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Vinicius Ritzmann (ritzmann.vinicius@gmail.com)
Independent Scholar https://orcid.org/0000-0002-9145-5769

Article

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Superluminal Communication with Polarized Entangled Photons

Vinicius Ritzmann*

*Independent Scholar. Orcid: 0000-0002-9145-5769. Correspondence: Ewaldo Ritzmann Street, number 822, Campo Lençol, Rio Negrinho, Santa Catarina, Brazil. E-mail: ritzmann.vinicius@gmail.com.

In this work, we show that Quantum Mechanics predicts that two people who share entangled polarized pairs of photons can communicate faster than light. We show this communication only occurs in one direction, from person B to A. Person B can send information to A by measuring the polarization of his photons in different directions. Person A can find out in which direction B has measured his photons by measuring how much light passes through an optical circuit. We show this communication is instantaneous because it is based on the collapse of the wave function of the entangled pair, which collapse is instantaneous. We conclude that regardless of whether this method of communication works or not in practice, we have something new because if it works, it would be a contradiction to the theories of Relativity, and if it does not work, Quantum Mechanics would be predicting something that does not happen in real life.

Keywords: Quantum Optics, Superluminal Communication, Polarization, Quantum Entanglement, Photonics.

1. Introduction

In 1935, Einstein, Podolsky, and Rosen published an article [1] that questioned whether Quantum Mechanics could be considered complete, as the theory predicts that two particles can assume a state in which both are instantly affected by a measurement made on just one of them. This is the so-called "Entangled State".

The theories of Relativity forbid faster-than-light communication, so since then, a long debate has started over whether this instantaneous influence on both entangled particles can be used for faster-than-light communication or not.

In Quantum Mechanics, two particles are entangled when their physical states are not independent, in which case it is guaranteed that if we find one of them in state A, for example, the other will certainly be in state B [2].

We cannot say that since the beginning of the entanglement, the particles are decided on their properties, because until the physical state of a quantum particle is measured, Quantum Mechanics says it will be in a superposition of states, not being in any of them yet [3].

Two entangled particles only decide which state to assume when one is measured, then the other will automatically assume some state, regardless of how far away the particles are at that moment [4]. Here is when the faster-than-light influence happens.

What we show in this article is an experiment that takes advantage of this instantaneous influence to allow two people to communicate faster than light. This experiment allows two distant people to send information only in one way, person B to person A, for example, but not vice-versa, with the entanglement of polarized photons.

The setup we present here is not unique; there are several ways to build an experiment capable of sending information instantly following the same principles of this one, but we will introduce this specific setup because it is simpler than most others are. A setup more feasible, but certainly more complex, will not be discussed here.

2. The Experiment

To begin, we will assume the photons used in the experiment already are in an entangled state. We will not discuss how to reach this state.

We will assume this to keep this article simple, thus, we ask the reader to assume that, at the beginning of the experiment, there are two entangled photons, starting from the same point, traveling in opposite directions (direction 1 and 2).

One direction goes to person "A" and the other goes to person "B".

Figure 01 below represents this situation:

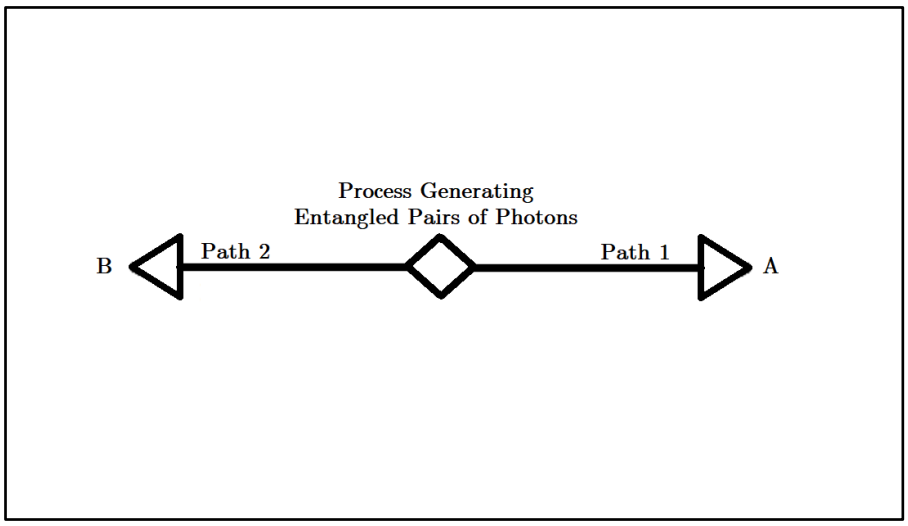

Figure 01: The Experiment Setup. The representation of the experiment, which consists of a source of entangled polarized photon pairs between the positions of person B and A. One of the photons goes to B and the other to A. The path to B should be slightly shorter than the path to A.

The quantum state of these two photons is described by the wave function below (Eq. 001), in this equation, we use the same mathematical formalism of the work of Ou [5]:

$$|\psi\rangle_{1,2} = \frac{1}{\sqrt{2}}\left(|V\rangle_1|V\rangle_2 + |H\rangle_1|H\rangle_2\right) \quad (001)$$

In Equation 001, the states V (from "Vertical") and H ("Horizontal") correspond to orthogonal polarization directions. The subscripts 1 and 2 mean that one of the photons goes on path 1 and the other on path 2. These two paths are in opposite directions. Path 1 leads to A, while path 2 leads to B.

Therefore, what Equation 001 tells us is that two photons are traveling opposite directions, if we measure their polarization on this basis VH, they will always have the same polarization V or H. There is a 50% chance that we will find both with polarization V, and 50% chance with polarization H.

We can prove that by changing the basis to one that is rotated 45°, we will still always measure the two photons having the same polarization, but on that basis, or we will find both with 45° polarization, represented by R, or 135°, represented by L:

$$|V\rangle = \frac{\sqrt{2}}{2}(|R\rangle + |L\rangle) \quad (002)$$

$$|H\rangle = \frac{\sqrt{2}}{2}(|R\rangle - |L\rangle) \quad (003)$$

$$|\psi\rangle_{1,2} = \frac{1}{\sqrt{2}}\left(|V\rangle_1|V\rangle_2 + |H\rangle_1|H\rangle_2\right)$$

$$|\psi\rangle_{1,2} = \frac{1}{\sqrt{2}}\left(\frac{1}{2}\left(|R\rangle_1 + |L\rangle_1\right)\left(|R\rangle_2 + |L\rangle_2\right) + \frac{1}{2}\left(|R\rangle_1 - |L\rangle_1\right)\left(|R\rangle_2 - |L\rangle_2\right)\right)$$

$$|\psi\rangle_{1,2} = \frac{1}{2\sqrt{2}}\left(|R\rangle_1|R\rangle_2 + |R\rangle_1|L\rangle_2 + |L\rangle_1|R\rangle_2 + |L\rangle_1|L\rangle_2 + |R\rangle_1|R\rangle_2 - |R\rangle_1|L\rangle_2 - |L\rangle_1|R\rangle_2 + |L\rangle_1|L\rangle_2\right)$$

$$|\psi\rangle_{1,2} = \frac{1}{2\sqrt{2}}\left(2|R\rangle_1|R\rangle_2 + 2|L\rangle_1|L\rangle_2\right)$$

$$|\psi\rangle_{1,2} = \frac{1}{\sqrt{2}}\left(|R\rangle_1|R\rangle_2 + |L\rangle_1|L\rangle_2\right) \quad (004)$$

Note that, if we measure on this basis the photon that follows path 1, we can find it with polarization R or L. There is a 50% chance to each measurement, and then we know that the other photon must have the same polarization as this one, even though this is another basis, not the VH from before.

When we measure one of the photons on the basis VH, the other photon collapses to a polarization that is V or H. If we measure, however, on the basis RL, the other photon must collapse to a polarization R or L. It is as if, somehow, the other photon receives the information of on which basis we measured its pair.

That is the important point here.

Let us assume that path 2 is a little shorter than path 1, so person B will receive his photon just before its pair reaches person A.

If B measures his photon on the basis VH, A will receive a photon with one of these two polarizations: V or H. However, if B measures the photon on the basis RL, A will receive a photon with polarization R or L, and that is completely noticeable to him.

Person A can do something on his own to find out if the photon he received is polarized R or L, or V or H, which is to put that photon in a 50/50 non-polarizing beam splitter with a third photon, an Ancilla photon, that he has generated with absolute certainty of its polarization.

If person A receives an already collapsed photon, he knows that this photon will have one of these four polarizations: V, H, L, or R. He will then place this photon in one of the inputs of a non-polarizing beam splitter with the photon he generated, polarized in the V direction, as shown by Figure 02:

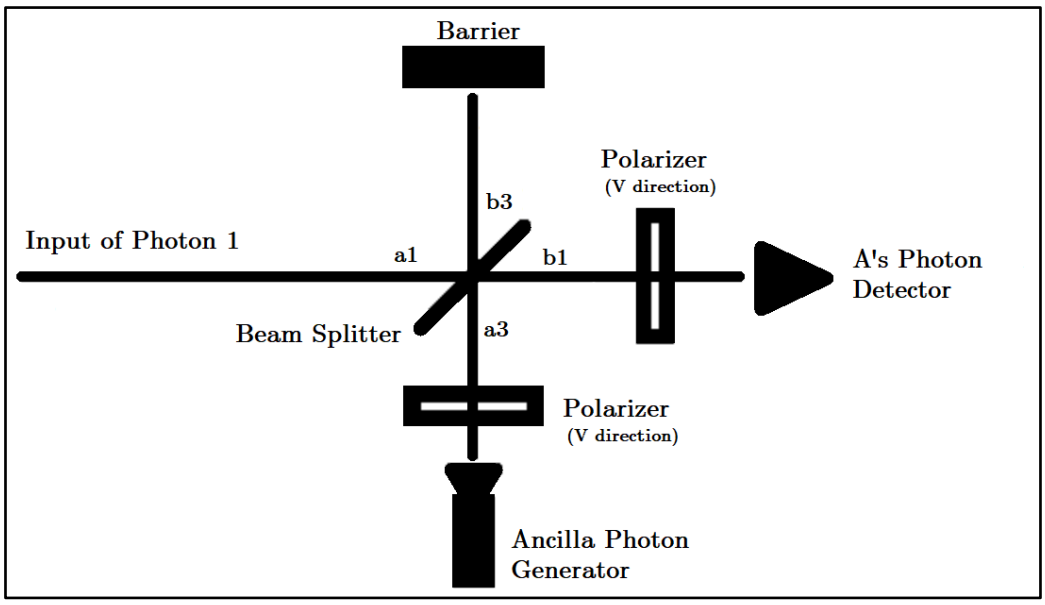

Figure 02. Person A's Circuit. The optical circuit person A can build to detect by his own on which basis person B measured his photons, made of a 50/50 non-polarizing beam splitter, two polarizers in the V direction, an Ancilla photon generator, and a photon detector.

The photon person A receives, coming from path 1, enters input a1 of the beam splitter. The photon that A generated, after crossing a polarizer to become polarized in the V direction, enters input a3.

At output b1, there is a polarizer in the V direction and after that, A's photon detector. There is a barrier in the b3 direction, just to say that it does not matter what goes out by b3.

The creation and destruction operators, which govern what enters and leaves the beam splitter, used in this article, are as follows:

$$\hat{U}\hat{a}_{1V}^{\dagger}\hat{U}^{\dagger} = \frac{\sqrt{2}}{2}\left(\hat{b}_{1V}^{\dagger} - \hat{b}_{3V}^{\dagger}\right) \quad (005)$$

$$\hat{U}\hat{a}_{3V}^{\dagger}\hat{U}^{\dagger} = \frac{\sqrt{2}}{2}\left(\hat{b}_{3V}^{\dagger} + \hat{b}_{1V}^{\dagger}\right) \quad (006)$$

$$\hat{U}\hat{a}_{1H}^{\dagger}\hat{U}^{\dagger} = \frac{\sqrt{2}}{2}\left(\hat{b}_{1H}^{\dagger} + \hat{b}_{3H}^{\dagger}\right) \quad (007)$$

$$\hat{U}\hat{a}_{3H}^{\dagger}\hat{U}^{\dagger} = \frac{\sqrt{2}}{2}\left(\hat{b}_{3H}^{\dagger} - \hat{b}_{1H}^{\dagger}\right) \quad (008)$$

So, if the a1 input photon is V:

$$|\psi\rangle_{input} = |V\rangle_1|V\rangle_3 \quad (009)$$

$$|\psi\rangle_{output} = \frac{\sqrt{2}}{2}\left(|V\rangle_1|V\rangle_1 - |V\rangle_3|V\rangle_3\right) \quad (010)$$

If the a1 input photon is H:

$$|\psi\rangle_{input} = |H\rangle_1|V\rangle_3 \quad (011)$$

$$|\psi\rangle_{output} = \frac{1}{2}\left(|H\rangle_1|V\rangle_3 + |H\rangle_1|V\rangle_1 + |H\rangle_3|V\rangle_3 + |H\rangle_3|V\rangle_1\right) \quad (012)$$

If the a1 input photon is R:

$$|\psi\rangle_{input} = \frac{\sqrt{2}}{2}\left(|V\rangle_1|V\rangle_3 + |H\rangle_1|V\rangle_3\right) \quad (013)$$

$$|\psi\rangle_{output} = \frac{\sqrt{2}}{2\sqrt{3}}\left(|V\rangle_1|V\rangle_1 - |V\rangle_3|V\rangle_3 + |H\rangle_1|V\rangle_3 + |H\rangle_1|V\rangle_1 + |H\rangle_3|V\rangle_3 + |H\rangle_3|V\rangle_1\right)$$
(014)

Finally, if the a1 input photon is L:

$$|\psi\rangle_{input} = \frac{\sqrt{2}}{2}\left(|V\rangle_1|V\rangle_3 - |H\rangle_1|V\rangle_3\right) \quad (015)$$

$$|\psi\rangle_{output} = \frac{\sqrt{2}}{2\sqrt{3}}\left(|V\rangle_1|V\rangle_1 - |V\rangle_3|V\rangle_3 - |H\rangle_1|V\rangle_3 - |H\rangle_1|V\rangle_1 - |H\rangle_3|V\rangle_3 - |H\rangle_3|V\rangle_1\right)$$
(016)

Note that there is a 50% chance of Equation 010 occurring and a 50% chance of Equation 012 occurring when B measures his photons on the basis VH. Thus, from Equation 010, there is a 25% chance that A will measure two photons, and from Equation 012, 25% chance of measuring one photon.

However, when B measures his photons on the basis RL, 50% of the time Equation 014 will occur, and 50% of the time Equation 016. Here, person A will only have a 16.66% chance of measuring two photons (8.33% from Equation 014, 8.33% from Equation 016).

Meanwhile, he has a 33.33% chance of measuring one photon (16.66% from Equation 014, 16.66% from Equation 016). Note A will measure fewer times two photons hitting the sensor simultaneously when B changes basis.

In general, even though he measures more times one photon alone hitting the sensor here, he will still measure less light.

This happens because the chance of A measuring any photon in both cases is the same, 50% (the sum of the chance of measuring two and one), but when two photons are measured simultaneously, twice as much energy is received by the sensor.

A's sensor receives more energy when B is using basis VH (8.33% more), which translates to A detecting more light when B uses this basis.

Thus, without any information about what B is doing, just using an Ancilla photon that A himself generated, and with a beam splitter, A can find out if B is measuring his photons on the basis VH or RL.

Person B and A can agree that if A notices that B is using basis VH, the binary bit zero is being sent, and when B switches to basis RL, bit one is being sent.

Person A will not take long to notice this change made by B, he only needs enough photons to arrive for him to be sure of his measurements. If B is far away, the information that he has changed his basis might take longer to get to A by other means

than the time A needs to realize this on his own, if this happens, faster-than-light communication will be taking place.

See, although path 2 must be slightly shorter than path 1 for person A to always receive already collapsed photons, the time it would take for the information to travel from B, by both paths 2 and 1, to A may be longer than the time needed by A to understand the information by his own.

3. Important Points and What Makes the Communication Instantaneous

Before we conclude the article, we want to highlight one strength and three weaknesses of this system. In addition, we want to talk about what makes this system an instantaneous communication system.

The strength of this system is that person A does not need to measure photon by photon to understand what B is sending him, the pairs of photons do not need to be created one by one either; there is a change in luminosity that A can measure instead of counting photons, that makes this communication more viable.

However, the first weakness is the number of photons needed for A's measurements. Note that with a single pair of entangled photons A cannot know for sure what B is doing. He needs several photons to see the change in luminosity, the more photons A receives, the more certain becomes which is the basis B is using to measure his photons.

The second weakness is the possibility of something block one of the paths. If that happens, A will lose contact with B.

The third weakness is that B needs to be closer to the photon source than A is, otherwise A will not receive already collapsed photons and his measurements will be inconsistent.

However, none of these weaknesses invalidates the fact that instantaneous communication is happening.

What makes it possible is two facts: first, that the collapse of the wave function is instantaneous according to Quantum Mechanics, so as soon as B measures his photon, the function collapses and, as it also describes A's photon, his photon is influenced by the measurement instantly.

The collapse allows the sending of information, but there is information because when B changes bases, it changes the state of A's photon as well.

If somehow, B switched bases and the collapse of the wave function did not generate different states for A, he would never be able to know what B did.

Another way to understand how this system achieves instantaneous communication is to realize that the information of what B did must travel faster than light to person A. If it did not travel instantly, person A could measure an amount of light that does not line up with what B did and as the information of what B did reach A, the facts would contradict each other.

To avoid this kind of contradiction within Quantum Mechanics, the only solution is for B's measurement information to propagate instantly.

4. Conclusion

We showed that faster-than-light communication is possible with the entanglement of polarized photons. In our experiment, person A monitoring one detector and with Ancilla photons can receive information from B because he measures part the time an amount of light and part the time another according to the will of B, and this change in light happens much quicker than light could travel the distance between them.

We discussed some strengths and weaknesses of this method of communication and showed that the communication is instantaneous because it relies on the collapse of the wave function of the entangled particles, which is instantaneous and affects both particles.

Finally, we must just remember that although theoretically, the communication discussed here is possible, only by carrying out experiments we will be able to know for sure if it is, in fact, possible.

However, regardless of whether this method of communication works or not in practice, we have something new, because if it works, we would be contradicting the theories of Relativity, and if it does not, we would have Quantum Mechanics predicting something that does not happen in real life.

Data Availability

Data sharing not applicable to this article as no datasets were generated or analyzed during the current study.

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