme should find applications in fundamental tests of quantum mechanics and satellite-based quantum communication. We will discuss the potential applications of this scheme to real quantum communication network.

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