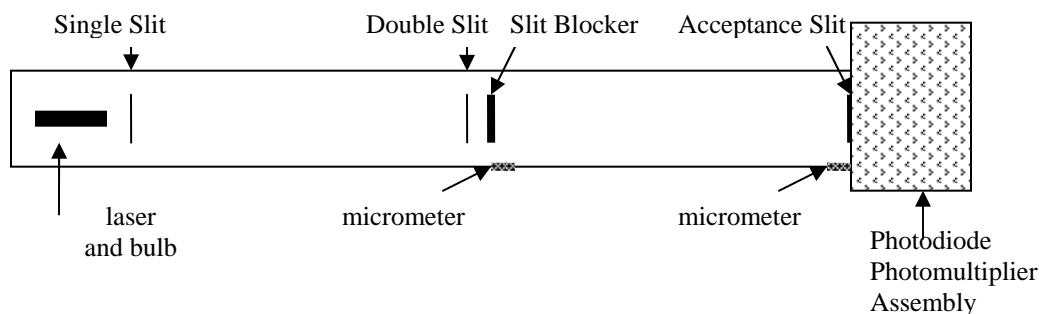


A Conceptual Tour of TeachSpin's Two-Slit Interference, One Photon at a Time

The apparatus consists of a U channel a little over a meter in length with a light tight removable cover. At one end the student can use either a laser or a small bulb. At the other end is a detection system which contains both a photodiode and a photo multiplier.



Just in front of the light source is a single slit which we call the *single slit source* because it is the source of the photons for the two slit interference pattern. The central maximum of the single slit pattern is adjusted so that it falls on the *double slit*, a pair of slits fifty centimeters along the channel. A moveable *slit blocker* is on the far side of the double slit. The blocker can be set to allow light from either or both slits to proceed down the channel. The slit blocker is manipulated with a micrometer mounted on the outside of the U channel. At the far end of the U channel is a moveable single slit we call the *acceptance slit*. The acceptance slit can be moved across the face of either the photodiode or photomultiplier. This, too, is attached to an external micrometer which monitors its location.

The bulb is mounted in front of the laser in such a way that it can be moved out of the way without being removed from the apparatus. Here is an experimental order we think sensible.

1. With the system opened, and using the laser, the student adjusts the single slit source and the double slit until they are properly aligned. A card placed just behind the double slit/slit blocker assembly shows a pair of thin red lines of laser light. Now the micrometer readings for both slits blocked, only left slit open, both slits open, and only right slit open can be determined.
2. The characteristic two slit pattern of the laser can easily be seen on a small white card placed in front of the acceptance slit.
3. With the laser on, the system is closed up and the photodiode turned on. The photodiode is connected to a voltmeter (through a current to voltage converter) to give relative intensity readings. The student moves the acceptance slit across the face of the photodiode and records the intensity pattern as a function of micrometer reading. Here, we want the student to get a quantitative record of the qualitative visual observation.

4. The system is opened, the laser turned off and the bulb lifted into place.

Now it is time to demonstrate that photons move singly and independently through the single slit and down the length of the apparatus.

5. The double slit, slit blocker, and acceptance slit are removed so that all of the photons passing through the single slit source can be counted by the photomultiplier. A very narrow band green filter is slid into place in front of the bulb. As the brightness of the bulb is decreased, the color spectrum will shift to the red, the light intensity in the green region will drop dramatically, and we will be able to get “one photon at a time”
6. The top is put on and secured. The protective default system now allows the photomultiplier to be activated. The shutter, which keeps the light from entering the photomultiplier, is still kept in place. The bulb intensity is set to about half of maximum.
7. The photomultiplier operating voltage and the discriminator threshold voltage are both adjustable parameters. They must be set so that the photomultiplier will optimally count green photons and optimally reject the dark current. (This can be done by the instructor or can be an opportunity for students to learn how to use a photomultiplier for proper photon counting.)
8. At the appropriate bulb intensity setting, the photomultiplier tube (PMT) gives a count rate on the order of 50×10^3 photons/second. For the green wavelength of interest, the PMT is about 5% efficient; it counts only about 1/20 of the green photons. Therefore, the total rate at which photons reach the PMT must be $20 \times 50 \times 10^3$ or about 10^6 /second. The average time between photon arrivals at the PMT is thus 10^{-6} second, alternatively 1 microsecond, or 1000 ns.

Any individual photon traverses the 1 meter length of the apparatus at a speed of $c = 3 \times 10^8$ m/s, spending a time of only $1/3 \times 10^{-8}$ seconds or about 3 ns, in flight. On average, therefore, there is a photon in flight between the single slit and the photomultiplier for only about 3 ns out of every 100 ns. This means that for 99.7% of the time there are “no” photons in flight, while for only 0.3% of the time there is “one” photon in flight in the apparatus. The probability of there being two photons in flight simultaneously is thus negligible. All the interference effects observed in this apparatus can thus be ascribed to the behavior of individual photons, coming through the single slit one at a time!

9. Once students have convinced themselves they will be getting one photon at a time, they close the photomultiplier and reopen the channel. Now they must reinsert the double slit, slit blocker and acceptance slit, and check the alignment.

10. The system is again closed and the photomultiplier shutter opened. With a frequency counter, students determine counts in 10 second intervals at various locations of the acceptance slit. A graph of photon count for 10 second intervals vs. location of the acceptance slit reveals the same general interference pattern observed with the photodiode. The actual spacing between the maxima shows that they are now looking at green photons rather than the red ones from the laser.

11. Another interesting activity is to locate the acceptance slit at a place which gives a minimum count rate for two slits and move the slit blocker to see what happens when one slit or the other is blocked. If you have two faucets and turn one off the flow rate cuts in half. Here, of course, the interference pattern changes to give an increased signal.

There are several noteworthy aspects of the design.

Careful fail safe systems protect the photomultiplier. Among other things, the photomultiplier gets no power unless the light tight cover is secured and the laser is off.

The entire photomultiplier/photodiode assembly can be detached from the U channel so that it can be used in other experiments. We felt this was too versatile (and too expensive) a component to have it locked into just one experiment.

As always, we want students to be able to explore every aspect of the instrument. The students will be able to study the dark current of the photomultiplier as a function of voltage and then look at readings from a low intensity light source as a function of voltage. While the dark current pattern is linear, the low intensity signal saturates. Interpreting these graphs helps students to understand both how photomultipliers work and how to choose the optimal operating and threshold voltage settings for this particular experiment..