INTERFERENCE AND DIFFRACTION

IDEA TO REMEMBER!

Waves interfere based on their phase offset!

OBJECTIVE:

Understand the wave characteristics of interference and diffraction using classic light wave experiments.

MATERIALS:


Optics bench


Red diode laser


Diffraction slits


Screen and clamps

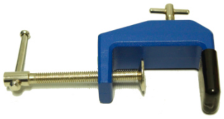


Table clamp


Tape measure

CONCEPT:

Take just a minute to look at the things around you. Notice the light sources. Notice the reflections and interesting phenomena. Can you visualize how light works? How is it moving and interacting with objects?

These are the kind of questions that Dutch physicist Christiaan Huygens (HOY-gənz), Robert Hooke, Isaac Newton, Thomas Young, and James Clerk Maxwell were asking when they experimented and postulated on the movement of light. Collectively, they and others discovered that light has both particle and wave characteristics, called *wave-particle duality*. Notice that our previous lab demonstrations on wave motion have helped us get to this point, as we are about to lay the foundation for the field of **quantum mechanics!**

Figure (1) shows the **interference** pattern produced by two water waves. **Interference is a wave phenomenon and occurs with all types of waves when two or more waves interact with each other.** All waves are created by vibrations, but light waves are not mechanical like sound and water. They derive from the vibrations of an electric charge, which have electric and magnetic components/axes. Being electromagnetic, they do not need a medium at all to propagate! Go to *Real World Applications* to learn more.

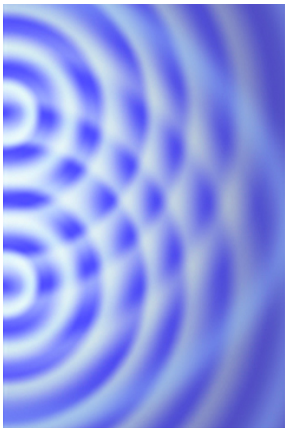


Figure 1 (OpenStax)

Double Slit

Figure (2) visualizes wave **interference**—that waves actually pass through each other because waves are not really objects! (Think back to the "Standing Wave on a String" and "Resonance Tube" labs.) **Figure (3)** illustrates the wave interference at a *double-slit* to produce an interference fringe pattern on a distant screen. We know that light acts like a wave because it produces this interference pattern.

To model interference you must understand **phase offset**, which represents the extra distance that one wave has to travel, see **Figure (4)**. First, notice that the source light (laser) is *monochromatic*, having a single wavelength λ, and *coherent*, meaning the waves are in phase. Past the double slit at specific angles, there are lines of coherence in which the waves interfere with each other in phase—where phase offset is near 0 or a whole integer multiple of wavelength $m\lambda$ (where is always $m = \pm1, \pm2, \pm3, \ldots$). These angles result in **constructive interference** (bright spots). *Incoherent waves* are those that are out of phase, around a half multiple of wavelength $(m+½)\lambda$ offset from each other, which result in **destructive interference** (dark spots).

We use trigonometry to determine the angles from the slits to spots on the pattern, as shown in Figure (3) and (4). So, the phase offset is now defined as:

$$m\lambda = d\,\sin\theta \quad (1) \qquad m = \pm1, \pm2, \pm3, \ldots$$

We can then solve for $\sin\theta$ and define the $\tan\theta$ relation, since we can easily find the distance x_m from the center to some point P,

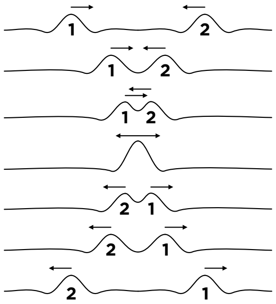
$$\sin\theta = \frac{m\lambda}{d} \quad (2) \qquad \tan\theta = \frac{x_m}{L} \quad (3)$$

According to small angle approximation, we can set $\sin\theta \approx \tan\theta$ for very small angles. Therefore, we can set Equation (2) and (3) equal to each other to solve for wavelength λ:

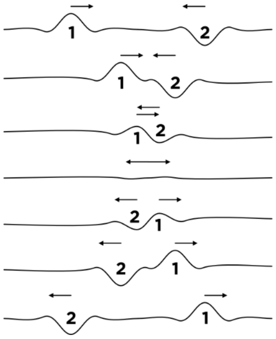
$$\frac{m\lambda}{d} = \frac{x_m}{L} \qquad (4)$$

IDEA TO REMEMBER!

Waves interfere based on their phase offset!



(a) *Progression of constructive interference, starting at top*



(b) *Progression of destructive interference, starting at top*

Figure 2

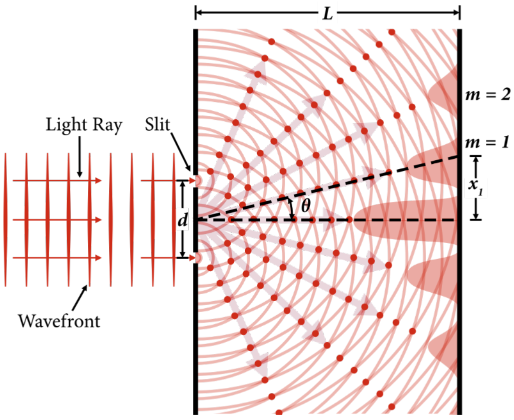


Figure 3

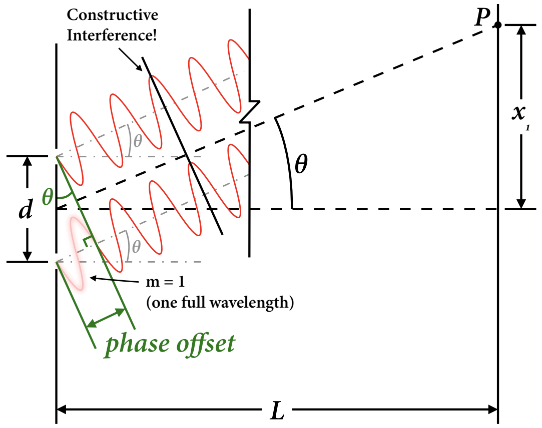


Figure 4: *What would the waves look like if the angle of P was not at a multiple (m = 1, 2, 3…) of the wavelength λ?*

Single Slit

IDEA TO REMEMBER!

Waves interfere based on their phase offset!

THINK: Interference at a single slit?? How can you have more than one wave emanating from one slit?...

Huygens derived a principle of waves in which each wavefront has small "wavelets" originating from an infinite number of points along the wavefront, as shown in Figure (5). This is the essence of **diffraction**, the phenomenon which causes a wave to spread out. This is happening all the time but it was simple enough to visualize and calculate single waves in double-slit interference without considering it. However, **with single slit interference, the equations for constructive and destructive phase offset swap**, as shown in Figures (5) and (6). Therefore, for single-slit interference multiples of the wavelength $m\lambda$ correspond to dark spots, but half wavelengths $(m+1/2)\lambda$ correspond to bright spots. So the equations below will be for destructive interference and the distance D refers to the slit width (whereas for double slits, d was the distance between the slits),

$$m\lambda = D\sin\theta \qquad (5) \qquad\qquad \sin\theta = \frac{m\lambda}{D} \qquad (6) \qquad\qquad \frac{m\lambda}{D} = \frac{x_m}{L} \qquad (7)$$

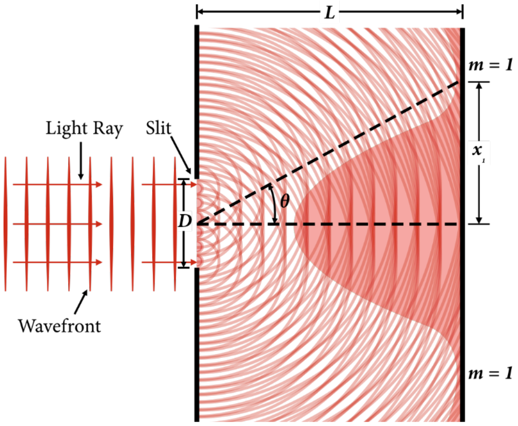


Figure 5 *Can you guess what the interference pattern will look like?*

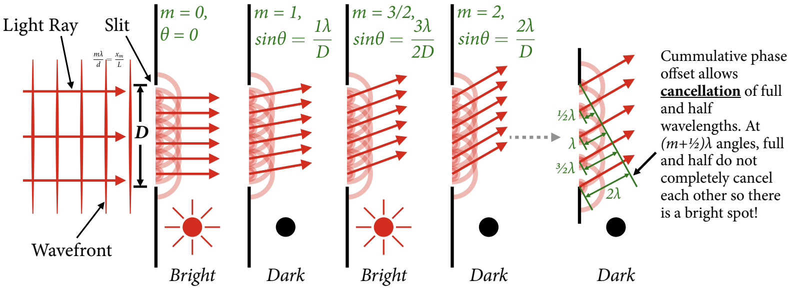


Figure 6 *Why does every multiple of wavelength now create a dark spot with single slit when it was a bright spot with double slit??*

Real World Applications

- Albert A. Michelson and Edward W. Morley created the interferometer to determine if light traveled through a "luminiferous aether", a theorized medium for light wave travel. The **LIGO interferometer** uses the same principle of interference to detect the changes in gravitational waves down to 10^{-18}m. ***That's 1 ten-thousandth the width of a proton! The smallest measurement ever made!***
- The **Lockheed Martin F–35** uses constructive and destructive interference in its phased array antenna radar to point its radar in multiple directions.
- Since interference is applicable to all waves, it is crucial to other technologies like **noise-canceling headphones**.

1) Veritasium: Using light to measure gravity!
2) Real Engineering: F-35 radar antenna array!

PRECAUTIONS:

Lasers produce a beam that is dangerous to the eye! DO NOT LOOK DIRECTLY INTO THE LASER AND NEVER POINT THE LASER IN ANOTHER'S EYE!

PROCEDURE:

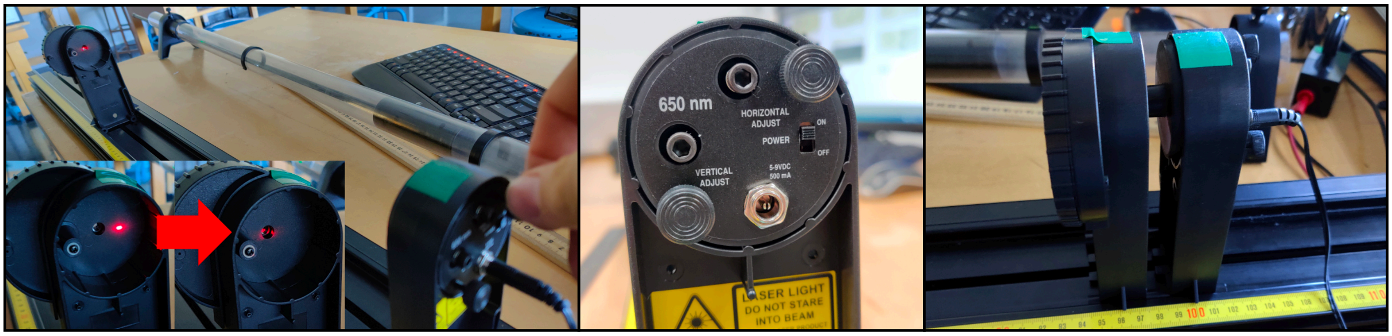
Part 1 — Double slit

1. ☐ Fill out the top information on the worksheet and complete the memory exercise—Questions M1–M3.
2. ☐ Read the *Concept* section.
3. ☐ Assemble the setup as shown in Figure (7).
    - 3.1. Switch off the lights.
    - 3.2. Snap the red diode laser into the optics track at 0 or 100cm—whichever side is toward the outside of the room—and snap the diffraction slits into the optics track halfway down the track.
    - 3.3. Turn on the laser and calibrate the alignment of the laser using the adjustment knobs, as shown in Figure (7a) and (7b).

IDEA TO REMEMBER!

Waves interfere based on their phase offset!

CONCEPT & PROCEDURE VIDEOS:

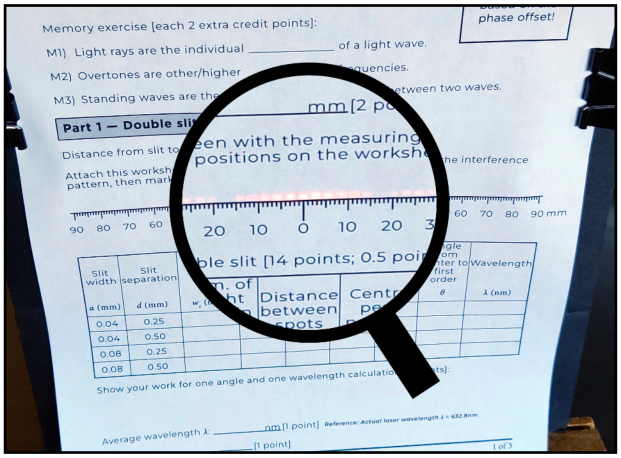


(a) (b) (c)

Figure 7

- 3.4. Move the diffraction slits to touch the laser, as in Figure (7c), and rotate the diffraction slit's wheel to the single slit with a slit width of "a = 0.02mm".
- 3.5. Clamp a screen on an adjacent table and measure the distance from the screen to the diffraction slits with a tape measure, as shown in Figure (8). **The screen should be at least 1.5m away.** Two people should handle the tape measure, being careful not to make the slits or screen move. **Record the measurement on your worksheet.**

Figure 8



phase offset!

Memory exercise [each 2 extra credit points]:

M1) Light rays are the individual ______________ of a light wave.

M2) Overtones are other/higher quencies.

M3) Standing waves are the etween two waves.

mm [2 po

Part 1 — Double sli

Distance from slit to

Attach this worksh pattern, then mark een with the measuring positions on the workshe he interference

90 80 70 60 20 10 0 10 20 3 60 70 80 90 mm

ble slit [14 points; 0.5 poi

Slit width a (mm)	Slit separation d (mm)	w_c (m	m. of ht	Distance between spots	Centr pe	ngle om nter to first order θ	Wavelength λ (nm)
0.04	0.25						
0.04	0.50						
0.08	0.25						
0.08	0.50						

Show your work for one angle and one wavelength calculatio ts]:

Average wavelength λ: ____________ nm [1 point] Reference: Actual laser wavelength λ = 632.8nm

____________ [1 point]

1 of 3

Figure 9

IDEA TO REMEMBER!

Waves interfere based on their phase offset!

4. ☐ Clamp your worksheet to the screen ("**Part 1**" side) so that the interference pattern aligns with the measuring line on your worksheet, as in Figure (9).

5. ☐ Use the measuring line to derive the information needed for the first four columns in Table 1. (Use a partner's worksheet to record the information.)

6. ☐ Turn the diffraction slit wheel and repeat Step 5 for each slit width and separation in Table 1.

7. ☐ Remove the worksheet from the screen and copy the Table 1 information from partner.

8. ☐ Calculate the angle and wavelength (show work on worksheet) and record in Table 1 on the worksheet.

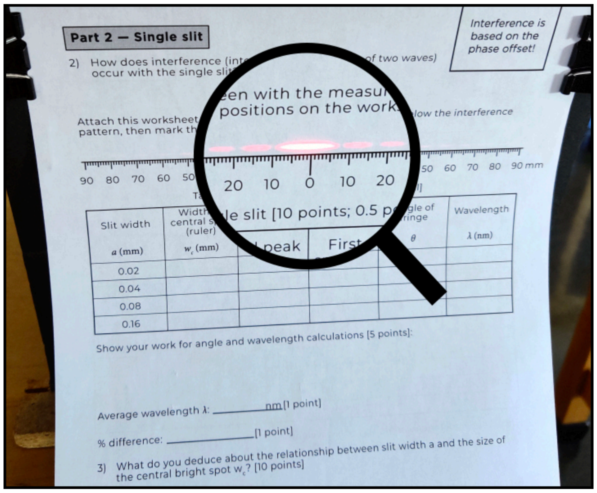
9. ☐ Calculate the average wavelength of the light source and the percent error and record on the worksheet.

10. ☐ Answer Question 1 on the worksheet.

Part 2 — Single slit

11. ☐ Clamp your worksheet to the screen ("**Part 2**" side) so that the interference pattern aligns with the measuring line on your worksheet, see Figure (10) on the next page.

12. ☐ Rotate the diffraction slits wheel to the single slit with a slit width of "a = 0.02mm". Do your best to locate the exact edges of the fringes.



Part 2 — Single slit

Interference is based on the phase offset!

2) How does interference (int of two waves) occur with the single sli

Attach this worksheet pattern, then mark th een with the measu positions on the work low the interference

90 80 70 60 50 20 10 0 10 20 50 60 70 80 90 mm

Ta le slit [10 points; 0.5 p

Slit width a (mm)	Width central s (ruler) w_c (mm)	peak	First	gle of ringe θ	Wavelength λ (nm)
0.02					
0.04					
0.08					
0.16					

Show your work for angle and wavelength calculations [5 points]:

Average wavelength λ: ____________ nm [1 point]

% difference: ____________ [1 point]

3) What do you deduce about the relationship between slit width a and the size of the central bright spot w_c? [10 points]

Figure 10

13. ☐ Repeat similar steps as Steps 5–9: Use the measuring line for the first two columns of Table 2, turn the diffraction slit wheel for each single slit width listed

in Table 2, copy information, calculate angle and wavelength, and calculate the average wavelength of the light wave and the percent error.

14. ☐ Based on what you learned in the *Concept* section and what you observe, answer Questions 2–5 on the worksheet.

15. ☐ Follow the **Let's THINK!** instructions below.

IDEA TO REMEMBER!

Waves interfere based on their phase offset!

Let's THINK!

- **Ask questions:** What are you learning here?... Why is this Physics concept important and how can it be used?... What do you not understand?... (For more information on this Physics topic, scan the QR codes in the *Real World Applications* and at the start of the *Procedure* section.)
- **Discuss** the concept and demonstration with your partner to help each other understand better. Discussion makes learning active instead of passive!
- For **FULL PARTICIPATION [15 points]** you must call on the TA when you have finished your group discussion to answer some comprehensive questions. If you do not fully understand and the TA asks you to discuss more, you must call on them one more time to be dismissed with full marks.
- **CONCLUSION [10 points]:** In the Conclusion section at the end of the worksheet, write 3 or more sentences summarizing this concept, how this lab helped you understand the concept better, and the real world implications you see. Do you still have questions? If so, write those as well.

Updated Date	Personnel	Notes
2022.10	Chase Boone	2022 Summer Improvement: Created new format.
2023.02	Chase Boone	R1: Clarifications and other edits.
2023.10	Chase Boone, Bob Swanson	R2: Improved graphics, wording, and worksheet.

Name: ______________________________ PH2233 Section #:__________

Name: ______________________________ TA Name:____________________

INTERFERENCE AND DIFFRACTION

WORKSHEET [70 points]

IDEA TO REMEMBER!

Waves interfere based on their phase offset!

Memory exercise [each 2 extra credit points]:

M1) Light rays are the individual ____________ of a light wave.
Hint: direction line.

M2) Overtones are other/higher ____________ frequencies.
Hint: baseline.

M3) Standing waves are the result of ______________ between two waves.
Hint: one word in this lab's title.

Part 1 — Double slit

Distance from slit to screen L: __________ mm [1 point]

Attach this worksheet to the screen with the measuring line below the interference pattern, then make marks according to the fields in Table 1 below.

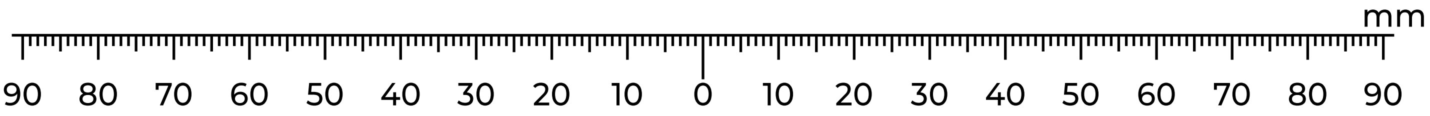


Table 1: Double slit [12 points; 0.5 point per cell]

Slit width (mm)	Slit separation d (mm)	Width of central area w_c (mm)	Num. of maxima (bright spots) in central area n	Distance between maxima $w_c/(n-1)$	First maxima position x_1 (mm)	Angle between center and first maximas θ (°)	Wavelength λ (nm)
0.04	0.25						
0.04	0.50						
0.08	0.25						
0.08	0.50						

Show your work for one angle and one wavelength calculation [5 points]:

Average wavelength λ: __________ nm [1 point] Reference: Actual laser wavelength λ = 650nm

% error: ____________________ [1 point]

1) What happens to the number of bright spots in the central area when the slit width increases? What happens to the size of the spots? [5 points]

IDEA TO REMEMBER!

Waves interfere based on their phase offset!

Part 2 — Single slit

Attach this worksheet to the screen with the measuring line below the interference pattern, then make marks according to the fields in Table 2 below.

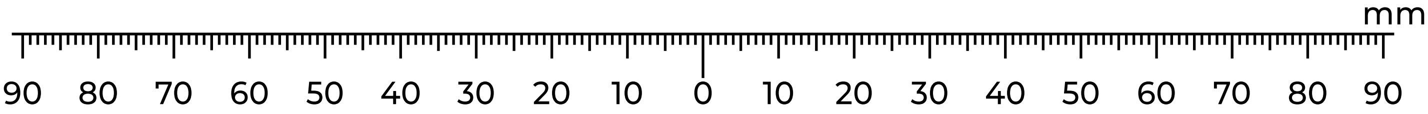


Table 2: Single slit [8 points; 0.5 point per cell]

Slit width D (mm)	Width of central bright area w_c (mm)	First minima (<u>dark spot</u>) position x_1 (mm)	Angle between central maxima and first minima θ	Wavelength λ (nm)
0.02				
0.04				
0.08				
0.16				

Show your work for angle and wavelength calculations [5 points]:

Average wavelength λ: ____________nm [1 point]

% error: ______________________ [1 point]

2) How does interference (interaction/combination of two waves) occur with the single slit? [5 points] Hint: read about single slit in *Concept*.

3) What do you deduce about the relationship between slit width D and the size of the central bright spot w_c? [5 points]

IDEA TO REMEMBER!

Waves interfere based on their phase offset!

4) What is the difference between double slit and single slit for a single wavelength 1λ (m = 1) phase offset? [5 points]

5) Explain why a single wave (from a single slit) does not fully cancel at $(m+1/2)\lambda$ phase offsets. [5 points] Hint: see Figure in *Concept*

Conclusion

Write 3 or more sentences summarizing this concept, how this lab helped you understand the concept better, and the real world implications you see. Do you still have questions? If so, write those here as well. [10 points]