On Completing Young's Double-Slit Experiment: Hyperbolic Nonlinearity and Fringe Count

Dong Zhang

Abstract

Young's original double-slit experiment demonstrated the presence of interference fringes—a defining feature of monochromatic wave behavior. However, two additional characteristics remain underexplored: the hyperbolic spatial nonlinearity of interference and the total number of observable fringes, given by the integer part of $2h/\lambda$, where h is half the slit separation and λ the wavelength. These features become especially relevant when the interfering entities are discrete particles, such as photons or electrons, whose arrival patterns are accumulated over time. In this paper, we argue that these two aspects are essential for a complete understanding of wave interference. We propose a multi-screen experimental setup to capture the predicted hyperbolic geometry and analyze publicly available laser interference images to compare observed fringe counts with theoretical expectations. Our results suggest that Young's experiment, as traditionally performed, is spatially incomplete, and further empirical verification is needed to capture the full structure of monochromatic interference.

1. Introduction

In a recent paper, Nath and Mandal formulated the interference pattern in Young's double-slit experiment using exact hyperbolic geometry. By defining monochromatic wave interference as the intersection of two circular wavefronts—each centered at one of the slits and differing in radius by an integer multiple of the wavelength—they showed that the resulting pattern forms a family of hyperbolas. The total number of such hyperbolas corresponds to the total number of interference fringes.

We interpret both the hyperbolic nonlinearity and the total fringe count as additional defining characteristics of monochromatic wave interference—complementary to the familiar vertical fringe pattern observed on a screen. Therefore, we argue that Young's experiment, as traditionally performed, is incomplete. It observes only one aspect—namely, the vertical fringe pattern along the Y-axis. Two other aspects, the horizontal X-axis hyperbolic structure and the total fringe count, remain unverified.

To address this, we propose a multiple-screen setup for testing the nonlinear structure and analyze a public image of green laser interference to estimate the fringe count and compare it with theoretical expectations.

2. Multiple-Screen Proposal for Verifying Nonlinearity

In the traditional Young's double-slit experiment, a single screen is placed far behind the slits to capture the interference pattern. While this setup successfully records vertically aligned fringes, it misses the early-stage curvature predicted by the exact hyperbolic formulation of monochromatic wave interference.

To observe the nonlinear structure more fully, we propose adding two additional screens at intermediate distances behind the slits. These screens should be positioned close enough to capture the early curvature of the hyperbolas, yet far enough to allow fringe formation. Alternatively, one may perform three separate experiments, each with the screen at a different distance, and compare the resulting fringe traces.

Such a setup would allow researchers to test whether the observed interference patterns follow the predicted hyperbolic trajectories—thereby completing the spatial characterization of monochromatic wave interference.

3. Interference Trilogy

Alternatively, to the multiple-screen proposal, one may consider using semi-transparent or layered media—such as fluorescent gels, photochromic materials, or low-density gases—that allow the trajectories of photons or electrons to be visualized without fully absorbing or terminating them as opaque screens do.

Such materials could offer a richer depiction of interference behavior, making it possible to observe what we call the interference trilogy: the evolution of a particle's wavefront before, during, and after the interference. Prior to interference, the signal should manifest as two distinct paths; at the point of interference, the paths converge or interfere into one; and afterward, the outcome could remain unified or split again, depending on the interaction and detection configuration.

This approach recognizes that, unlike water waves whose interference occurs at discrete points formed by intersecting crests and troughs of expanding circular fronts (which are difficult to track experimentally), photons and electrons offer the advantage of interacting with photo-sensitive materials. These materials make it possible to record their passage through space, potentially capturing the full spatial and temporal structure of interference—not just a final detection point.

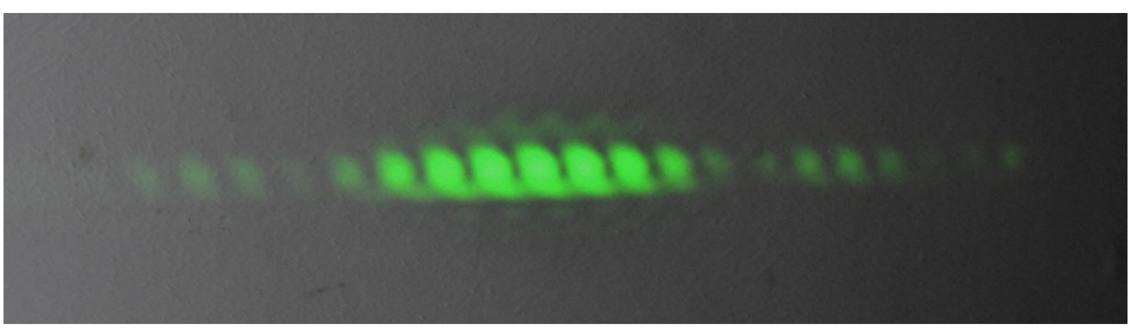
In the continuous case—such as water or sound waves—interference occurs at the intersection points of expanding crests or troughs (circles or spheres) from each source. These waves meet, interfere momentarily, and continue on their separate trajectories as independent wavefronts. There is no permanent fusion; the interference is transient and localized. In contrast, for discrete entities like photons or electrons, the result after interference is less clear. If two distinct photons or electrons were to interfere, they might continue on their separate ways unchanged or fuse into a single entity—though such behavior remains experimentally undefined. If the interfering components are instead two parts of a previously unified photon or electron (as postulated in self-interference scenarios), then their reunion must result in a single discrete entity, not a fractional or partial one. This discreteness requirement implies strict timing, directionality, and phase alignment—constraints not faced by continuous wave media—and suggests that the post-interference outcome may carry deeper physical meaning than mere superposition.

4. Verifying Fringe Count

To verify whether the observed interference pattern aligns with the predicted number of fringes, we turn to a high-resolution public image of green laser interference, widely circulated and attributed to a version of Young's double-slit experiment.

According to monochromatic wave theory, the total number of bright fringes across the visible pattern is determined by the integer part of $2h/\lambda$, where h is half the slit separation and λ is the wavelength of the monochromatic light. The observed image provides an opportunity to compare the visible fringe count with this theoretical prediction.

Figure 1: Green laser interference pattern from Young's double-slit experiment, showing fringes. Image source: Wikimedia Commons, licensed under CC BY-SA 3.0 [15].



This widely circulated image captures a classic Young's double-slit interference pattern. Although precise slit dimensions are no longer listed, prior captions stated 0.4 mm slit width and 0.1 mm slit spacing. The pattern provides a visual reference for evaluating fringe count and distribution relative to theoretical predictions based on monochromatic wave interference.

While the associated Wikipedia caption once specified a slit width of 0.4 mm and slit spacing of 0.1 mm, those details have since been removed. In the absence of precise measurements, we proceed with these approximate values and take a conservative estimate of the green laser wavelength at λ=550 nm. This gives:

$$\lfloor 2h/\lambda \rfloor = \lfloor 0.1\text{mm}/550\text{nm} \rfloor = \lfloor 181.8 \rfloor = 181$$

Thus, if the light truly exhibits monochromatic wave behavior, we expect up to 181 interference fringes. While this number may exceed the visible range of the image, the count remains an important theoretical boundary for fringe formation.

Moreover, since photons and electrons arrive one at a time and their interference patterns are integrated over time, their distributions should reflect not only the existence of all interference fringes but also their relative visibility. In classical wave interference, fringe intensity follows a sinusoidal or envelope distribution, with central fringes being the brightest. For photons and electrons, the accumulation process should reveal a complete and symmetrical set of fringes around the center, unless limited by apparatus or slit asymmetries. Therefore, both the total number and spatial distribution of observed fringes can serve as additional tests for the completeness of Young's experiment.

Statements and Declarations

Funding: The author declares that no funds, grants, or other support were received during the preparation of this manuscript.

Ethics approval: The author declares that this research involves no human or animal participants.

Consent for publication: The author affirms that this research involves no human or animal participants.

Availability of data and material: Not applicable.

References

[1] T. Young, The Bakerian Lecture: Experiments and Calculations Relative to Physical Optics, Philos. Trans. R. Soc. Lond. 94, 1 (1804).

[2] U. Sinha, C. Couteau, T. Jennewein, R. Laflamme, and G. Weihs, Ruling out multi-order interference in quantum mechanics, Science 329, 418 (2010).

[3] H.-C. Jeong, E. D. Williams, and T. L. Einstein, Steps on surfaces: experiment and theory, Surf. Sci. Rep. 34, 171 (1999).

[4] R. P. Feynman, R. B. Leighton, and M. Sands, The Feynman Lectures on Physics, Vol. 3: Quantum Mechanics (Addison-Wesley, 1965).

[5] E. Buks and M. Heiblum, Dephasing in electron interference by a "which-path" detector, Nature 391, 871 (1998).

[6] M. Arndt, O. Nairz, J. Vos-Andreae, C. Keller, G. van der Zouw, and A. Zeilinger, Wave–particle duality of C60 molecules, Nature 401, 680 (1999).

[7] L. Vervoort, Wave-particle duality: An information-theoretic approach, Found. Phys. 45, 1 (2015).

[8] Rescale, An Introduction to AI in Physics Simulation, https://rescale.com/blog/an-introduction-to-ai-in-physics-simulation (2022).

[9] Carnegie Mellon University, AI Expands Potential for Discovery in Physics, https://www.cmu.edu/news/stories/archives/2024/november/ai-expands-potential-for-discovery-in-physics (2024).

[10] Q. Zhang et al., Experimental separation of wave–particle duality in photons, Light Sci. Appl. 11, 116 (2022).

[11] TeachSpin Inc., Two-Slit Interference: One Photon at a Time, https://www.teachspin.com/two-slit.

[12] D. Halliday, R. Resnick, and J. Walker, Fundamentals of Physics, 10th ed. (Wiley, 2014).

[13] J. Peatross and M. Ware, Physics of Light and Optics, BYU Department of Physics, https://optics.byu.edu/docs/opticsbook.pdf.

[14] Wikipedia contributors, Wave–Particle Duality, https://en.wikipedia.org/wiki/Wave%E2%80%93particle_duality.

[15] Wikimedia Commons contributors. "Interference of a green laser passing through two slits." Wikimedia Commons, 17 April 2007. https://commons.wikimedia.org/wiki/File:Double-slit_experiment_results_Tanamura_2.jpg (accessed August 2, 2025). Licensed under CC BY-SA 3.0.

[16] Anton Paar, Double slit experiment, https://wiki.anton-paar.com/dk-en/double-slit-experiment/, Accessed May 17, 2025.

[17] The double-slit experiment, https://opencurve.info/the-double-slit-experiment/, Accessed May 17, 2025.

[18] Nath, S., & Mandal, P. (2019). Shape of interference fringes in Young's double-slit experiment. Physics Education (India), 35(4), 51–57.

[19] Nath, S., & Mandal, P. (2021). Multiple slit interference: a hyperbola-based analysis. European Journal of Physics, 42(3), 035403.

[20] Nath, S., & Mandal, P. (2023). Hyperbolic geometry and exact path-difference equations for Young's double-slit interference. European Journal of Physics, 42(6), 065403.