The Delayed Quantum Eraser Experiment Explained Classically

Declan Traill

This paper discusses the well-known experiment performed by Kim et al [1] (see FIG. 2. In that paper for the experimental setup used. I have also included a diagram of the setup (Fig 1, below) that you can refer to) and analyses it from a Classical Physics perspective. I show that the result of the experiment can be explained by Classical Physics and does not require "Spooky action at a distance" due to entangled particles, as Einstein famously once put it, nor events modifying the past due to the delayed choice aspect of the experiment.

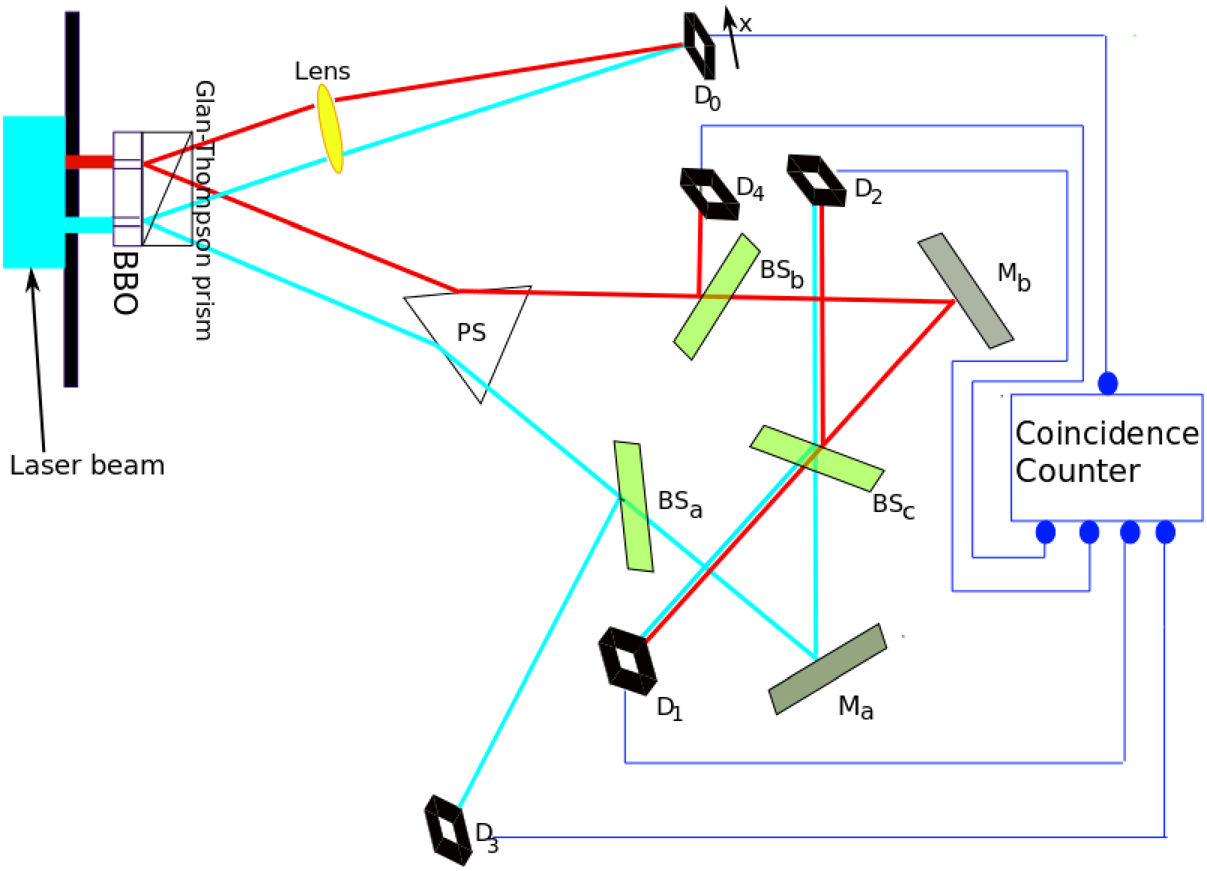

Fig 1 The experimental setup used by Kim et al [1]. Attribution for this image is given in Ref [5].

The first thing one must realize in order to make sense of the experiment is that photons are not discrete particles, but are continuous Electromagnetic waves. Sure, atoms emit and absorb Electromagnetic energy in fixed quantum amounts, which gives rise to the wave packets of Electromagnetic energy that we refer to as Photons, but there is nothing binding this wave energy into a discrete particle. Thus, when 'photons' of light pass through a double-slit or a beam splitter the wave energy is free to be split up into different sub-quantum amounts down different paths.

We can see that this in fact must be the case when we observe single photons passing through Mach-Zehnder Interferometers [2,3]. When this happens, interference patterns are still observed in the output from the Interferometer when one of the path lengths in the Interferometer is altered to make it shorter or longer that the other path. This could only happen if Electromagnetic energy was passing down both paths.

The next thing to realize is that, as atoms absorb and emit light in quantum amounts, sub-quantum Electromagnetic waves will interact with (and pass through) optical atomic media, but any interactions that require absorption and then re-emission of the light quanta will not be able to occur as there is insufficient energy in the Electromagnetic wave to cause any quantum shifts to occur in the atoms.

Thus, in the case of the experiment conducted by Kim et al [1], the light photons will arrive at the double-slit at the start of the experiment and, depending on the exact position and polarisation of the photon, it will either pass entirely (or almost entirely) through one of the two slits, or will diffract through both slits (with varying proportions of energy passing through each). When the latter occurs, sub-quantum amounts of Electromagnetic energy emerge from both slits A and B and proceed on to the BBO crystal. The process of SPDC which occurs in this crystal to convert 351.1nm light into two beams of 702.2nm light works based on the conservation of energy and momentum [4], so the same laws will apply to the sub-quantum light waves that emerge from the double-slit and will result in sub-quantum 702.2nm photons being generated in the BBO crystal.

After the BBO crystal, the sub-quantum 702.2nm photons will continue through the apparatus to the beam splitters. However, in order to reflect at the beam splitters (BSA & BSB), the atoms in the beam splitter would need to absorb the photon's energy and then re-emit it in a different direction (i.e., cause it to be reflected); but the Electromagnetic waves don't possess the full quantum amount of energy required to affect such a quantum shift, so these waves will always be transmitted through these beam-splitters.

The sub-quantum Electromagnetic waves proceed further into the experimental apparatus after they have passed through the beam splitters to where they meet fully reflective mirrors. These mirrors do not cause reflection to occur in the same way as with a beam splitter, but will (nearly) perfectly reflect any incident Electromagnetic waves (of the right frequency for the mirror material). So, the sub-quantum waves will reflect at these mirrors and continue on to the beam splitter marked BS. At BS the energy of the two sub-quantum waves recombines. Now there is a full quantum of the photon's energy present at the beam splitter, so this time the photon may either reflect or transmit at beam splitter BS, because there is enough energy present in the photon to allow for reflection as well as transmission. Thus, there will be a resulting signal detection at either D1 or D2.

Meanwhile, down the other path of the experiment (the other photons generated by the BBO at A and B) the light waves are recombined at D0. In the case where sub-quantum wave energy emerged from both A and B, the waves will interfere upon recombination (and form a full quantum of photon energy) and generate the interference fringes seen when the detector D0 is moved by the stepper motor. Thus, we can see that when Electromagnetic energy travels through both A and B detections will occur at D1 or D2 and there will be interference fringes at D0.

If, however, the original photon passes entirely through A or B then this is the only way that the detection can occur at D3 or D4. This is because a full quantum amount of photon energy is required to reflect at the beam splitters BSA and BSB in order to reflect and reach D3 or D4, so the result shown in FIG. 5. In Kim et al [1] is obtained. This figure shows no interference fringes, as one would expect Classically for a single pair of photons, one passing to detector D0 and the other to detectors D3 or D4. Another thing to note here is that when such photons reach BSA or BSB they can still transmit or reflect, so there can be detections at D1 and D2 as well as at D3 and D4. The result of such detections is evident in the two figures FIG. 3. And FIG. 4. in Kim et al, as the interference fringe peaks vary in height (and from a different base level) following the shape of the curve seen in FIG. 5. This is due to the detections from single pairs of photons passing through the apparatus (as a result of the original photon passing entirely through A or B) distorting the neat interference fringes one would expect from a pure signal due to two interfering light beams.

References

[1] *Kim, Yoon-Ho; R. Yu; S. P. Kulik; Y. H. Shih; Marlan Scully (2000). "A Delayed "Choice" Quantum Eraser". Physical Review Letters.* ***84*** *(1): 1–5. arXiv:quant-ph/9903047.,*
Last accessed 13/12/2020

[2] ScienceDirect, “Mach-Zehnder Interferometers”, 2020 Elsevier B.V.

https://www.sciencedirect.com/topics/physics-and-astronomy/mach-zehnder-interferometers,
Last accessed 13/12/2020

[3] Khokhlov. D.L. “Interference of a Single Photon in the Mach-Zehnder Interferometer”, **7-10,** Quantum Information Review, (2019).

http://www.naturalspublishing.com/files/published/f721wno893296q.pdf
Last accessed 13/12/2020

[4] Wikipedia, “Spontaneous parametric down-conversion”,

https://en.wikipedia.org/wiki/Spontaneous_parametric_down-conversion,
Last accessed 13/12/2020

[5] Noestmm, PNGHUT,

https://pnghut.com/png/CW8jEALu4U/quantum-eraser-experiment-double-slit-delayed-choice-wave-particle-duality-wheelers-wave-transparent-png

Last accessed 16/12/2020