11.4: Spooky Action at a Distance

In 1935, Einstein raised the stakes in the quantum debate significantly. Along with his postdoctoral co-authors, Boris Podolsky and Nathan Rosen, published one of the most famous papers in the history of the quantum theory debates. The EPR paper [14] (so called based on the initials of the authors) would create a veritable firestorm within the community that championed the Copenhagen interpretation of Quantum Mechanics.

The EPR paradox

The EPR paper proposed a paradox in the form of a thought experiment, much as the several thought experiments proposed by Einstein to Bohr at the various Solvay Conferences. In the paradox, Einstein used the concepts of a conserved center of mass and conserved momentum in a fragmenting particle to show that either a measurement on one fragment must affect the properties of the other, or that the quantum theory had to be incomplete.

The thought experiment involved the fragmentation of a particle into two fragment particles. The fragment particles would be linked through a single wavefunction describing the entire system. After some time of traveling apart, it was assumed that the two fragment particles could no longer interact as they were physically separated by a distance.

At some point following the fragmentation, the position is measure for one of the fragment particles. This, thought the conservation of the center of mass, would determine the position of the other particle. Then, by measuring the momentum of the counter fragment, the momentum of the first fragment would be determined through the conservation of momentum. As such, there would be simultaneous knowledge of both position and momentum for both particles, in violation of the Uncertainty Principle.

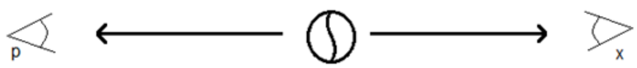

Figure 11.4.1

The argument in the EPR paper was that since a measurement on one fragment determined the properties of the counter fragment, and that the two fragments were separated in space, that the properties of the counter fragment must have been determined all along, irrespective of having been measured. (Einstein referred to the phenomenon of measurement on one fragment affecting properties on the counter fragment as “Spooky action at a distance.) In other words, Indeterminacy as suggested by the Heisenberg Uncertainty Principle must be a fallacy. The only other explanation possible was that the Quantum Theory had to be incomplete. With this argument, people had to take very seriously the possibility that a theory of “local reality” in which properties exist with definite values, as opposed to only coming to being through the interaction with a detector of some sort, as a distinct possibility.

Bohr responded within months. He attacked a specific assumption of the set up of the EPR paradox, namely that a measurement of the properties of one particle would not “disturb the system in any way.”

Hidden Variables

The EPR paradox was both eloquent and succinct. It touched off quite a storm within the community as well as it shock the very foundations of the quantum theory. But perhaps even more interestingly, it spurned a whole new avenue of research into understanding the ramifications. Specifically troubling was the idea that the wavefunction describing a system did not, in fact, provide a complete description of that system.

Scientists began to wonder if there might be some “hidden variables” in a system that allowed properties to be both hidden under the vagueness of a wavefunction and also determined by the definite values of the variables, irrespective of whether or not the system was observed or measured.

In 1951, David Bohm published a textbook [15] on quantum theory that included a good deal of discussion on the EPR paradox. In it, he suggested measuring the nuclear spins of hydrogen atoms that result from the dissociation of a singlet-state hydrogen molecule. The spins would be correlated through the conservation of angular momentum and could thus take the place of the measurements of position and momentum in the EPR version.

In Bohm’s version of the EPR experiment (sometimes called the EPRB experiment) the spin states of the hydrogen atoms would be correlated as the atoms would be “entangled”. And since angular momentum had to be conserved, measurement of the spin of one atom along the laboratory fixed z-axis would determine the value along the z-axis for the other atom. But what if the measurement was made along the x- or y-axes? If the EPR definition of reality is to be believed, these values must also be determined (or real.)

Of course quantum mechanics only allows for the measurement of one of the components, as the operators for the three components do not commute. Thus, if the EPR definition of reality is correct, then the wavefunction by necessity must be incomplete. There would need to be hidden variables.

Even more significantly, Bohm's proposed experiments could be carried out in a laboratory, rather than being limited to the realms of thought.

---

14. B. P. Albert Einstein and N. Rosen, "Can Quantum-Mechanical Description of Physical Reality Be Considered Complete?," Physical Review, vol. 47, pp. 777-780, 1935. W430W9405
15. D. Bohm, Quantum Theory, New York: Prentice-Hall, 1951. W430W9405
