

EPR Paradox

A. Einstein was skeptical of QM, particularly its Copenhagen interpretation

Example recounted by James Cushing in “Philosophical Concepts in Physics”: In 1927 Einstein developed a thought experiment that he claimed showed that the HUP, $\Delta E \Delta t \geq \hbar/2$, can be violated. He proposed a box having a clock-controlled shutter that would allow a single photon to be emitted. The shutter would open with as small a Δt as desired. The energy of the photon would be determined to desired accuracy by weighing the box before and after the shutter allows the photon out and using $E = mc^2$. One could thereby get $\Delta E \Delta t < \hbar/2$.

Bohr figured out that Einstein had neglected to consider an aspect of his own theory of general relativity in which the loss of mass leads to a change in the gravitational field which affects the rate that the clock measures time. Bohr showed quantitatively that inclusion of these considerations leads to no violation of HUP.

B. EPR's argument

Einstein, Podolsky and Rosen devised a thought experiment to show that Quantum Mechanics is an incomplete description of reality. The argument presented here is similar to that made by EPR.

EPR defined a theory to be complete if and only if it includes all real quantities. A quantity was defined to be real if it could be predicted with certainty, without disturbing the system.

There are two detectors located a (large) distance apart. Two particles are prepared so that the total momentum is zero. Thus if you know p_1 you also know p_2 . Likewise, the state of the system is such that if you know x_1 , you also know x_2 .

If Detector 1 is set up to measure momentum we can predict (with certainty) that the momentum at Detector 2. Thus, the momentum at Detector 2 can be said to be real quantity. EPR went on to argue that we **could have** measured position at Detector 1, if we liked. If we had done so, we could have predicted (with certainty and without disturbing the system) the outcome of the position for the particle at Detector 2. Thus, EPR argued, we can predict with certainty the value of the momentum and position at detector simultaneously, without disturbing that system. However, according to Quantum Mechanics, if we know the position exactly then we totally do not know the momentum. So Quantum Mechanics, according to the Copenhagen Interpretation, says that we cannot simultaneously know (with certainty) both the position and momentum. So, according to EPR, Quantum Mechanics does not include the two real quantities momentum and position, so quantum Mechanics is incomplete.

B. The Copenhagen interpretation

The realistic view of EPR was contrary to the widely held Copenhagen interpretation of Quantum Mechanics, promoted largely by Niels Bohr. Bohr argued that although the statement "I could have measured ..." makes no sense. For him properties of systems are only defined with respect to their measurement devices.