A Quantum Mechanical Interpretation of Reality and the EPR Paradox

(draft received a grade of A-)

The advent of quantum mechanics has led many physicists to begin questioning the physical reality of nature. There are three distinct viewpoints of reality and the effects that a quantum mechanical interpretation has on it: the realist, orthodox and agnostic. Einstein, Podolsky and Rosen addressed this division of interpretations and gave their own conclusions in 1935 with the now famous EPR paradox stated in their “Can Quantum-Mechanical Description of Physical Reality Be Considered Complete?”[1].

In the orthodox viewpoint, it is believed that the statistical distribution given by a system’s wave function defines the system. It is not until the act of measurement that the system attains a definite state. This is best described with the Schrodinger’s Cat thought experiment. A cat is placed in a box containing a radioactive sample, a Geiger counter connected to a hammer, and a vial of cyanide. If an atom in the sample decays, the Geiger counter will activate the hammer and smash open the vial of cyanide, not a good thing for the cat. A radioactive sample with a known decay rate is chosen. After a period of time where the sample is equally likely to have decayed as not, we look in the box and check the health of the cat. We will find that the cat is dead or is still alive. However, according to the orthodox view, the cat is both alive and dead until the box is checked. The system is in a superposition of equally likely states and will remain that way until a measurement is taken. It is the measurement that forces the system to “take a stand,” to choose between live cat or dead cat. The measurement will also influence future measurements of the systems. That is, if you look in the box and see a dead cat then the chances are high that when you look in the box five minutes later the cat will still be dead. This is called “collapsing” the wave function. The wave function is no longer a good description of the system now that our measurement has forced a state upon it. This puts a great deal of importance on the act of measurement. Without the act of “looking in the box,” all systems that can be described by a quantum mechanical interpretation exist in a perpetual limbo of superposition states, according to the orthodox viewpoint.

The realist position holds that if you get a measurement from a system described by a probability distribution then the system has actually been in that state from the beginning. So when you look in the box and see a dead cat then the cat was that way prior to your checking the box. The sampled decayed at some point prior to looking in the box and the cat has been dead since that time. This belief that the system has been in the state prior to the measurement removes the importance of the act of measurement.

The final stance is the agnostic response. People with this belief avoid the question completely on the basis that it does not matter. The equations work and the philosophical implications are of no consequence. This is the most practical of approaches but not very interesting.

In the EPR paper, the authors make an argument for the realist position using theoretical arguments and thought experiments. They make the contention the quantum mechanics is incomplete. They define this concept thusly,

> "In a complete theory there is an element corresponding to each element of reality. A sufficient condition for the reality of a physical quantity is the possibility of predicting it with certainty," [3]

They hold that since the knowledge of one non-commuting operator precludes the knowledge of another then the "description of reality given by the wave function is incomplete." [4] They go on to prove this conclusion using a thought experiment that leads to a paradox.

A simplified example of the EPR paradox has been derived by David Bohm [5]. A neutral pi meson, or pion, will decay into an electron and its anti-matter equivalent, the postiron. Since the pion has spin zero, the conservation of angular momentum demands that the electron and positron have opposite spins. That is, if one has spin up then the other has spin down and vice versa. Since either configuration is equally likely to exist, we do not know what state the particles are in until we observe them. It is also true that as soon as the state of one is measured, say the electron, we know what the state of the other is.

Now take this example to the extreme. Assume the pion decays, the electron and positron are allowed to move off to a great distance from one another, 10 meters or 10 light years. As soon as we measure the spin of one of the particles, we can say with complete certainty what state the other particle is in. By observing the electron, we collapse its wave function the instant we measure its state. We, also, collapse the wave function of the positron *the instant* we observe the electron that is 10m or 10 light years away. A realist would hear this and say, "Of course! The electron and positron had those spins the entire time. We just didn't know it until we looked." The orthodox viewpoint is something else entirely. They would hold that the two particles were entangled in a superposition of two equally likely states and it was not until the act of measurement that the system obtained a definite state. When we looked at the electron, we set the state of not only the electron; we set the positron that lies 10 meters or 10 light years away *instantaneously*.

Einstein, Podolsky and Rosen considered this interpretation nonsense. They thought that such "spooky action-at-a-distance"[6] showed the fallacy of the orthodox viewpoint. The EPR argument is based upon the belief that no information can travel faster than the speed of light. The instantaneous influence of measuring the electron and setting the state of the positron violates this concept of locality. EPR did not doubt the predictions of quantum mechanics to a point. They thought it was a valid set of equations that gave reliable results, to a point. However, EPR did not see quantum mechanics as a valid interpretation of reality. They believed that it was an incomplete theory. That is, there must be some deeper understanding that scientists did not have yet. This concept of the hidden variable, a single or set of values that would better describe the nature of the wave function, became a hot topic for several years following the EPR paper.

Bibliography

Not done yet