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

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Abstract
The article proposes a modification of the Aspect's experiment to test the hypothesis of nonlocality, which can be described by Lorentz-invariant equations with infinite-order derivatives. For such a modified experimental scheme, if the hypothesis is correct, the CHSH inequality is expected to hold for critical Cirel'son angles, for example, S=1.414 for $a = 0°, a' = 45°, b = 22.5°, b' = 67.5°$. In the case of the standard, unmodified experimental scheme, the CHSH inequality is known to be violated for these angles, S=2.7. The proposed modification consists not only of closing the locality loophole by switching the paths of the entangled photons to polarizers at different angles but also of physically interrupting (blocking) the photon paths after their separation. Moreover, this interruption must be performed before switching the paths to other polarizers.

Keywords:non-locality, Aspekt's Experiment.

1 Introduction

The quantum eraser double-slit experiment is a variation of Young's experiment, demonstrating how observing the which-path information of a particle destroys the interference pattern, while "erasing" that information restores it. The experiment illustrates wave-particle duality and quantum entanglement. There also exists a "delayed-choice" version, where the decision to erase or not to erase the information is made after the photon has already passed through the slits, with the interference pattern appearing or disappearing accordingly. This experiment is a variation of the classic double-slit experiment that shows the decision of whether a particle behaves as a wave or as 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 violating Bell's inequalities 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 created. These two photons propagate in two different directions. In this experiment, one direction is labeled as p and the other as s. Photons traveling along path p are referred to here as p-photons, while those traveling along path s are called s-photons. The double-slit interference pattern is created by the s-photons. They pass through a double slit to detector Ds. The p-photons go directly to detector Dp. If polarizers that destroy interference (QWP1, QWP2) are placed in front of each of the two slits on the s-photon path, no interference is observed when there is no polarizer on the p-photon path. Introducing a polarizer on the p-photon path restores the interference pattern of the s-photon. Notably, the optical path of the p-photon to polarizer POL1 can be longer than the path of the s-photon to detector Ds. This creates an "apparent" retrocausality paradox"a later measurement on the p-photon affects the statistics of the s-photons. To resolve this paradox, one can assume that the polarization states of the entangled photons are not set 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 distant polarizers.

The hypothesis that photons can instantly "sense" the presence and orientation of distant polarizers is possible within a certain mathematical formalism describing this. If photons are described using some kind of differential equations, then the order of derivatives in them must be infinite to ensure nonlocality. Such equations should 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 in experiments with entangled photons. However, physical effects related to nonlocality may be an area where Special Relativity is locally violated.

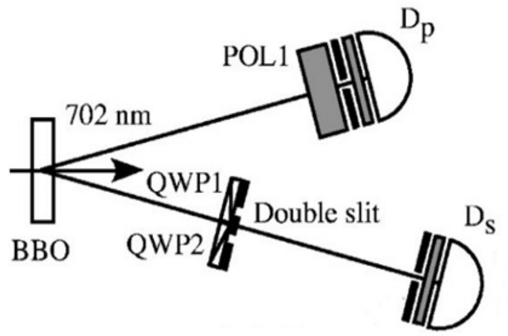

Figure 1: Fig.1. Schematic of the quantum eraser experiment.

2 On Modifying the Aspect's Experiment Scheme

Let us consider the proposed experimental scheme to test the hypothesis. In Aspect's experiments, path switching of photons during their flight was already used to close the locality loophole. To eliminate the possibility of information exchange between photons after their separation, the entangled photon pairs were separated by a spatial interval. This was necessary so that the entangled photon pair would separate and could no longer exchange information, even at the speed of light.

However, if we consider the hypothesis that photons can instantly obtain information about the presence and orientation of polarizers, such a restriction would be insufficient. It is necessary to account for polarizers both along the photons' direction of motion and in the opposite direction. Therefore, it is also proposed to physically interrupt the photon path (e.g., by blocking) after their separation. Moreover, this interruption must 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). Here, "terminators" refer to axisymmetric devices that absorb photons. After the photons pass the first switches, these switches close the presumed physical paths for superluminal information transfer (Fig. 3). Then, before the photons reach the second switches, these switches open the paths to polarizers I(a) and II(b) (Fig. 4). Thus, if nonlocal effects are caused by entangled photons instantly obtaining information about polarizers I(a) and II(b) and about each other, then blocking the optical path should cause the nonlocal effects to disappear.

Quantitatively, this would be expressed in the fulfillment 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 of

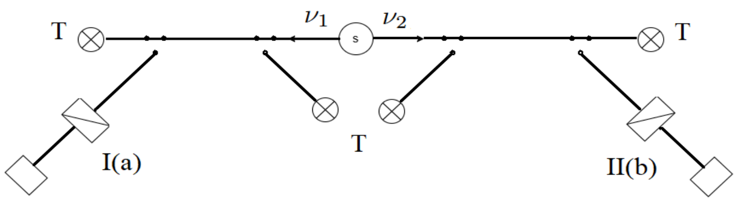

Figure 2: Fig.2. Schematic of the experiment with photon blocking after separation, at the moment of photon emission.

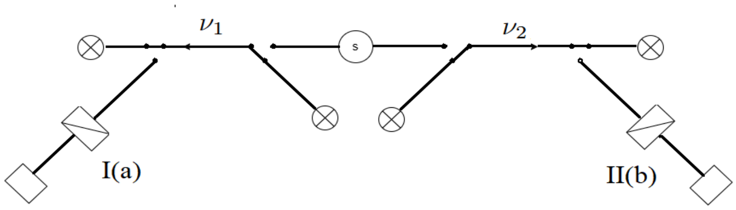

Figure 3: Fig.3. Schematic of the experiment with photon blocking after separation; the photons have passed the first switches but have not yet reached the second switches.

polarizers I(a) and I(b). Since the hypothesis proposed in the article assumes the disappearance of nonlocal effects with the proposed modified Aspect experiment scheme, the value of S, if the hypothesis is correct, should be calculated as in the classical case:

$$E(\theta_a, \theta_b) = \iint \cos(2(\alpha - \theta_a)) \cos(2(\beta - \theta_b))\rho(\alpha, \beta), d\alpha, d\beta \tag{1}$$

For a uniform distribution $\rho(\alpha, \beta)$, and anticorrelated polarization $\beta = \alpha + 90°$ we obtain $E(\theta_a, \theta_b) = -(1/2)cos(2(\theta_a - theta_b))$. Choosing the critical Cirel'son angles $a = 0°, a' = 45°, b = 22.5°, b' = 67.5°$ we get S=1.414. Whereas for the unmodified case of the Aspect's experiment, S=2.7 for similar angles.

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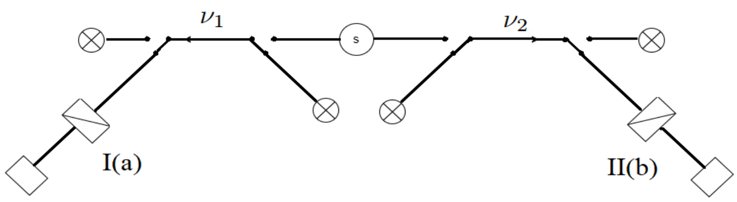

Figure 4: Fig.4. Schematic of the experiment with photon blocking after separation; the photons have not yet reached the second switches, which have already switched to the polarizers.