Quantum Eraser

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This experiment aimed to better understand features of quantum mechanics such as wave-particle duality and the concepts of observation and information through an optical experiment analogous to the quantum eraser while giving an introduction to optical systems and alignment.

AIM

To investigate an interesting aspect of the uncertainty principle of quantum mechanics whereby coherence in an interference experiment can be first destroyed by setting up the experiment such that the path a photon took can be known, and then regained by 'erasing' that information.

INTRODUCTION & METHOD

The quantum eraser is an extension of Young's double split experiment. Young's experiment established the dual particle-wave nature of the universe by showing that if one could determine which slit a photon went through, then a series of dots would appear on the screen behind the slits, demonstrating that photons behave like particles. Furthermore, if one could not determine which slit a photon went through, then an interference pattern would appear on the screen behind the two slits, demonstrating that photons behave like waves. The same effect was also observed with matter. This led to the question of whether one could obtain the information of which slit a photon went through, causing particle like behavior, but subsequently delete it to regain wavelike behavior. The experiment proposed to answer this question is called the quantum eraser.

As an analogy to the quantum eraser, a Mach-Zehnder interferometer was set up with extra polarizes. The general principle of an interferometer is that it merges light sources to create an interference pattern. In this case the interference pattern is a circular set of rings because of the interference caused by the division of amplitude, sometimes called Haidinger fringes. The half-mirrors divide the amplitude and the amplitude of a wave effects its intensity. These intensity differences cause the light and dark fringes. As in FIG. 1. a laser was directed through a lens and a quarter-λ plate before being split into two beams by a half-mirror each of these two beams was them passed through a polarizer and recombined/allowed to interfere on a second half-mirror. A screen was placed at both outputs of this final half-mirror to view the pattern that was created. Note a lens was used to disperse the light output by the laser so interference patterns could be observed on the screens rather than single points on each screen. After that a quarter-λ plate was used to circularly polarize the light in order for the remaining polarizers to be able to strip off a plane wave component of that light, thus determining which path was taken by the photons. Linear polarizers transmit the amplitude parallel to the polarization axis only, so the transmission of a linear polarizer as a function of angle θ between polarisation axis and polarisation direction is the magnitude of the amplitude times $\cos\theta$. A roughly square geometry was used to keep the distance each beam traveled along its path once being split the same. As a note to anyone trying to recreate this experiment, the beam was kept level above the bench top at 12.8 cm ± 0.05 cm and since the set up is very precise and sensitive to ≈ 100 nm path differences between the upper and lower beams it helps to align the beams an the second half-mirror first before adjusting the second half-mirror to bring the beams together on each screen.

FIG. 1. Experimental Setup

A laser is used as a light source instead of say a light bulb because it produces highly monochromatic light. This is necessary because the precision required to align the beams and be able to see the interference pattern would not be possible without a single highly-stable wavelength. The specific laser used in this experiment was a Class 2 Helium-Neon laser. Class 2 is a safety rating refering to a laser with an output power below 1 milliwatt. In a HeNe laser, He and Ne gas are mixed in a roughly 10:1 ratio of He to Ne. The He atoms are then excited and collide with the Ne atoms, exciting them as well. Eventually this causes fast radiative decay to occur along the 632.8 nm wavelength line once enough Ne atoms are excited. Optical amplification is then used to get a stable, continuous laser beam.

FIG. 2. Quarter wave plate set to 45˙, lower path polariser set to 90˙, upper path polariser set to 0˙, final polariser set to 0˙

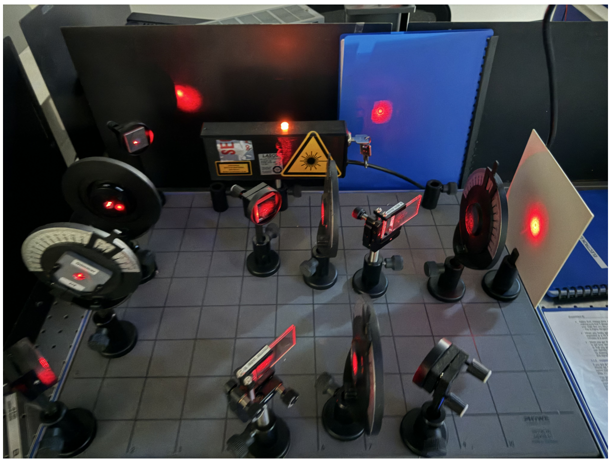

FIG. 3. Quarter wave plate set to 45˙, lower path polariser set to 0˙, upper path polariser set to 0˙, final polariser set to 0˙

RESULTS & ANALYSIS

As can be seen from FIG. 2. there is not a circular ring pattern on either screen. Thus, if the path of the photon is known by knowing the polarization of the beam it came from, then the photons behave like particles and do not interfere to form a ring-like pattern, instead forming a blur of points. As can be seen from FIG. 3. there is a circular ring pattern on both screen. Thus, if the path of the photon is not known by knowing the polarization of the beam it came from, then the photons behave like waves and interfere to form a ring-like pattern. As can be seen from FIG. 4. there is a circular ring pattern on the right screen but no pattern on the top screen. This confirms the results of FIG. 2. and FIG. 3, but setting the final polariser to 45˙ to 'erase' the information of which beam the photons came from before reaching the screen reproduces the circular interference pattern.

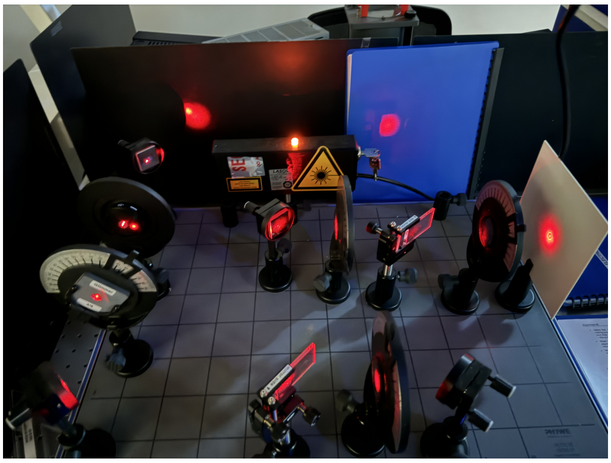

FIG. 4. Quarter wave plate set to 45˙, lower path polariser set to 90˙, upper path polariser set to 0˙, final polariser set to 45˙

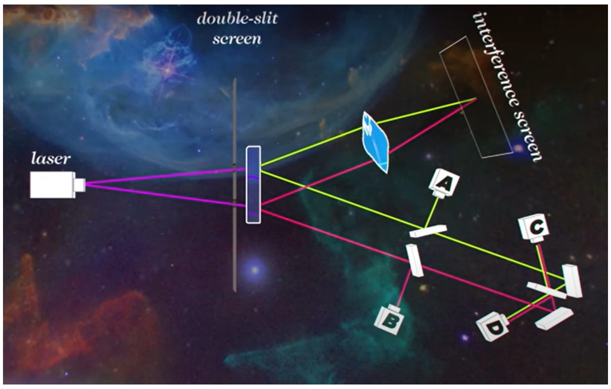

FIG. 5. Quantum Eraser

It should be noted that this analogy is flawed because it is largely classical. Maxwell's equations are the realm of classical physics at this scale. One can trace the paths of the beams and note the angles of the polarizers to completely and deterministically predict the patterns displayed on the screens. In an actual quantum eraser experiment these deterministic qualities are not present. In the 1999 Delayed Choice Quantum Eraser experiment a crystal that creates an entangled pair of photons from an incoming photon was in front of a double-slit screen before a laser. One of the entangled photons passed to a screen and the other passed to a set of detectors a distance farther than that of the path to the screen. When detectors A or B lit up, scattered dots appeared on the screen. When only the photons whose counterparts end up at detectors C or D were considered, an interference pattern was again observed. This set up eliminates any meddling from the observer before the photons reach a detector or screen unlike the Mach-Zehnder interferometer which essentially exploits optical properties to form a desired, analogous result.

CONCLUSIONS

In the presented Mach-Zehnder interferometer set up, imperfectly analogous to the quantum eraser, destroying the information of which path a photon took before reaching a screen recreates the pattern that would be present on the screen had one never known which path the photon took to begin with.

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