QUANTUM ENTANGLEMENT AND EPR PAIRS

-SAI MIHIR. J

It all began in the year 1935 when Albert Einstein thought he had finally found the key to explain quantum mechanics. Something, so strange, so countered all logical views of the universe. He thought it had held the key to proving that the quantum theory was incomplete. It's called entanglement!

The most bizarre, the craziest and the most ridiculous prediction that quantum mechanics makes is entanglement.

So, what is entanglement?

Entanglement is a theoretical prediction that comes from the equations of quantum mechanics. Two particles can become entangled if they are close together and their properties become linked.

When we talk in the language of qubits, EPR pairs are a particular case of entangled particles or pairs of qubits. EPR stands for Einstein-Podolsky-Rosen, the 3 scientists who proposed the EPR paradox that said that particles can actually interact in such a way that it is possible to measure bot their momentum and their position more accurately than the Heisenberg's Uncertainty principle and leading to the consequence of Quantum Entanglement.

Remarkably, quantum mechanics says that even if we separated those particles sending them in opposite directions, they could remain entangled, inextricably connected. To understand how weird this is, let's consider a property of electrons called spin.

Unlike, any spinning object, like a spinning top, an electron spin, as with other quantum qualities is generally completely fuzzy and uncertain until, the moment we measure it and when we do, we'll finds that its either spinning clockwise or counterclockwise. Its kind of like a spinning wheel with equal red and blue colours distributed evenly and alternatively on the wheel. When the wheel stops turning, It will randomly land on either red or blue. Now, lets imagine a second wheel. If these two wheels behaved like entangled particles, then every time one landed red, the other is guaranteed to land on blue and vice-versa.

Now, since the wheels are not connected, that's suspicious enough. But, the quantum mechanics that was embraced by Niels Bohr went even further predicting that if one of the pair were far away, even on the moon, with no wires or transmitters to connect them, still if we look at one and find red the other was sure to be blue. In other words, if we measured a particle, not only would we affect it, but our measurements would also affect its entangled particle pair no matter how distant it was.

For Einstein, this kind of a weird, long-range connections between spinning wheels and particles was so bizarre and ludicrous, that he called it as a "spooky action at a distance".

So how could the choice to act on one particle have anything to do with what happens to the other? Its like a present-day Wi-fi connection at home , but now u cannot connect to it!

Einstein could not accept the way entanglement worked. He believed that there was a simpler explanation to this problem and that entangled particles could exist and why they were linked that did not involve any type of a mysterious long-distance connection. He assumed the entangled particles were more like a pair of shoes!

Imagine if someone separated the two shoes, putting each one in a case. One, delivered to us and the other to a friend far away, say the North Pole. Before we look inside our case, we know that it has either a left shoe or a right shoe, and when we open the case, if we find a left shoe, then at that instant we know that the case at the North Pole must contain a right shoe, even though we haven't looked inside it.

So, now there is nothing mysterious about this. Obviously, by looking inside the case, we haven't affected either shoe. The case we had got had the left shoes and the one at the North Pole has always had the right shoe. That was very sure the moment the shoes were separated and sent away. This was the ideology that Einstein thought about entangled particles.

Whatever configuration the particles are in must have been fully determined from the moment they were separated.

So, now we are caught at the confusion of what quantum entanglement was actually; were particles like spinning wheels that could be linked immediately by their random results even across long-distances or was their no "spooky" connection after all, instead it was decided well before the particles were looked. This left Quantum mechanics as an incomplete picture of reality.

In 1964 , in his research paper, "On The Einstein Podolsky Rosen Paradox", John S. Bell had actually solved the problem of quantum entanglement and convinced that the quantum mechanical view of approaching this problem was probably wrong. Bell had discovered how to tell if entangled particles were really communicating like "spooky" action or if there was no spooky action at all and the particles were already set and defined in their own ways. With some clever mathematics Bell showed that if spooky action were not at work, then quantum mechanics wasn't merely as incomplete as what Einstein had thought.

The problem was finally solved in 1974 by John Clauser, a Ph.D. student at the Columbia University, built a machine that could measure thousands of pairs of entangled particles and compare their spins in many different directions. The results proved to be shocking and proved that Entanglement was Real. Quantum particles could be linked to across space and measuring one particle can in fact instantly affect its distant pair as if the space between them didn't even exist!

The Bell States proved that upon measuring the first qubit, we obtained two possible results for the second qubit: 0 with ½ probability, and 1 with also ½ probability.

This implied that the outcomes of the measurement were correlated. John Bell became the first person to prove that this correlations in measurement in the Bell States were stronger and that quantum mechanics allowed information processing beyond what was possible in the classical world. The Bell measurement played an important role in the concept of quantum information science saying that qubits were present in mixed states; between 0 and 1 or both, and it would collapse to one state from the various superposed states when measured by Quantum measurement.

Quantum Entanglement was indeed an important resource crucial for quantum computing. The use of EPR pairs in quantum computing did pave the way to the concepts of Quantum teleportation and Superdense coding, which led people to build more sophisticated applications and change the view about Quantum Entanglement and Quantum mechanics itself!