Experimental Quantum Teleportation

Quantum teleportation-transmission and reconstruction of over arbitrary distances of the state of a quantum system is described experimentally. During this process, we take a photon; transfer its property (polarization) to another photon-even if the two photons are remote locations. An initial photon, which carries the polarization that is to be transferred, and one of a pair of entangled photons are subjected to a measurement such that the second photon of an entangled pair gets the polarization of the initial. This scheme could also be used to provide links between quantum computers.

1. Introduction

1. Introduction: The dream of teleportation is simply reappearing at some distant locations without having to pass through any physical means [1]. To make a copy of that object at a distant location we do have to worry about the original parts and components. In order to bring these things into reality, Quantum teleportation was proposed by a team of six scientists in 1993 [2]. The original proposal was focused on teleporting the quantum state of a two-state system, such as polarization of a photon or spins half particles [3]. Such teleportation has been demonstrated in the laboratory by two groups of scientists. One at the university of Innsbruck and the other at the university of Rome. Both of them teleported the polarization state of a photon by using the technique called "entanglement", the essential feature of quantum mechanics [1]. This scheme works only for quantum scale particles like photons, atoms and ions. Although no physical laws prevent for doing it in macroscopic objects, it is simply not possible due a to variety of engineering reasons [4]. Because of this unique property (such as entanglement) makes science fiction fans disappointed!!.

Before 1993 scientists did not take Teleportation seriously, because it was thought to violate Heisenberg's uncertainty principle of quantum mechanics. According to uncertainty the principle, we cannot measure simultaneously and precisely both position and momentum i.e. the more precisely an object is scanned, the more it is disturbed by the scanning process. But the six scientists overturned this idea in 1993 [2]. They have suggested that it is possible to transfer the quantum state (at least polarization) of a quantum particle (photon) on to another quantum particle (photon) by using celebrated and paradoxical features of quantum mechanics known as the Einestin-Podolosky-Rosen (EPR) correlation or entanglement.

Here I would like to address the experimental work done by the University of Innsbruck group, which was the first milestone experimental verification of quantum teleportation. They produced a pair of entangled photons by the method of parametric down-conversion [1] and using two-photon interferometer for analyzing entanglement. They were successful in detecting the transfer of a quantum property (i.e. state of polarization) from one photon to another photon.

2. Analyzing the problem: Here we give two names ALICE and BOB. Suppose Alice has some particles in some quantum state $|\psi\rangle$ and she wants Bob, at some far distance, to have a particle in the same state. The initial state of a particle $|\psi\rangle$ (in our case photon) is described by

$|\Psi_1\rangle = \alpha|\rightarrow\rangle + \beta|\uparrow\rangle$. Here $|\rightarrow\rangle$ indicates horizontal polarization and $|\uparrow\rangle$ Vertical polarization. α and β are two complex numbers satisfying the relation $|\alpha|^2 + |\beta|^2 = 1$. Now Alice wants to teleport this state to Bob at distant locations. Which is shown in fig. (1). The initial state of an entangled particle 2 and 3 is given by

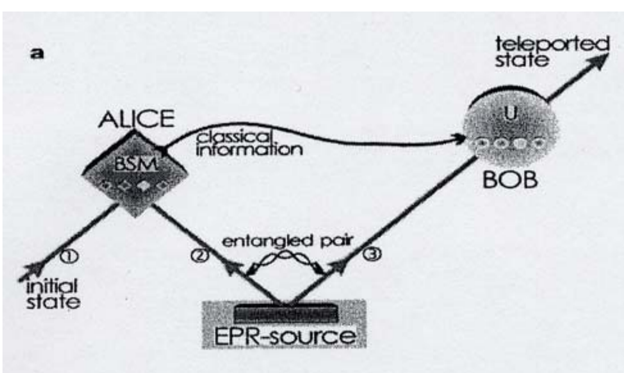
$|\Psi^{-}{}_{23}\rangle = \frac{1}{\sqrt{2}}(|\rightarrow\rangle_2|\uparrow\rangle_3 - |\uparrow\rangle_2|\rightarrow\rangle_3)$. It clearly shows that it is the superposition of the states of the particle, 2 and 3, which are vertically and horizontally polarized. This is one of the four Bell's states [5]. This entangled state does not contain individual property of the particles but surely we can say that they are orthogonal to each other (i.e. in opposite state). Clearly we can say that if we know the state of one particle then we can predict the states of the other particle or vice versa. One question that arises here is how could a measurement on one of the particles instantly affect the state of the other particle which is far away? Einstein could not accept this idea and called it "spooky action at a distance" [1].

3. How does teleportation work? Here I would like to explain briefly how teleportation works. As shown in figure (1) Alice has particle 1 in its initial state $\left|\Psi_1\right\rangle = \alpha\left|\rightarrow\right\rangle + \beta\left|\uparrow\right\rangle$ and particle 2. But particle 2 is entangled with particle 3. As particle 1 gets entangled with particle 2 then its state is given by one of the four possible Bell's states. Four possible Bell's states are given by

$$\left|\Psi^-{}_{12}\right\rangle = \frac{1}{\sqrt{2}}(\left|\rightarrow\right\rangle_1\left|\uparrow\right\rangle_2 - \left|\uparrow\right\rangle_1\left|\rightarrow\right\rangle_2)$$

$$\left|\Psi^+{}_{12}\right\rangle = \frac{1}{\sqrt{2}}(\left|\rightarrow\right\rangle_1\left|\uparrow\right\rangle_2 + \left|\uparrow\right\rangle_1\left|\rightarrow\right\rangle_2)$$

$\left|\phi^\pm{}_{12}\right\rangle = \frac{1}{\sqrt{2}}(\left|\rightarrow\right\rangle_1\left|\rightarrow\right\rangle_2 \pm \left|\uparrow\right\rangle_1\left|\uparrow\right\rangle_2)$. Now particle 1 and 2 get entangled so that they are in a common state (i.e. $\left|\Psi^-{}_{12}\right\rangle$). Now we can comfortably say that whatever the state of particle 1 is particle 2 has its opposite state i.e. particle 1 is orthogonal with particle 2. But initially particle 2 and 3 were entangled and has common state $\left|\Psi^-{}_{23}\right\rangle$ i.e. particle 2 is orthogonal with particle 3. "Quantum mechanics predicts that [1] once particle 1 and 2 are projected in to $\left|\Psi^-{}_{12}\right\rangle$ particle 3 is spontaneously projected on to the initial state of particle 1". So we conclude that particle 3 is in the same state as the particle 1 was. The final state of particle 3 is $\left|\Psi_3\right\rangle = \alpha\left|\rightarrow\right\rangle + \beta\left|\uparrow\right\rangle = \left|\psi_1\right\rangle$.



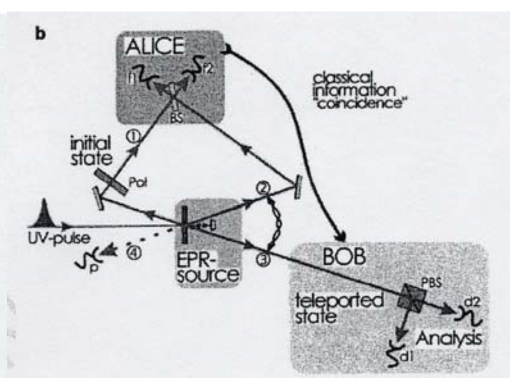


Fig. (1) ref. [1]　　　　Fig.(2) Ref.[1]

Fig 1 and 2 shows the experimental set-up for quantum teleportation

Hence during the Bell state measurement particle 1 will loose its own identity and become entangled with particle 2. The original state of particle 1 i.e. $|\Psi_1\rangle$ will be destroyed as soon as it reaches Alice. Hence we conclude that particle 3 is not cloned but is a consequence of teleportation. Recently teleportation has been observed over 10 km distances [1].

4. Experimental set up to produce entangled photons: Inside a non-linear crystal an ultraviolet photon having wavelength 490nm spontaneously splits into two infrared photons having wavelength 780nm labeled as A and B. They are orthogonally polarized (H and V, horizontally and vertically respectively) and propagate along the two directions where the two cones intersect as shown in the figure 3. The corresponding polarized-entangled two-photon state is given by.

$$|\Psi^{+}{}_{12}\rangle = \frac{1}{\sqrt{2}}(|\rightarrow\rangle_1|\uparrow\rangle_2 + |\uparrow\rangle_1|\rightarrow\rangle_2).$$

With the help of additional half wave or quarter wave plates we can produce any of the four EPR Bell's states [2].

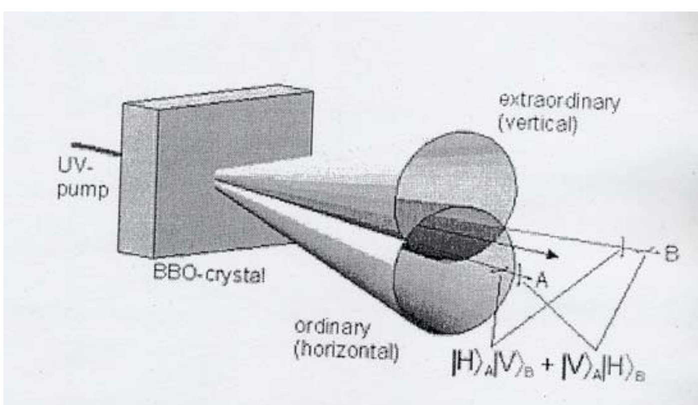


Fig.(3) Ref.[1]

5.Results: First of all we would like to give the theoretical result of the teleportation, which will then be compared with experimental results. Initially we take the polarization state of photon 1 as $+45^0$. Teleportation will work as soon as photon 1 and 2 are detected in the state $\left|\Psi^-{}_{12}\right\rangle$, which occurs in 25% of all four possible cases. This is the entangled state of particle 1 and 2 (i.e. $\left|\Psi^-{}_{12}\right\rangle$) and will be identified by recording a three-fold coincidence between the two bell-state detectors (f_1, f_2) and one of the detectors analyzing the teleported state placed behind the polarizing beam splitter (PBS).

Once we detect f1f2 coincidence (between detectors f1 and f2) then photon 3 should also be polarized at $+45^0$. Now this photon 3 is analyzed by passing through the PBS. Detector d_1 will detect only -45^0 polarization where as detector d_2 will detect $+45^0$ polarization. So in this case detector d_2 ($+45^0$ polarization) would always fire when detector f_1 and detector f_2 fired. Except due to noise, it was never the case that-45^0 polarization detector (d_1) fired in coincidence with detector f_1 and f_2. Therefore recording a three fold coincidence $d_2f_1f_2$ ($+45^0$) together with the absence of a three-fold coincidence $d_1f_1f_2$(-45^0) is a proof that the polarization of photon 1 has been teleported to photon 3. Fig 4 gives the theoretical summary of the result. The graph shows the three-fold coincidence $d_2f_1f_2$ versus delay between the arrival of photon 1 and 2 at Alice's beam splitter (see fig 2). So in fig. 4 ***a*** $d_1f_1f_2$ (-45^0) three fold coincidence versus delay where as in fig. 4 ***b*** $d_2f_1f_2$ three fold coincidence versus delay. A photon polarization state at -45^0 is a dip to zero at zero delay in the three fold coincidence rate with the detector analyzing -45^0 ($d_1f_1f_2$) (a) and a constant value for the detector analyzing $+45^0$ ($d_2f_1f_2$) figure 4 (b). The shaded region shows the teleportation region.

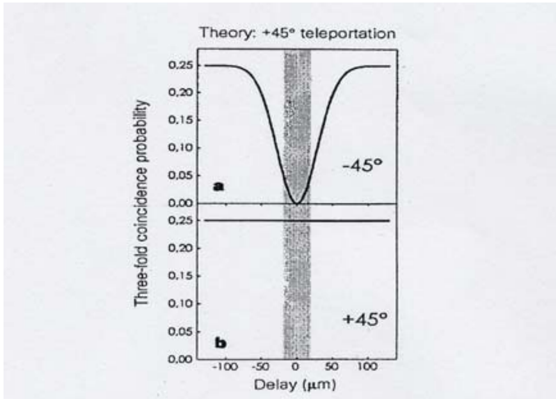


Fig.(4) Ref.[1]

Theoretical prediction for the three-fold coincidence probability between two Bell's state detectors (f1,f2) and one of the detectors analyzing the teleported state.

The experimental result of teleportation for (+45^0 polarization) is as shown in figure 5 ***a***, ***b*** where as for (-45^0 polarization) in figure 6 ***a***, ***b***. We want to compare these results with theoretical results, which is shown in fig 4 ***a***, ***b***. The strong decrease in the -45^0 analysis and a constant signal for the +45^0 polarization shows that photon 3 is polarized along the direction of photon 1, conforming teleportation. Similar results are obtained for -45^0 polarizations, which are shown in figure 6 ***c***, ***d***.

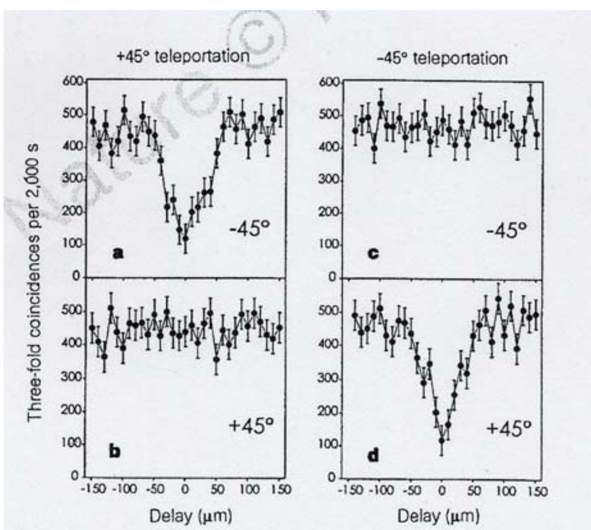


Fig.(5) ref[1] Fig.(6) ref.[1]

Experimental results. The three-fold coincidence rates $d_1f_1f_2$ (-45^0) and $d_2f_1f_2$ (+45^0) in the case that the photon state to be teleported is polarized at +45^0 (***a*** and ***b***) or at –45^0 (***c*** and ***d***). The coincidence rates are plotted as a function of the delay between the arrival of photon 1 and 2 at Alice's beam splitter.

6.**Conclusions**: The scheme, which is described above works only for quantum-scale particles, like photon. Although no physical laws want to prevent quantum teleportation for humans and automobiles. Due to certain constraints, teleportation could not be implemented in macroscopic objects because of unique property (such as entanglement that make teleportation possible) quickly breaks down as object size increases.

Also quantum teleportation does not allow for faster than light communication, although the teleported particle attains the polarization value instantly. In this scheme, teleportation is achieved 25% of the time. On the application part of the teleportation one could allow us to transfer the state of example fast-deciphering, short-lived particles, on to some more stable systems. Also teleportation could be used in quantum computers and quantum memories [1] etc.

References:

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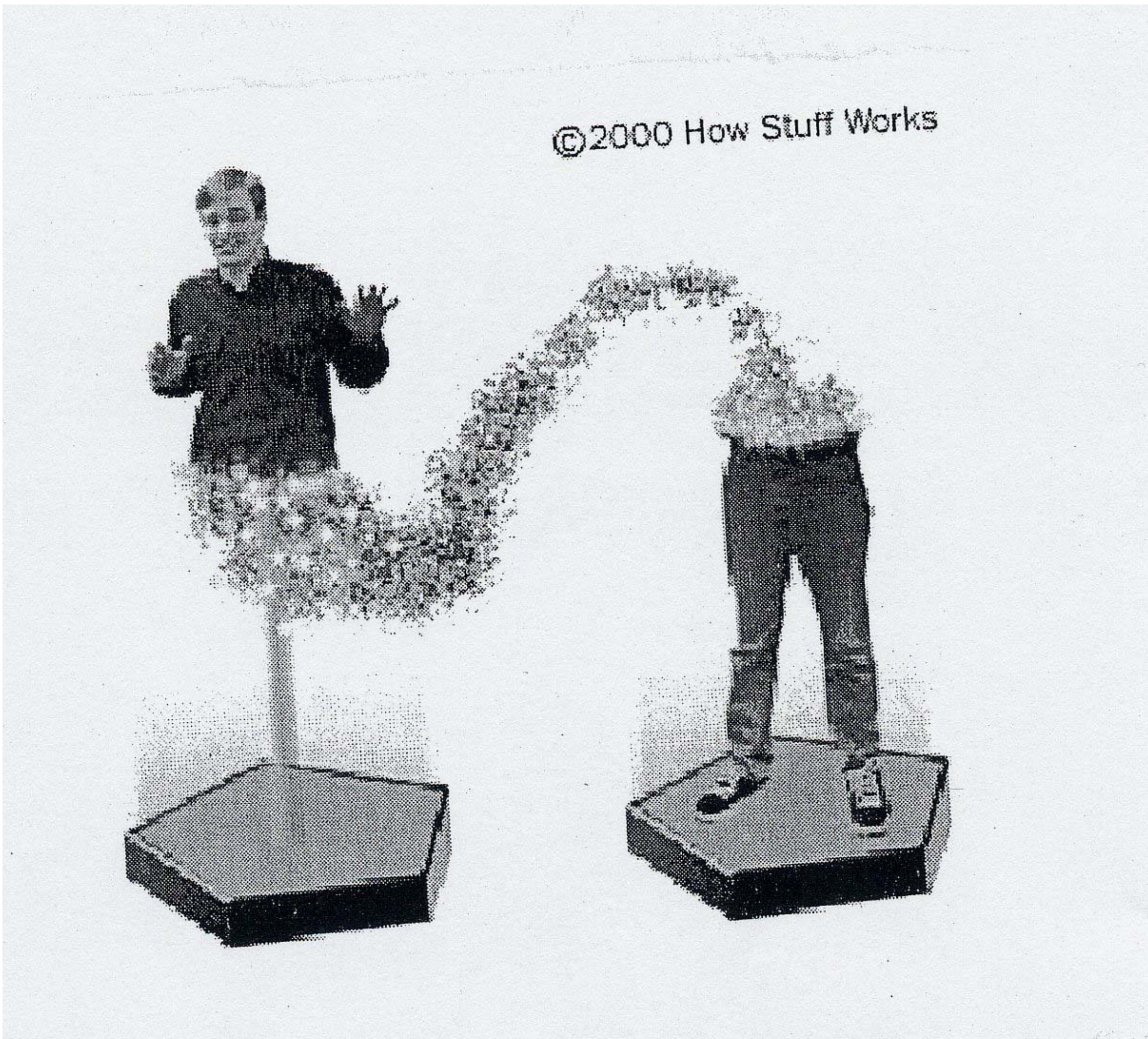
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A Project work on

“Experimental Quantum Teleportation”

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