King Saud University
College of Science
Physics & Astronomy Dept.

PHYS 111 (GENERAL PHYSICS 2)
CHAPTER 35: The Nature of Light and the principles of ray Optics
LECTURE NO. 8

Presented by Nouf Saad Alkathran

35.4 analysis Model: Wave Under reflection

When a light ray traveling in one medium encounters a boundary with another medium, part of the incident light is reflected.

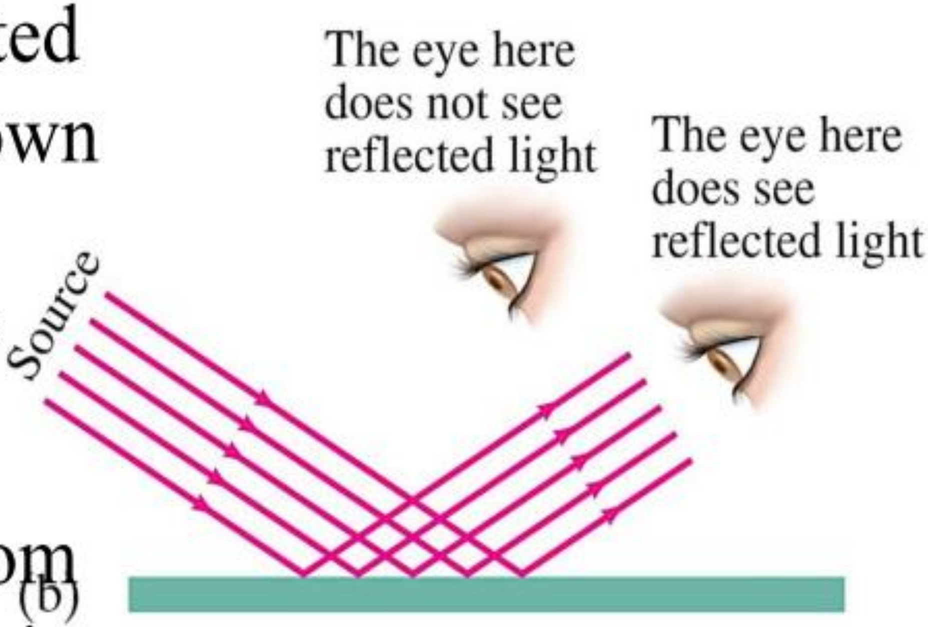
The Texture of a Surface Affects how it Reflects Light

The manner in which light is reflected from a surface depends on the surface's smoothness.

- Specular reflection
- Diffuse reflection

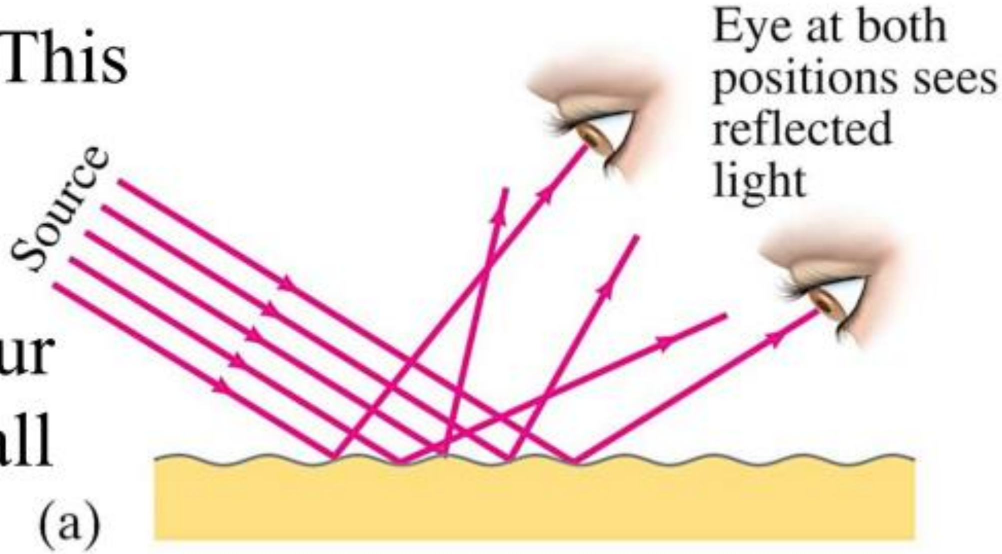
Specular Reflection

- Light reflected from smooth, shiny surfaces, such as a mirror or water in a pond, is reflected in one direction only, as shown in the **Figure** . This type of reflection is called *specular reflection.*
- With specular reflection (from a mirror), your eye must be in the correct position.



Diffuse Reflection

- Light that is reflected from a rough, textured surface, such as paper, cloth, is reflected in many different directions. This type of reflection is called *diffuse reflection.*
- With diffuse reflection, your eye sees reflected light at all angles.

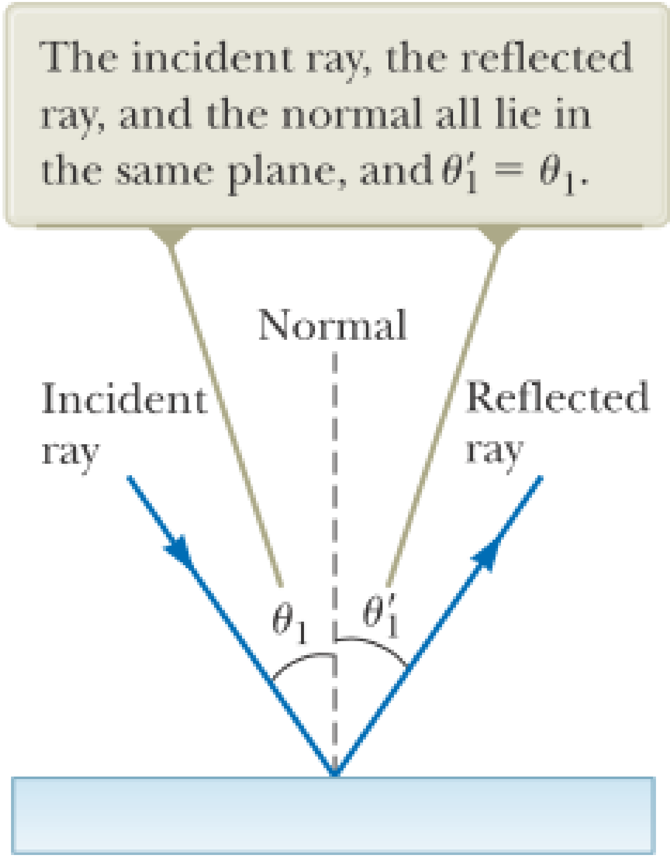


(a)

The Law of Reflection

Consider a light ray traveling in air and incident at an angle on a flat, smooth surface as shown.

The incident and reflected rays make angles θ and $\theta^{\sim}$ respectively, where the angles are measured between the normal and the rays.



(The normal is a line drawn perpendicular to the surface at the point where the incident ray strikes the surface.)

The Law of Reflection

Experiments and theory show that the angle of reflection equals the angle of incidence:

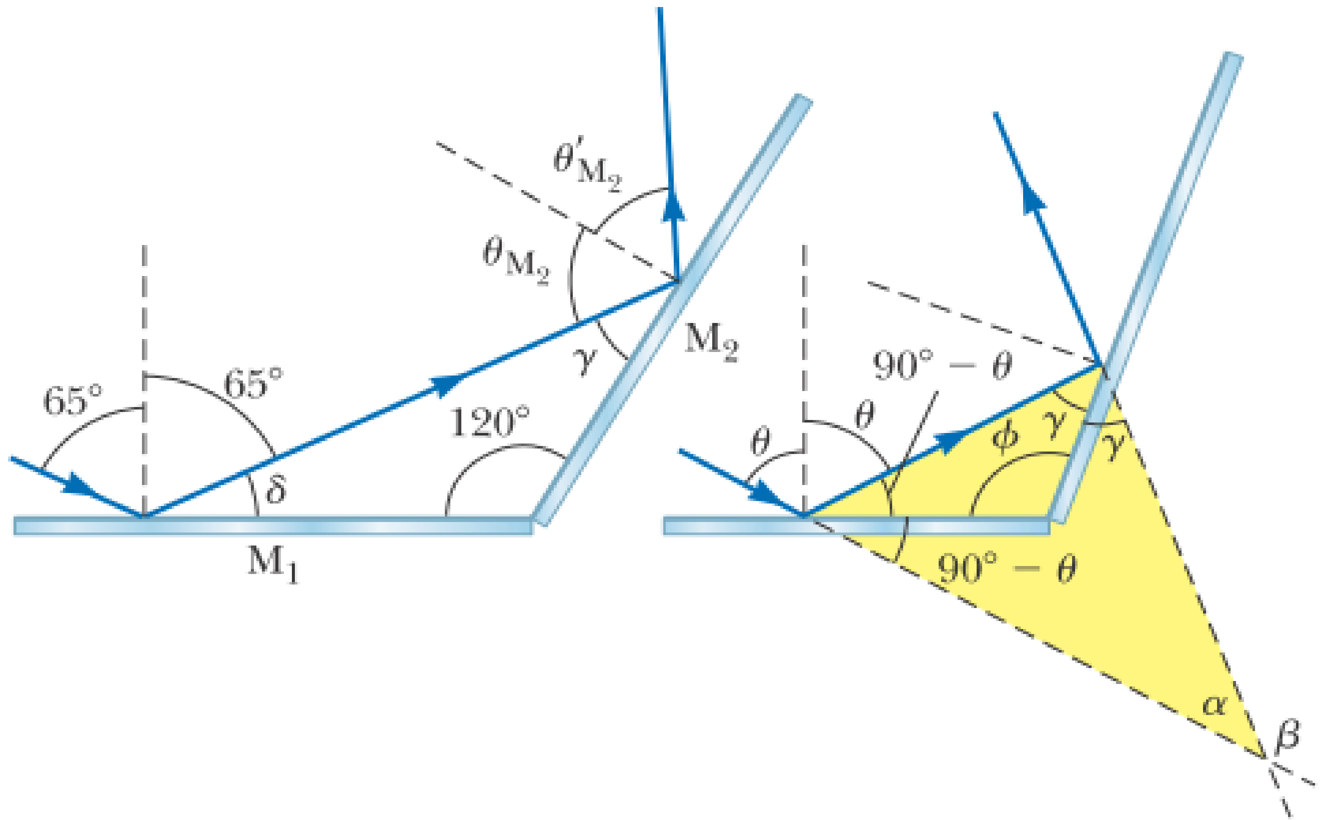
$$\theta_1' = \theta_1$$

angle of incoming light ray = angle of reflected light ray

This relationship is called the law of reflection.

Example 35.2 The Double-Reflected Light Ray

Two mirrors make an angle of 120° with each other as illustrated in Figure 35.7a. A ray is incident on mirror M_1 at an angle of 65° to the normal. Find the direction of the ray after it is reflected from mirror M_2.



Solution 35.2

$$\delta = 90^\circ - 65^\circ = 25^\circ$$

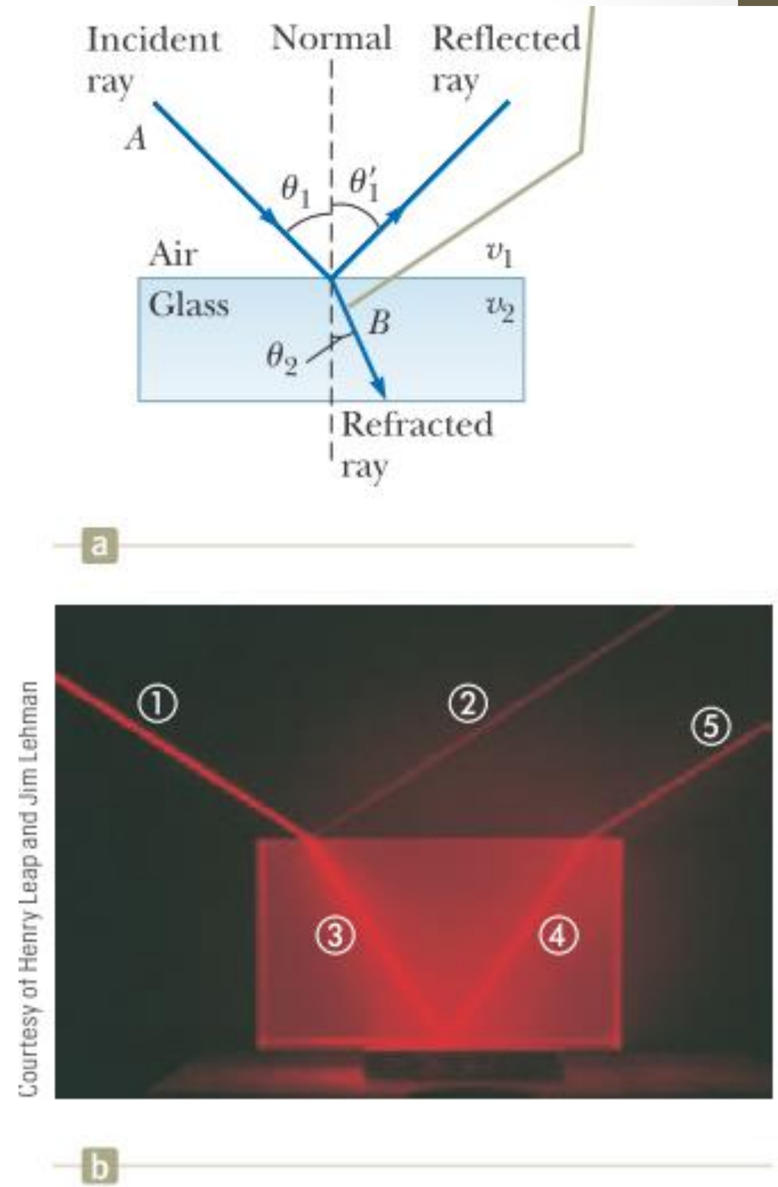
$$\gamma = 180^\circ - 25^\circ - 120^\circ = 35^\circ$$

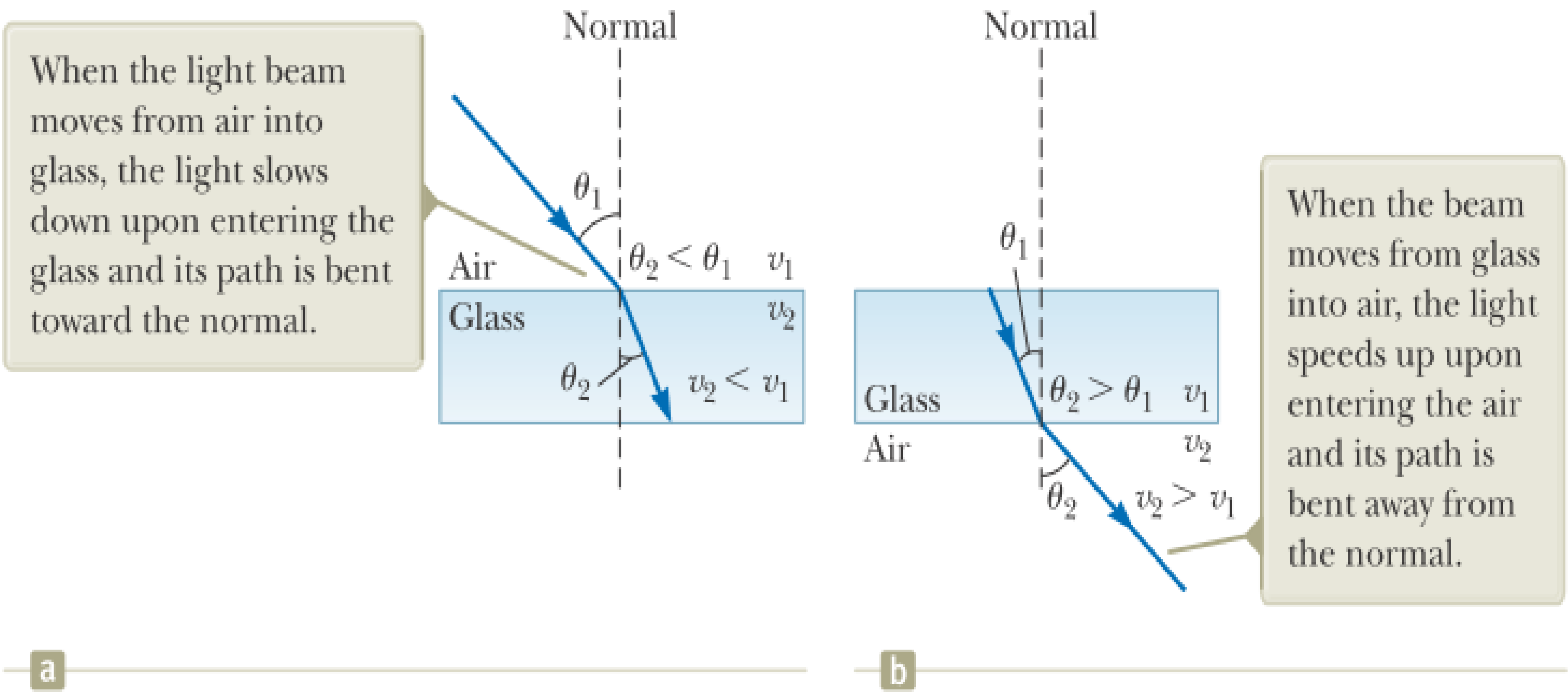
$$\theta_{M_2} = 90^\circ - 35^\circ = 55^\circ$$

$$\theta'_{M_2} = \theta_{M_2} = \boxed{55^\circ}$$

35.5 Analysis Model: Wave Under Refraction

when a ray of light traveling
through a transparent medium
encounters a boundary leading
into another transparent
medium as shown,
part of the energy is reflected
and part enters the second
medium.




When the light beam moves from air into glass, the light slows down upon entering the glass and its path is bent toward the normal.
Normal
θ_1
Air
Glass
$\theta_2 < \theta_1$
v_1
v_2
θ_2
$v_2 < v_1$
a
Normal
θ_1
Glass
Air
$\theta_2 > \theta_1$
v_1
v_2
θ_2
$v_2 > v_1$
When the beam moves from glass into air, the light speeds up upon entering the air and its path is bent away from the normal.
b

The ray that enters the second medium changes its direction of propagation at the boundary and is said to be refracted.
The angle of refraction, θ_2, depends on the properties of the two media and on the angle of incidence θ_1 through the relationship

$$\frac{\sin \theta_2}{\sin \theta_1} = \frac{v_2}{v_1}$$

where v_1 is the speed of light in the first medium and v_2 is the speed of light in the second medium.

Index of Refraction

In general, the speed of light in any material is less than its speed in vacuum. In fact, light travels at its maximum speed c in vacuum. It is convenient to define the index of refraction n of a medium to be the ratio

$$n \equiv \frac{\text{speed of light in vacuum}}{\text{speed of light in a medium}} \equiv \frac{c}{v}$$

Snell’s law of refraction.

- We are now in a position to express $\frac{\sin\theta_2}{\sin\theta_1} = \frac{v_2}{v_1}$ in an alternative form.

- replacing the v_2 *and* v_1 term with $\frac{c}{n_2}$ and $\frac{c}{n_1}$
- gives

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

- it is therefore known as Snell’s law of refraction

Example 35.3 Angle of Refraction for Glass AM

A light ray of wavelength 589 nm traveling through air is incident on a smooth, flat slab of crown glass n_g= 1.52 at an angle of 30.0° to the normal.

(**A**) Find the angle of refraction.

Rearrange Snell's law of refraction to find $\sin\theta_2$:

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

$$\sin\theta_2 = \frac{n_1}{n_2}\sin\theta_1 = \frac{1}{1.52}\sin 30°$$

$\sin\theta_2$= 0.329 $\rightarrow$ $\theta_2 = \sin^{-1} 0.329 = 19.2°$

(**B**) Find the speed of this light once it enters the glass.

$$v = \frac{c}{n} = \frac{3\times10^8}{1.52} = 1.97 \times 10^8 \text{ m/s}$$

Example 35.4 Light Passing Through a Slab AM

A light beam passes from medium 1 to medium 2, with the latter medium being a thick slab of material whose index of refraction is n_2 (Fig. 35.15). Show that the beam emerging into medium 1 from the other side is parallel to the incident beam.

$$(1)\quad \sin\theta_2 = \frac{n_1}{n_2}\sin\theta_1$$

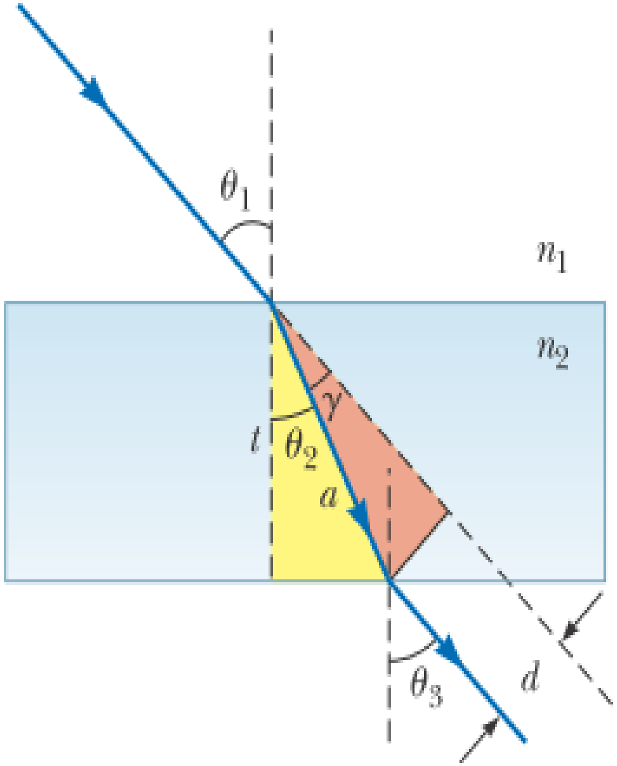
$$(2)\quad \sin\theta_3 = \frac{n_2}{n_1}\sin\theta_2$$

$$\sin\theta_3 = \frac{n_2}{n_1}\left(\frac{n_1}{n_2}\sin\theta_1\right) = \sin\theta_1$$

$$\theta_3 = \theta_1$$

$$d = a\sin\gamma = a\sin(\theta_1 - \theta_2) \qquad a = \frac{t}{\cos\theta_2}$$

$$d = \frac{t}{\cos\theta_2}\sin(\theta_1 - \theta_2)$$

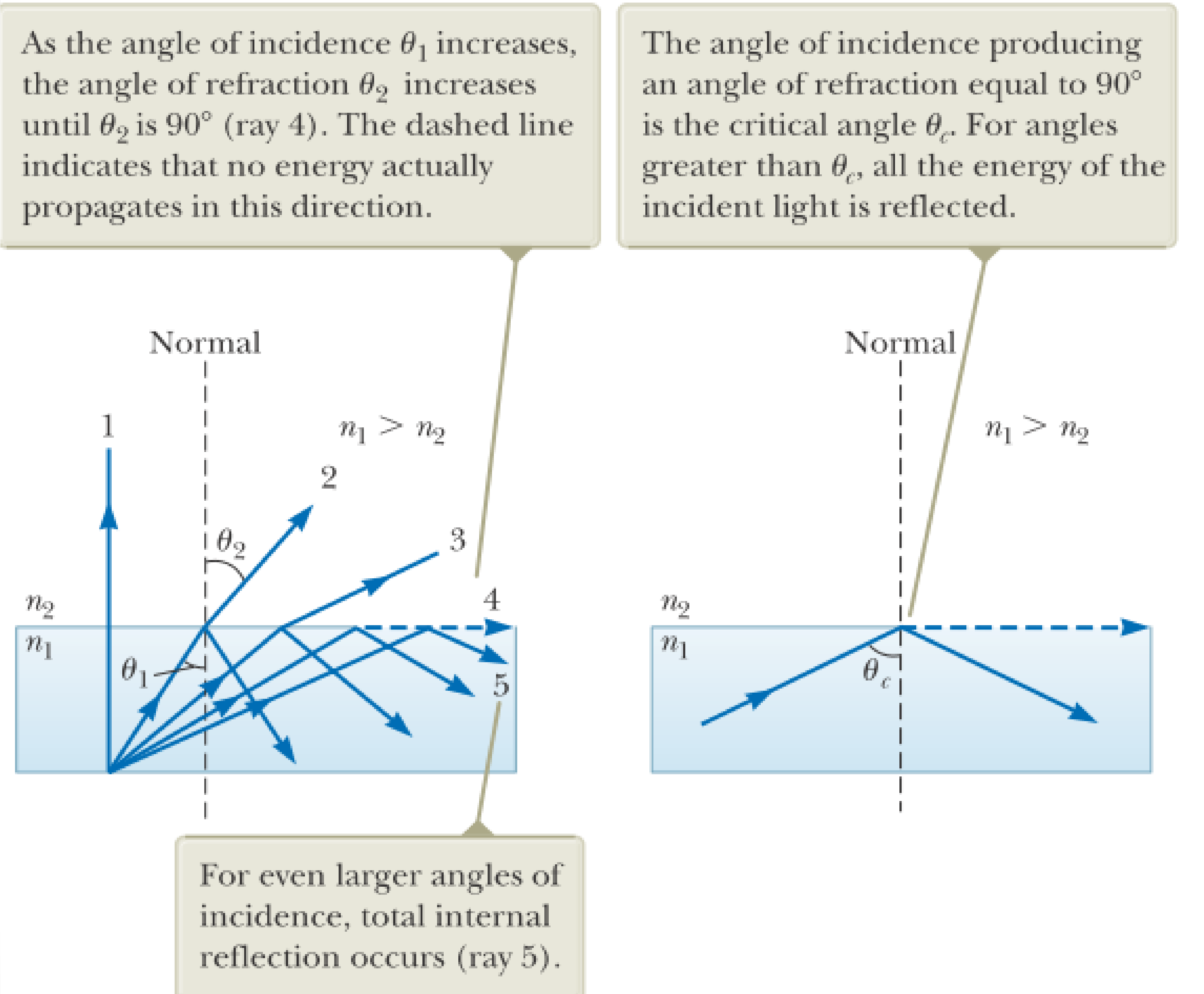


35.8 Total Internal Reflection

Total internal reflection can occur when light is directed from a medium having a given index of refraction toward one having a lower index of refraction.

Optical Fibers

An interesting application of total internal reflection is the use of glass or transparent plastic rods to "pipe" light from one place to another.



As the angle of incidence θ1 increases, the angle of refraction θ2 increases until θ2 is 90° (ray 4). The dashed line indicates that no energy actually propagates in this direction.
The angle of incidence producing an angle of refraction equal to 90° is the critical angle θc. For angles greater than θc, all the energy of the incident light is reflected.
Normal
1
2
3
4
5
n1 > n2
θ2
θ1
n2
n1
Normal
n1 > n2
n2
n1
θc
For even larger angles of incidence, total internal reflection occurs (ray 5).

35.8 Total Internal Reflection

- Consider a light ray travels in medium 1 and meets the boundary between medium 1 and medium 2, where n_1 is greater than n_2 .
- In the figure, labels 1 through 5 indicate various possible directions of the ray consistent with the wave under refraction model. The refracted rays are bent away from the normal because n_1 is greater than n_2 .
- At some particular angle of incidence θ_c , called **the critical angle**, the refracted light ray moves parallel to the boundary so that $\theta_2 = 90°$

35.8 Total Internal Reflection

- For angles of incidence greater than θ_c , the ray is entirely reflected at the boundary as shown by ray 5.

- We can use Snell's law of refraction to find the critical angle when $\theta_1 = \theta_c$ and $\theta_2 = 90°$

$$n_1 \sin \theta_c = n_2 \sin 90° = n_2$$

$$\sin \theta_c = \frac{n_2}{n_1} \quad (\text{for } n_1 > n_2)$$

Example 35.6 A View from the Fish's Eye

Find the critical angle for an air–water boundary. (Assume the index of refraction of water is 1.33.)

$$\sin \theta_c = \frac{n_2}{n_1} = \frac{1.00}{1.33} = 0.752$$

$$\theta_c = \boxed{48.8^\circ}$$

Summary

- The index of refraction n
- Wave Under Reflection.
- The law of reflection
- Wave Under Refraction
- Snell's law of refraction
- Total internal reflection

The End