# Single Photon Interference

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(Dated: December 11, 2017)

Waves when sent through two parallel slits produce an interference pattern. One would expect single particles fired through these two slits to form two lines shadowing the slits. This, however, is not the case when one fires single photons through a double slit. Instead, the double slit interference pattern still occurs. This reveals the important wave nature of the photon. In this experiment my partner and I attempted to recreate and demonstrate this fundamental quantum effect.

PACS numbers: 03

## INTRODUCTION AND THEORETICAL BACKGROUND

This experiment focused on the wave nature of the photon. A single photon's wavefunction passes through both slits in a double slit set up. Even though a photon is a single particle the splitting of the wavefunction through the slits should result in a traditional wave's double slit interference pattern. A single photon can still only be measured in one place after the slits. However, By singly firing many photons and measuring their locations a probability distribution of where they will land should become apparent. This probability distribution should correlate directly to the interference pattern of the single photon's wavefunction.[2]

## APPARATUS

The general set up consisted of a rectangular meter long tube connected to a Hamamatsu R 212 photomultiplier tube. The top of the tube was removable to adjust our internal set up. At the end of the tube opposite the PMT a blue LED was placed behind a filter to narrow our range of wavelengths. The filter was centered around:

$$\lambda = 415 \text{ nm}$$

with a half peak height width of 80 nm. The filtered light was then passed through a collimating single slit before reaching our double slit at:

$$\mathrm{D} = 50 \text{ cm}$$

away from the PMT. In front of the PMT an accepting slit was placed with the ability to be adjusted by a micrometer on the outside of the rectangular tube. All of these slits were set up in magnetic slides which were attachable to magnetic frames within the rectangular tube. They also all had a slit width and height of:

$$\mathrm{w} = 0.085 \text{ mm}$$
$$\mathrm{h} = 10.0 \text{ mm}$$

respectively. With the double slit slide having a slit spacing of[1]:

$$\mathrm{d} = 0.353 \text{ mm}$$

The PMT required a minimum 9 V from our power supply to work, but it was most stable at the recommended setting of:

$$\mathrm{V} = 15 \text{ V}$$

This PMT's signal was fed to an oscilloscope, to allow us experimenters to make sure it was registering incoming photons correctly. It was also fed through a discriminator to a counting board. This allowed for the counting of incident photons on the PMT, which along with the adjustable accepting slit gave the necessary data to test the single photon interference pattern.

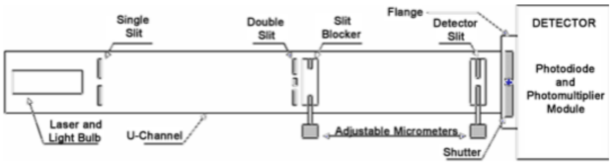

FIG. 1: Tube Diagram[1]

## EXPERIMENTAL PROCEDURE

To begin our experiment we first had to take inherent photon counts without any slits in. This lets us find both what LED voltages allow us to presume only single photons passing through our apparatus as well as the individual slit efficiencies. Our LED Voltage we used and average no slit photon count over ten 5 s intervals on the day we took our data were:

$$\text{LED V} = 2.36 \pm 0.02 \text{ V}$$
$$\text{count} = 3940000$$

From this count we could determine what percent of the time a photon was in our apparatus, if this is low enough it is safe to assume that only one photon is in the system at a time. The PMT is approximately 20% efficient in regards to 415 nm wavelength photons. This in addition to the fact that we measured over a 5s interval gives us a:

$$t = 2.54 * 10^{-}7 \text{ s}$$

gap between photons. As it takes approximately 3.3 ns for our photon to move down the meter long tube there is a photon in our tube:

$$\approx 1.3 \text{ \% of the time}$$

At such a low percent it is unlikely that two photons would concurrently be within the apparatus. From this we were also able to measure our slit efficiencies:

$$\begin{aligned} \text{collimating eff.} &= 19 \text{ \%} \\ \text{double slit eff.} &= 7 \text{ \%} \\ \text{accepting eff.} &= 5 \text{ \%} \end{aligned}$$

With the single photon nature of our experiment confirmed a background count with the LED power off and the PMT shutter closed was taken. Now we proceded by steadily adjusting our accepting slit micrometer in .05 mm intervals from 2.0 mm to 5.15 mm. At each interval three 5 s counts were taken.

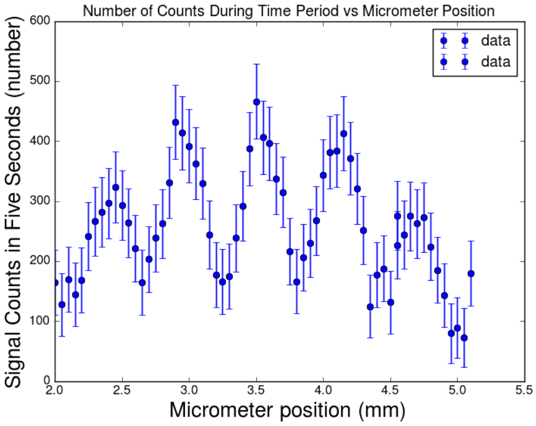

FIG. 2: Interference Pattern

## SUMMARY OF FINDINGS

It took many tries to find a good LED voltage which both gave us visible results on top of our background counts while still maintaining single photon conditions. This background was averaged over ten 5 s intervals coming out to:

$$\text{background} = 330 \text{ counts/s}$$

Our data at LED voltage of 2.36 V as seen in figure 2 shows a double slit interference pattern. Using:

$$y = m\lambda D/d$$

and our known frequency, slit width, and spacing, we determine a theoretical interference peak spacing:

$$y = 0.59 \pm 0.06 \text{ mm}$$

The error coming from our imperfect filter causing $\lambda$ to not be exact. Figure 2 shows our results falling within this expected result. As the slits are not set in place, but instead are required to be placed on to magnet mounts we tested how imperfect placement of the accepting slit impacted our results. When we slanted our accepting slit by 10% either way our interference pattern generally vanished. This is expected as accepting photons over a larger horizontal range should smooth out the interference pattern.

## CONCLUSION

In this experiment we attempted to view an interference pattern as single electrons passed through a double slit. The experimenters before us had successfully done this using green light, but we used a blue light to which the PMT was more sensitive. It appears we have also been able to identify a double slit interference pattern with a small likelihood that multiple photons were passing through our double slit concurrently. Future experimenters may find it useful to increase the accuracy of the filter as that should stabilize peak location and definition by having closer to a single wavelength of photons.

## ACKNOWLEDGEMENTS

I would like to thank my lab partner Nate Avish as well as the wonderful senior scientists of Boston University's Advanced Lab, Yaokun Situ, Daniel Arcaro, and Professor Larry Sulak.

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[1] apparatus reference:
TeachSpin, Two Slit Interference, One Photon at a Time, (2007).
[2] quantum theory reference:
R.D. Prosser, Quantum Theory and the nature of interference, (1974).