Lab 2: Diffraction

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Abstract

In this lab, the effects of shining light through different types of slits were observed. The resulting patterns were sketched and measured, then analyzed using the diffraction equation for single slits, $a = \frac{m\lambda D}{y}$, and the interference equation for double slits, $d = \frac{m\lambda D}{y}$. The error of all the measured quantities was propagated throughout the calculations.

1 Experiments

1.1 Experiment 1: Diffraction from a Single Slit

1.1.1 Data

Figure 1: **Table 1.1**: The data for the 40 µm single slit.

	$m = 1$ (cm)	$m = 2$ (cm)
Distance between side orders	3.4 ± 0.05	7.0 ± 0.05
Distance from center to side (y)	1.7 ± 0.025	3.5 ± 0.025
Calculated slit width	$3.81 \times 10^{-3} \pm 56.1 \times 10^{-6}$	$3.71 \times 10^{-3} \pm 27.3 \times 10^{-6}$
% difference	$4.87 \pm 101 \times 10^{-3}$	$7.52 \pm 78.3 \times 10^{-3}$

$$\text{Slit-to-screen distance}(D) = 96 \pm 0.05\text{cm}$$

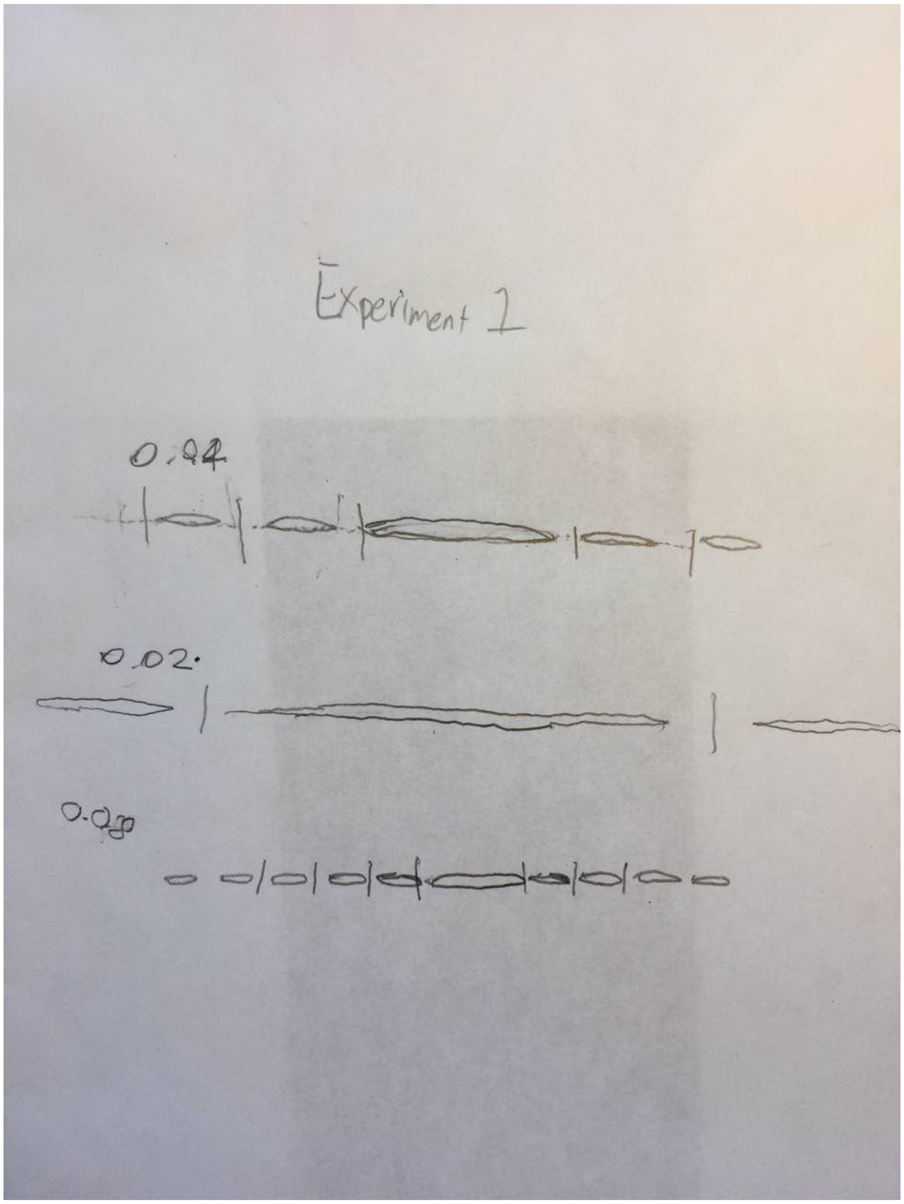

Figure 2: The sketches of the observed diffraction patterns. The top is of 40 µm, the middle is of 20 µm, and the bottom is of 80 µm.

1.1.2 Analysis

For the value of the slit-to-screen distance and the values measured for the distance between the side orders, the error is ± 0.05cm because that is half of the smallest increment of measurement on our measuring device, a ruler. When the measured values for the distance between the side orders are divided to find the distance from the center of the screen to the side of the envelope (y), the error of the measured values must also be divided by the same amount. Therefore, since the measured values are divided by 2, the error must also be cut in half. The error for y is ± 0.025cm.

The slit width, a, is calculated with $a = \frac{m\lambda D}{y}$, where $m \in \mathbb{Z}$ is the order number, λ is the wavelength, D is the distance between the slit and the screen onto which the image is projected, and y is the distance from the center of the screen to the side of the m^{th} minimum. The average wavelength of the diode laser is 670 nm. For the first order, when $m = 1$, the base value of the slit width can be calculated:

$$a = \frac{m\lambda D}{y}$$
$$a = \frac{(1)(67.0 \times 10^{-6})(96)}{(1.7)}$$
$$a = 3.81 \times 10^{-3}\text{cm}$$

Since the two values with uncertainty, D and y, are being divided, the error of a can be found with:

$$\delta a = a\sqrt{\left(\frac{\delta D}{D}\right)^2 + \left(\frac{\delta y}{y}\right)^2}$$
$$\delta a = (3.81 \times 10^{-3})\sqrt{\left(\frac{(0.05)}{(96)}\right)^2 + \left(\frac{(0.025)}{(1.7)}\right)^2}$$
$$\delta a = 56.1 \times 10^{-6}\text{cm}$$

The same method was used to find the slit width for the second order, where $m = 2$ and $y = 3.5 \pm 25 \times 10^{-3}$cm.

The percent difference between the experimental values of the slit width, $a_{e1} = 3.81 \times 10^{-3} \pm 56.1 \times 10^{-6}$cm and $a_{e2} = 3.71 \pm 27.3 \times 10^{-6}$cm respectively, and its theoretical value, $a_t = 40 \times 10^{-3}$mm, can be found with $\%_{diff} = \frac{|a_e - a_t|}{\left(\frac{a_e + a_t}{2}\right)} \cdot 100\%$. The percent difference for the first order is:

$$\%_{diff} = \frac{|a_{e1} - a_t|}{\left(\frac{a_{e1} + a_t}{2}\right)} \cdot 100\%$$
$$\%_{diff} = \frac{|(38.1 \times 10^{-6}) - (40 \times 10^{-6})|}{\left(\frac{(38.1 \times 10^{-6}) + (40 \times 10^{-6})}{2}\right)} \cdot 100\%$$
$$\%_{diff} = 4.87\%$$

Since the only value with error in the calculation, a_{e1}, is in both the numerator and denominator, the error propagation equation from above, $\delta\%_{diff} = \%_{diff}\sqrt{\left(\frac{\delta x}{x}\right)^2 + \left(\frac{\delta y}{y}\right)^2}$, can be used to find the error in the percent difference of the first order:

$$\delta\%_{diff} = \%_{diff}\sqrt{\left(\frac{\delta a_{e1}}{a_{e1}}\right)^2 + \left(\frac{\delta a_{e1}}{a_{e1}}\right)^2}$$

$$\delta\%_{diff} = (4.87)\sqrt{\left(\frac{(56.1 \times 10^{-6})}{(3.81 \times 10^{-3})}\right)^2 + \left(\frac{(56.1 \times 10^{-6})}{(3.81 \times 10^{-3})}\right)^2}$$

$$\delta\%_{diff} = 101 \times 10^{-3}\%$$

These methods were also used to calculate the percent difference and its error for the second order.

1.1.3 Questions

1.1.3.1

The distance between the minima decreases as the slit width increases.

1.2 Experiment 2: Interference from a Double Slit

1.2.1 Data

Figure 3: **Table 2.1**: The data for the 40 µm/25 µm double slit.

	$(m = 1)$ (cm)	$(m = 2)$ (cm)
Distance between side orders	0.5 ± 0.05	1.0 ± 0.05
Distance from center to side (y)	0.25 ± 0.025	0.5 ± 0.025
Calculated slit separation	$25.7 \times 10^{-3} \pm 2.57 \times 10^{-3}$	$25.7 \times 10^{-3} \pm 1.29 \times 10^{-3}$
% difference	$2.76 \pm 390 \times 10^{-3}$	$2.76 \pm 196 \times 10^{-3}$

slit-to-screen distance $(D) = 97 \pm 0.05$cm

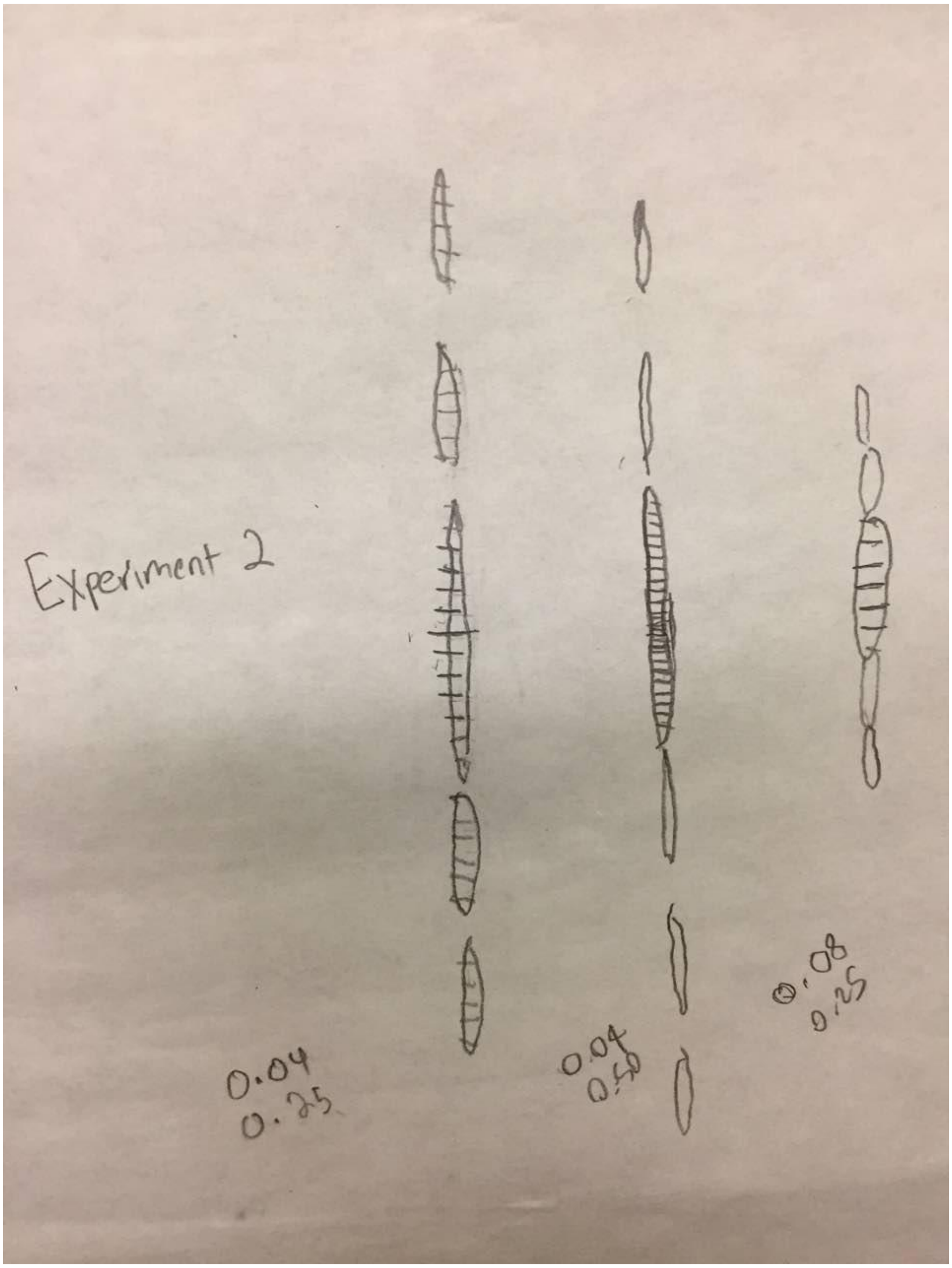

Figure 4: Sketches of the various interference patterns.

1.2.2 Analysis

To get the values of y for the first and second orders, the measured distance between the side orders was divided by a constant, 2. Since the values were divided by a constant, the error of the original value must be divided by that same constant, $\delta y = \pm 0.025$cm.

The slit separation was calculated the same way as the slit width in Experiment 1, using $d = \frac{m\lambda D}{y}$, where $m \in \mathbb{Z}$ is the order, $\lambda = 670\,\text{nm}$ is the average wavelength of the diode laser, $D = 97 \pm 0.05$cm is the distance between the slit and screen, and $y_1 = 0.025 \pm 0.025$cm and $y_2 = 0.5 \pm 0.025$cm are, respectively, the distances from the center of the pattern to the first and second order maxima. The error of the slit separation was also calculated using the same formula from Experiment 1, $\delta a = a\sqrt{\left(\frac{\delta D}{D}\right)^2 + \left(\frac{\delta y}{y}\right)^2}$.

The percent difference between the experimental values of the slit separation, $a_{e1} = 25.7 \times 10^{-3} \pm 2.57 \times 10^{-3}$cm and $a_{e2} = 25.7 \times 10^{-3} \pm 1.29 \times 10^{-3}$cm, and its theoretical value, $a_t = 0.25$mm, may be determined the same way as in Experiment 1, by using $\%_{diff} = \frac{|a_e - a_t|}{\left(\frac{a_e + a_t}{2}\right)} \cdot 100\%$. The error of the percent difference was also calculated as it was in Experiment 1, by using $\delta\%_{diff} = \%_{diff}\sqrt{\left(\frac{\delta x}{x}\right)^2 + \left(\frac{\delta y}{y}\right)^2}$.

1.2.3 Questions

1.2.3.1

When the slit separation is increased, the distance between maxima decreases.

1.2.3.2

When the slit width in increased, the distance between maxima stays the same.

1.2.3.3

When the slit separation is increased, the distance to the first minima in the diffraction envelope stays the same.

1.2.3.4

When the slit width is increased, the distance to the first minima in the diffraction envelope decreases.

1.3 Experiment 3: Comparisons of Diffraction and Interference Patterns

1.3.1 Data

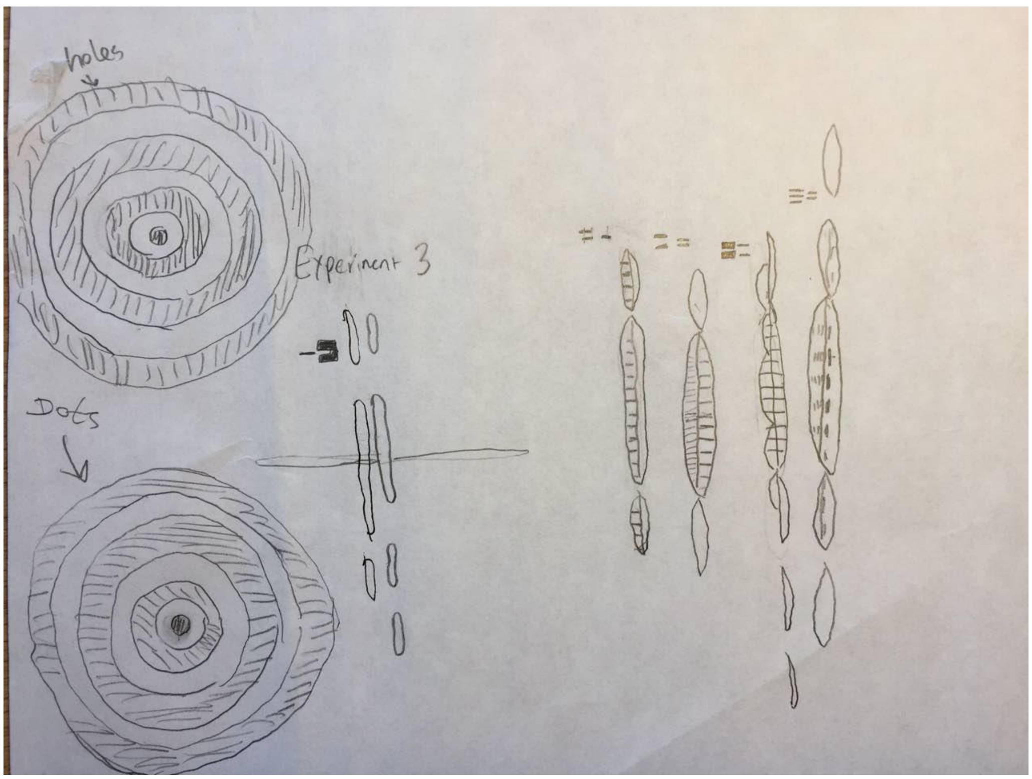

Figure 5: The sketches of the slit disk comparisons and the diffraction patterns. The diffraction pattern comparisons are in order from left to right.

1.3.2 Questions

1.3.2.1

While the single and double slits share a wave envelope when the slit width is the same, the single slit lacks the smaller division within the envelope present in the double slit.

1.3.2.2

As the slit separation is increased, the envelope of the double slit pattern retains its size, but the separation of the inner minima decreases.

1.3.2.3

As the slit width is increased, the wave envelope bunches together, as seen in Figure 1.3.1, but the inner minima separation stays the same.

1.3.2.4

While the envelope and inner slit separation is the same between double and triple slit patterns, the triple slit pattern has another diffraction pattern occurring each maximum that is perpendicular to the inner pattern of the double slit.

1.3.2.5

While the diffraction patterns from both a slit and a line share envelope patterns, they have some noteworthy differences. Not only does the line allow far more light to pass through than the slit, it also has a horizontal component to its pattern that the slit lacks.

1.3.2.6

While both the dot pattern and hole patterns form concentric rings, the dot pattern is darker than the hole pattern, but it has more well defined rings.

2 Conclusion

Experiment 1 was a success because the percent difference between the calculated and theoretical slit widths was relatively small; the greatest difference is for the second order calculations at $7.52 \pm 78.3 \times 10^{-3}\%$. Experiment 2 was similarly successful, with a maximum percent difference of only $2.76 \pm 390 \times 10^{-3}\%$. The differences between the several comparisons in Experiment 3 were well observed.