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Extended Abstract

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Young's double-slit interference with nondegenerate biphotons

Jun Xiong, Shuang Wu, De Jian Zhang, Hai Bo Wang and Kaige Wang
Beijing Normal University, China
E-mail: junxiong@bnu.edu.cn

n classical optics, Young's double-slit experiment with colored coherent light gives rise to individual interference fringes for each light frequency, referring to single-photon interference. However, two-photon double-slit interference has been widely studied only for wavelength-degenerate biphoton, known as subwavelength quantum lithography. In this work, we report double-slit interference experiments with two-color biphoton. Different from the degenerate case, the experimental results depend on the measurement methods. From a two-axis coincidence measurement pattern we can extract complete interference information about two colors. The conceptual model provides an intuitional picture of the in-phase and out-of-phase photon correlations and a complete quantum understanding about the which-path information of two colored photons.

Young's double-slit interference is one of the most fundamental and important effects in physics, and the first experimental observation established the wave nature of light. In the early days of quantum mechanics, the phenomenon was regarded as a single-photon effect, and it still is the best example to illustrate wave-particle duality, the uncertainty principle and complementarity. Richard Feynman described the double-slit experiment as one "which is impossible, absolutely impossible, to explain in any classical way, and which has in it the heart of quantum mechanics. In reality, it contains the only mystery "

wo-photon interference of a quantum entangled source can be interpreted with the concept of biphoton coherence. A pair of entangled photons produced in the SPDC process forms a biphoton, which plays the role as an independent entity with apparent "first-order coherence", although each individual photon does not satisfy the first-order coherence. As for a thermal light source, the interference information can be extracted through the intensity correlation measurements. A theoretical comparison between the two sources was performed.

The entangled photon pairs produced in SPDC consist of signal and idler photons with different wavelengths, satisfying momentum conservation. Unlike single-photon interference, there are two configurations in which two-photon double-slit interference can occur according to the way that the two photon pairs travel through the double-slit.

The double-slit interference with two-color biphotons can be understood by a model which is similar to those proposed. In the conceptual model one of the detectors is reset to a position symmetric to the double-slit, while either of the two detectors can be regarded as a source emitting a photon at the corresponding frequency. The two-photon interference occurs between two paths: one is denoted by two solid lines and the other by two dashed lines between D1 and D2. For Scheme I, source D1 emits a blue photon and travels to slit S1 (or S2), where the blue photon converts immediately to a red photon and continuously travels to detector D2. As for Scheme II, source D1 emits a blue photon and travels to slit S1 (or S2), then a red photon, immediately created at the other slit S2 (or S1) replacing the blue one, travels to detector D2. When D1 as the blue source is fixed, detector D2 records the interference pattern for the red photon, equivalent to one-photon double-slit interference. The same case occurs when D2 is fixed and D1 records one-photon double-slit interference for the blue beam. Just as for the single-photon double-slit interference, in Scheme I we do not have any which-path information for the biphotons. In Scheme II, however, we do know that each photon passes through a single-slit each time but we still have no knowledge of its color. When the two photons are degenerate and unentangled in Scheme II, the two-photon interference becomes the Hanbury-Brown and Twiss type interference of two independent photons13. In this case, the detectors are still unable to tell which slit the photon came from. As a matter of fact, in all the cases, the detectors can identify the photon color but can never know which path it took.

In conclusion, the double-slit interference with two-color biphoton exhibits more interesting phenomena than other biphoton interference experiments, and may afford a complete understanding of two-photon interference. We proposed a two-axis interference pattern to replace the conventional interference fringe in Young's double-slit experiment, and this is necessary to describe complete interference information about two-color frequencies. We can now understand that the subwavelength interference observed in previous studies is actually the result of sum-frequency interference for degenerate photon pair while the difference-frequency effect disappears. The conceptual model has manifested that the interference of two-color biphoton can be regarded as the correlation of two colored photons, embodying the nonlocality nature of quantum entanglement. The work provides an intuitive picture of in-phase and out-of-phase non-degenerate photon correlations, and a complete and general description about the which-path information of two colored photons in quantum interference.

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