Online laboratory assignment 10 – Reflection, refraction, and dispersion

Purpose: to experiment with classical properties of light rays at interfaces.

Introduction

The field of ray optics involves the study of the propagation of light. Ray optics assumes light travels in a fixed direction in a straight line as it passes through a uniform medium and changes its direction when it meets the surface of a different medium or if the optical properties of the medium are nonuniform in either space or time.

As with waves on strings, when a light ray traveling in one medium encounters a boundary with another medium, part of the incident light is reflected. Experiments and theory show that the angle of reflection θ_r equals the angle of incidence θ_a,

$$\theta_r = \theta_a$$

Light travels at its maximum speed c in vacuum. It is convenient to define the index of refraction n of a medium to be the ratio

$$n = \frac{c}{v}$$

where v is the light's phase velocity in the medium. The original experimental discovery of the relationship between the reflected and refracted (transmitted) light is credited to Willebrord Snell known as Snell's law of refraction,

$$n_a \sin\theta_a = n_b \sin\theta_b$$

When the material with the incident light has a greater refractive index that the refracting material, then there are incident angles in which no refracted angle can satisfy Snell's law. Thus, the light is totally reflected. Total internal reflection will occur when the angle of incidence is above the critical angle,

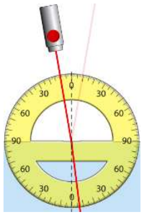
$$\theta^{crit} = \sin^{-1}\frac{n_b}{n_a}$$

A material's index of refraction depends on the wavelength of light. This dependence on the wavelength is referred to as dispersion. For example, the index of refraction of glass increases when the wavelength of light is shifted from red to blue. By shining white light into a glass prism, the colors of light can be separated. This same phenomenon is observed in nature in the form of a rainbow.

Laboratory assignment

Part 1: Low index to high index interface

1. Run the "Bending light" PhET simulation.
2. Select the Intro button.
3. Press the red button to turn on laser which passes from one medium to another.
4. Place the protractor as shown below so that you may measure the incident, reflected, and refracted angles with respect to the normal direction.

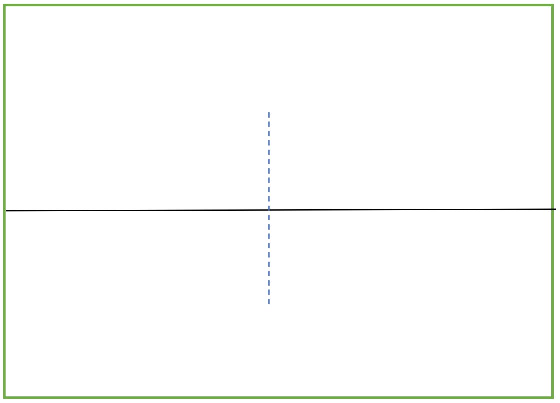


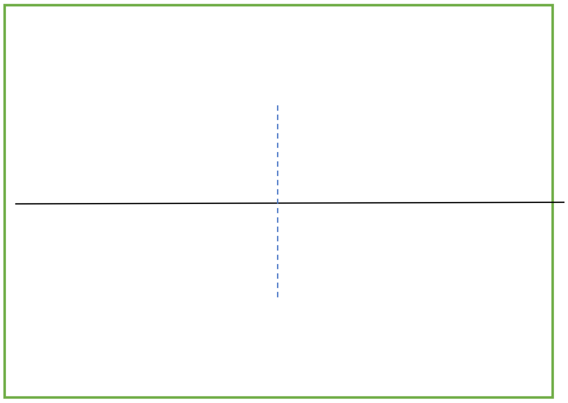
5. Set the incident material to air ($n_a = 1.00$) and the refraction material to water ($n_b = 1.33$).
6. Select an incident angle of 10.0°. Record the incident, reflected, and refracted angles in Table I.
7. Repeat the measurement for all other angles in Table I and fill in the rest of Table I.

Table I: Reflection and refraction at an air/water interface

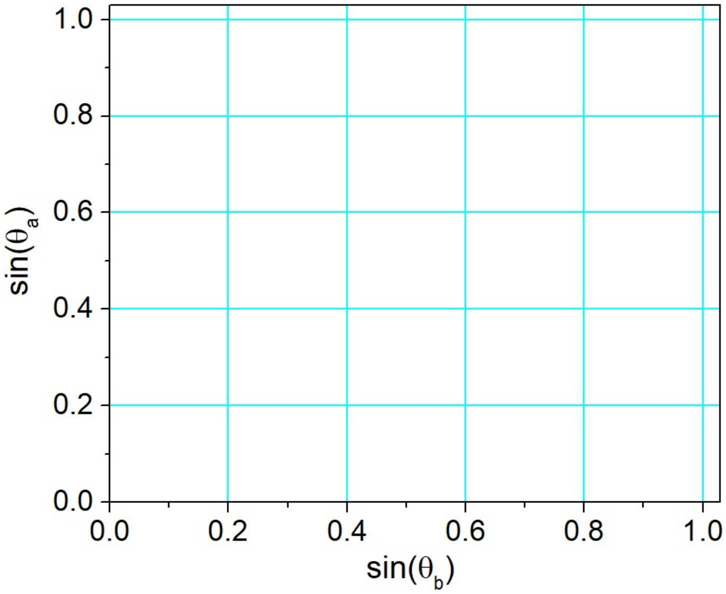
Incident Angle (θ_a)	Reflected Angle (θ_r)	Refracted Angle(θ_b)
10.0°		
20.0°		
30.0°		
40.0°		
50.0°		
60.0°		
70.0°		

8. Draw the ray diagrams below for the 20.0° and 50.0° incident angle cases.





9. Plot the incident angle vs. the refracted angle on the below graph.



10. Determine the slope of the graph with uncertainty.

Slope = ____________ ± ____________.

Part 2: Total internal reflection

11. Now choose the incident material to be glass ($n_a = 1.50$) and the refracting material to be water ($n_b = 1.33$).
12. Slowly increase the angle from the normal direction. You should see the refracted beam rapidly moving to higher angles.
13. Continue to increase the incident angle until the refracted beam disappears. Record the critical angle at which the refracted beam disappears.

$$\theta_{a,exp}^{crit}(\text{glass/water}) = \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_.$$

14. Calculate the theoretical critical angle for total internal reflection.

$$\theta_{a,calc}^{crit}(\text{glass/water}) = \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_.$$

15. Determine the percent difference between the experimental and calculated values of the critical angle.

$$\%\text{ diff (glass/water)} = \left|\frac{\theta_{a,exp}^{crit} - \theta_{a,calc}^{crit}}{\theta_{a,exp}^{crit}}\right| = \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_.$$

16. Next keep the incident material to be glass ($n_a = 1.50$) and change the refracting material to be air ($n_b = 1.00$).

17. Slowly increase the angle from the normal direction until the refracted beam disappears. Record the critical angle at which the refracted beam disappears.

$$\theta_{a,exp}^{crit}(\text{glass/air}) = \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_.$$

18. Calculate the theoretical critical angle for total internal reflection.

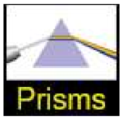
$$\theta_{a,calc}^{crit}(\text{glass/air}) = \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_.$$

19. Determine the percent difference between the experimental and calculated values of the critical angle.

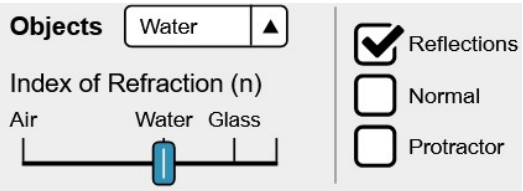
$$\%\text{ diff (glass/air)} = \left|\frac{\theta_{a,exp}^{crit} - \theta_{a,calc}^{crit}}{\theta_{a,exp}^{crit}}\right| = \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_.$$

Part 3: Dispersion in a water droplet

20. Select the “prisms” tab at the bottom of the screen.



21. Set the object index of refraction to water ($n_b = 1.33$) and check the “Reflections” box.



Objects Water

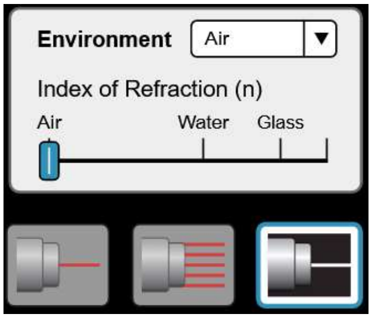
Index of Refraction (n)

☑ Reflections

☐ Normal

☐ Protractor

22. Select the environment index of refraction to air ($n_a = 1.00$) and select the white light source as shown below.



Environment Air

23. Drag the circular object in front of the light source so that the incident beam will be at a low incident angle as shown below.

24. Turn on the light source with the red button. Describe what you see.

25. Slowly raise the light source relative to the circular object until the incident beam is an a high angle of incidence. Describe what you see.

26. Write a brief conclusion for the laboratory assignment.