Complementarity, Wave Particle Duality and Quantum Entanglement- Theory and Experiments

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We present an investigation of wave-particle duality for a photon that is generated from genuine point sources, i.e., a pair of nonlocally entangled two-level atoms. The point source nature justifies a free-space exact spherical wave treatment. More importantly, it allows a systematic quantitative analysis of the source effects on a quantum particle's duality property. Surprisingly, duality is found to be a conditional phenomenon depending on the photon's atomic source state. It can be tuned maximum, medium, and even minimum (completely absent) by the atomic state purity μ_s through an exact Pythagorean relation $\mu_s^2 = V^2 + D^2$ [1] with visibility V and distinguishability D representing the photon's wave and particle properties respectively. The visibility V also equals to the entanglement in the source state, which translates into the path entanglement for the photon state. The results can be tested in various practical physical systems. We discuss a recent experimental work by Yoon and Cho [2] that confirms our source-controlled duality relation. The experimental setup is based on the original work of Mandel and collaborators [3,4] on inducing coherence by using single photons from two SPDC's and by clever use of the photon added coherent states [5].

References

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