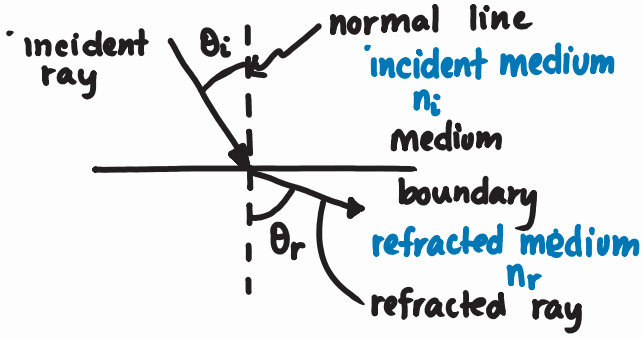
Snell's Law

Willebrord Snell was a Dutch research physicist who measured the angles of light as they entered different media. He found a relation between the angle of incidence and the angle of refraction.

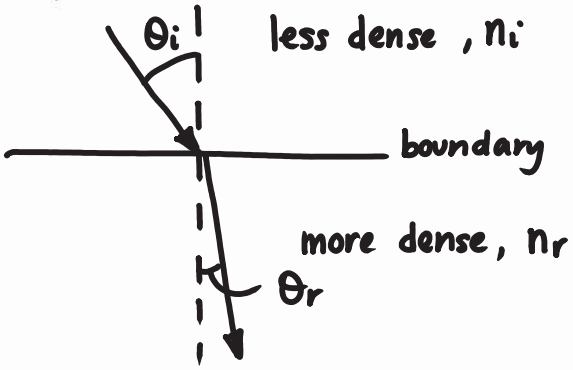


$$n_i \sin\theta_i = n_r \sin\theta_r$$

Snell's Law

(θ_i & θ_r must be in degrees)

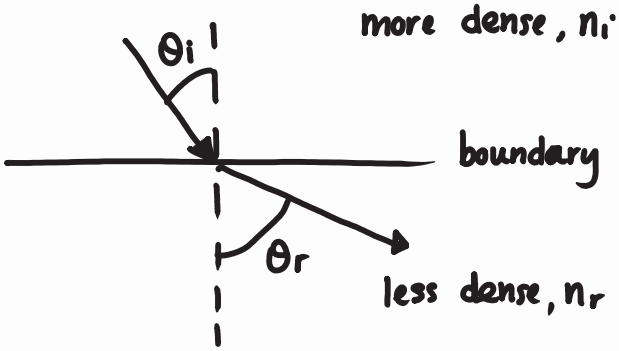
- When light travels from a **less dense to a more dense** medium, the light **slows down**, and the refracted ray is bent **towards** the normal. (going from lower ***n*** value to higher ***n*** value)



$n_i < n_r$

$\theta_i > \theta_r$

- When light travels from a **more dense to a less dense** medium, the light **speeds up**, and the refracted ray is bent **away from** the normal. (going from higher ***n*** value to lower ***n*** value)

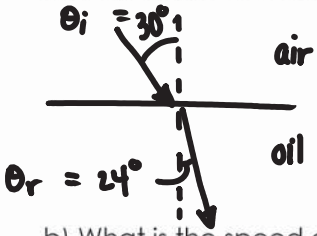


$n_i > n_r$

$\theta_i < \theta_r$

Example 1: A ray of light starts in air and has an angle of incidence of 30° to some cooking oil.

a) If an angle of refraction of 24° is produced in the oil, what is the index of refraction of the oil?



$n_i \sin\theta_i = n_r \sin\theta_r$

$\frac{(1.0003)(\sin 30^\circ)}{\sin 24^\circ} = \frac{n_r(\sin 24^\circ)}{\sin 24^\circ}$

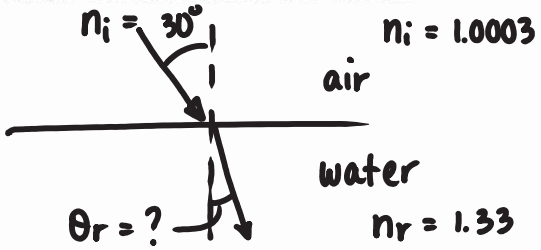
$n_r = 1.23$

b) What is the speed of light in cooking oil?

$n = \frac{c}{v}$ (from last day)

$1.23 = \frac{3.0\times10^8}{v} \Rightarrow v = \frac{3.0\times10^8}{1.23} = 2.44\times10^8 \text{ m/s}$

Example 2: A ray of light travels from air into water. If the angle of incidence was 30° what will be the angle of refraction in the water?



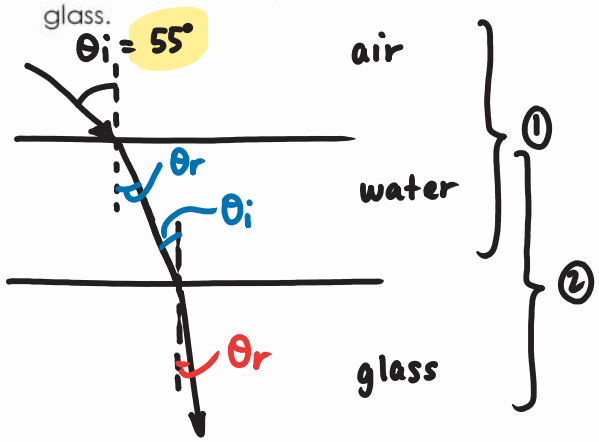
$n_i \sin\theta_i = n_r \sin\theta_r$

$\frac{(1.0003)(\sin 30)}{1.33} = \frac{(1.33)\sin\theta_r}{1.33}$

$\sin\theta_r = 0.3771$

$\theta_r = \sin^{-1}(0.3771) = 22^\circ$ (round to nearest degree)

Example 3: A ray of light travels from air ($n = 1.0003$) into water ($n = 1.33$) and then into glass ($n = 1.50$). The angle of incidence between air and water is 55°. Find the angle of refraction in the glass.



① air and water

$n_i \sin\theta_i = n_r \sin\theta_r$

$\frac{(1.0003)(\sin 55^\circ)}{1.33} = \frac{(1.33)\sin\theta_r}{1.33}$

$\sin\theta_r = 0.6161$

$\theta_r = \sin^{-1}(0.6161) = 38^\circ$

② water and glass

$n_i \sin\theta_i = n_r \sin\theta_r$

$\frac{(1.33)(\sin 38^\circ)}{1.50} = \frac{(1.50)\sin\theta_r}{1.50}$

$\sin\theta_r = 0.5463$

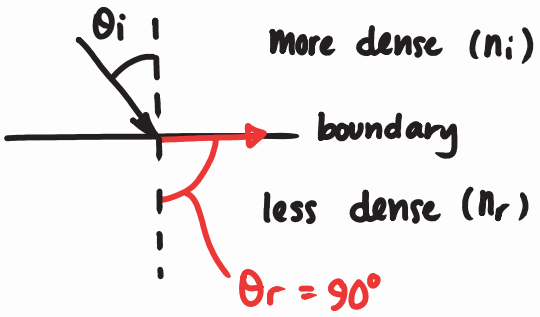
$\theta_r = \sin^{-1}(0.5463)$

$\theta_r = 33^\circ$

Critical Angle

more dense — less dense

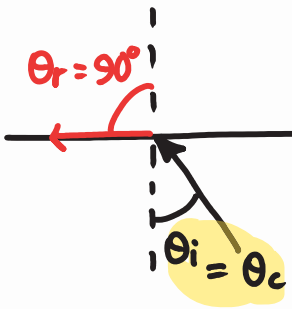
When light travels from a higher index of refraction to a lower one ($n_i > n_r$) and if the incident angle (θ_i) is big enough then the refracted angle (θ_r) will be 90°. We call this incident angle the critical angle θ_c



$\theta_i = \theta_c$ ← critical angle

$\theta_r = 90°$

Example 4: Find the critical angle for light traveling from water to air



$n_i \sin\theta_i = n_r \sin\theta_r$

$\frac{(1.33)\sin\theta_c}{1.33} = \frac{(1.0003)(\sin 90^\circ)}{1.33}$

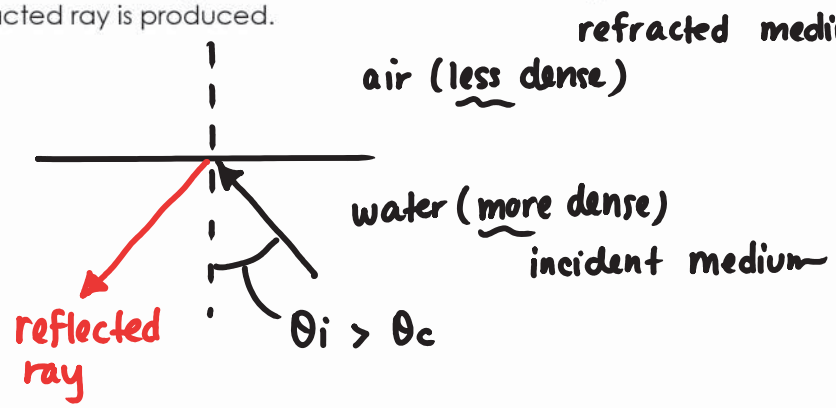
$\sin\theta_c = 0.7521$

$\theta_c = \sin^{-1}(0.7521)$

$\theta_c = 49°$

Total Internal Reflection

For any angle of incidence bigger than the critical angle **no light** enters the new medium. All light is reflected according to the law of reflection. We say that total internal reflection has occurred. No refracted ray is produced.



If $\theta_i > \theta_c$, total internal reflection occurs.