Interference of Light Waves

Equipment and Safety:

- ***Do not look directly into the laser. Do not point the laser at other people.***
- ***Be careful about reflections. It's easy to accidentally send a laser reflection into someone's eye.***
- PASCO Optics Track
- Laser, Adjustable Laser Stand
- Diffraction Grating, holder, and stand
- Meter stick and ruler
- PASCO Diffraction Slits (OS-8442)
- PASCO Wireless Diffraction Sensor with USB cable

Objectives

- *To measure the wavelength of laser light using a diffraction grating.*
- *To measure the distance between two slits using interference of laser light.*

Introduction

Light can be treated in terms of "rays" that propagate in straight lines for many circumstances. However, light has a dual character and as a result, when the ray model fails, the wave nature of light is of central importance. The wave properties of light are responsible for such phenomena as the operation of a CD, the appearance of images on a TV screen, and the brilliant iridescent colors of a butterfly's wing. If the dimensions of objects encountering light are large compared to the wavelength of light, light can be treated as a bundle of rays, each ray being a line along which light energy flows. If the dimensions are comparable with the wavelength of light, then the wave theory of light explains the observed optical effects.

The simplest example of diffraction is called the two-slit experiment. A beam of light hits a barrier that blocks most of the light. There are, however, two small slits in the barrier that allow light to pass through. Light propagating from the two slits to a distant screen along parallel paths makes an angle θ with respect to the normal of the slits. The difference in path length is $d \sin\theta$, where d is the slit separation.

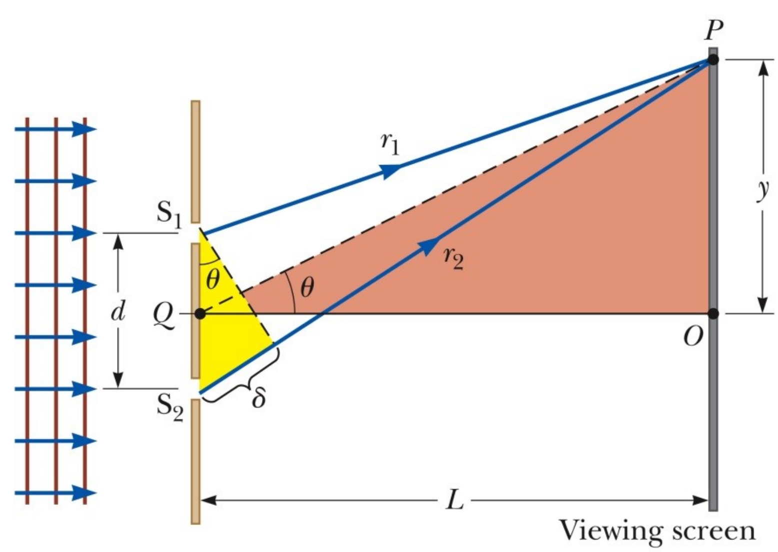

Figure 1. Geometry of the two-slit experiment, including the path length difference δ.
(Source: Serway/Jewett, Physics for Scientists & Engineers, 9th Ed.)

If the path length difference is an integer number of wavelengths, there is constructive interference. So, the conditions for Bright Fringes (Constructive Interference) are:

$$d \sin\theta = m\lambda \qquad \textbf{\textit{Constructive if }} \boldsymbol{m = 0, \pm 1, \pm 2, \ldots}$$

If the path length difference is in halfway in between integer multiples of the wavelength, there is destructive interference. So, the conditions for Dark Fringes (Destructive interference) are:

$$d \sin\theta = m\lambda \qquad \textbf{\textit{Destructive if }} \boldsymbol{m = \pm 0.5, \pm 1.5, \pm 2.5, \ldots}$$

Usually, the angle θ is measured by measuring a large triangle. The adjacent side is L and the opposite side is y in Figure 1. So the angle is found from:

$$\tan\theta = \frac{y}{L}$$

A ***diffraction grating*** is just a series of slits in a barrier. In practice, this is usually done by starting with a transparent film and drawing lines or scratching grooves. As above, we call the spacing *d*. The difference in path length for rays from neighboring slits is the same: $d \sin\theta$

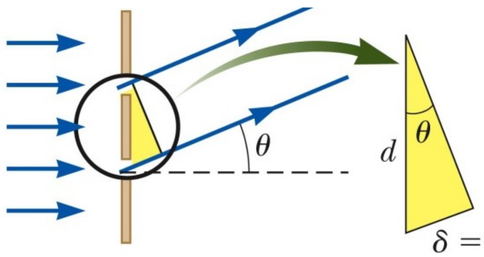

Figure 2. Geometry of the path length difference of a diffraction grating.
(Source: Serway/Jewett, Physics for Scientists & Engineers, 9th Ed.)

The conditions for Constructive Interference in a diffraction grating are the same as in the two-slit experiment. With the diffraction grating, any time *m* is not an integer, there is destructive interference.

A diffraction grating is often characterized in term of the ***line density.*** This is the number of lines per unit length, N. For example, a particular grating might have 2250 lines/cm. The corresponding slit separation, *d* is simply the inverse of the line density.

$$d = \frac{1}{N}$$

In the example, the line spacing is $d = 1/(2250 \text{ lines/cm}) = 0.000444 \text{ cm} = 4.44\ \mu$m.

The ***two-slit experiment*** involves the same kind of diffraction and interference as the diffraction grating. Instead of many alternating lines and slits, there are just two slits. With fewer slits, there is less opportunity for interference, and the diffraction pattern is blurrier. The bright spots are about half as wide as their separation. Still, it is straightforward to measure the separation of the bright spots and relate it to the distance between the slits, using the same math as above.

Part #1. Diffraction Grating

1. The viewing screen is a white, plastic board that should be attached to the optics track a 0 cm.
2. Mount the laser on the other side of the optics track, pointing toward the screen.
3. Place a diffraction grating between the laser and the screen. Then, move the diffraction grating so you can see five bright spots the viewing screen.
4. Measure the distance $\boldsymbol{L}$ between the screen and the diffraction grating.
5. Calculate the slit separation d from the grating density of 530 lines/mm.
6. Measure position of each spot from the central bright spot, $\boldsymbol{y_m}$. Record the values on one side of the central spot as negative. The diffraction order is the "dot number", with the middle one being zero.

Diffraction order, m	Position y_m (m)	$\sin\theta = \dfrac{y_m}{\sqrt{y_m^2 + L^2}}$
-2		
-1		
0	0	0
1		
2		

Table 1. Positions of several diffraction spots in the diffraction grating experiment. The grating has a density of 530 lines/mm. For all data points, the grating-screen distance is $L =$ ___________.

7. Plot **sin$\boldsymbol{\theta}$ vs. $\boldsymbol{m}$.** Use a linear fit to find the slope of the graph.
8. Use the slope and the slit separation to find the experimental wavelength λ.
   Hint: $m\lambda = d\sin\theta$, so $\lambda = \frac{d\sin\theta}{m}$. Substitute out $\sin\theta\,/m$ using the slope of the graph.

Quantity (Units)	**Value**
Distance L (m)	
Grating Density (lines/mm)	530
Grating Spacing d (m)	
Slope of sinθ vs. m	
Experimental Wavelength λ (nm)	
Accepted Wavelength (nm)	
% Error	

Table 2. Experimental results for the diffraction grating setup.

9. Look up the wavelength that corresponds to your laser. You may have a red, HeNe or diode laser.

Part #2. Two-Slit Experiment

In this Part, you'll shine the laser through two slits and use the diffraction pattern to experimentally check the slit separation.

1. Leave laser in same position as Part 1 but replace the Diffraction Grating with the Diffraction Slits with the dial side (i.e. side with various settings) facing the laser.
2. Mount the PASCO Wireless Diffraction Sensor to the optics track while positioning the white screen of the sensor at 10 cm mark. Connect sensor to the computer with the USB cable.
3. Set the Diffraction Slits to the Double Slit with a=0.04 mm and d=0.25 mm.
4. Adjust the Diffraction Slits on the optics track until a diffraction pattern is visible on the white screen. (approx. 20 - 40 cm from the Diffraction Sensor)
   NOTE: Proper alignment is required for a clear diffraction pattern to appear. Make sure laser is aligned with the slits and sensor. Height of the laser should be the same as the hole in the screen.

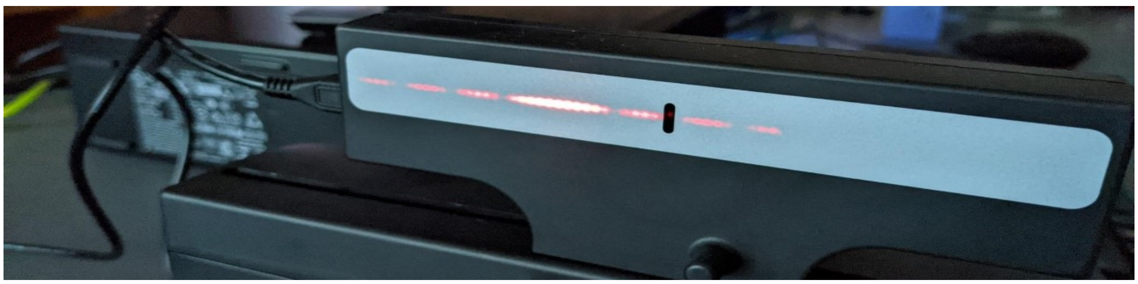

Figure 1: Laser, slits, and sensor are aligned properly showing an alternating pattern that is vertically centered.

5. Measure distance between triangular tabs on the Diffraction Slits and position of the white screen.
6. Open the PASCO Capstone software called *Interference of Light ps550.cap*.
7. Turn crank on the Diffraction Sensor until the hole in the white screen is left of the central spot (i.e bright, middle band).
8. Start recording data. Then, SLOWLY crank the Diffraction Sensor to the right until the hole in the screen is right of the central spot. Stop recording.
9. Measure positions of central maximum and 3 peaks on each side of the central maximum with the Captone Coordinate tool.
10. Calculate Relative Position, y_m by subtracting position of central maximum from each position.

Diffraction order, *m*	Position (mm)	Relative Position y_m (mm)	$\sin\theta = \frac{y_m}{\sqrt{y_m^2 + L^2}}$
3			
2			
1			
0		0	0
−1			
−2			
-3			

Table 3a. Positions of diffraction spots in the two-slit experiment with light of wavelength $\lambda =$ _________, slit separation of $d =$ __________, and the screen distance $L =$ ________.

11. Plot **sinθ vs. m** and use a linear fit to find the slope of the graph.
12. Use the slope and the Experimental wavelength, λ from Part 1 to find the slit separation d.

    Hint: $m\lambda = d \sin\theta$, so $d = \frac{m\lambda}{\sin\theta} = \frac{\lambda}{\sin\theta\ /m}$. Substitute out $\sin\theta\ /m$ using the slope of the graph.
13. Compare the experimental slit separation d to the label on the Diffraction Slits.

Quantity (Units)	**Value**
Distance L (mm)	
Slope of sinθ vs. m	
Experimental Wavelength from part 1, λ (m)	
Experimental Slit Separation, d (mm)	
Actual Slit Separation, d (mm)	
% Error	

Table 4a. Experimental results for the 2-slit experiment setup.

Repeat Part #2 for the next double-slit, which has $a = 0.04$ mm and $d = 0.50$ mm. Report your results in a new graph and Tables 3b and 4b, modeled after Tables 3a and 4a.

Requirements for the Lab Report:

(Note: if this lab report is assigned as a Data Report, omit the Main Body and incorporate a summary of the described discussion points into the Abstract.)

The report must contain a **Header** at the top (Title of Lab, Authors, and Date)

The **Abstract** is a summary of the entire Main Body, so write it last. Place **Abstract** at the top of report.

The **Main Body** of the report must address the following:

- The **Introduction** should describe the basic principles of diffraction and light-wave interference. Describe the basics of the diffraction grating and double-slit experiments. Include the objectives of the lab.
- The **Methods** should describe broadly what was done, using what tools, and what was measured/recorded.
    - Explain how sin θ, grating spacing, and wavelength were determined in Part 1. Explain how slit separation was calculated in Part 2. Explain the difference in methods for Part 1 and Part 2. Use equations to support your statements.
- The **Discussion** should incorporate the following:
    - Data summary of the results for Part 1 including quantities worked into sentences. How did your calculated wavelength compare with the established wavelength of the laser? What are some potential errors for Part 1?
    - Data summary of the results for Part 2 including quantities worked into sentences. How did your calculated slit separation compare with the label on the equipment? What are some potential errors for Part 2? How did the slit separation affect the diffraction peak separation?
- **Conclusions** based on the quantitative data.

- **Data Section** must contain the following:
  [Each table and graph should be labeled and descriptively captioned.]
    - 6 Tables
    - 3 Graphs with trendline equations.