Regarding the experimental study of nonlocality in quantum physics.

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Two simple ways of experimentally studying the properties
of the nonlocal memory of quantum systems are discussed.

The concept of nonlocality appeared, apparently, together with quantum mechanics and is still widely discussed in the scientific community [1]. At the same time, the physical essence of nonlocality remains unclear.

If we assume that "quantum mechanics is a theory about information" [2], then it is logical to associate nonlocality with information.

For quite a long time, there are a number of direct and indirect experimental evidence of non-equivalence of the forward and reversed processes in quantum physics [3, 4]. The difference between the differential cross sections of the forward and reversed processes can reach many orders of magnitude. This is the physical basis for all nonlinear optics.

Such nonequivalence directly implies the existence of a memory of quantum systems about their initial state. Without such memory, it is impossible to distinguish a forward process from a reversed one. If the size of a macroquantum system is large, then it should be expected that its memory will be non-local.

Here we are referring primarily to such quantum effects as bunching (Hanbury-Brown-Twiss effect) and antibunching (Hong-Ou-Mandel effect) [5]. Two entangled photons enter the beam splitter and can exit it together (antibunching) or separately (bunching). This is a typical reversed (or partially reversed) process. Its direction is determined by the initial state of the quantum system, that is, where and how these photons were formed [6, 7].

For the experimental study of the nonlocal properties of the memory of quantum systems in the case of using beam splitters, the most convenient option is the so-called "delayed choice" [8]. In this case, the experimenters act on the photons after their interference has occurred on the beam splitter. Figure 1 shows a simplified scheme of such an experiment performed in [9]. Two entangled photons arrive at the beam splitter (1) and then enter at two detectors D1 and D2. Between the beam splitter and one of the detectors there are quartz plates (2), with the help of which the experimenters change the delay between the entangled photons. A typical HOM effect is observed.

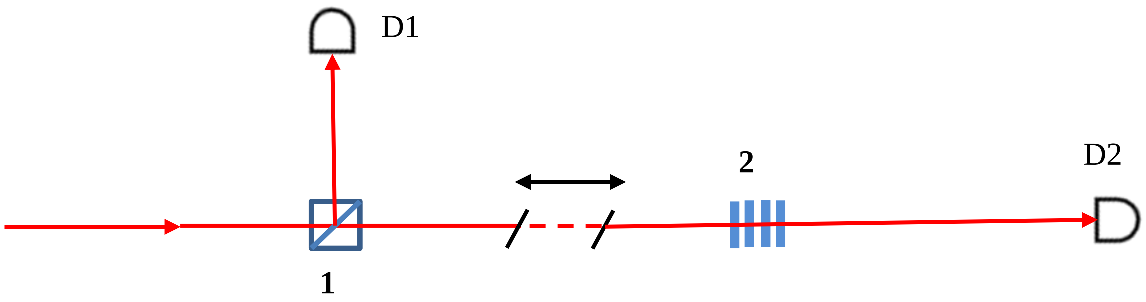

Figure 1.

The situation looks like a violation of causality: the interference of photons on the beam splitter (consequence) occurs in time earlier than their interaction with quartz plates (cause). This is the manifestation of the nonlocality of the memory of quantum system. To study the properties of memory nonlocality, the distance between the beam splitter and the quartz plates should be increased up to several kilometers. Unfortunately, this experiment [9] was not completed [10].

Another version of the experiment with a beam splitter of the "delayed choice" type is shown in Figure 2 [6]. Here, a photon (or photons) enters the Michelson interferometer and then the detector D. An additional polarizer P can be installed between the interferometer and the detector. It performs the function of the so-called “quantum eraser” [11]. In its presence, when one of the interferometer mirrors moves, a typical interference pattern is observed. There is no interference without an additional polarizer. This is again a manifestation of the nonlocality of the memory of the quantum system. For its experimental study, we can change the distance between the beam splitter and the additional polarizer up to several kilometers.

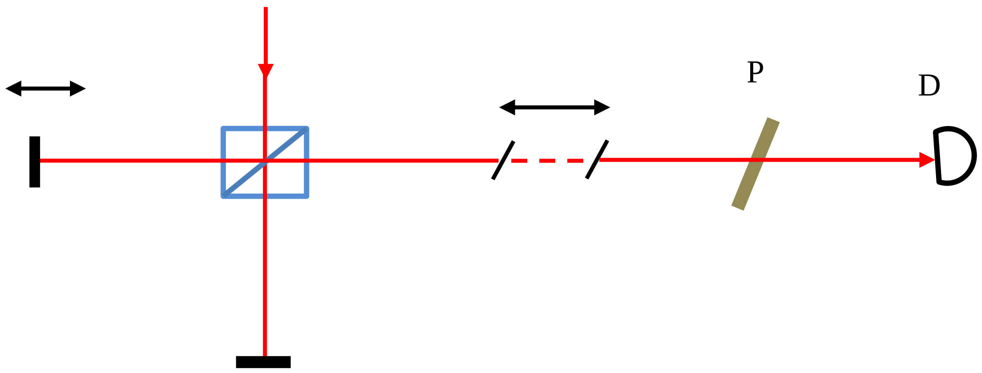

Figure 2. Simplified scheme of experiment with Michelson interferometer.

These are rather simple experiments (it can also easily include a "delayed choice" option). I understand why our experimenters are afraid to carry them out. The results of such experiments will be rather difficult to publish, since it is based on the still radical concept of non-invariance of time reversal in quantum physics. I hope that eventually there will be a bold experimenter who will conduct such experiments. I would have done it myself, if I had the necessary equipment nearby.

1 - M. Genovese, and M. Gramegna, “Quantum Correlations and Quantum Non-Locality: A Review and a Few New Ideas”, Appl. Sci., **9**, 5406 (2019).

2 – C. Rovelli,” Relational Quantum Mechanics”, Int. J. of Theor. Phys., **35**, 1637 (1996), e-print, arXiv:quant-ph/9609002

3 - V.A. Kuz’menko, “Time reversal noninvariance in quantum physics”, e-print, viXra:2004.0160

4 - V.A. Kuz’menko, “THE ARROW OF TIME. On the time reversal noninvariance in quantum physics”, LAP Lambert Academic Publishing, (2021), ISBN: 978-620-3-91168-8

5 - A. Aspect, “Hanbury Brown and Twiss, Hong Ou and Mandel effects and other landmarks in quantum optics: from photons to atoms”, e-print, arXiv:2005.08239
6 - V.A. Kuz’menko, "On the physical nature of Hanbury-Brown-Twiss and Hong-Ou-Mandel effects", Fund. J. of Mod. Phys., **15**, 1 (2021), e-print, viXra:2012.0188
7 - M. Hennrich, A. Kuhn, and G. Rempe, “Transition from Antibunching to Bunching in Cavity QED”, Phys. Rev. Lett., **94**, 053604 (2005).
8 - V. Jacques, E. Wu, F. Grosshans, F. Treussart, P. Grangier, A. Aspect, and J.F. Roch, “Delayed-Choice Test of Quantum Complementarity with Interfering Single Photons”, Phys. Rev. Lett., **100**, 220402 (2008).
9 - T.B. Pittman, D.V. Strekalov, A. Migdall, M.H. Rubin, A.V. Sergienko, and Y.H. Shih, “Can Two-Photon Interference be Considered the Interference of Two Photons?”, Phys. Rev. Lett., **77**, 1917 (1996).
10 - V.A. Kuz’menko, “On the Experimental Study of Nonlocality in Quantum Physics”, e-print, viXra:1902.0331
11 – Y.H. Kim, R. Yu, S.P. Kulik, Y. Shih, and M.O. Scully, “Delayed “Choice” Quantum Eraser”, Phys. Rev. Lett., **84**, 1 (1999).