Double Slit Interference: One Photon at a Time

Jim Napolitano January 21, 2026

This experiment has two parts. In the first part, you will demonstrate a phenomenon well known from introductory physics, namely the interference of a light wave that passes simultaneously through two closely spaced "slits." In the second part, you will demonstrate that the same phenomenon, but with a different light source, so weak that you can detect single photons at a time, along with a different detector.

This brief writeup should be enough to get you through the experiment, but for more information, you can take a look at the TeachSpin documentation page for this experiment:

`https://www.teachspin.com/two-slit`

I actually like the TeachSpin writeup a lot. It is clear and provides useful details including how they are able to get a light source intensity low enough so that you can count the individual photons.

Young's Experiment

You almost certainly learned about Young's double slit experiment in introductory physics. Performed in the 19th century, this was considered "proof" that light was a wave. A coherent light wave is produced by passing the light from some source through a single slit, then this light passes through two closely spaced slits, leaving an interference pattern on a screen some distance downstream from the double slits.

This situation was analyzed simply by considering the horizontal positions on the screen where the light emerging from each of the two slits interferes constructively, leading to alternating light and dark fringes. See Figure 1, taken from a once-popular textbook. The distance between the two slits S_1 and S_2 is d, and the distance from the double slits to the screen C is D.

A bright fringe appears when the distances r_1 and r_2 from each slit to the screen differ by an integral number of wavelengths λ. This distance is marked b in Figure 1 and is easy to calculate in the limit that $D \gg d$ where the two rays can be approximated by parallel lines. In this case, $b = d \sin\theta$, so bright fringes appear at angles

$$\sin\theta = n\frac{\lambda}{d} \qquad n = 0 \pm 1, \pm 2, \cdots \tag{1}$$

Of course, this simple analysis tells you nothing about the relative intensity of the bright fringes. For this, a more detailed calculation using electromagnetic theory is required. The

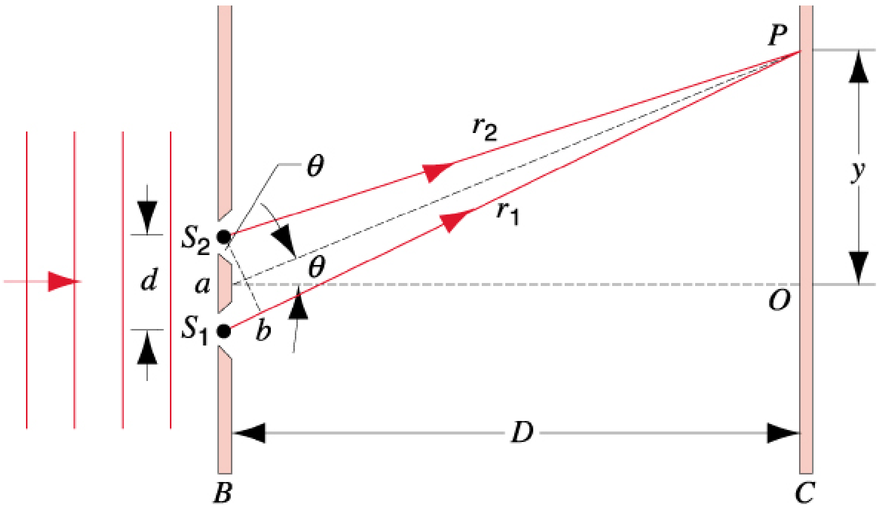

Figure 1: Analysis of double slit interference, taken from *Physics* by Halliday, Resnick, and Krane, 5th Edition. The symbol a marks the midpoint between the slits. It is not the width of the slits, as used in the Equation (2).

calculation is actually very complicated, and one usually resorts to "scalar diffraction theory" where we assume all components of the wave follow the wave equation independently. Adding more approximations, one arrives at something called the "Fraunhofer diffraction integral"[1] over the aperture, which in our case consists of two infinitely long slits. After a straightforward integration where each of the two slits has width a, one finds for the intensity

$$I(\theta) = I_0 \left(\frac{\sin u}{u}\right)^2 \cos^2 v \qquad \text{where} \qquad u = \frac{\pi a}{\lambda}\sin\theta \qquad \text{and} \qquad v = \frac{\pi d}{\lambda}\sin\theta \tag{2}$$

Since $d \gg a$ for the usual two-slit situation, we have an intensity that oscillates in θ like $\cos^2 v$, inside an "envelope" $(\sin u/u)^2$. There are intensity maxima at

$$v = 2\pi n \qquad \text{or} \qquad d\sin\theta = n\lambda$$

just as given in Equation (1). The intensity envelope is the effect of "single slit" diffraction.

Photons

The debate that Young's experiment supposedly settled was between light as a "wave" or light as "particles." Since the early 20th century, though, starting with Planck's hypothesis and then with experiments on the photoelectric effect, Compton effect, and atomic spectroscopy, it became popular to refer to light as made up of particles that came to be called "photons" and to talk about "wave particle duality."

In fact, it took some time for people to use the word "photon" to mean a packet of energy of electromagnetic radiation. See the article *Anti-photon* by (Nobel laureate) Willis Lamb in

[1] The classic textbook "Fundamentals of Optics", Fourth Edition, by Jenkins and White is probably still the best reference. Chapter 16 focusses on the Double Slit. Our formula comes from their Equations (16) on page 340. I've found factors of two inconsistencies in other books, so beware.

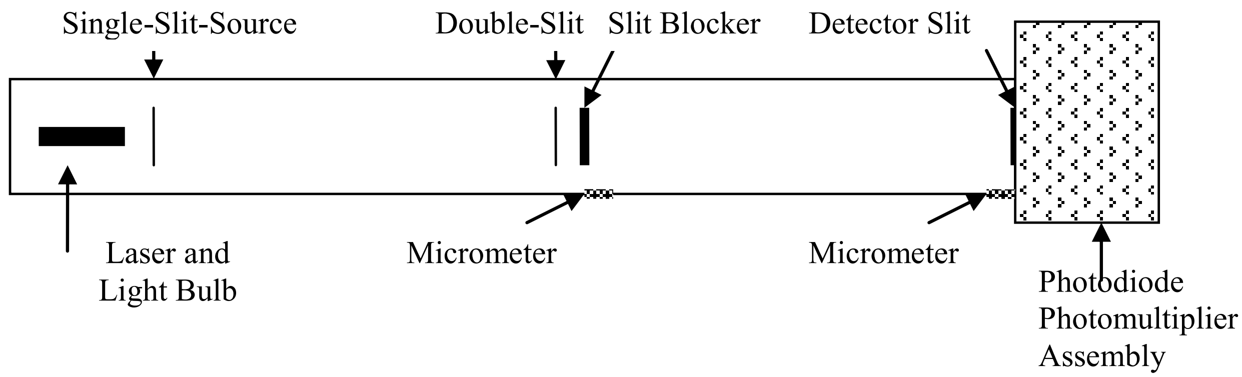

Figure 2: Schematic diagram of the "double slit" apparatus. Not drawn to scale.

Applied Physics B 60 (1995) 77 for a fascinating history of the term, and why Lamb resisted thinking of light this way. Nevertheless, it is very tempting to think of light as made up of a collection of little bullets emanating from some source, where the energy of each bullet is just $h\nu = hc/\lambda$.

If we indeed think of light as made up of photons, then Young's experiment becomes mysterious. Why would one photon emitted at some time be correlated in angle with a different photon emitted some time earlier or later? In other words, why would two photons emitted at different times interfere with each other at all? Why would there even be the phenomenon of diffraction?

The point of this experiment is to show that even if light is detected as individual photons, you still get the same interference pattern as if you'd detected the light as a wave. The trick is to change the light source from one that is high intensity to one of much lower intensity, which necessitates a change in the way the light is detected, from a wave-sensitive device at high intensity, to a photon-sensitive device at low intensity.

The Apparatus

Both kinds of measurements are taken with the same physical apparatus, switching between the two light sources and detectors. See Figure 2. The common elements for both measurements are a single slit to ensure coherence from the source (more important for the weak light bulb than for the laser); the double-slit; a moveable sheet that can block light coming through the slits; and a moveable single slit that allows light to pass through to the detector. The assembly is enclosed in a light tight box with a removable cover, and the slit blocker and detector slit positions can be adjusted using externally mounted micrometers.

You will observe the interference patters from the laser and the light bulb by moving the detector slit across the detector and recording the intensity at each position. For the laser, the detector is a photodiode that produces a current that is proportional to the detected intensity. For the light bulb, the detector is a photomultiplier tube (PMT) which observes individual photons.

When writing your reports, be mindful of the ways in which the different light source work. The laser is straightforward enough, but it is tricky to get a weak enough source for the second part of the measurement. The TeachSpin writeup provides you with some values and suggests some exercises you can do to better understand how such a weak light source is created, and what are the implications for this kind of measurement.

Measurements and Analysis

Follow the procedure given in the TeachSpin writeup under "Experiments." **Making sure the light detectors are turned off**, you begin by opening up the top of the U-channel and align and calibrate using the laser source. *This will take some patience and care.* Use the white card that fits into the U-channel slot to observe the laser at different points along the beam line to make sure you see what you expect. If you put the card in front of the detector slit, you can the two-slit interference pattern well enough, perhaps with the room lights dimmed. Adjacent maxima should be about 1 mm apart.

Note that you have a choice of different double-slit masks. Also note that your measurements can include data with one of the two slits covered up using the slit blocker. This will allow you to measure the single-slit diffraction envelope of the double slit data.

When you have everything aligned *close and secure the U-channel lid* and turn on the photodiode detector. Observe the output voltage change as you use the micrometer to move the detector slit across the face of the detector. If everything is aligned correctly, then the interference maxima should be obvious. Take data (and record it in your log book) as a function of the slit position, as read by the micrometer.[2]

Data taken by Lidia Lapinski (Class of 2025) is shown in Figure 3. The curves show the double and single slit intensity patterns from Equation (2, using the specifications for the laser wavelength and the slit widths and separations, and the measured distance from the double slit mask to the detector. The only adjustable parameters are the background level and the position of the center of the interference pattern. The same parameters are used for both plots.

Once you have gotten a satisfactory data set with the laser, you can switch the instrument to use the light bulb and the PMT detector. *Remember to turn everything off when you*

[2]It is not obvious how to read a micrometer, but it is easy to find explanations, including videos, online.

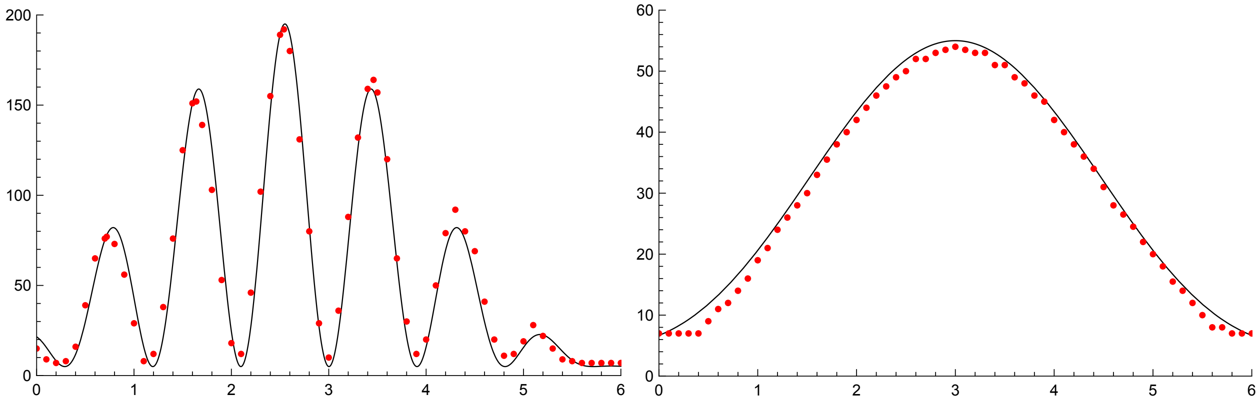

Figure 3: Data and analysis of measurements using the laser light source with photodiode detector. The left shows the double slit interference pattern, while the right shows the result when the slit blocker closes off one of the two slits. In both cases, the horizontal axis gives the position of the detector slit in mm.

open up the U-channel to change the light source. The photon counting detector operates very differently than the photodiode, and your data will no longer be a voltage but a certain number of counts of photons detected. You'll need to be sure to take each data point for some fixed, or carefully recorded, period of time.

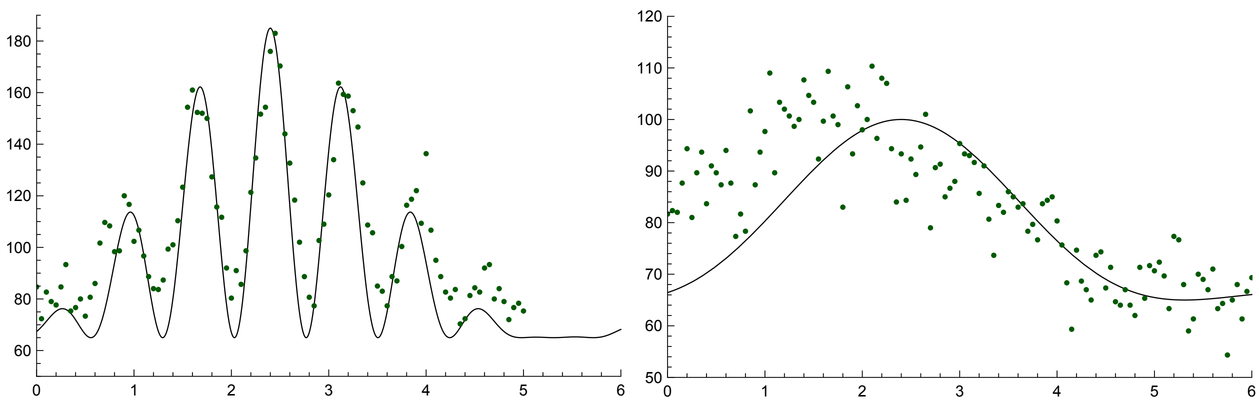

Figure 4: Same as Figure 3 but now with a weak light source and a PMT detector. Here the vertical axis is counted photons, not voltage. Note that the interference filter on the bulb has a shorter wavelength than for the laser, so the interference maxima are closer together.

Lidia's data for single photon detection is shown in Figure 4. The interference maxima are clearly visible and well matched to the intensity prediction, although there is a higher level of constant background. (Note the suppressed zero on the vertical scales of both plots.)