16.2.2: Refraction

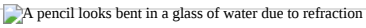


Figure 14.2.1

When a light ray passes at an angle through the boundary between optically different media, the light does not travel in a straight line. The pencil in the glass of liquid shown above is a normal straight pencil. The light that travels from the pencil through the liquid, through the glass, and into the air is bent differently than light from the portion of the pencil that is not in the liquid. Your eye assumes the light from both portions of the pencil moved in a straight line, but the two portions of the pencil do not appear to be lined up. Your eye thinks the pencil is broken.

Refraction of Light

The speed of light is different in different media. If the speed of light is slower in a particular medium, that medium is said to be more **optically dense**. When a wave front enters a new medium at an angle, it will change directions. If the light is entering a more optically dense medium, the light bends toward the normal line. If the light is entering a less optically dense medium, the light will bend away from the normal line. Remember that the normal line is the line perpendicular to the medium interface.

In the sketch below, light wave fronts are moving upward from the bottom of the page and encounter a boundary into a more optically dense medium. The light waves bend toward the normal line. Because the right end of the wave fronts enter the new medium first, they slow down first. When the right side of the wave front is moving more slowly that the left side, the wave front will change directions.

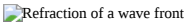


Figure 14.2.2

When light is traveling from air into another medium, **Snell's Law** states the relationship between the angle of incidence and angle of refraction is

$n=\sin\theta_i/\sin\theta_r$

where θ_i is the angle of incidence, θ_r is the angle of refraction, and n is the ratio of the two sines and is called the **index of refraction**. Snell's Law may be stated that a ray of light bends in such a way that the ratio of the sine of the angle of incidence to the sine of the angle of refraction is a constant.

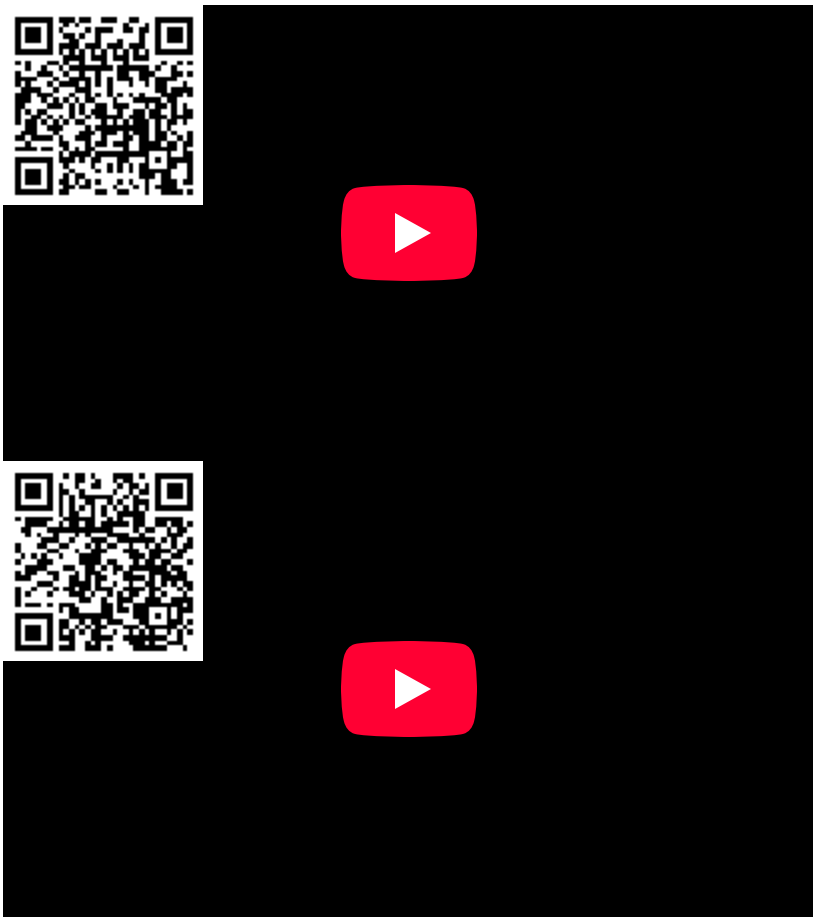
The index of refraction is also related to the relative speeds of light in a vacuum and in the medium.

n=speed of light in a vacuum/speed of light in the medium

When a ray of light is traveling from medium into another medium, Snell's Law can be written as $n_i\sin\theta_i=n_r\sin\theta_r$.

Indices of Refraction

Medium	n_
Vacuum	1.00
Air	1.0003
Water	1.36
Ethanol	1.36
Crown Glass	1.52
Quartz	1.54
Flint Glass	1.61
Diamond	2.42



Example 14.2.1

A ray of light traveling through air is incident upon a slab of Flint glass at an angle of 40.0∘. What is the angle of refraction?

Solution

$n=\sin\theta_i/\sin\theta_r$ *so* $\sin\theta_r=\sin\theta_i/n=0.643/1.61=0.399$

The angle of refraction=$\sin^{-1}.399=23.5^\circ$

Example 14.2.2

What is the speed of light in a diamond?

Solution

speed of light in diamond=speed of light in a vacuum/n=3.00×10^8m/s /2.42

speed of light in diamond=1.24×10^8 m/s

In the Least Time simulation below, you can adjust the sliders so that light travels from air to a denser material like glass or diamond. Then, drag the incident ray and refracted rays to the correct angles according to Snell's Law. When you have found the path of least time - a red light ray will shoot out across the both materials! Very exciting!

Effects of Refraction

Bending the Sun's Rays

Because air is slightly more optically dense than a vacuum, when sunlight passes from the vacuum of space into our atmosphere, it bends slightly towards the normal. When the sun is below the horizon and thus not visible on a direct line, the light path will bend

slightly and thus make the sun visible by refraction. Observers can see the sun before it actually comes up over the horizon, or after it sets.

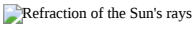


Figure 14.2.3

Mirages

In the Figure below, the sun shines on the road, heating the air just above the road. The difference in density between the hot air over the road and the surrounding air causes the hot air to refract light that passes through it. When you look at the road, you see a **mirage**. What appears to be water on the road is actually light coming from the sky that has been refracted as it passes through the hot air above the road. This phenomenon is common on hot roads and in the desert.

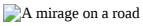


Figure 14.2.4

Summary

- The speed of light is different in different media.
- When a wave front enters a new medium at an angle, it will change directions. If the light is entering a more optically dense medium, the light bends toward the normal line. If the light is entering a less optically dense medium, the light will bend away from the normal line.
- When light is traveling from air into another medium, Snell's Law states that $n=\sin\theta i \sin\theta r$.
- The index of refraction is also related to the relative speeds of light in a vacuum and in the medium. n=speed of light in a vacuum/speed of light in the medium
- When a ray of light is traveling from one medium into another medium, Snell's Law can be written as $n i \sin\theta i = n r \sin\theta r$.

Review

1. Light moving through air is incident on a piece of crown glass at an angle of 45°. What is the angle of refraction?
2. A ray of light passes from air into water at an incident angle of 60°. Find the angle of refraction.
3. Light passes from water into a block of transparent plastic. The angle of incidence from the water is 31° and the angle of refraction in the block is 27°. What is the index of refraction for the plastic?
4. The index of refraction of water is 1.36. What is the speed of light in water?
5. If the speed of light in a piece of plastic is 2.00×10^8 m/s, what is the index of refraction for the plastic?

Additional Resources

Study Guide: Geometric Optics Study Guide

Real World Application: Is That A Mirage?

PLIX: Play, Learn, Interact, eXplore: Refraction: Light Entering Water, Refraction Slider

Videos: