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Quantum theory and Paradoxes

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Abstract: We want to review the Paradoxes in quantum mechanics and show that despite the large number of interpretations and ideas in Quantum Mechanics, Quantum Three variant Loic (QTL) solves the quantum well-known paradoxes.

Index Terms (Keywords) — Paradox, The EPR paradox, The Schrödinger's Cat paradox, The Wheeler's delayed choice paradox, Wigner's friend paradox, The Afshar paradox, Popper's paradox, Quantum Three variant Loic (QTL).

1. Introduction

A paradox is a proposition that can not be described by mathematical logic because it is “true and false”. A physical paradox is an apparent contradiction in physical descriptions of the universe. While many physical paradoxes have accepted resolutions, others defy resolution and may indicate flaws in theory. In physics as in all of science, contradictions and paradoxes are generally assumed to be artifacts of error and incompleteness because reality is assumed to be completely consistent, although this is itself a philosophical assumption. When, as in fields such as quantum physics and relativity theory, existing assumptions about reality have been shown to break down, this has usually been dealt with by changing our understanding of reality to a new one which remains self-consistent in the presence of the new evidence. A significant set of physical paradoxes are associated with the privileged position of the observer in quantum mechanics. Most of these paradoxes came in the form of 'thought experiments', which could only be conducted in theory; other paradoxes came in the form of practical experiments. These experiments were designed to demonstrate 'flaws' in the probabilistic interpretation, and formed the themes of intense debates. We will focus on several paradoxes that have a historical background.

2. The EPR paradox

The EPR paradox (or Einstein–Podolsky–Rosen paradox) is a thought experiment which challenged long-held ideas about the relation between the observed values of physical quantities and the values that can be accounted for by a physical theory. "EPR" stands for Einstein, Podolsky, and Rosen, who introduced the thought experiment in a 1935. The arguments in the EPR paper are very similar to ones which Einstein himself made in correspondences to friends, but are not exactly the same. The first thing to notice is that Einstein was not trying to disprove Quantum Mechanics in any way. In fact, he was well aware of its power to predict the outcomes of various experiments. What he was trying to show was that Quantum Mechanics could not be a complete theory of nature and that some other theory would have to be invoked in order to fully describe nature. The argument begins by assuming that there are two systems, A and B (which might be two free particles), whose wave functions are known. Then, if A and B interact for a short period of time, one can determine the wave function which results after this interaction via the Schrödinger equation or some other Quantum Mechanical equation of state. Now, let us assume that A and B move far apart, so far apart that they can no longer interact in any fashion. In other words, A and B have moved outside of each other’s light cones and are therefore spacelike separated. With this situation in mind, Einstein asked the question: what happens if one makes a measurement on system A? Say, for example, one measures the momentum value for system A. Then, using the conservation of momentum and our knowledge of the system before the interaction, one can infer the momentum of system B. Thus, by making a momentum measurement of A, one can also measure the momentum of B. Recall now that A and B are spacelike separated, and thus they cannot communicate in any way. This separation means that B must have had the inferred value of momentum not only in the instant after one makes a measurement at A, but also in the few moments before the measurement was made. If, on the other hand, it were the case that the measurement at A had somehow caused B to enter into a particular momentum state, then there would need to be a way for A to signal B and tell it that a measurement took place. But, the two systems cannot communicate in any way! If one examines the wave function at the moment just before the measurement at A is made, one finds that there is no certain-ty as to the momentum of B because the combined system is in a superposition of multiple momentum eigenstates of A and B. So, even though system B must be in a definite state before the measurement at A takes place, the wave function description of this system cannot tell us what that momentum is! Therefore, since system B has a definite momentum and since Quantum Mechanics cannot predict this momentum, Quantum Mechanics must be incomplete.

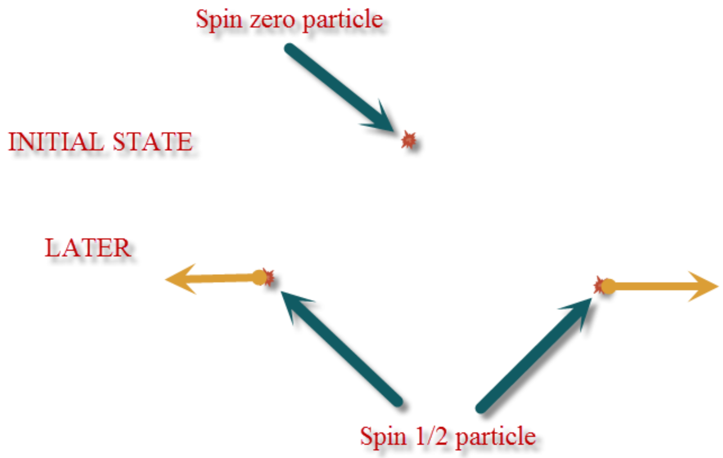

Figure 1 the EPR experiment

3. The Schrödinger's Cat paradox

Schrödinger's cat is a thought experiment, often described as a paradox, devised by Austrian physicist Erwin Schrödinger in 1935. It illustrates what he saw as the problem of the Copenhagen interpretation of quantum mechanics applied to everyday objects. The thought experiment presents a cat that might be alive or dead, depending on an earlier random event. A cat, along with a flask containing a poison, is placed in a sealed box shielded against environmentally induced quantum decoherence. If an internal Geiger counter detects radiation, the flask is shattered, releasing the poison that kills the cat. The Copenhagen interpretation of quantum mechanics implies that after a while, the cat is simultaneously alive and dead.

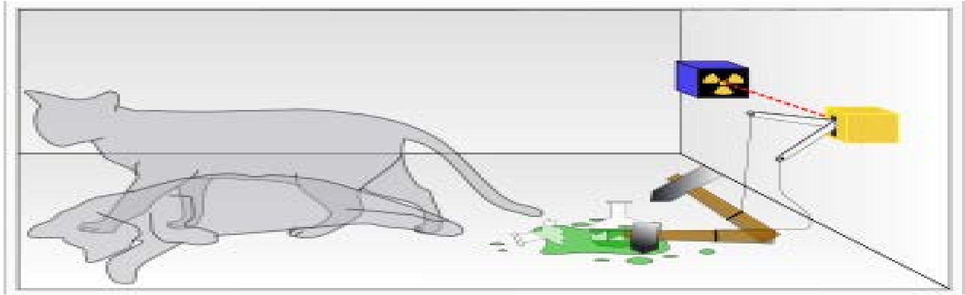

Fig 2 Schrödinger's Cat paradox

Mathematically the wave function for this cat can be written by the following equation:

$$\Psi = \textbf{Error! Bookmark not defined.Error! Bookmark not defined.}\alpha\ \textbf{Error! Bookmark not defined.}\sum_{i=1}^{n} \Psi_{\mathrm{i}} \qquad 3\text{-}1$$

$$\Psi = \frac{1}{\sqrt{2}}\ \Psi_{\text{alive}} + \frac{1}{\sqrt{2}}\ \Psi_{\text{dead}} \qquad \text{3-2}$$

While in classic mechanics cat's state is as follow:

Either; $\Psi = \Psi_{\text{alive}}$ or $\Psi = \Psi_{\text{dead}}$

Or in probability language:

$$P_{\text{alive}} = \int_{\Omega} \left|\Psi(x,y,z,t)\right|^2 d\tau \qquad \text{3-3}$$

$$P_{\text{dead}} = \int_{\Omega} \left|\Psi(x,y,z,t)\right|^2 d\tau \qquad \text{3-4}$$

If: after observation the cat be alive then:

$$P_{\text{alive}} = \int_{\Omega} \left|\Psi(x,y,z,t)\right|^2 d\tau = 1 \qquad \text{3-5}$$

And,

$$P_{\text{dead}} = \int_{\Omega} \left|\Psi(x,y,z,t)\right|^2 d\tau = 0 \qquad \text{3-6}$$

If: after observation the cat be death then:

$$P_{\text{live}} = \int_{\Omega} \left|\Psi(x,y,z,t)\right|^2 d\tau = 0 \qquad \text{3-7}$$

$$P_{\text{dead}} = \int_{\Omega} \left|\Psi(x,y,z,t)\right|^2 d\tau = 1 \qquad \text{3-8}$$

But before observation we have:

$$0 \leq p \leq 1 \qquad \text{3-9}$$

Yet, when we look in the box, we see the cat either alive or dead, not a mixture of alive and dead. Schrödinger applied quantum mechanics to a living entity that may or may not be conscious. In Schrödinger's original thought experiment, he describes how one could, in principle, transform a superposition inside an atom to a large-scale superposition of a live and dead cat by coupling cat and atom with the help of a "diabolical mechanism". He proposed a scenario with a cat in a sealed box, wherein the cat's life or death was dependent on the state of a subatomic particle. Schrödinger's famous thought experiment poses the question, when does a quantum system stop existing as a mixture of states and become one or the other? (More technically, when does the actual quantum state stop being a linear combination of states, each of which resembles different classical states, and instead begins to have a unique classical description?). In the Copenhagen interpretation of quantum mechanics, a system stops being a superposition of states and becomes either one or the other when an observation takes place. This experiment makes apparent the fact that the nature of measurement, or observation, is not well-defined in this interpretation. Some interpret the experiment to mean that while the box is closed, the system simultaneously exists in a superposition of the states "decayed nucleus/dead cat" and "undecayed nucleus/living cat", and that only when the box is opened and an observation performed does the wave function collapse into one of the two states. Schrödinger did not wish to promote the idea of dead-and-alive cats as a serious possibility; quite the reverse. The thought experiment serves to illustrate the bizarreness of quantum mechanics and the mathematics necessary to describe quantum states. The Schrödinger cat thought experiment remains a topical touchstone for all interpretations of quantum mechanics. How each interpretation deals with Schrödinger's cat is often used as a way of illustrating and comparing each interpretation's particular features, strengths, and weaknesses.

4. The Wheeler's delayed choice paradox

Wheeler's delayed choice experiment is a thought experiment proposed by John Archibald Wheeler in 1978. Wheeler proposed a variation of the famous double-slit experiment of quantum physics, one in which the method of detection can be changed after the photon passes the double slit, so as to delay the choice of whether to detect the path of the particle, or detect its interference with itself(14). Wheeler's experiment consisted of a standard double-slit experiment, except that the detector screen could be removed at the last moment, thereby directing light into two more remote telescopes, each one focused on one of the slits. This allowed a "delayed choice" of the conventional double-slit experiment shows that determining which path a particle takes destroys the interference pattern. To avoid the notion that the photon somehow "knows" when the "other" slit is open or closed (or is being watched), Wheeler suggested detecting which slit the photon used only long after it passed through the slits. Wheeler asked what happens when a single photon, presumably already determined to get detected as part of a two-slit interference pattern, suddenly gets detected in a path coming from only one slit. Does the interference pattern then disappear?

In terms of the traditional double-slit apparatus, the Wheeler delayed choice experiment is to put telescopes that are pointed directly at each of the two slits behind the removable detector wall. If the photon goes through telescope A it is argued that it must have come by way of slit A, and if it goes through telescope B it is argued that it must have come by way of slit B. Compare that assertion with Young's diagram of the propagation of light through double slits:

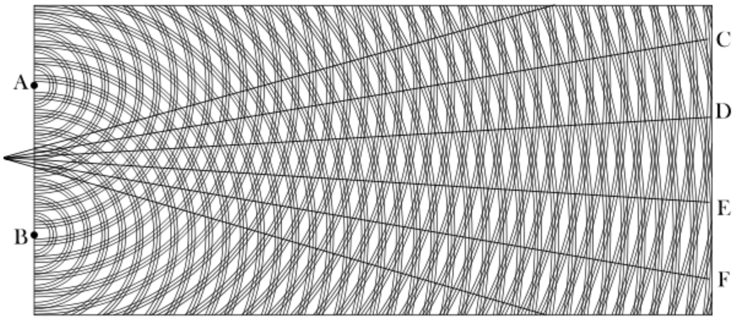

Fig 3 double slits

Observer, i.e. a choice made after the presumed photon would have cleared the midstream barrier containing two parallel slits. The two telescopes, behind the (removed) screen could presumably "see" a flash of light from one of the slits, and would detect by which path the photon traveled. According to the results of the double slit experiment, if experimenters do something to learn which slit the photon goes through, they change the outcome of the experiment and the behavior of the photon. If the experimenters know which slit it goes through, the photon will behave as a particle. If they do not know which slit it goes through, the photon will behave as if it were a wave when it is given an opportunity to interfere with itself. The double-slit experiment is meant to observe phenomena that indicate whether light has a particle nature or a wave nature. The fundamental lesson of Wheeler's delayed choice experiment is that the result depends on whether the experiment is set up to detect waves or particles.

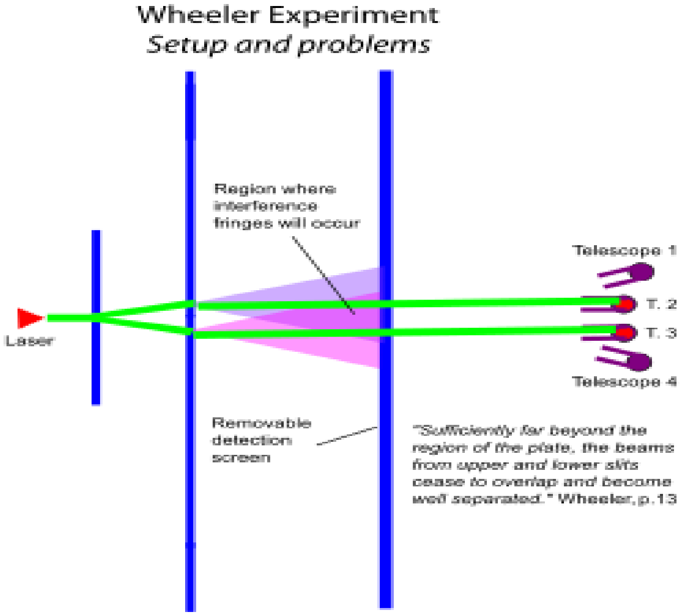

Fig 4 Wheeler's delayed choice thought experiment.

Wheeler planned a thought experiment in which two ways of observing an incoming photon could be used, and the decision of which one to use could be made after the photon had cleared the double-slit part of the apparatus. At that point a detection screen could either be raised or lowered. If the detection screen were to be put in place, Wheeler fully expected that the photon would interfere with itself and (if many more photons were permitted to follow it to the screen) would form part of a series of fringes due to interference. If, on the other hand, the detection screen were to be removed, then:

Sufficiently far beyond the region of the plate, the beams from upper and lower slits cease to overlap and become well separated. There place photo detectors. Let each have an opening such that it records with essentially 100 percent probability a quantum of energy arriving in its own beam, and with essentially zero probability a quantum arriving in the other beam.

In that case, he argues, "one of the two counters will go off and signal in which beam and therefore from which slit the photon has arrived.

5. Wigner's friend paradox

Wigner’s friend is a thought experiment proposed by the physicist Eugene Wigner; it is an extension of the Schrödinger's cat experiment designed as a point of departure for discussing the mind-body problem in quantum mechanics. The Wigner's Friend thought experiment posits a friend of Wigner who performs the Schrödinger's cat experiment after Wigner leaves the laboratory. Only when he returns does Wigner learn the result of the experiment from his friend, that is, whether the cat is alive or dead. The question is raised: was the state of the system a superposition of "dead cat/sad friend" and "live cat/happy friend," only determined when Wigner learned the result of the experiment, or was it determined at some previous point? Wigner designed the experiment to illustrate his belief that consciousness is necessary to the quantum mechanical measurement process. If a material device is substituted for the conscious friend, the linearity of the wave function implies that the state of the system is in a linear sum of possible states. It is simply a larger indeterminate system. However, a conscious observer (according to his reasoning) must be in either one state or the other, hence conscious observations are different, hence consciousness is material. Wigner discusses this scenario in "Remarks on the mind-body question", one in his collection of essays, Symmetries and Reflections, 1967. The idea has become known as the consciousness causes collapse interpretation.

6. The Afshar paradox

The Afshar experiment is an optical experiment which investigates the principle of complementarity in quantum mechanics. The result of the experiment, which was first devised and carried out by Shahriar Afshar in 2001, is in accordance with the standard predictions of quantum mechanics; however, it is controversially claimed to violate complementarity and specifically the Englert-Greenberger duality relation; others disagree, as the debate continues. Afshar's experiment uses a variant of the classic Thomas Young double-slit experiment to create interference patterns to investigate complementarity. Such interferometer experiments typically have two "arms" or paths a photon may take. One of Afshar's assertions is that, in his experiment, it is possible to check for interference fringes of a photon stream (a measurement of the wave nature of the photons) while at the same time observing each photon's path (a measurement of the particle nature of the photons). Afshar claims that his experiment invalidates the complementarity principle and has far-reaching implications for the understanding of quantum mechanics, challenging the Copenhagen interpretation.

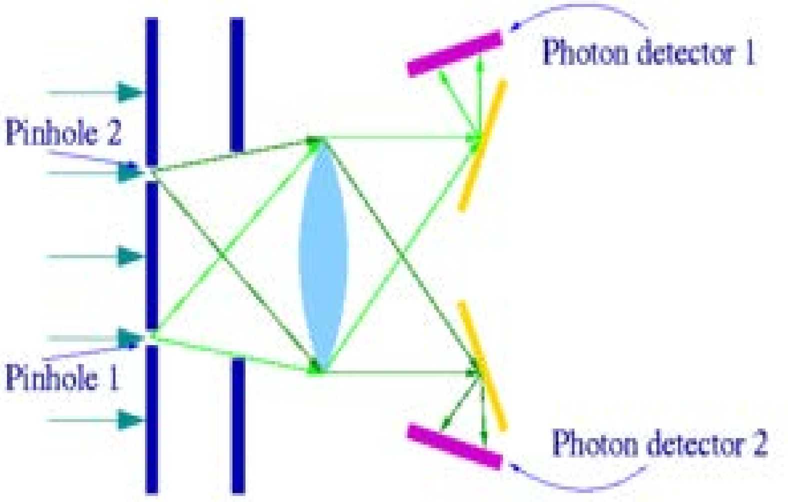

Fig 5-1 Experiment without obstructing wire grid

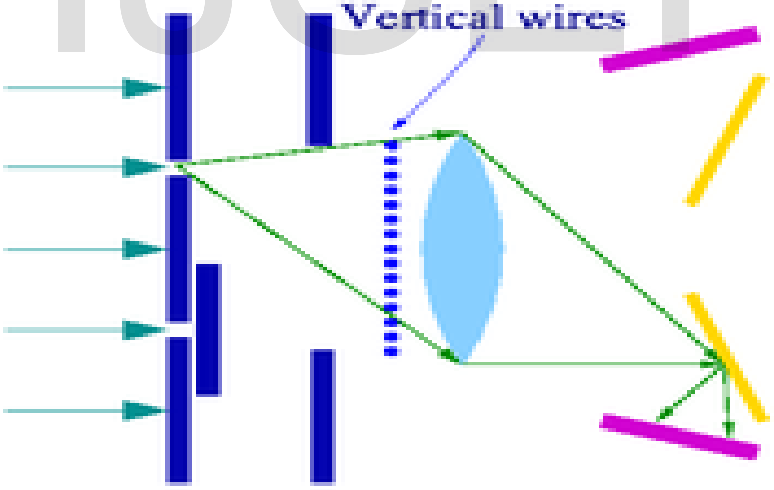

Fig 5-2 Experiment with obstructing wire grid and one pinhole covered

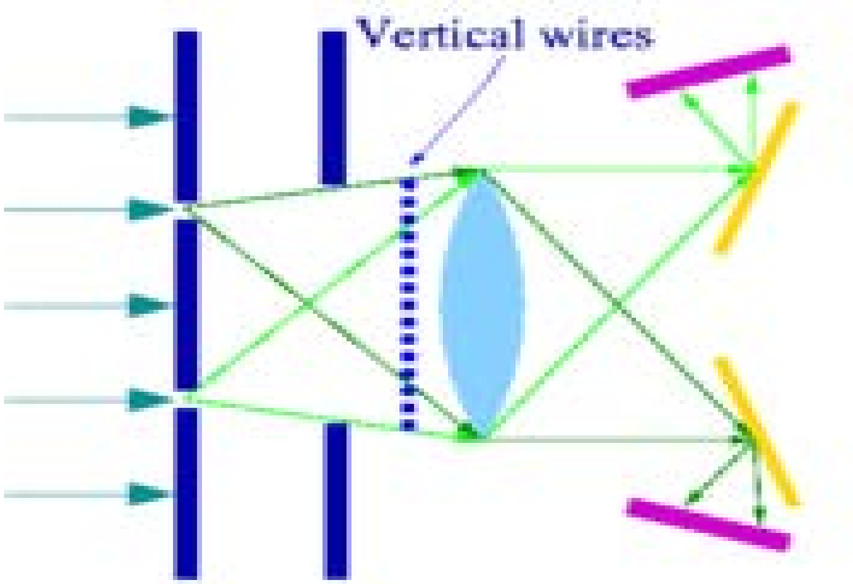

Fig 5-3 Experiment with obstructing wire grid and both pinholes open.

The experiment uses a setup similar to that for the double-slit experiment. In Afshar's variant, light generated by a laser passes through two closely spaced circular pinholes (not slits). After the dual pinholes, a lens refocuses the light so that the image of each pinhole is received by a separate photon-detector (Fig.2-5-1). In this setup, Afshar argues that a photon that goes through pinhole number one impinges only on detector number one, and similarly, if it goes through pinhole two. Therefore according to Afshar, if observed at the image plane, the setup is such that the light behaves as a stream of particles and can be assigned to a particular pinhole.

When the light acts as a wave, because of interference one can observe that there are regions that the photons avoid, called dark fringes. Afshar now places a grid of thin wires just before the lens (Fig.2-5-2). These wires are placed in previously measured positions of the dark fringes of an interference pattern which is produced by the dual pinhole setup when observed directly. If one of the pinholes is blocked, the interference pattern can no longer be formed, and some of the light will be blocked by the wires. Consequently, one would expect that the image quality is reduced, as is indeed observed by Afshar. Afshar then claims that he can check for the wave characteristics of the light in the same experiment, by the presence of the grid. At this point, Afshar compares the results of what is seen at the photo-detectors when one pinhole is closed with what is seen at the photo-detectors when both pinholes are open.

When one pinhole is closed, the grid of wires causes some diffraction in the light, and blocks a certain amount of light received by the corresponding photo-detector. When both pinholes were open, however, the effect of the wires is minimized, so that the results are comparable to the case in which there are no wires placed in front of the lens (Fig.2-5-3). Afshar asserts this experiment has also been conducted with single photons and the results are identical to the high flux experiment, although these results were not available at the time of the talk at Harvard. Afshar's conclusion is that the light exhibits a wave-like behavior when going through the wires, since the light goes through the spaces between the wires when both slits were open, but also exhibits a particle-like behavior after going through the lens, with photons going to a given photo-detector. Afshar argues that this behavior contradicts the principle of complementarity since it shows both complementary wave and particle characteristics in the same experiment for the same photons.

7. Popper's paradox

POpper’s experiment is an experiment proposed by the 20th century philosopher of science Karl Popper, an advocate of strict scientific method who opposed the Copenhagen interpretation, to test that standard interpretation of Quantum mechanics. Popper's experiment is similar in spirit to the thought experiment of Einstein, Podolsky and Rosen (The EPR paradox) although not as well known. The current consensus is the experiment was based on a flawed premise, and thus its result does not constitute a test of quantum mechanics. The experiment does remain important, however, from a historical point of view, and also because it exemplifies the pitfalls that one comes across in trying to make sense out of quantum mechanics.

Popper's proposed experiment consists of a source of particles that can generate pairs of particles traveling to the left and to the right along the x-axis. The momentum along the y-direction of the two particles is entangled in such a way so as to conserve the initial momentum at the source, which is zero. Quantum mechanics allows this kind of entanglement. There are two slits, one each in the paths of the two particles. Behind the slits are semicircular arrays of detectors which can detect the particles after they pass through the slits

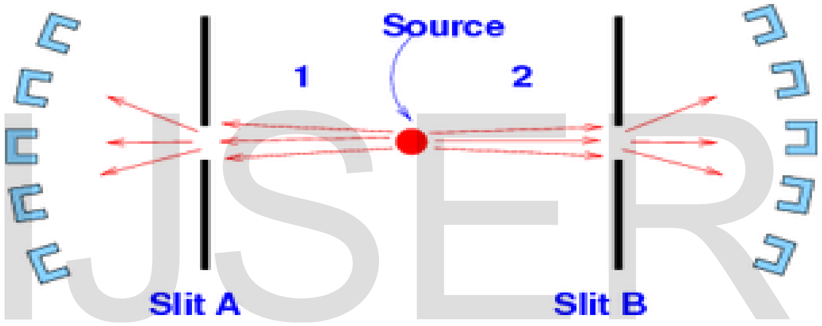

Fig 6-1 Experiment with both slits equally wide. Both the particles should show equal scatter in their momenta.

Popper argued that because the slits localize the particles to a narrow region along the y-axis, from the uncertainty principle they experience large uncertainties in the y-components of their momenta. This larger spread in the momentum will show up as particles being detected even at positions that lie outside the regions where particles would normally reach based on their initial momentum spread.

Popper suggests that we count the particles in coincidence, i.e., we count only those particles behind slit B, whose other member of the pair registers on a counter behind slit A. This would make sure that we count only those particles behind slit B, whose partner has gone through slit A. Particles which are not able to pass through slit A are ignored.

We first test the Heisenberg scatter for both the beams of particles going to the right and to the left, by making the two slits A and B wider or narrower. If the slits are narrower, then counters should come into play which are higher up and lower down, seen from the slits. The coming into play of these counters is indicative of the wider scattering angles which go with narrower slit, according to the Heisenberg relations.

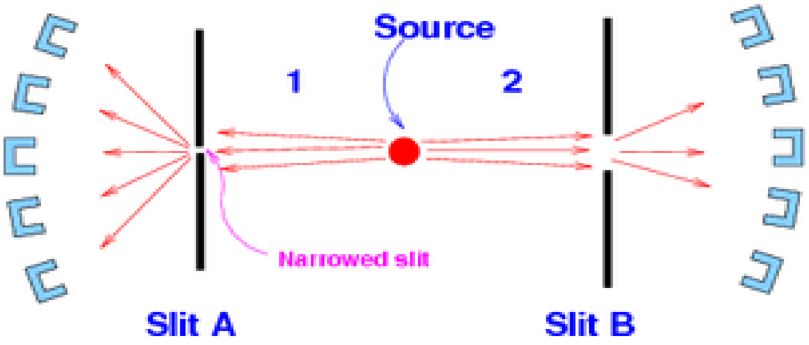

Fig 6-2 Experiment with slit A narrowed, and slit B wide open.

Should the two particle show equal scatter in their momenta? If they do not, Popper says, the Copenhagen interpretation is wrong. If they do, it indicates spooky action at a distance, says Popper.

Now we make the slit at A very small and the slit at B very wide. According to the EPR argument, we have measured position "y" for both particles (the one passing through A and the one passing through B) with the precision Δy, and not just for particle passing through slit A. This is because from the initial entangled EPR state we can calculate the position of the particle 2, once the position of particle 1 is known, with approximately the same precision. We can do this, argues Popper, even though slit B is wide open.

We thus obtain fairly precise "knowledge" about the y position of particle 2 - we have "measured" its y position indirectly. And since it is, according to the Copenhagen interpretation, our knowledge which is described by the theory - and especially by the Heisenberg relations - we should expect that the momentum p_y of particle 2 scatters as much as that of particle 1, even though the slit A is much narrower than the widely opened slit at B.

Now the scatter can, in principle, be tested with the help of the counters. If the Copenhagen interpretation is correct, then such counters on the far side of slit B that are indicative of a wide scatter (and of a narrow slit) should

Now count coincidences: counters that did not count any particles before the slit A was narrowed. To sum up: if the Copenhagen interpretation is correct, then any increase in the precision in the measurement of our mere knowledge of the particles going through slit B should increase their scatter. Popper was inclined to believe that the test would decide against the Copenhagen interpretation, and this, he argued, would undermine Heisenberg's uncertainty principle. If the test decide in favor of the Copenhagen interpretation, Popper argued, it could be interpreted as indicative of action at a distance.

8. Conclusion

Despite the large number of interpretations and ideas in Quantum Mechanics, Quantum Three variant Loic (QTL) solves the quantum well-known paradoxes. For example let’s consider EPR paradox, we can go ahead as follows:

Mathematical logic: according to uncertainty principle when we measure exact momentum for particle at a time then there is uncertainty in its position in the same time, then if we put its momentum (true) then its position must be (false), then the conjunction of the two will be (false):

$$\mathbf{T} \wedge \mathbf{F} = \mathbf{F}$$

Quantum Three variant Loic (QTL): we can put the exact momentum (true) and put the position as (uncertainty) then the conjunction of them will be (true)

$$\mathbf{T \wedge U = T}$$

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