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.***
- Laser
- Diffraction Grating
- Grating holder and stand
- Meter stick and ruler
- Metal Washer for mounting a hair.

Objectives

- *To measure the wavelength of laser light using a diffraction grating.*
- *To measure the thickness of a piece of human hair 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.

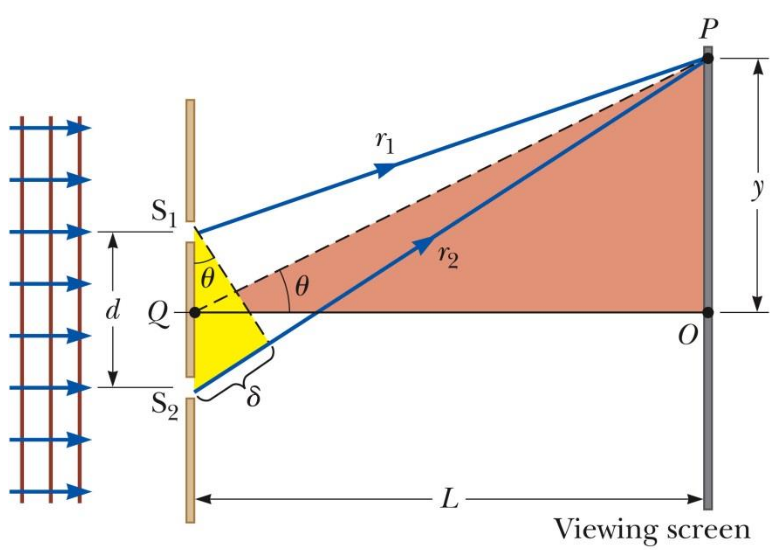

Figure 1. Geometry of the two-slit experiment, including the path length difference δ.
(Source: Serway/Jewett, Physics for Scientists & Engineers, 9th Ed.)

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

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

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:

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

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: $d \sin\theta$

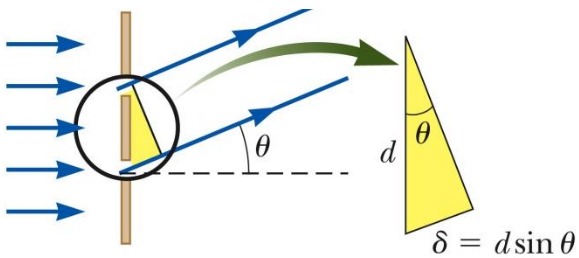

Figure 2. Geometry of the path length difference of a diffraction grating.
(Source: Serway/Jewett, Physics for Scientists & Engineers, 9th Ed.)

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

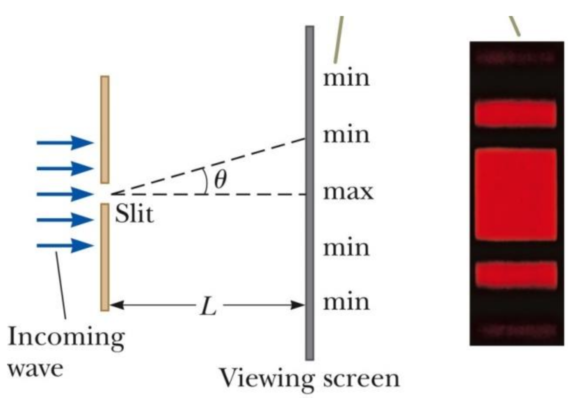

Figure 3. Geometry of single-slit diffraction.
(Source: Serway/Jewett, Physics for Scientists & Engineers, 9th Ed.)

Single-Slit Diffraction: When light of a single wavelength λ passes through a slit of width a, a diffraction pattern of bright and dark fringes is formed.

The mechanism behind single-slit diffraction is explained in the textbook. The conditions for Dark Fringes in a Single-Slit Experiment are very similar to the two-slit equations:

$$m\lambda = a\sin\theta \qquad \text{Destructive if } m = \pm 1, \pm 2, \pm 3, \ldots$$

Notice that the $m = 0$ case is the central bright area. That's just the light that goes straight through.

Why do we care about single-slit diffraction? Mainly because it can be used to find the size of small objects. This is because of Babinet's principle.

Babinet's principle: A theorem concerning diffraction that states that the diffraction pattern from an opaque body is identical to that from a hole of the same size and shape except for the overall forward beam intensity. The principle is most often used in optics but it is also true for other forms of electromagnetic radiation and is a general theorem of diffraction and holds true for all waves. Babinet's principle finds most use in its ability to detect *equivalence* in size and shape. Diffraction patterns from apertures or bodies of known size and shape are compared with the pattern from the object to be measured. For instance, the size of red blood cells can be found by comparing their diffraction pattern with an array of small holes.

Part #1. Diffraction Grating

1. Shine a laser toward a screen.
2. Place a diffraction grating between the laser and the screen. Position it so you can see two bright spots on either side of the main laser spot.
3. Measure the distance L between the screen and the diffraction grating
4. Measure position of each spot, relative to the central bright spot, y_m. Spots on one side should have positive positions while spots on the other side should have negative positions.
5. Use the positions and L to determine the sine of the diffraction angle for each spot. Either use $\sin(\text{atan}(y_m/L))$ or use the formula in the column header.

Diffraction order m	Position y_m of spot (m)	$\sin\theta_m = \frac{y_m}{\sqrt{(y_m)^2 + L^2}}$
2		
1		
0	0	0
−1		
−2		

Table 1. Positions of several diffraction spots in the diffraction grating experiment. The screen was a distance L = ________________ from the diffraction grating.

6. Plot **sinθ vs. m.**
7. Use a linear fit to find the slope of the graph
8. Calculate the slit separation d from the grating density.
9. Use the slope and the slit separation to find the wavelength λ. **Hint:** $\frac{\sin\theta}{m} = \frac{\lambda}{d}$

Quantity (Units)	**Value**
Distance L (m)	
Grating Density (lines/mm)	530
Grating Spacing d (m)	
Slope of $\sin\theta$ vs. m	
Wavelength λ (nm)	

Table 2. Experimental results for the diffraction grating setup.

10. Look up the wavelengths that correspond to the color of the laser dots to assure that your calculated wavelength is reasonable.

Part #2. Measuring the width of a hair.

1. Mount a human hair to one of the washers and place it in front of the laser beam, about 1 to 2 meters from the screen. You should see the laser spot with small lines of light on either side, in a direction perpendicular to the hair.
2. Look closely at the lines of light to notice the dark fringes.
3. Measure the distance ***L*** between the screen and the washer.
4. Tape a sheet of paper to the screen and mark positions of the central spot and each dark fringe.
5. Measure position of each spot from the central bright spot, $\boldsymbol{y_m}$.
6. Record the values on the left side of the central spot as negative.

Diffraction order m	Distance y_m from central spot (m)	$\sin\theta = \frac{y_m}{\sqrt{(y_m)^2 + L^2}}$
3		
2		
1		
0	0	0
−1		
−2		
-3		

Table 3. Positions of several diffraction spots in the hair experiment. The hair was a distance ***L*** = ____________ from the hair during the experiment.

7. Plot **sin*θ* vs. *m*.**
8. Use a linear fit to find the slope of the graph.
9. 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 hair width a at the end. There is no grating.

10. Use the slope and the wavelength λ to find the width of the hair, a. **Hint:** $\frac{\sin\theta}{m} = \frac{\lambda}{a}$
11. The result should be within a range of normal hair thickness or between 25 to 135 μm.

Requirements if Data Report:

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

Abstract Section must contain the following in paragraph form:

- Brief Introduction that includes objectives and basic theory of the lab. Include:
    - Description of the basic principles of diffraction and light-wave interference.
    - Description of the double-slit experiment and Babinet's Principle.
- Methodology describing broadly what was done, using what tools, and what was measured/recorded.
    - *Part 1*: Explain how sin θ, grating spacing, and wavelength were determined.
    - *Part 2*: Explain how sin θ and hair width were calculated.
    - Explain the difference in methods for Part 1 and Part 2, and use equations to support your statements for both parts.
- Data Summary including quantities worked into sentences. Address the following:
    - *Part 1*: How did your calculated wavelength compare with the established wavelength of a Red Helium Neon laser (large, plugin laser)? What are some potential errors for Part 1?
    - *Part 2*: How did your calculated hair width compare with the established range of human hair widths? What are some potential errors for Part 2?
- The lab manual contains several imperatives in each part of the lab that will guide you with the discussion. Make sure to incorporate the imperatives from the lab manual in the text.

Data Section must contain the following:

[Each table and graph should be labeled and descriptively captioned.]

- 4 Tables

2 Graphs with trendline equations.

Requirements if Formal Report:

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

The **Abstract** is a summary of the Main Body, so write it last. Place **Abstract** at the top of report. It must still contain a summary of everything, but more concise. (Much shorter introduction, describe method but don't elaborate on any method steps, give most important experiment results, summarize conclusions.)

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 double-slit experiment and Babinet's Principle. 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 hair width 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 a red Helium Neon laser (large, plugin laser) or a diode laser (handheld laser pointer)? 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 hair width compare with the established range of human hair widths? What are some potential errors for Part 2?
- **Conclusions** based on the quantitative.

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