# Chapter 23
# Light: Geometric Optics

Lecture 1

The University of Jordan/Physics Department

Prof. Mahmoud Jaghoub

أ.د. محمود الجاغوب

## 23–1 The ray model of light

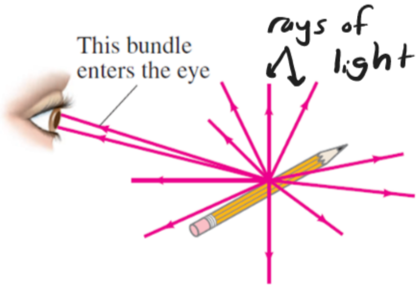
Ray model of light: light travels in straight lines in uniform transparant media (like air and glass)

Light rays coming from every point on the pencil enter the eye ⇒ can see the object

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

Speed of light in vacuum is

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



rays of light

**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 $c = 3\times10^8$ m/s in vacuum. In other transparant 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 $\frac{3}{4} = \frac{c}{v} \Rightarrow v = \frac{4}{3}c = 1.33c = 2.26\times10^8$ m/s

Cleary, n=1 for vacuum ⇒ light has maximum speed of $c = 3\times10^8$ m/s in vacuum. In all other transparant media $n<1$ i.e $v<c$

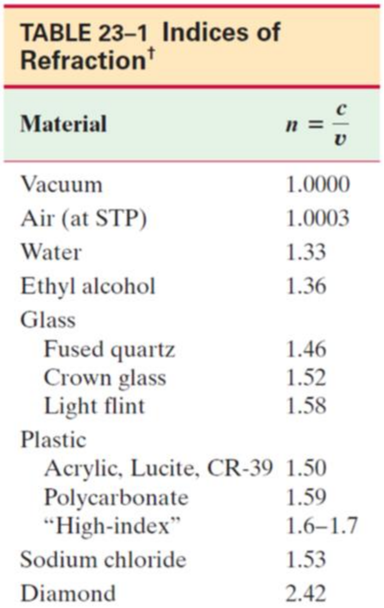
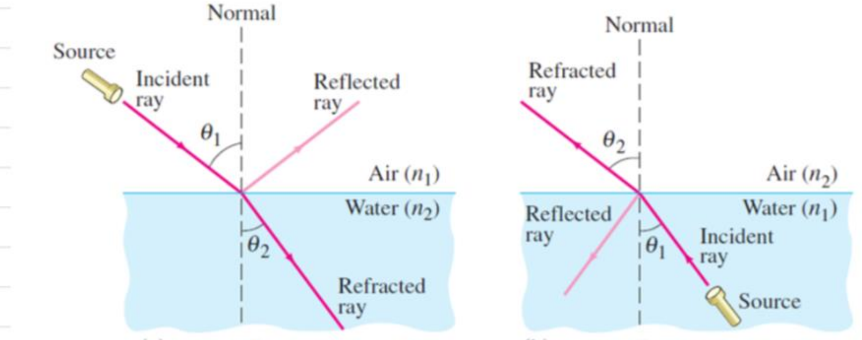


**TABLE 23–1 Indices of Refraction†**

| Material | $n = \frac{c}{v}$ |
|---|---|
| Vacuum | 1.0000 |
| Air (at STP) | 1.0003 |
| Water | 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



(a) $n_2 > n_1$: Ray bends toward ⊥ (b) $n_1 > n_2$: Ray bends away from ⊥

**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 → water ⇒
light changes direction as it passes from air → water. $\overset{\text{for air}}{n_1} < \overset{\text{for water}}{n_2}$

This change in direction is called Refraction.

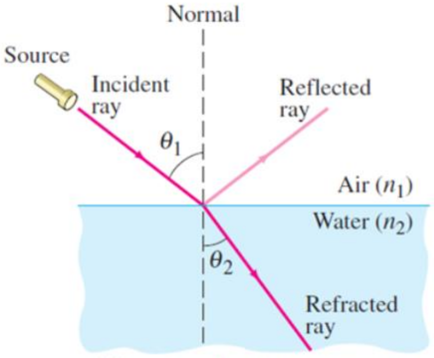
$\theta_1$ : angle of incidence

$\theta_2$ : 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 → higher dense medium ⇒ refracted light bends towards the normal i.e

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



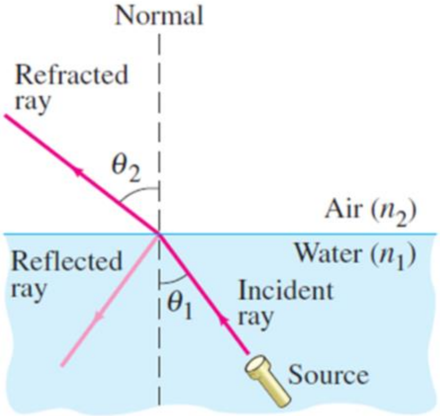
(a) $n_2 > n_1$: Ray bends toward ⊥

In fig(b), light moves from water → air ⇒ more dense → less dense media i.e $\overset{\text{for water}}{n_1} > \overset{\text{for air}}{n_2}$

∴ 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 ⊥

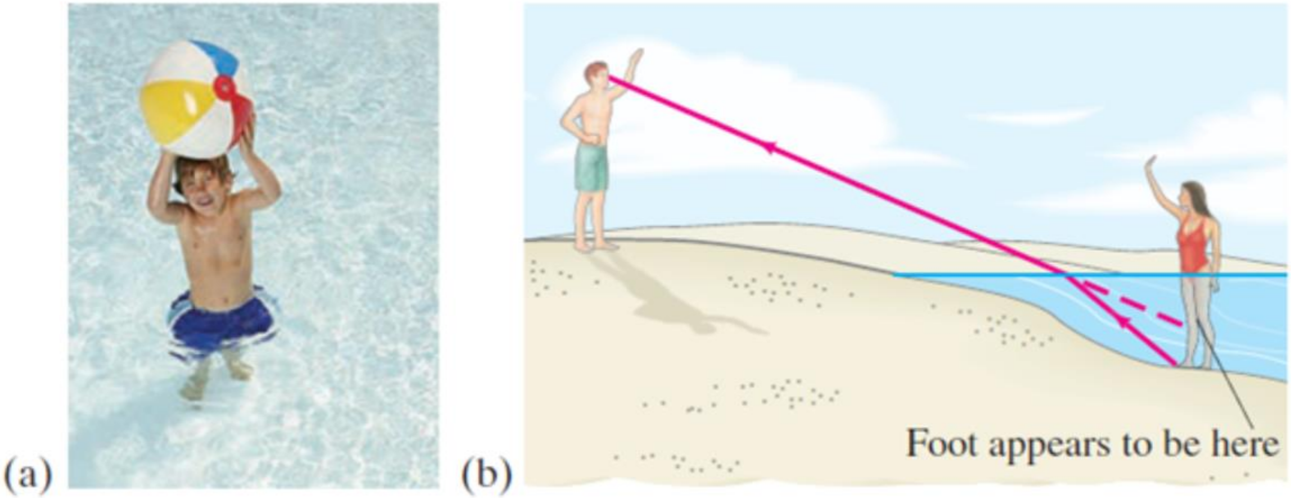
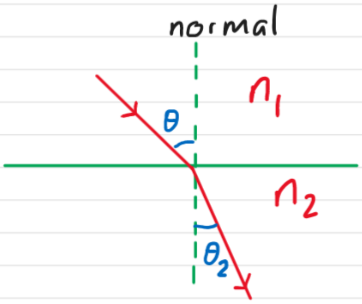


**FIGURE 23–22** (a) Photograph, and (b) ray diagram showing why a person's legs look shorter standing in water: a ray from the bather's foot to the observer's eye bends at the water's surface, and our brain interprets the light as traveling in a straight line, from higher up (dashed line).

## 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 $\theta_A$ in the glass; (*b*) what is the angle $\theta_B$ at which the ray emerges from the glass?

Apply Snell's law twice.

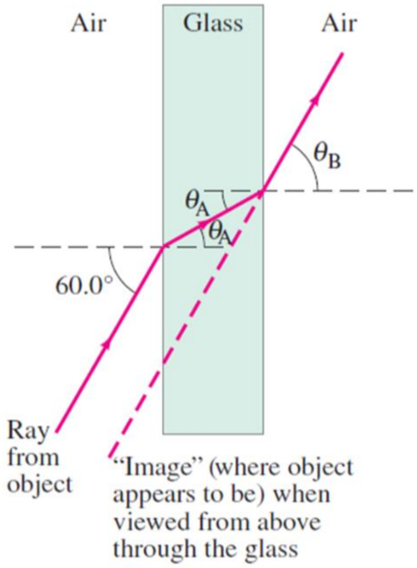
① Left hand side face

air → 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

glass → air : $n_1 = 1.5 \;, n_2 = 1.0$

from graph clearly angle of incidence is $\theta_A$.

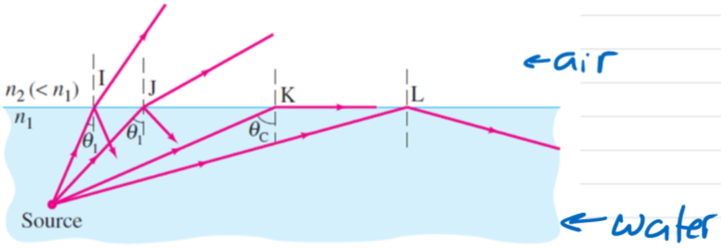
∴ angle angle of refraction $\theta_B$ is

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

∴ 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 of higher density (low speed) to a medium of lower density (high speed) ⇒ 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 $\theta_c$ (called critical angle) ⇒ Refracted ray travels parallel to the surface; i.e $\theta_2 = 90^\circ$

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

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

$\therefore$ at $\theta_1 = \theta_c \Rightarrow \theta_2 = 90^0 \Rightarrow \sin\theta_c = \frac{n_2}{n_1}$

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

But from Snell's law $\sin\theta_2 = \frac{n_1}{n_2} \overbrace{\sin\theta_1}^{> \frac{n_2}{n_1}}$

$\therefore \sin\theta_2 > 1$ 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 transparant fibres is called a fibre-optic cable or light pipe.

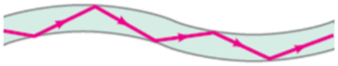


**FIGURE 23–29** Light reflected totally at the interior surface of a glass or transparent plastic fiber.

Fibre-optic cables are use in:

- communications: lead to very fast and larg 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.