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.

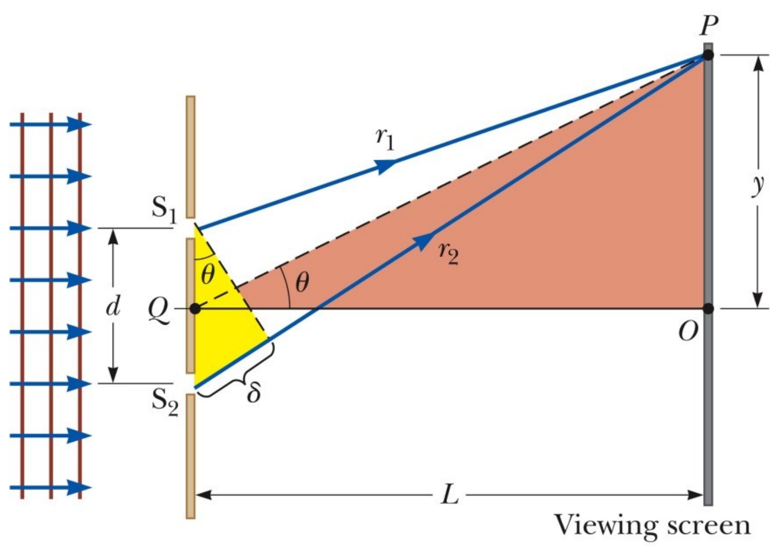

Figure 1. Geometry of the two-slit experiment, including the path length difference δ.
(Source: Serway/Jewett, Physics for Scientists & Engineers, 9th Ed.)

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: $d \sin\theta$

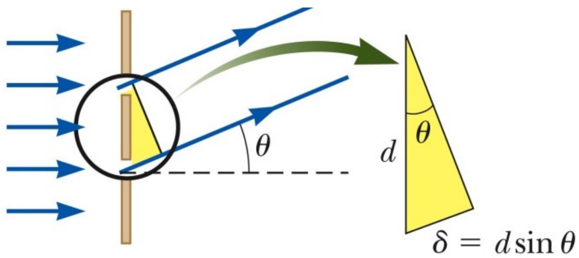

Figure 2. Geometry of the path length difference of a diffraction grating.
(Source: Serway/Jewett, Physics for Scientists & Engineers, 9th Ed.)

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 $d = 1/(2250 \text{ lines/cm}) = 0.000444 \text{ cm} = 4.44\ \mu\text{m}$.

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. For the diffraction grating experiment, the viewing screen is a box or wooden board. Place the track near the screen.
2. Mount the laser on the optics track, far from the screen, pointing toward the screen.
3. Place a diffraction grating between the laser and the screen.
   Move the grating so you can see five bright spots.
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)	Deflection angle θ_m	$\sin\theta_m$
−2			
−1			
0	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 $L =$ __________________. The deflection angle is calculated by $\text{atan}(y_m/L)$.

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 $d = \frac{m\lambda}{\sin\theta} = \frac{\lambda}{\sin\theta\,/m}$. 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	
Expt. Wavelength λ (nm)	

Table 2. Experimental results for the diffraction grating setup.

9. Look up the wavelengths that correspond to the color of the laser dots to assure that your calculated wavelength is reasonable. You may have a HeNe laser or a red diode laser.
10. Remove the diffraction grating from the optics track for Part #2.

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. Position the optics track so one end is near the computer.
2. Mount the PASCO Wireless Diffraction Sensor to the optics track, and connect it to the computer with the short USB cable.
3. Mount the laser to the other end of the optics track, pointing toward the diffraction sensor.
4. Set the Diffraction Slits to the Double Slit with a=0.04 mm and d=0.25 mm.
5. Place the Diffraction Slits on the optics track, close to the laser (a few cm away).
6. Make sure the laser is aligned with the grating and sensor.
   a. When the laser is aligned, the diffraction pattern will be projected onto the sensor screen. The horizontal position isn't important, but the height should be the same as the opening in the screen.

7. Measure the distance from the slit pattern to the screen, and record the laser wavelength from Part #1, so that the parameters can be communicated in the Table 3 caption.
8. Open the PASCO Capstone software called *Interference of Light ps550.cap*.
9. Turn the crank on the Diffraction Sensor all the way to the left. (Be gentle when it hits the end stop.)
10. Start recording data, and slowly crank the scanner until it reaches the far right. Slowdown in the regions where the bright spots lie, so that there are several points for each peak.
11. Use the software graph tools to measure the position of the several consecutive peaks around the brightest one. Once the brightest peak's position is known, subtract it from each position to produce relative positions called y in our formulas.

Diffraction order m	Position (mm)	Relative Position y_m (mm)	Angle θ_m	$\sin\theta_m$
3				
2				
1				
0		0	0	0
−1				
−2				
-3				

Table 3. Positions of several diffraction spots in the two-slit experiment. The laser used had a wavelength of $\lambda =$ _______________, the slits were at a distance of $d =$ _______________, and the screen was $L =$ _______________ from the slits. The diffraction angle was calculated with $\text{atan}(y_m/L)$.

12. Calculate each angle and the sine of each angle. Don't forget that y/L must be computed with compatible units (both mm or both meters).
13. Plot **sinθ vs. m** and use a linear fit to find the slope of the graph.

14. Build a Table 4, similar to Table 2, to present the calculations of this part. Note: Now you know the wavelength first and you will calculate the experimental slit separation d at the end. There is no grating, so don't include that in the Table.
15. Use the slope and the wavelength λ 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.
16. Compare the experimental determination of d to the label on the Diffraction Slits.

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 data plot and Tables 5 and 6, modeled after Tables 3 and 4.

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.