Interferance at Single Photon Level

Rahmat Saeedi
University of Alberta, Edmonton, Alberta, Canada, T6G 2R3
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Interference at single photon level (obtained by reducing Hg lamp intensity using Natural Density filters) is investigated in this paper. Diffraction patterns of a double slit displayed an interference pattern with fringe separation of 3.04±0.08 mm which agrees with theoretical value of 3.01±0.01 mm. A similar measurement using a single slit revealed an interference effect with fringe separation of 5.2±0.1 mm which agreed with the theoretical value of 5.3±0.1 mm. A qualitative collapse of wavefunction was also observed using HeNe and double slit with polarizers at each slit, but no quantitative measurement was obtained. The collapse of the wavefunction was observed while the single photon condition was not in place.

INTRODUCTION

The dual nature of light investigations date back to 17th century when competing theories were proposed by Huygens [1] and Isaac Newton [2]. Through the work of Albert Einstein on photoelectric effect [3], Louis de Broglie on wave nature of particles, and others on quantum mechanics, current theories holds that *all particles have a wave nature* (and vice versa). This phenomenon is known as waveparticle duality and has been observed not only for elementary particles (such as electrons [4, 5] and hadrons [6–9]) but also for atoms and molecules [10]. These two "faces" are mutually exclusive, as described in most standard texts; meaning sometimes behaving like one, sometimes like the other, but never like both at the same time [12]. Additionally, M. Dersarkissian from Temple University, PA, USA purposed a Galactic equivalent of waveparticle duality in his 1984 paper [11] based on quantized red-shifts for galaxies.

In this paper single photon interference would be investigated; an experiment similar to ref. [13, 14]. The intensity of 433.92 nm Hg light would be reduced using Natural Density ND, filters so that the probability of interference of photons with one another is negligible. After passing single photons through a test slit, the interference pattern would be collected using a photomultiplier PMT.

RESULTS

Setup

Mercury light source intensity was reduced using ND and 433.92 nm filter, one of which was placed inside the light tight box as seen in FIG. 1. To reduce the noise level, a continuous flow of cold water was used to stabilize the PMT temperature which was used approximately 20 minutes after applying high voltage HV for the first time. Micrometers attached to test and detector slits allowed for alignment of the setup and a timer and pulse counter circuit connected to PMT allowed for intensity measurements. The timer and HV were set to a fixed

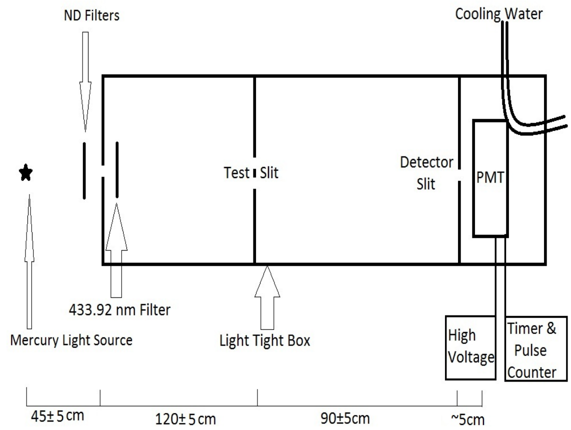

FIG. 1: Experimental Setup. A single slit of width 0.11±0.01 mm was used as the detector slit.

amount for the duration of the experiment. The position of the detector slit (single slit of width 0.11±0.01 mm) was varied and counts (corresponding to intensity) were recorded. The average number of photons in the space between the source and the detector N (excluding those blocked by the slit) is given by [13, 14]:

$$N = rL/C\varepsilon \tag{1}$$

where r, L, C, and ε are count rate recorded, distance from the source to detector, speed of light, and the quantum efficiency of PMT, respectively. Provided by the manufacturer, ε was 26%±3%. Based on our experimental setup a rate of less than 10^6 counts/seconds would give a $N < 5\%$. Count rates of less than 10^6 was easily achieved in this setup. To improve the signal to noise ratio SNR, measurements of dark counts (while the light beam was blocked) and bright counts (while light striking the PMT) were made for various HV. The result, as seen in FIG. 2 indicates 1450±30 V would have the best SNR. The usual constructive interference condition for

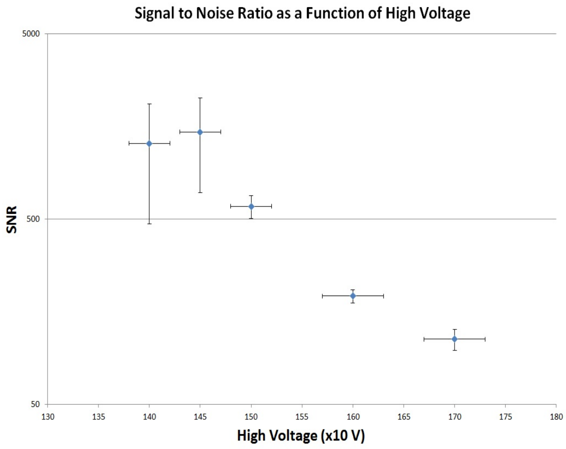

FIG. 2: SNR measurements of the PMT. As seen above SNR is optimized at HV of approximatly1450V.

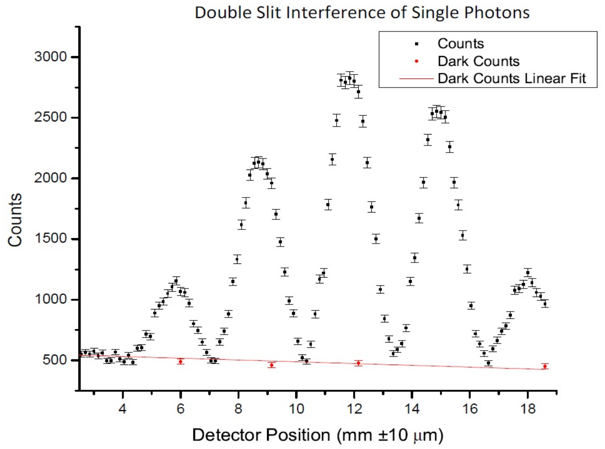

FIG. 3: Single photon interference using a test double slit of width 0.125±0.001 mm is shown above. The dark counts decreases gradually as PMT stabilizes further while collecting data. Fringe separation found to be 3.04±0.08 mm which corresponds to test slit detector distance of 88±2 cm, agreeing with our measurements. The uncertainty in the counts was assumed to be square-root of the counts, treating them as independent random events.

single and double slit is as follows respectivly:

$$(n+\frac{1}{2})\lambda \approx w\frac{x}{L} \tag{2}$$

$$n\lambda \approx d\frac{x}{L} \tag{3}$$

Where n, λ, x, w, d, and L are fringe order, wavelength of the light, fringe distance, width of the slit, separation of the slits, and the distance from test slits to detector slit.

Double Slit

ND filter 3 was used to investigate a double slit of width 0.04±0.01 mm and separation of 0.125±0.001 mm. Count rates of order $1.5\text{x}10^4$ was obtained in our earlier measurements using ND filter 2 and 3 together; Hence, using ND filter of 3 alone would correspond to r $\approx$ $1.5\text{x}10^6$ counts/s, satisfying single photon criterion. The interference obtained is shown in FIG. 3 in which gradual decrease in dark counts is visible. Fringe separation found to be 3.04±0.08 mm which corresponds to test-slit-detector distance of 88±2 cm, (using 3) agreeing with our measurements. (See FIG. 1.) Fringe separation was expected to be 3.01±0.01 mm (using Equ. 3) which also agrees with our obtained value.

Figure 3 show an interference pattern as expected, indicating that single photons behave as waves at the double slit; Their probability amplitude Ψ goes through both slit and interfere with one another, giving rise to an interference patterned probability $\Psi\Psi^*$ at the detector slit. Finally the asymmetry about the central fringe is due to the angle of light source and the test slit.

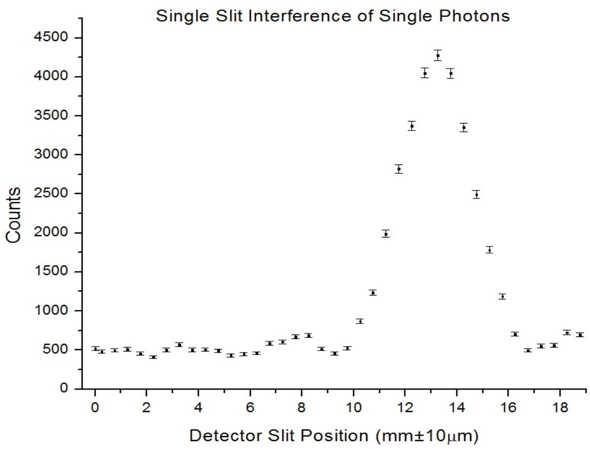

FIG. 4: Single photon interference using a test single slit of width 0.11±0.01 mm is shown above. Fringe separation found to be 5.2±0.1 mm which corresponds to test-slit-detector distance of 109±17 cm, agreeing with our measurements. The uncertainty in the counts was assumed to be square-root of the counts.

Single Slit

ND filter 1 and 3 were used to investigate a single slit of width 0.11±0.01. Count rates of order $1.45\text{x}10^5$ per second was obtained when the test and detector slits were removed, satisfying single photon criterion. The interference obtained is shown in FIG. 4 and the fringe separation found to be 5.2±0.1 mm which corresponds to test-slit-detector distance of 109±17 cm, (using 3) agreeing with our measurements. (See FIG. 1.) The theoretical

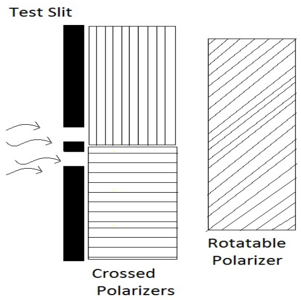

FIG. 5: A double slit with crossed polarizer and a rotatable polarizer prepared to investigate the collapse of the ψ. The thickness of the polarizer was on the order of 1 mm which was the main issue in failure of collapsing the wavefunction.

fringe separation was expected to be 5.3±0.1 mm (using Equ. 2) which also agrees with our obtained value.
Figure 4 show an interference pattern as expected, indicating that single photons behave as waves at the slit; Their probability amplitude Ψ goes through the slit and interfere according to Huygens Principle, giving rise to an interference patterned probability $\Psi\Psi^*$ at the detector slit.

Collapse of Wavefunction

To collapse the wavefunction, a double slit with two crossed polarizers and an additional polarizer which could be rotated was prepared as shown in in FIG. 5. We expected to observe a single slit interference when the rotatable polarizer was perpendicular to any of the double-slits polarizers. On the other hand, when the rotatable polarizer was at 45 degree with respect to the double-slits polarizers, we expected to see two overlapped single slit interferences with a small separation between their central maxima[15–17]. This phenomenon was observed qualitatively using a HeNe laser while the single photon condition was not satisfied. We were unable to obtain qualitative measurements mainly due to unsuitable polarizers available whose thickness was of the order of slit separation, hence introducing diffraction due to the edge of the polarizers.

CONCLUSION

In this paper interference at single photon level was investigated. Diffraction patterns of a double slit of separation 0.125±0.001 mm displayed an interference pattern with fringe separation of 3.04±0.08 mm which agrees with theoretical value of 3.01±0.01 mm (see FIG. 3). A similar measurement using a single slit of width 0.11±0.01 mm revealed an interference effect with fringe separation of 5.2±0.1 mm which agrees with the theoretical value of 5.3±0.1 mm (see FIG. 4). A qualitative collapse of wavefunction while the single photon criterion was not satisfied was observed in an attempt using crossed polarizers, but quantitative measurements were not obtained.

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