Reflection and Refraction

SP212 - General Physics II

United States Naval Academy
Annapolis

All rays of light travel at the same speed in a vacuum.

$$c = 3.00 \times 10^8 \text{ m/s} \qquad \text{Speed of light in a vacuum}$$

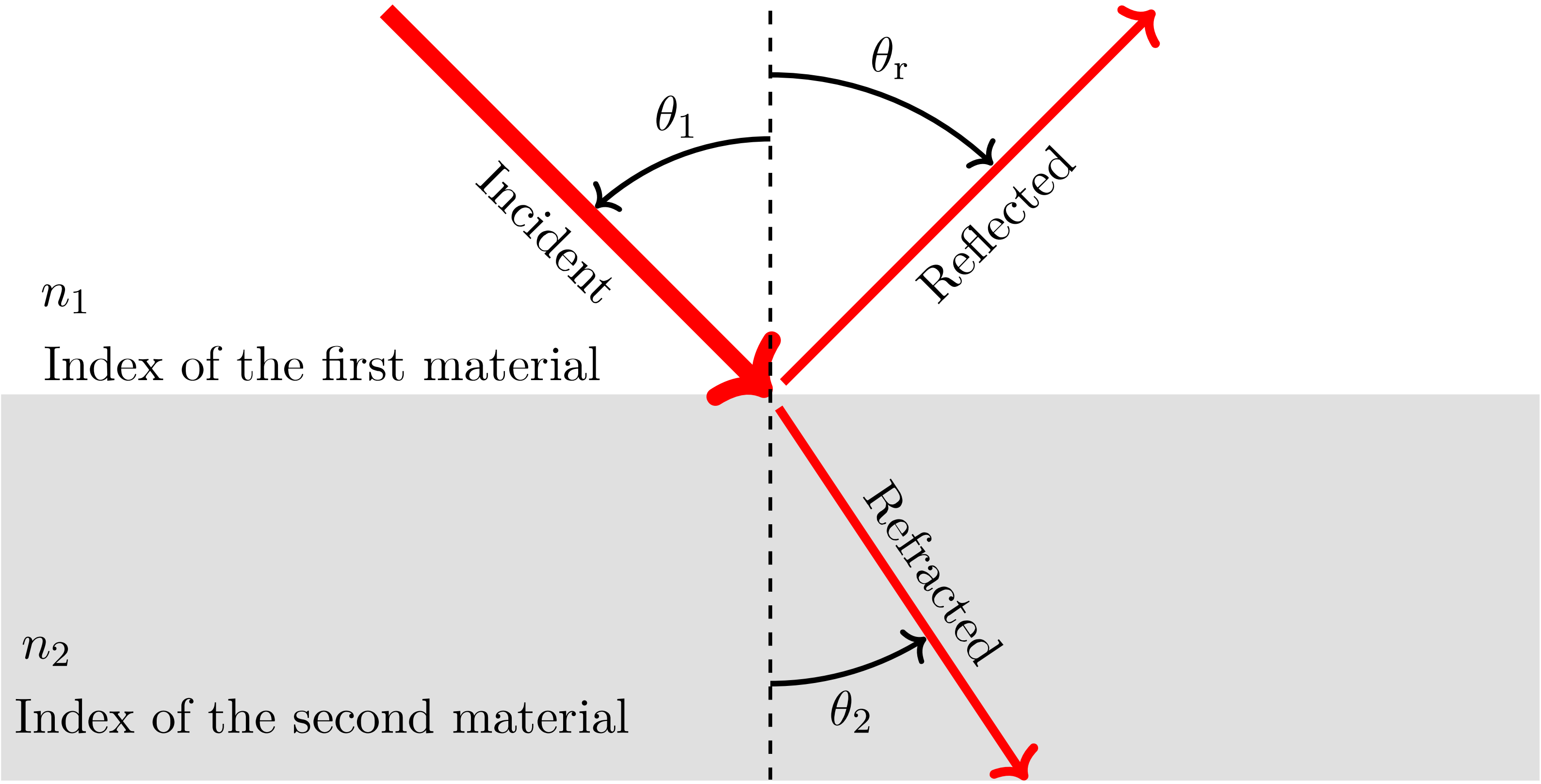
When light passes from vacuum into a material, it will slow down. The index of refraction of that material is the ratio by which it slows down.

$$n = \frac{c}{v} \qquad \text{Index of refraction}$$

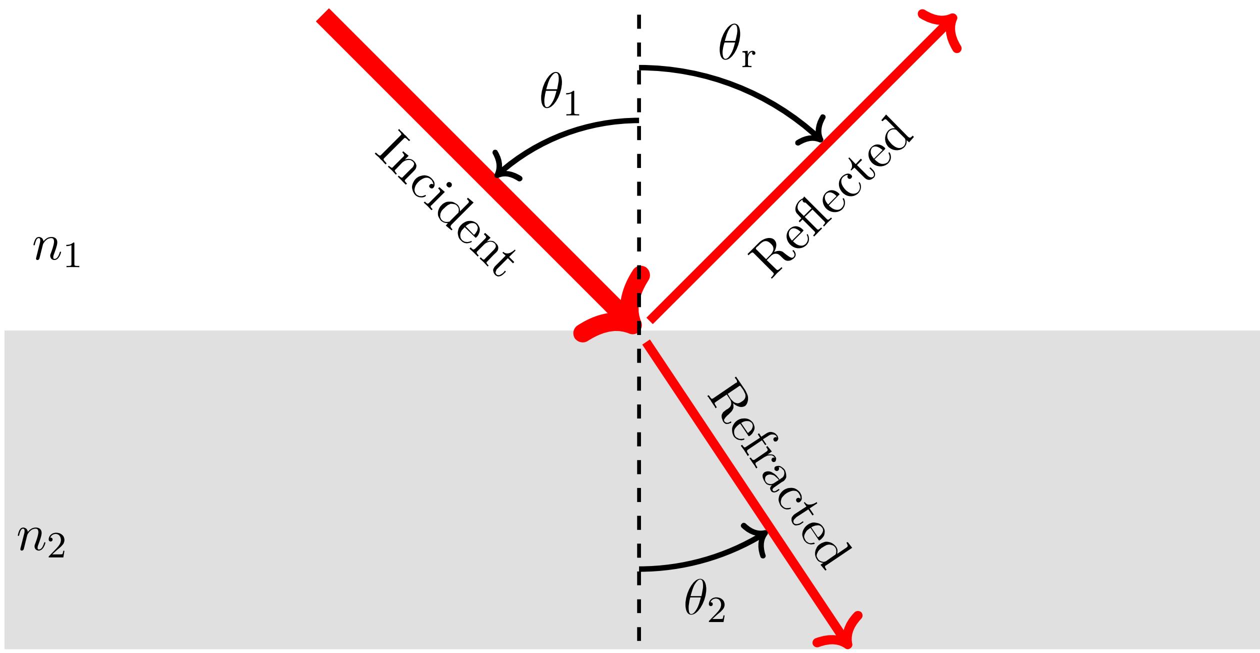
- n is the index of refraction of the material [unitless, ≥ 1]
- $c = 3.00 \times 10^8$ m/s is the speed of light in a vacuum
- v is the speed of light in the material [units are m/s]

Examples: $n_{\text{air}} \approx 1.00$, $n_{\text{water}} = 1.33$, $n_{\text{glass}} \approx 1.4$ to 1.6 (depending on type of glass)

When light traveling in a material is incident upon an interface with a second material, some of the light will be reflected back into the first material while some of the light will be refracted (bent) as it passes into the second material.

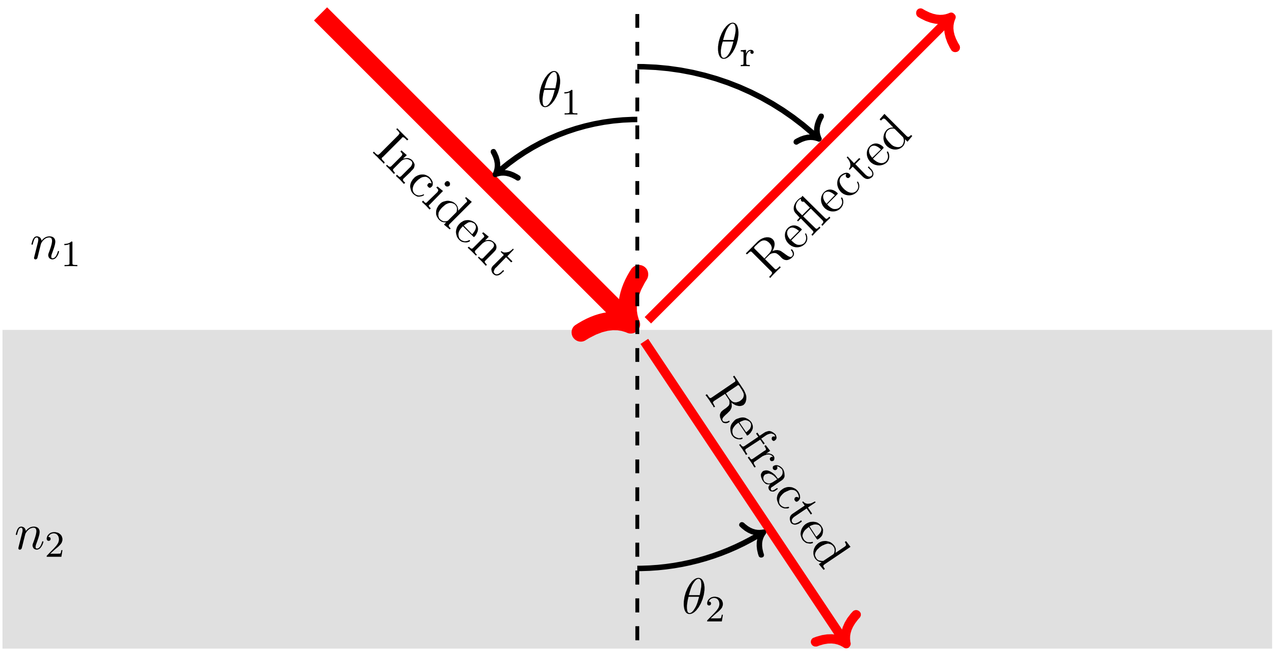


All angles are measured relative to the <u>normal</u>: the direction perpendicular to the interface between the two materials.



$\theta_1 = \theta_r$ The law of reflection

The angle of incidence equals the angle of reflection.



$n_1 \sin\theta_1 = n_2 \sin\theta_2$ Snell's law (the law of refraction)

- Suppose $n_2 > n_1$: therefore $\theta_2 < \theta_1$, the refracted light bends towards the normal
- Suppose $n_2 < n_1$: therefore $\theta_2 > \theta_1$, the refracted light bends away from the normal

Snell's Law: $n_1 \sin\theta_1 = n_2 \sin\theta_2$

We can rearrange this to $\sin\theta_2 = \frac{n_1}{n_2}\sin\theta_1$

When $n_1 > n_2$, there will be some θ_1 angles such that $\frac{n_1}{n_2}\sin\theta_1 > 1$. But $\sin\theta_2$ can never exceed 1. If you tried to solve for θ_2 you'd get a domain error.

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When $n_1 > n_2$, there will be a critical angle $\theta_c = \sin^{-1}\frac{n_2}{n_1}$. If the incident angle exceeds this critical angle (if $\theta_1 > \theta_c$) there will be total internal reflection. This means that *there will be no refracted ray of light.* 100% of the light will be reflected.

$$\sin\theta_c = \frac{n_2}{n_1}$$ Critical angle for total internal reflection

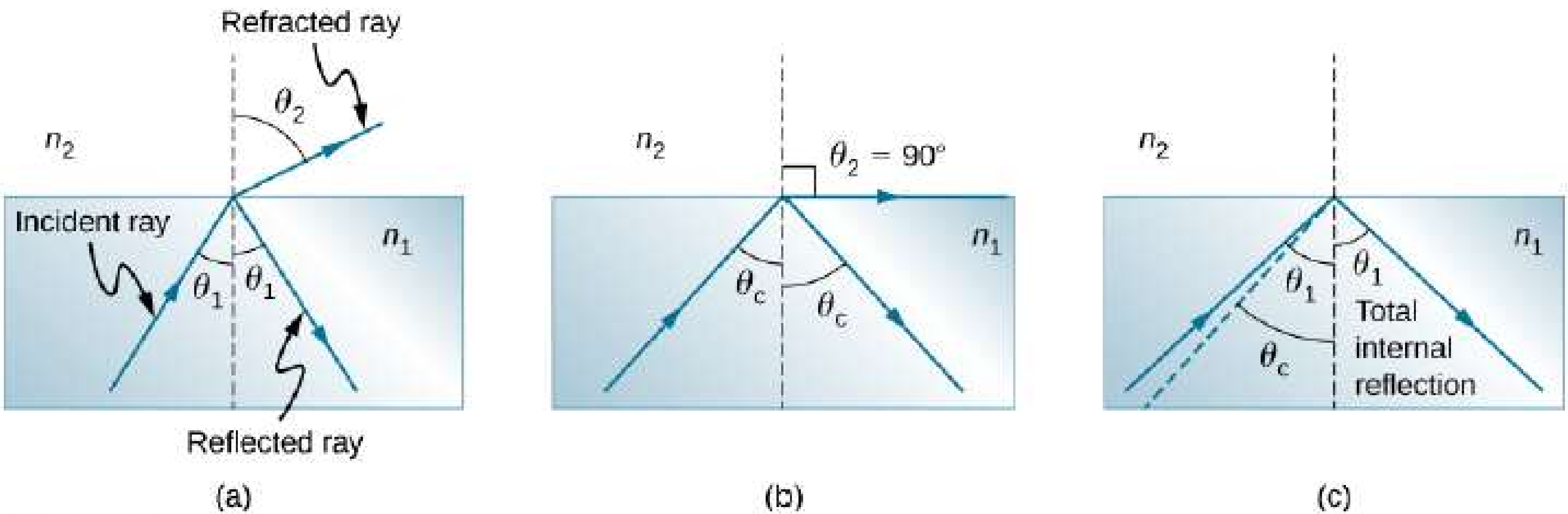

FIGURE 1.14 (a) A ray of light crosses a boundary where the index of refraction decreases. That is, $n_2 < n_1$. The ray bends away from the perpendicular. (b) The critical angle θ_c is the angle of incidence for which the angle of refraction is $90°$. (c) Total internal reflection occurs when the incident angle is greater than the critical angle.

Fig. 1.14 from *OpenStax University Physics, Volume 3*

Fiber optic cables use TIR to carry information long distances with little loss.

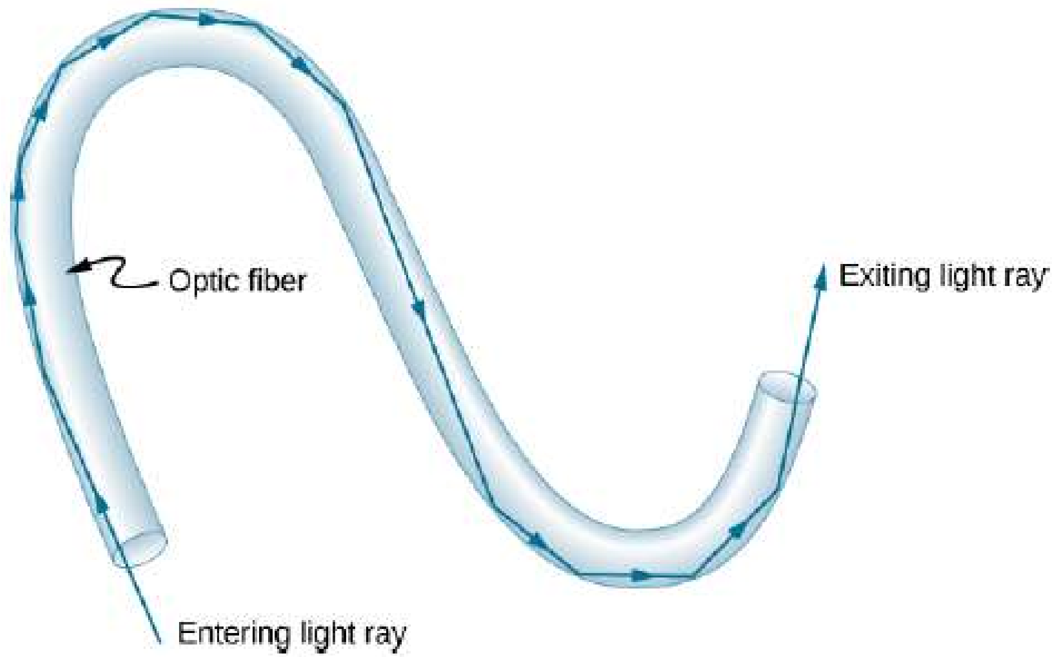

FIGURE 1.15 Light entering a thin optic fiber may strike the inside surface at large or grazing angles and is completely reflected if these angles exceed the critical angle. Such rays continue down the fiber, even following it around corners, since the angles of reflection and incidence remain large.

Fig. 1.15 from *OpenStax University Physics, Volume 3*

Example:

A fiber optic cable is made out of a material with an index of refraction of 1.55 surrounded by a *cladding* material. What should the index of the cladding material be such that the critical angle is equal to $55°$?

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The critical angle is given by $\theta_c = \sin^{-1}\dfrac{n_2}{n_1}$. Therefore $55° = \sin^{-1}\dfrac{n_2}{1.55}$.

This gives us $n_2 = 1.55 \sin 55° = 1.27$.