About the Experimental Study of Nonlocality in Quantum Physics

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Abstract

There is a long-forgotten experiment in quantum physics in which nonlocality manifests itself in a quite direct and obvious way. The basic properties of nonlocality can be experimentally studied there using very simple tools.

Keywords: Entanglement; Time reversal noninvariance; Quantum memory; HOM effect; Nonlocality

Introduction

The concept of nonlocality is strongly connected with quantum physics. It is also associated with the concept of entanglement. "Entanglement, according to Erwin Schrodinger the essence of quantum mechanics, is at the heart of the Einstein-Podolsky-Rosen paradox and of the so called quantum-nonlocality-the fact that a local realistic explanation of quantum mechanics is not possible as quantitatively expressed by violation of Bell's inequalities" [1]. The discussion and study of the problem of nonlocality in quantum physics began with the famous work of Einstein-Podolsky-Rosen on the incompleteness of quantum mechanics and the possible "spooky action at a distance" [2].

Description

The problem of nonlocality in quantum physics has long been actively discussed in the scientific community [3]. To date, the experimental study of nonlocality usually consists of creating a rather complex optical scheme with entangled photons, carrying out measurements and calculations. The so-called Bell or Clauser-Horne-Shimony-Holt (CHSH) inequalities are calculated [4]. Violation of these inequalities indicates a certain nonlocality. However, it is not clear what the physical essence of this nonlocality is.

The situation is similar in general with quantum mechanics. This is a mathematical theory based on the Schrödinger equation. It is claimed, that it brilliantly describes the experimental results. However, it does not have any clear physical meaning. For many decades, attempts have been made to give it a physical interpretation. "New interpretations appear every year. None ever disappear" [5]. Obviously, the situation is at deadlock. Philosophers say that in this case a paradigm shift is needed. Such a paradigm in quantum mechanics is the idea of time symmetry. The prevailing point of view is still that". a remarkable fundamental fact of nature: all known laws of physics are invariant under time reversal" [6].

At the same time, for many years there have been a number of direct and a huge number of indirect experimental proofs of the nonequivalence of forward and reversed processes in quantum physics [7]. It is difficult to understand why our scientific community stubbornly ignores this experimentally proven fact. The recognition of the non-invariance of time reversal in quantum physics makes it easy and natural to explain the physical nature of entanglement and nonlocality.

If the forward and reverse processes are not equivalent, then there must inevitably be some kind of memory of the quantum system about its initial state. Without such memory, it is impossible to distinguish a direct process from a reversed one. This memory (as the physical equivalent of entropy) is the physical essence of the concept of entanglement. Entanglement is a memory of quantum system about its initial state, which manifests itself through inequality of differential cross-sections of forward and reversed processes [8]. The difference in differential cross-sections can be many orders of magnitude. In fact, this is the physical basis for most effects in nonlinear optics.

Nonlocality, obviously, is a property of this memory. We don't know where this memory is stored, but we can experimentally study its nonlocal properties. The experiment has been known for many years in which the nonlocal memory of a quantum system manifests itself in a completely direct and obvious way. We are talking about the experiment performed in [9]. The authors of this work did not understand what kind of thing they are dealing with and this experiment (direction) is practically forgotten today. Below we will discuss the details of this experiment and indicate the directions of its development.

Figure 1 shows the scheme of this experiment and its result [9]. Here, the Hong-Ou-Mandel (HOM) effect was studied using collinear entangled photons obtained by down conversion in a nonlinear type II crystal. The delay between photons was regulated by quartz plates, in which photons with different polarizations propagate at different speeds. Two entangled photons arrive at the beam splitter and then enter at two detectors D1 and D2. When photons were synchronized with quartz plates, a typical HOM effect was observed.

The most interesting thing here is that the manipulations with quartz plates are carried out after the beam splitter, but not before it (as in the vast majority of works). It looks like a violation of causality. The splitting of photons by a beam splitter (consequence) precedes the cause (plates manipulation). However, it is not about the violation of causality, of course. We are dealing with an obvious manifestation of nonlocality. The photons, coming to the beam splitter, in some mysterious way "know" what will happen later and behave accordingly.
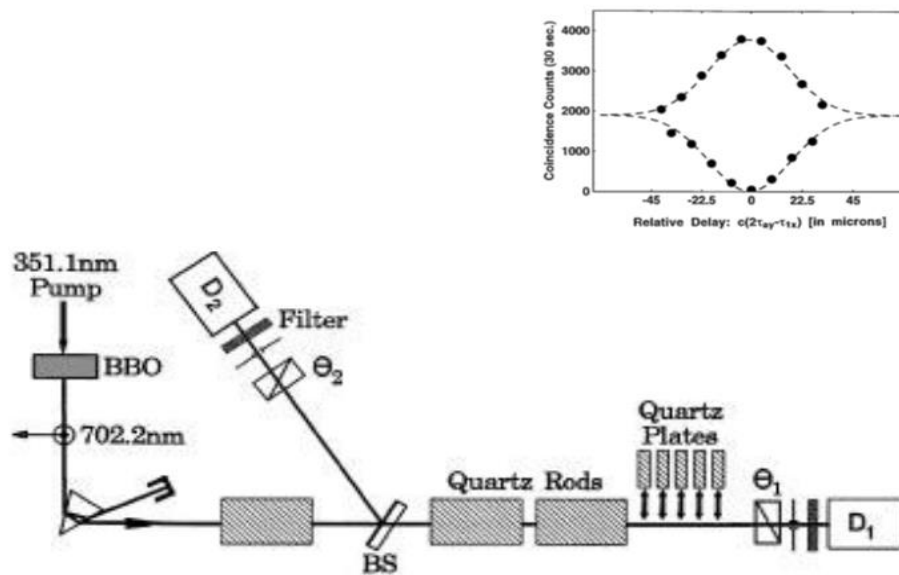

FIG. 1. **Scheme of the experiment and its result.**

This situation is completely analogous to that which exists in the classical two-slit interference. When a photon or electron passes through a slit, it somehow mysteriously "knows" about the existence of the second slit [9,10]. In the case of slits, for various reasons, we cannot spread them far apart. However, in the case of the HOM effect, we can separate the beam splitter and quartz plates at least several kilometers away [11]. We can experimentally study in this way nonlocality of quantum memory. 10 m, 100 m, 1000 m, 10 km. At some distance the HOM effect should disappear. In this case, we will get an idea of the degree of nonlocality of the memory of this quantum system.

Then we can try to determine how fast this "knowledge" spreads. If a high-speed Pockels cell is used instead of quartz plates to synchronize photons (as in [12]), then in the version of the so-called "delayed choice" [13-16], the speed of information (memory) propagation in space can be measured. Could this speed be greater than the speed of light?

Conclusion

The experiments discussed today are very simple. There are a large number of experimenters who have all the necessary equipment for such experiments. We hope that someone will at last carry out these important, interesting and simple experiments.

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