About the experimental study of counterfactual communication

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Abstract

Counterfactual communication involves the transmission of information without particles traveling in the transmission channel. Here we propose an explanation of the physical nature of the phenomenon of counterfactual communication and a simpler and more convenient protocol for its experimental study based on the Hong-Ou-Mandel effect.

Keywords: counterfactual communication, HOM effect, quantum memory, nonlocality, time reversal noninvariance.

Counterfactual communication involves the transmission of information without particles traveling in the transmission channel. It is based on the idea of an interaction-free detection proposed in [1]. The idea of counterfactual communication has aroused great interest. Over the years, many theoretical [2 - 9] and experimental [10 - 14] works have been carried out. Experiments confirm the possibility of counterfactual communication. However, the study of counterfactual communication has not yet gone beyond demonstration experiments. The reason seems to be that there is still no clear understanding of the physical nature of the phenomenon.

Nevertheless, an explanation of the physical nature of counterfactual communication exists. It is unusual, but very simple. When a single photon passes through one of the arms of the Mach-Zehnder interferometer ([1] Fig. 1), it somehow mysteriously "knows" whether the second arm of the interferometer is currently open or closed. This situation is completely analogous to the classical experiment of single photon interference on a double slit. When a photon passes through a slit, it somehow mysteriously "knows" whether the second slit is open or closed at that moment [15].

You may laugh, but this is the most correct explanation of the physical nature of the phenomenon. The physical equivalent of photon's "knowledge" is the nonlocal memory of the quantum system **as a whole**. This non-local memory is the physical essence of the entanglement concept [16]. The nonlocal memory of a quantum system is a consequence of the noninvariance of time reversal in quantum physics. The noninvariance of time reversal in quantum physics (in other words, the nonequivalence of forward and reversed processes) has a number of direct and a huge number of indirect experimental proofs [17]. Thus, the study of the properties of counterfactual communication is reduced to the study of the properties of non-local memory of quantum systems about their initial state.

The experimental study of the counterfactual communication so far are limited to the use of various variants of Mach-Zehnder or a Michelson-type interferometers. However, there is a much simpler and more convenient protocol based on the Hong-Ou-Mandel (HOM) effect. Figure 1 shows a simplified scheme of such an experiment.

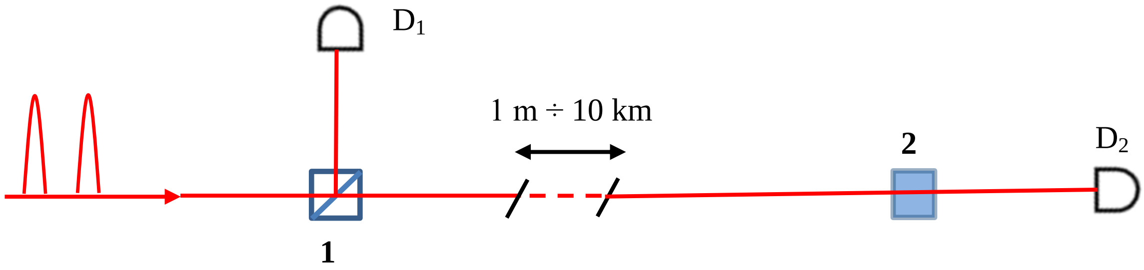

Figure 1. Simplified experimental scheme for the case when the entangled photons delay control device is located after the beam splitter. 1 - beam splitter, 2 - Pockels cell.

Two entangled photons with orthogonal polarization enter to an unpolarized beam splitter (50:50) and then to two single photon detectors (D_1 and D_2). A Pockels cell is installed in front of one of the detectors, with the help of which it is possible to change the delay between photons (synchronize their phases). Such experiments have been conducted before. In the work [18] quartz plates were used to control the delay between photons, while in the work [19] a Pockels cell was used. A typical HOM effect was observed. It is fundamentally important here that both the quartz plates and the Pockels cell were located **after** the beam splitter. It looks like a violation of causality. The splitting of photons by a beam splitter (consequence) precedes the cause (plates manipulation). However, we are dealing with an obvious manifestation of nonlocality.

The same thing happens as in the cases discussed above: the photons, coming to the beam splitter, in some mysterious way “know” about the properties of the entire quantum system **as a whole** at that moment. They “know” whether their phases will be synchronized or not, and behave on the beam splitter accordingly.

If we move the Pockels cell away from the beam splitter at a distance of 1 m ÷ 10 km, then somewhere the observed HOM effect should disappear. This will characterize the degree of nonlocality of the quantum system's memory. And, this determines at what distance counterfactual communication can operate.

If a high-speed Pockels cell is used to synchronize photons, then in the version of the so-called “delayed choice” [20], the speed of information (memory) propagation in space can be measured. Could this speed be greater than the speed of light?

The equipment used in [19] made it possible to measure all of this. The only thing missing was an optical fiber to move the Pockels cell away from the beam splitter. The discussed experiments 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 [21].

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