Physics Labs

General Physics Experiment 11

Interference and Diffraction of Light

Objectives:

- To measure the wavelength of light emitted by a Helium-Neon laser.
- To observe the character of single slit diffraction.
- To observe the character of double slit diffraction.

Equipment:

- Helium-Neon laser
- Diffraction grating, 750 lines per mm
- Slide of single slits, 0.02, 0.04, 0.08, 0.16 mm width
- Slide of double slits, 0.04, 0.08 mm width; 0.25, 0.5 mm separation
- Foam slit holders and wood grating holder block
- Wooden stand (vertical wooden board on a base)
- Meter stick, two meter stick
- CD
- Lycopodium powder
- Clear plastic ruler
- Graphical Analysis software

Physical Principles:

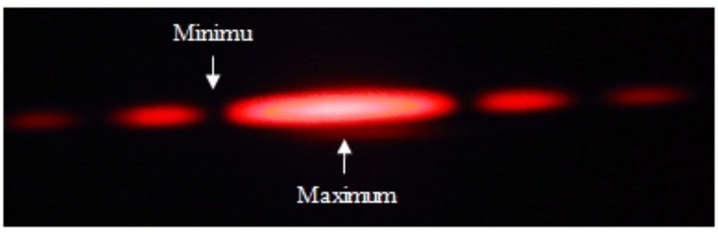
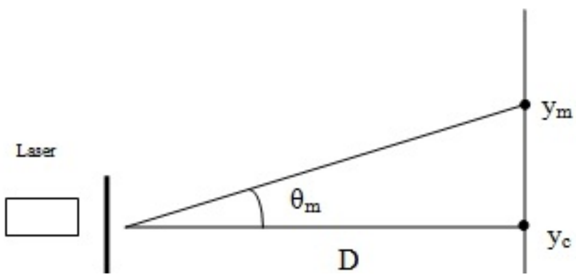


Figure 1 *The bright spots are the maxima, the dark spots between*



them are the minima.	 **Figure 2** *Geometry of diffraction grating top view*

Diffraction Grating

A diffraction grating consists of a series of opaque and transparent strips. Light passing through the grating is broken up into portions which come through each slit. The light from the various slits interfere with one another producing dark and bright fringes. Bright fringes occur when the path length of the light from adjacent slits to the screen is an integral multiple of the wavelength. These bright fringes or constructive interference are given by:

$$d\sin(\theta) = m\lambda$$

(1)

where d is the distance between adjacent slits (d = 1/750000 = 1.333×10-6 meters), θ is the angle from grating-source line, and m is the order number (an integer counting left and right from the central maxima)

Double slit

The double slit is a special case of the diffraction grating with 2 slits. Therefore equation **(1)** gives the condition for the location of the bright fringes.

Single slit

When light passes through a single slit, the light from different portions of the slit interferes, again producing a series of bright and dark fringes. Total destructive interference will occur when

$$a\sin(\theta_m) = m\lambda$$

(2)

where a is the width of the slit, θ is the angle of the dark center from the source-slit line, and m is the order number.

Small Angle

In the case of a small angle, θ_m, the sine of the angle can be approximated with the angle itself in radians. Thus, equation **(2)** can be rewritten as

$$a\theta_m = m\lambda$$

(3)

The angle θ_m in equation **(3)** is the same as the one in Figure 2 and for small angles it is given by

$$\theta_m \approx \sin(\theta_m) = \frac{y_m}{L}$$

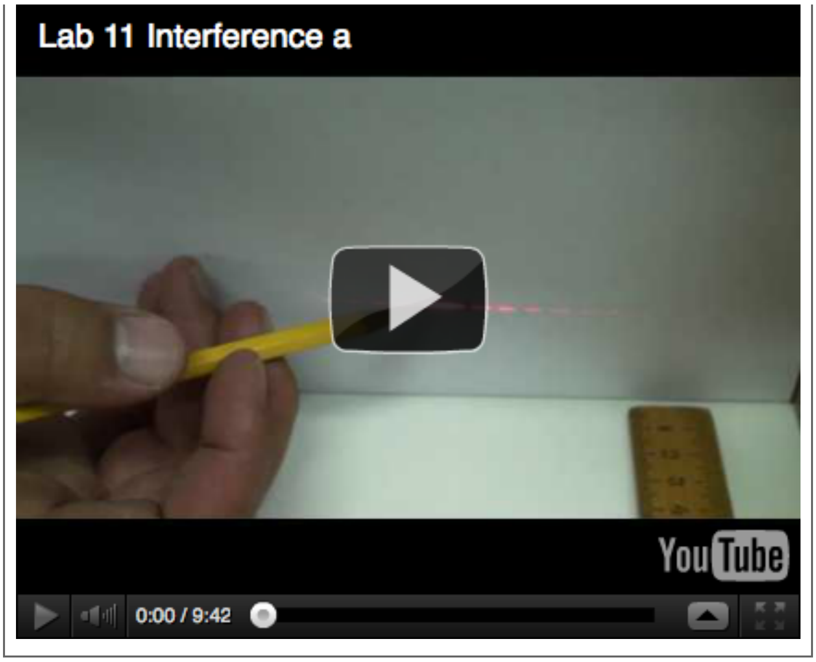
(4)

From equations **(3)** and **(4)** the following relation can be written

$$y_m = \frac{L\lambda}{a}m$$

(5)

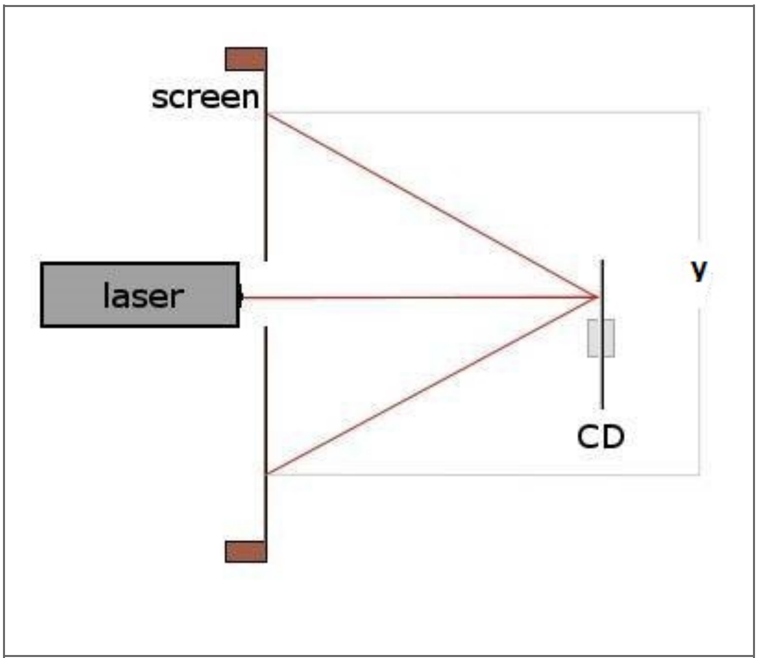
Procedure:



A. Diffraction Grating

1. Place the diffraction grating into the foam holder block.
2. Tape a blank sheet of paper to the wooden stand.
3. Position the holder so that the grating is 0.5 m from the wooden stand and parallel with it.
   a. Try and get your distance to be as close to .5m as possible and still have the refraction on the screen.
4. Direct the laser beam through the diffraction grating.
   a. Make sure that the grating is perpendicular to the laser beam, measurements can be wrong if the maxima are not centered around the central maximum.
5. Mark the position of the first two order maxima and the central maximum on the paper.
6. Remove the paper and measure the distance between your two extreme marks and divide by 2. This is the distance to the first order maxima, y_1.
7. Using the given 1/d = 750,000 lines per meter, and $\theta_1 = \tan^{-1}\left(\frac{y_1}{L}\right)$, calculate θ_1.
8. Calculate the wave length of the helium-neon laser red line using the equation for constructive interference of a diffraction grating.
9. Compare your measured wavelength and the accepted value of 632.8 nm.

B. Groove Spacings on a CD



CD setup (birds eye view)

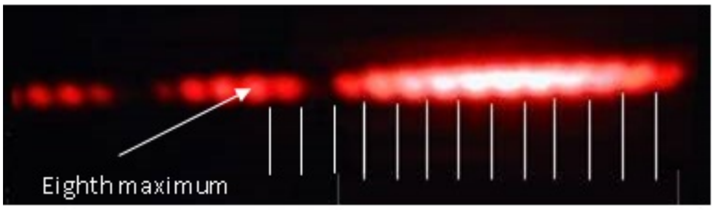
1. Insert a CD into the foam holder so that the beam reflects off the CD and onto the paper taped to the two wooden stands. (see CD setup)
   a. The two boards should be separated by a small slit to let the laser light through.

   b. Reflect the reflected laser light directly back into the laser (this is the central maximum), the refracted light should be seen on the wooden stands (these are the diffuse maximum).
2. Mark the centers of the two diffuse maxima on either side of the laser.
3. Measure the distance separating the diffuse maximum, (y), and divide by 2, (y_1).
4. Record the distance from the CD to the paper, (L).
5. Calculate θ and then $sin(\theta)$ using:

$$\theta = \tan^{-1}\frac{y_1}{L}$$

6. Using λ = 632.8 nm calculate the spacing, (d), noting that in this case m = 1.
7. Compare with the industry standard of 1.6 µm for a CD. (The standard for a DVD is 0.74µm and for a Blu-ray disc is 0.32 µm)

C. Double slit interference



Measure 10 fringes

Use: .25 mm slit space and a slit width of 0.04 mm

1. Place a double slit slide in the foam holder and position it about 1 - 1.5 m from the wooden stand.
2. Move the laser until it is directed through the double slit that has a slit separation of 0.25 mm and a slit width of 0.04 mm.
3. Tape an 8.5”x11” of paper on the wooden stand with the long side horizontal.
4. Mark the first eleven fringes record the total distance.
5. To get the width of the central maxima, (y_1), divide by 10.
   a. Since the perfectly destructive and perfectly constructive interferences are evenly spaced, we can use the distance between the first two destructive minima (width of central maxima) as the same distance between the first two constructive maxima.
   b. With this approximation we can use the equation for constructive interference.
6. Calculate λ using the width of the central maxima, (y_1 as the width to the first order maximum), the distance between the screen and the double slit, (L), the distance, (d), between the slits, and the small angle approximation.

$$\sin\theta \approx \frac{y_1}{L}$$

so constructive interference can be expressed as:

$$\lambda \approx d\frac{y_1}{L}$$

7. Compare with the wavelength of 632.8nm

D. Width of Single Slit

Use: 0.02 mm slit width

1. Tape a blank sheet of paper to the wooden stand and position it so that it is on its side.
2. Mount the single slit slide in the foam holder and position it 50 cm from the wooden stand.
3. Move the foam holder and slide sideways until the laser beam passes through the 0.02 mm wide slit.
   a. The diffraction pattern should have a maximum brightness and sharpness. Make sure the slide is perpendicular to the beam so that the diffraction pattern is symmetrical about the central maximum.
4. Position the paper with the long side horizontal so that the central minima is near the center of the sheet.
5. Use a pencil to carefully mark the centers of the diffraction minima (dark bands).
6. Measure the distance between the two first-order minima and divide by two to get y_1.
7. From y_1, the distance from the screen to the slit L, and λ find a or slit width.

$$a = width = \frac{\lambda L}{y_1}$$

8. Compare with the printed slit width.

E. Width of Lycopodium Spores

1. Dip the end of your microscope slide into the Lycopodium powder to a depth of .5 inch and knock of any excess so that a thin approximately even distribution is obtained.
2. Set the laser about 1 m from the stand and shine the beam through the powder on the slide.
3. Tape a piece of paper on the stand and mark the central bright spot that appears.
4. Measure the diameter of the circumference of the central bright spot and divide by 2 to get the radius, (R).
5. Measure the distance from the slide to the screen, (L).
6. Calculate the size of the diffracting objects (powder spores) using:

$$d = \frac{1.22\lambda L}{R}$$

where λ = 632.8 nm

7. Compare your answer to the diameter of lycopodium spores, 25 to 40 µm.

F. Spacing of Atoms in a Graphite Crystal

Through Electron Diffraction

Ask your instructor for the setup

1. Measure the diameter of the largest bright circle and divide by 2 to get the radius, (R).
2. Measure the distance from the screen to the graphite crystals, (L)
3. Record the Voltage, (V)
4. Calculate and record the Bragg Angle.

$$\theta = \frac{1}{2}\tan^{-1}\frac{R}{L}$$

5. Calculate and record the crystal spacing.

$$2d\sin\theta = \lambda$$

Note the wavelength of an electron beam is given as $\lambda = \sqrt{\frac{1.505}{V}}$

6. Compare with the accepted value of .123 nm.

Further Investigation

Treat the double slit as a single slit.

1. Explain why the pattern is similar to the single slit.
2. Calculate the slit width for each slit using the single slit pattern it creates.

eJOURNAL REPORT 11

Instructions

- Copy and paste this entire eJournal Report section into a blank WORD file.
- Complete the report in WORD.
- You may wish to modify borders in the tables.
- Submit your report by uploading the WORD in our class D2L site. If the D2L site is down, email

the completed report file directly to a lab TA or to physics@andrews.edu [mailto:physics@andrews.edu].

Score: /30

Layout: /2

- Title:
- Names: (Indicate who the scribe was. Alternate duties for each lab.)
- Date
- Time In & Out:

Preliminaries: /4

- Personalized Statement of Objectives:
- Methods Used: (Insert a labeled webcam image of apparatus. Describe what and how measurements are made.)
- Predictions:

Data: /8 and Results: /6

A. Diffraction Grating

1. Describe your data collection techniques for measuring the wavelength of a He-Ne laser.
2. Insert a labeled image of your setup and the maxima on the screen.
3. Record the distance separating the diffraction grating and the paper screen:
    a. L =
4. Record the distance from the central maximum to the first-order maximum:
    a. y_1 =
5. Calculate the corresponding angle,
    a. Angle = …rad or deg (keep only one, you decide on radians or degrees).
6. Calculate the slit spacing,
    a. d = 1/(750,000) =
7. Calculate the wavelength of the laser
    a. λ = ….m
    convert to nm
    b. λ = ….nm
8. Compare your measured wavelength with the accepted value of 632.8 nm:
    a. % differnce =

B. Groove Spacings of a CD

1. Describe procedure for determining the spacings of grooves on a CD.
2. Insert a labeled image of your setup.
3. Record the average distance of the first maxima on both sides from the central maximum:
    a. y_1 ave =
4. Record the distance from the CD to the screen:
    a. L =
5. Calculate the corresponding angle:
    a. Angle = ….rad or degrees (you choose).
6. Determine the spacing, d, for m = 1:
    a. d = ….m
    convert to micro meters
    b. d = ….µm.
7. Compare with the industry standard of 1.6 µm (or 0.74 µm if you used a DVD):
    a. % Difference =
8. What would you expect for the angle of the first maximum if this experiment were performed on a DVD (or CD if you used a DVD in your experiment)?
9. What if the same experiment were performed on a blu-ray disk?

C. Double Slit Interference

1. Describe your procedure for measuring the location of the nth interference maximum.
2. Insert a labeled image of your apparatus and the interference pattern.
3. Record the distance from the double slit to the observation screen:
    a. L =
4. Record the distance of your ten fringes:
    a. y_{10} =
5. Divide by ten to get the average maxima width:

    a. $y_{10}/10 = y_1$ ave. =
6. Use this as the distance to the first order maximum, and calculate λ:
    a. $\lambda =$
7. Compare with the wavelength of the laser, 632.8 nm
    a. % Difference =

D. Width of Single Slit

1. Describe your data collection technique for determining the width of the slit.
2. Insert a labeled image of your setup and the diffraction pattern.
3. Measure the distance from the slit to the screen:
    a. L =
4. Record the average distance of the first maxima on both sides from the central maximum:
    a. y_1 ave =
5. Calulate and record the slit width
    a. a = ….m
       convert to millimeters
    b. a = ….mm
6. Compute the percent difference between the value of a from this experiment and the value of 0.02 mm printed on the slit:
    a. % difference =
7. What happens to the width of the central maximum if the slit width is increased?

E. Width of Lycopodium Spores

1. Describe your procedure.
2. Insert labeled image.
3. Record the radius of the central bright region:
    a. R =
4. Record the distance from the spores to the screen:
    a. L =
5. Calculate the size of the diffracting spores:
    a. Width = …. m
       convert to micrometers
    b. width = …. µm
6. What would happen to the radius of the central bright region if the spores were smaller in size?
7. Compare the width with the spore range of 25 to 40 µm.

F. Spacing of Atoms in a Graphite Crystal

1. Describe your procedure.
2. Record L
    a. L =
3. Record R
    a. R =
4. Caclulate the Bragg Angle:

$$\theta = \frac{1}{2}\tan^{-1}\frac{R}{L} =$$

5. Calculate d (your value for d will be in nm)

$$d = \frac{\sqrt{\frac{1.505}{V}}}{2\sin\theta} =$$

6. Compare d with .123 nm
    a. %Difference =

Further Investigation

1. Treat the double slit as a single slit and explain why the pattern is so similar to the single slit.
2. Calculate the slit width for the double slit using the single slit pattern it creates.

Conclusion: /4

In this section you can include general statements saying:

- Whether your measurements confirm the stated objectives.
- What fundamental physical laws were illustrated by the experiment
- How the experimental error could have been reduced in the experiment.

Also include a constructive critique of the lab, stating what went well, what didn't, and how the laboratory could be improved.

Abstract: /4

This is a formal statement of what this laboratory experiment was all about.

Included in this paragraph should be something about:

- The Objectives
- Your Results
- Your Conclusions

Certification: /2

- Document your completion of this lab with your partner by inserting a webcam photo of yourself, your partner, your apparatus, and your TA.
- Include a statement that the work done in this lab and submitted in this report is yours and your partners.
