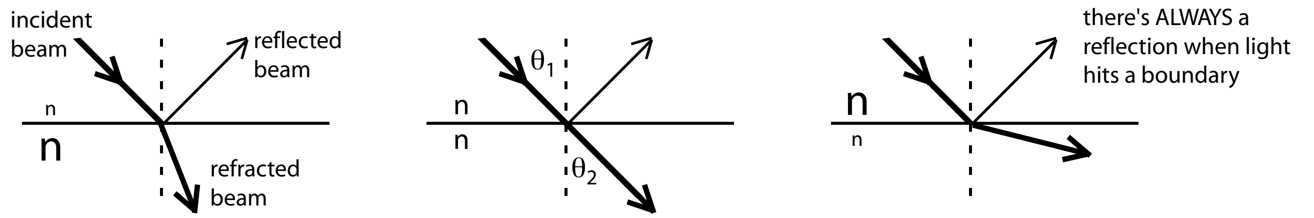
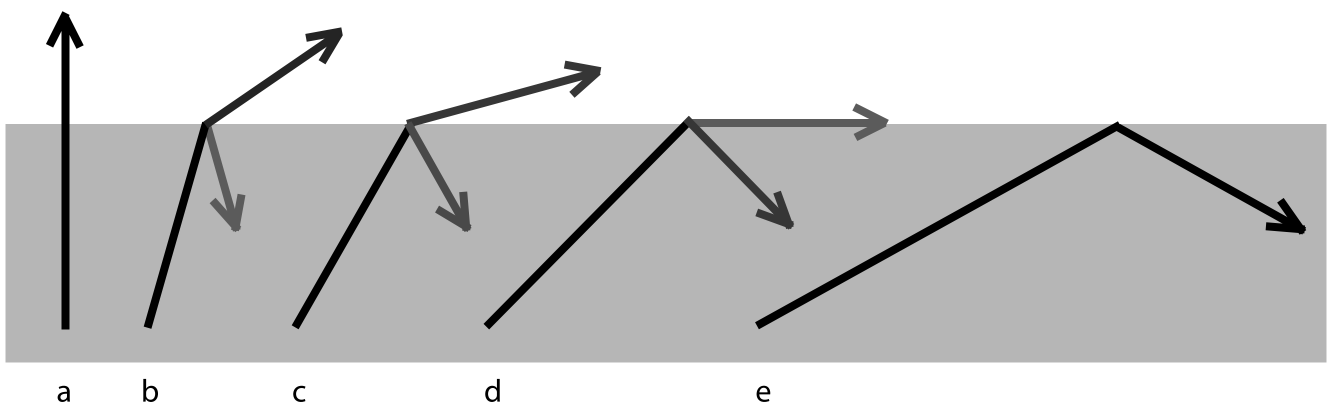
PhyzGuide: Total Internal Reflection



When light travels from an optically less dense medium to a more dense medium, it is bent toward the normal ($\theta_2 < \theta_1$). When light travels from a more dense medium to a less dense one, it is bent away from the normal ($\theta_2 > \theta_1$).

As a result, light incident at any angle from air (small n) to water (larger n) will be refracted into the water. But light emerging from water to air is a more interesting case. Consider what happens as light hits the water to air boundary at increasingly larger angles of incidence.



a. light is incident at $\theta_1=0^\circ$; most of the light is refracted at $\theta_2=0^\circ$, some of it is reflected back into the water

b. and **c**. light is incident at a higher angle; some of the light is refracted out into the air (notice that the angle of refraction is approaching 90˚), some of the light is reflected back into the water (notice the trends in the intensity of the refracted and reflected beams)

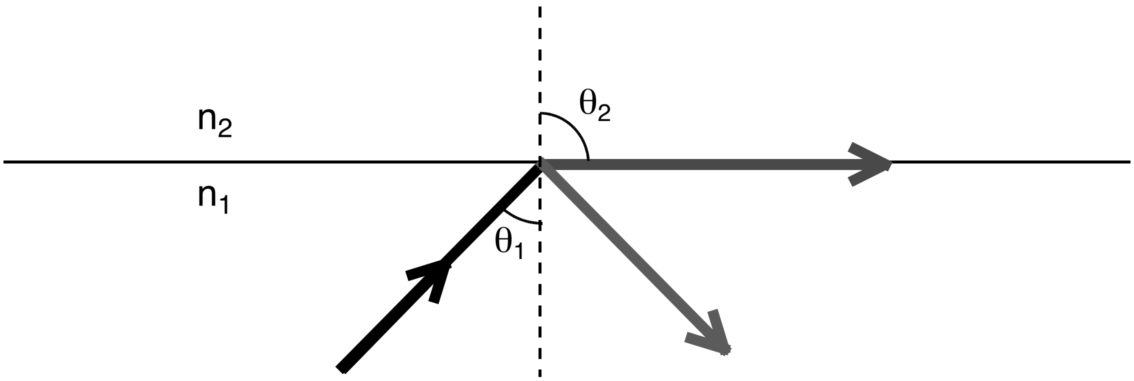
d. for this angle of incidence (called the **critical angle** θ_c), the angle of refraction is 90˚—the refracted beam grazes the surface of the water

e. any incident angle higher than that in case d results in **total internal reflection**—none of the light refracts out into the air

When light is incident on the water to air boundary at an angle greater than the critical angle, all the light is reflected—there is *no* refraction! This condition is called **total internal reflection** (TIR)—100% of the light incident on the boundary is reflected. Mirrors reflect only 85-95% of the light that hits them, so TIR provides a more effective reflection.

It is important to note that total internal reflection can occur only when light is incident on a boundary between an optically more dense material to an optically less dense material. TIR can occur when light hits a glass to air boundary, but TIR cannot occur when light hits an air to glass boundary.

A natural question to ask about total internal reflection is, "What is the minimum angle of incidence at which TIR occurs?" Obviously, TIR does not occur at $\theta_1 = 0°$ (figure *a* in the diagram). TIR does not occur in figure *c,* but it does occur in figure *e*. The crossover to total internal reflection occurs in figure *d*.



When the angle of refraction is 90˚, the angle of incidence is called the critical angle ($\theta_c = \theta_1$ when $\theta_2 = 90°$). So what is the critical angle for a given boundary? Snell's law will throw some non-refracting light on this question.

Snell's law is $n = \sin\theta_1 / \sin\theta_2$, and the index of refraction when light passes from medium 1 to medium 2 is $n = n_2 / n_1$.

Writing this for the critical case (when the angle of refraction is 90˚)

$n_2/n_1 = \sin\theta_c / \sin 90°$ ...and since sin90˚ = 1... $n_2 / n_1 = \sin\theta_c$

solving for θ_c

$\theta_c = \text{Sin}^{-1} (n_2 / n_1)$ ...if the second medium is air, n_2=1... $\theta_c = \text{Sin}^{-1} (1/n)$

n = index of refraction of dense material

For example, the critical angle for water is

$$\theta_c = \text{Sin}^{-1} (1/n) = \text{Sin}^{-1} (1/1.33) = 49°$$

Total internal reflection is the principle behind **fiber optics**. In an optical fiber, light hits the glass to air boundary at an angle higher than the critical angle, and is therefore reflected back into the glass. If the glass is bent at a gradual angle, the light will follow the curve, so the path of the light can be bent in an optical fiber.