

EXPERIMENT O-4

Diffraction and Interference

Abstract

Measurements of diffraction and interference patterns are used to determine the wavelength of light from a helium-neon laser. This wavelength is then used to find the thickness of a human hair, demonstrating "Babinet's principle".

References

Reese, University Physics, Brooks/Cole (2000): Sections 24.1 to 24.4 and 24.7.
Huggins, Physics2000, Moose Mountain Digital Press (1999): pages 33-6 to 33-11.

Pre-Lab

Please do this section before coming to lab. If this is your first Physics 107-108 experiment, begin by obtaining the lab notebook described in the course bookstore list. Read the first two pages of "The Intro Lab - Getting Started" found at the *Modern Physics Lab – Getting Started/Lab Guidelines* link on the physics 108 web page. It describes how to set up your lab notebook. Number your notebook pages (both sides), and begin a Table of Contents on page 1 by listing this experiment as the first entry. As described in "Getting Started", start your pre-lab notes for this lab at the top of page 2. Read the remainder of "Getting Started", answering the tutorial questions as you go along and recording the key points you learn in the lab notebook. If you need help with this or any part of the pre-lab, feel free to ask your professor or a lab instructor!

Review the reference materials listed above. Note that the word "diffraction" is used to describe what happens to light that passes through a single slit of width **a**, while "interference" is used when discussing the overlapping of two or more diffracted beams of light from very narrow slits separated by distance **d**. In this experiment you will sometimes see diffraction and interference simultaneously, and the trick will be distinguishing one from the other.

Begin by finding a textbook figure that plots, as a function of angle, the intensity of light emerging from a single slit of width **a**. Note that at certain angles the intensity is zero. These give the locations of diffraction minima (dark spots) that you can see on a wall if you shine a laser beam through a single slit. Find an equation that gives you the angles corresponding to the **diffraction minima** for monochromatic light passing through a single slit of width **a**. In this experiment all observable diffraction minima appear at very small angles, so you can use the small angle approximation, $\sin \theta = \theta$ (in radians). Rewrite the textbook equation using this approximation, and solve it for the wavelength, λ . You'll use this result in lab to find the wavelength of a laser.

Next, find a textbook figure that plots intensity vs. angle for 2-slit interference. Find the equation that describes the locations of intensity maxima (bright spots) in the interference pattern. Using this equation how would you find the intensity minima for the interference pattern. Rewrite the equation, using the small angle approximation, and find out how much the angle changes when you move from one "max" to the next. Compare to the change in angle when you go from one "min" to the next. As you can see, these spacings are uniform, i.e. all the interference bright spots have the same width. This is different from diffraction, in which the central bright spot is twice as wide as all the others. In lab, a good way to reduce the effect of measurement uncertainty is to measure the total width of a large number of bright spots and then divide by the appropriate number when calculating the wavelength.

To make sure you are prepared, read the **Procedure** section below, and feel free to ask questions!

Apparatus

Helium-neon laser
35mm slide with single and double slits
Slide Holder
Microscope Lamp

Traveling Microscope
Dial Caliper
Tape Measure

Procedure

Examine the 35mm slide. It has a single slit (A) and 5 double slits (B thru F) arranged side by side across the width of the slide. With the slide in its holder so that the slits are vertical, place the holder a few cm in front of the laser, so the laser beam goes through the single slit. Adjust the height of the holder so the laser beam is near the middle of the slit's length. A diffraction pattern should appear on the far wall. Expand the pattern by making the slit to wall distance as large as possible, tape a piece of white paper to the wall so that the diffraction pattern is spread out across the paper, and dim the lights to see the pattern clearly. Note that the laser beam is wider than the slit, so that by **gently** sliding the base of the slide holder from side to side on the table you can vary the brightness of the diffraction pattern. The pattern is brightest when the center of the laser beam is at the center of the slit's width. Use a little masking tape to mark the location of the slide holder's base on the table, so if it gets moved you can replace it without altering the slit to wall distance.

Begin marking the places on the paper where the different parts of the diffraction pattern are located. Later you will measure the distances between marks to find the sizes and locations of the different parts of the pattern. Some good things to mark are the locations of the intensity minima (dark spots), and the center of the entire pattern. **QUESTION 1:** *Which parts of the pattern should you mark in order to get the laser's wavelength with smallest possible uncertainty?* Use different markings for different things, make the marks in such a way that your estimates of the uncertainties in their locations are also indicated, and try to go out as far as possible on either side of the pattern's center. Check that your marking system makes sense by (without moving anything!) blocking the laser beam, turning on the lights, and examining the paper. Can you visualize the diffraction pattern using only the marks you made? When you've finished marking, measure the distance between the slit and the center of its diffraction pattern on the wall.

Keeping the paper's location on the wall the same, move the slide holder sideways, and examine the different interference/diffraction patterns produced by the double slits labeled B through F. Observe how your markings from the single slit diffraction pattern correlate with the patterns for the double slits. Make sure you can distinguish between interference and diffraction in the double slit patterns, and check your understanding with an instructor. **QUESTION 2:** *The spacing of the interference minima is always _____ than that of the diffraction minima. Why?*

Without changing the slide to wall distance, move the double slit labeled either C or D in front of the laser. Move the paper so the new pattern is separated from the marks from the single slit, but leave room for a third pattern to be added later. Center the laser beam on the double slit (i.e., in the opaque region *between* the slits), such that each slit gets the same amount of light making the interference minima clear as possible. Notice how the pattern is affected if more light goes through one slit than the other. Once again, mark the center of the pattern and the points of minimum intensity. Carefully distinguish between the diffraction minima and the interference minima. When you've finished marking, shift the paper again and repeat this entire procedure, using a different double slit each time, until you have markings for as many double slits as there are members in your lab group. Make sure that for each pattern you have recorded the distance from slide to wall, and which double slit was used. Take the paper from the wall, and tape it immediately into your notebook. You may make a photocopy later for your partner's notebook.

Place the 35mm slide on the movable microscope stage, so that the slit lengths are perpendicular to the direction the stage moves. Using the microscope, measure the width, **a**, and the spacing, **d**, for each slit set used. Remember that **d** is the distance from center to center (or left-edge to left-edge, etc.), **not** the width of the opaque region between slits. You should be able to measure the distances to $\pm 0.001\text{mm}$ (do you know why?). To avoid potentially large sources of uncertainty, eliminate "backlash" in the micrometer screw by always turning it in the same direction, and don't touch the eyepiece or readjust the focus during a measurement procedure. Use the "three times - alternating partners" approach to justify your uncertainty for this type of measurement.

Babinet's Principle

So far, you have seen diffraction and interference by slits, which are narrow transparent strips in an otherwise opaque slide. It happens that the same phenomena occur with opaque strips in a transparent slide. For example, shining the laser at a thin wire produces a diffraction pattern almost exactly like the one from a single slit. This is known as Babinet's Principle. In this part of the experiment you'll use your laser wavelength and the diffraction pattern from a human hair to find the hair's thickness.

Tape samples of hair to the slide holder, and look at the diffraction patterns they produce. **QUESTION 3:** *From your observations, what is the difference between the diffraction pattern of the hair and that of a single slit of the same width?* Mark at least one pattern as you did before, make sure the hair to wall distance is recorded, and then feel free to make up some original experiments of your own. When you are finished, immediately tape the marked paper into your lab notebook. Also, directly measure the diameter of your hair sample(s), using the traveling microscope.

Sample Calculations

Select one pair of symmetrically placed marks, with large order number **m**, on either side of the center of the single slit diffraction pattern. From the distance $2y_m$ between these marks and your measured slit width **a**, calculate a best value for the laser wavelength. In a similar way, calculate the best wavelength using the interference data for one of your double slits, but be careful: interference order numbers are counted differently, and give intensity maxima rather than minima! Finally, use one of your wavelength results and one-diffraction order for a hair sample to calculate a value for the hair's thickness. Compare this value to the measured thickness.

Dismantle the apparatus, unplug any equipment, remove tape from the counter top, and return the lab to its original state.

Analysis

From the marks made for your single slit diffraction pattern, measure the distances between symmetrically placed minima (minima with the same order number on either side of the pattern's center), recording the results in a table in your notebook. Do the same for the **interference** minima from one double slit pattern, each lab partner analyzing a different double slit pattern.

Following Sample Analysis O-4 found on the *Laboratory Handouts* page linked to from the Physics 108 web page, start an Excel table for the single slit, with columns for order number **m**, the distance $2y_m$ between the corresponding symmetrically placed minima, the slit width **a**, the slit to screen distance **L**, and the calculated wavelength λ . In your notebook, using normal algebra, write an equation for λ in terms of $2y_m$, **a**, and **L**. On the Excel worksheet, enter the data from your notebook table in the first two columns (**m** and $2y_m$). Enter your best values for **a** and **L** on all rows, and use Excel formulas to calculate the corresponding wavelengths and their average value. In your notebook, write the Excel formula used to calculate λ for your

first row of data. If your table has at least 10 rows, use the standard deviation technique to find the partial uncertainty in the wavelength with respect to (a.k.a. wrt) $2y_m$. Do you see why this gives the partial wrt $2y_m$? If there are fewer than 10 rows, estimate this partial uncertainty from the scatter in your results. Skip a worksheet row, and do a partial uncertainty analysis for the remaining variables, a and L , that went into your wavelength calculations. Putting everything together, state a final result for λ , as determined from your single slit experiment.

Important: In this and future labs, be sure to write in your lab book the Excel formulas used for calculations, and be sure your printed spreadsheets include the row and column labels that appear in these formulas.

Following the steps of the last paragraph (the only differences are the formulas), analyze your double slit interference data, obtaining a second "final result" for λ . This time, be sure that you include enough data so that you can use the standard deviation technique to get the partial uncertainty wrt $2y_m$. Compare your result for λ to the one obtained by your lab partner, if any, and to your own single slit result. State clearly which results agree with each other within uncertainty limits and which do not.

Finally, using your favorite final result for λ and a single diffraction order (choose the one you think will give the least uncertainty), determine the thickness of a hair sample. Use "worst case" analysis to find the uncertainty, and compare to the hair thickness you measured in lab.

Questions

4. Which hair thickness is more accurate: the one measured with the microscope or the one found from diffraction? Explain.

Write a conclusion that summarizes and interprets your results. Suggest ways you could improve the results if you were to repeat the experiment, mention problems you had in lab, etc...