ON QUANTUM ENTANGLEMENT

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Abstract
Quantum entanglement, a term coined by Erwin Schrodinger in 1935, is a mechanical phenomenon at the quantum level wherein the quantum states of two (or more) particles have to be described with reference to each other though these particles may be spatially separated. This phenomenon leads to paradox and has puzzled us for a long time. The behaviour of entangled particles is apparently inexplicable, incomprehensible and like magic at work. Locality has been a reliable and fruitful principle which has guided us to the triumphs of twentieth century physics. But the consequences of the local laws in quantum theory could seem "spooky" and nonlocal, with some theorists questioning locality itself. Could two subatomic particles on opposite sides of the universe be really instantaneously connected? Is any theory which predicts such a connection essentially flawed or incomplete? Are the results of experiments which demonstrate such a connection being misinterpreted? These questions challenge our most basic concepts of spatial distance and time. Modern physics is in the process of dismantling the space all around us and the universe will never be the same. Quantum entanglement involves the utilisation of cutting edge technology and will bring great benefits to society. This paper traces the development of quantum entanglement and presents some possible explanations for the strange behaviour of entangled particles. Published in International Journal of Automatic Control System, Vol. 5: Issue 2, 2019.

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1. Introduction

Quantum entanglement had riled Einstein, who had dubbed it "spooky action at a distance", as it appears to contradict the basic tenet of the Special Theory of Relativity, viz., the principle that no object could exceed the velocity of light – 186,000 miles per second. This phenomenon also appears to contradict the principle of cause and effect. Though initially it was thought that the phenomenon was due to some loophole in the experiments that discovered it, it has since been confirmed as a true phenomenon without any loophole.

There are now much research activities on the utilisation of quantum entanglement in communication and computation. [1, 2, 6]

2. Entangled Particles

Quantum entanglement is a phenomenon wherein the quantum properties of two (or more) particles become codependent, with the properties of one being instantaneously affected by measurements conducted on the other.

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Entangled systems need special preparation, e.g., a pair of electrons having opposite spins, as is specified by the Pauli exclusion principle, has to be created, with the actual spin of each particle remaining in a state of quantum uncertainty (a situation described as "entanglement of the wavefunction" by Erwin Schrodinger) On the separation of the pair of particles, even by a huge distance, and on measuring one particle's spin the other particle's spin will automatically resolve itself in the other direction. This effect occurs instantaneously, apparently breaching the velocity of light and the rules of relativity, a phenomenon that Einstein referred to as "spooky action at a distance".

In quantum teleportation, a pair of entangled particles are used to transmit information about a third object instantaneously from one place to another. The original particle with information to be teleported is scanned. The scanning process disrupts the original particle and modifies both the entangled particles, which are separated by a large distance, instantaneously. The treatment process recreates the properties of the original particle. A "teleported" replica is thus formed. [1, 4, 7, 8]

3. Development

Einstein thought that things in the universe exist in their own right and the uncertainties pertaining to quantum mechanics indicated that something was not right with the theory and our interpretation of it. In 1935, Einstein and his colleagues, Boris Podolsky and Nathan Rose, published a paper on an imaginary experiment which resulted in a paradox known as the Einstein-Podolsky-Rosen or EPR paradox which exposes the weaknesses of quantum entanglement. Einstein believed that everything in the world exists independently of us and that no signals carrying information could travel faster than the velocity of light. He reasoned that the two particles in the thought experiment must know already which state the other was in when they separated and they carried that knowledge with them and were not switching state simultaneously at faraway distances.

However, the numerous quantum experiments over many decades had proven him wrong. Quantum entanglement does in fact happen and entangled particles do appear to "communicate" with each other across space faster than the velocity of light. Experiments with more than two entangled particles switching states together across many tens of kilometres have already been conducted.

A host of applications for new forms of remote communication, such as sending instant messages over vast reaches of space, has been made possible by quantum signaling at a distance. This makes it possible for quantum computers to perform many calculations simultaneously across the entire memory of the computer.

The units of quantum information are "quantum bits" or "qubits" (for short). Qubits would adopt one of two quantum states, similar to the way computers use binary code to transmit messages as long sentences of 0's and 1's. But qubits are better in that they could also exist in a mix of states thereby allowing computations to be carried out in a way that we could only dream about, besides being able to communicate instantaneously (i.e., in excess of the velocity of light) while the binary code of the normal computer only operates within the velocity of light and is thus slower.

However, the indeterminacy which gives power to quantum signaling also implies that it is not possible to transmit a complete set of information from one location to another as there would be a gap somewhere in what we could know, which is in accordance with

Heisenberg’s uncertainty principle. Thus human teleportation, as is depicted in science fiction, is not possible.

Though transmitting human atoms a la human teleportation is not possible, it is possible to use quantum teleportation to move information across space. For instance, two persons each holding one of a pair of entangled particles could use them to convey qubits by making particular measurements.

These two persons have to first acquire a pair of entangled particles, e.g., two entangled photons, each of them taking one photon away. One person’s qubit might be in some state that he wants to send to the other person. Even if the former does not know what that state is, he could make the other person’s photon give him that message. The former destroys his photon when he makes a measurement of the photon. However, the other person’s photon now takes over and the other person extracts the information by making his own measurement.

There is no teleportation of matter in this case as nothing actually travels anywhere. Apart from the first exchange of the two photons during the process of entanglement, there is no direct communication between the two entangled photons. The first person’s original message is destroyed in the sending process and its content is recreated at the location of the second person.

Entangled particles could also be used to send coded messages allowing only the intended receiver to read them. An eavesdropper would break the purity of the entanglement resulting in the message being ruined for good.

Einstein was understandably unhappy with quantum entanglement; he evidently found it hard to accept the universe as a web of quantum connections with innumerable particles speaking to their distant twins. However, the universe appears to be one large quantum system.

In the Schrodinger’s Cat thought experiment, quantum states are superpositioned; both the cat and the atomic nucleus in the box are in two states simultaneously. If one opens the box, one finds the cat either dead or alive and the nucleus decayed or intact. In the terms of quantum mechanics, the cat and the atomic nucleus are “entangled”.

Two identical particles created in one process typically are entangled and remain so even if separated by long distances, the two particles being in a superposition of two quantum states. However, if one checks on one of them one’s measurement immediately affects the quantum state of the other particle.

Einstein and his colleagues Podolsky and Rosen argued that if two particles remain entangled over long distances messages between them have to travel faster than light, which contradicts the Special Theory of Relativity. In 1964, John Bell, who was also skeptical of quantum entanglement, in his thought experiment produced a measurement which enabled experimenters to distinguish between a link which took place at the time of measurement and one in which there were “hidden variables” which set up the values which would be measured before the particles separated, this distinguishing factor being known as Bell’s inequality. Bell was a theorist and did not know how this measurement could be put into practice, though he had set a benchmark with what became known as “Bell’s theorem” which made it possible to check the validity of the remarkable claims made by quantum theory – if experimental results fell outside a certain range (known as “Bell’s inequality”) then Bell’s theorem was true and local reality was invalidated. In 1984, Alan Aspect carried out such an experiment on photons, obtaining the experimental proof of their entanglement.

In 2012, on a dark, moonless night, an experiment on quantum teleportation was carried out using a laser to beam photons between different islands of the Canaries, setting the distance record for quantum teleportation of 89 miles, i.e., 144 kilometres. These photons were intimately linked to one another via the quantum property of entanglement so that an action made on one of the pair of photons immediately affected its entangled partner however far apart. The team which was led by Anton Zeilinger at the University of Vienna sent one of an entangled pair of photons through the air to a detector which is on the next island. They then used that pair as a quantum communication line to transmit information about another quantum object, successfully reconstructing it at the other end of the line. In fact, quantum teleportation between the Canary Islands had led to satellite links.

Quantum teleportation may appear like science fiction. Thus when computer scientist Charles Bennett of IBM in New York and his colleagues first proposed quantum teleportation in 1993 it attracted immediate attention. Quantum teleportation is now a serious area of research, having applications in quantum technologies for telecommunications and computing. It has been demonstrated in various systems, e.g., within electric circuits and between clouds of caesium atoms. It is also considered for space exploration, e.g., for a global quantum communications network, teleporting to orbiting satellites may be necessary. [3, 5, 9, 10]

4. Possible Explanations

The author proposes several possible interpretations or explanations for the strange behaviour of entangled particles, which are as follows:-

First Interpretation

The two entangled particles may be linked by some kind of electromagnetic “force/link”, the analog of which is the mechanical system of two similar physical objects, e.g., two similar balls or two similar wheels, linked by a rod. For instance, one of these two similar objects, e.g., two similar balls, is directly joint, connected, to one end of the rod while the other object (ball) is joint to the other end of the rod through two similar interlocking gears which are mechanically arranged in such a way that the turning of one of these objects (balls) at one end of the rod by a certain fraction of a revolution in one direction would result in the object (ball) at the other end of the rod turning by the same fraction of a revolution in the opposite direction at the same instant (i.e., instantaneously). What happens is that turning, e.g., the first object (ball) joint or connected directly to (one end of) the rod would turn the rod in the same direction by the same fraction of a revolution at the same instant, the rod would turn the first gear joint to it at its other end in the same direction by the same fraction of a revolution at the same instant, this gear would turn the similar gear interlocked with it in the opposite direction by the same fraction of a revolution at the same instant, and, as the other object (ball) is joint to this second gear that turns in the opposite direction the other object (ball) itself also turns in the opposite direction by the same fraction of a revolution at the same instant (all these various actions taking place at the same time, all at once, simultaneously). On the other hand, if the second object (ball) joint to the second interlocked gear were turned instead it would cause the first object (ball) joint directly to the rod at the other end to turn in the opposite direction by the same fraction of a revolution at the same instant. This analogous mechanical principle might apply to the behaviour of the two entangled particles, whose “spooky action at a distance" is however abstract and invisible to the eyes unlike the above-described mechanical action which is visible to the eyes.

The following describes how the above-stated mechanical principle might apply to the behaviour of the two entangled particles. Any spin motion (measured) in one of the particles may theoretically cause instantaneous motion (e.g., spin or vibratory) in the electromagnetic "force/link" that links this particle to the other particle (as per the case of the first object (ball) and the rod in the above-described mechanical example). This instantaneous motion of the electromagnetic "force/link" may theoretically effect instantaneous motion in the other particle (as per the case of the rod and the second object (ball) in the above-described mechanical example) which may spin in the opposite direction (as it has been conditioned to do so through the entanglement process in accordance with the Pauli exclusion principle). (Note Carefully: The motions of the two entangled particles and the electromagnetic "force/link" may theoretically take place simultaneously, at the same instant or instantaneously (as is in the case of the moving objects/parts in the above-described mechanical example).)

<u>Second Interpretation</u>

The two entangled particles may theoretically be simultaneously controlled by a "brain" or "controller". This "brain/controller" may theoretically issue a signal to both particles at the same instant causing them to act as they do at the same instant. This is comparable, e.g., to a computer issuing a command to two printers (or other equipment) at the same instant causing the two printers to print at the same instant (parallel processing comes to mind), with the two printers programmed to respond differently to the same command at the same instant (e.g., one printer prints blue ink in response to a command while the other printer prints red ink in response to the same command at the same instant).

<u>Third Interpretation</u>

Information from one of the two entangled particles may theoretically be carried to the other particle by an extremely fast carrier wave that travels faster than the velocity of light causing the other particle to act with an opposite spin at practically the same instant. (Note: Since the speed of this carrier wave theoretically exceeds the velocity of light and light may be required to detect it, it may be undetectable.) [11]

<u>Fourth Interpretation</u>

There may theoretically be an unknown influence, a mysterious undiscovered force, at work.

5. Programming

Equipment controlled by computers such as robots have to be programmed to get them to work in a certain way, e.g., one programming method involves walking the robot through the operating sequence to "teach" it the operating sequence. Entanglement of two particles is rather similar to the programming of an equipment with a computer resulting in the two particles acting the way they are expected or "programmed" to.

6. Conclusion

As quantum entanglement may be the result of tachyons, i.e., faster-than-light particles, at work, it may thus signify the existence of tachyons, which is another outstanding challenge in physics.

Also, according to the Copenhagen interpretation of quantum physics, which many physicists accept, quantum particles could be in more than one state simultaneously and the probability wave which predicts their position enables them to act as though they were in more than one place.

According to the Many Worlds Interpretation (which does away with the idea of waveforms collapsing to provide a specific value on being observed) of Hugh Everett, who was determined to find a way to explain the strange behaviour of quantum particles, each time a quantum particle could have more than one state the world branches, with the particle existing in one state in one version of the universe and in the other state in the second version of the universe, though in reality what we experience is just a single path through each of these worlds. This characteristic of quantum particles may also explain quantum entanglement.

Many theorists have speculated that a mini-wormhole could join entangled particles, which explains why the entangled particles give matching results when measured. By means of this mini-wormhole, two particles which appear to be apart could in fact be adjacent or perhaps even the same thing when seen from two different angles.

Quantum entanglement may also be a case of nonlocality at work whereby what happens in one place depends on what happens elsewhere.

Entanglement may also be likened to the case whereby a light switch controls two (or more) light bulbs such that when the light switch is turned on the two (or more) light bulbs are lighted simultaneously.

The important question is whether one of the above-mentioned truly explains the strange behaviour of entangled particles, wherein experimental evidence would incontrovertibly validate the explanation. [1, 5, 11, 12]

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