# Single Slit Diffraction & Interference

## Theory - Diffraction

When monochromatic, coherent light falls upon a small single slit it will produce a pattern of bright and dark fringes. These fringes are due to light from one side of the slit interacting (interfering) with light from the other side. The positions of the minima (destructive interference – appears dark because of a lack of light) for a single slit are given by the equation

$$m\,\lambda = a \sin\theta_m$$

where $\lambda$ is the wavelength of the light, a is the width of the slit, $\theta$ is the angle between the central axis of the slit and maximum, and m is an integer = 0, 1, 2, 3, ....

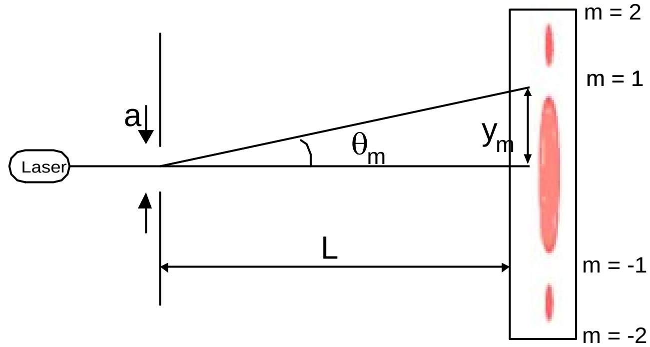



**Fig. 1:** Diagram of a single slit experiment

For a large L (L>>y), we can approximate $\sin\theta_m$ by $y_m/L$. Thus, our equation for the minima becomes

$$m\,\lambda = a\,(y_m/L)$$

Note that we can find the width of the central maximum through:

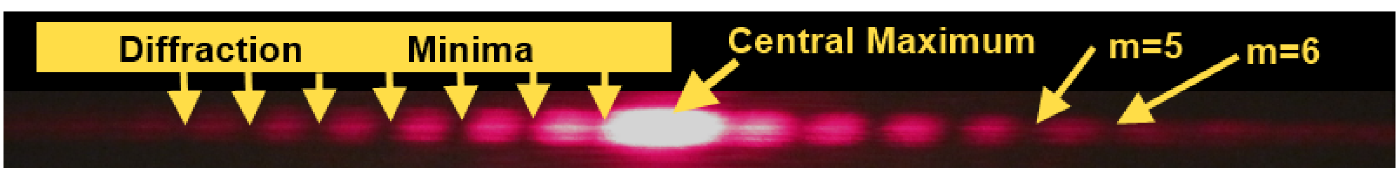
$$\Delta y_o = (y_1 - y_{-1}) = (L(1)\lambda)/a - (L(-1)\lambda)/a = 2(L\lambda)/a$$

For the width of the first maximum and the following maxima:

$$\Delta y_1 = (y_2 - y_1) = (L(2)\lambda)/a - (L(1)\lambda)/a = (L\lambda)/a$$

$$\Delta y_2 = (y_3 - y_2) = (L(3)\lambda)/a - (L(2)\lambda)/a = (L\lambda)/a = \Delta y_1$$

The following Figure shows a pattern similar to what we see in a lab setting. Labels pinpoint the pattern features.




## Theory - Interference

A similar pattern appears when we combine light from two identical source. Since it is practically impossible to obtain two light sources that are identical, we obtain the same effect by shining light from a laser on two closely spaced slits. Each of the slits acts then as a source. We use a laser because the light produced by a laser is monochromatic and coherent.

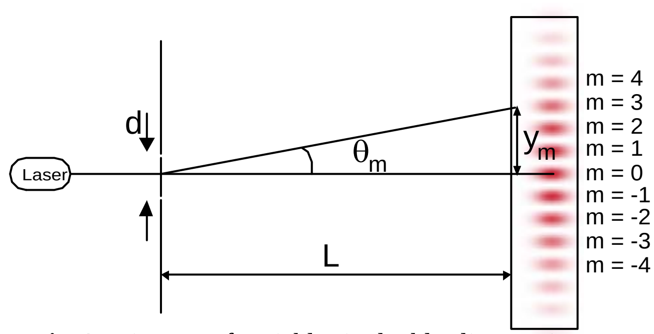



**Fig. 3:** Diagram of variables in double slit experiment

Shining light on the two slits results in a static pattern of constructive and destructive interference fringes like the one shown in Figure 3. These can be projected on a screen behind the slits and appear as bright and dark fringes called maxima and minima. The positions of constructive, bright, interference fringes are given by:

$$m\,\lambda = d \sin\theta_m$$

where $\lambda$ is the wavelength of the light, d is the separation of the slits, $\theta_m$ is the angle between the central axis of the slit and the m-th position of constructive interference, and m is an integer = 0, 1, 2, 3, ....

While this looks very much like the equation that we use for single slit diffraction, it should be noted that this equation refers to maxima, and not minima.

If we restrict ourselves to only consider those maxima that are close to the central maximum, then the angle $\theta_m$ is small. Furthermore, if L, the distance between the slits and screen is large, we can approximate sin $\theta_m$ by $y_m/L$, where, $y_m$ is the distance from the central maximum to the m-th maximum. Thus:

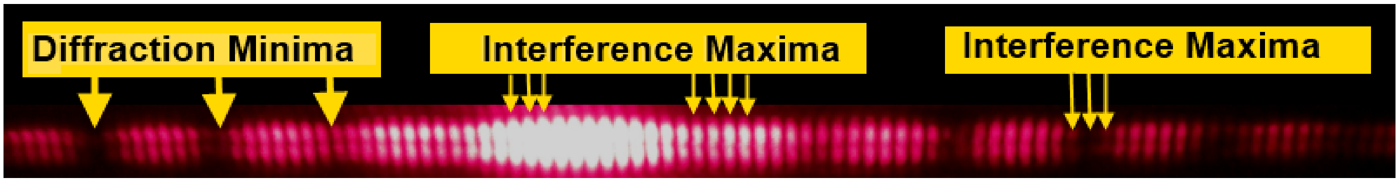
$$m \lambda = d\, y_m/L$$

From this expression, we can show that the separation between two consecutive bright fringes is given by:

$$\Delta y = L\, \lambda/d$$

This formula can enable us to determine the wavelength of the laser beam by just measuring the separation or width of the individual maxima.

Actually, as shown by the following Figure, the pattern that is observed for a double slits is a combination of two patterns, one due to the one slit diffraction and one due to the interference between the two slits.




## Theory – Multiple Slits and Gratings

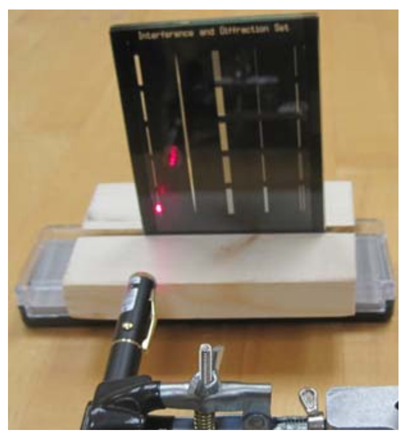
One might ask about what happens when we have more then two slits, lets say 3, 4, or a 1000. It can be shown that in this case, the position of the maxima is given by the same equation as the equation used for two slits. However, the fringes are much narrower, in addition to these bright maxima; faint secondary maxima appear in between. The more slits are present, the thinner the bright fringes become and the fainter the secondary fringes get. This is especially true when the number of slits is very large, secondary fringes become practically invisible.

One set-up involving a large number of slits is called a diffraction grating. It consists of a very large number of slits that are all parallel and separated by very small distances. The positions of the maxima due to a grating are given by:

$$m \lambda = d \sin \theta_m$$

Note that this equation is the same as the equation used for the double slit. However, for gratings, since d is very small, to observe some of the higher order fringes, we usually have to place the screen very close to the grating. **This means that the small angle approximation cannot be used**.

## Procedure – Single Slit Diffraction




In this part, we will investigate the patterns due to a single slit. The setup is shown in the Figure. Paper taped to a square whiteboard can be used as a screen. The provided lasers are rated at 650 nm and 532 nm.

1. Set up the laser on one end of the lab bench, with the screen on the other. The slit accessory should be placed between the two, a few centimeters away from the laser and as far from the white screen as possible.
2. Turn the laser on and position it such that the beam is striking the smallest slit. A pattern similar to Figure 2 should be visible on the screen.
3. Mark the positions of the as many fringes as you can by penciling the position of the minima.
4. Measure the distance from screen to slits.

Distance from slits to screen = L = _______

5. Remove the paper and measure the width of the central maximum and the width of the other fringes.
6. Use the data to calculate the width of the slit.
7. Note the manufacturer data. They provide the width of each of the slits as a multiple of the number 0.087865 mm.
8. Repeat the experiment for the other slit widths.

| Slit | Manufacturer data | Width of Central fringe | Number of Fringes Measured | Average width of Fringes | Measured Slit width | Percent difference |
|---|---|---|---|---|---|---|
| Bottom slit | a= 0.087865 mm | | | | | |
| 2nd slit | 2 a | | | | | |
| 3rd slit | 4 a | | | | | |
| 4th slit | 8 a | | | | | |
| Top slit | 16 a | | | | | |

9. Replace the laser by the green laser and measure the width of the fringes as indicated in the following table.

| Slit | Manufacturer data | Width of Central Maximum | Width of other Fringes |
|---|---|---|---|
| Bottom slit | a= 0.087865 mm | | |

10. Answer the following questions.

    a) How does the average value of the slit width compare to the one given by the manufacturer?

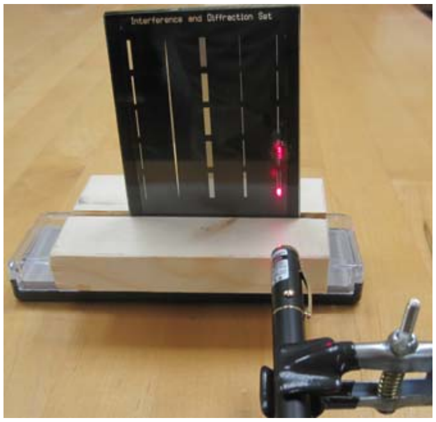
    b) If we knew the size of the slit, could we have used the same method to measure the wavelength of light?

    c) What is the effect of slit width on the positions of the diffraction minima?

    d) Compare the diffraction pattern obtained by the green laser to the one obtained with the red laser? Does the difference in pattern width correspond to what you have expected?

    e) What are the sources of error in this experiment?

### Procedure - Interference




In this part, we will investigate the patterns due to a double slit. The setup is shown in the Figure.

1. Use the same set-up as last time, while using the double slit patterns.
2. Turn the laser on and position the beam such that it is striking the bottom double slits (the slit width as provided by the manufacturer is a = 0.087865 mm, the slit separation is d = 1.317975 mm).
3. Tape a blank sheet of paper to the white board and mark the positions of the as many interference fringes as you can. **<u>(Note that the fringes can be very narrow, be careful not to confuse them to the diffraction fringes. Refer to Figure 4 above for guidance)</u>**
4. Remove the paper and measure the following:

Distance from slits to white screen = L = ________

5. Repeat the same procedure for all four double slits.
6. For each slit separation, calculate the corresponding slit separation and compare the value you have obtained with the manufacturer value.

| Slits | Manufacturer data | Number of Fringes Measured | Average width of Fringes | Measured Slit separation | Percent difference |
|---|---|---|---|---|---|
| Bottom slits | a= 0.087865 mm<br>d=1.317975 mm | | | | |
| 2nd slits | a= 0.087865 mm<br>d=0.615055 mm | | | | |
| 3rd slits | a= 0.087865 mm<br>d=0.263595 mm | | | | |
| 4th slits | a= 0.087865 mm<br>d=0.087865 mm | | | | |

7. Replace the laser by the green laser and measure.

| Slits | Manufacturer data | Number of Fringes Measured | Average width of Fringes |
|---|---|---|---|
| 3rd slits | a= 0.087865 mm<br>d=0.263595 mm | | |

8. Answer the following questions.

   a) What is the effect of slit separation on the position of the positions of the maxima?

   b) How does the position of the diffraction minima correspond to the data you have collected in part 1 of the experiment?

   c) Compare the interference pattern obtained by the green laser to the one obtained with the red laser?

   d) What if we use a light source that is made up of light at two wavelengths, green and red, how would the interference pattern look?

## Procedure – Multiple Slits

In this part, we will investigate the patterns due to more than 2 slits.

1. Use the same set-up as last time, while using the multi-slit patterns. It is right next the double slit patterns.
2. Use the green laser for this part.
3. Turn the laser on and position the beam such that it is striking the second from the top pattern (it corresponds to a 2-slit pattern with a = 0.043933 mm, and d = 0.087865 mm).
4. Tape a blank sheet of paper to the white board.

5. Mark a rectangle of about 10 cm width at around the middle of the observed pattern.
6. Mark the positions of principle maxima (very bright spots) that fit within the rectangle.
7. Determine whether you have secondary maxima between the principle maxima.
8. Repeat the same procedure for all four multi-slit patterns.

| Slit Pattern | Manufacturer data | Number of Principal Fringes Measured | Number of Secondary Maxima Observed |
|---|---|---|---|
| 2 slits | a= 0.043933 mm<br>d=0.087865 mm | | |
| 3 slits | a= 0.043933 mm<br>d=0.087865 mm | | |
| 4 slits | a= 0.043933 mm<br>d=0.087865 mm | | |
| 10 slits | a= 0.043933 mm<br>d=0.087865 mm | | |

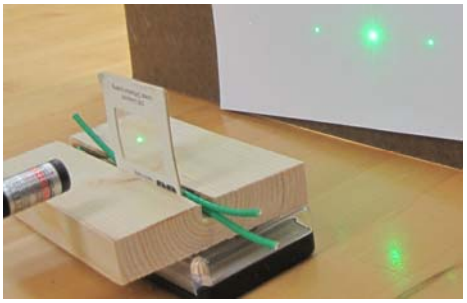
9. Answer the following questions.

   a) Did the position of the principal maxima change as we increased the number of slits without changing a and d?

   b) What is the effect of the increase in the number of slits on the principal maxima?

   c) What is the relationship between the number of slits and the number of observed secondary maxima?

## Procedure – Grating



In this last part, we will investigate the patterns due to a diffraction grating. The setup is shown in the Figure. Note that the screen is now placed close to the grating.

1. Use the green Laser and the 500 line grating.
2. Tape a blank sheet of paper to the white screen and mark the positions of as many bright maxima as you can.
3. Remove the paper and measure the following.

Distance from grating (slits) to white screen = L = _______

Number of bright maxima marked: N = _______

Position of first order fringe: $y_1$ = _______ $\theta_1$ = _______ (calculate the angle)

4. Use the data obtained and 532 nm for the wavelength of the laser light to find the slit separation d:

Slit separation: d = _______ Number of slits per mm: n = _______

Position of second order fringe: $y_2$ = _______ $\theta_2$ = _______ (calculate the angle)

5. Use the data obtained and 532 nm for the wavelength of the laser light to find the slit separation d:

Slit separation: d = _______ Number of slits per mm: n = _______

10. Answer the following questions.
    a) How does the measure n compare to the value marked of the grating slide sleeve?

    b) Should there be secondary maxima between the principal maxima and if yes, why do you think we don't observe them?

    c) What if we use a light source that is made up of light at two wavelengths, green and red, on a grating how would the interference pattern be different?

    d) Why do you think gratings are the more preferred device used in spectroscopy?