Experiment 9: Interference and Diffraction

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Abstract

The experiment determined the intensity profiles for a single-slit and double-slit experimentally and compared it to the theoretical profiles by measuring the intensity of light from a laser through a single and double slit and using theoretical equations, respectively. The resulting experimental pattern plots for both single and double slit experiments were almost a match to the theoretical plots that were superimposed on them. The Fresnel number was calculated to be 0.0113 ± 0.0054. *The width of the single slit was found to be* $9.017x10^{-5}m \pm 0.001m$ *and the double-slit separation between slits was found to be* $4.81x10^{-4}m \pm 0.001m$.

1 Introduction

Wave fronts going through a slit create interference between the waves which produce a pattern on the plane of projection. The pattern produced on the plane will depend on the type of slit the wave fronts pass through. The diffraction pattern produced from a single slit and the interference pattern from the double slit are aspects of the same phenomena. In single slit diffraction, the diffraction pattern on the projection plane has bright and dark fringes, with the center having the maximum intensity and the dark and bright fringes alternate in the pattern. The bright fringes after the central maximum are lower in intensity. This single-slit diffraction pattern will be acquired using a laser and a single-slit of a certain width and similarly for a double-slit of a separation between slits. The theoretical diffraction pattern can be found using equation 1. The pattern itself depends on the number of slits and their width or separation.

1.1 Single-Slit equations

$$I = I_0 \frac{\sin^2 \beta}{\beta^2} \tag{1}$$

$$\beta = \frac{\pi b}{\lambda} \sin\theta \tag{2}$$

$$\sin(\theta) = \frac{(x - x_c)}{l} \tag{3}$$

$$b = \frac{L\lambda}{\Delta x} \tag{4}$$

$$F = \frac{b^2}{L\lambda} \tag{5}$$

The equation for intensity, I, that is distributed is given by the following equation depending on β. I_0, is the intensity at the central maximum, λ is the wavelength, θ is the angle of a diffracted ray from the optical axis, and b is the width of the slit. The, x, is a location of the light probe on the axis and x_c is the location of the light probe on the center of the central maximum. The, l, is the distance from the laser to the probe. L is the distance from the slit to the projection plane. Δx is the separation between the central maximum and successive minima. F, is the Fresnel number. d, is the separation between the slits.[1]

1.2 Double-Slit equations

$$I = I_0 \frac{\sin^2(\beta)}{\beta^2} \cos^2\alpha \tag{6}$$

$$\alpha = \frac{\pi d}{\lambda} \sin(\theta) \tag{7}$$

$$d = \frac{L\lambda}{\Delta x} \tag{8}$$

From Young's double-slit interference experiment, a similar result is displayed on the plane. The interference pattern, like the single slit pattern, has the maximum intensity at the center and alternating bright and dark fringes. The difference lies in the amount of fringes, with the double slit pattern showing more fringes than the single slit. The envelope of the single-slit pattern fits the double-slit pattern.

[1] pg. 27-29 Physics 325 Optics Laboratory Manual

2 Sample Calculations

$$\begin{aligned}
b &= \frac{L\lambda}{\Delta x} \\
&= \frac{(1.14m \pm 0.0005m)(632.8x10^{-9}m \pm 0.1x10^{-9}m)}{0.8x10^{-2}m \pm 0.001m} \\
b &= 9.017x10^{-5}m \pm 0.001m
\end{aligned}$$

$$\begin{aligned}
F &= \frac{b^2}{L\lambda} \\
&= \frac{(9.017x10^{-5} \pm 0.001m)^2 m^2}{(1.14m \pm 0.0005m)(632.8x10^{-9}m \pm 0.1x10^{-9}m)} \\
F &= 0.0113 \pm 0.0054
\end{aligned}$$

$$\begin{aligned}
d &= \frac{L\lambda}{\Delta x} \\
&= \frac{(1.14m \pm 0.0005m)(632.8x10^{-9}m \pm 0.1x10^{-9}m)}{0.15x10^{-2}m \pm 0.001m} \\
d &= 4.81x10^{-4}m \pm 0.001m
\end{aligned}$$

$$F = 0.0113 \pm 0.0054 < 0.05$$

3 Experimental Procedure and Design

After setting up the LabPro and light probe assembly with the positioner. The procedure for this experiment involves two parts. The first is the part of the experiment with a single-slit and the second with a double-slit.

The following steps were taken in the conduction of this experiment:

1. The first thing to do was to connect the power supply and the positioner. This will supply power that is dependent on the position. The positioner itself will be able to move in only one direction/axis for the purposes of this experiment. The light intensity probe (channel 1 on LabPro which is connected to the positioner will be able to measure the intensity of light of the patterns created by the laser (632.8nm) and slit.

2. Setting LoggerPro to collect data for 15s at a sampling rate of 150 samples/s, the next step was to calibrate the positioner at one end of the axis to be approximately -9.5V and the other end to be 9.5V. To do this, I calibrated the voltage probe (channel 2 of LabPro in this case) in LoggerPro to measure the location of the positioner in centimeters instead of voltage. This was done by using a ruler and measuring the ends of the axis of the positioner, such that as the positioner moves, the measurement is in centimeters.

3. After the initial setup of the apparatus and calibration, the first part of the experiment can be started. Single-slit diffraction was measured and graphed using the positioner and LoggerPro, respectively. This was accomplished by aligning the light probe to the height required to measure the incoming light waves and collecting data as the light probe is slid from one side to the other along the axis perpendicular to the incoming diffraction pattern. This will create a graph on LoggerPro of the pattern as seen in figure 1. Next, the intensity profile that is to be expected from a single-slit was superimposed on the profile we just graphed to see how accurate the measurement was. The theoretical intensity profile was obtained by using equations 1 to 5.

4. The second part of the experiment follows a similar procedure to the first. The experimental intensity profile is created using a double-slit and LoggerPro following the same steps as in part one. The theoretical intensity profile is instead created from using equations 6 to 8.

4 Graphs and Results

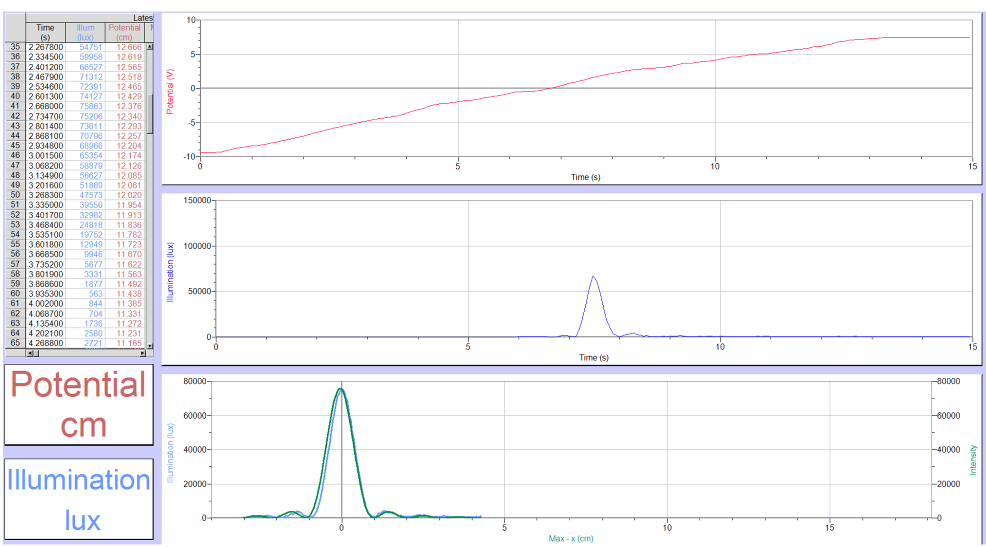

Figure 1: Graphs from calibration and single-slit diffraction pattern

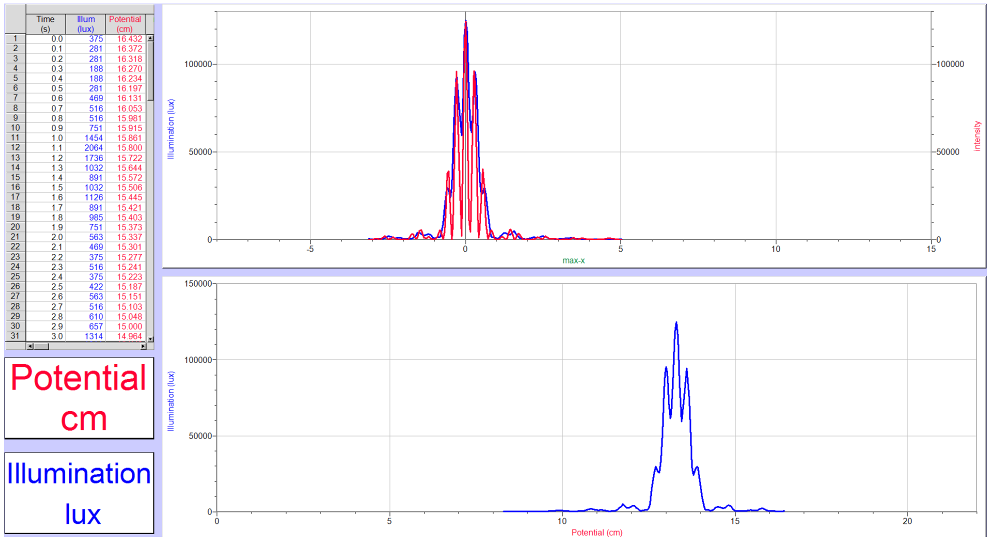

Figure 2: Double-slit interference pattern

The final result for the width of the slit, b, was $9.017x10^{-5}m \pm 0.001m$. The separation between the slits, d, was $4.81x10^{-4}m \pm 0.001m$. The Fresnel number was 0.0113 ± 0.0054, which is less than 0.05 [2].

Figure 1 shows the three plots, the top being a linear increase in the potential as the positioner moves from one side of the axis to the other. The middle plot is simply making sure that the sensor is reading illumination between 60,000 and 120,000 Lux. The bottom graph is the result of the experimental diffraction pattern and the superimposed pattern from the theoretical formula.

Figure 2 shows the result of the double-slit interference pattern from experiment along with the superimposed pattern from theory. The bottom plot is the isolated, non-zeroed, theoretical interference pattern.

5 Discussion

It can be noted from the experimental and theoretical graphs for both single and double slit experiments that the experimental results confirm the theoretical predictions of intensity equations 1 and 6. The theoretical and experimental graphs are very close to matching, but there are slight differences in the two for both single and double slit results. These differences could potentially be accounted for by noting some sources of error that accumulated in the procedure of the experiment. Measurement errors involving a ruler might have occurred in the measuring of the distance between the laser and the slit as well as the distance between the slit and the projection plane. The light intensity probe is also a source of error as it isn't capable of measuring the pattern continuously, but instead

[2] F<0.05 is considered reasonable for this experiment

is capable of measuring in small increments, which doesn't create the smoothness that is seen from theoretical equation plots. The calculations for the theoretical equation for the intensity profiles are effected by errors in the measurements of the variables needed. The values for the slit width and the separation between slits were accurate enough to create experimental and theoretical graphs that almost match, perhaps repeated measurements using a ruler or other length measuring device might improve the accuracy of the results. overall, the experiment was a success in showing the accuracy between the experimental and theoretical graphs with minor error accumulation as expected. Repeated execution of this experiment, perhaps with difference wavelength lasers and varying slits and lengths would further increase understanding of the phenomena of wave diffraction/interference.

6 Conclusion

The purpose of this experiment was to learn about diffraction and interference patterns created using the single and double slit experiments and the resulting comparisons between the experimental and theoretical graphs. The experimental and theoretical results were almost one-to-one with minor differences created by errors in the experiment. A further interesting exploration would be to see if there is a method to create smoother experimental graphs using a light probe.

References

[1] D. Rosa. Physics 325, Laboratory Manual. University of Victoria, 2021.