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ON THE PHYSICAL NATURE OF HANBURY-BROWN-TWISS AND HONG-OU-MANDEL EFFECTS

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Abstract

The physical nature of the nonrandom quantum phenomena of bunching-antibunching of photons in a beam splitter is discussed. The physical explanation is based on the fact that the forward and reverse processes are not equivalent in quantum physics. The possibility and necessity of an experimental study of the nonlocality of memory of quantum systems is also discussed.

When two photons simultaneously come to the beam splitter (50 : 50), they can randomly go out in different directions (repulsion - bunching) or in one direction (gluing - antibunching). If this happens in a nonrandom way, the result is usually called Hanbury-Brown-Twist (bunching) or Hong-Ou-Mandel (antibunching) effects [1]. Bunching-antibunching is a

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rather unsuccessful, ambiguous terminology (these terms are sometimes confused).

Nonrandom quantum bunching-antibunching effects are no less surprising and mysterious than the famous double-slit interference. Here we have a standard situation in quantum physics, when there is a mathematical description (descriptions) of a physical phenomenon, but there is no any intelligible physical explanation of it [2-4]. A physical explanation of the HOM effect was previously proposed in [5]. We will look at this explanation in more detail here.

Today, we have more than sufficient number of direct and indirect experimental evidence for the strong nonequivalence of forward and reversed processes in quantum physics [6]. This non-equivalence directly presupposes that the quantum system has a memory about its initial state. Quantum processes that lead a quantum system towards its initial state have a maximum differential cross section. In fact, this is the physical basis of nonlinear optics.

Interference of photons (or photon) on a beam splitter is a quantum process. Its direction depends on the initial state of the quantum system. In other words, it depends on the method of appearance (birth) of photons. If photons are born together, as in down conversion [7] or in four-photon mixing [8], then the process reversed to the initial state (or partially reversed) will be the gluing of photons. In this case, we have an antibunching (HOM) effect. If photons are generated separately, as in thermal radiation [9], laser radiation (stimulated emission), or radiation from different atoms [10], then we have a predominantly bunching (HBT) effect.

A good illustration here is the experimental scheme shown in Figure 1. Unfortunately, we failed to find a description of such an experiment in the literature (the closest scheme was used in [11]). It is described on the website [12]. Here is a typical scheme for observing the HOM effect. However, a second beam splitter is installed instead of the second detector. The original photon is split in a nonlinear crystal into signal and idler photons, which are separately directed to the beam splitter. The HOM effect is observed at the output of the first beam splitter. And at the output of the second beam splitter, the HBT effect is observed.

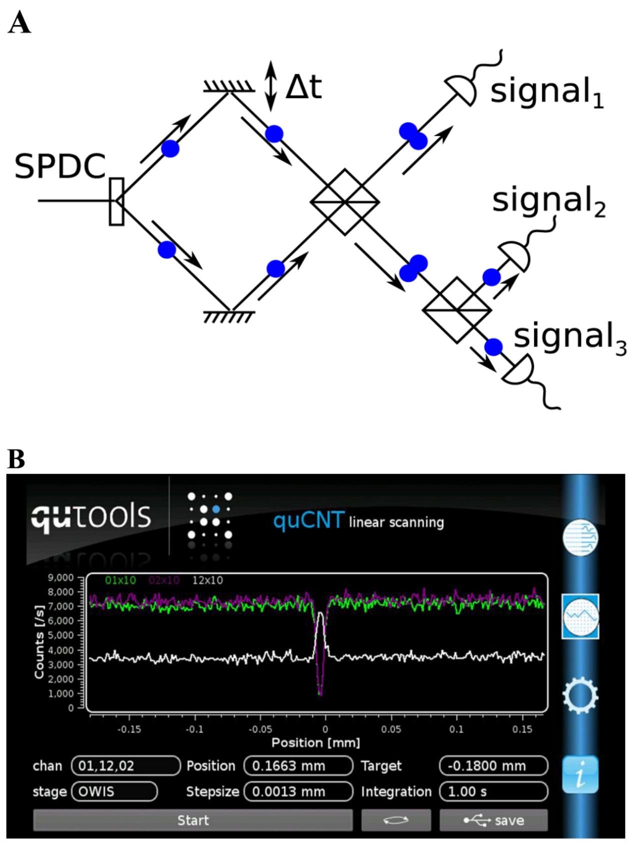

Figure 1. (A) Scheme of the experiment to observe joint HOM and HBT effects. (B) Dependencies of coincidences on the delay between photons. The green and purple lines are the coincidences between detector 1 and detectors 2 and 3, respectively. We see a HOM dip here. The white line corresponds to the coincidences between detectors 2 and 3. We observe here a peak corresponding to the HBT effect [12].

The physical explanation is that for the first beam splitter, the initial state of the quantum system includes the state of the photon before the nonlinear crystal (the photons are combined). For the second beam splitter, the more "fresh" initial state is the state of photons after the nonlinear crystal, where they are separated in space. Therefore, a bunching (HBT) effect is observed on the second beam splitter. If we direct these photons to the third beam splitter, we can expect that there will be a HOM effect again, since the more "fresh" initial state here will be the combined state of the photons after the first beam splitter.

This physical explanation is not complete and final, since the HOM effect is observed in a number of cases when photon sources are spaced apart and independent of each other [13]. Here, the degree of indistinguishability of photons is of fundamental importance. In this case, the situation looks as if the quantum system is "mistaken", taking indistinguishable photons as being born together. This problem requires further experimental study.

Despite this difficulty, this explanation for the non-random quantum bunching-antibunching phenomena is the first and only physical explanation to date.

The size of macro quantum systems indicates the probable nonlocality of quantum memory. The problem of nonlocality in quantum physics has long been actively discussed in the scientific community [14]. This is mainly about Bell's inequality and its analogues. This is pure mathematics again. Violation of these inequalities indicates a certain nonlocality. However, it is not clear what the physical essence of this nonlocality is. What hidden parameters should it be attributed to?

We believe that nonlocality should be attributed to the memory of quantum systems. This quantum memory itself can be experimentally studied by measuring the differential cross sections of forward and reversed processes [6]. And experiments with beam splitters make it possible to experimentally study the nonlocality of this memory.

Interference of photons (photon) occurs at the beam splitter. In most experiments with beam splitters, the photons are manipulated before they enter the beam splitter. But there are experiments where manipulations with photons are performed after the beam splitter [15, 16]. This situation looks like a violation of causality: the interference of photons (consequence) occurs in time before manipulation with them (cause). In reality, this is a direct indication of the nonlocality of the memory of the macro quantum system. The photons "know" what will happen after the beam splitter and behave accordingly in the beam splitter.

We can experimentally study this nonlocality of quantum memory. The study of nonlocality here comes down to spreading the beam splitter and the device for manipulating photons as far as possible in space [17]. In this case, we will get an idea of the degree of nonlocality of the memory of this quantum system. Experiments of the delayed choice type are also possible here [18-20]. These are experiments with the HOM effect.

Similar possibilities are presented by experiments with the so-called "quantum eraser". The simplest version of such an experiment is shown in Figure 2 from the same site [21]. Here are the results of an experiment on the interference of photons (photon) in a Michelson interferometer. In the first case (without an additional polarizer), there is no interference. Interference appears after the introduction of an additional polarizer at the output of the interferometer. Again, we can place the additional polarizer many kilometers away from the interferometer and gain insight into the nonlocality properties of the memory of this quantum system. Experiments of the delayed choice type are also possible here [18-20].

These are very simple experiments to date. It is surprising that they have not yet been carried out.

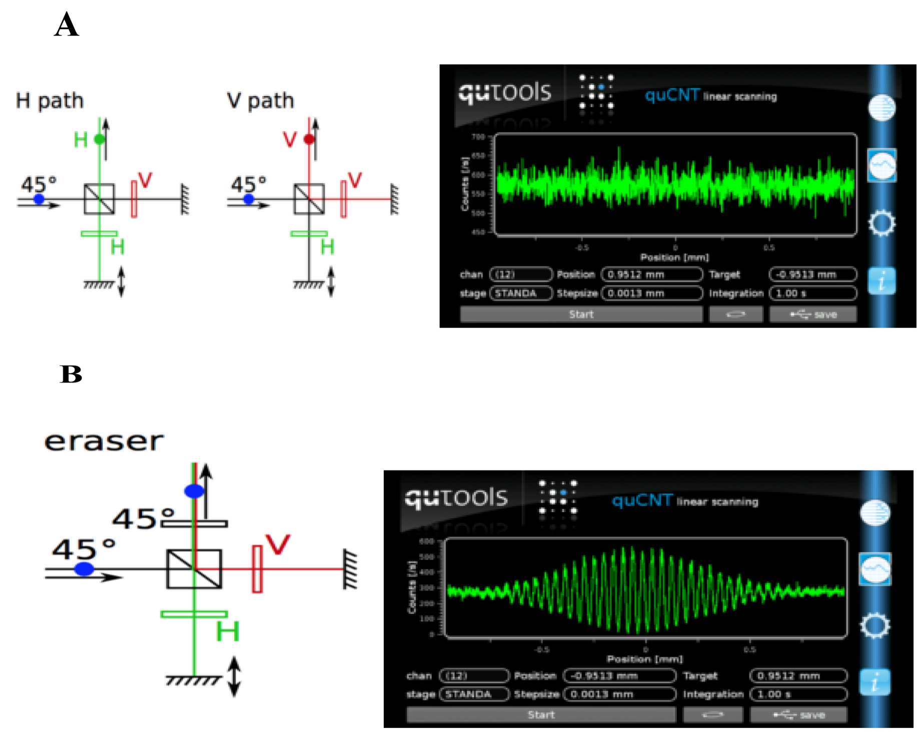

Figure 2. Scheme and results of the experiment with "quantum eraser" [21]. (A) Photons with diagonal polarization (45^0) arrive at the input of the interferometer. Polarizers (one horizontal and one vertical) are added to two arms of the interferometer. There is no interference. (B) Added the third (additional) polarizer at the interferometer output. Interference appears.

Conclusion

The quantum non-random bunching-antibunching phenomena is ultimately a consequence of the fundamental property of quantum physics - its non-invariance of time reversal. The same consequence is the memory of quantum systems. We can experimentally study this memory by measuring the differential cross sections of forward and inversed processes. Experiments with beam splitters provide a good opportunity to study the nonlocality of the memory of quantum systems.

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