Proposed experiment on the continuity of quantum entanglement

MASANORI SATO

Honda Electronics Co., Ltd.,
20 Oyamazuka, Oiwa-cho, Toyohashi, Aichi 441-3193, Japan
msato@honda-el.co.jp

ABSTRACT. We propose experiments of quantum entanglement for investigating the EPR problem with the polarization directions of photons. These experiments are performed to investigate whether or not the defined polarization directions in an entangled state are teleported between entangled photons. EPR-type sequential experiments can be performed using a twin-photon beam and two pairs of linear polarization analyzers setting at cross-Nicol condition (i.e., setting at orthogonal to each other). If the third filter whose polarization angle is 45° is set between the first cross-Nicol filters, the beam intensity is changed from 0 to 12.5 %, and at the second cross-Nicol filters, the beam intensity is changed from 0 to 25 %. In this experiment, we predict that the "continuity of quantum entanglement" under a pure Hamiltonian evolution is detected.

1 Introduction

Bell [1] repeatedly mentioned the de Broglie-Bohm picture in his book. "Indeed it was the explicit representation of quantum nonlocality in that picture which started a new wave of investigation in this area. Let us hope that these analyses also may one day be illustrated, perhaps harshly, by some simple constructive model."

Clauser and Horne [2] and Aspect [3] proposed experiments of Bell inequalities. There were many experiments on the violation of Bell inequalities [4~8]. In 1981, Aspect and coworkers [6] showed experimentally the violation of Bell inequalities clearly using acousto-optical switches. Weihs and coworkers [8] also showed experimentally the violation of Bell inequalities via parametric down-conversion. Theories and experiments investigating Bell inequalities were summarized by Mandel and Wolf [9]. We have proposed experiments of quantum entanglement for investigating the EPR problem with polarization direction, using parametric down-conversion of laser [10]. We showed that we could investigate whether or not the influence of another photon on the polarization direction is detected [10].

We know that there exists a problem of causality, which forbids superluminal information transmission, (consequently, there is no continuity of quantum entanglement). Eberhard [11] mentioned that EPR correlation cannot enable the transmission of signals of any kind including, for example, those that are faster than light. He showed that the average spin properties of a particle are not changed by the detection of another particle which is in an entangled state [11]. However, Bell pointed out the importance of individual measurements. Holland [12] mentioned "nonlocality in the individual process, statistical locality" and also discussed the problem of signaling via quantum entanglement," Yet the statistical compatibility of quantum mechanics with relativity in this case seems to be something of an accident." We believe that the difference between statistical and individual measurements should be tested experimentally. We think it is important to calculate mathematically, however it is rather difficult to calculate the sequential situation of the entangled polarization direction after passing through two polarization analyzers. Therefore there is some merit to this proposed experiment. Of course, this proposal may not be particularly new, however, at this stage, we did not find any proposal which specially designed to test the continuity of quantum entanglement. We consider that the experiment which tests the continuity of
quantum entanglement is consciously avoided owing to the violation of causality. An experimental condition that violates causality does not take into account. For example, delayed-choice experiments by Hellmuth and coworkers [13], experimental condition that violates causality is carefully

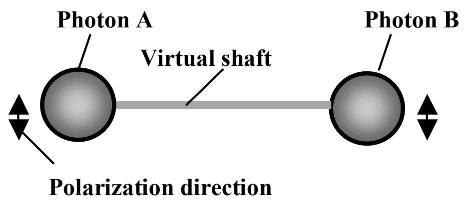

Fig. 1 Proposed illustration of quantum entanglement: The polarization directions of photons A and B are bound by a virtual shaft. Therefore, the polarization directions of photons A and B rotate as if these photons are one particle.

eliminated. (Experimental conditions strictly satisfied causality.) This is the reason why there is few proposal of testing the continuity of quantum entanglement.

We propose an experiment on the continuity of quantum entanglement using twin-photon beams and two pairs of linear polarization analyzers, and show the illustration of the Bell theorem and quantum entanglement. Thereafter, we discuss causality and quantum entanglement from the viewpoint of individual measurement and statistical procedures.

2 Proposed illustration of quantum entanglement

Figure 1 shows the proposed illustration of quantum entanglement. The polarization directions of photons A and B are bound by virtual shaft. Therefore the polarization directions of photons A and B rotate as if they are one particle. At this stage, the virtual shaft represents the hidden variables. This model violates Bell inequalities.

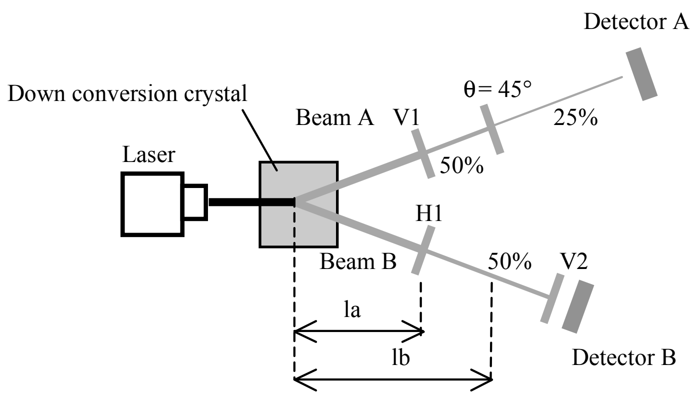

Figure 2 Experimental setup: A down-conversion crystal generates a twin-photon beam by the type-2 down conversion of an incident laser beam. Two polarization analyzers, H1 and V2, are set orthogonal to each other, that is, under the cross-Nicol condition. If a polarization analyzer, whose polarization angle is 45°, θ= 45°, is set after the polarization analyzer V1, we can test whether the condition of the polarization direction of beam A is teleported to beam B.

3 Proposed experiment on the continuity of quantum entanglement

Figure 2 shows the experimental setups of the proposed experiment. Argon-ion laser pumps a BBO (Beta-Barium-Borate) crystal to produce polarization entangled photon pairs via spontaneous parametric down conversion [8]. In these experiments, we detect the intensity of twin-photon beams. We do not check the correlation of entangled photon pairs. Therefore, the proposed experiment is feasible. A down conversion crystal generates a twin-photon beam by the type-2 down conversion of an incident laser beam. Beam A is filtered by a vertical polarization analyzer V1, and thereafter by a polarization analyzer $\theta = 45°$ (whose polarization angle is 45°). The photon densities of beam A are changed from 100% to 50% by passing through the polarization analyzer V1, and from 50% to 25% by passing through the polarization analyzer $\theta = 45°$. Beam B is filtered by a horizontal polarization analyzer H1, and thereafter by a vertical polarization analyzer V2. In this experiment, if beam A does not pass through polarization analyzer $\theta = 45°$, beam B is not detected by detector B (i.e., the photon density detected by detector B is 0). This is because the horizontal polarization analyzer H1 is set orthogonal to the vertical polarization analyzer V2 (i.e., cross-Nicol condition).

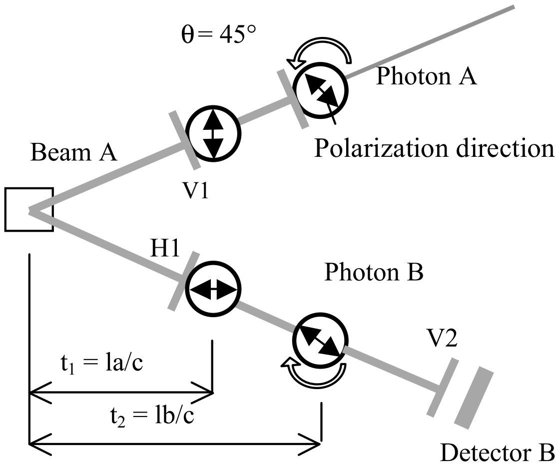

Figure 3 Proposal of the rotation of polarization direction through quantum entanglement: The illustration shows the entanglement of polarization directions. The polarization direction of photon B is not orthogonal to the polarization analyzer V2; therefore, photon B can be detected by detector B with a 50% probability. We can detect a beam intensity of 25% by detector B.

In the experimental setup shown in Fig. 2, using polarization analyzers V1 and θ= 45°, if entanglement continues after the beams pass through the polarization analyzers V1 and the horizontal polarization analyzer H1, there is a possibility that we can detect photons on detector B. We assume that quantum entanglement in the polarization direction occurs as shown in Fig. 1, i.e., the polarization directions are bound by virtual shaft.

In this experiment, we can predict the following two possible answers: (1) The first polarizer projects the entangled state on a nonentangled one, or (2) the continuity of entanglement under a pure Hamiltonian evolution is detected. At this stage, when the experiments have not been carried out, we would consider the latter.

However, the continuity of entanglement indicates that we can transmit a signal through quantum entanglement. For example, the detection by detector B provides information on using the polarization analyzer θ= 45°, because we cannot detect photons by detector B, when polarization analyzers H1 and V2 are set orthogonal to each other.

Beams A and B are in an entangled state, and if photons A and B are in an entangled state after they have passed through polarization analyzers V1 and H1 at time t_1, thereafter, at time t_2 when photon A passes through the polarization analyzer θ= 45°, photon B will change its polarization direction. Figure 3 is the illustration, which shows the entanglement of polarization direction. This indicates that the polarization directions of photon B is not orthogonal to the polarization analyzer V2; therefore, photon B can be detected by detector B with a 50% probability. We can detect a beam intensity of 25% by detector B.

Figure 4 shows the conceptual illustration of total spin 0 state. Type-1 down conversion is used. A photon pair from EPR photon source is filtered by Vertical filter pair. Then photon A is filtered by 45° filter, thereafter photon A and B are filtered by Horizontal filter pair. We obtain the intensity of photon A as 12.5% at Detector A. At Detector B, we would predict a detection of beam intensity of 25% rather than 0%. It indicates that the condition of the polarization direction of photon B is teleported to that of photon A. However, in this experimental setup, the existence of 45° filter can be a superluminal signal. (See discussion.)

4 Discussion

A. Suspend the restriction of causality

Tentatively, we restrict causality as information transmission through photons, therefore, superluminal information transmissions through photons are not possible, because information is transmitted by photons. However, information transmission, which does not occur through photons would not be restricted by causality. Quantum entanglement does not occur through photons, therefore, there is a possibility that information transmission is not restricted by light speed. Of course, information transmission through quantum entanglement should be tested experimentally.

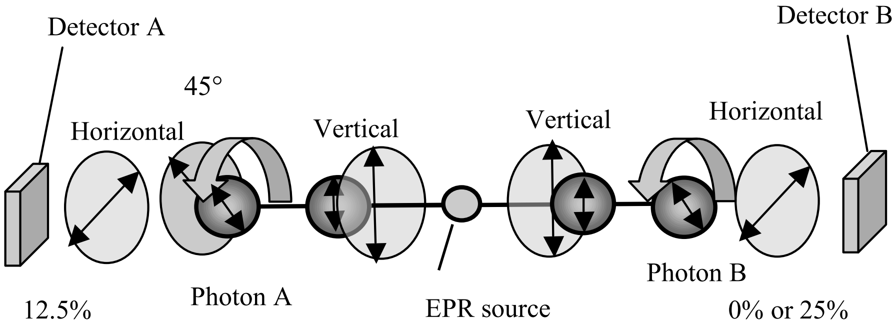

Figure 4 Illustration of the rotation of polarization direction: A photon pair from the EPR source is filtered by a vertical filter pair. Then photon A is filtered by a 45° filter. We predict that information on the polarization direction is teleported to photon B, i.e., the polarization direction of photon B is changed. Thereafter, photons A and B are filtered by a horizontal filter pair. We obtain a beam intensity of 12.5% for photon A at detector A. At detector B, we would predict a detection of beam intensity of 25% rather than 0%. The vertical and horizontal filters are set orthogonal to each other (i.e., cross-Nicol condition), then nonentangled photons cannot pass through the filter pair. Therefore, we can carry out the experiments with little disturbance of nonentangled photons.

B. Individual measurement and statistical procedures

Bell pointed out the importance of individual measurements, as evidenced by his statement, "The de Broglie-Bohm picture agrees with quantum mechanics in having the eigenvalues as the result of individual measurements." However, there have been only a few reports on individual measurements. Holland pointed out "the quantum theory of motion permits more detailed prediction to be made pertaining to the individual process."

On the other hand, there are many reports arguing against superluminal information transmission through quantum entanglement by Eberhard [11], Ghirardi et al [14], and Holland [12]. They pointed out that information disappear after averaging. Causality will be satisfied after averaging, (i.e., information will disappear after averaging). For example, we cannot distinguish the signals between 0101 and 1100 after averaging. We can only obtain 1/2. We believe that information disappears after averaging. However, it dose not deny the possibility of information transmission via individual measurements.

5 Conclusion

We examined the proposed experiment on the continuity of quantum entanglement from the viewpoint of causality and individual measurements. In these experiments, we will detect the density of twin-photon beams, but not the correlation. Therefore, it is easy to perform the experiments. The merit of these experiments in practice is the possibility of new interesting physics. At this stage, when the experiments have not been carried out, we would consider that there exists the continuity of quantum entanglement.

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