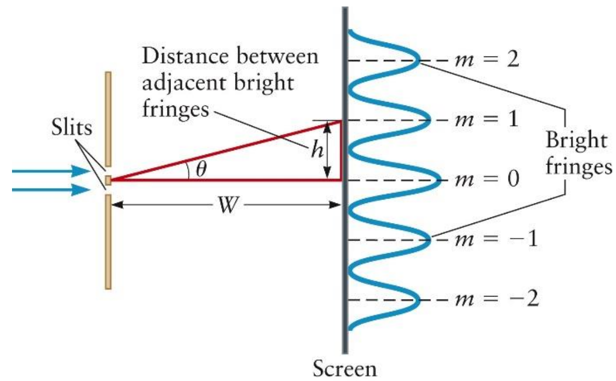
PH 212 Lab 14: Diffraction

Introduction

The diffraction of light through a slit or around a barrier is a fascinating demonstration of the wave nature of light. Since the interference patterns that result depend on the size and shape of the barrier or slit, diffraction can be a powerful measuring tool. In today's lab, you will use diffraction to perform various measurements.

This is a **Type II** lab. You do not need to write an Introduction, but you should **draw an experimental setup for Part 1 and Part 4** with **each variable in your equation for that part labeled on the picture** (*h, w, m, d,* θ)

Background

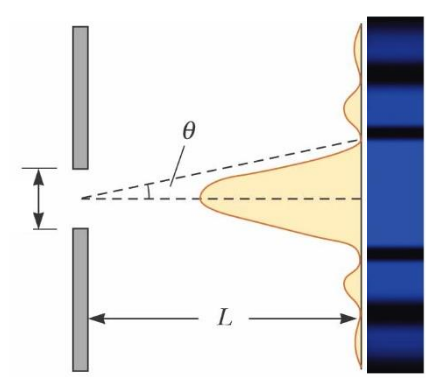


In class, we studied the interference pattern that results when a single source of light shines through two (or more) narrow slits in a barrier. If the slits are very narrow compared to the distance between them, the intensity pattern seen on a distant wall is as indicated to the right. Places of maximum intensity appear to our eyes as bright spots and places of minimum intensity appear to our eyes as dark spots.

Maximum intensity (bright spots) will be seen at angles given by:

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

where d is the spacing between the slits, θ is measured from the original direction of the light wave, and *m* = 0, ±1, ±2, …



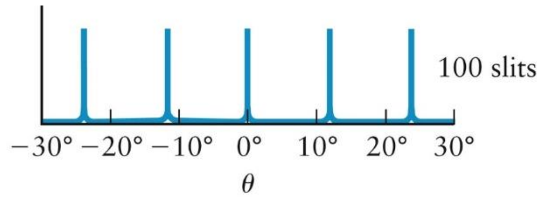
In the same way, we also considered the pattern that results from diffraction through a single slit. The exact mathematical form of the intensity pattern is beyond the scope of this class, but we will be able to derive an equation for the points of maximum destructive interference. For this case, we could show that minimum intensity (dark spots) will be seen at angles given by

$$D\ sin\theta = m\lambda$$

where D is the width of the single slit, and m = ±1, ±2, ±3, …

A diffraction grating has many slits that are equally spaced. The spacing between the slits *d*, is equal to the reciprocal of the number of lines per unit length:

$$d = \frac{1}{N}$$



Like the double slit, maximum intensity (bright spots) will be seen at angles given by

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

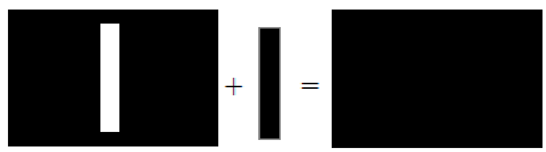
where d is the spacing between the slits, θ is measured from the original direction of the light wave, and *m* = 0, ±1, ±2, … The more slits there are, the narrower the bright bands will appear.

For all of the above patterns, $\tan\theta = \frac{h}{W}$.

The above results also apply to the “complement" of each shape. In other words, the diffraction pattern produced by a single rectangular barrier of width D has the same features as the pattern produced by a rectangular aperture of the same size, and so on.

The Opposite of a Slit: Babinet’s Principle

Rather amazingly, light hitting a small solid object, like a piece of hair, creates the same interference pattern as if the object were replaced with a hole of the same dimensions. This idea is Babinet’s Principle, and the reason behind it is summed up by the pictoral equation at right. If you add an object to a hole of the same size, you get a filled hole. EM waves hitting those objects must add in the same fashion, that is, the electric fields produced when light hits the hole, when added to the electric fields produced by the small object, must add to the electric fields produced when light hits the filled hole. Since no light can get through the filled hole, $E_{hole} + E_{object} = 0$. Thus we find that the electric fields coming out of the hole are equal and opposite to the electric fields diffracting off of the small object. Since the observed interference pattern depends on intensity, the square of the electric field, the hole and the object will generate identical diffraction patterns. By measuring properties of the diffraction pattern we can thus measure the width of the small object. In this lab the small object will be a piece of your hair.



The above section “The Opposite of a Slit: Babinet’s Principle” was taken from (http://ocw.mit.edu/courses/physics/8-02-physics-ii-electricity-and-magnetism-spring-2007/experiments/experiment9.pdf)

Experimental Procedure

Part 1: Finding the Wavelength of the Laser Beam

Warning: Be careful not to shine the laser beam towards anyone's eye during this lab. Also, be careful that the laser beam does not hit anyone's eye after reflecting off a shiny surface.

1. Mount your red laser pointer on a stand and aim at a section of the wall that is white and free of decorations. Your stand should be about one meter away from the wall. You can use either a laser stand or a ring stand with clamp.
2. Take out the diffraction grating (600 lines / mm) from your Pasco optics kit, and mount it on a component holder. Place the grating on a stool in front of the laser, so that the laser light shines through the grating before hitting the wall. Try to aim the laser and grating so that the beam hits the wall at a 90° angle. You can use a small binder clip to keep the laser beam on.
3. With a meter stick, measure the distance between the central maximum (m =0) and the first bright spot on either the left or right (m = ±1). This is *h.* **Record your answer** in your notebook with a reasonable number of significant digits. If you are having trouble measuring *h,* due to obstructions on the wall, you can move your grating and laser closer to the wall or to a different section of the wall.
4. Use a piece of string to measure the perpendicular distance from the grating to the wall. (Cut a piece of string that is equal to the length of the distance, then measure the string). **Record** this in your notebook as *W.*
5. Using the appropriate **diffraction grating** formulas in your notes, calculate the wavelength of your laser pointer to an appropriate number of significant digits. Do not use the equation for small θ. Instead, use the tangent equation to find θ. Then, use the sin θ equation to find λ. **Record your calculations and your answers** in your notebook.
6. The laser beams are supposed to have λ = 650 nm. **Calculate** the percent error and record in your notebook.

Questions

1. Try changing *W.* How does increasing or decreasing *W* change the interference pattern? Does this make sense in light of the equations?
2. If we were using a green laser, how would this affect the interference pattern?

Part 2: CD Groove Spacing

The shiny side of a CD has grooves (called pits) that are spaced at a specific distance in order to hold data. A laser in a CD player reads the information stored in these pits. The pits can act like a **diffraction grating** when light is reflected off of them. The distance between tracks in the pit is usually 1.6 μm.

1. Use a large binder clip to mount a CD on a stool, so that the shiny side is facing the wall.
2. Shine your laser pointer directly at the CD, so that the beam reflects and creates an interference pattern on the wall. You may either hold your laser manually or mount it as before.
3. Move your pointer around the CD until the interference pattern is as horizontal as possible (try aiming your pointer at a region directly to the left or right of the center of the CD).
4. Repeat steps 3-5 from Part I to find the spacing between tracks (*d*). **Record** your calculations and result in your notebook.
5. **Calculate and record** the percent error between your measurement and the industry standard of 1.6 μm.

Part 3: DVD Groove Spacing

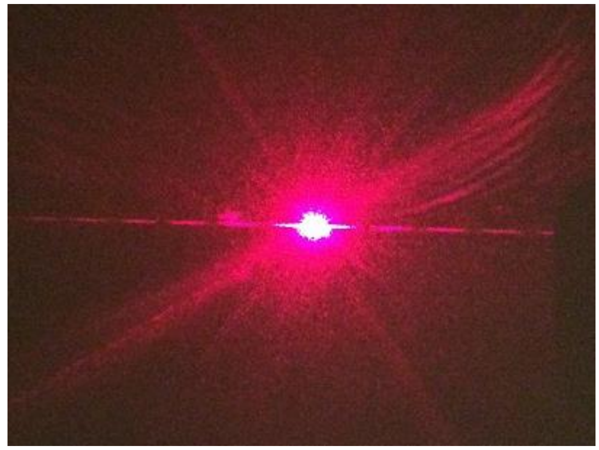
Repeat the procedure used in Part 2 for a DVD. The spacing between tracks on a DVD is usually 0.74 μm.

Questions

3. When the slit spacing was decreased (from CD to DVD), how did the interference pattern on the wall change? Does this make sense in light of the equations?
4. CD players use lasers with λ = 780 nm (infrared) to read CD's. DVD players, on the other hand, use λ = 650 nm (red). As you have seen, the smaller wavelength used in DVD players allows the physical DVD tracks to be narrower than the physical CD tracks. This allows a DVD to hold more data than a CD. Blue–ray discs use blue light. Why do you think the industry is now moving towards blue-ray? What might be one reason why blue-ray technology was not available earlier?

Part 4: Measuring the Width of a Human Hair

1. Cut a short length of hair from each team member's head. Using one of the component holders from your Pasco Optics Kit, tape one hair vertically across the component holder. (If you have a serious problem with having your hair cut, let the professor know and you will be excused).
2. Mount your laser so that it shines at the hair and to the wall. Try to point the laser at a 90° angle from the wall (as straight as possible).



3. Tape a piece of blank paper to the wall, so that the interference pattern is on the paper. Your interference pattern should look something like the picture on the right.
4. Use a pencil to mark the edges of the bright and dark spots on the horizontal line radiating from the circle in the center.
5. Use a string to measure *W,* the distance from the hair to the wall and **record** in your notebook.
6. Untape the paper from the wall, and measure the distance from the center of the central maximum to the center of the first node (dark spot). **Record in your notebook.**
7. Use the appropriate **single slit** equation to **calculate and record** the width of the hair along with its color. Again, use the formulas involving tangent and sine rather than the small angle approximation.
8. Repeat the above procedure for each team member.
9. Turn in your paper with one team member's lab report (write all team members names on the paper).

Questions

5. In your own words, explain Babinet's principle and why your hair had the same interference pattern as a single slit.
6. According to an online source, the width of a human hair varies from 17 μm to 181 μm, with blonde hair usually being thinnest and black hair usually being thickest. Did you find this to be true in your experiment?

Conclusion

1. Restate your results and percent errors from each part. Were your results mostly in line with the expected numbers?
2. Discuss sources of error for at least 2 parts of the lab.
3. Discuss one or two things you learned from this lab.