On the Modification of the Aspect Experiment Scheme with Entangled Photons to Eliminate "Superluminal Loopholes".

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Abstract

This article proposes a modification of the Aspect experiment to test the hypothesis of nonlocality that can be described by Lorentz-invariant equations with derivatives of infinite order. Such a hypothesis can resolve the apparent retrocausality paradox in quantum eraser experiments with delayed choice. A scheme for modifying the Aspect experiment is proposed, which will yield separable quantitative results regardless of the validity of the proposed hypothesis. The proposed modification consists not only in eliminating the locality loophole by switching the paths of entangled photons to polarizers at different angles but also in physically interrupting the photon paths (blocking) after their separation. Moreover, this interruption should be performed before switching the paths to other polarizers. For such photons, if the hypothesis is valid, a violation of the CHSH inequality is expected.

Keywords:non-locality, Aspekt Experiment.

The double-slit quantum eraser experiment is a variation of Young's experiment, demonstrating how observation of which-path information destroys the interference pattern, and its "erasure" restores it. The experiment demonstrates wave-particle duality and quantum entanglement. There is also a variant with "delayed choice", where the decision to erase information or not is made after the photon has already passed through the slits, and the interference pattern appears or disappears accordingly. This experiment is a variation of the classic double-slit experiment that shows that the decision of whether the particle behaves as a wave or a particle can be delayed and even reversed after it has already passed through the slits. The results of such experiments are considered within the framework of Bell's inequality violations and the absence of hidden parameters [1-5].

In the experiment [4] Fig.1, entangled photons are generated via a process called spontaneous parametric down-conversion. This occurs in a special crystal, beta-barium borate (BBO). Two entangled photons (702.2 nm) are generated. These two photons fly apart in two different directions. In this experiment, one direction is denoted as p and the other as s. The photons moving along the p path are called p-photons here, and those moving along the s path are called s-photons. The double-slit interference pattern is created by s-photons. They pass through the double slit to detector D_s. The p-photons go directly to detector D_p. If polarizers that destroy interference (QWP1, QWP2) are placed in front of each of the two slits on the s-photon path, then interference is not observed in the absence of a polarizer on the p-photon path. Introducing a polarizer on the p-photon path restores the s-photon interference pattern. In this case, the optical path of the p-photon to polarizer $POL1$ can be longer than the path of the s-photon to detector D_s. This creates an "apparent" retrocausality paradox " a later measurement of the p-photon affects the statistics of the s-photons. To resolve this paradox, one can assume that the polarization settings of the entangled photons occur not when the p-photons pass through the interference-restoring polarizer but earlier, during the generation of the entangled photons. It is assumed that during generation, the entangled pair nonlocally accounts for the remote polarizers. Correlations of these polarizations must satisfy the predictions of quantum mechanics.

The hypothesis that photons can instantaneously "sense" the presence and orientation of polarizers at a distance is possible with a specific mathematical formalism for describing this. If photons are described using some differential equations, then the order of derivatives in them must be infinite to ensure nonlocality. Such equations must use only Lorentz-invariant operators to preserve Lorentz invariance on average.

Such hypotheses, as violating the theory of relativity, are usually immediately dismissed and are not tested experimentally in experiments with entangled photons. Although physical effects related to nonlocality may be an area where special relativity is locally violated.

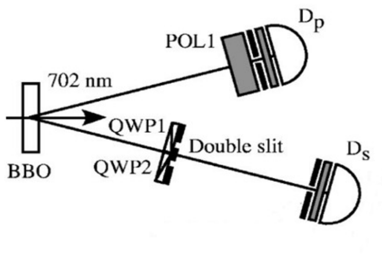

Figure 1: Schematic of the quantum eraser experiment.

1 On a Modification of the Aspect Experiment Scheme.

Let's consider the proposed experimental scheme for testing the hypothesis. In Aspect experiments, switching of photon paths during their flight was already used to eliminate the locality loophole. To exclude the possibility of information exchange between photons after their separation, entangled photon pairs were separated by a spatial interval. This was necessary so that the pair of entangled photons would separate and could no longer exchange information even at the speed of light. However, if we consider the hypothesis that photons can instantaneously obtain information about the presence and orientation of polarizers, then such a limitation will be insufficient. Therefore, it is also proposed to physically interrupt the photon paths (e.g., block them) after their separation. Moreover, this interruption should be performed before switching the paths to other polarizers.

Therefore, the following scheme is proposed: Upon separation, the entangled photons are directed along paths without polarizers to optical terminators T, Fig 2. After passing the first switches, these switches close the assumed physical paths for superluminal information transmission Fig.3. Then, before the photons reach the second switches, these switches open the path to polarizers I(a) and II(b) Fig.4. Thus, if nonlocal effects are caused by the fact that entangled photons can instantaneously obtain information about polarizers I(a) and II(b) and about each other, then closing the path will lead to the disappearance of nonlocal effects.

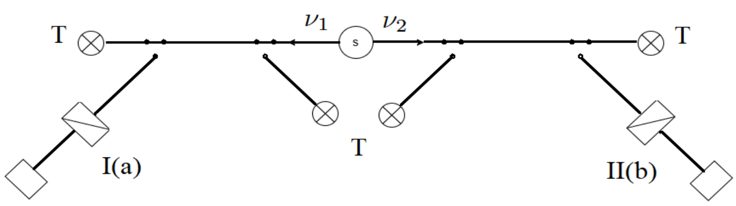

Figure 2: Schematic of the experiment with photon blocking after separation, as the photons are emitted.

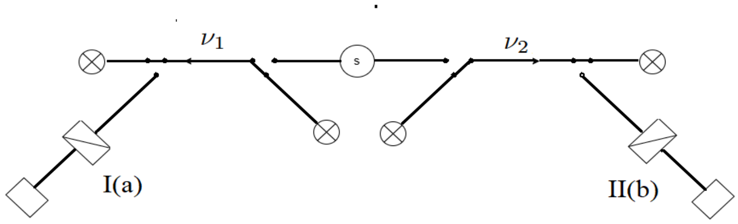

Figure 3: Schematic of the experiment with photon blocking after separation, photons have passed the first switches but have not reached the second switches.

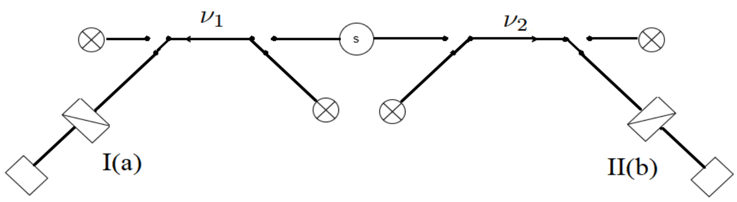

Figure 4: Schematic of the experiment with photon blocking after separation, photons have not reached the second switches, which have already switched to polarizers.

Quantitatively, this will be expressed by the satisfaction of the CHSH (Clauser-Horne-Shimony-Holt) inequality $S = |E(a,b) - E(a,b') + E(a',b) + E(a',b')| \leq 2$ for any angles a, a', b, b' of the polarizers I(a) and I(b), including, for example, $a = 0°$, $a' = 45°$, $b = 45°$, $b' = -45°$.

References

[1] A. Aspect, J. Dalibard, G. Roger, Phys. Rev. Lett., **49**, 25, 1804-1807, (1982).

[2] A. Aspect, A. Bells Theorem: The Naive View of an Experimentalist. In: Quantum [Un]speakables. Springer, Berlin, Heidelberg. (2002).

[3] Y.-H. Kim, R. Yu, S. P. Kulik, Y. Shih. Phys. Rev. Lett. 84, 1, (2000).

[4] S. P. Walborn, M. O. Terra Cunha, S. Padua, C. H. Monken. Phys. Rev. A 65, 033818, (2002).

[5] X. Ma, J. Kofler, A. Zeilinger. Delayed-choice gedanken experiments and their realizations. Rev. Mod. Phys. 88, 015005, (2016).