

### 3.6.1 Refraction

Refraction is the change in direction of waves when they pass from one medium into another, where the speed of the wave is different. For water waves refraction can occur when waves move from deep water to shallow water or vice versa.

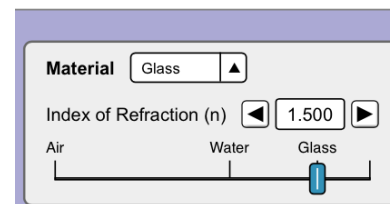
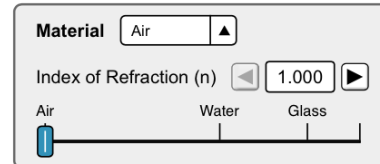
Run the following simulation:

[https://phet.colorado.edu/sims/html/bending-light/latest/bending-light\\_en.html](https://phet.colorado.edu/sims/html/bending-light/latest/bending-light_en.html)

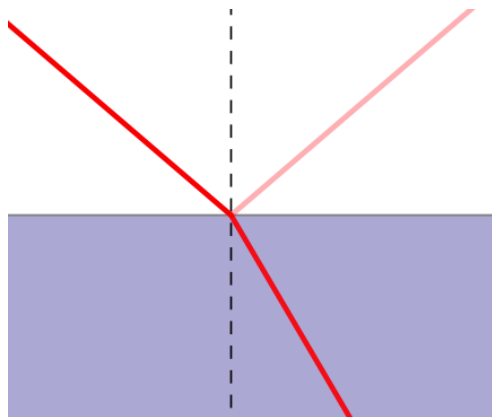
Choose the 'More Tools' simulation.

Click on the button on the light source to turn on.

Choose the settings, right:



You should see the following:



*Label: the incident ray, the refracted ray, the reflected ray, the angle of incidence ( $\theta_i$ ), the angle of refraction ( $\theta_r$ ), the normal line. Draw arrows on the rays to show the direction the light is travelling.*

*How does the angle of refraction compare to the angle of incidence?*

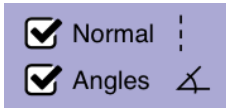
(1) *Change the angle of incidence, what do you notice about the angle of refraction?*

The relationship between the angle of incidence and the angle of refraction is given by:

$$\frac{\sin \theta_i}{\sin \theta_r} = \text{constant} = \frac{\text{refractive index of medium 2}}{\text{refractive index of medium 1}} = \frac{n_2}{n_1}$$

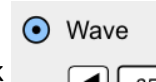
$$n_1 \sin \theta_1 = n_2 \sin \theta_2$$

This is known as Snell's law.



Click to show the angles.

(2) *Read off the angles and enter them into the formula above. You should get a value for the refractive index of glass.*



The reason for why the ray of light changes can be observed if you click

(3) *What do you notice about the speed of the waves in air compared to glass?*

(4) *What do you notice about the wavelength in air compared to glass?*

(5) *How does the frequency of light compare in the two media? How can you tell?*


The refractive index tells you about the relative speed of light in the two media:

$$n_1 c_1 = n_2 c_2$$

$$\frac{n_1}{n_2} = \frac{c_2}{c_1}$$

where  $n_1$ =refractive index of medium 1,  $n_2$ =refractive index of medium 2,  $c_1$ =speed in medium 1,  $c_2$ =speed in medium 2.

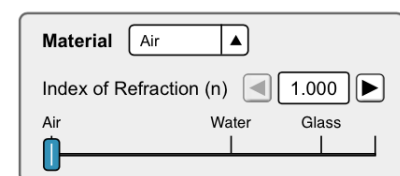
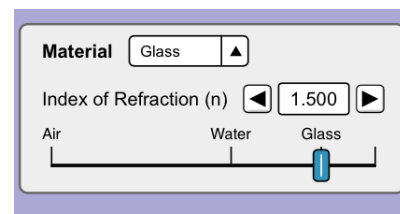
(6) *For air into glass, plug in the refractive indexes to find  $\frac{c_2}{c_1}$ . Given that the speed of light in air is approximately  $3 \times 10^8 \text{ ms}^{-1}$ , calculate the speed in glass.*

Now choose  and the settings, right:

Change the angle of incidence.

You should find an angle (the critical angle) when the ray no longer passes into the air but only reflects (total internal reflection).

(7) *What is the critical angle for a ray travelling from glass to air?*



We can actually find the critical angle ( $\theta_c$ ) for any two media using Snell's law. We just need to set the angle in the second (less optically dense medium) to be  $90^\circ$ .


$$n_1 \sin \theta_c = n_2 \sin 90^\circ$$

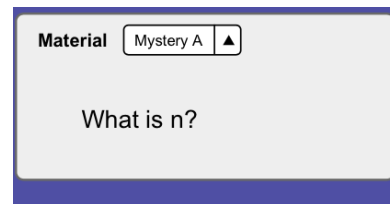
$$\theta_c = \sin^{-1} \left[ \frac{n_2}{n_1} \right]$$

(8)  Check that this works for glass into air.

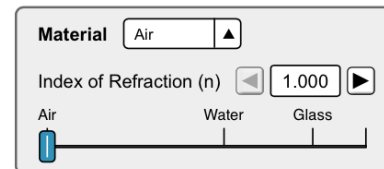
Now select the settings, right:


You are going to use two methods to determine the refractive index of Mystery A.


(9)  Set the angle of incidence to  $16^\circ$ , and record angle of refraction. Use Snell's law to determine the refractive index of Mystery A.



the



(10)  Now adjust the angle of incidence to find the critical angle. Use the formula for critical angle to find the refractive index of Mystery A.

(11)  If you like a further challenge, find the refractive index of Mystery B.