Is Faster-Than-Light Communication Possible?

Article · January 2006

DOI: 10.1063/1.2169326

Raymond Jensen
Lake Michigan College

Is Faster-Than-Light Communication Possible?

Raymond W. Jensen

Department of Mathematics, University of Notre Dame, Notre Dame IN 46556

rwjst4@alumni.nd.edu

Abstract. It is shown here using elementary quantum mechanics that a method exists for transmitting signals faster than the speed of light. The method relies on measurement of the uncertainty of momentum for one photon of each pair. The uncertainty is affected by whether momentum or position is measured for the partners, due to Heisenberg's uncertainty principle. For each pair the effect is instantaneous; so if the measurement of momentum uncertainty, done on one end, is distant from the momentum/position measurement switching done on the other end, then such behavior can be utilized for faster-than-light signaling.

Keywords: correlation, entanglement, FTL, interferometer, polarization, signaling, superluminal, uncertainty.
PACS: 42.79.Sz

INTRODUCTION

It has been claimed that it is impossible to communicate instantaneously *via* a two-particle correlated system (Dušek, 1999) (although some experiments seem to indicate otherwise (Zeilinger, 1999)). The argument is based on the fact that the probability p_i of obtaining an eigenvalue a_i, after observable operation **A** is done on one photon of a correlated pair, is unaffected by operations done on the second photon of the pair. This argument repudiates attempts at faster-than-light information transfer using probabilities of such eigenvalues, however it does not eliminate methods of faster-than-light information transfer which rely on measurement of the uncertainty of eigenvalues.

Consider a pair of correlated photons, 1 and 2, which have been emitted by a source S. The wavefunction for this system is

$$|\psi\rangle = \frac{1}{\sqrt{2}}\left(|1+\rangle|2+\rangle + |1-\rangle|2-\rangle\right). \tag{1}$$

The symbols + and – refer to polarizations of the photons. If two polarizers are used, one to measure the polarization of each photon, and the relative angle between polarizers is 0, then + and – in (1) may be regarded as absorption and transmission of the photon by its respective polarizer. A more sophisticated approach is to use a beam splitter instead of polarizers, and a pair of detectors. In this case, + may represent one path out of the beam splitter and –, the other path. See figure 1.

Now, suppose that the path, or polarization, of photon 1 has been measured prior to photon 2. That is, photon 1 is made to pass through the apparatus shown in figure 1 before the detection of photon 2. Then from equation (1), the new wavefunction, now representing only photon 2, becomes either

$$|\phi\rangle = |2+\rangle \tag{2a}$$

or

$$|\phi\rangle = |2-\rangle, \tag{2b}$$

depending on whether $|1+\rangle$ or $|1-\rangle$ was measured for photon 1, respectively. Note that until photon 2 reaches its detector, it is *undetermined* as to whether it is in state (2a) or (2b) (unless the outcome of photon 1 is already known). Nevertheless, photon 2 is in a *determinate* state; *i.e.* it is either in one state or the other. (Hereafter (2) will be referred to as a single "state" for clarity.)

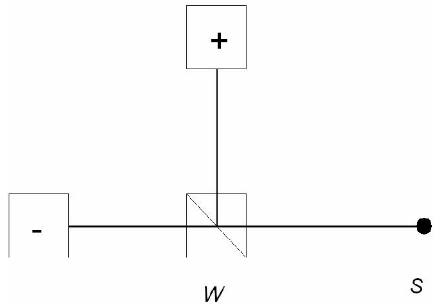

FIGURE 1. Upon exit from source S, a photon can take either the + (vertical) or the – (horizontal) path after passing through a beam splitter *W*. The boxes marked + and – are detectors.

If the beam splitter and two-detector apparatus of figure 1 are replaced by a single detector, which acts as a "quantum eraser," as shown in figure 2, and if photon 1 is allowed to reach the detector before photon 2 is detected, then the polarization of photon 1 remains *indeterminate.*

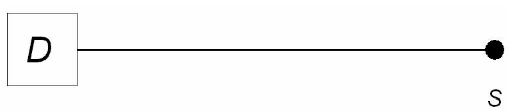

FIGURE 2. The beam splitter and two detectors of figure 1 have been replaced by a single detector *D.*

Therefore, the new wavefunction for photon 2 is, after photon 1 detection,

$$|\phi\rangle = \frac{1}{\sqrt{2}}\left(|2+\rangle + |2-\rangle\right). \tag{3}$$

Hence the polarization of photon 2 in this case remains *indeterminate* as well, prior to measurement. Although above we insist that photon 1 be measured prior to photon 2, this ordering is not necessary, but only used here for purposes of clarity. Of course when relativity theory is taken into account, which event precedes which becomes a matter of what reference frame one is in anyway; nevertheless, the outcomes of the experiments are agreed upon by all observers.

Question: Is it possible to ascertain whether photon 2 is in the *determinate* state (2) or in the *indeterminate* state (3) without knowing how photon 1 was measured? If not for single photon, then is it possible to distinguish between states (2) and (3) for a population of photons, provided that *all* are either in state (2) or in state (3)? For if it is possible, then a basis for faster-than-light communication has been found. In the next section, it is shown that one is able to distinguish between the states in question. How one may use this ability, to transmit signals "faster than light," is the subject of section 3.

DISCRIMINATING BETWEEN AN INDETERMINATE STATE AND A DETERMINATE STATE

Consider again the two-photon correlated system represented by equation (1). Suppose now we subject this system to the apparatus shown in figure 3.

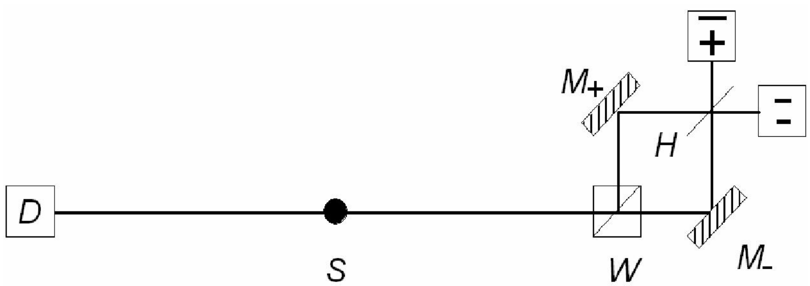

FIGURE 1. Photon 1 propagates left, to a single detector *D*. Photon 2 propagates right, to a Mach-Zehnder interferometer: M_+ and M_- are mirrors for the + and – paths, respectively, *H* is a half-silvered mirror, and the boxes labeled $\overline{+}$ (read "plus bar") and $\overline{-}$ (read "minus bar") are detectors.

On the right side is a Mach-Zehnder interferometer, on the left is a single detector. Suppose photon 1 propagates toward the left and 2 towards the right. Since the polarization of photon 1 is never measured, the wavefuction (1) "collapses" to equation (3) upon photon 1 detection and photon 2 takes an indeterminate path through the interferometer. If $N >> 1$ correlated photon pairs are allowed to pass through the apparatus, then interference patterns, as shown in figure 4, are obtained from the photons passing through the interferometer, by varying the difference ΔL between + and – path lengths of the interferometer. These patterns have been observed by Aspect and co-workers (Grangier, 1986; Ruhla, 1999) in a similar experiment.

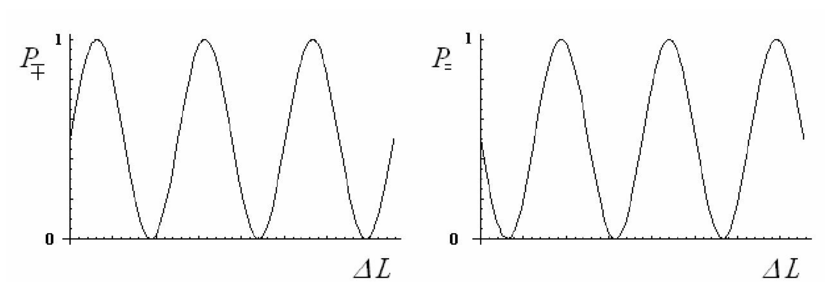

FIGURE 2. Probability, or normalized intensity of photons for the $\overline{+}$ (left) and $\overline{-}$ (right) detectors of the Mach-Zehnder interferometer of figure 3 *vs.* difference in length ΔL of the + and – paths through the interferometer. As ΔL is changed in the interferometer, the ratio of photon absorption between detectors changes, giving the interference patterns shown. In this case the momentum measurement of the photons is precise.

The transformation equations between the unbarred basis of photon 2 and the barred basis of the interferometer detectors are

$$\begin{aligned} |2+\rangle &= \cos(\Delta\phi)\left|\overline{2+}\right\rangle - \sin(\Delta\phi)\left|\overline{2-}\right\rangle \\ |2-\rangle &= \sin(\Delta\phi)\left|\overline{2+}\right\rangle + \cos(\Delta\phi)\left|\overline{2-}\right\rangle \end{aligned} \tag{4}$$

where $\Delta\phi = 2\pi\Delta L/\lambda$, λ being the wavelength of the (monochromatic) photons passing through the interferometer. Using equations (3) and (4), the probability of photon absorption by the two detectors can be calculated; these are:

$$
\begin{aligned}
P_{\mp} &= \frac{1}{2}\left[1+\sin\left(2\Delta\phi\right)\right] \\
P_{=} &= \frac{1}{2}\left[1-\sin\left(2\Delta\phi\right)\right]
\end{aligned}
\quad . \tag{5}
$$

Equations (3), when plotted, give the graphs shown in figure 5.

Suppose now that the apparatus of figure 3 is changed so that the polarization of photon 1 is determined. See figure 5.

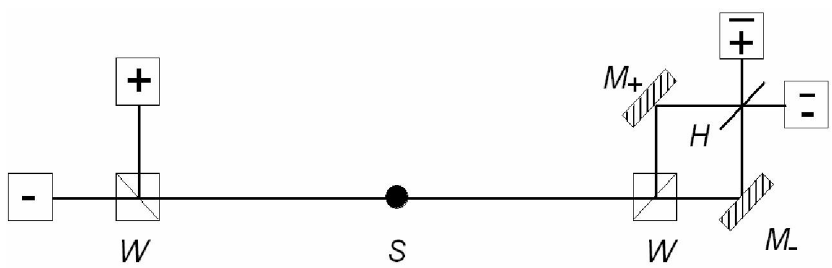

FIGURE 3. Same apparatus as in figure 3, except now the polarization of photon 1 is measured, as was done in figure 1.

Upon photon 1 detection, wavefunction (1) "collapses" to state (2). Hence photon 2 takes a determinate path through the interferometer (*i.e.* either the + or – path), and as a consequence no interference pattern appears, after $N >> 1$ such photons are passed through the interferometer; as shown in figure 6. It should be emphasized that the succeeding photons must be separated by a large enough distance so that they do not interfere with each other.

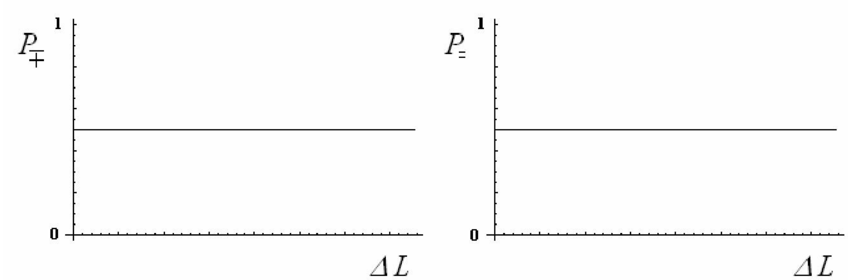

FIGURE 4. Probability, or normalized intensity of photons for the $\mp$ (left) and = (right) detectors of the Mach-Zehnder interferometer of figure 5 *vs.* difference in length ΔL of + and – paths through the interferometer. As ΔL is changed in the interferometer, the ratio of photon absorption between detectors does not change, but remains at 50%. In this case, the measurement yields no momentum information about the photons; *i.e.* momentum is entirely uncertain.

Using equations (2) and (4), the probabilities in this case can also be calculated:

$$
P_{\mp} = P_{=} = \frac{1}{2} . \tag{6}
$$

Equations (6) give the graphs shown in figure 6.

The appearance or lack thereof, on the right, of interference patterns, can be interpreted in terms of the *Heisenberg uncertainty principle*: precise photon position measurement on one side of the apparatus necessitates imprecise wavelength (momentum) measurement on the other, and *vice versa*.

Summarizing, if a sequence of photons are either ***all*** in the determinate (2) state or ***all*** in the indeterminate state (3), then ***it is possible*** to determine which state they are all in, without the aid of any outside knowledge. That this is possible is demonstrated by the difference between measurement results of figures 4 and 6.

METHOD OF COMMUNICATION

What has been shown in the previous section forms a basis for faster-than-light communication. In pursuit of this, we may construct an apparatus that alternates in configuration, between that of figure 3 and figure 5. See figure 7.

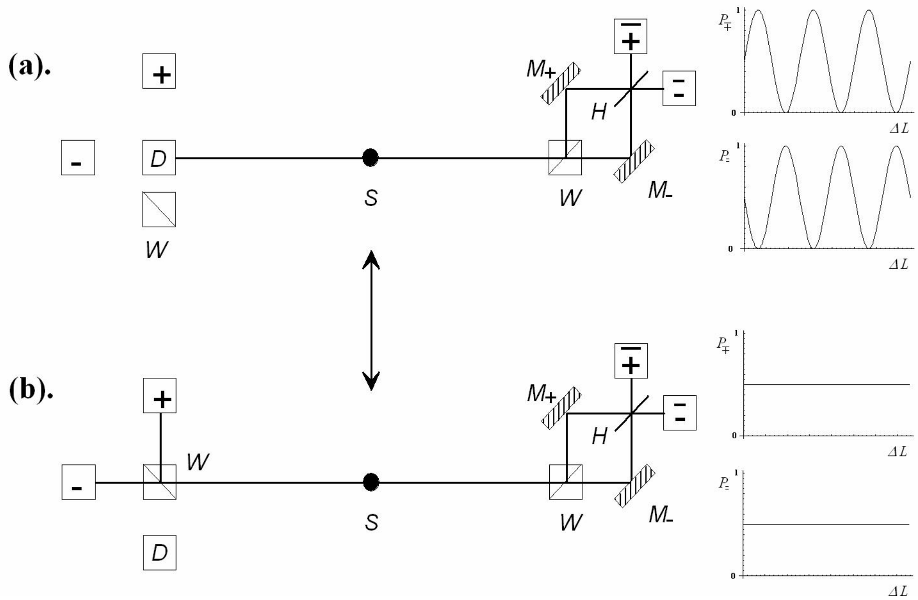

FIGURE 5. This apparatus switches between the configuration of figure 3 (a) and figure 5 (b). In doing so, the beam splitter *W* and detector *D* on the right switch positions. Observed photon intensity from the interferometer detectors in either configuration is shown to the right.

When the apparatus is in configuration (a), the stream of photons 2 forms an interference pattern. While in configuration (b), no interference pattern is formed. By repeatedly switching the apparatus from one configuration to the other, while allowing a sufficient number of correlated photon pairs to be emitted between switching and standardizing switching intervals, a sequence of *bits* of information may be sent from the left side of the apparatus to the right, when a particular bit is associated with the appearance, or lack thereof, of an interference pattern on the right.

For example, let the appearance of an interference pattern correspond to the integer 1 and the absence of an interference pattern correspond to 0. Then the *sequence* of digits (bits) 0, 1, 0, 1 may be transmitted from left to right by initially setting the apparatus on the left to configuration (b), then switching to configuration (a), then to (b) again, then finally to (a). Thus on the right, a sequence of: no interference pattern, interference pattern, no interference pattern, interference pattern, is measured. Thus the receiver on the right interprets this sequence as 0, 1, 0, 1; the original sequence of bits sent from the left. See figure 8.

Now, the photons on the right either begin to form an interference pattern, or they do not, as an *instantaneous* response to what their correlated partners encounter on the left. The actual interference pattern or lack thereof requires $N >> 1$ photons to construct, so a bit of information is not transmitted instantaneously. Nevertheless, if the time required to construct a bit of information is Δt, and if M bits of information are to be transmitted, then so long as the spacing between left and right portions of the apparatus is greater than $cM\Delta t$ (c = speed of light), information transmission using this method is faster than using a conventional light pulse to send the information. In other words, information can be transmitted "faster than light" using the method above.

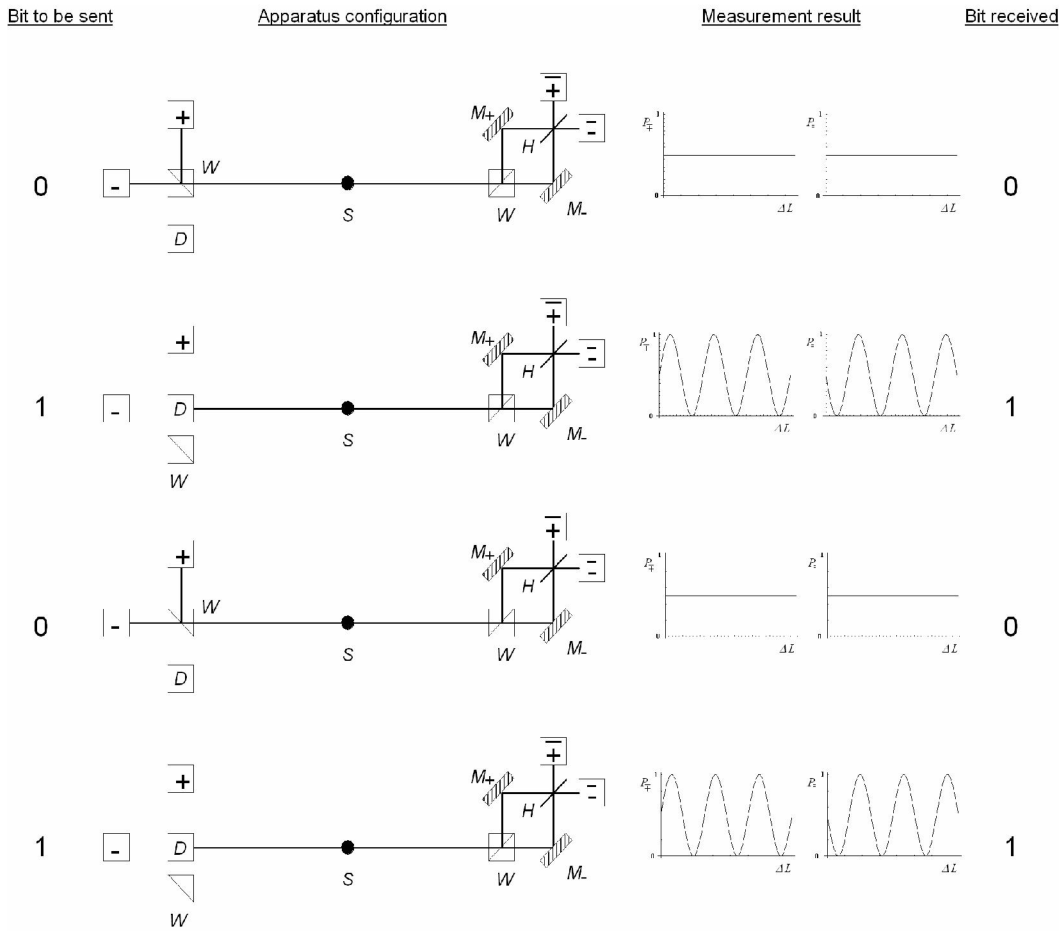

FIGURE 6. The sender on the left side of the apparatus of figure 7 sends the sequence of bits 0, 1, 0, 1 to the receiver on the right by repeatedly switching the apparatus. The receiver interprets a 0 from the lack of an interference pattern during an allotted time interval, and a 1 from the appearance of an interference pattern during an allotted time interval, hence 0, 1, 0, 1 is the information received.

CONCLUSION

Current "orthodox" quantum theory maintains that it is impossible to transmit information faster than the speed of light. However above, it has been shown that it should in fact be possible, if "orthodox" quantum theory holds good. The conflict between conclusions has to do with the fact that in the former argument, it is assumed that the only way to remotely extract information using correlated photons is to rely on measurement of probabilities of eigenvalues. In the method explained above, the *uncertainty* of a single eigenvalue was measured instead. Depending on what was done to the photons on the left, the uncertainty of photon momentum (or wavelength) measurement on the right was increased or decreased, as evidenced by the appearance or disappearance of an interference pattern, respectively. The monochromatic photons on the right yielded only one momentum eigenvalue; so it's probability of occurence was always 100%. But the uncertainty in momentum measurement did change. It is this change in uncertainty which makes faster-than light communication possible.

REFERENCES

Dušek, M., *Instantaneous Action at a Distance in Modern Physics : Pro and Contra*, ed Viv Pope Nova Science, Commack, 1999, p. 391.

Grangier, P., Roger, G. and Aspect, A., "Experimental evidence for a photon anticorrelation effect on a beam splitter: a new light on single-photon interference," *Europhysics Letters* **1**(4), 73 (1986).

Ruhla, C., *The Physics of Chance*, Oxford U. Press, Oxford, 1999, p. 158.
Weihs, G., Jennewein, T., Simon, C., Weinfurter, H., and Zeilinger, A, *Phys. Rev. Lett.* 81 (1998) p 5039
Zeilinger, A., "Experiment and the foundations of quantum physics," *Reviews of Modern Physics* **71**, 288 (1999).