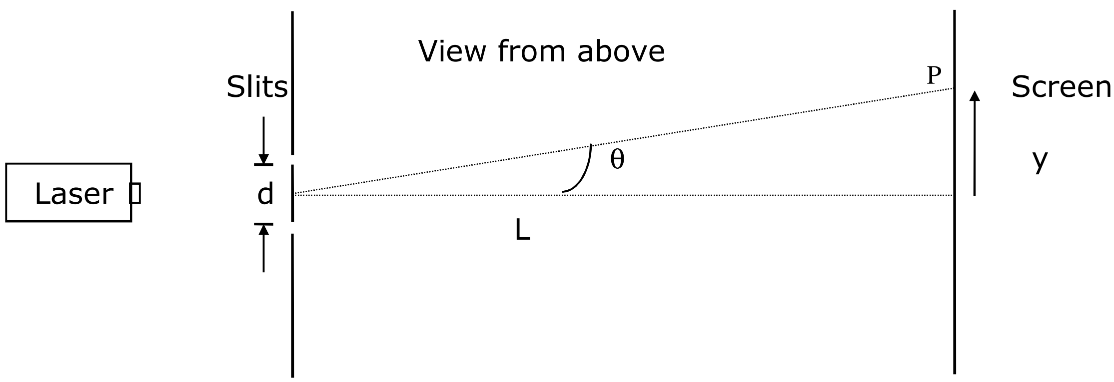
Physics 216 Laboratory 3
Interference and Diffraction

Overview

In this lab, you will investigate the interference and diffraction patterns produced by monochromatic (single-wavelength) light passing through rectangular slits. The goal is to investigate, first qualitatively and then quantitatively, how the features of the patterns depend on such things as the size, number, and separation between the slits. Finally, you will use diffraction to determine the width of a human hair.

Laser safety: You must exercise caution in using lasers, since lasers can cause permanent eye damage to yourself or others. We are using low-power (class 2) visible light lasers. Your blink reflex and the low power (< 1 mW) of the lasers means protective eyewear is not required for this class of laser, but you should never shine laser light into anyone's eyes, or stare into any type of laser. Always take common-sense precautions against looking into the beam. *Never* align a laser by sighting back along the beam. Keep the laser below (or above) eye height whenever possible. Keep the laser turned off, or its shutter closed, when you're not actively using it.

Equipment: 650 nm diode laser, optical bench and slit sets, meter stick, ruler, paper (to use as screen).



For a **double-slit** interference pattern, the pattern of light and dark stripes (fringes) is produced by constructive and destructive interference of the light waves from the two slits. If the difference in path length is zero or any whole number of wavelengths, the light waves from the two slits will be in phase, producing a bright fringe. The directions of the centers of the bright fringes (maxima) are given by the equation $d\sin\theta_m = m\lambda$. In this equation, d is the spacing between the slits, θ is the angle between the centerline and the center of the bright fringe, m is an "order counting" integer (m = 0 for zero path-length difference, m = +1 or −1 for λ path-length difference, m = +2 or −2 for 2λ path-length difference, etc.), and λ is the wavelength of the light.

For a **single-slit** diffraction pattern, the directions of the centers of the dark fringes (minima) on either side of the center of the diffraction pattern are given by $a\sin\theta_p = p\lambda$, where *a* is the width of the slit, λ is the wavelength of the light, θ is the angle between the centerline and the center of the dark fringe, and p is an order-counting integer (here m = ±1, ±2, …, but NOT p=0.)

Investigation I: Qualitative features of diffraction and interference patterns

Activity 1.1: Single slit

Look at the slide with the single slits. Make sure you understand the information on the slide. Which way should the slit be oriented to produce a horizontal diffraction pattern?

Make sure that your laser is not pointed near anyone's eyes. Then turn on the power to your laser and open the shutter. Set up the laser so that it shines through a single slit of width 0.04 mm and adjust it till it produces a single-slit diffraction pattern. Look at the pattern as projected on a sheet of paper attached to a surface at least two meters away from the slit. So that you can quantitatively compare this pattern with later patterns, pick some relevant dimension (such as the distance between the first minima on either side of the broad central maximum) and mark that on the sheet of paper on which the pattern is projected.

What happens if you move the surface on which the pattern is projected closer to the slit? Why?

This means that the slit-screen distance is a variable you will want to control as you're looking at the patterns produced by different arrangements and sizes of slits.

Predict what will happen to the pattern if a single slit of twice the width is used. Then try it out, making any necessary measurements to compare to the first slit's pattern. What similarities and differences do you observe between the two patterns?

Repeat for a narrower slit.

Summarize: how does the single-slit pattern change if the slit gets wider? narrower?

How would your patterns be different if you used a laser with a shorter wavelength?

→ Checkpoint 1

Activity 1.2: Two slits

Now let's look at patterns produced by two slits. First, look at the pattern produced by the laser shining through the 0.04 mm wide, 0.250 mm separation double slit (so that each individual slit has the same slit width as the first single slit you used). Again, so that you can make some quantitative comparisons between patterns, make some appropriate measurements (I'll let you decide what those are here) and mark them on the sheet. What similarities and differences do you see between the single slit and the double slit patterns?

What changes to the pattern would you predict if the width of each slit doubles (to 0.08 mm), but the separation remains the same at 0.250 mm? Try it. Describe what happens (you may want to mark features of the pattern on your sheet for further comparison).

What changes to the pattern would you predict if the separation of the slits is increased to 0.500 mm, but the width of each slit remains the same at 0.08 mm? Try it. Describe what happens.

Summarize: Which features of the double-slit pattern change if the width of each slit changes?

Which features change if the separation between slits changes?

How would your patterns be different if you used a laser with a shorter wavelength?

→ Checkpoint 2

Activity 1.3: Multiple slits

Finally, look at patterns produced by more than two slits. Use the slide with 2, 3, 4, and 5 slits with the same spacing and width. Look carefully at the patterns. Mark any features that are needed for a careful comparison.

Summarize: how does the pattern change when more slits are added, while keeping the same slit width and separation?

Why do you think that diffraction gratings (which are often used to measure wavelengths precisely) typically have a very large number (thousands!) of slits?

→ Checkpoint 3

Investigation II: Quantitative measurements : double slit

Activity 2.1

In this activity, you'll determine the positions of several maxima for a given double slit, and then use your measurements to determine the wavelength of your laser.

Choose a set of the double slits (think about which slits will give you a pattern that can be measured most accurately, and be prepared to justify why you chose the ones you did). Use the slits to produce an interference pattern with the laser. Tape a piece of paper to the wall to act as the screen on which the image will be formed. Use a slit-to-screen distance of at least 2 meters.

In order to find θ, you'll need to measure the distance *L* between the slits and the image screen, and also the distance *y* from the center of the interference pattern to the center of each bright fringe (maximum). Think about the best way to do these measurements, then carry out your plan. Enter the values in a table (such as the one below) along with the value of m that each fringe corresponds to. Do this for at least four different fringes. Be careful with units!

Side (left or right of center)	*m*	*y*	*L*	θ *(deg)*	*λ*

For each measured maximum, calculate the angle θ. Then using the known slit separation and the double-slit equation, calculate the laser wavelength.

Find the average wavelength and its uncertainty (standard error of the mean) for the complete set of measurements. How well does the measured value compare to what's printed on the laser?

→ Checkpoint 4

Investigation III: Application experiment

<u>Activity 3.1</u>

It can be shown that the diffraction pattern produced by an obstacle is the same as that produced by the same size and shape slit, except that the very center of the pattern may be different. (This is Babinet's principle.)

Use this idea to measure the width of a human hair. Figure out what you need to measure, and how you will measure it (come up with several possible ideas, and then choose the experimental design that you think is best). Record the details of what you did (what you measured, how you measured it). Include labeled sketches if appropriate. Analyze the data (including uncertainty) and decide if the experimental outcome makes sense.

→ Checkpoint 5