Two Experiments to test Bohr's Complementarity Principle

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Abstract

We suggest two possible experiments to verify the mysterious passing of single photon through both the slits simultaneously. The first experiment aims to measure polarization of photons reaching the screen using polarization detectors fixed on the screen on both sides of the midway line made up of locus of points equidistant from both the slits and further using two types of synchronization setups. Again, using the same two types of synchronization setups, we suggest the second experiment which is based on a simple idea, justified by uncertainty principle. We suggest that we can distinguish between photons that have definitely gone through both the slits simultaneously and those other photons that have gone only through any single slit, either through the one on the left side or through the other on the right side, at a time. We fix in the second experiment photon detectors on the screen on both sides of the midway line made up of locus of points equidistant from both the slits. These experiments aim at achieving experimental confirmation for complementarity principle due to N. Bohr.

1. Introduction: Bohr's complementarity principle of quantum mechanics [1] characterizes the mutually exclusive nature of some pairs of variables that complement each other to make up a complete classical description as per the classical dynamics. Bohr's principle states that physical apparatus available to the experimenter has such properties that more precise measurements than those indicated by uncertainty principle [2] cannot be made. In essence, according to Bohr's complementarity principle two complementary physical observables cannot both be measured for any given quantum particle without the measurement of one observable affecting the measurement of the other observable. An example of two complementary physical observables in quantum mechanics is the observation of the wave and particle nature of light simultaneously. The application of principle of complementarity in this case states that we can not observe and measure the purely wave and particle like behavior of a single photon (the particle of light) at the same

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time. The most basic way of showing the wave like nature of light is to create interference pattern using two coherent rays of light. When this is done, an interference pattern is created as the peaks and troughs of the two waves which reinforce each other at certain well defined locations and cancel each other out at certain other well defined locations. After photoelectric effect light is also a stream of particles called photon. For double slit experiment copenhegan interpretation says that if it is known which way (through which slit) the photon goes, it is impossible to demonstrate interference, i.e. the interfearing photon never goes through single slit but only goes as an nonlocalized thing through both the slits! The demonstration of this is to block one of the holes, at which point the interference pattern disappears and it is replaced by a consant illumination depicting a clear path that the photon has taken.

2. **Two Simple Experiments:** We now proceed to discuss two simple experiments that can be carried out to provide a conclusive justification of Bohr's complementarity principle. In the first experiment we detect the polarization type of photons reaching the detector screen to conclude about whether they have passed through any single slit or they have passed through both the slits simultaneously. The first experiment is about finding out the polarization type of the photons exiting through slits and reaching the detector screen in two types of synchronization setups. In the second experiment we grant validity of uncertainty principle which will confine the photons arriving at detector screen differently in two types of synchronization setups that we use during the experiment. The second experiment, based on expected validity of uncertainty principle, which if produces two different ranges around the midway vertical line representing locus of points equidistant from both the slits to photons that arrive through some single slit and so not producing any interference pattern and to photons that that arrive through both the slits simultaneously and so are producing interference pattern then by these expected results we will justify the conclusive validity of not only Bohr's complementarity principle but also in turn the assumed validity of Heisenberg's uncertainty principle. This second experiment is based on simple detection of the presence of photons at certain locations on the screen. The automatic limiting for the arrival of photons on the screen as the outcome of the suggested experiment using two types of synchronization setups will be seen justifying conclusively both Bohr's complementarity principle as well as Heisenberg's uncertainty principle.

First Experiment:

1) We use a laser source kept equidistant from two slits of weak laser light to provide a weak coherent source ensuring of a single photon in transit from source to detector screen at a given instant of time.
2) We fix two plane polarizer films as explained below: We fix first plane polarizer on the left slit to convert the light incident on the left slit from single laser source that we use into plane polarized light with plane of polarization oriented at certain angle, say 10 degrees, leftwards with the vertical. We fix the second plane polarizer at right slit to convert the light incident on the right slit into plane polarized light with plane of polarization oriented at 10 degrees rightwards with the vertical. This arrangement will cause the light exiting from left slit (right slit) and traveling towards screen in plane polarized form with its electrical vector oscillating in a plane inclined by 10 degrees leftwards (rightwards) with the vertical line.
3) We fix the detectors at the screen to record the polarization type of light reaching the regions of the detector screen.
4) We use a pair of slits used in usual double slit experiment.
5) We set up a mechanism for opening and closing of slits in the desired synchronization to allow /disallow the light reaching from the source to screen in a predefined way in accordance with two experimental arrangements, A) and B), for two types of desired synchronization setups as given below.

We perform this experiment with two types of synchronization setups:

A) Making a provision for closing of both the slits for exactly half time and opening both of them for half time of a given time interval by any suitable arrangement. Thus, for this experiment we synchronize in such a way that either both the slits are open or both the slits are closed for the light from centrally located coherent weak laser source reaching these slits.
B) We perform the same experiment again by making a provision for first slit to be opened and second slit to be closed for exactly half time and first slit to be closed and second slit to be opened for left-out half time of a given time interval by any suitable arrangement. Thus, for this experiment we achieve the

synchronization in such a way that exactly one slit is open and the other slit is closed. Both the slits are never open or never closed for the light from centrally located coherent weak laser source reaching these slits.

Expected Results for Synchronization of type A):

1) We expect to observe that for first half time there is total darkness (through the photon detector-counter readings) on the detector screen (when both slits are closed) as no photon is reaching the intensity detector screen.

2) For left-out half time if the photon is emerging simultaneously from both the slits reaching the detector (producing interference pattern) then due to superposition principle the photon that will reach the screen will be vertically polarized at the location of central bright band of the interference pattern with amplitude of this light equal to vector sum of two amplitudes of polarized light emerging with 10 degrees leftwards polarization and 10 degrees rightwards polarization. In short, we expect detection of photons with different polarizations at different locations that have become bright due to interference. Thus, in this experiment the photons in transit between slits and screen are nonlocalized ones and pass through both the slits simultaneously.

Expected Results for Synchronization of type B):

I) We never expect to observe total darkness at any time as the light is reaching the detectors on the screen at all times from some one slit.

II) For first half time, when the left slit is open, at a point exactly in front of the left slit the uniform illumination on the screen with reduced intensity will be seen and the photons detected at screen will be leftwards plane polarized, exactly same as the light emerging from left slit. For other half of total time, we will observe at a point exactly in front of the right slit the uniform illumination on the screen with reduced intensity and the photons detected at screen will be rightwards plane polarized, exactly same as light emerging from right slit. At a given instant of measurement we will find photons either all leftwards plane polarized or rightwards plane polarized, and we never observe at any given instant the equal number of leftwards as well as rightwards polarized photons. Thus, in this experiment the photons in

transit between slits and screen are completely localized ones having well defined trajectory.

Second Experiment:

1) We use a laser source kept equidistant from two slits of weak laser light to provide a weak coherent source ensuring of a single photon in transit from source to detector screen at a given instant of time.
2) We fix photon detectors on centrally drawn horizontal line perpendicular to central vertical line up to sufficiently long distance. We fix these light detectors along the screen on both sides of central vertical line, formed by locus of points equidistant from both the slits where central bright band gets formed in standard double slit experiment.
3) The distance, measured from central bright band, up to which we fix the photon detectors is decided by the narrow slit width of the slits we use. If the slit width of the slits we use is Δx say, then the photon detectors should be ideally fixed up to length related to the number $\frac{h}{\Delta x}$, h stands for Planck's constant, which will be explained soon. On both sides of the position of central vertical line, representing location of central bright band in the standard double slit experiment, we will need to fix light detectors up to length related to the number mentioned above.
4) We use a pair of slits used in usual double slit experiment. We set up a mechanism for opening and closing of slits in the desired synchronization to allow /disallow the light reaching from the source to screen in a predefined way in accordance with two experimental arrangements, A) and B), for two types of desired synchronization setups same as used in the first experiment.

Expected Results for Synchronization of type A):

1) We expect to observe that for first half time there is total darkness (through the photon detector-counter readings) on the detector screen (when both slits are closed) as no photon is reaching the intensity detector screen.
2) As we are performing normal double slit experiment for second half of time we expect formation of usual interference pattern on the screen. Let d be the distance between the slits we have used. Now, if

the photon is going through both the slits simultaneously as a nonlocalized object then uncertainty in position for this photon is of the order $(d + 2\Delta x)$ and therefore in accordance with uncertainty principle the uncertainty in momentum will be of order $\left(\dfrac{h}{d + 2\Delta x}\right)$ and therefore the spread for photon to reach the locations on the screen will be restricted by this uncertainty in momentum. In other words, the weakest bright band that will be detected by light detectors fixed horizontally as described above will be limited by this uncertainty in momentum.

Expected Results for Synchronization of type B):

I) We never expect to observe total darkness at any time as the light is reaching the detectors on the screen at all times from some one slit.
II) For first half time, when the left slit is open, at a point exactly in front of the left slit the uniform illumination on the screen on both sides with reducing intensity will be seen and the range up to which the detectors will locate the photons at screen and the range up to which they will be detected will be much wider than the one in the first case on the left side of the screen as seen below: Now, as the photon is going through the left slit only as a localized object then uncertainty in position for this photon is of the order (Δx) and therefore in accordance with uncertainty principle the uncertainty in momentum will be of order $\left(\dfrac{h}{\Delta x}\right)$ and therefore the spread for photon to reach the locations on the screen will be much wider by this new value of uncertainty in momentum. In other words, the range up to which the weakest light that will be detected by light detectors fixed horizontally as described above will be much wider than the one in the first case by this new uncertainty in momentum from vertical line in front of left slit. Similarly for second half time, when the right slit is open, at a point exactly in front of the right slit the uniform illumination on both sides of the screen with reducing intensity will be seen and the range up to which the detectors will locate the photons at screen and the range up to which they will be detected will be much wider than the one in the first case, this time, on the right side.

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Conclusion: The successful execution of these experiments will provide a conclusive justification of Bohr's complementarity principle.

References

1. N. Bohr, Atomic Theory and the Description of Nature, Phys. Rev., 48, 696, 1935; Nature, 121, 580, 1928.
2. W. Heisenberg, Z. Physik, 43, 172, 1927.