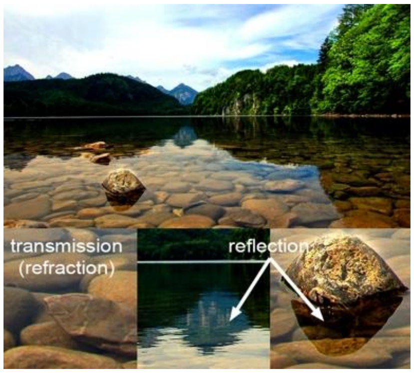


Lab Sim 05: Reflection and Refraction

Introduction

Light hits a boundary: now what? Depending on what the light has run into, it might bounce off (reflecting) or continue to pass through the new medium (refracting). Sometimes both things happen at the same time—you have no doubt experienced looking through a window and noticing that not only can you see what's on the other side, but you can also see your own reflection in the pane.

Objectives

- Demonstrate the Law of Reflection for both plane and curved mirrors
- Observe the refraction of laser light through an acrylic prism
- Simulate refraction between multiple surfaces to develop a quantitative Law of Refraction
- Determine the conditions for total internal reflection and calculate the critical angle for a water-air interface

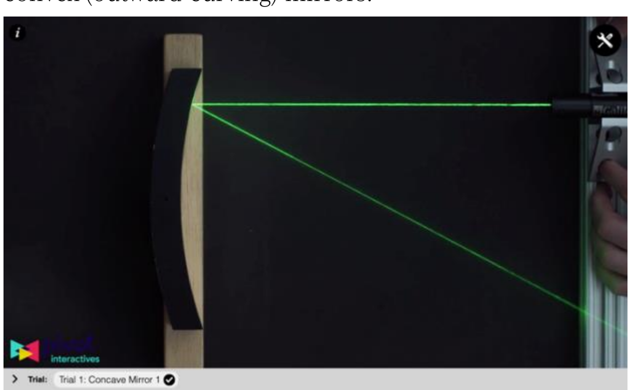
Pivot Interactives

This exercise requires the online simulation (Lab 05: Reflection and Refraction). You should sign in to your Pivot account and choose the correct Interactive from the PHYS 1420 selection.

The Law of reflection

Use the first video to demonstrate to yourself the Law of Reflection: $\theta_i = \theta_r$, or angle of incidence = angle of reflection. Pay specific attention to the method for measuring these angles.

Observe reflection for both concave (inward-curving) and convex (outward-curving) mirrors.



You do not need to measure anything, but you should be thinking about *how* you would go about measuring the incident and reflection angles.

1) (1 point) True or false: The Law of Reflection, while true for plane (flat) mirrors, is not valid for curved mirrors.

2) (2 points) Briefly describe how you could measure the angles of incidence and reflection for a curved mirror in order to prove (or disprove) the Law of Reflection.

Defining the Index of Refraction

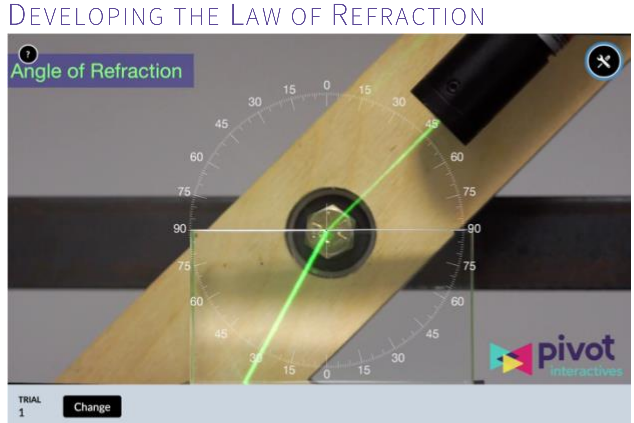
The index of refraction n of a material is pretty simply defined: $n = \frac{c}{v}$, where $c = 3 \times 10^8 \frac{\text{m}}{\text{s}}$, the speed of light in vacuum, and v is the speed of light through the medium.

Note that, because vacuum is the fastest medium (well, lack of medium) for light, $v < c$ for anything that isn't vacuum. This means that $n > 1$, and the larger n is, the slower light travels through the medium.

In the third video, green laser light passes from air to a piece of acrylic. The index of refraction for the acrylic is $n = 1.5$.

3) (1 point) Calculate the speed of light v as it travels through the acrylic.

Developing the Law of Refraction



Place the protractor as shown above and play the video. Don't measure anything yet; just observe the incident and refracted beam of laser light.

4) (1 point) The angles of incidence (θ_i) and refraction (θ_r) are always measured
   A. with respect to the horizontal.
   B. with respect to the vertical.
   C. with respect to the surface of the interface.
   D. with respect to the normal to the interface.

5) (1 point) The angles of incidence (θ_i) and refraction (θ_r)
   A. are always measured in degrees.
   B. are always measured in radians.
   C. are always measured in minutes of arc.
   D. can be measured in any units; it does not matter as long as you measure consistently. We just happen to be comfortable with degrees.
6) (1 point) As the angle of incidence increases,
   A. the angle of refraction decreases.
   B. the angle of refraction increases.
   C. the angle of refraction does not change.
7) (1 point) What does the index of refraction have to do with anything?
   A. Nothing. Why should it?
   B. A material with a higher index will have an angle of refraction greater than the angle of incidence. So if we replaced the acrylic with something like diamond ($n = 2.42$), θ_r through the diamond will be greater than θ_i in the air.
   C. The higher the index of refraction, the greater the bending of the refracted beam. Using our diamond example, if the acrylic bends from $\theta_i = 45°$ in air to $\theta_r = 30°$ in acrylic, then in diamond, θ_r will be some value smaller than $30°$.
   D. The higher the index of refraction, the smaller the bending of the refracted beam. Using our diamond example, if the acrylic bends from $\theta_i = 45°$ in air to $\theta_r = 30°$ in acrylic, then in diamond, θ_r will be some value greater than $30°$ and less than $45°$.

Without looking up Snell's Law (yet!), let's test out the direct relationship between the incident and refractive angles. Literally, just plot the angle of refraction as a function of the angle of incidence.

8) (5 points) Collect the data (at least ten pairs of angles, being sure to label the columns and include units) and prepare the graph!

Angle of incidence θ_i	Angle of Refraction θ_r
5°	
10°	
etc	

9) (2 points) Does the graph appear linear? Can you make and support an argument that the graph is a line?
10) (2 points) What is the slope of your linear regression? Can you make a mathematical link between your slope and the index of refraction of the acrylic?
11) (2 points) What is the y-intercept of your graph? According to your direct observation, what *should* that intercept be??
12) (2 points) If it was 1621 and you were a well-educated Dutch astronomer and mathematics professor, would you feel confident publishing these results and declaring that this direct relationship can be used to explain refraction? Why or why not?

Applying Snell's Law of Refraction

Open this simulation frame if it does not open automatically within your Pivot window. This simulation will allow you to test out the relationship you developed above by using it to determine the index of refraction for an unknown material.

The simulation will also allow us to visualize total internal reflection, which the video does not show us.

Within the frame, choose air (making $n_i = 1$) as your incident medium, and select either Mystery A or Mystery B as your refractive medium.

Drag the protractor into the frame and position it carefully. Pushing the red button turns the laser on, and you can drag the laser to change the angles of incidence.

13) (8 points) Collect **at least eight** pairs of incident and refraction angle data. Use Snell's Law ($n_i \sin\theta_i = n_r \sin\theta_r$) to determine what you are going to graph and how you will use that graph to determine the refractive index of your Mystery Medium.
14) (2 points) Identify which Mystery Medium you analyzed (A or B) and what its index of refraction is. Use this table to suggest the composition of your medium and comment on your confidence in your result.

Total Internal Reflection

The previous examples showed a transition from a faster (lower index) medium to a slower (higher index) medium. This time, let's look at a slow-to-fast transition.

Using the refraction simulation, change the incident medium to glass, and the refractive medium to air.

Without making any measurements, grab the laser and increase the angle of incidence, starting from $\theta_i = 0$.

15) (2 points) List two observations for this example of refraction that are noticeably different than your previous observations.
16) (1 point) The critical angle θ_c is defined as the maximum incident angle for which the beam is refracted. For larger incident angles, there is no refracted beam, just total internal reflection. Carefully adjust the laser until the refracted beam just disappears. What is your measured θ_c?

Mathematically, the critical angle can be predicted using Snell's Law:

$$n_i \sin\theta_i = n_r \sin\theta_r$$

When $\theta_i = \theta_c$, the angle of refraction $\theta_r = 90°$. Conveniently, $\sin(90°) = 1$ and Snell's Law becomes:

$$n_i \sin\theta_c = n_r \sin(90°)$$
$$\sin\theta_c = \frac{n_r}{n_i}$$
$$\theta_c = \sin^{-1}\left(\frac{n_r}{n_i}\right)$$

17) (1 point) Calculate the critical angle for the glass.

When you have completed this lab exercise in Pivot, please be sure to submit your responses. This lab is due no later than Tuesday, 26 July 2022, at 11:59 PM CDT