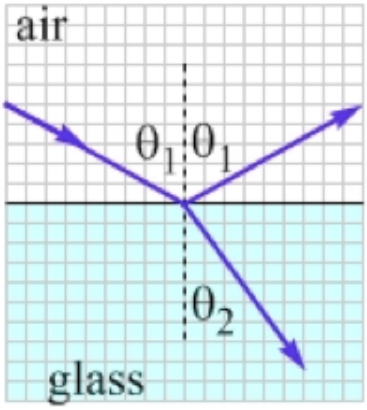
24-1 Refraction

Important Ideas

- Index of refraction $n = \frac{c}{v}$.
- When light is incident on the interface (i.e. boundary) between two media, part of the wave reflects and part of the wave transmits into the next medium. The reflected ray ones the law of reflection. The refracted ray obeys Snell's Law.



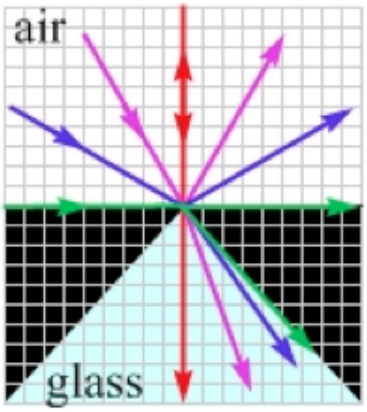
- Snell's Law

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

When light transmits from a lower n medium to a higher n medium it bends *toward* the normal, and the angle of refraction is less than the angle of incidence.

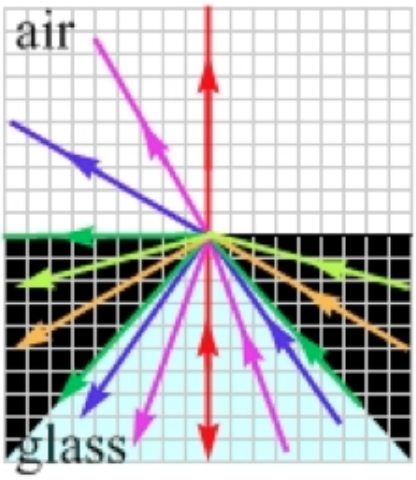
When light transmits from a higher n medium to a lower n medium it bends *away* from the normal, and the angle of refraction is greater than the angle of incidence.

- In the image below, light incident in air at 90° refracts at 41.8° in the glass. Thus, it is impossible for any incident light to travel through the dark shaded region ($\theta_2 > 41.8°$) in the image.



Incident angle	Refracted angle
0°	0°
30.0°	19.5°
60.0°	35.3°
90.0°	41.8°

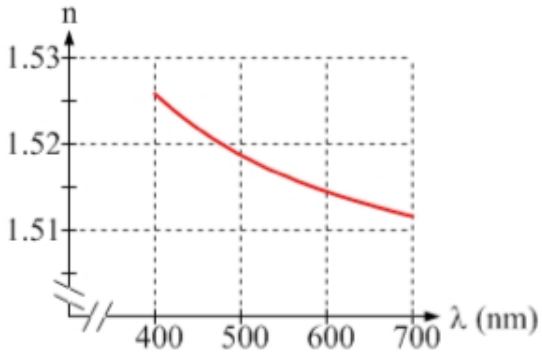
The paths of rays are reversible. Suppose that light travels from glass to air, if light is incident at $\theta = 41.8°$ in the glass, then it refracts at 90° in the air. If incident angles are greater than 41.8°, no light is transmitted and all of the light will be reflected within the glass.



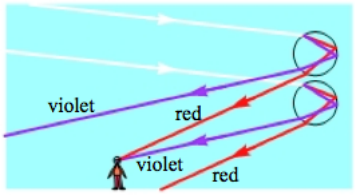
- The critical angle is the angle of incidence that gives refraction at 90°. Rays with indent angles larger than the critical angle will only reflect. This is called *total internal reflection*. This *only* occurs when rays travel in a medium of higher index of refraction and reflect from an interface of a medium with a lower index of refraction. The critical angle is the angle beyond which total internal reflection occurs.

$$\theta_c \quad = \quad \sin^{-1}\left(\frac{n_2}{n_1}\right)$$

- The index of refraction depends (slightly) on wavelength. If white light traveling in air is incident on water, for example, a red wavelength refracts less than a violet wavelength. As a result, the water separates the white light into its component colors–a rainbow. You can also see this with light traveling through a glass prism or a plastic bike reflector, for example.

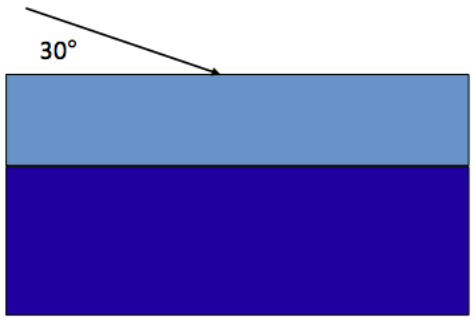


- To understand how a rainbow is formed, remember that you can generally only see a rainbow after it has rained, when the Sun is fairly low in the sky, and when you are looking away from the Sun.



Examples

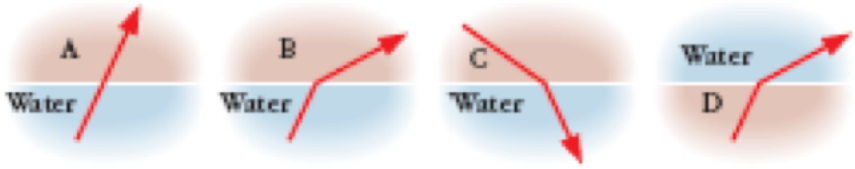
1. Laser light in air strikes a flat surface of glass (n=1.5) at the angle shown. On the other side of the glass is water (n=1.33). At what angle does it travel through the water?



2. It's nighttime, and you've dropped your goggles into a swimming pool that is 3.8 m deep. If you hold a laser pointer 1.0 m above the edge of the pool, you can illuminate the goggles if the laser beam enters the water 2.5 m from the edge. How far are the goggles from the edge of the pool?

3. An underwater diver sees the sun 54° above the horizontal. At what angle is the sun above the horizon to a person in a boat?

4. Above are four rays of light from the same monochromatic laser source. Each ray passes from one medium to another. Water is always one of the two media; the other media (A, B, C, and D) may be different. Which of the following correctly compares the index of refraction of the media?



(a) $n_B = n_D > n_C > n_A$

(b) $n_C > n_D = n_B > n_A$

(c) $n_D > n_B = n_C > n_A$

(d) $n_A > n_C > n_B = n_D$

5. Can light passing from air into water be totally internally reflected? If so, what is the critical angle? Can light passing from water into air be totally internally reflected? If so, what is the critical angle?

6. For light traveling from air to glass at an angle $\theta_1 > 0$, which color will have a greater angle of refraction, red or violet light?

(a) red

(b) violet

(c) neither, they bend the same amount