

Chapter 23

Light: Geometric Optics

Lecture 1

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23-1] The ray model of light

Ray model of light: light travels in straight lines in uniform transparent media (like air and glass)

Light rays coming from every point on the pencil enter the eye \Rightarrow can see the object.

In the figure, light rays travel in straight lines at different angles \Rightarrow Geometric Optics

Speed of light in vacuum is

$$c = 3 \times 10^8 \text{ m/s}$$

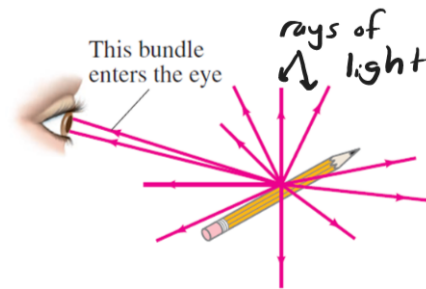


FIGURE 23-1 Light rays come from each single point on an object. A small bundle of rays leaving one point is shown entering a person's eye.

23-4] Index of Refraction

Light has the maximum speed of $c = 3 \times 10^8$ m/s in vacuum. In

other transparent media, its speed is less than c .

In water speed of light is $\frac{3}{4}c$.

The ratio $n = \frac{c}{v}$ is defined as the index of refraction

since $c > v \Rightarrow n > 1$ (Always, except for vacuum)

\Rightarrow for water $\frac{4}{3} = \frac{c}{v} \Rightarrow v = \frac{3}{4}c = 0.75c = \underline{2.25 \times 10^8 \text{ m/s}}$

Clearly, $n=1$ for vacuum \Rightarrow light

has maximum speed of $c = 3 \times 10^8$ m/s

in vacuum. In all other transparent

media $n > 1$ i.e. $v < c$

TABLE 23-1 Indices of Refraction[†]

Material	$n = \frac{c}{v}$
Vacuum	1.0000
Air (at STP)	1.0003
<u>Water</u>	1.33
Ethyl alcohol	1.36
Glass	
Fused quartz	1.46
Crown glass	1.52
Light flint	1.58
Plastic	
Acrylic, Lucite, CR-39	1.50
Polycarbonate	1.59
"High-index"	1.6–1.7
Sodium chloride	1.53
Diamond	2.42

23-5] Refraction: Snell's Law

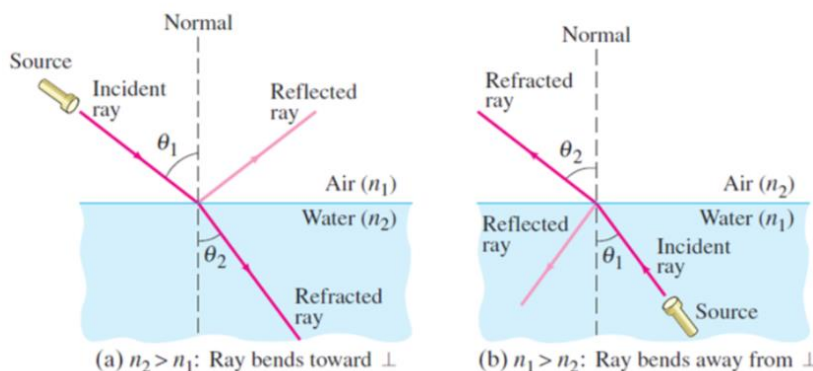


FIGURE 23-21 Refraction.

(a) Light refracted when passing from air (n_1) into water (n_2): $n_2 > n_1$.
 (b) Light refracted when passing from water (n_1) into air (n_2): $n_1 > n_2$.

(a) light passes from air \rightarrow water \Rightarrow
 light changes direction as it passes from air \rightarrow water. $n_1 < n_2$
 for air \downarrow n_1 \leftarrow for water n_2

This change in direction is called Refraction.

θ_1 : angle of incidence

θ_2 : angle of refraction

dotted vertical line is perpendicular to the surface between the two media (air and water)

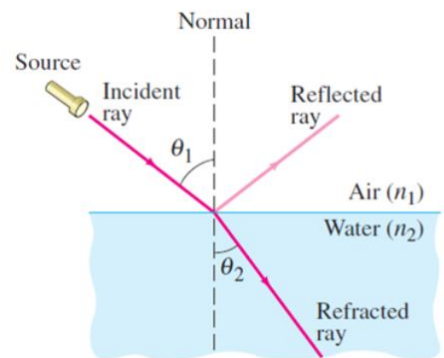
When $n_1 < n_2$ i.e light moves

from less dense \rightarrow higher dense

medium \Rightarrow refracted light bends

towards the normal i.e

$$n_1 < n_2 \Rightarrow \theta_1 > \theta_2$$



(a) $n_2 > n_1$: Ray bends toward \perp

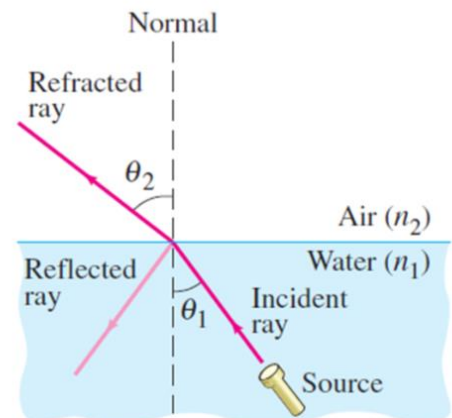
In Fig(b), light moves from water

\rightarrow air \Rightarrow more dense \rightarrow less dense
 media i.e $n_1 > n_2$
 for water \downarrow n_1 \leftarrow for air n_2

\therefore Refracted light bends away from the normal, that is when

$$n_1 > n_2$$

$$\Rightarrow \theta_1 < \theta_2$$



(b) $n_1 > n_2$: Ray bends away from \perp

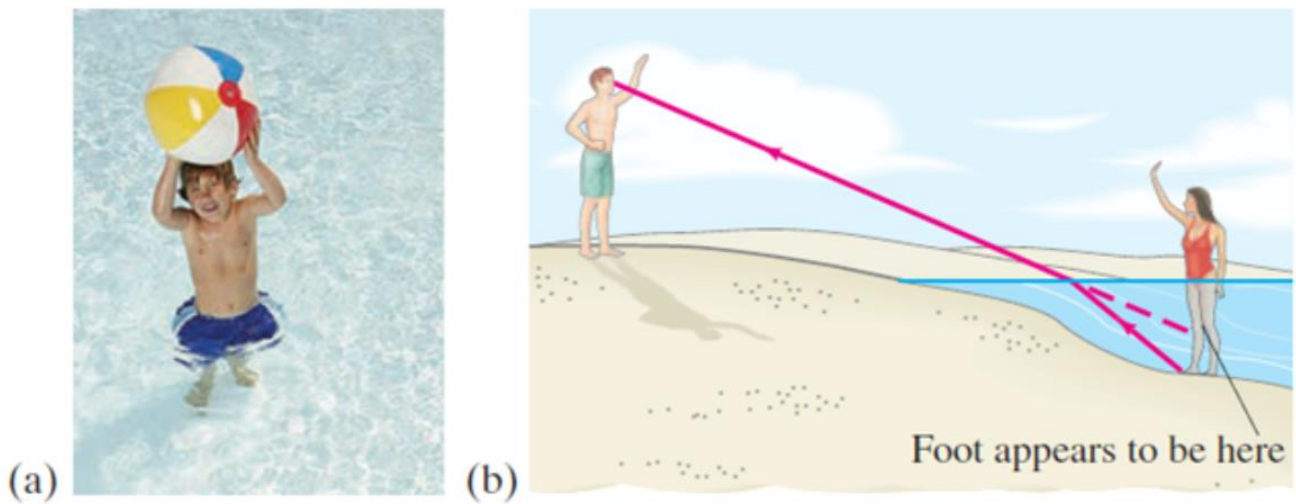
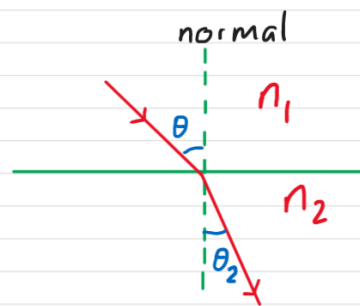


FIGURE 23-22 (a) Photograph, and (b) ray diagram showing why a person's legs look shorter standing in water: a ray from the bather's foot to the observer's eye bends at the water's surface, and our brain interprets the light as traveling in a straight line, from higher up (dashed line).

Snell's Law

$$n_1 \sin \theta_1 = n_2 \sin \theta_2$$

Note: incident ray, refracted ray and the normal are all in the same plane



From Snell's law:

$$\frac{n_1}{n_2} = \frac{\sin \theta_2}{\sin \theta_1} \Rightarrow$$

if $n_1 < n_2 \Rightarrow \theta_2 < \theta_1$ (refracted light bends towards normal)
 $n_1 > n_2 \Rightarrow \theta_2 > \theta_1$ (refracted light bends away from normal)

EXAMPLE 23-8 **Refraction through flat glass.** Light traveling in air strikes a flat piece of uniformly thick glass at an incident angle of 60.0° , as shown in Fig. 23-24. If the index of refraction of the glass is 1.50, (a) what is the angle of refraction θ_A in the glass; (b) what is the angle θ_B at which the ray emerges from the glass?

Apply Snell's law twice.

① Left hand side face

$$\text{air} \rightarrow \text{glass} \Rightarrow n_1 = 1, n_2 = 1.50$$

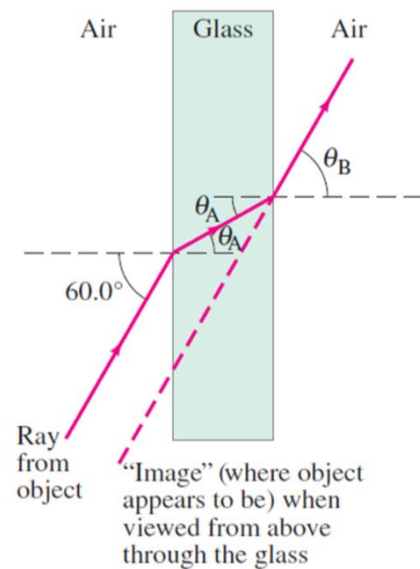
$$\theta_1 = 60^\circ, \theta_2 = \theta_A = ?$$

$$\sin \theta_A = \frac{1}{1.5} \sin 60^\circ = 0.5774$$

$$\Rightarrow \theta_2 = 35.3^\circ$$

② Right hand side face

$$\text{glass} \rightarrow \text{air} : n_1 = 1.5, n_2 = 1.0$$



from graph clearly angle of incidence is θ_A .

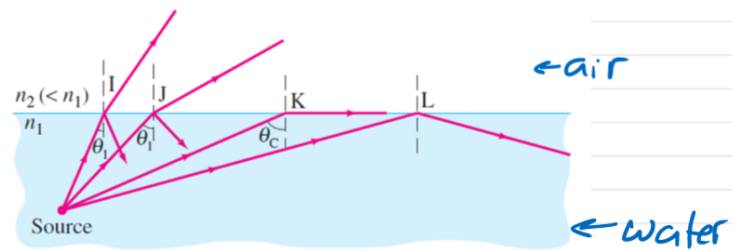
\therefore angle of refraction θ_B is

$$\sin \theta_B = \frac{1.50}{1.00} \sin \theta_A = 0.866 \Rightarrow \theta_B = 60^\circ$$

\therefore The direction of light is unchanged by passing through a flat piece of glass of uniform thickness.

23-6] Total Internal Reflection: Fibre Optics

When light passes from a medium of higher density (low speed) to a medium of lower density (high speed) \Rightarrow light is refracted away from the normal.



In the figure, for cases I and J part of the ray is refracted and part is reflected. Since $n_1 > n_2 \Rightarrow$ refracted light is bent away from the normal. At angle θ_c (called critical angle) \Rightarrow Refracted ray travels parallel to the surface; i.e. $\theta_2 = 90^\circ$

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

$$\therefore \sin \theta_1 = \frac{n_2}{n_1} \sin \theta_2$$

$$\therefore \text{at } \theta_1 = \theta_c \Rightarrow \theta_2 = 90^\circ \Rightarrow \sin \theta_c = \frac{n_2}{n_1}$$

$$\text{If } \theta_1 > \theta_c \Rightarrow \sin \theta_1 > \frac{n_2}{n_1}$$

$$\text{But from Snell's law } \sin \theta_2 = \frac{n_1}{n_2} \sin \theta_1 > \frac{n_1}{n_2} \cdot \frac{n_2}{n_1} = 1$$

$\therefore \sin \theta_2 > 1$ WHICH CANNOT HAPPEN

since $\sin \theta \leq 1 \Rightarrow$

For $\theta_1 > \theta_c$ NO light is refracted and all light is reflected. This is called total internal reflection

Total internal reflection occurs ONLY when light passes from a medium of higher refractive index to a medium of lower refractive index.

Fibre Optics; Medical Instruments

Total internal reflection is the principle underlying the use of fibre optics.

Glass and plastic fibres as thin as few micrometers are used to manufacture optic fibres.

A bundle of such transparent fibres is called a fibre-optic cable or light pipe.

FIGURE 23-29 Light reflected totally at the interior surface of a glass or transparent plastic fiber.



Fibre-optic cables are used in:

- **communications**: lead to very fast and large transmission of data. Fibres can support more than 100 separate wavelengths, each can carry more than 10 gigabits of data per second.

- **medicine**: optic-fibres are used in medicine to provide clear pictures of human organs.

bronchoscope: optic-fibre cable used to view the lungs.

Colonoscope: optic-fibre cable used to view the colon.