LIGHT DISPERSION

IDEA TO REMEMBER!

Wavelength can determine the pattern of interference!

OBJECTIVE:

Understand why white (polychromatic) light can disperse into different colors.

MATERIALS:

PASCO 550 Interface

Optics bench

Triple laser

Triple laser wedge

Optics bench clamp

Diffraction slits

Diffraction scanner

CONCEPT:

Polychromatic dispersion happens when light containing multiple colors (wavelengths) is split up (separated) into its constituent colors. In nature, this dispersion occurs when white light **refracts** inside water droplets, diamonds, or crystals. White light is the resultant of the superposition of thousands of wavelengths, with some being in the visible light range. Each of those wavelengths will have a slightly different refraction angle, as shown in Figure (1). **<u>This is the physics of a rainbow!</u>**

Today we are going to use monochromatic light to individually measure the different distances and angles of each wavelength. We will do this by studying the interference patterns of three different wavelengths of light through a double-slit and then by refracting two different wavelengths of light through water.

THINK: Is there a physical difference between monochromatic dispersion and polychromatic dispersion?

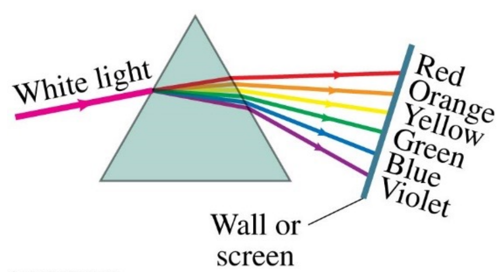

Figure 1

Double Slit Interference Patterns

The double-slit interference patterns made by light follow these equations:

$$sin\theta = \frac{m\lambda}{d} \quad (1) \qquad tan\theta = \frac{x_m}{L} \quad (2)$$

where L is the distance from the slits to the screen, x is the distance from the center spot to an adjacent spot, d is the distance between the slits, and, in today's calculations, $m = 1$. As shown in Figure (2), the interference pattern works out that each angle θ that creates a phase offset equal to a multiple m of the wavelength λ creates *constructive interference*, which results in a bright area. (The interference and diffraction from a single slit would be the opposite.)

THINK: How does the wavelength change the angle of constructive interference, and thus the pattern of interference?

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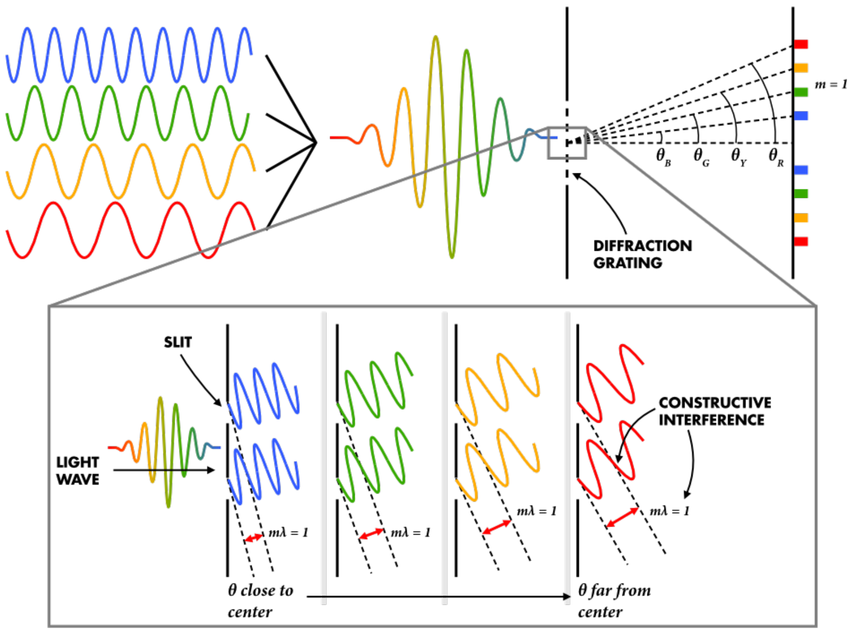

Figure 2

This is true for each wavelength. For example, the interference pattern in Figure (3) is for a blue wavelength of light, but a different wavelength will interfere at a different angle and, hence, will make a different pattern of spots (fringes) on the screen. (This is sometimes called the *angle of deviation*.) If white light had been used, the pattern on the screen for $m = 0$ and 1 would look like Figure (4). This is *polychromatic dispersion!*

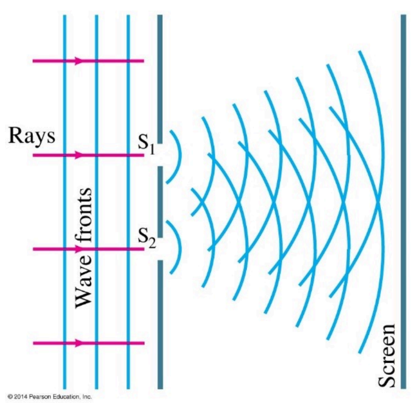

Figure 3

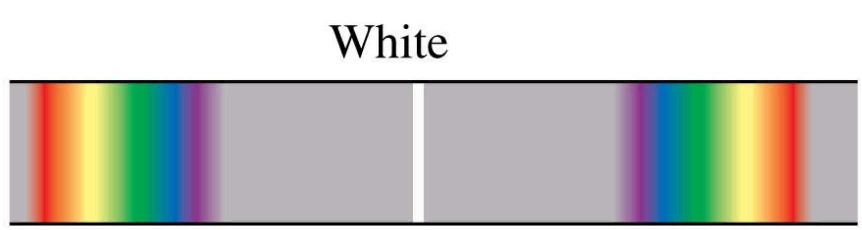

Figure 4

Refraction for Different Colors

In simple terms, the dispersion of light that occurs in refraction is because each color will have a slightly different index of refraction within the substance. See Figure (5). For instance, when we see in a textbook that the index of refraction for light in water is 1.33, we are seeing an average index of refraction. Microwave-wavelengths will have an index less than 1.33 in water and UV-wavelengths will have an index greater than 1.33 in water. Using the Snell's Law equation, you will be solving to see what the index of refraction is for red and violet colors of visible-light in water:

$$n_1 sin\theta_1 = n_2 sin\theta_2 \tag{3}$$

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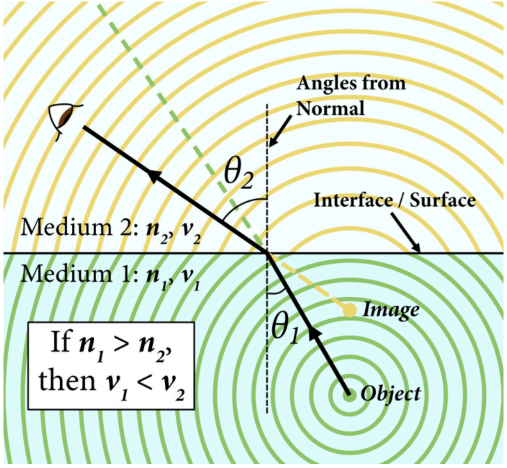

Figure 5 Light changes direction at the interface of two mediums.

Real World Applications

- Of course, the classic source of polychromatic light is the **Sun**. However, other stars produce polychromatic light that varies in hue based on the surface temperature of each star.
- When designing the **James Webb Space Telescope**, scientists chose to separate light wavelengths using **diffraction gratings** for high and medium resolution and a **prism** for low resolution!
- Engineers must account for the angle of deviation when designing camera lens systems; **lens flare**, or glare, occurs when light internally reflects and scatters within the lens system.

1)
2)

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! ⚠

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CONCEPT & PROCEDURE VIDEOS:

PROCEDURE:

1. ☐ Fill out the top information on the worksheet and complete the memory exercise—Questions M1–M3.

2. ☐ REQUIRED: Read the *Concept* section.

Part 1 – Double slit

3. ☐ This part requires that the lab lights be turned OFF.

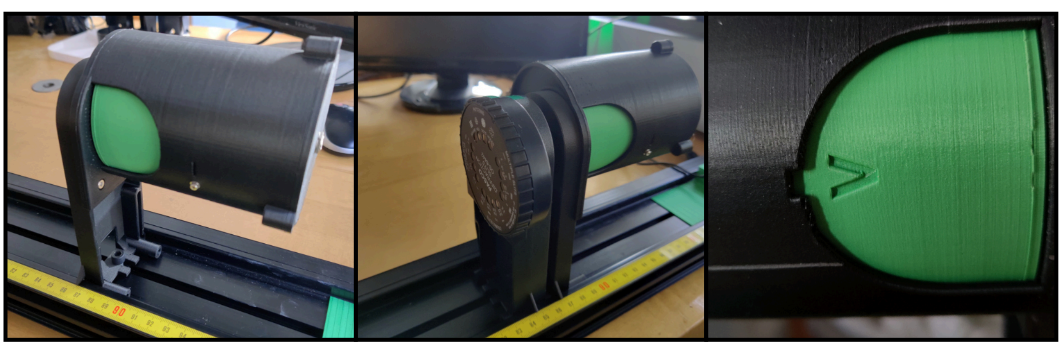
4. ☐ Assemble the setup as shown in Figure (6) and (7).

   4.1. Insert the Triple laser apparatus into one end of the Optics bench (near 0 or 100cm), and use the Optics bench clamp to hold it down, as shown in Figure (6a).

   4.2. Insert the Diffraction slits into the Optics bench as close as possible to the Triple laser with the wheel facing out, see Figure (6b). Rotate the wheel to the double slit labeled "a = 0.04mm" and "d = 0.25mm".

   4.3. CAUTION: **The Triple laser apparatus activates one of the three lasers when the green core rotates into an exact position.** The indications of the three positions are as follows: a letter representing the laser will align with a notch on the side, as in Figure (6c), and each position can be perceived tactilely with a slight detent bump. Make sure that the laser aligns with the center hole for proper alignment.

   4.4. Plug the Triple laser into wall power and rotate the green core to cycle through all three lasers. Make sure all of the lasers turn on successfully. NOTE: We will calibrate the beam alignment for each laser in a future step, so do not be concerned if the beam does not go through the hole initially.



(a) (b) (c)

Figure 6

4.5. Open the PASCO Capstone software, and hold the power button on the back of the Diffraction scanner until the LED begins to flash. Connect your scanner wirelessly in the *Hardware Setup* menu. See Figure (7a).

4.6. Insert and lock the Diffraction scanner into the Optics bench near the end. NOTE: As shown in Figure (7b). Make sure that unwanted lights are behind the scanner when in use.

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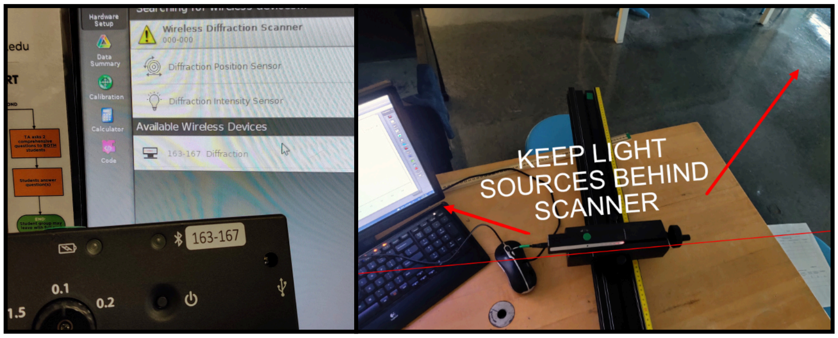

(a) (b)

Figure 7

4.7. Measure the distance between between the Diffraction scanner and the Diffraction slits using the Optics bench and record on the worksheet (**convert to mm**).

5. ☐ Rotate the green core of the Triple laser so that any letter aligns with the notch.

(a) (b)

Figure 7

6. ☐ Each laser is aligned slightly differently so you must calibrate the alignment of each beam with the Diffraction scanner, therefore, you may need to use the Triple laser wedge under the Triple laser feet, twist the Triple laser to one side or the other, or even hold it with your fingers, as shown in Figure (8).

7. ☐ Click on *Graph* on the right sidebar and select *Light intensity %* for the y-axis and *Position (mm)* for the x-axis. Set the sample rate (near the *Record* button at the bottom) to 20–40Hz.

8. ☐ Using the Diffraction scanner's crank wheel, position the scanner head to the left or right side of the visible light pattern of the central bright region.

9. ☐ Click *Record* and rotate the scanner wheel **slowly** and with a constant speed across the pattern. Click *Stop* when the scanner slit travels across the entire light pattern.

10. ☐ Zoom-in/expand the graph so that you can clearly see the data for the central region, so that it fills most of your graph. Then, near the top of the screen select the *Coordinates tool* and drag the tool to the tip of the center fringe and record the position in Table 1 on the worksheet. Do the same for the first fringe left and right of center.

IDEA TO REMEMBER!

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11. ☐ Calculate the average distance to the first fringes and the average angle. Record these in Table 1 on the worksheet.

12. ☐ Calculate the wavelength of the laser and record in Table 2 on the worksheet. Be sure to show your calculations for one of the angles and wavelengths.

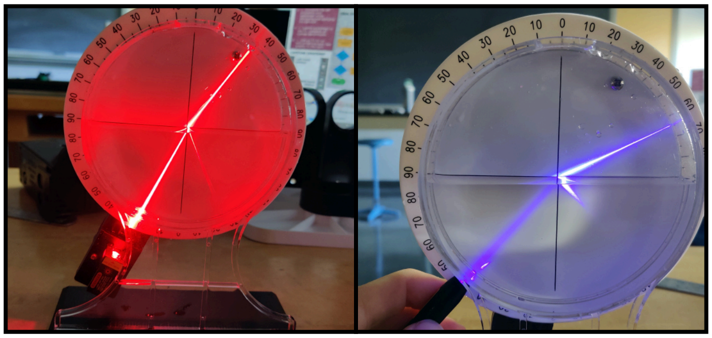
13. ☐ Repeat steps 5–12 for the remaining lasers. Disconnect the Triple laser from power when complete.

14. ☐ Calculate the percent errors for the three colors (wavelengths) and answer Questions 1–3 on the worksheet.

Part 2 – Refraction of Different Colors

15. ☐ Go to the sink and slowly fill water in the refraction tank to the halfway line and return to your table.

16. ☐ Turn on the red laser that is attached to the back of the tank and swivel it so that the light is entering into the water first (light is at the bottom of tank) with an incident angle θ_1 in the water of 40°. See Figure (9a).



(a) (b)

Figure 9

17. ☐ Observe and record the refracted angle θ_2 in the air (coming out of the water) in Table 3 on the worksheet. NOTE: Recall that these angles must be with respect to the normal (the vertical in this case).

18. ☐ Use the Snell's Law equation to calculate the index of refraction of the red light in water n_1. Show your work and record this in Table 3 on the worksheet. NOTE: Recall that the index of refraction in air n_2 is approximately 1.

19. ☐ Turn off the red laser and swing it out of the way. Turn on and position the violet laser pointer, doing your best to repeat steps 16–18 using the violet laser pointer, as shown in Figure (9b). Record your results in Table 3 on the worksheet.

20. ☐ After you have calculated the index of refraction in water for violet, go back to the tank and observe what happens if you use and incident angle of 55° with either color to answer Questions 4–5 on the worksheet.

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

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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
2023.09	Mark Worthy, Chase Boone	Created and formatted into new lab manual layout.

Name: ______________________________ *PH2233* Section #: __________

Name: ______________________________ TA Name: ______________

LIGHT DISPERSION
WORKSHEET [70 points]

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Memory exercise [each 2 extra credit points]:

M1) Unlike water / sound waves, light waves do not need a __________ to propagate.

Hint: in space, no one can hear you scream.

M2) Visible light travels (faster / slower) in air than in water.

Hint: Snell's law; smaller index, faster speed.

M3) To calculate interference you must understand phase ____________ between two waves.

Hint: extra distance traveled by a wave.

Part 1

Distance from slit to scanner *L*: __________ **mm** [2 point] **(Convert to mm)**

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

Color	Width of central area w_c (mm)	Num. of fringes in central area n	Center peak position (mm)	First fringe left of center position (mm)	First fringe right of center position (mm)	Average distance to first fringe from center $x_{1, avg}$ (mm)	Average angle from center to first fringe $\theta_{1, avg}$ (°)

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

Table 2: Laser wavelengths [6 points; 1 point per cell]

Color	Calculated wavelength λ (nm)	Actual wavelength λ (nm)	% error
Violet		450	
Green		532	
Red		635	

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1) Which color had the smallest central region (least spread out)? [5 points]

2) Which color had the greatest distance from the center peak to its first fringe? [5 points]

3) Why? [5 points]

Part 2

Table 3: Water Tank [4 points; 1 point per cell]

Color	Refraction angle in air θ_2 (°)	Index of refraction in water n_1
Red		
Violet		

Show your work for one index of refraction calculation. [8 points]

4) What happened when you tried the 55° incident angle? Why? [8 points]

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]

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