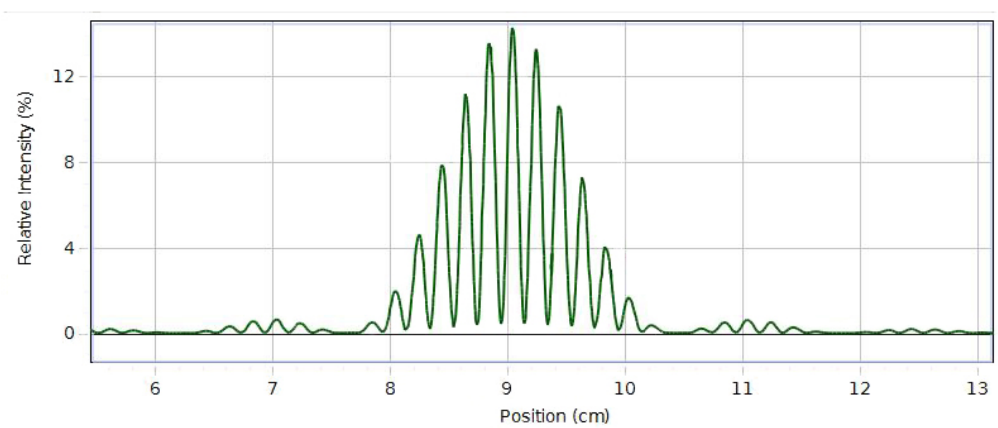
Interference and Diffraction of Light

Equipment

1	Basic Optics Track, 1.2 m	OS-8508
1	High Precision Diffraction Slits	OS-8453
1	Red Diode Laser	OS-8525A
1	Green Diode Laser	OS-8458
1	Aperture Bracket	OS-8534B
1	Linear Translator	OS-8535
1	High Sensitivity Light Sensor	PS-2176
1	Rotary Motion Sensor	PS-2120

Introduction

The distances between the central maximum and the diffraction minima for a single slit are measured by scanning the laser pattern with a light sensor and plotting light intensity versus distance. Also, the distance between interference maxima for two or more slits is measured. These measurements are compared to theoretical values. Differences and similarities between interference and diffraction patterns are examined, including the effect of changing the wavelength of the light.



Double Slit Interference Pattern

Single Slit Theory

When diffraction of light occurs as it passes through a slit, the angle to the minima (dark spot) in the diffraction pattern is given by

$$a \sin\theta = m\lambda \ (m=1,2,3, \ldots) \qquad (1)$$

where "a" is the slit width, θ is the angle from the center of the pattern to a minimum, λ is the wavelength of the light, and m is the order (m = 1 for the first minimum, 2 for the second minimum, ...counting from the center out).

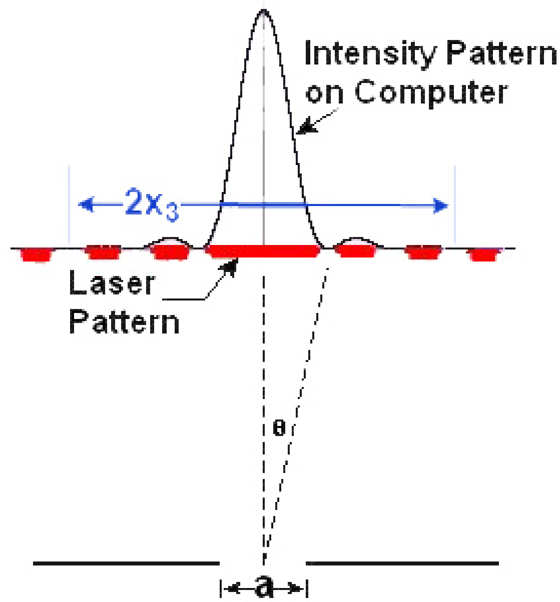


Figure 1: Single Slit Diffraction

In Figure 1, the laser light pattern is shown just below the computer intensity versus position graph. The angle theta is measured from the center of the single slit to the first minimum, so m equals one for the situation shown in the diagram. Notice that the central spot in the interference pattern is twice as wide as the other spots since m=0 is not a minimum.
Since theta is a very small angle, $\sin\theta \sim \tan\theta = x_m/L$, where x_m is the distance from the center of central maximum to the m^{th} minimum on either side of the central maximum and L is the distance from the slit to the screen.

$$\sin\theta \approx \tan\theta = x_m/L \qquad (2)$$

It is easier to measure the distance ($\Delta x = 2x_m$) from the m^{th} minimum on one side to the m^{th} minimum on the other side than to try to judge the center of the pattern. Equation (2) becomes

$$\sin\theta \approx \tan\theta = \Delta x / 2L \qquad (3)$$

Our accuracy will be improved by making (Δx) as large as possible. The slit width is not known very well. The uncertainty in the width is +/- 0.005 mm. That is a 25% uncertainty for the 0.020 mm slit. So instead of using the slit width to calculate a value for the laser wavelength, we use the known wavelength of the laser to calculate a more accurate value for the slit width.

Double Slit Theory

When interference of light occurs as it passes through two slits, the angle from the central maximum (bright spot) to the side maxima in the interference pattern is given by

$$d \sin \theta = n\lambda \quad (n=0,1,2,3, \ldots) \qquad (4)$$

where "d" is the slit separation, θ is the angle from the center of the pattern to the n^{th} maximum, λ is the wavelength of the light, and n is the order (0 for the central maximum, 1 for the first side maximum, 2 for the second side maximum ...counting from the center out).

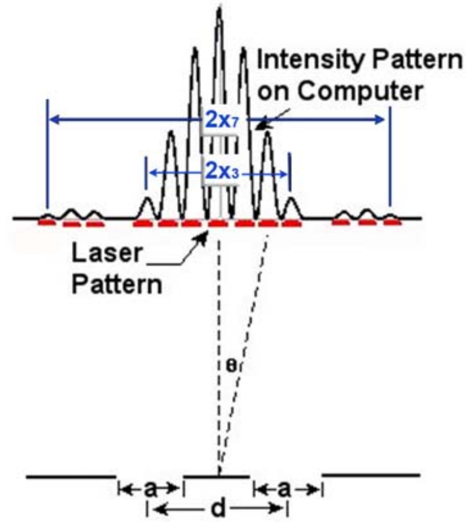


Figure 2: Double Slit Interference

In Figure 2, the laser light pattern is shown just below the computer intensity versus position graph. The angle theta is measured from the midway between the double slit to the second side maximum, so n equals two for the situation shown in the diagram.

As before, theta is a small angle and Equation (3) still holds:

$$\sin \theta \approx \tan \theta = \Delta x / 2L \qquad (3)$$

where $\Delta x = 2x_n$ is the distance from the n^{th} side maximum on one side to the n^{th} side maximum on the other side of the central maximum and L is the distance from the slits to the screen. Since it is more accurate to measure from the n^{th} maximum on one side to the n^{th} maximum on the other side, we will measure $2x_{n.}$.

Note that the single slit diffraction pattern is also present in the double slit pattern. It is responsible for the broad minima that occur (see Figure 2). This means we must be careful when counting n in the double slit pattern since a double slit maximum can be suppressed by a single slit minimum.

Pre-Lab Questions

1. For a single slit, as the slit width is increased, what happens to the pattern? Does the angle to the first diffraction minimum increase or decrease or stay the same?

2. For a double slit, as the slit width is increased, what happens to the pattern? Does the angle to the first diffraction minimum increase or decrease or stay the same? Does the angle to the first interference maximum increase or decrease or stay the same?

3. For a double slit, as the slit separation is increased, what happens to the pattern? Does the angle to the first diffraction minimum increase or decrease or stay the same? Does the angle to the first interference maximum increase or decrease or stay the same?

4. For a double slit, as the wavelength is decreased, what happens to the pattern? Does the angle to the first interference maximum increase or decrease or stay the same?

Figure 3: Complete System

Setup

1. Mount the laser on the end of the optics bench. Mount the High Precision Single Slit disk to the optics bench with the printed side toward the laser as shown. Turn on the laser. CAUTION: Never shine the laser beam directly into anybody's eye! To select the desired slits, just rotate the disk until it clicks into place with the 0.02 mm aperture slit illuminated by the laser.

2. Mount the Rotary Motion Sensor on the rack of the Linear Translator and mount the Linear Translator to the end of the optics track (see Figure 4). Arrange things so the black stop block on the linear translator arm is on the left side as viewed from the laser and all the way against the bracket. Mount the Light Sensor to the Aperture Bracket (set on slit #6) with the 3 cm black rod. Mount the black rod in the Rotary Motion Sensor rod clamp. The Light Sensor should be aligned with the bracket so it points parallel to the optics track.

3. Move the light sensor until you can see the beam somewhere on the white screen. Use the adjustment screws on the laser (see Figure 5) to adjust the position of the laser beam from left-to-right and up-and-down to make the pattern on the white screen as bright as possible. Once this position is set, it is not necessary to make any further adjustments of the laser beam when viewing any of the slits on the disk. When you rotate the disk to a new slit, the laser beam will be already aligned. Since the slits click into place, you can easily change from one slit to the next, even in the dark.

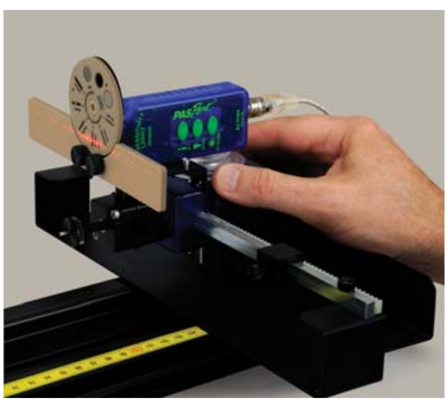


Figure 4: Mounting the Light Source

Figure 5: Aligning the Laser

4. Move the Light Sensor up or down until the light pattern is centered on the slits shown in Figure 6. Use slit #6.

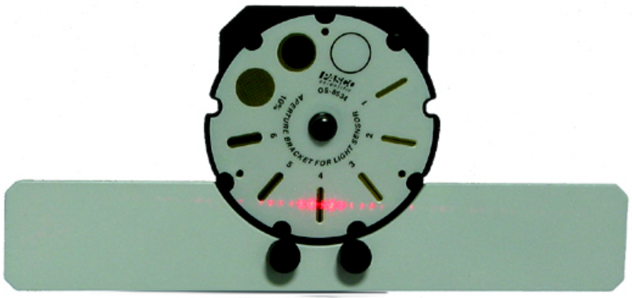


Figure 6: Aligning the Light Sensor Vertically

5. Set the Light Sensor for maximum sensitivity by pressing the 0-1 button. If the Light Intensity goes too high (it will flat line at 100% on the graph), turn the sensitivity down by pressing the (0-100) button on the Light sensor.

6. Plug the Rotary Motion Sensor and the Light Sensor into the *PASPORT* inputs on the 850 Universal Interface.

7. Click open the Hardware Setup button at the left of the screen. Click on the Rotary Motion Sensor icon. To the right of where it says Rotary Motion Sensor at the bottom of the Hardware Setup panel, click on the Gear icon. In the Linear accessory line, click on the white triangle and select Rack & Pinion. Click OK. Click the Hardware Setup button to close the screen.

8. In Capstone, set the Common Sensor Sample Rate to 25 Hz. Create a graph of Relative Intensity vs. Distance.

9. Create a table as shown below.

Table I: Measurement Summary

Label	a (mm)	d (mm)	m	n	Δx (m)	Calculated Slit Width (mm)	Calculated λ (nm)	λ %Difference (%)
0.02 mm	0.020	0.00						
0.04 mm	0.040	0.00						
0.04a-0.25d Run	0.040	0.25						
0.04a-0.25d Run	0.040	0.25						
0.04a-0.50d Run	0.040	0.50						
0.04a-0.50d Run	0.040	0.50						
0.04a-0.25d Green Run	0.040	0.25						

Single Slit Procedure

1. Measure the distance between the slits (front of Slit Disk) and the screen. You can use the scale on the track, but it is easier and more accurate to use a meter stick. Record the wavelength of the laser (printed on its back).

2. Turn out the room lights.

3. Observe the pattern on the screen as you rotate the Single Slit to each of its four positions (0.16, 0.08, 0.04, 0.02 mm). How does the pattern change as you decrease the slit width? Answer Question 1 in the Conclusions section. Set the disk to the 0.02 mm slit.

4. Move the Light Sensor so the Rotary Motion Sensor (RMS) is against the black stop block on the linear translator arm. If the positions are all negative when you start taking data, click on the Hardware Setup and click on the properties gear for the Rotary Motion Sensor and check "Change Sign".

5. Click on the RECORD button. Then slowly turn the RMS pulley to scan the pattern. Hold the rear of the RMS down against the linear translator bracket so it does not wobble up and down as it moves. Click on STOP when you have finished the scan. If you make a mistake, simply delete the run using the Delete Last Run button at bottom of screen and do the scan again. If the intensity maxes out (100%), change the gain setting on the light sensor and repeat the run. Click on Data Summary at the left of the screen. Double-click on Run #1 and re-label it "0.02 mm". Click Data Summary to close it.

6. Repeat for the 0.04 mm slit. Press the 0-100 button on the Light Sensor. Label the run "0.04 mm".

Single Slit Analysis

1. Select the 0.02 mm Run. Click the Scale-to-Fit button on the graph toolbar. Ignore the noise on the central maximum. It mostly arises because the beam from the solid state laser is not very well collimated resulting in the horizontal spread of the beam. This means different parts of the beam from the laser strike the slit at slightly different angles (from the left or right of the beam instead of the center of the beam), resulting in slightly different path lengths to the screen and some additional interference in the pattern. It does not affect the positions of the minimums.

2. We need to expand the vertical scale to see the minimums more clearly. Click and drag the vertical scale to expand the scale. Continue until you can clearly see the 1st minimums (nearest the central max).

3. Click on the Coordinate Tool from the graph toolbar. Drag the crosshairs to the 1st minimum on the left. Right-click on the Coordinate Tool and select Show Delta. Drag the delta to the1st minimum on the right. Record the delta position in the "Δx" column of the table under the Data tab. Note: If the delta value does not have 3 significant figures, right-click on the Coordinate Tool and go to its properties and change the number of significant figures to 3.

4. Solve Equation (1) for the slit width and substitute Equation (3) into Equation (1). Calculate the slit width and enter it into the table.

5. Repeat steps 1-4 for the 0.04 mm Run. Your accuracy will be improved by using minimums further from the center if you can see them clearly. Record the "m" value in the table to reflect the minimum you actually measured. You must use the same minimum on each side of the center!

Double Slit Procedure

1. Note where the index foot is on the bottom of the Single Slit holder with respect to the yellow scale on the Optics Bench. Replace the Single Slit holder with the Double Slit holder so the index foot is in the same position. The distance to the screen should be the same as it was for the single slit experiment.

2. Change to slit #2 on the Light Sensor bracket and push the 0-100 button. Turn out the room lights.

3. Observe the pattern on the screen as you rotate the Double Slit to each of its four positions (a = 0.04 mm & d = 0.25 mm, etc.). How does the pattern change? Can you see the single slit diffraction pattern? Answer Question 2 in the Conclusions section. Set the disk to the a = 0.04 mm and d = 0.25 mm position.

4. Move the Light Sensor so the Rotary Motion Sensor (RMS) is against the black stop block on the linear translator arm. Set the Light Sensor for max sensitivity (0-100).

5. Click on the RECORD button.

6. Then slowly turn the RMS pulley to scan the pattern. Hold the rear of the RMS down against the linear translator bracket so it does not wobble up and down as it moves. Click on STOP when you have finished the scan. If the intensity maxes out (100%), change the gain setting on the light sensor and repeat the run. Click on Data Summary at the left of the screen. Double-click on the current Run #1 and re-label it: "0.04a-0.25d". Click Data Summary closed.

7. Repeat for the 0.04 mm wide slit with slit separation 0.50 mm. Set the Light Sensor bracket to slit #1 and press the 0-100 button. Label the run "0.04a-0.50d".

Double Slit Analysis

1. Select the 0.04a-0.25d Run. Click the Scale-to-Fit button.

2. Click on the Coordinate Tool (graph toolbar). Right-click in the center of the crosshairs and select tool properties. Then increase the number of significant figures to 4. We actually want 4 decimal places which means 4 significant figures when the positions is greater than 0.1 meters.

3. We need to expand the horizontal scale to see the maxima more clearly. The pattern should look like the example on the Intro page.

4. Under the central diffraction pattern, select a maximum that is far to the left of the central max as possible. For example, the n=5 max. (Recall that the central max is n=0.) Drag the crosshairs to the 5th maximum on the left. Right-click on the Coordinate Tool and select Show Delta. Drag the delta to the 5th maximum on the right. Record the delta position in the

"Δx" column of the table under the Data tab. If the number of your max was different from 5, enter your value in "n" column.

5. Your precision will be improved if you can use a larger value of n. We need to expand the vertical scale to see the maximums more clearly. Click and drag the vertical axis upward. Continue until the peak with the cursor on it is near the top of the graph.

6. Recall that you know the n value for the peak the cursor is on and for the corresponding peak on the other side of center. Count n values out as far as you can (you can generally tell how many 2 slit peaks were suppressed by the single slit diffraction pattern). Enter your values in the table under the data tab in the second 0.04a-0.25d Run line. Don't forget to change the "n" value in the table to match the value you used.
7. Solve Equation (4) for the wavelength and substitute Equation (3) into Equation (4). Calculate the wavelength and enter it into the table.

Double Slit with Green Laser

1. Note where the index foot is on the bottom of the red laser with respect to the yellow scale on the Optics Bench. Replace the red laser with the green laser so the index foot is in the same position. The distance from the slits to the screen should be the same as it was before.

2. Align the green laser beam in the same manner as you did before for the red laser.

3. Turn out the room lights.

4. Set the disk to the a = 0.04 mm and d = 0.25 mm position.

5. Move the Light Sensor so the Rotary Motion Sensor (RMS) is against the black stop block on the linear translator arm. Set the Light Sensor for max sensitivity (0-100) and the Light Sensor slit to #2.

6. Click on the RECORD button.

7. Then slowly turn the RMS pulley to scan the pattern. Hold the rear of the RMS down against the linear translator bracket so it does not wobble up and down as it moves. Click on STOP when you have finished the scan. If the intensity maxes out (100%), change the gain setting on the light sensor and repeat the run. Click on Data Summary at the left of the screen. Double-click on the current run and re-label it: 0.04a-0.25d Green. Click Data Summary closed.

Double Slit with Green Laser Analysis

1. Select the 0.04a-0.25d Green Run. Click the Scale-to-Fit button.

2. Click on the Coordinate Tool (graph toolbar). Right-click in the center of the crosshairs and select tool properties. Then increase the number of significant figures to 4. We actually want 4 decimal places which means 4 significant figures when the positions is greater than 0.1 meters.

3. We need to expand the horizontal scale to see the maxima more clearly. The pattern should look like the example on the Intro page.

4. Under the central diffraction pattern, select a maximum that is far to the left of the central max as possible. For example, the n=5 max. (Recall that the central max is n=0.) Drag the crosshairs to the 5th maximum on the left. Right-click on the Coordinate Tool and select Show Delta. Drag the delta to the 5th maximum on the right. Record the delta position in the "Δx" column of the table under the Data tab. If the number of your max was different from 5, enter your value in "n" column.

5. Your precision will be improved if you can use a larger value of n. We need to expand the vertical scale to see the maximums more clearly. Click and drag the vertical axis upward. Continue until the peak with the cursor on it is near the top of the graph.

6. Recall that you know the n value for the peak the cursor is on and for the corresponding peak on the other side of center. Count n values out as far as you can (you can generally tell how many 2 slit peaks were suppressed by the single slit diffraction pattern). Enter your values in the table under the data tab in the second 0.04a-0.25d Green Run line. Don't forget to change the "n" value in the table to match the value you used. Calculate the wavelength as you did for the red laser and enter it into the Data table.

Single Slit Comparison to Double Slit

1. Select the 0.04 mm run and the 0.04a-0.25d run on the graph.

2. How are these patterns similar?

3. How are these patterns different?

Comparison of Double Slits Having Different Slit Separations

1. Select the 0.04a-0.25d run and the 0.04a-0.50d run on the graph.

2. How are these patterns similar?

3. How are these patterns different?

Comparison of Red and Green Wavelengths

1. Select the 0.04a-0.25d run and the 0.04a-0.25d Green run on the graph. You may want to change the colors of these runs to Red and Green in the Data Summary.
2. Which wavelength is longer: Red or Green?
3. How are these patterns similar?
4. How are these patterns different?
5. Do Equations (1) and (4) predict these differences?

Conclusions

1. Using your eyes, how does the single slit pattern change as you increase the slit size?
2. Using your eyes, how does the double slit pattern change as you increase the slit separation?
3. How does the Single Slit Diffraction change as you vary the slit width (a)? Does this agree with your answer to Question 1 above?
4. How does the Double Slit pattern change as you vary the slit separation (d)? Does this agree with your observations from Question 2 above?
5. How does the Double Slit pattern change as you vary the wavelength? Does this agree with your answer to the pre-lab question?