Delayed “Choice” Quantum Eraser

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Team 8
Discovery of Double-Slit Interference

- An interference pattern arises when photons pass through two parallel slits.
- Originally carried out by Thomas Young in 1801.
- Any attempt to figure out which slit the photon went through destroys the interference pattern.
  - Example: By having a detector either before or after the slits.

source: https://www.testandmeasurementtips.com/thomas-young-and-the-double-slit-experiment/
"Which Way" Experiment to Determine Photon Path

- Coherence of the waves allows for the interference pattern to be observed.
- "which way" experiment is a modification of the double-slit experiment used to determine which slit the photon passes through.
- A test that is performed after the photons have passed through the slits is known as a delayed choice experiment.

source: [https://www.testandmeasurementtips.com/thomas-young-and-the-double-slit-experiment/](https://www.testandmeasurementtips.com/thomas-young-and-the-double-slit-experiment/)
Wheeler's Proposal to Determine "Which Way"

- In 1978, John Wheeler proposed a delayed choice experiment.

A. Peruzzo et al., A Quantum Delayed-Choice Experiment (Science, 2012).
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  The relative phase can be tuned to observe output at D' with certainty given the second beamsplitter (erased “which way”).

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Wheeler's Proposal to Determine "Which Way"

● In 1978, John Wheeler proposed a delayed choice experiment.

The presence (or absence) of a second beamsplitter allows the observer to choose whether to measure “which way” or interference.

The relative phase can be tuned to observe output at D’ with certainty given the second beamsplitter (erased “which way”).

A. Peruzzo et al., A Quantum Delayed-Choice Experiment (Science, 2012).
Wheeler’s Delayed “Choice” Quantum Eraser

- Having both beam splitters constitutes a “quantum eraser”.
- Having single beam splitter constitutes a “which way”.
- Ensure a spacelike separation between the two beam splitters.
- Particle cannot know in advance which experiment is performed.
- Allows us to combine the quantum eraser with a delayed choice.
Experimental Setup

Pair of entangled photons generated at A or B

Detection Screen D₀

Collection of beam splitters and detectors D₁ through D₄

Full apparatus used in the experiment
Effect of Path Information on Detector Screen Distribution

Joint detection rate $R_{01}$ between detectors $D_0$ and $D_1$

Joint detection rate $R_{03}$ between detectors $D_0$ and $D_3$
Interference Disappears when Considered Collectively

The sum of the interference patterns produces a distribution similar to that of the photons whose which-path information was known.
Conclusion

The study concluded that:

- Particlelike and wavelike behaviors of a photon can be determined via quantum entanglement.

- The which-path or both-path information of a quantum can be erased or marked by its entangled twin even after the registration of the quantum itself.
Critique

- Paper lacks information about experimental errors and uncertainties.

- For example, resolution of the step motor (determines photon location along x axis) is not provided.
Citation evaluation

Total citations = 336 (scopus)

Source: scopus
Citation evaluation

Total citations = 336 (scopus)

Number of citations in recent years shows continued interest in related topics.

Source: scopus
Influence of the paper

- Sparked debate about the interpretation of data
- Retrocausality
- Popular interpretations: photon travels through both the slits
  - Pilot wave
  - Many-worlds
  - Spontaneous-collapse

Source: What Is Real?: The Unfinished Quest for the Meaning of Quantum Physics by Adam Becker
Delayed Eraser Implementation on a reconfiguration integrated photonic device

Controlled addition of the second beam splitter using parameter $\alpha$.

Peruzzo, Alberto; Shadbolt, Peter J.; Brunner, Nicolas; Popescu, Sandu; O'Brien, Jeremy L. (2012). "A quantum delayed choice experiment". Science. 338 (6107): 634–637
Delayed Eraser Implementation on a reconfiguration integrated photonic device

Experimental setup where $H \rightarrow$ hadamard, $CH \rightarrow$ controlled hadamard.

Peruzzo, Alberto; Shadbolt, Peter J.; Brunner, Nicolas; Popescu, Sandu; O'Brien, Jeremy L. (2012). "A quantum delayed choice experiment". *Science*. **338** (6107): 634–637
Delayed Eraser Implementation on a reconfiguration integrated photonic device

(a) Measured data
(b) Simulated data

Peruzzo, Alberto; Shadbolt, Peter J.; Brunner, Nicolas; Popescu, Sandu; O'Brien, Jeremy L. (2012). "A quantum delayed choice experiment". Science. 338 (6107): 634–637
Delayed Eraser Implementation on a reconfiguration integrated photonic device

- Delayed choice of Wheeler’s proposal is replaced by a quantum controlled beam-splitter followed by a Bell inequality test.
- Continuous tuning between particle and wave measurements
- Maximal violation of Bell inequality
- Photon could not have known in advance whether to behave as a wave or a particle.

Peruzzo, Alberto; Shadbolt, Peter J.; Brunner, Nicolas; Popescu, Sandu; O'Brien, Jeremy L. (2012). "A quantum delayed choice experiment". Science. 338 (6107): 634–637
Summary

- Wheeler’s thought experiment to determine whether photons somehow know the information about the experimental apparatus continues to provoke interpretations.
- Sean Carroll in his blog calls it “The Notorious Delayed-Choice Quantum Eraser.”
- Experimentally, using entangled photons to show the behaviour was the key achievement of Kim et al. (2000).