EPR paradox

The version of EPR paradox presented in this article is due to David Bohm. I chose to present this version instead of the original one by Einstein, Podolsky and Rosen, since the former is much clearer and easier to understand than the latter.

A particle called "pion" can decay into two photons (i.e. the light particle). As pion doesn't carry the intrinsic angular momentum called "spin," the sum of the spins of two photons must be zero. For a photon, two possible spins are possible: $|\mathrm{up}\rangle$ and $|\mathrm{down}\rangle$. Therefore, if the spin of one of the photons is measured to be $|\mathrm{up}\rangle$, the other has to be $|\mathrm{down}\rangle$, and vice versa. This is also what is confirmed by experiments.

However, notice that the spin of the first photon is in a mixture of the two spin states before the measurement; only when its spin is measured is the first photon in the definite eigenstate: either $|\mathrm{up}\rangle$ or $|\mathrm{down}\rangle$, but not both.

Now, let's say that a pion decayed and two photons were created, and they flew apart very far. Suppose you measure the spin of one of the photons. Then, the spin of the other one will be determined immediately. For example, if the spin of the first one becomes $|\mathrm{up}\rangle$, the spin of the other one will immediately become $|\mathrm{down}\rangle$.

Notice that this would imply that the information that the spin of the first photon is measured and its value is $|\mathrm{up}\rangle$ is transmitted to the other photon immediately, no matter how far they are apart. This is troublesome, since Einstein's theory of special relativity suggests that no information can fly faster than light.

Therefore, Einstein, Podolsky and Rosen suggested that Copenhagen interpretation of quantum mechanics was not correct, even though they didn't doubt that it predicts the right value for experiments. This suggests why they titled their paper "Can Quantum-Mechanical Description of Physical Reality be Considered Complete?" ("Quantum-Mechanical Description" here refers to Copenhagen interpretation since it is the mainstream interpretation.)

Nevertheless, most contemporary physicists believe that EPR paradox is not a genuine paradox, as they think that it is due to wrong classical (i.e. as opposed to quantum) and macroscopic (i.e. as opposed to microscopic world to which quantum laws apply) intuitions.

Final comment. Even though the EPR-type experiments suggest that information can travel faster than light (of course, assuming that Copenhagen interpretation is correct), there is no possible way that we, humans can use this property to send our own messages faster than the speed of light. Let me clarify this. Suppose Romeo asked Juliet to marry him, before leaving for the moon shortly. Juliet said that she needed time, and told him that she would send her response when Romeo is on the moon. To use the EPR technology, which is supposed to transmit information faster than light, actually, instantaneously, they agreed that, if the photon arriving at the moon, has spin up, it means that she has accepted his proposal, and if it has spin down, it means that she has refused his proposal. So, between the moon and the Earth, there was a pion decaying, and it arrived at the Earth, and Juliet decided to accept his proposal. Juliet wants Romeo to get the spin up photon on the moon. This means that Juliet needs to measure the photon arriving at the Earth spin down, to send the message of her acceptance. However, it is not Juliet who decides that the photon on the Earth must be measured to be spin down. She is just the one who measures the spin of the photon whatever it is, even though the spin of the photon is determined on the instance she measures it, not before, according to the Copenhagen interpretation. Thus, she cannot send her message instantaneously using the EPR technology. All she can do is preparing a spin up photon here on the Earth, and send it directly to the moon. It would take the time just the speed of light takes.

Summary

- EPR paradox suggests that Copenhagen interpretation of quantum mechanics is not complete. However, most contemporary physicists believe that there is way out.