Reply to “Comment on ‘Direct counterfactual transmission of a quantum state’”

Zheng-Hong Li,[1,2,3] M. Al-Amri,[1,2] and M. Suhail Zubairy[1]

[1] *Institute for Quantum Science and Engineering (IQSE) and Department of Physics and Astronomy, Texas A&M University, College Station, Texas 77843-4242, USA*

[2] *The National Center for Applied Physics, KACST, P.O.Box 6086, Riyadh 11442, Saudi Arabia*

[3] *Department of Physics, Shanghai University, Shanghai 200444, China*

(Received 4 April 2016; published 2 June 2016)

We address criticisms made in the preceding Comment by Vaidman regarding our claims of counterfactuality of transmission of a quantum state in our recent work.

DOI: 10.1103/PhysRevA.93.066302

The preceding Comment by Vaidman [1] is critical of our claim of counterfactuality in a recent article [2] on quantum state transfer. His main criticism is identical to that made by him to our earlier paper on a counterfactual communication protocol [3] and his arguments are essentially the same as presented in his Comment published in Ref. [4], to which we replied in Ref. [5].

Vaidman's argument against counterfactuality in both Refs. [2,3] hinges critically on the nonzero value of the weak value in the transmission path. In his words, an “appropriate criterion for the presence of a particle in the channel is given by the analysis of the trace it leaves. If the channel is such that a single particle passing from Bob to Alice leaves an infinitesimal trace there, then the counterfactuality of a protocol using this channel can be decided according to the trace left due to the protocol operation.” This criterion, however, leads to counterintuitive results, such as (in the words of Vaidman) “the photon did not enter the interferometer, the photon never left the interferometer, but it was there” [6], that are in clear disagreement with the standard quantum mechanics. Our claims of counterfactuality are based on the premise that if the photon did not enter the interferometer, the photon never left the interferometer, then it was *not* there. This statement, in accordance with the standard quantum mechanics, is the crux of our argument.

The argument of Vaidman based on a weak trace was addressed in great detail in our paper [7] (which is not cited in the preceding Comment), and we showed that his argument is incorrect. Our basic premise is that the interference is lost when a measurement is made, no matter how weak it is. The weak trace therefore cannot be a proof of the existence of the photon in the transmission channel. We notice that the same problem appears in one of Vaidman's recent papers [8], which is the Ref. [7] cited in his Comment. Vaidman's calculations and arguments are based on a disturbed system. His method does not give a satisfactory proof of the lack of counterfactuality in our protocols.

Next we turn to the validity of our claim of counterfactuality. There is no disagreement in the case when Bob blocks (by putting an absorber) at each stage of passage after the public channel [e.g., in Fig. 2(b) of Ref. [3]]. The contentious situation is the unblocked situation when Bob allows the photons to be reflected at each stage at his end. A simplified version with single inner and outer Mach-Zehnder interferometers is presented in Fig. 1 of Ref. [5]. We note that the results based on standard quantum mechanics (the probabilities of getting clicks at various detectors) in this latter situation remain identical whether we do or do not insert a blockade at location E in Fig. 1 of Ref. [5]. This happens because the probability of the photon being at this location is strictly zero in our setup. According to the theory of Vaidman, in one instance (path open at E) there is a nonzero weak trace present in the public channel (region C), thus destroying counterfactuality, whereas, in the other instance (path blocked at E), the weak trace in the public channel is zero and we obtain counterfactuality. We, however, claim counterfactuality in both instances with no contradiction. This point raised in our Reply [5] has not been addressed in any of Vaidman's multiple publications on the subject.

We should add that the unblocked situation in Refs. [2,3] (and in Ref. [5]) is very similar to the interaction-free measurement [9] whose key point is that a “bomb” located in one arm of a Mach-Zehnder interferometer (MZI) can be found without being exploded. In other words, according to the measurement result, we can infer the history of the photon which must pass through the arm excluding the bomb. Thus the counterfactuality is ensured by the nonexplosion of the bomb. The “trajectory” of the photon is thus determined. In Fig. 1 of Ref. [5] [and similarly in Fig. 2(b) of Ref. [3]), D_3 corresponds to the bomb in our setup. The lack of click at D_3 guarantees counterfactuality. Just as in the interaction-free measurement in a single MZI, the trajectory is determined by the measurement result—a click at D_1 determines the trajectory to be along path A.

In conclusion, Vaidman's criticism of our claim of counterfactuality in Refs. [2,3] is incorrect. The questions raised in the preceding Comment have been answered in our previous papers.

[1] L. Vaidman, preceding Comment, Phys. Rev. A **93**, 066301 (2016).

[2] Z.-H Li, M. Al-Amri, and M. S. Zubairy, Phys. Rev. A **92**, 052315 (2015).

[3] H. Salih, Z.-H Li, M. Al-Amri, and M. S. Zubairy, Phys. Rev. Lett. **110**, 170502 (2013).

[4] L. Vaidman, Phys. Rev. Lett. **112**, 208901 (2014).

[5] H. Salih, Z.-H Li, M. Al-Amri, and M. S. Zubairy, Phys. Rev. Lett. **112**, 208902 (2014).

[6] L. Vaidman, Phys. Rev. Lett. **98**, 160403 (2007).

[7] Z.-H. Li, M. Al-Amri, and M. S. Zubairy, Phys. Rev. A **88**, 046102 (2013); L. Vaidman, *ibid.* **88**, 046103 (2013).

[8] L. Vaidman, J. Phys. A: Math. Theor. **48**, 465303 (2015).

[9] A. C. Elitzur and L. Vaidman, Found. Phys. **23**, 987 (1993).

