Loophole-free experiments on different types of nonlocality

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The nonlocality of entangled states was pointed out by Eintein, Podolsky, and Rosen in 1935 [1]. According to quantum theory, when two systems are entangled, a local measurement carried out on one of them instantaneously collapses the state of the other distant one. EPR thus argued that the quantum state cannot describe the real factual situation. There are different types of nonlocality, each constituted by the assumption made on the theory describing the systems. The hierarchy of nonlocality [2] starts with non-separability, showing failure of local hidden state theory. This is followed by EPR-steering nonlocality, an asymmetrical concept similar to the EPR thought experiment. The strongest type is Bell nonlocality, which shows the failure of any conceivable local hidden variable theory. Experimental realizations testing nonlocality can have imperfections that could open so-called loopholes. The three main loopholes are the detection loophole (photon ensemble is a fair sample) [3]. The locality loophole (no hidden communication) [4], and the freedom of choice loophole [5] (measurement is independent of production of the pairs). Invoking any of these assumptions renders an experiment vulnerable to possible explanation by a local realistic theory. The realization of a loophole-free experiment is an important goal for the physics community with strong implications for quantum technologies. Here we give an overview of experiments with photons addressing loopholes on different types of nonlocality. With photons a loophole-free EPR-steering test was possible [6] and for Bell nonlocality all three major loopholes were closed in separate experiments. The locality and freedom of choice loophole were closed by Scheidl et al. [5]. With the recent development of TES detectors and the use of a Bell inequality with only 2/3 detection efficiency the fair sampling assumption was closed recently by Giustina et al. [7], opening up the way to a completley loophole-free Bell test.

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