# Fluids, Thermodynamics, Waves, & Optics
# Optics
# Lab 7
# Refraction

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# Overview

- Purpose
- Part 3.1: Refraction
- Part 3.2: Total internal reflection
- Part 3.3: Refracting surfaces
- Part 4.4: Light as a wave and dispersion

# Purpose of the Lab

To explore basic ray optics including the refraction of beams of light.

You will use the Bending Light PhET simulation to explore the behavior of light as it moves from one medium to another. You will use simulated prims to observe total internal reflection, refraction at a curved surface, and dispersion.

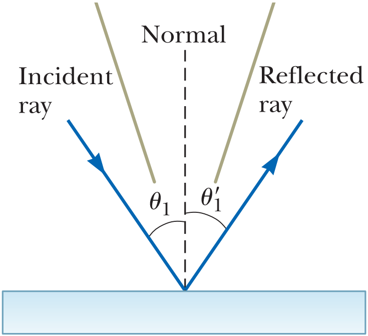
# Theory: Reflection

Specular (mirror-like) reflection:

Courtesy of Henry Leap and Jim Lehman

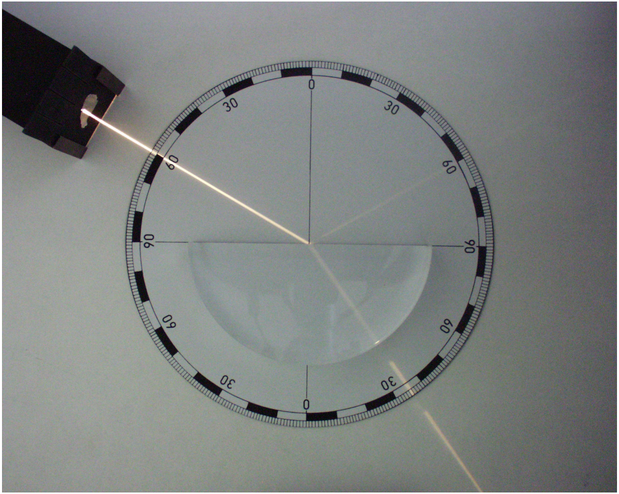
# Law of Reflection

$$\theta_i = \theta_{\text{refl}}$$



# Refraction

When light rays pass from one medium into another, they are often observed to bend.




[1] Image from Wikipedia, by Zátonyi Sándor.

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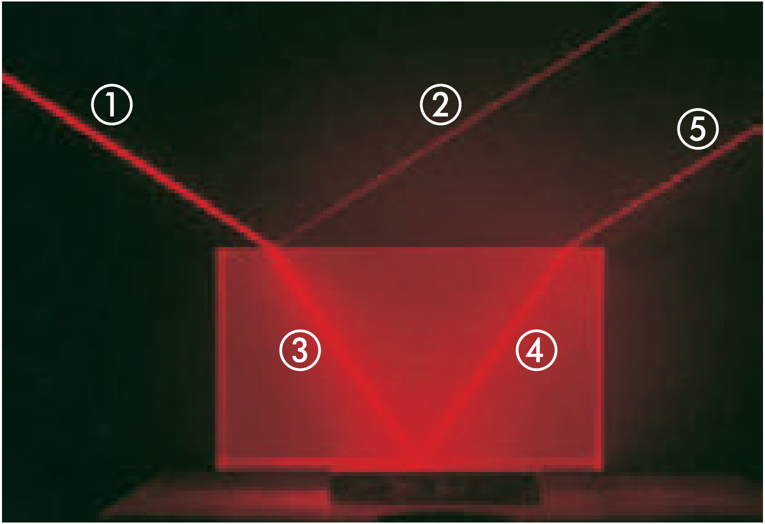



Courtesy of Henry Leap and Jim Lehman

# Refractive Index

Light *at a particular frequency* moves at different speeds in different media.

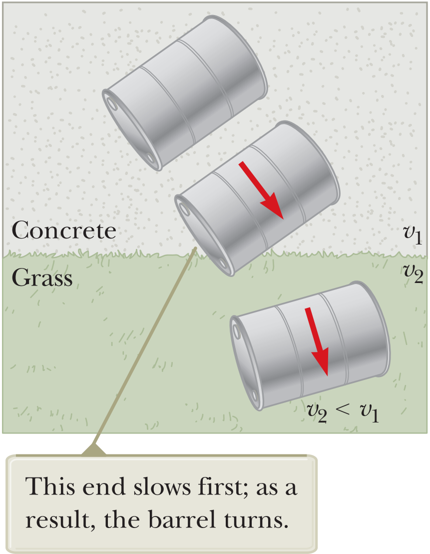
**Refractive index of a medium, $n$**

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

where $v = \frac{\omega}{k}$ is the phase velocity of light with angular frequency $\omega$ in that medium.

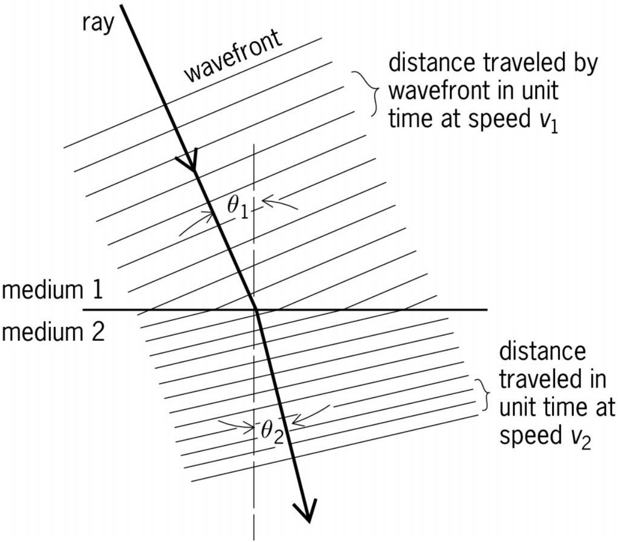
The larger the refractive index, $n$, the slower the speed in that medium.

# Refraction



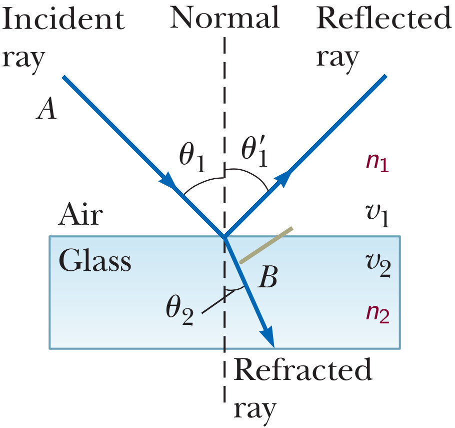

[1]Serway & Jewett, 9th ed, page 1066.

# Refraction




[1] McGraw-Hill Concise Encyclopedia of Physics. © 2002 by The McGraw-Hill Companies, Inc.

# Refraction: Snell's Law

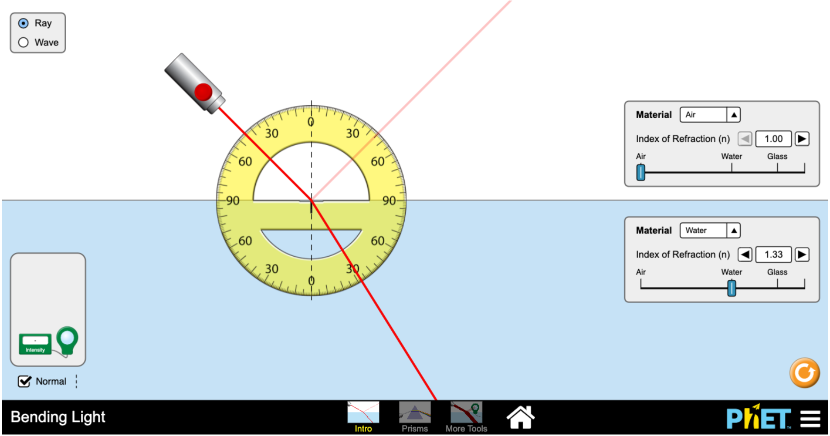



**Snell's Law**:

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

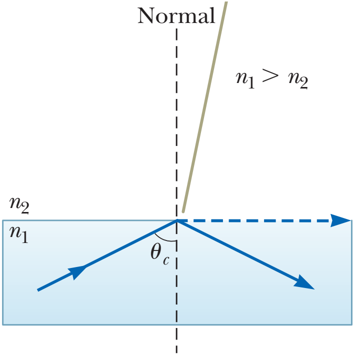
[1] Willebrord Snell discovered this law experimentally.

# Intro: Refraction Setup



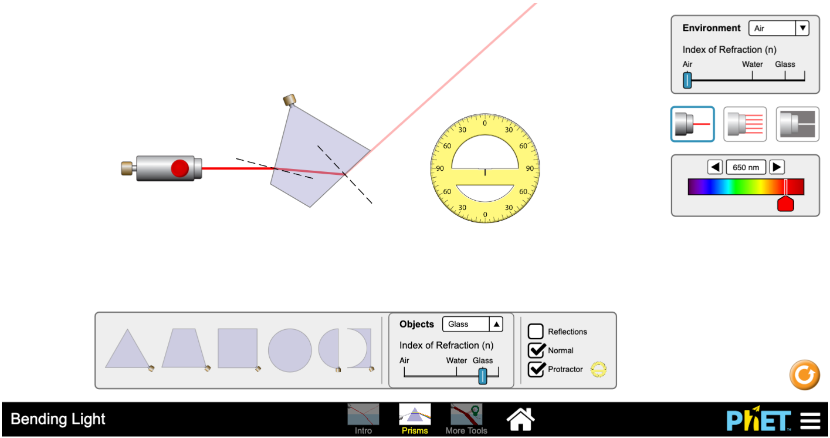
# Total Internal Reflection

The **critical angle**, $\theta_c$, is the maximum angle of incidence such that there could be a refracted ray. The ray would just skim along the surface between the media.

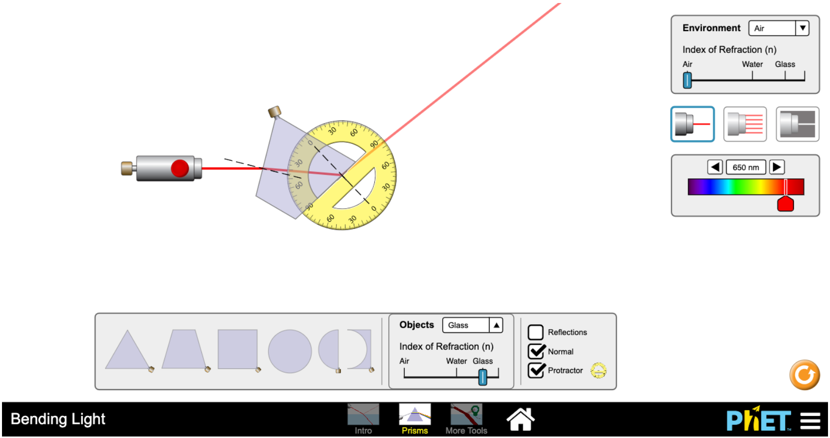



In this case, the angle of refraction $\theta_2 = 90^\circ$.

# Prisms: Total Internal Reflection Setup



# Prisms: Total Internal Reflection Setup



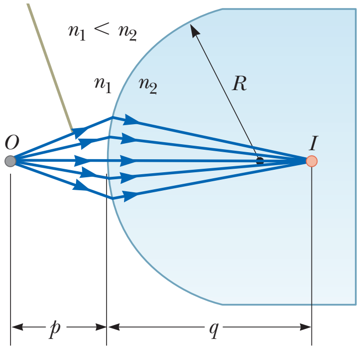
# Theory: Images Formed by Refraction

When light rays change media they are bent.

This also can form images.

# Images Formed by Refraction

We can find the location and size of the image formed by considering paraxial rays.

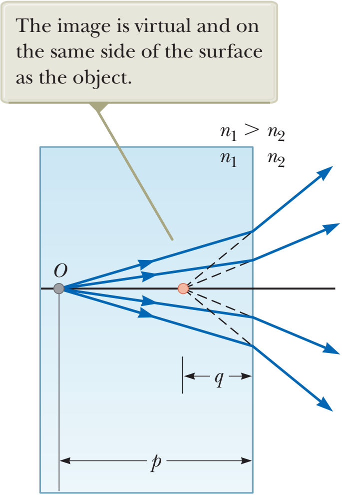



For paraxial rays:

$$\frac{n_1}{p} + \frac{n_2}{q} = \frac{n_2 - n_1}{R}$$

# Flat Refracting Surfaces

(Like a rectangular fish tank.)




In this case $R \to \infty$.

$$\frac{n_1}{p} + \frac{n_2}{q} = 0$$

And so

$$q = -\frac{n_2}{n_1} p$$

# Flat Refracting Surfaces Example (Problem 30)

A cubical block of ice 50.0 cm on a side is placed over a speck of dust on a level floor. Find the location of the image of the speck as viewed from above. The index of refraction of ice is 1.309.

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$$\frac{n_1}{p} + \frac{n_2}{q} = \frac{n_2 - n_1}{R} \; , \; R \to \infty$$

$$\Rightarrow q \;\; = \;\; -\frac{n_2}{n_1}\, p$$

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$$\frac{n_1}{p} + \frac{n_2}{q} = \frac{n_2 - n_1}{R} \text{ , } R \to \infty$$

$$\begin{aligned} \Rightarrow q &= -\frac{n_2}{n_1}\, p \\ &= -\frac{1}{1.309}\,(50.0 \text{ cm}) \\ &= \underline{38.2 \text{ cm}} \end{aligned}$$

# Sign Conventions for Refracting Surfaces!

$$\frac{n_1}{p} + \frac{n_2}{q} = \frac{n_2 - n_1}{R}$$

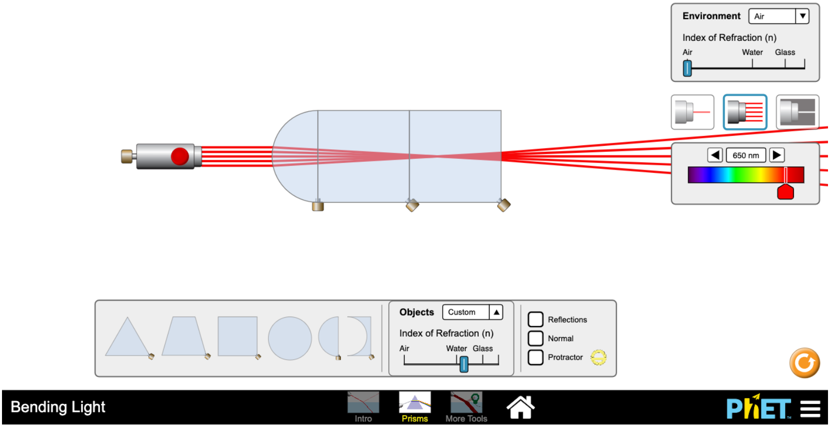
| Variable | is Positive | is Negative |
|---|---|---|
| $p$ | object in front of surface | [virtual object][1] |
| $q$ | image behind surface (real) | image in front of surface (virtual) |
| $h'$ (and $M$) | image upright | image inverted |
| $R$ | object faces convex surf. ($C$ behind surface) | object faces concave surf. ($C$ in front of surface) |

$C$ is the center of curvature.

$M = \frac{h'}{h} = -\frac{n_1 q}{n_2 p}$

[1] Will be useful in derivations.

# Prisms: Refracting Surfaces Setup



# More Tools: Light as a wave