Experiment #17: Refraction

OBJECTIVES

The transmission of light across a boundary between two media is accompanied by a change in both the speed and wavelength of the wave. This can result in a change of direction at the boundary, a phenomenon known as refraction. In this experiment you measure the change in direction of light beams as they refract or reflect at a boundary to determine the index of refraction of a transparent object. The objectives of this experiment are as follows:

1. To measure the angles of incidence and refraction at a boundary between media
2. To observe total internal reflection at a boundary between media
3. To calculate the critical angle of a boundary between media

THEORY

The index of refraction is a property of transparent substances that has been independently discovered several times, but is attributed to Willebrord Snellius whose name is associated with the law (you can't make this stuff up). Mathematically, Snell's law describes the relationship between the angle of incidence of a beam of light as it intersects a new transparent medium and the angle of refraction as enters that transparent medium.

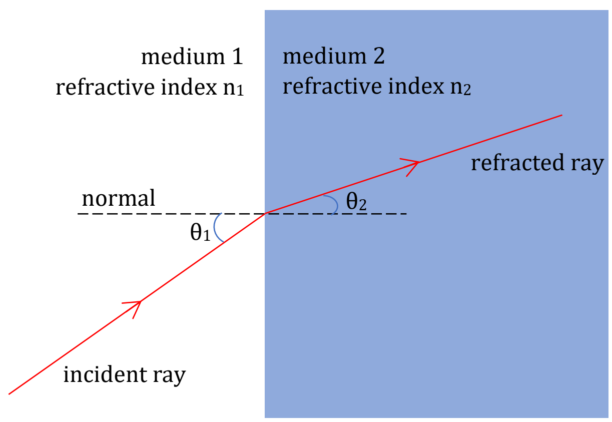


Figure 6.1: Refraction overview

Snell's law quantifies the relationship that is observed in Figure 6.1:

$$n_1 \cdot \sin\theta_1 = n_2 \cdot \sin\theta_2 \quad (6.1)$$

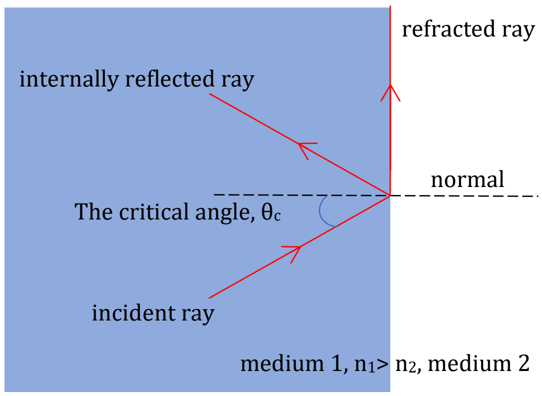
where n_1 is the index of refraction of medium 1, n_2 is the index of refraction medium 2, θ_1 is the angle that the light ray makes with respect to the normal in medium 1, θ_2 is the angle that the light ray makes with respect to the normal in medium 2.

The index of refraction of any medium (n_i) is the ratio of the speed of light in vacuum (c) to the speed of light in that medium (v_i), as shown in equation 6.2.

$$n_i = \frac{c}{v_i} \quad (6.2)$$

where $c = 3.00\times10^8$ m/s (the accepted value for the speed of light in vacuum, a constant).
A very good approximation for the refractive index of air is 1.00, i.e. $n_{air}=1.00$.

On observation, it can easily be seen that as light travels from a lighter medium to a denser one (i.e. $n_1<n_2$), the refracted light ray bends *towards* the normal. Conversely, when light travels from a denser medium to a lighter one (i.e. $n_1>n_2$), the refracted light ray bends *away* from the normal. But when you think about it, how much "away from the normal" is possible? One can only get as far as 90° without leaving the medium! When the refracted ray exceeds 90°, it's not refraction anymore, instead light is reflected back into the same medium it started from, and this phenomenon is known as **total internal reflection**. Note that this only happens for light traveling from a denser medium to a lighter one (see figure 6.2 below).



The **critical angle** (θ_c) is the angle of incidence for which the angle of refraction is 90°. Beyond the critical angle, 100% of the incident light is reflected back into the same medium.

Figure 6.2: Total internal reflection

Accepted Values

The glass used in this experiment is made of Lucite. The accepted value for the refractive index of Lucite is **1.50**. The mystery media have no accepted value for their refractive indices. It is up to the experimenter to determine their values!

Data

Medium	Measurement	Magnitude (°)	Refractive index
Air	Angle of incidence ($40° < \theta_i < 60°$)		n_a=
Glass	Angle of refraction		
Air	Angle of incidence ($60° < \theta_i < 90°$)		n_b=
Glass	Angle of refraction		
Glass	Critical Angle (θ_c)		n_c=
Air	Angle of incidence (θ_i)		n_A=
Mystery Medium A	Angle of refraction		
Air	Angle of incidence (θ_i)		n_B=
Mystery Medium B	Angle of refraction		

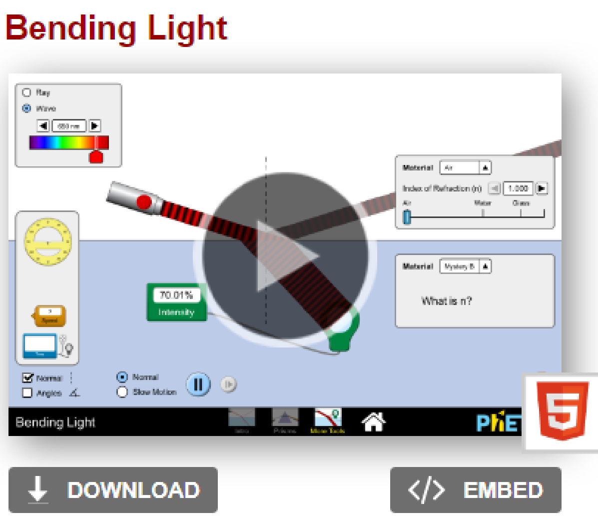
Analysis

1. Use equation 6.1 to calculate the refractive index of glass in the first three scenarios on the data table (n_a, n_b, and n_c).
2. Find the average experimental value for the refractive index of Lucite, n.
3. Calculate the error (as a percentage) in your average experimental value calculated above.
4. Calculate the speed of light in Lucite.
5. Use equation 6.1 to calculate the refractive index of "Mystery A" and "Mystery B" media.

Click on this link to start your experiment on refraction:

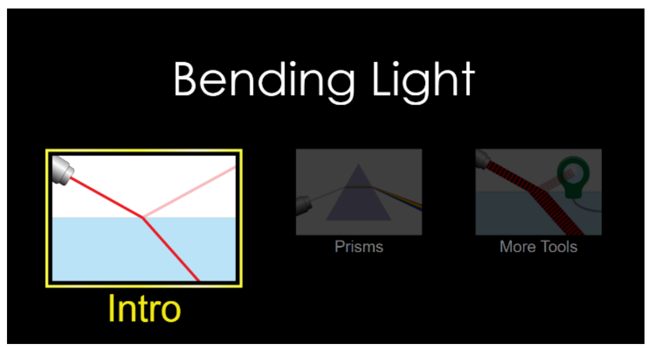
https://phet.colorado.edu/sims/html/bending-light/latest/bending-light_en.html

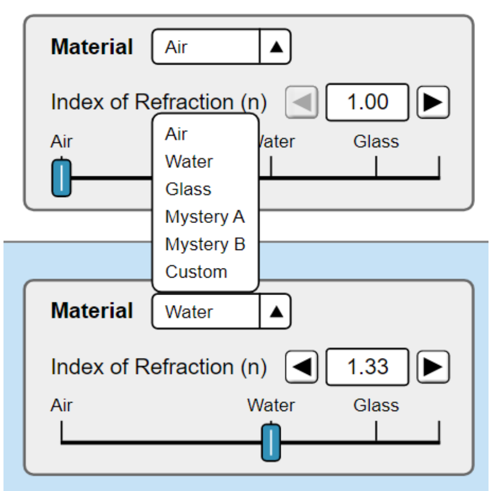
Tutorial for the online applet



Click on the center of the image to go straight to the simulation.

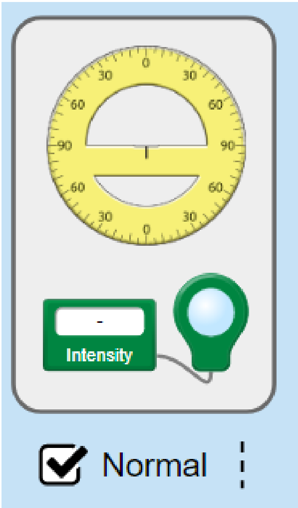
Select the first option available: “Intro”





Make sure the top material is “Air”, while the bottom one is “Glass”. The bottom one will be “Water” by default, the examples on this tutorial will show measurements for light traveling from Air to Water. Make sure the measurements you take are from Air to Glass (and glass to air for the critical angle measurement).

You will also have to switch to two additional media (Mystery A and Mystery B) after you get a hang of the layout of this applet.



Click and drag out the protractor from the side panel on the bottom left corner of your screen.

Make sure the "Normal" is checked. The normal line is a line that is perpendicular to the surface where light is entering from one medium to another.

All angles are measured from the normal line.

The angle of incidence (θ_i or θ_1) is the angle of the incoming ray.

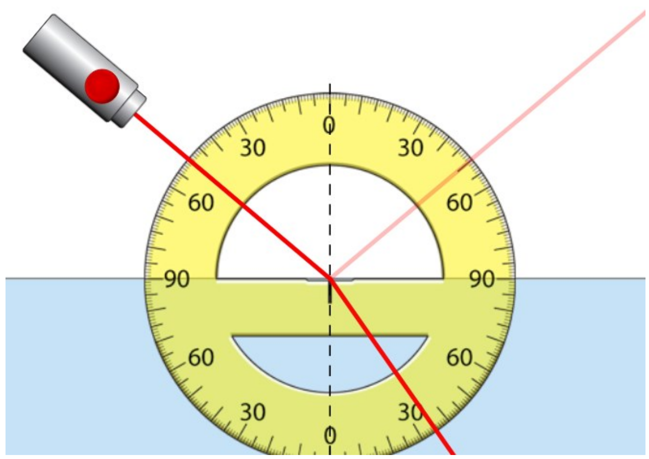
The angle of refraction (θ_r or θ_2) is the angle of the refracted (bent) ray.

You can turn the laser on by hitting the red switch on it. You can click and drag the body of the laser emitter to adjust the angles as needed (take the measurements according to what the data table states).

Here is an example of light with an angle of incidence of 50° and an angle of refraction that is 35°.

To calculate the refractive index of the second medium, we rearrange Snell's Law to solve for n_2:

$$n_2 = \frac{n_1 \sin\theta_1}{\sin\theta_2} = \frac{(1)\sin 50°}{\sin 35°} = 1.34$$



Now you have all the instructions you need to begin the experiment!