Quantum Teleportation Passion Project Essay

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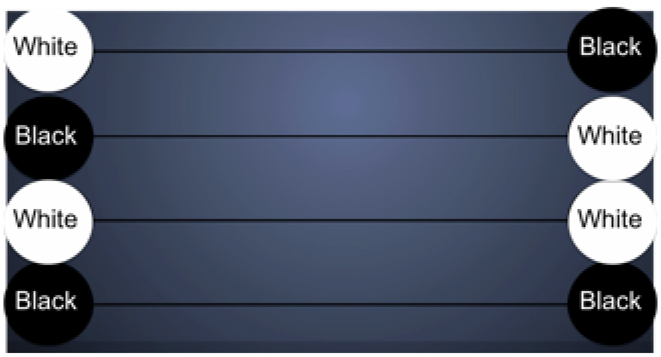
"How does or will teleportation work?" was one of the many questions that I always wanted answered. So for my Passion Project I wanted to learn how teleportation would work, as well as how it will change humanity. The main reason why I wanted to study this topic was because this question has always been going round my head ever since I was in the 1st grade and I saw Star Trek for the first time. Also I love pushing my brain to its max and this topic was able to do that and give me a hard challenge. The way I did my research was by take notes, then look at those notes and review them until I understood the concept. My main resources for my Passion Project and notes were two novels and one website. The two novels were "Dance of the Photons From Einstein to Quantum Teleportation" by Anton Zeilinger and "The Physics of Quantum Information" by the authors: Dirk Bouwmeester, Artur Ekert, and Anton Zeilinger. Also the main website I used was Wikipedia. My research took me two months to finish, but in those two months I have mostly understood the concept of teleportation. Well, I was doing my research I quickly learned that teleportation physics is something completely different on its own. See, teleportation does not work like in Star Trek; where an object's particles are converted into energy, then sent to the location that the object is wished to be teleported to, after that the object is rebuilt from its particles at the location. This idea of teleportation does not work because there are certain laws that prevent such an action. Such as when particles are moved to a location to fast or slow, it changes the particle's state into something different. Instead, to do teleportation one would have to stop thinking logically and start thinking theoretically. When I started diving deeper into my research for this subject, it later leads me to Quantum Teleportation.

"What is Quantum Teleportation?" one would ask. Well quantum teleportation is the process in which quantum information is transmitted exactly from one location to the other. Quantum information also known as a qubit; is the state of a particle, which can be found from the particle's spin (position and momentum). Every particle has a qubit because without it the particle cannot fusion. A qubit is like the classical bit with the values 1 and 0, but instead a qubit can have the values 0 and 1 at the same time. This happens because it is believed every quantum object (any object build of particles) have a superposition, which basically means a quantum object can have multiple states at the same time. But when a quantum object is measured (measured by it's position and momentum) it is no longer in a superposition and has a state (qubit) of it's own. So until the particle is measured, its qubit will be both 1 and 0 at the same time. The way scientists can tell whether a particle's qubit is 1 or 0 is by seeing which spin it is at. For example if the spin of the particle was at the $|\uparrow\rangle$ (spin up state means the particle is spinning up), then that would basically mean the particle has a qubit value of 1 or $|1\rangle$ mathematically and if the particle was at the state $|\downarrow\rangle$ (spin down state means the particle is spinning down), then the state would basically mean the particle has a qubit value of 0 or $|0\rangle$ mathematically. Now what does a qubit have to do with quantum teleportation? Well see this is the information that we need for teleportation. We basically need to get the qubit of all the particles in an object, and then send it to the location that it is wished to be teleported to. Now like I said early we can't really "send" a particle's qubit because like there are laws that prevent anyone from doing so. But what we can do is copy the qubit state of a particle, and then gives that state to another particle. Now this is no easy task, but it can be done with Quantum Entanglement.

Quantum entanglement is when more than one particle act together in an entangled system and this means that entangled particles act like one object when they are apart from each other, even though physically they are two different objects. Also an entanglement state is can be written mathematically as either $|\psi^{+}\rangle$, $|\psi^{-}\rangle$, $|\phi^{+}\rangle$, and $|\phi^{-}\rangle$. Think of entanglement like a human body. Even though all of our body parts are so very different, they still act like one so we can operational. Forcing two particles very close to each other, so close that the particles almost touch one another, can do entanglement of two or more particles. Now this may seem easy to do and it kind of is but there is a slight chance that the particles may be forced to close to one another, so that the particles touch each other and then cause a nuclear explosion. Entanglement is a large part of teleportation because it can do a very intriguing thing that no physics cannot truly grasp. So lets say there were two particles 1 and 2, and a male scientist. If the scientist were to measures particle 1 first, he will then get a random measurement result, which will be particle 1's qubit. But when he measures particle 2 (remember it is still entangled with particle 1), he will then get a 100% opposite measurement result, which is a qubit that is opposite of particle 2. For example if the scientist measured particle 1 and learned particle 1's spin was $|\uparrow\rangle$ (spin up), then particle 2 will would have a spin of $|\downarrow\rangle$ (spin down) and vice versa. Not only that but no matter the distance the entangled particles will be about to do this, so distance does not affect how the particles communicate. So if particle 1 and 2 were billions of light years apart from one another, they will still be able to do this action as if they were one centimeter apart from each other. Not only that but you can manipulate the qubit of an entangled particle and it will change the other particle's qubit. Meaning for example; if particle 1 and 2 were entangled and particle 1 had a qubit of $|0\rangle$, then particle 2 would have a qubit of $|1\rangle$ (opposite state from particle 1). Then when you manipulate particle 1 (changing it's position and momentum) to the qubit $|1\rangle$, particle 2 in an instant will change to a qubit of $|0\rangle$. One important thing to know about entanglement is if you were to change an entangled particle's qubit in a way that it is not similar to the other particle it is entangled too, then it will no longer be entangled.

Knowing this quantum physicists use the equation: $|\psi\pm\rangle_{12}\ |\phi\pm\rangle_{12}=(|0\rangle_1|1\rangle_2\pm|1\rangle_1|0\rangle_2)/\sqrt{2}$ in order to know the entangled state of particles. Where 1 and 2 is representing particles 1 and 2, $|0\rangle$ and $|1\rangle$ representing the two particle's qubits when in superposition, $|\psi\pm\rangle\ |\phi\pm\rangle$ representing different outcomes of a particle's entangled state, ± would represent a type of and the qubits in this equation is divided by $\sqrt{2}$ to show that the two particles are no longer two different particles but one (even though they are still two different particle physically). Also if you were to manipulate two entangled particles you would see that there would be four possible entangled state outcomes. Start thinking of two entangled particles as the color white and color black. The scientist can have the option to not manipulate particles white and black, which would not change where the two particles were. This would be the first possible outcome. Or he could manipulate particle white so that it becomes black and then particle black will become particle white. This would be second possible outcome. He could also manipulate particle white or black in a way that particle white stays white and particle black becomes white. This would be the third possible outcome. Finally he could manipulate particle white or black in a way that particle white becomes black and particle black stays black. These would be the four possible entangled state outcomesok for particle 1 and 2:



Their could not be any more possible entangled outcomes for those two particles after these four outcomes because if the scientist were to manipulate particle white and black in any other way to get another possible outcome then he would damage the entangled state of the two particles and they will most likely no long be entangled with one another. Mathematically the four possible entangled state outcomes for two entangled particles would be:

<u>Particle White and Black:</u>

$|\psi+\rangle_{WB}=(|0\rangle_W|1\rangle_B+|1\rangle_W|0\rangle_B)/\sqrt{2}$

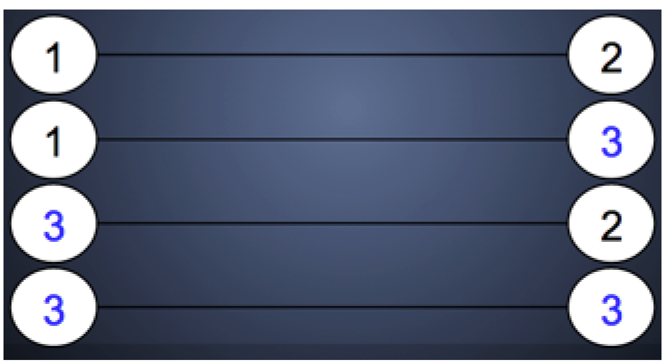
$|\psi-\rangle_{WB}=(|0\rangle_W|1\rangle_B-|1\rangle_W|0\rangle_B)/\sqrt{2}$

$|\phi+\rangle_{WB}=(|0\rangle_W|0\rangle_B+|1\rangle_W|1\rangle_B)/\sqrt{2}$

$|\phi-\rangle_{WB}=(|0\rangle_W|0\rangle_B-|1\rangle_W|1\rangle_B)/\sqrt{2}$

Now $\psi+$, $\psi-$, $\phi+$, and $\phi-$ once again represents an entangled state for the two particles, $|0\rangle$ and $|1\rangle$ the two particle's two bits, W and B represents particle White and Black, the adding or subtracting of the qubits shows how the particle's qubit (state) were manipulated in order to get the entangled state, and (once again) $\sqrt{2}$ showing how the two particles are no longer two different objects instead they are one of the same. The physics of entanglement helps physicist conduct teleportation.

In quantum teleportation there different ways and ideas to do teleportation relating to entanglement. One idea is where Alice wishes to teleport particle 1 to Bob. For Alice to teleport the particle she first finds a particle to entangle particle 1 to, which would be particle 2. Then she would force the two particles very close to one another , so they become entangled. After that she would send particle 2 to Bob's location, by lunching at the speed of light. The two particles have not been measured yet. When particle 2 gets to the Bob's location, Alice will measure particle 1's qubit. She would then send her measurements to Bob, he would manipulate particle 2. Bob will manipulate particle to in a way that particle's qubit becomes particle 1's qubit. When particle 1 is in Bob's hands, particle 2 would be in Alice's hand. Alice would then give particle 2 a different qubit, so particle 1 will no longer recognize particle 2 and they will both stop being entangled. How this would work with an object is simple to. One would have to do the same steps Alice and Bob did, but with the entire particle's that make up that object. Now the math behind this is the same as with the entangled particles White and Black, instead W is 1 and B is 2. The problem with this type of teleportation is, there is a very high chance of damaging the state of particle 1. Manipulating particle 2 in the wrong way can damage particle 1's qubit. By this I mean you can manipulate particle 2 and it would change the state of particle 1 and when that state is lost one can never get it back. So doing this type of teleportation is way too dangerous, but there is little safer way of teleporting a particle and it involves two entangled particles and a particle that will be teleported. Another different way of teleportation is just like the one mentioned above, but instead it involves not two particles but three particles. Bennett and Wiesner proposed this type of teleportation. For this teleportation we have two entangled particles (1 and 2), particle 1 is sent to Alice and particle 2 is sent to Bob. Alice wishes to teleport a particle to Bob. First a particle that is wished to be teleported is sent to Alice. This particle is called particle 3. Second, Alice forces the two particles close to each other (not too close to be entangled with the particle). Third, Alice measures both particles 1 and 3, and then uses those measurements to force them to get entangled. Now for some reason when Alice forces particle 1 and 3 to get entangled when she really shouldn't, particle 3 then all of a sudden disappears. When this happens the two entangled particles get four different outcomes: one is where particle 1 is replaced as particle 3, the other is where particle 2 is replaced as particle 3, another is where both particles 1 and 3 is replaced as, the final possible outcome is where particles 1 and 2 are not replaced at all and particle 3 does not exist. These four possible outcome are shown in the image below:



Also these four possible outcomes have their own four possible entangled states, which is written mathematically as:

Entangled particle 1 and 2:

$|\psi+\rangle_{12}=(|0\rangle_1|1\rangle_2+|1\rangle_1|0\rangle_2)/\sqrt{2}$

$|\psi-\rangle_{12}=(|0\rangle_1|1\rangle_2-|1\rangle_1|0\rangle_2)/\sqrt{2}$

$|\phi+\rangle_{12}=(|0\rangle_1|0\rangle_2+|1\rangle_1|1\rangle_2)/\sqrt{2}$

$|\phi-\rangle_{12}=(|0\rangle_1|0\rangle_2-|1\rangle_1|1\rangle_2)/\sqrt{2}$

Entangled particle 1 and 3:

$|\psi+\rangle_{13}=(|0\rangle_1|1\rangle_3+|1\rangle_1|0\rangle_3)/\sqrt{2}$

$|\psi-\rangle_{13}=(|0\rangle_1|1\rangle_3-|1\rangle_1|0\rangle_3)/\sqrt{2}$

$|\phi+\rangle_{13}=(|0\rangle_1|0\rangle_3+|1\rangle_1|1\rangle_3)/\sqrt{2}$

$|\phi-\rangle_{13}=(|0\rangle_1|0\rangle_3-|1\rangle_1|1\rangle_3)/\sqrt{2}$

Entangled particle 3 and 2:

$|\psi+\rangle_{32}=(|0\rangle_3|1\rangle_2+|1\rangle_3|0\rangle_2)/\sqrt{2}$

$|\psi-\rangle_{32}=(|0\rangle_3|1\rangle_2-|1\rangle_3|0\rangle_2)/\sqrt{2}$

$|\phi+\rangle_{32}=(|0\rangle_3|0\rangle_2+|1\rangle_3|1\rangle_2)/\sqrt{2}$

$|\phi-\rangle_{32}=(|0\rangle_3|0\rangle_2-|1\rangle_3|1\rangle_2)/\sqrt{2}$

Entangled particle 3 and 3:

$|\psi+\rangle_{33}=(|0\rangle_3|1\rangle_3+|1\rangle_3|0\rangle_3)/\sqrt{2}$

$|\psi-\rangle_{33}=(|0\rangle_3|1\rangle_3-|1\rangle_3|0\rangle_3)/\sqrt{2}$

$|\phi+\rangle_{33}=(|0\rangle_3|0\rangle_3+|1\rangle_3|1\rangle_3)/\sqrt{2}$

$|\phi-\rangle_{33}=(|0\rangle_3|0\rangle_3-|1\rangle_3|1\rangle_3)/\sqrt{2}$

(NOTE: numbers 1,2, and 3 represents particles 1, 2 and 3 in the teleportation. Also these other symbols are defined at the start of this essay)

Now if Alice and Bob are lucky they will get the outcome were particle 2 is replaced as particle 3 and the teleportation of particle 3 would be done, but sadly it is very unlikely. So what happens after one of the outcomes happens is, Alice sends her measurement results to Bob through a Classical Channel (telephone, email, letter, etc.). When Bob get's Alice's measurements, he will then uses those measurements to manipulate his particle 2. He will try to manipulate particle 2 in a way that it becomes the same state of particle 3. Finally, Bob will study particle 3 to make sure it is 100% identical to the original particle 3 before it was it was teleported. When all of this is done the teleportation has been done. This type of teleportation is believed to be the best and safest way to teleport particles, also many physicists have used this type of teleportation. One physicist who used this type of teleportation is Anton Zeilinger.

Physicist Anton Zeilinger was able to teleport a particle about 89 miles using the teleportation protocol proposed by Bennett and Wiesner. He was able to teleport one photon 89 miles from the two islands La Palma and Tenerife. The way he did it may see different to understand, but it is just like what I said earlier in this essay about entanglement and protocol proposed by Bennett and Wiesner.

-Zelinger first sends a UV-pulse (ultraviolet light) beam that goes through a crystal which makes the photons (photons A and B) entangled, then the pulse hits a mirror and goes through the crystal again making another pair of entangled photons (photons X and Y). Photon A is sent to Zelinger who is on the island La Palma and photon B is sent to his friend Bob who is on the island Tenerife, this pair of entangled photons (A and B) will be used to TP the qubit information. Also the two islands are about 89 miles apart from each other. Photon X goes through a polarizer, where Zelinger imprints the qubit info that he wants to teleport. Then photon Y is used as a trigger to tell if the imprint on particle X worked or not, also the trigger will tell if the imprint worked when it is no longer entangled with photon X because X is giving new info and Y can no longer recognize X so it stops being entangled with it. When X is no longer entangled with Y, it is ready to be teleported.

-Second Zelinger sends photons X and A through a Fiber Coupler (in-fiber beam splitter). This fiber Coupler acts like a 50-50 beam splitter, so for any of the two output (Particle X's and particle A's beam), half of the light ends up in one output and other half in the other output. Then the two outputs are sent to two polarizing beam splitters (PBS), which makes the makes particle X's and A's beam go one path if it is horizontally polarized and the other path if it is vertically polarized (H and V), Zelinger then uses the detectors H and V to tell what position the photons are in. Also it tells him their state. Now we measure theses two photons behind the two polarizing beam splitters (PBS), we are then able to project the original photons A and X into a certain entangled state. When this happens particle X disappears. After that Zelinger sends the information he got from the H and V measurements of the two photons to Bob, through a classical channel.

[1] ***Electro-optical modulator***: A device used to move particles in a direction, or the manipulate it. If no voltage is applied the photon just passes through without modification. If the right amount of voltage is applied the photon is rotated in the desired way (modification)

-Third Bob gets his photon B, which is entangled with photon A. The classical channel, which is basally how Zelinger and Bob commentated with each other, tells Bob, the measurements of the two particles X and A that Zelinger found. Then what Bob has

to do is rotate his photon (manipulate it), this was done by using an electro-optical modulator (EOM)[1]. NOTE an EOM work like this: If no voltage is applied the photon just passes through without modification. If the right amount of voltage is applied the photon is rotated in the desired way (modification). We can identify the state of the photon by measuring its polarization, using the polarizing beam splitter (PBS). The PBS can be rotated around the beam axis in order to identify any linear polarization. To know if the teleportation worked or not is if the only correct one of the two detectors behind the beam splitter registers the photon (X) and never the other one. It must be the detector that corresponds to the initial polarization of the teleported photon X.
-Fourth, if all of this was done right, then the teleportation of the qubit was successful and Bob now has photon X with the qubit information.
Anton Zeilinger was able to successfully teleport a photon by doing these steps stated above, but teleportation also has some problems that even Zeilinger knows.
Like with every great thing, teleportation has its problems. One problem with teleportation is if were to do quantum teleportation on anything, you would be forced to destroy that object. Then imprint a 100% copy of that object's information into a new set of particles. Many people believe doing quantum teleportation will kill the soul of the person and just leave a copy of that person. Which to those people is very wrong. Also if the people who were to do a person's or object's teleportation and did incorrect measurements, then that person or object will die before it can even be teleported. Not only that but with teleportation, it would take decades just to teleport one thing, because everything is just built of too many particles. To give you a scale this dot (.) has about 25 million particle in it. Not only that, but just sending entangled particles to a location will take time if it were in space because space's size is many light years. So to transport a particle to a planet that was light years away from Earth will take years to arrive. So the teleportation will have to wait for years because the fastest speed we can send a particle is the speed of light. Quantum teleportation may have many problems, but it also has its many successes.
Quantum teleportation has many successes that can help mankind in many ways. One success it has is how fast it can transport things on Earth. With quantum teleportation humans can transport goods in just minutes. Also with quantum teleportation we can teleport information fast. Not only that but teleportation can help use with trivializing. So no need for people to take hour long or daylong trips anymore. Also countries will no longer need to spend their money on expensive planes and plane gases. So even though quantum teleportation has a lot of problems it still has some very good successes that can help mankind growth.
Over all quantum teleportation is mainly theoretical, but it has been proven to work and if that is true mankind is one step closer to not only learning how to teleport and how particles art the way they act.
For me this concept was amazing and was able to change my view of life. I have learned not only about quantum teleportation, but I also learned a little bit about quantum mechanics. I have also learned the true power of particles and how just a few can change the way mankind thinks. Also I am now kind of into Quantum Physics, even though it is a pain to understand. Not only that, but I have learned new ways to teach myself and many other new ways of studying. This would be very useful to me, since I am starting high school next year. I enjoyed doing this Passion Project and I hope I can do something similar to it in my high school. So over all I would like to thank Morey for giving me the opportunity to do an exciting project that was able to challenge my intellect and give me a great amount of knowledge.