I. SPOOKY ACTION AT A DISTANCE – ENTANGLED STATES

Bohr-Einstein Debate

From 1925 onwards...the debate still continues.

Einstein: Quantum theory is incomplete and probabilistic nature is attributed to that. There are hidden variables

Bohr: No hidden variables and probabilistic nature and uncertainty is intrinsic and fundamental to nature.

EPR paradox – spooky action at a distance

Einstein, Podolski and Rosen proposed an experiment that would reveal the incompleteness of quantum science.

The EPR idea is to transmit two particles from one source to distant receivers. Particles are separated by a distance and hence it takes finite amount of time to communicate between the two receivers. The measuring of the properties of one of the particles at one of the receiver can in no way influence the outcome of measurement at the other receiver.

EPR proposed a thought experiment in which a source emits two equal mass particles, which fly east and west with equal speeds.

For definiteness, consider a box with two electrons, one with spin up and another with spin down, that is, system of two electrons where total spin is zero. Now we put a partition in the box and separate two electrons. Suppose we measure the spin of one of the electron. If we measure the spin of one of them, we instantaneously know the spin of the other. EPR argued that this thought experiment proves that quantum mechanics is incomplete.

In summary, we did not disturb the spin of particle 2 when we measure the spin of particle 1. Since we know the spin of 2 by measuring the spin of 1, that means that spin of 2 was fixed. That is electron “2” was in a definite spin state. This is in contrast to probabilistic nature of quantum
physics. However, Bohr argued that since we cannot measure the spin of electron 2, this question is irrelevant.

**Bell Inequality**

John Bell was a northern Irish physicist, and the originator of Bell’s theorem, an important theorem in quantum physics regarding hidden variable theories.

In 1964, he found an experimental way of resolving the problem of whether or not there are hidden variables in quantum physics. In particular, is quantum theory amenable to a complete, classical, deterministic description using local hidden variables. He discovered that in the back-to-back emission of two particles, as in EPR experiment, there are certain directly observable statistical correlations that could be measured and can test hidden variable theory. His theory is known as Bell’s inequality. – he devised a set of “inequalities” – statements where “X” must be greater than or equal to “Y”, if there are hidden variables, that is system acts like a deterministic system. These inequalities will be violated if entangled states are present.

Starting 1970, several experiments have been carried out to test Bell’s inequality. In almost all cases, results are consistent with the fact that there are no hidden variables.