PHYS 111
1ST semester 1439-1440

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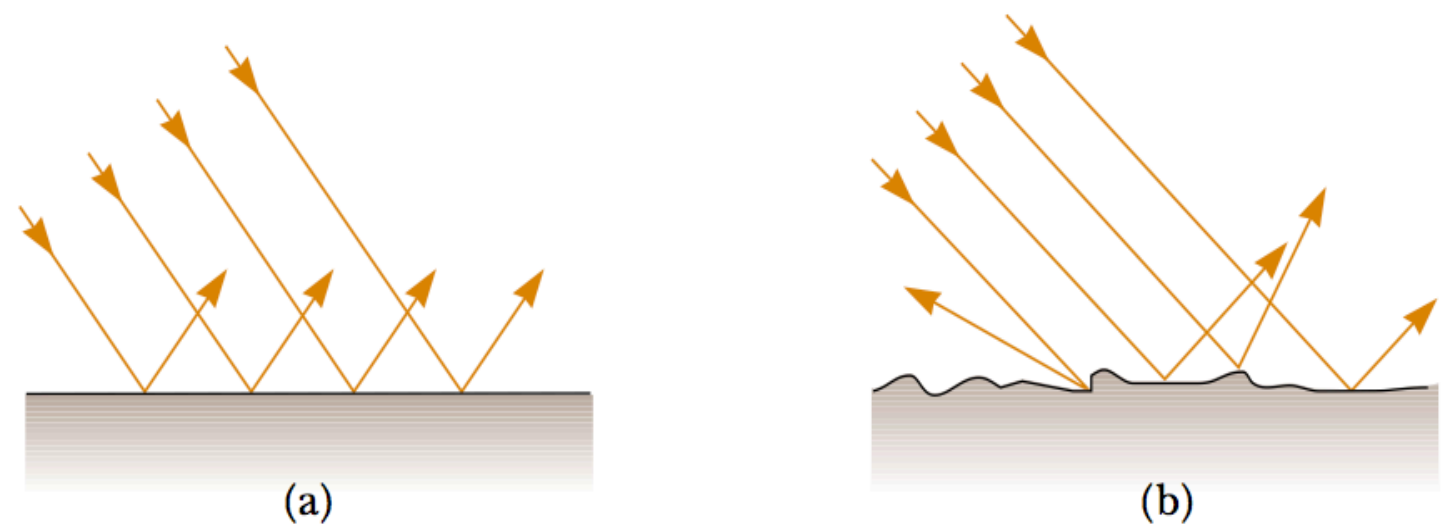
Lecture 15

Chapter 35

The Nature of Light and the Laws of Geometric Optics

35.4 Reflection

- When a light ray traveling in one medium encounters a boundary with another medium, part of the incident light is reflected.
- Reflection of light from such a smooth surface is called **specular reflection.**
- Reflection from any rough surface is known as **diffuse reflection.**



35.4 Reflection

- Consider a light ray traveling in air and incident at an angle on a flat, smooth surface.
- The **incident** angle θ_1 and the **reflected** angle θ_2 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.)
- Experiments and theory show that **the angle of reflection equals the angle of incidence:**

$$\theta_1' = \theta_1$$

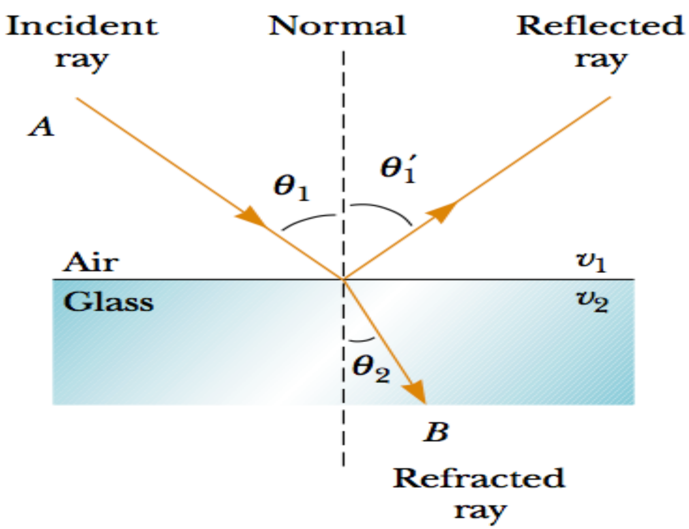
- The **law of reflection.**

35.5 Refraction

- When a ray of light traveling through a transparent medium, part of the energy is **reflected** and part **enters** the second medium.
- The ray that **enters** the second medium is bent at the boundary and is said to be **refracted.**
- The incident ray, the reflected ray, and the refracted ray all lie in the same plane.
- The **angle of refraction,** θ_2,depends on the properties of the two media and on the angle of incidence

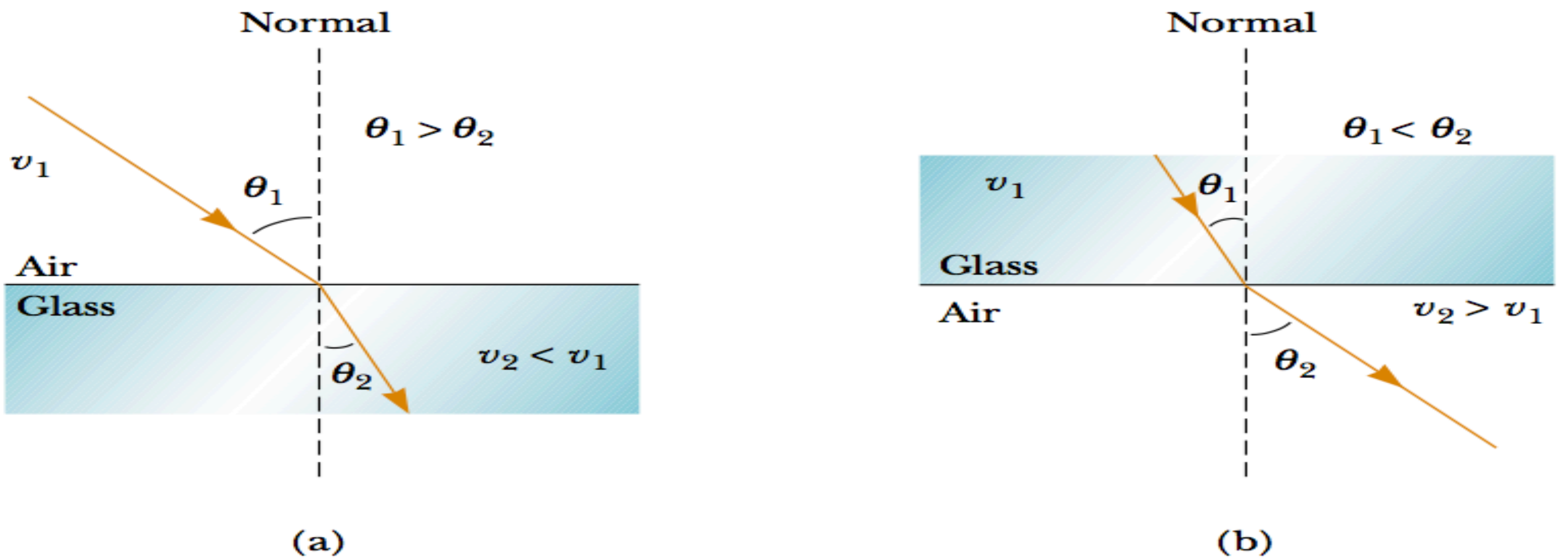
$$\frac{\sin\theta_2}{\sin\theta_1} = \frac{v_2}{v_1} = \text{constant}$$

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



35.5 Refraction

- When light moves from a material in which its speed is **high** to a material in which its speed is **lower**, the angle of refraction θ_2 is less than the angle of incidence θ_1, and the ray is bent *toward* the normal.
- If the ray moves from a material in which light moves **slowly** to a material in which it moves more **rapidly**, θ_2 is greater than θ_1, and the ray is bent *away* from the normal.



Index of Refraction

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

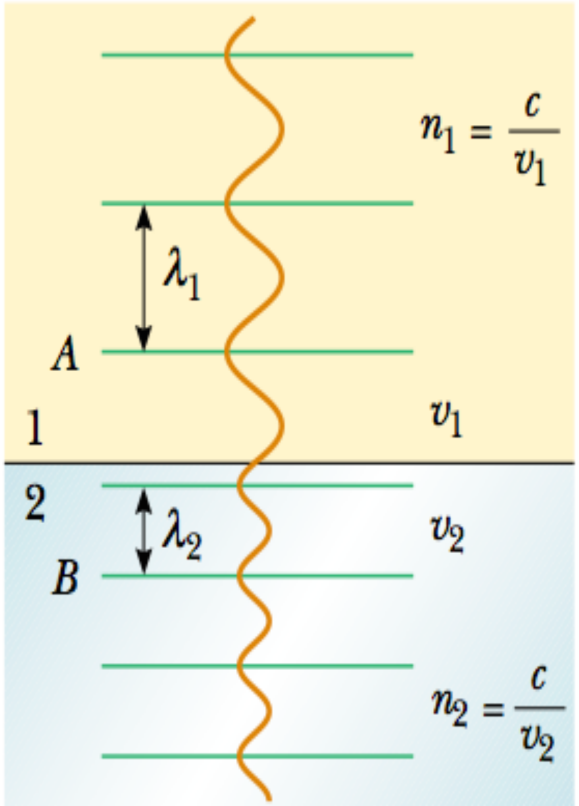
$$n \equiv \frac{\text{speed of light in vacuum}}{\text{speed of light in a medium}} = \frac{c}{v}$$

- The index of refraction is a dimensionless number greater than unity because *v* is always less than *c*.
- *n* is equal to unity for vacuum.

Index of Refraction

- As light travels from one medium to another, its **frequency** does not change but its **wavelength** does.

$$v_1 = f\lambda_1 \qquad \text{and} \qquad v_2 = f\lambda_2$$



Index of Refraction

- The relationship between index of refraction and wavelength

$$\frac{\lambda_1}{\lambda_2} = \frac{v_1}{v_2} = \frac{c/n_1}{c/n_2} = \frac{n_2}{n_1}$$

$$\lambda_1 n_1 = \lambda_2 n_2$$

- If medium 1 is vacuum, then $n_1=1$

$$n = \frac{\lambda}{\lambda_n}$$

- where λ is the wavelength of light in vacuum and λ_n is the wavelength of light in the medium whose index of refraction is n.
- Because $n>1$, $\lambda_n < \lambda$.

Snell's law of refraction.

- If we replace the v_2/v_1 term with n_1/n_2, we obtain

$$\frac{\sin\,\theta_2}{\sin\,\theta_1} = \frac{v_2}{v_1} = \text{constant}$$

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

Quick Quiz 35.3 Light passes from a material with index of refraction 1.3 into one with index of refraction 1.2. Compared to the incident ray, the refracted ray (a) bends toward the normal (b) is undeflected (c) bends away from the normal.

Example 35.3 An Index of Refraction Measurement

A beam of light of wavelength 550 nm traveling in air is incident on a slab of transparent material. The incident beam makes an angle of 40.0° with the normal, and the refracted beam makes an angle of 26.0° with the normal. Find the index of refraction of the material.

Solution Using Snell's law of refraction (Eq. 35.8) with these data, and taking $n_1 = 1.00$ for air, we have

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

$$n_2 = \frac{n_1 \sin \theta_1}{\sin \theta_2} = (1.00) \frac{\sin 40.0°}{\sin 26.0°}$$

$$= \frac{0.643}{0.438} = 1.47$$

From Table 35.1, we see that the material could be fused quartz.

Example 35.4 Angle of Refraction for Glass

A light ray of wavelength 589 nm traveling through air is incident on a smooth, flat slab of crown glass at an angle of 30.0° to the normal, as sketched in Figure 35.15. Find the angle of refraction.

Solution We rearrange Snell's law of refraction to obtain

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

From Table 35.1, we find that $n_1 = 1.00$ for air and $n_2 = 1.52$ for crown glass. Therefore,

$$\sin \theta_2 = \left(\frac{1.00}{1.52}\right) \sin 30.0° = 0.329$$

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

Because this is less than the incident angle of 30°, the refracted ray is bent toward the normal, as expected. Its change in direction is called the *angle of deviation* and is given by $\delta = |\theta_1 - \theta_2| = 30.0° - 19.2° = 10.8°$.

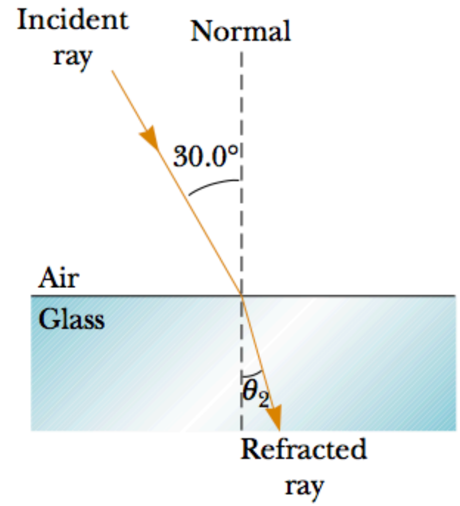


Figure 35.15 (Example 35.4) Refraction of light by glass.

Example 35.5 Laser Light in a Compact Disc

A laser in a compact disc player generates light that has a wavelength of 780 nm in air.

(A) Find the speed of this light once it enters the plastic of a compact disc ($n = 1.55$).

Solution We expect to find a value less than 3.00×10^8 m/s because $n > 1$. We can obtain the speed of light in the plastic by using Equation 35.4:

$$v = \frac{c}{n} = \frac{3.00 \times 10^8 \text{ m/s}}{1.55}$$

$$v = \boxed{1.94 \times 10^8 \text{ m/s}}$$

(B) What is the wavelength of this light in the plastic?

Solution We use Equation 35.7 to calculate the wavelength in plastic, noting that we are given the wavelength in air to be $\lambda = 780$ nm:

$$\lambda_n = \frac{\lambda}{n} = \frac{780 \text{ nm}}{1.55} = \boxed{503 \text{ nm}}$$