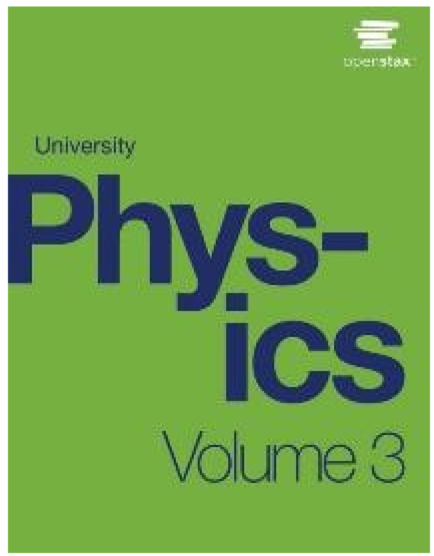
UNIVERSITY PHYSICS

Chapter 1 THE NATURE OF LIGHT

PowerPoint Image Slideshow



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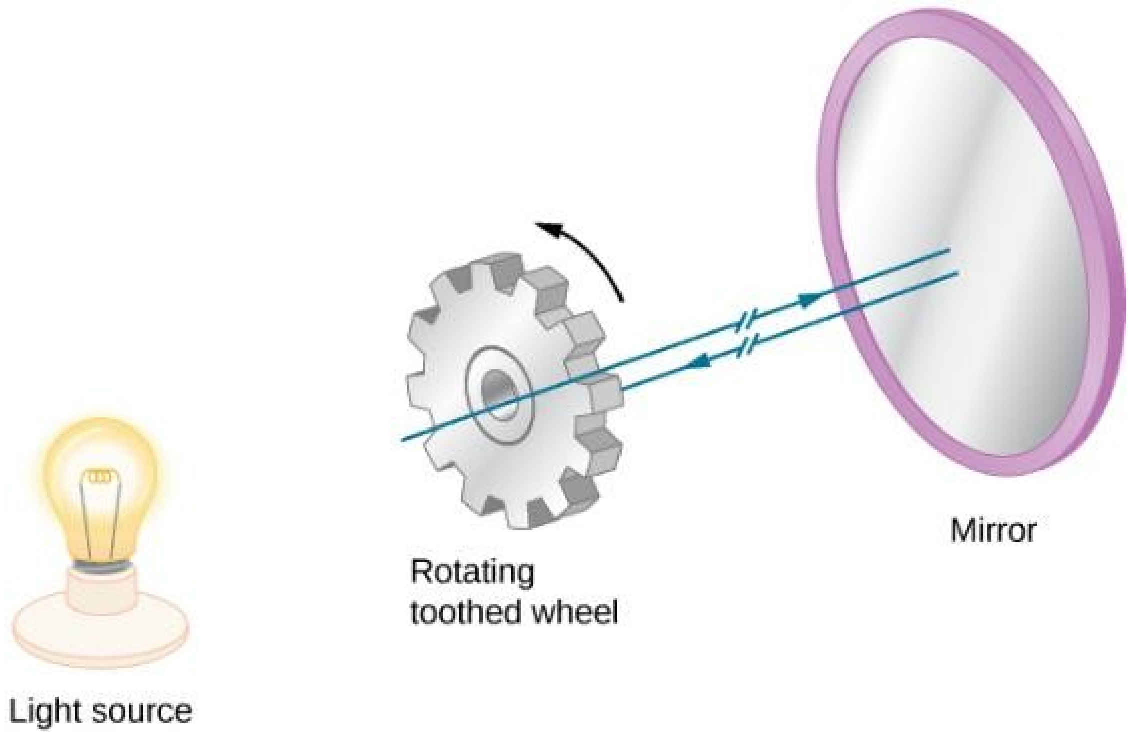
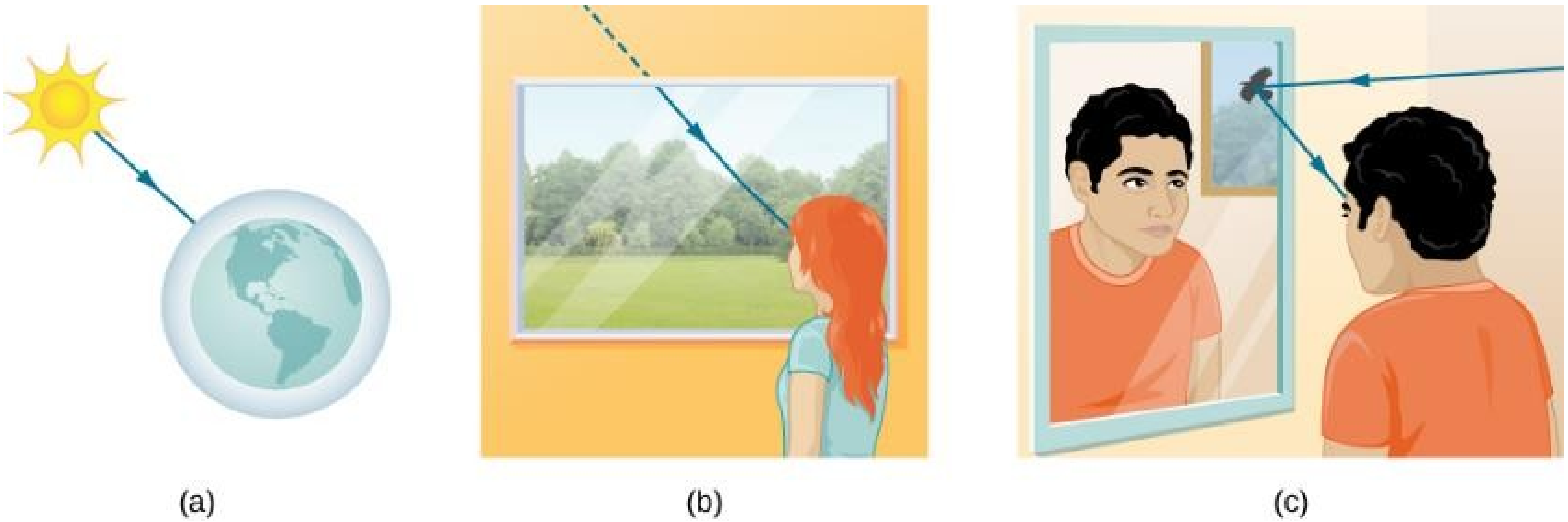
Introduction

FIGURE 1.3



Fizeau's method for measuring the speed of light. The teeth of the wheel block the reflected light upon return when the wheel is rotated at a rate that matches the light travel time to and from the mirror.

FIGURE 1.4



Three methods for light to travel from a source to another location.

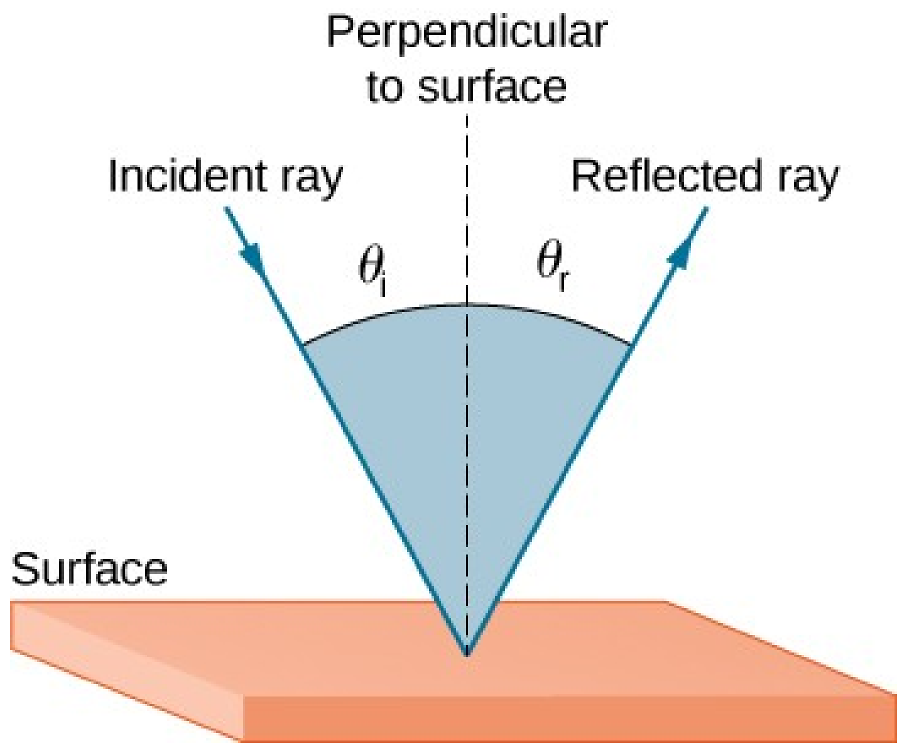
a) Light reaches the upper atmosphere of Earth, traveling through empty space directly from the source.

b) Light can reach a person by traveling through media like air and glass.

c) Light can also reflect from an object like a mirror. In the situations shown here, light interacts with objects large enough that it travels in straight lines, like a ray.

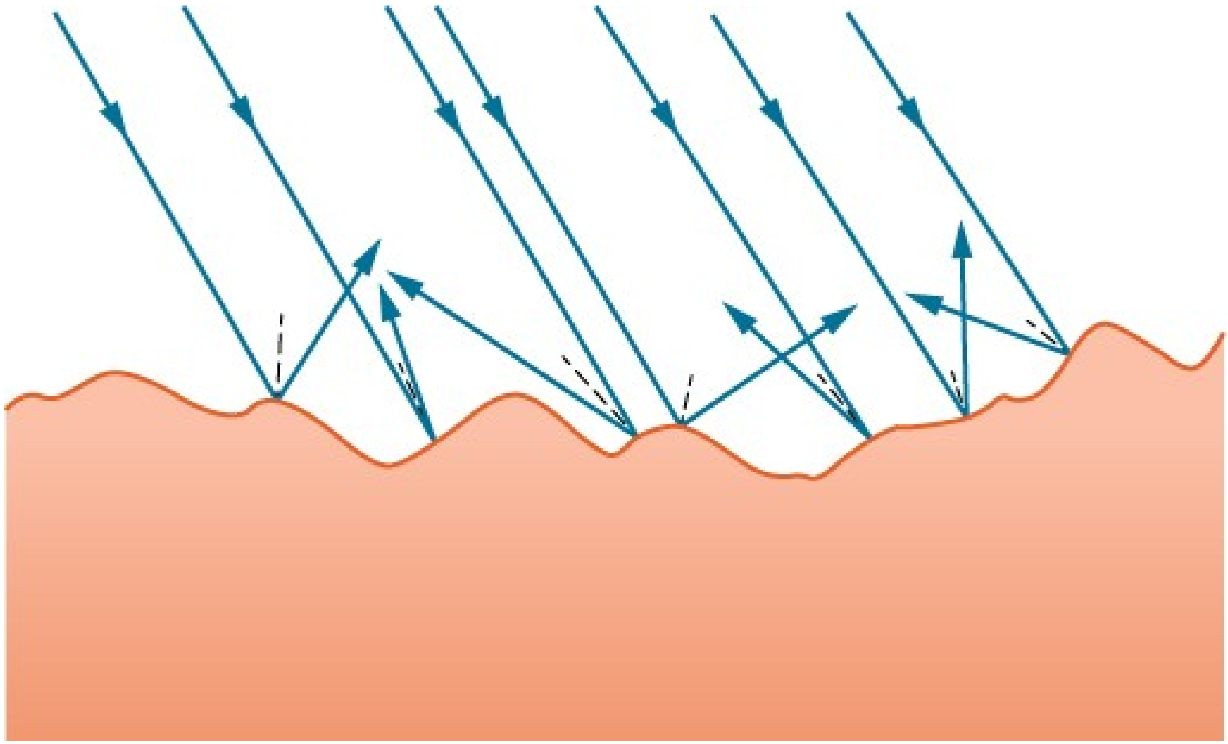
Law of reflection

FIGURE 1.5



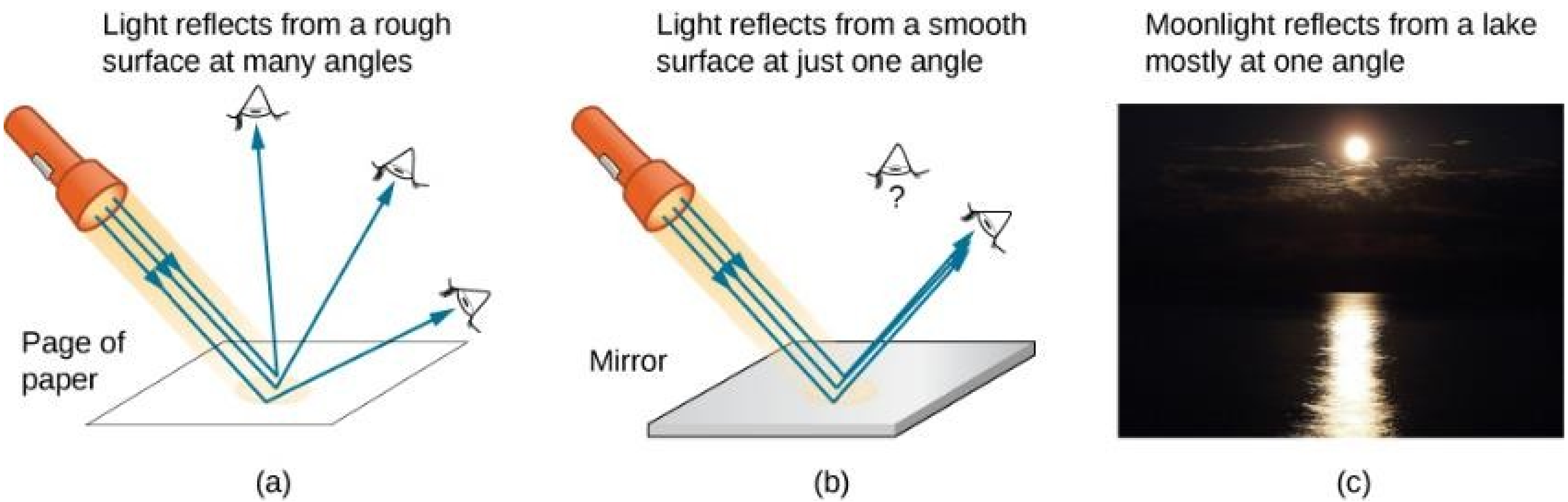
The law of reflection states that the angle of reflection equals the angle of incidence— $\theta_r = \theta_i$. The angles are measured relative to the perpendicular to the surface at the point where the ray strikes the surface.

FIGURE 1.6



Light is diffused when it reflects from a rough surface. Here, many parallel rays are incident, but they are reflected at many different angles, because the surface is rough.

FIGURE 1.7

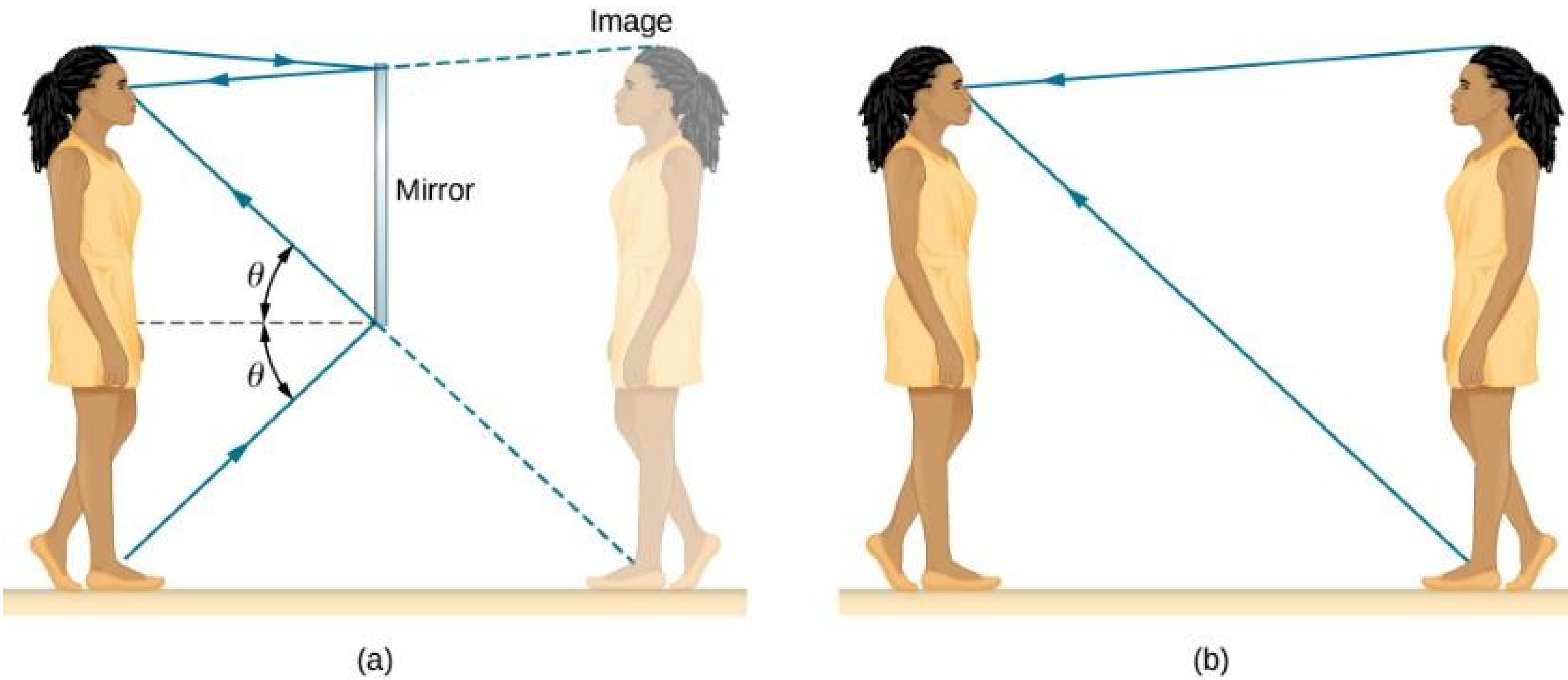


a) When a sheet of paper is illuminated with many parallel incident rays, it can be seen at many different angles, because its surface is rough and diffuses the light.

b) A mirror illuminated by many parallel rays reflects them in only one direction, because its surface is very smooth. Only the observer at a particular angle sees the reflected light.

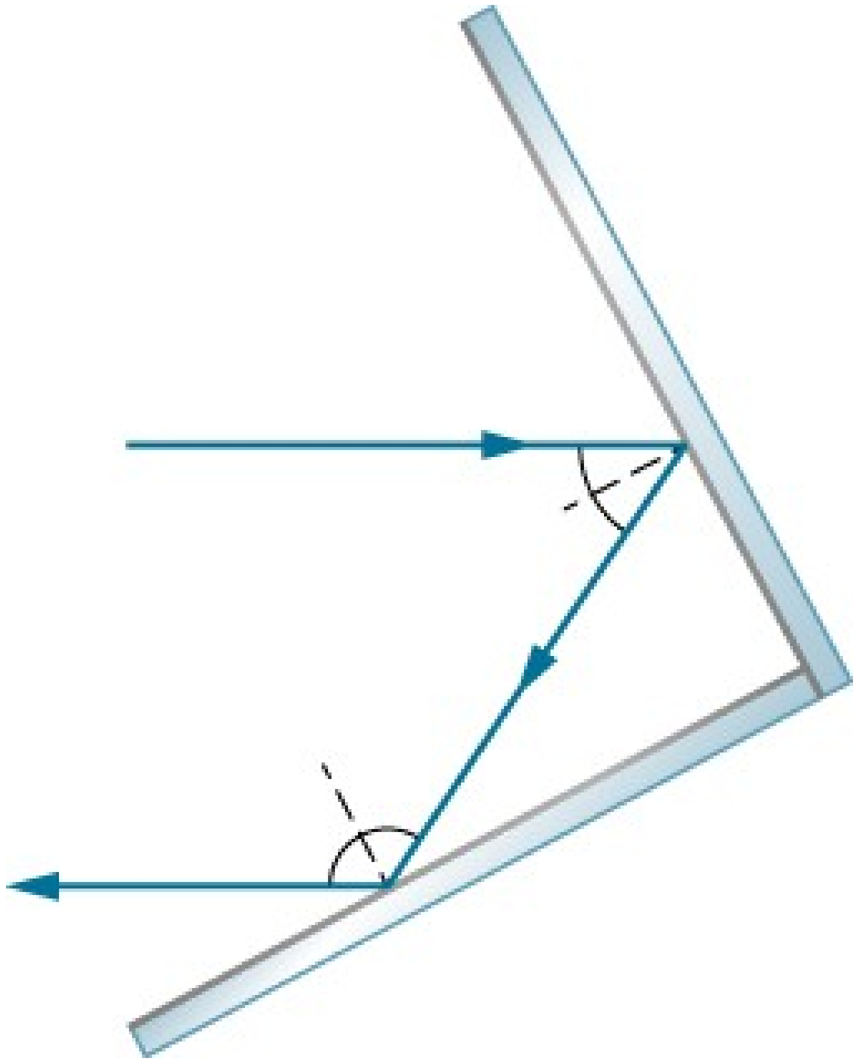
c) Moonlight is spread out when it is reflected by the lake, because the surface is shiny but uneven. (credit c: modification of work by Diego Torres Silvestre)

FIGURE 1.8



(a) Your image in a mirror is behind the mirror. The two rays shown are those that strike the mirror at just the correct angles to be reflected into the eyes of the person. The image appears to be behind the mirror at the same distance away as (b) if you were looking at your twin directly, with no mirror.

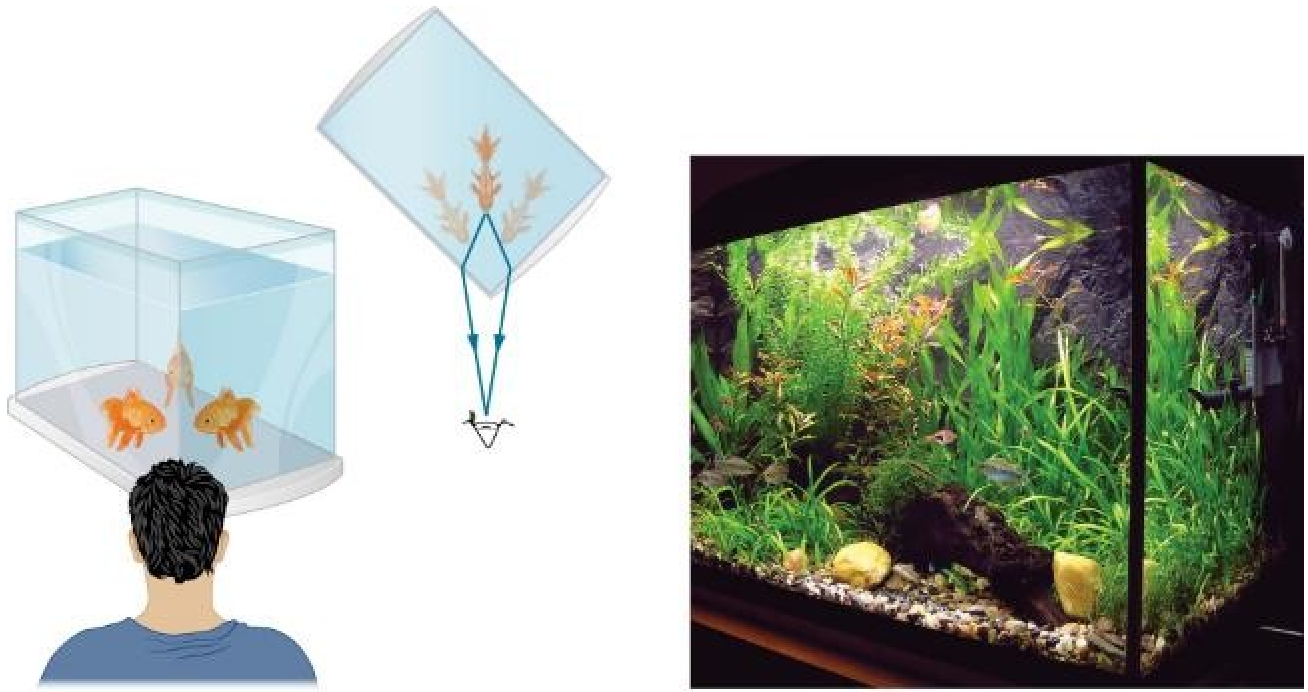
FIGURE 1.9



A light ray that strikes two mutually perpendicular reflecting surfaces is reflected back exactly parallel to the direction from which it came.

Refraction

FIGURE 1.12

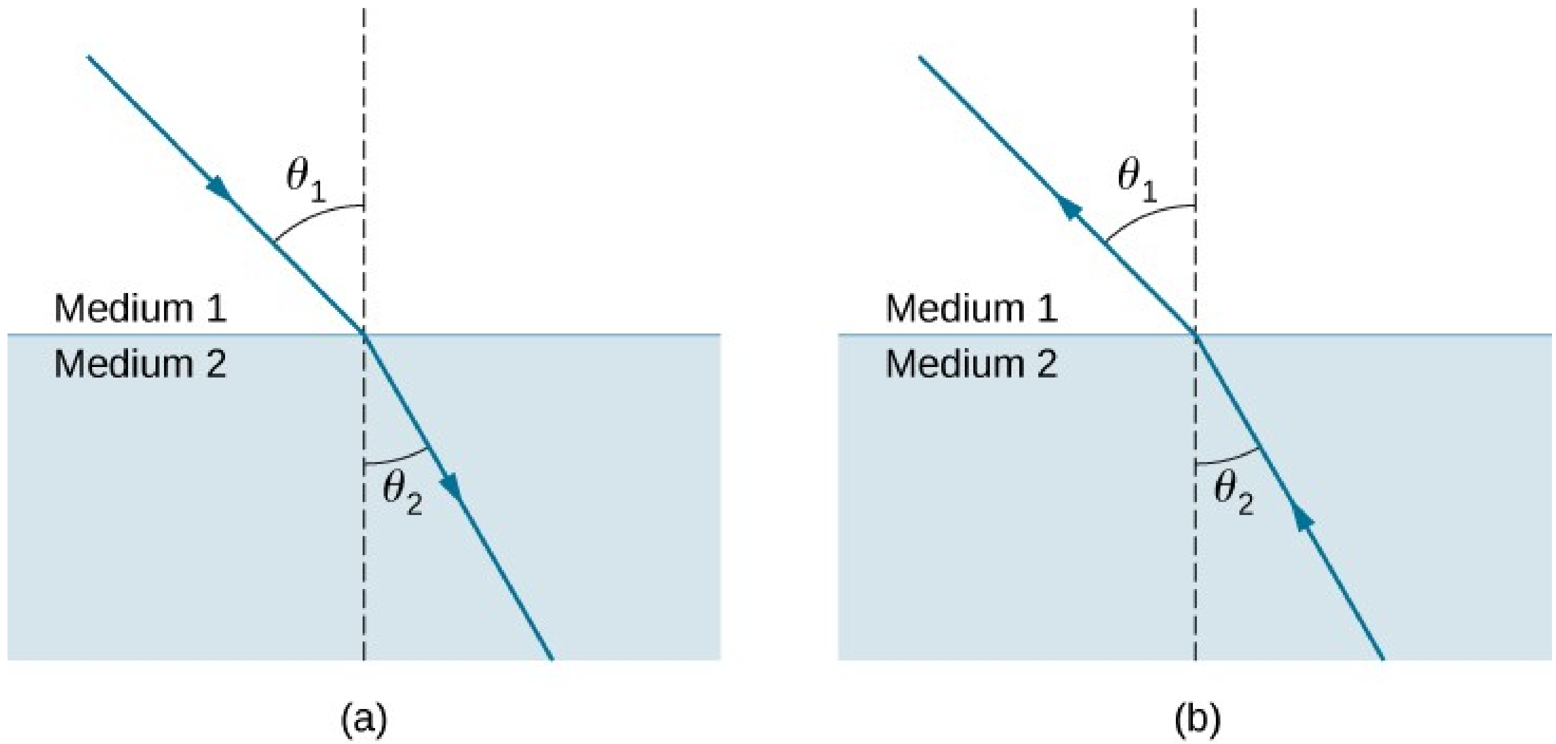


(a) (b)

a) Looking at the fish tank as shown, we can see the same fish in two different locations, because light changes directions when it passes from water to air. In this case, the light can reach the observer by two different paths, so the fish seems to be in two different places. This bending of light is called refraction and is responsible for many optical phenomena.

b) This image shows refraction of light from a fish near the top of a fish tank.

FIGURE 1.13



The change in direction of a light ray depends on how the index of refraction changes when it crosses from one medium to another. In the situations shown here, the index of refraction is greater in medium 2 than in medium 1.

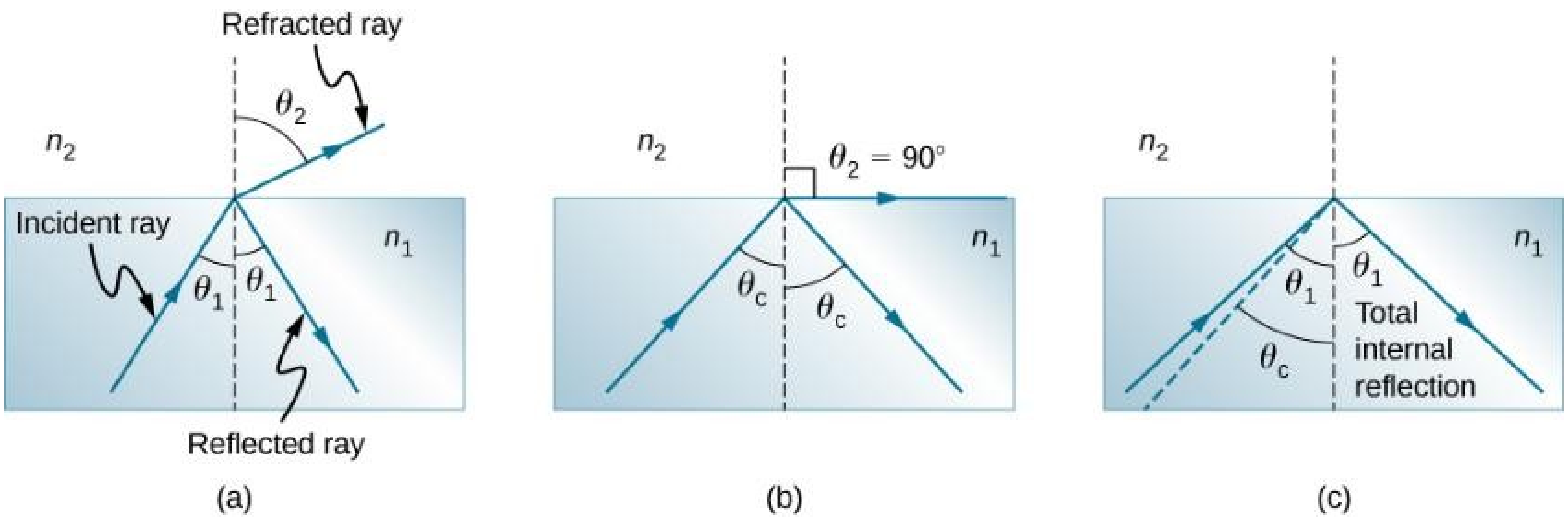
a) A ray of light moves closer to the perpendicular when entering a medium with a higher index of refraction.

b) A ray of light moves away from the perpendicular when entering a medium with a lower index of refraction.

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

Total internal reflection

FIGURE 1.14



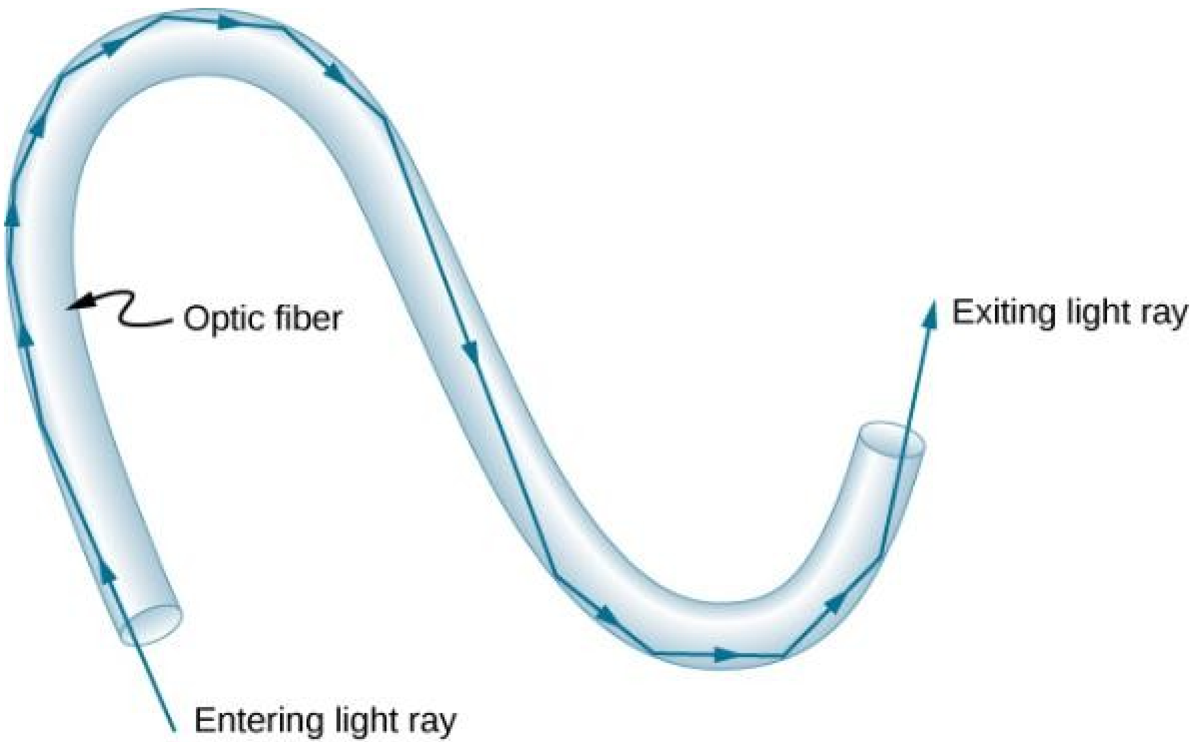
a) A ray of light crosses a boundary where the index of refraction decreases. That is, $n_2 < n_1$. The ray bends away from the perpendicular.

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.

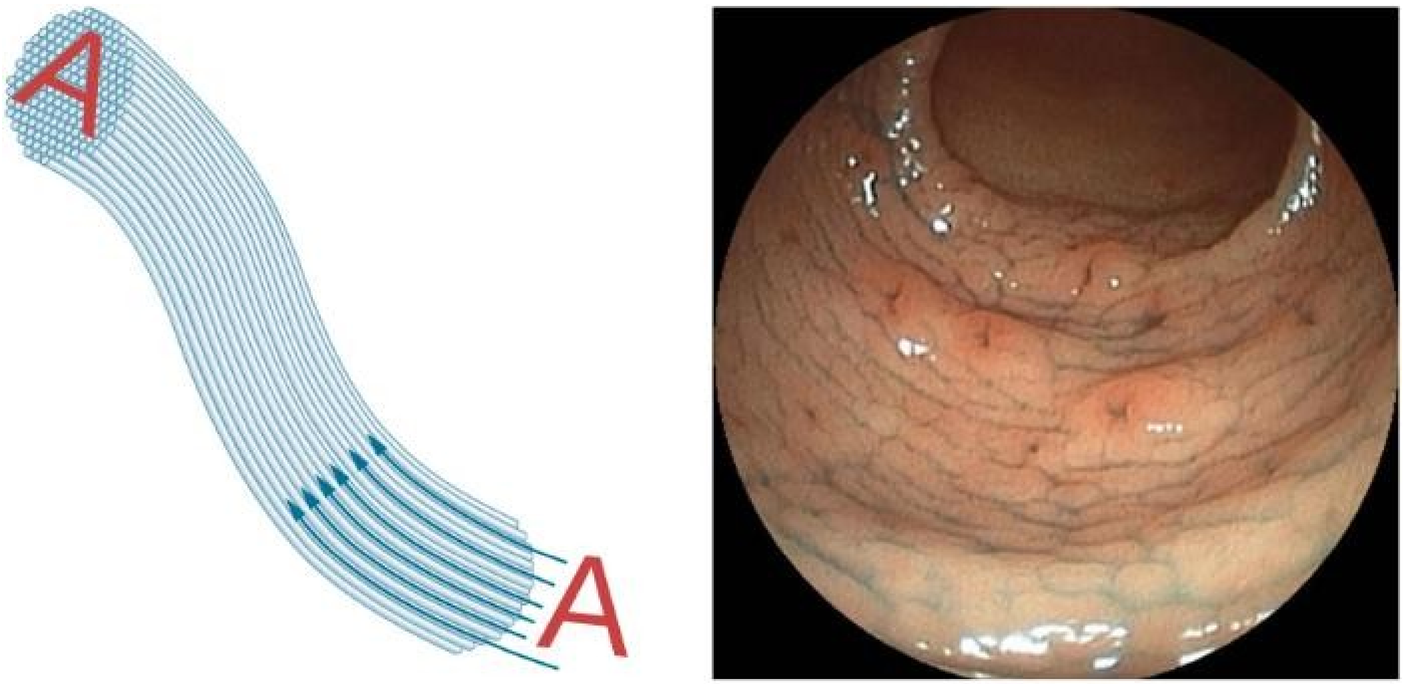
Applications

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.

FIGURE 1.16



(a) (b)

a) An image “A” is transmitted by a bundle of optical fibers.

b) An endoscope is used to probe the body, both transmitting light to the interior and returning an image such as the one shown of a human epiglottis (a structure at the base of the tongue). (credit b: modification of work by “Med_Chaos”/Wikimedia Commons)

FIGURE 1.17

Fibers in bundles are clad by a material that has a lower index of refraction than the core to ensure total internal reflection, even when fibers are in contact with one another.

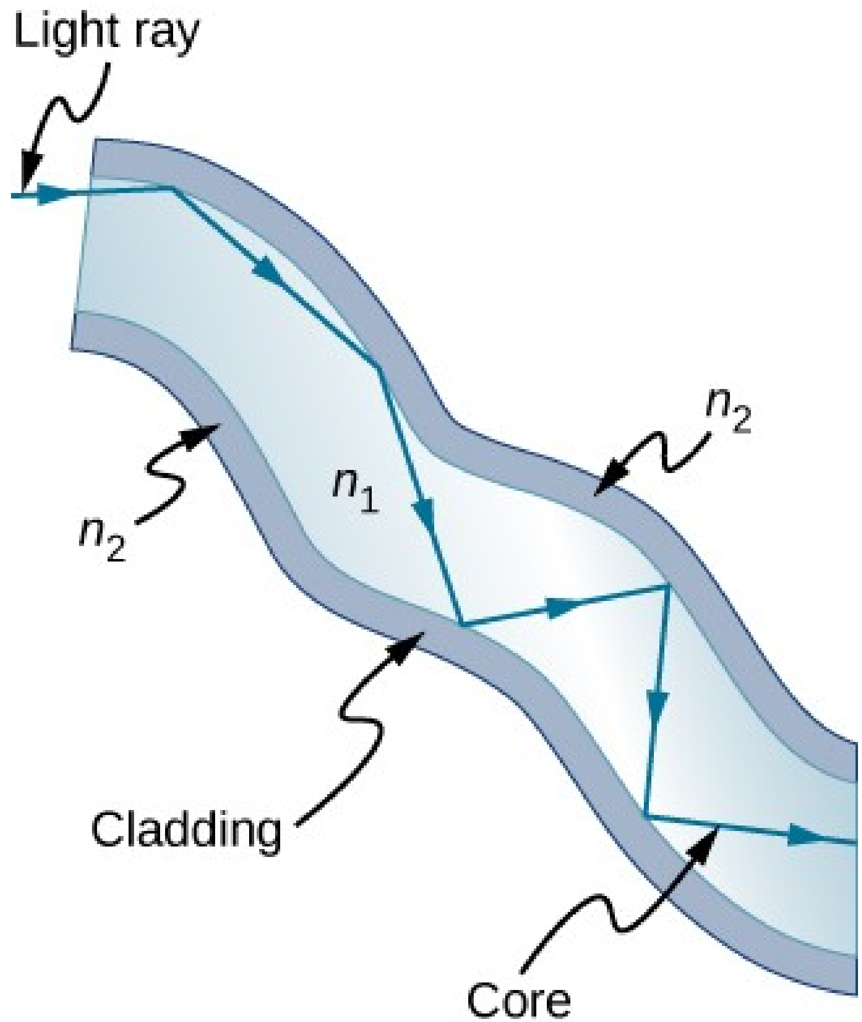
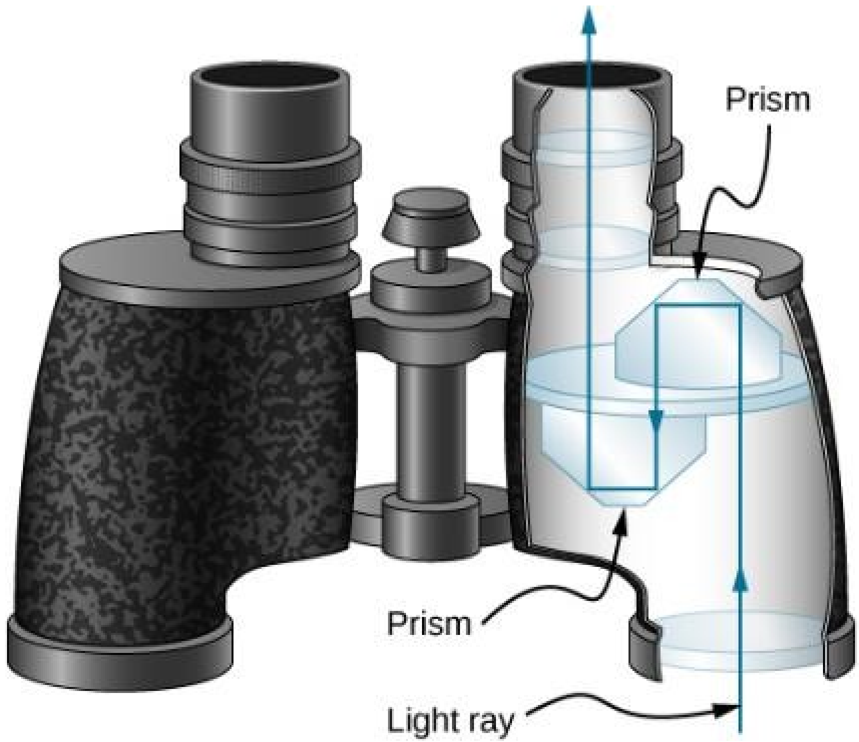
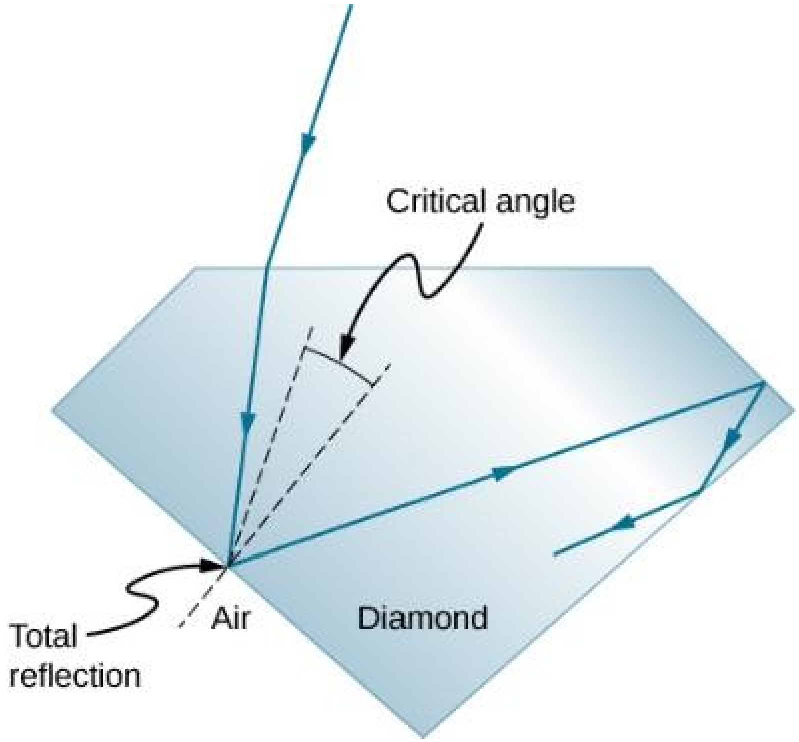


FIGURE 1.18



These binoculars employ corner reflectors (prisms) with total internal reflection to get light to the observer's eyes.

FIGURE 1.19



Light cannot easily escape a diamond, because its critical angle with air is so small. Most reflections are total, and the facets are placed so that light can exit only in particular ways—thus concentrating the light and making the diamond sparkle brightly.

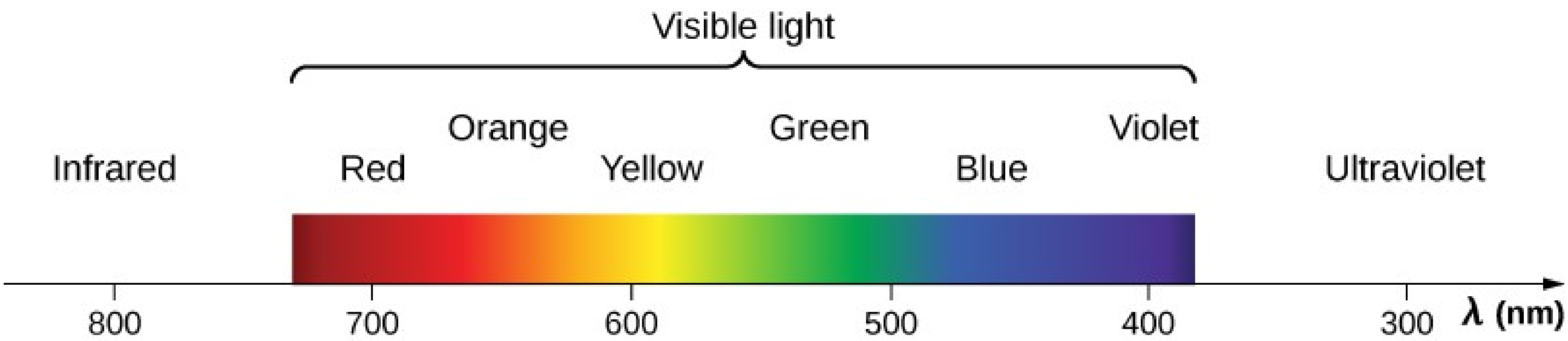
Dispersion: Separation of colors

FIGURE 1.20

(a) (b)

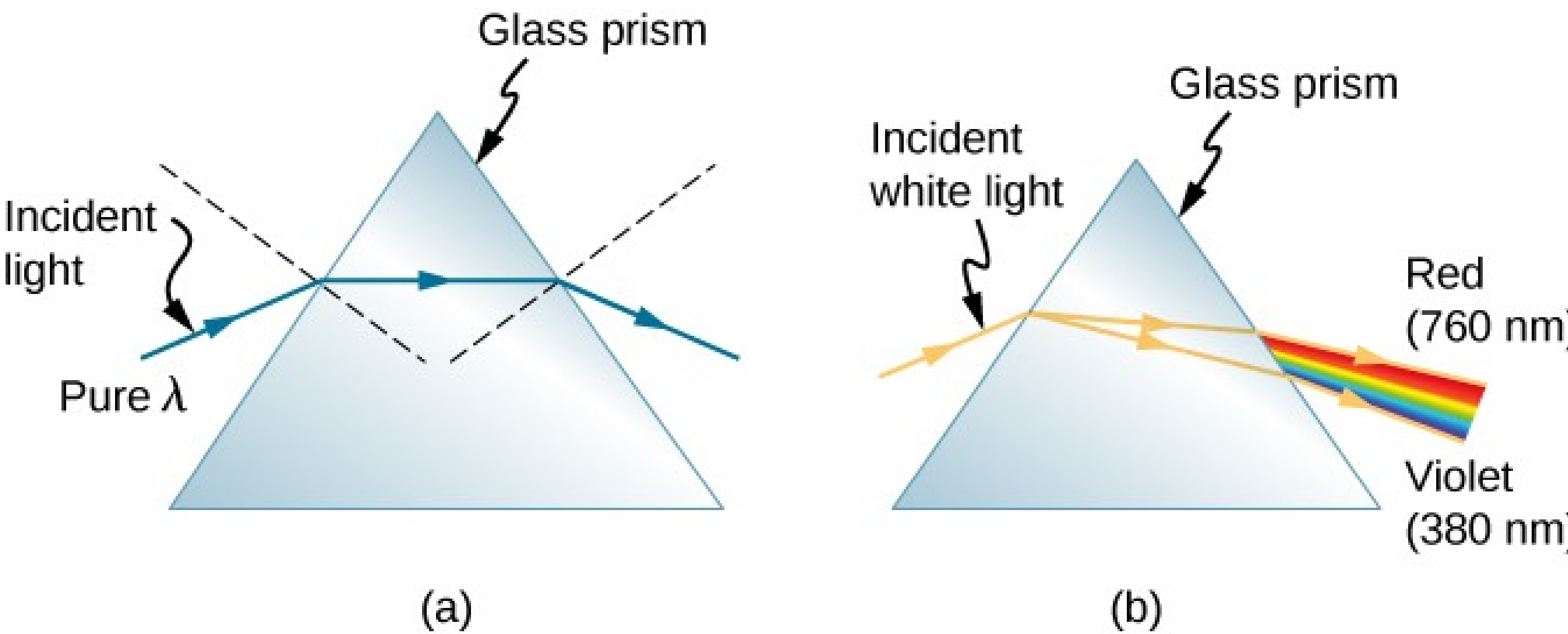
The colors of the rainbow (a) and those produced by a prism (b) are identical. (credit a: modification of work by “Alfredo55”/Wikimedia Commons; credit b: modification of work by NASA)

FIGURE 1.21



Even though rainbows are associated with six colors, the rainbow is a continuous distribution of colors according to wavelengths.

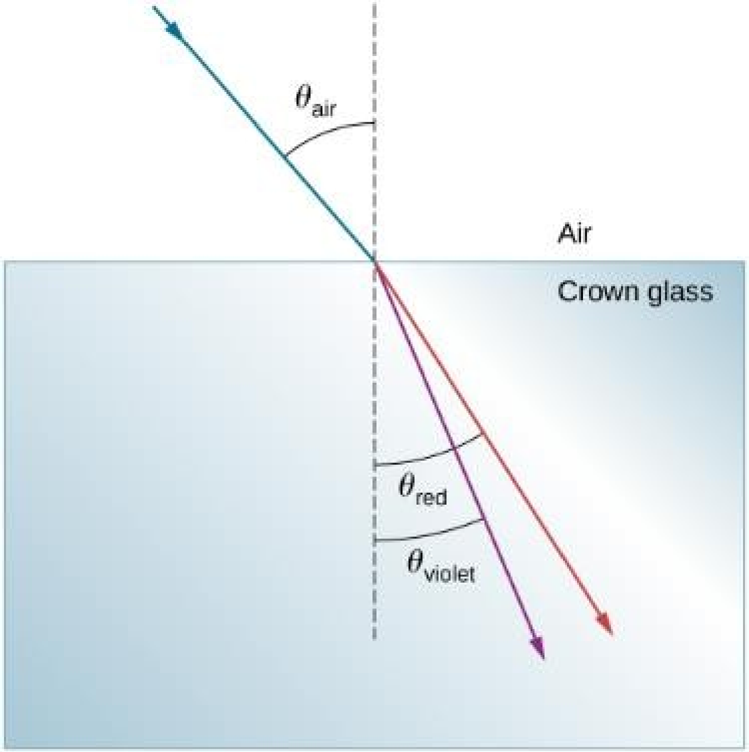
FIGURE 1.22



a) A pure wavelength of light falls onto a prism and is refracted at both surfaces.

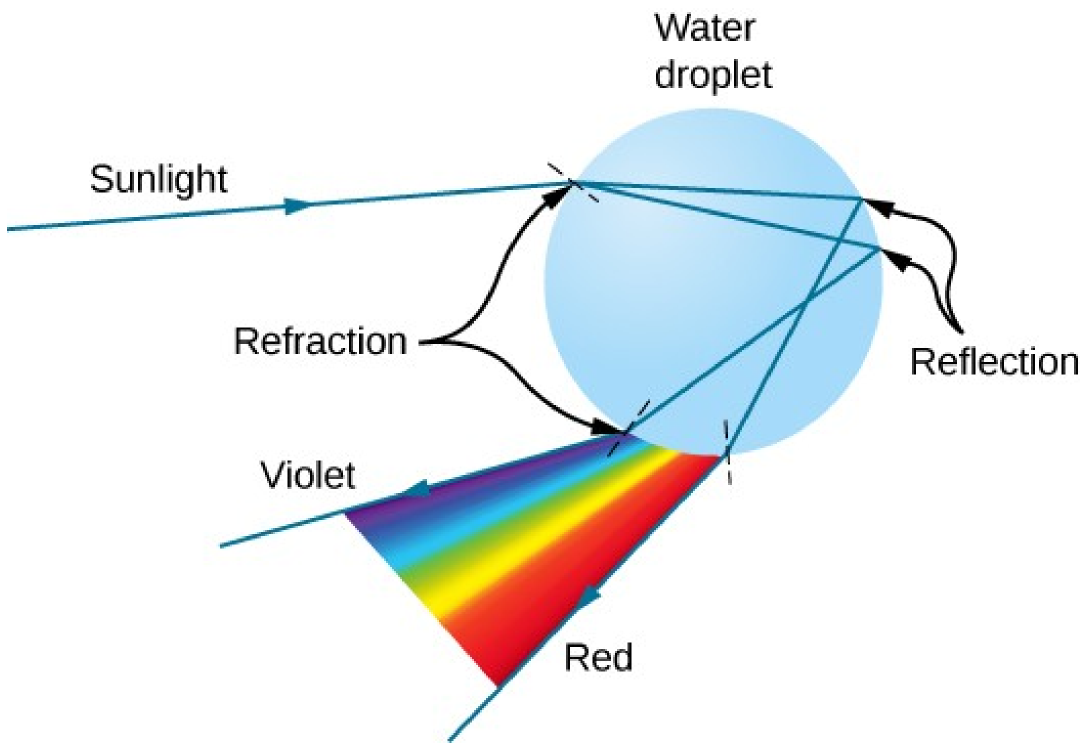
b) White light is dispersed by the prism (shown exaggerated). Since the index of refraction varies with wavelength, the angles of refraction vary with wavelength. A sequence of red to violet is produced, because the index of refraction increases steadily with decreasing wavelength.

EXAMPLE 1.5



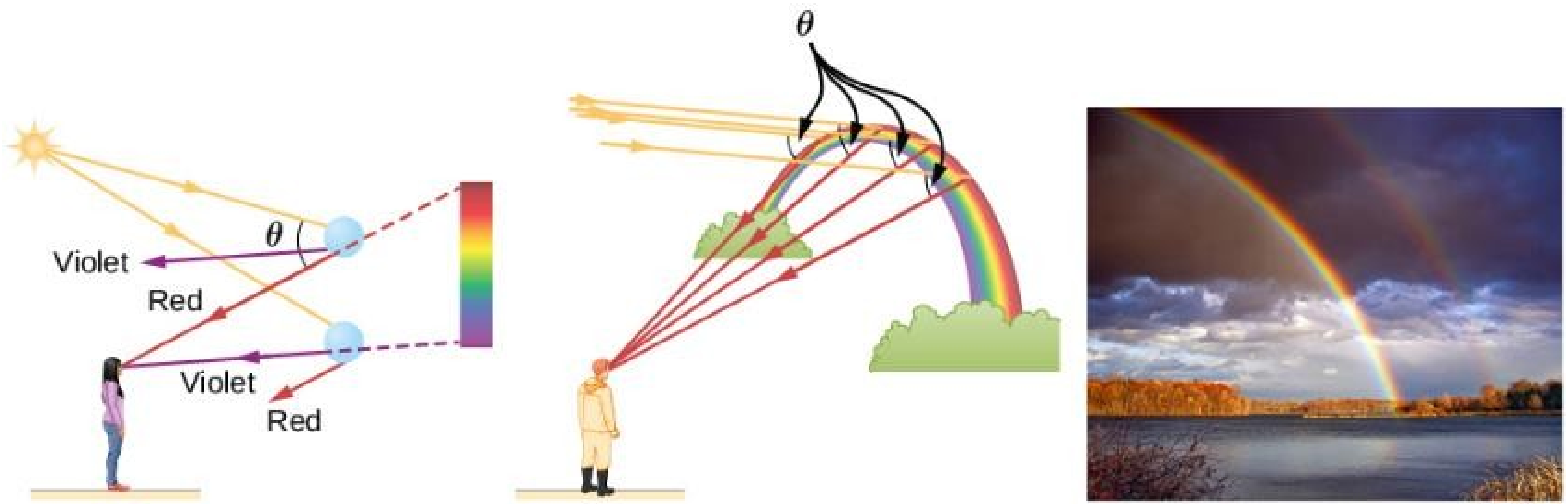
A beam of white light goes from air into crown glass at an incidence angle of 43.2° . What is the angle between the red (660 nm) and violet (410 nm) parts of the refracted light?

FIGURE 1.23



A ray of light falling on this water drop enters and is reflected from the back of the drop. This light is refracted and dispersed both as it enters and as it leaves the drop.

FIGURE 1.24



(a) (b) (c)

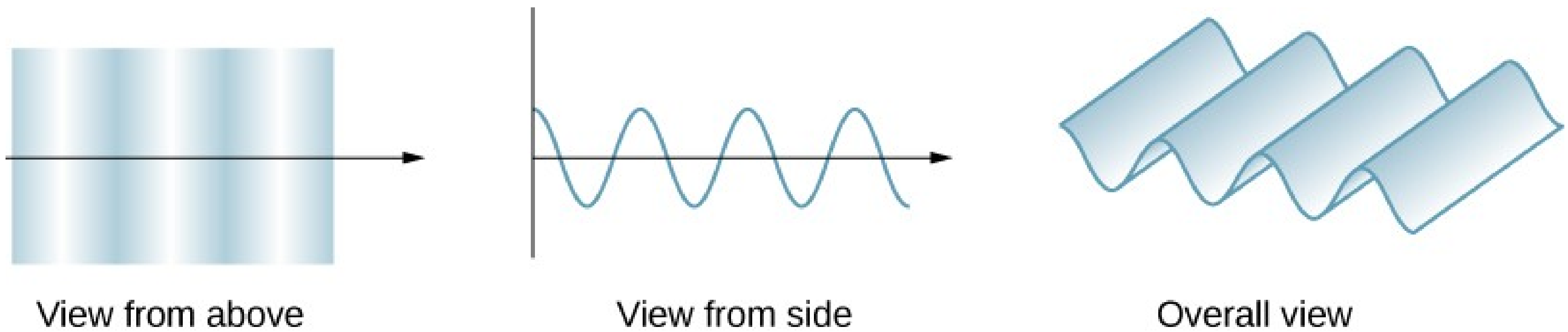
a) Different colors emerge in different directions, and so you must look at different locations to see the various colors of a rainbow.

b) The arc of a rainbow results from the fact that a line between the observer and any point on the arc must make the correct angle with the parallel rays of sunlight for the observer to receive the refracted rays.

c) Double rainbow. (credit c: modification of work by “Nicholas”/Wikimedia Commons)

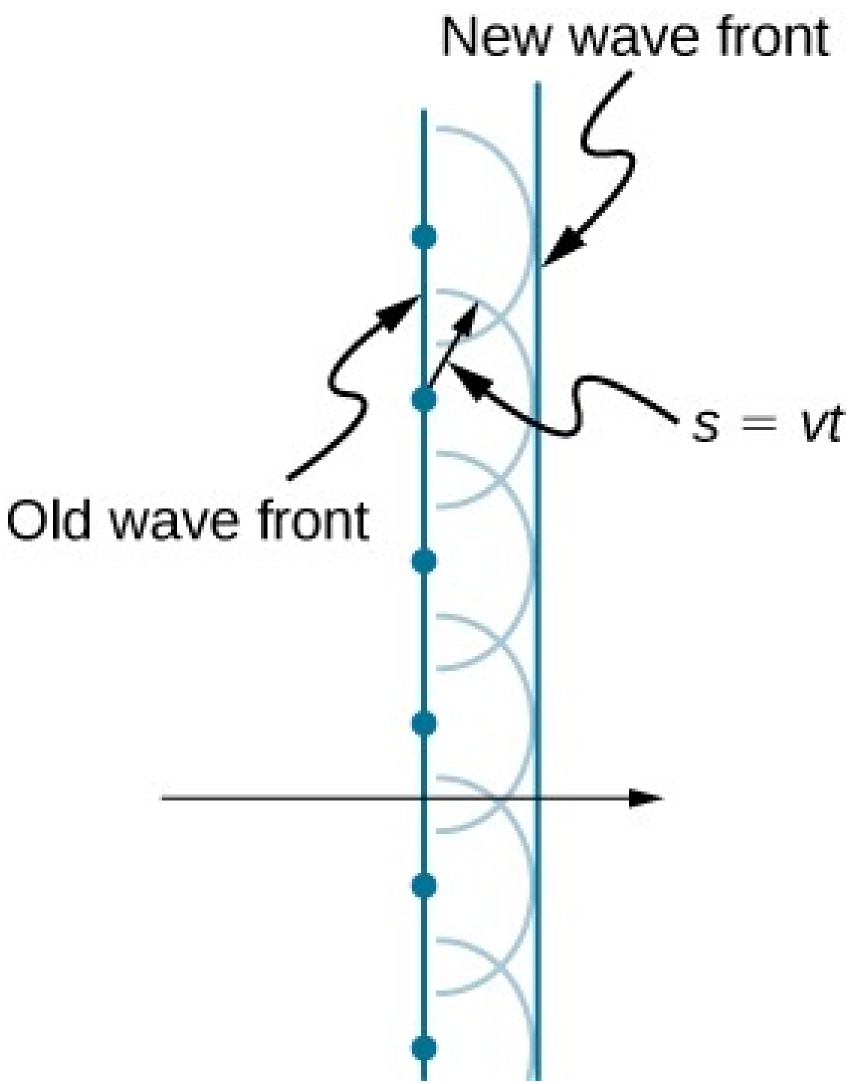
Huygen’s principle

FIGURE 1.25



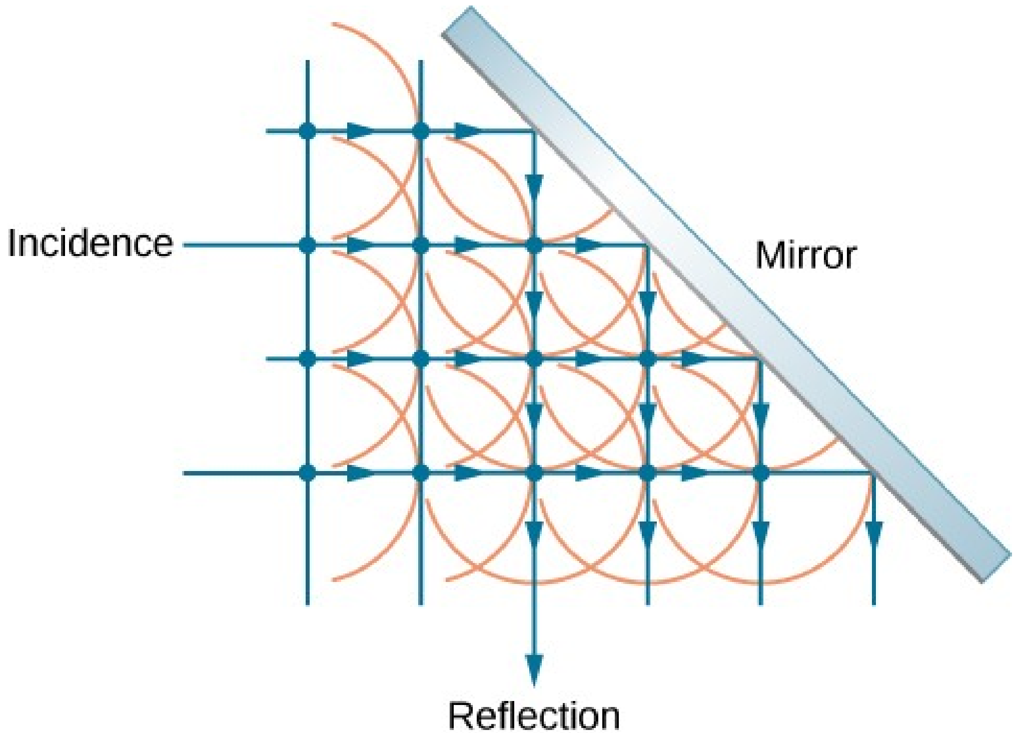
A transverse wave, such as an electromagnetic light wave, as viewed from above and from the side. The direction of propagation is perpendicular to the wave fronts (or wave crests) and is represented by a ray.

FIGURE 1.26



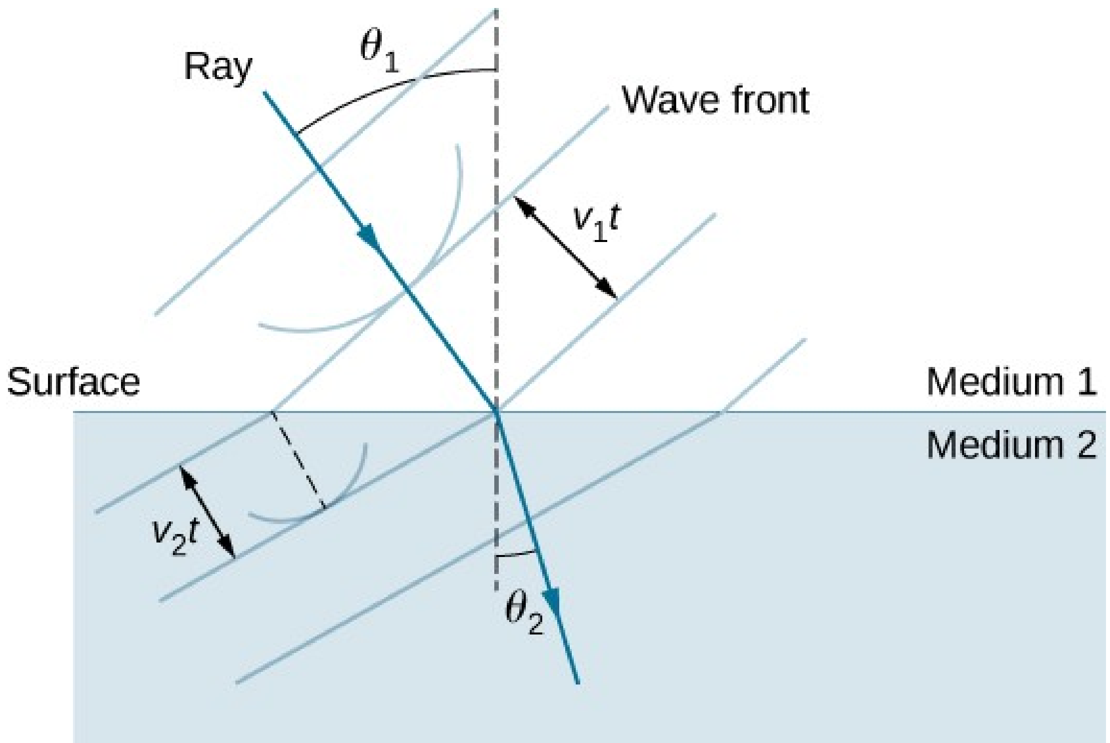
Huygens's principle applied to a straight wave front. Each point on the wave front emits a semicircular wavelet that moves a distance $s = vt$. The new wave front is a line tangent to the wavelets.

FIGURE 1.27



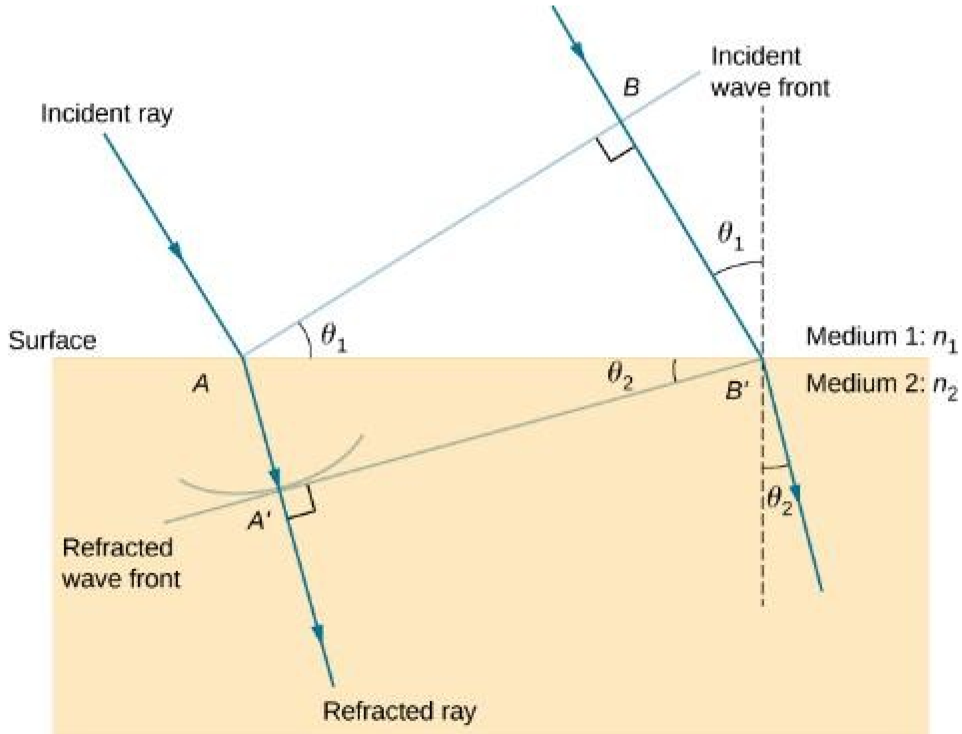
Huygens's principle applied to a plane wave front striking a mirror. The wavelets shown were emitted as each point on the wave front struck the mirror. The tangent to these wavelets shows that the new wave front has been reflected at an angle equal to the incident angle. The direction of propagation is perpendicular to the wave front, as shown by the downward-pointing arrows.

FIGURE 1.28



Huygens's principle applied to a plane wave front traveling from one medium to another, where its speed is less. The ray bends toward the perpendicular, since the wavelets have a lower speed in the second medium.

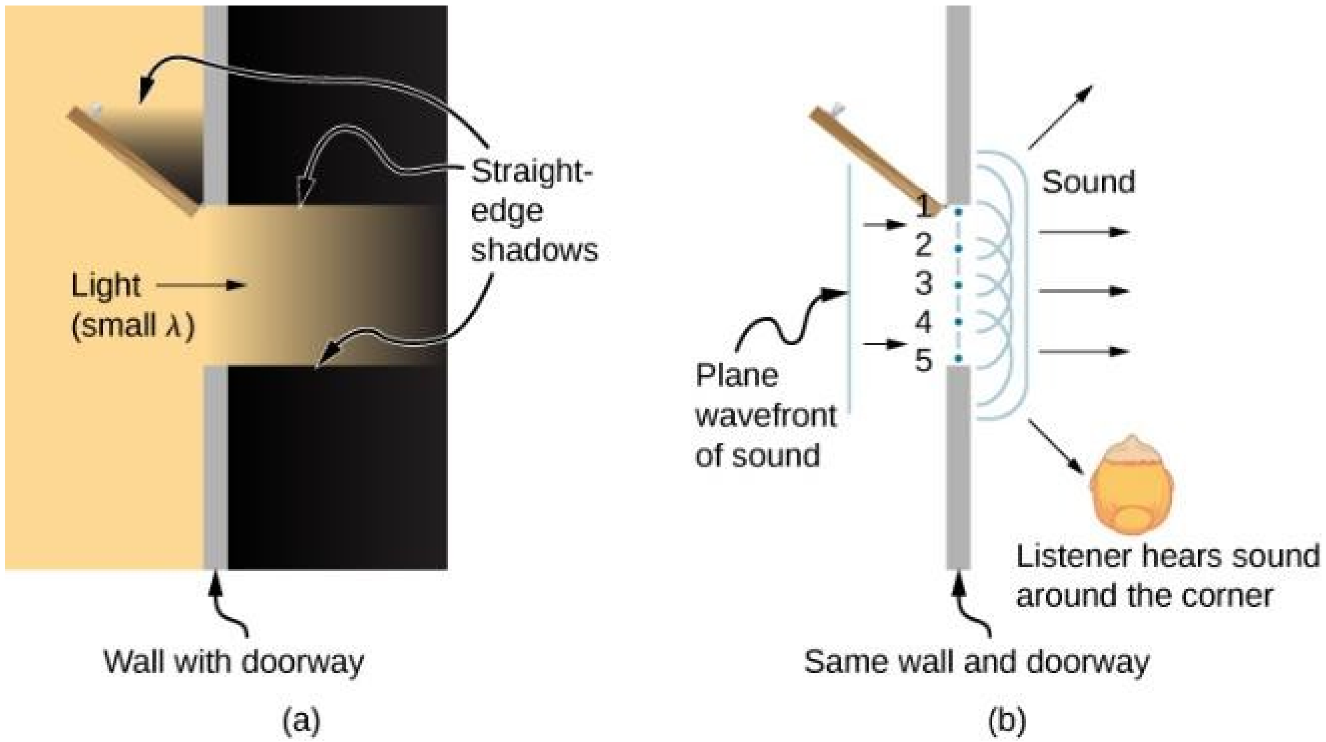
FIGURE 1.29



Geometry of the law of refraction from medium 1 to medium 2.

Diffraction

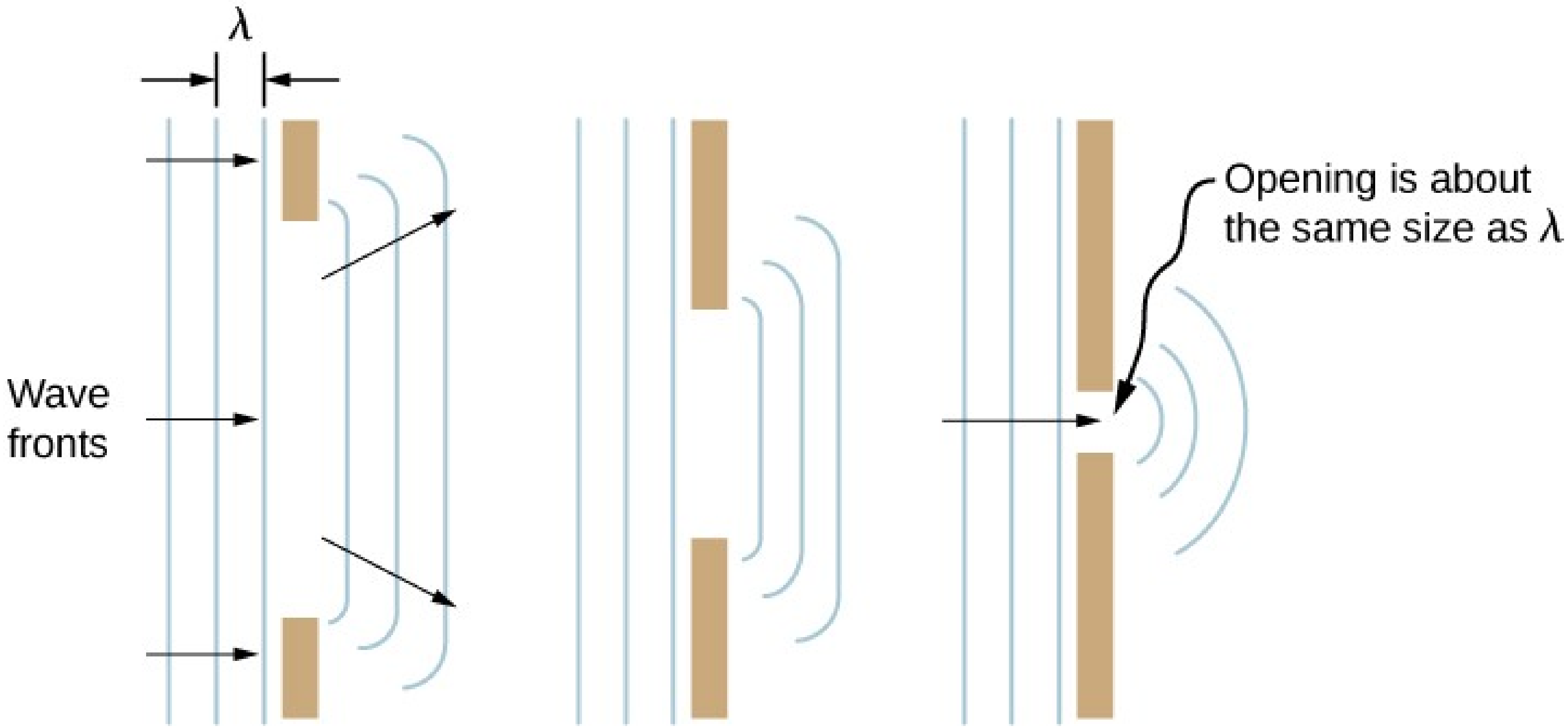
FIGURE 1.30



a) Light passing through a doorway makes a sharp outline on the floor. Since light's wavelength is very small compared with the size of the door, it acts like a ray.

b) Sound waves bend into all parts of the room, a wave effect, because their wavelength is similar to the size of the door.

FIGURE 1.31



Huygens's principle applied to a plane wave front striking an opening. The edges of the wave front bend after passing through the opening, a process called diffraction. The amount of bending is more extreme for a small opening, consistent with the fact that wave characteristics are most noticeable for interactions with objects about the same size as the wavelength.

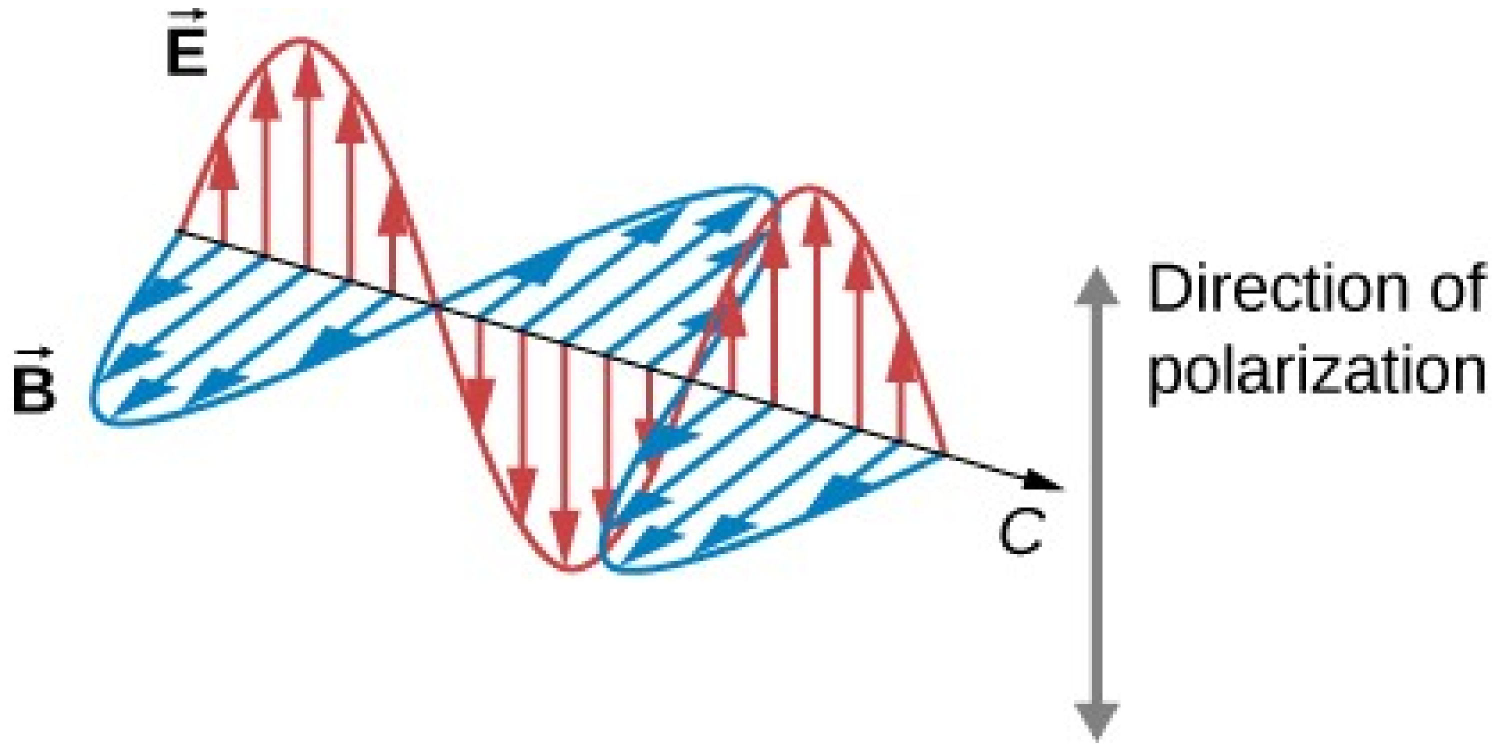
Polarization

FIGURE 1.32

(a) (b)

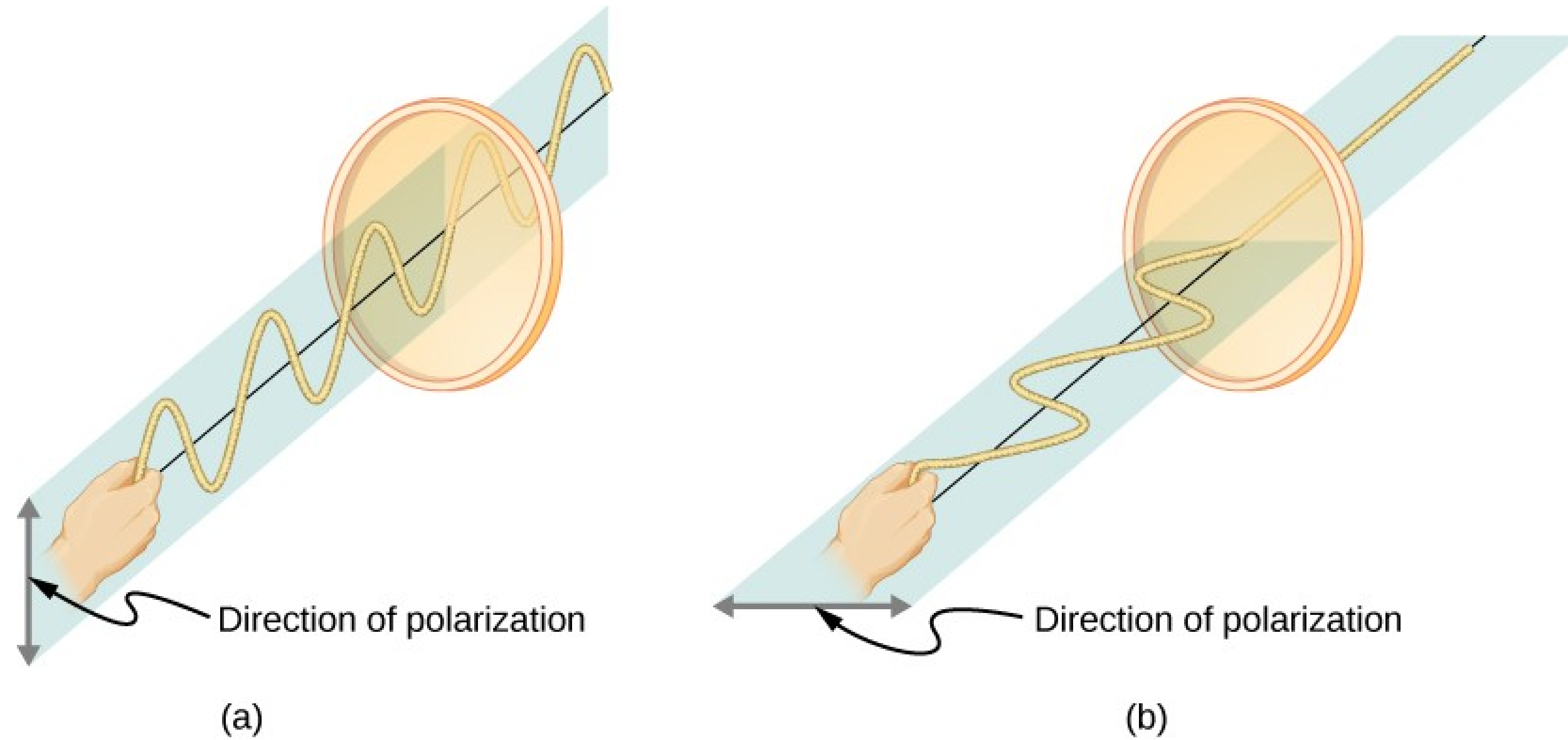
These two photographs of a river show the effect of a polarizing filter in reducing glare in light reflected from the surface of water. Part (b) of this figure was taken with a polarizing filter and part (a) was not. As a result, the reflection of clouds and sky observed in part (a) is not observed in part (b). Polarizing sunglasses are particularly useful on snow and water. (credit a and credit b: modifications of work by “Amithshs”/Wikimedia Commons)

FIGURE 1.33



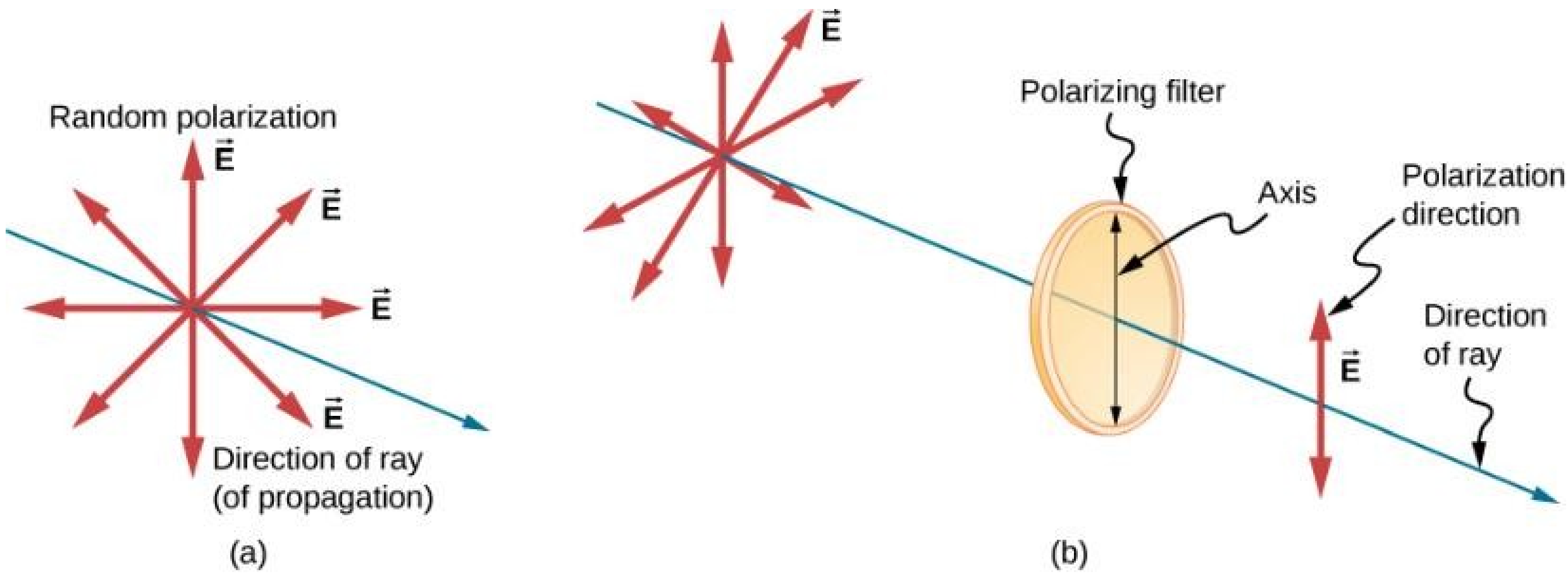
An EM wave, such as light, is a transverse wave. The electric () and magnetic () fields are perpendicular to the direction of propagation. The direction of polarization of the wave is the direction of the electric field.

FIGURE 1.34



The transverse oscillations in one rope (a) are in a vertical plane, and those in the other rope (b) are in a horizontal plane. The first is said to be vertically polarized, and the other is said to be horizontally polarized. Vertical slits pass vertically polarized waves and block horizontally polarized waves.

FIGURE 1.35

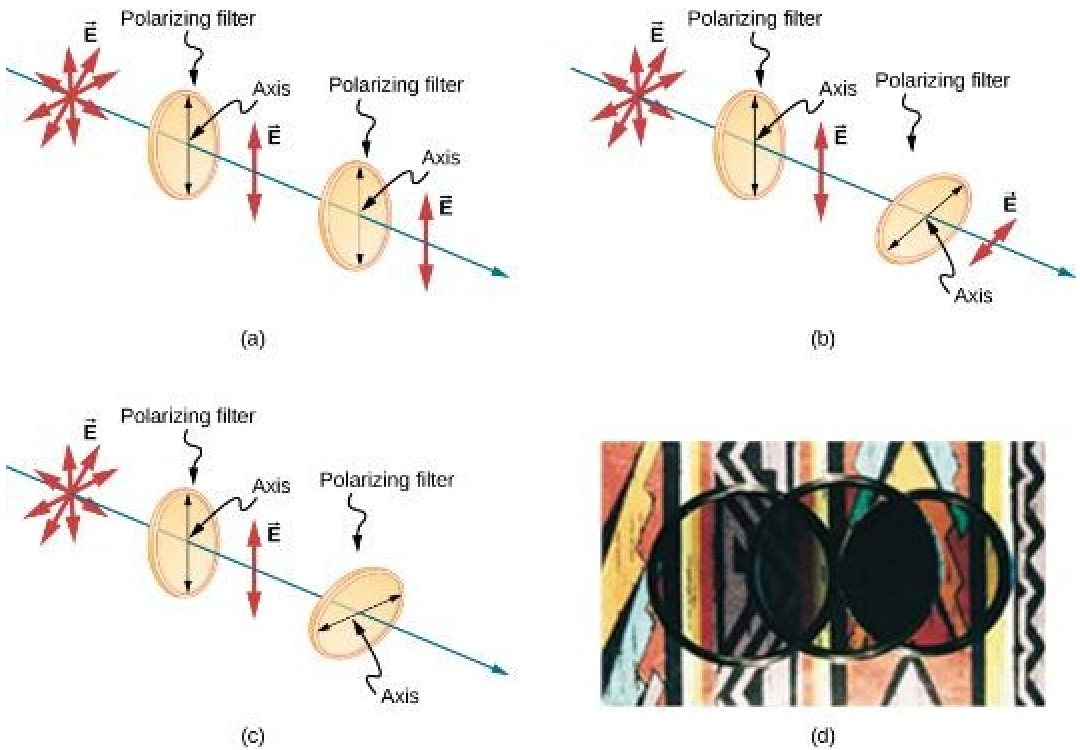


The slender arrow represents a ray of unpolarized light. The bold arrows represent the direction of polarization of the individual waves composing the ray.

a) If the light is unpolarized, the arrows point in all directions.

b) A polarizing filter has a polarization axis that acts as a slit passing through electric fields parallel to its direction. The direction of polarization of an EM wave is defined to be the direction of its electric field.

FIGURE 1.36



The effect of rotating two polarizing filters, where the first polarizes the light.

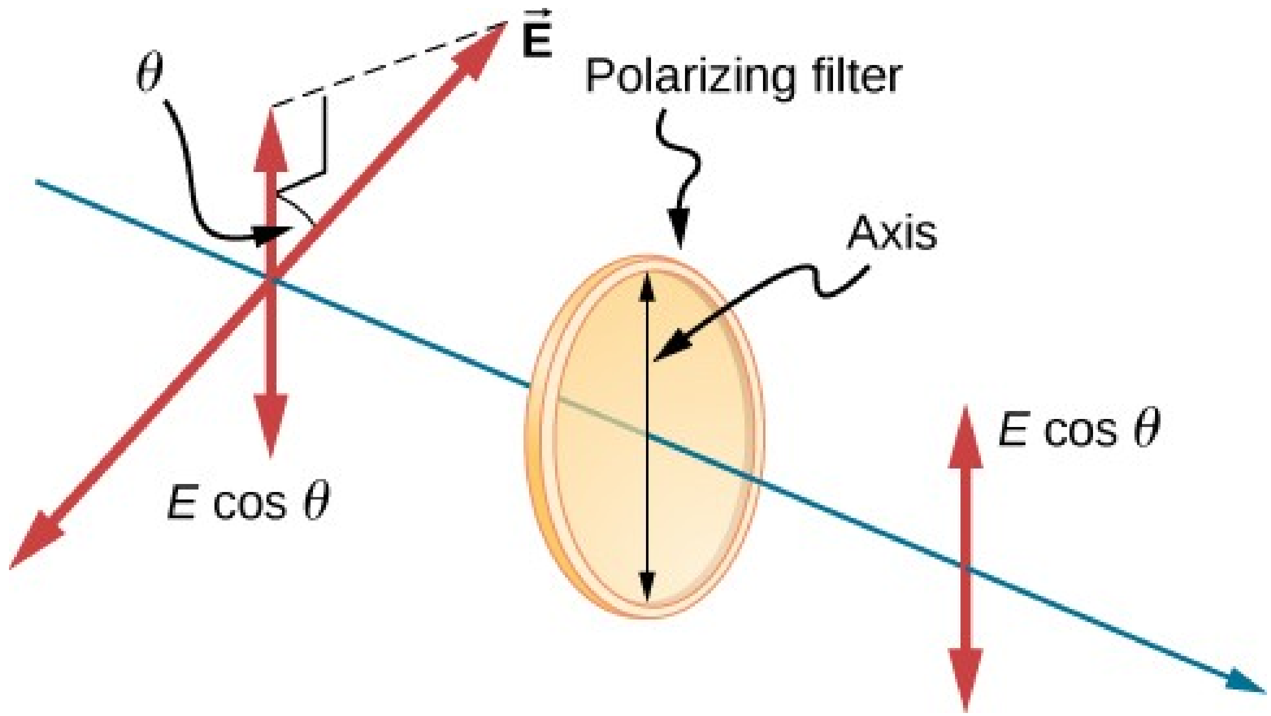
a) All of the polarized light is passed by the second polarizing filter, because its axis is parallel to the first.

b) As the second filter is rotated, only part of the light is passed.

c) When the second filter is perpendicular to the first, no light is passed.

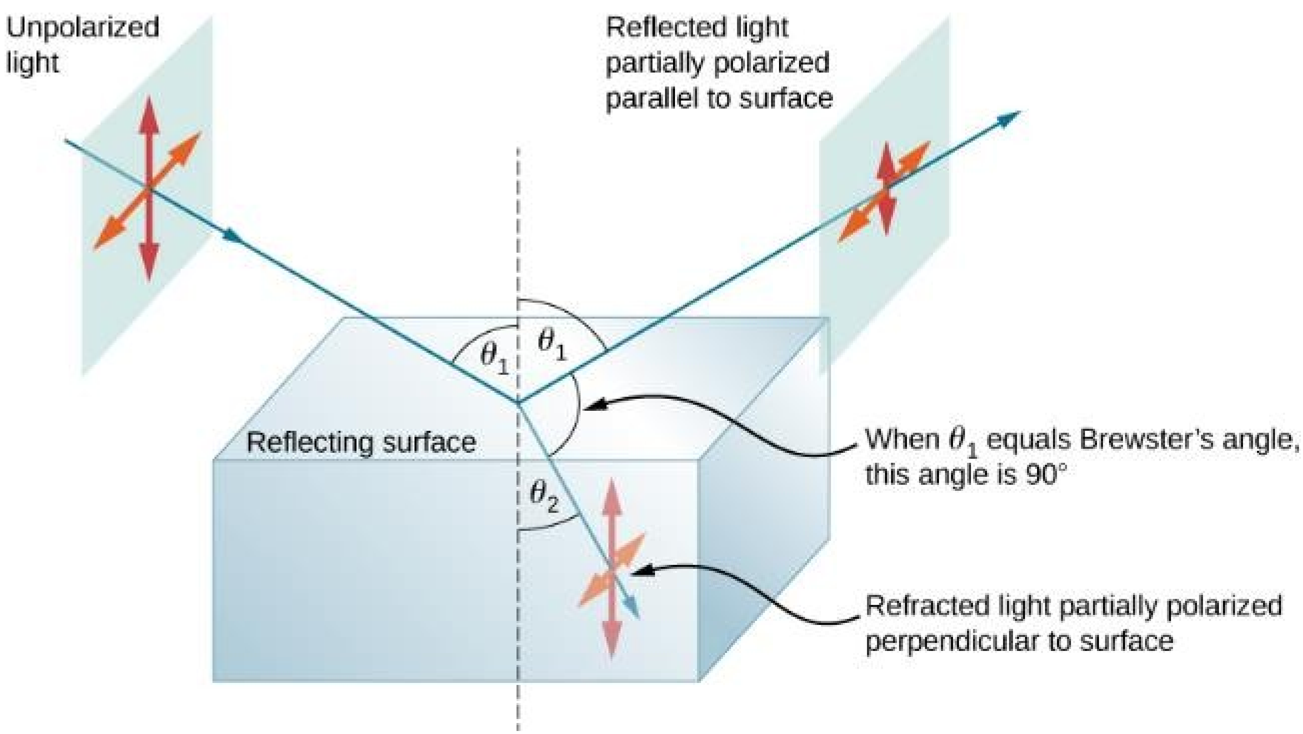
d) In this photograph, a polarizing filter is placed above two others. Its axis is perpendicular to the filter on the right (dark area) and parallel to the filter on the left (lighter area). (credit d: modification of work by P.P. Urone)

FIGURE 1.37



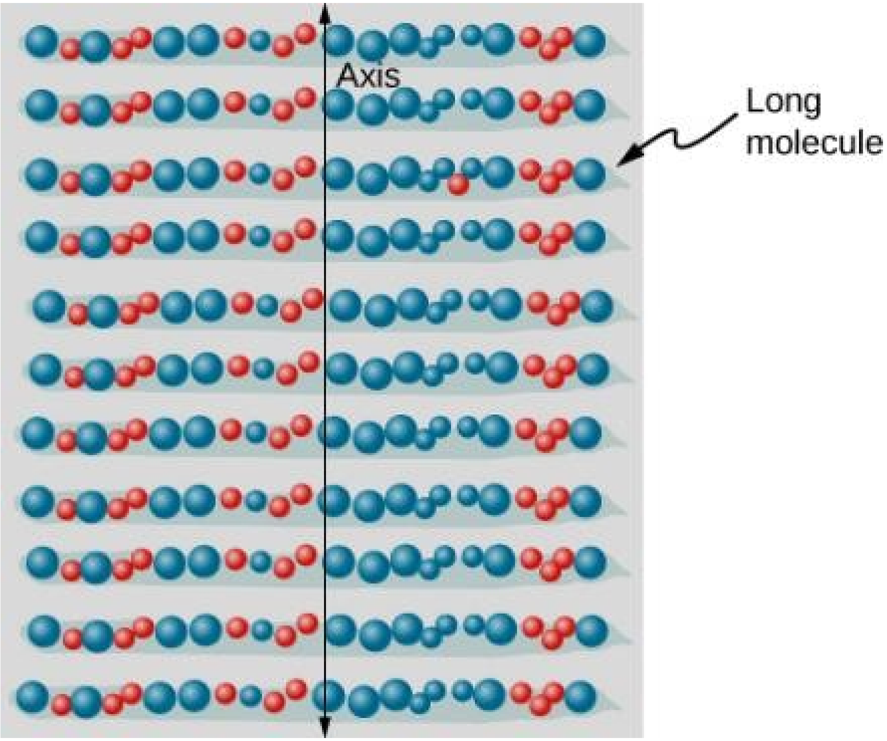
A polarizing filter transmits only the component of the wave parallel to its axis, reducing the intensity of any light not polarized parallel to its axis.

FIGURE 1.38



Polarization by reflection. Unpolarized light has equal amounts of vertical and horizontal polarization. After interaction with a surface, the vertical components are preferentially absorbed or refracted, leaving the reflected light more horizontally polarized. This is akin to arrows striking on their sides and bouncing off, whereas arrows striking on their tips go into the surface.

FIGURE 1.39



Long molecules are aligned perpendicular to the axis of a polarizing filter. In an EM wave, the component of the electric field perpendicular to these molecules passes through the filter, whereas the component parallel to the molecules is absorbed.

FIGURE 1.40

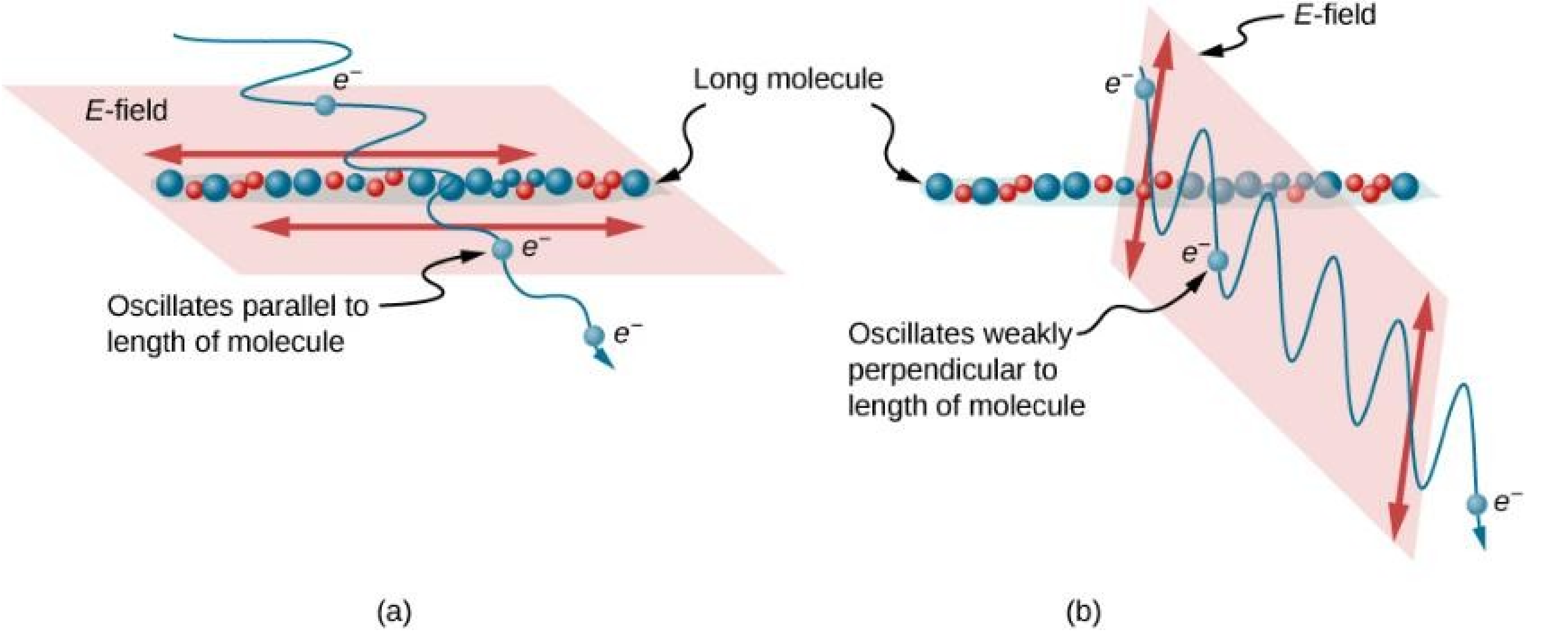
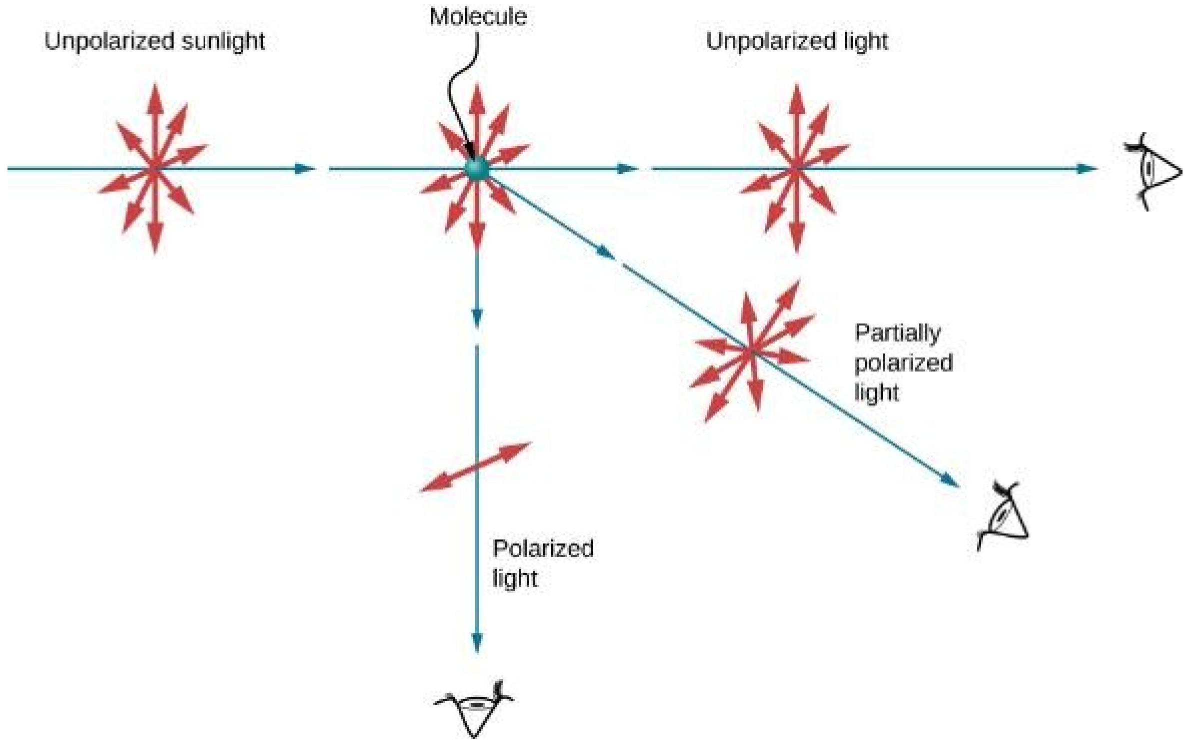


Diagram of an electron in a long molecule oscillating parallel to the molecule. The oscillation of the electron absorbs energy and reduces the intensity of the component of the EM wave that is parallel to the molecule.

FIGURE 1.41



Polarization by scattering. Unpolarized light scattering from air molecules shakes their electrons perpendicular to the direction of the original ray. The scattered light therefore has a polarization perpendicular to the original direction and none parallel to the original direction.

FIGURE 1.42

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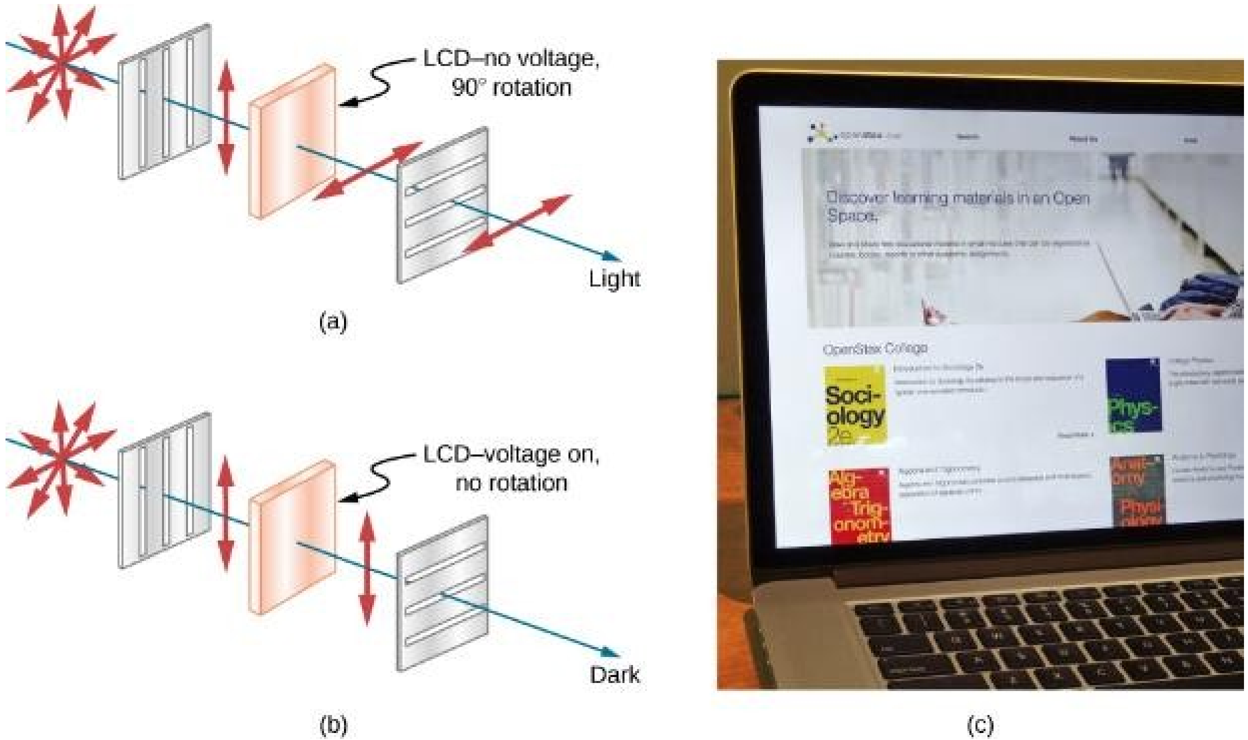
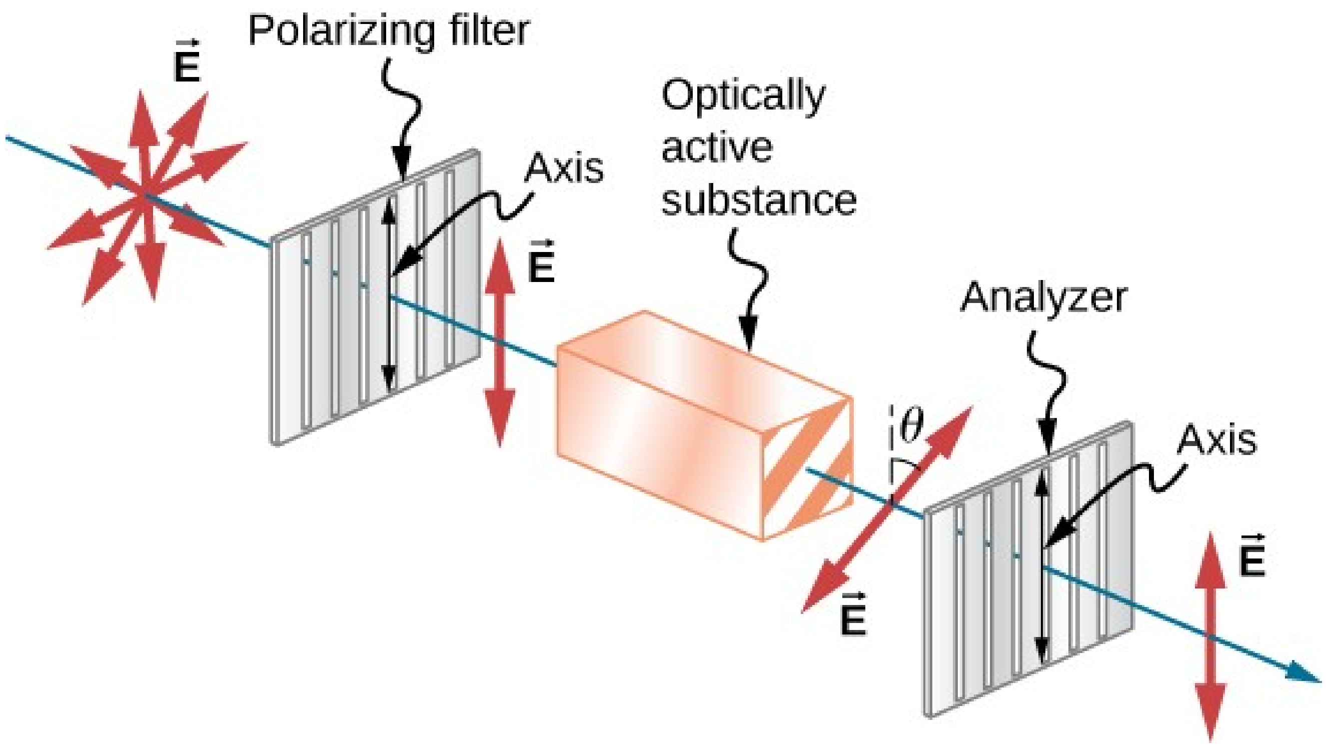


a) Polarized light is rotated 90° by a liquid crystal and then passed by a polarizing filter that has its axis perpendicular to the direction of the original polarization.

b) When a voltage is applied to the liquid crystal, the polarized light is not rotated and is blocked by the filter, making the region dark in comparison with its surroundings.

c) LCDs can be made color specific, small, and fast enough to use in laptop computers and TVs.

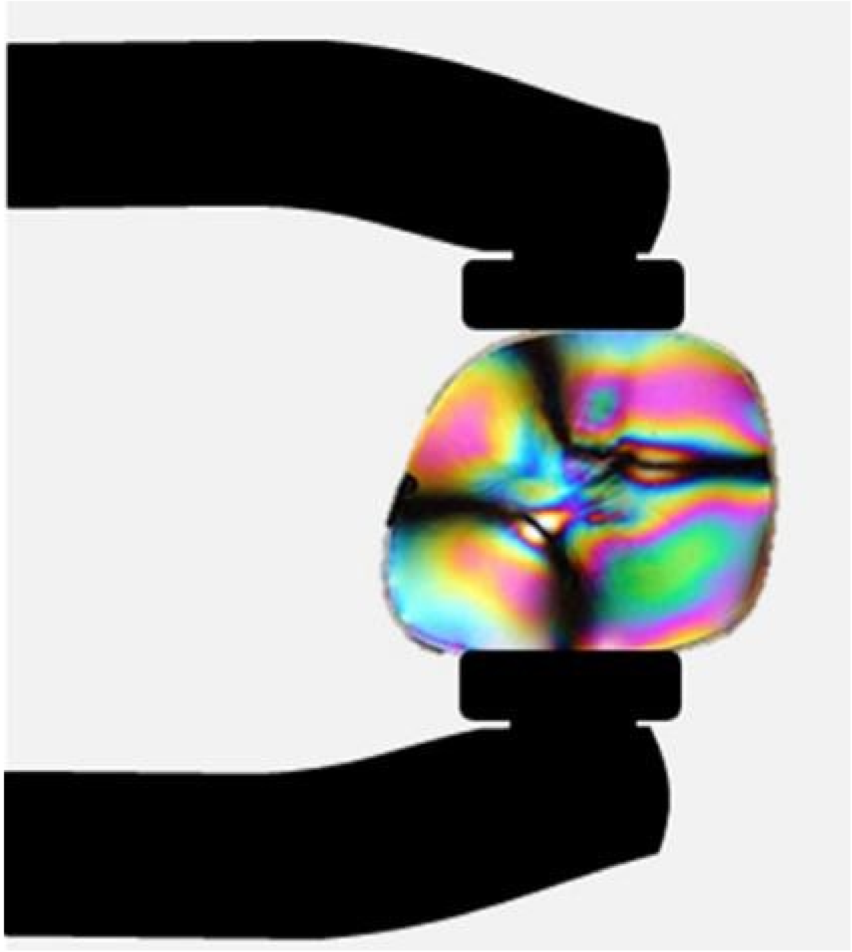
FIGURE 1.43



Optical activity is the ability of some substances to rotate the plane of polarization of light passing through them. The rotation is detected with a polarizing filter or analyzer.

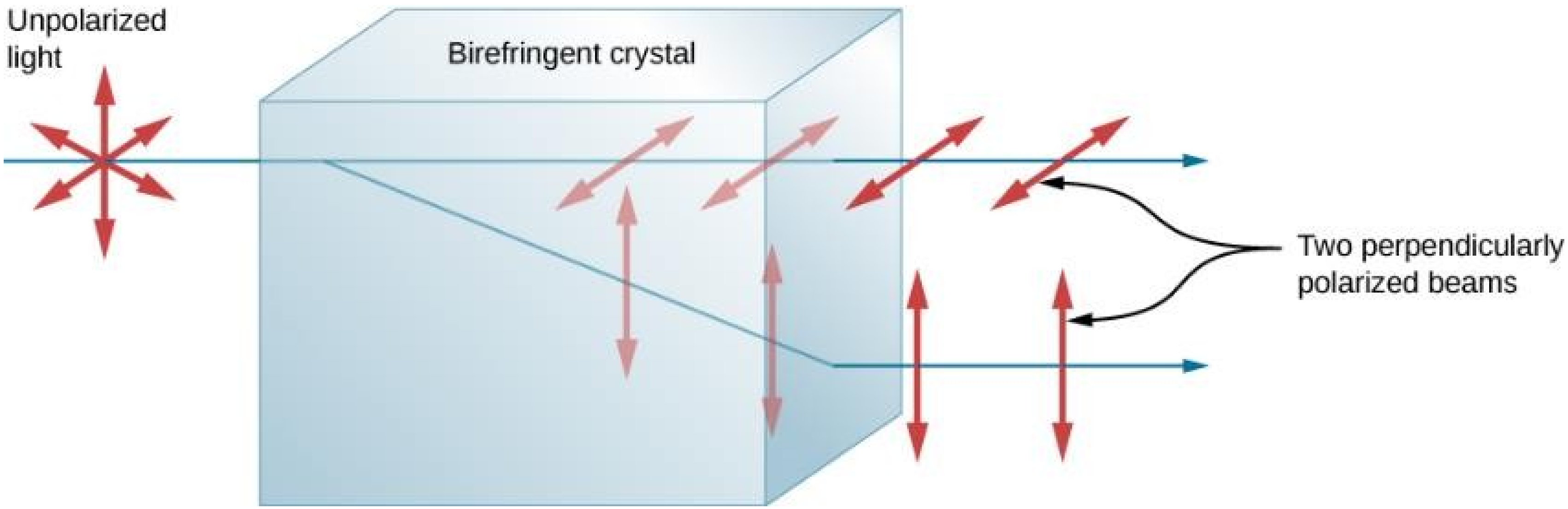
FIGURE 1.44

Optical stress analysis of a plastic lens placed between crossed polarizers. (credit: “Infopro”/Wikimedia Commons)



Birefringance

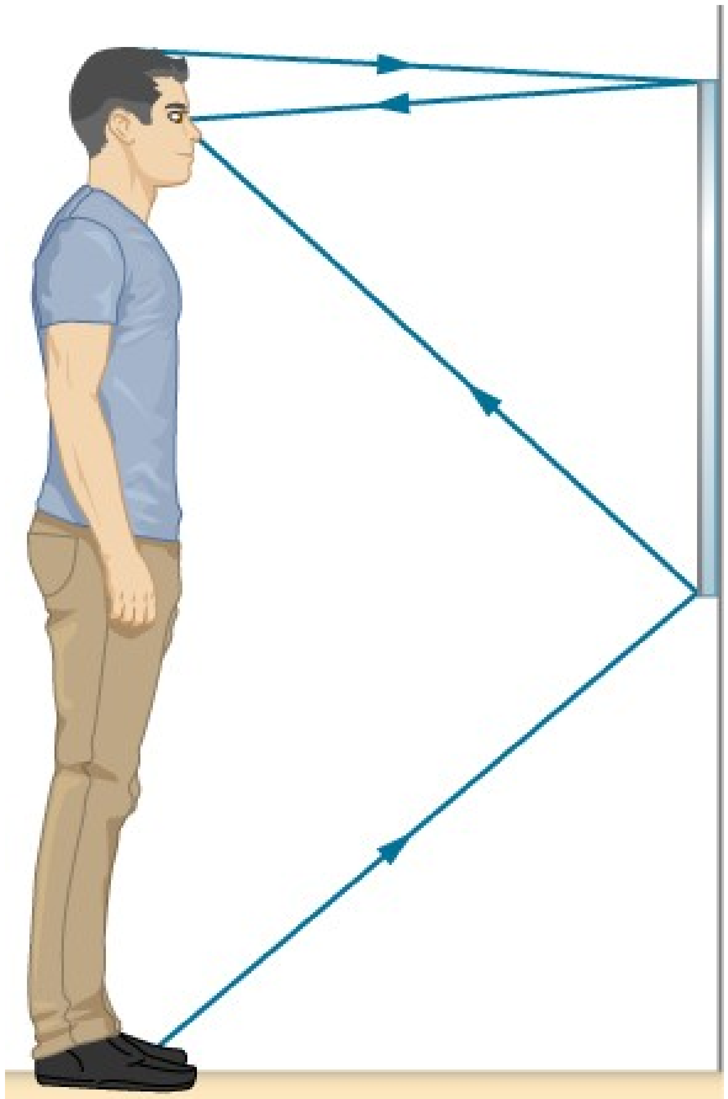
FIGURE 1.45



Birefringent materials, such as the common mineral calcite, split unpolarized beams of light into two with two different values of index of refraction.

Birefringance

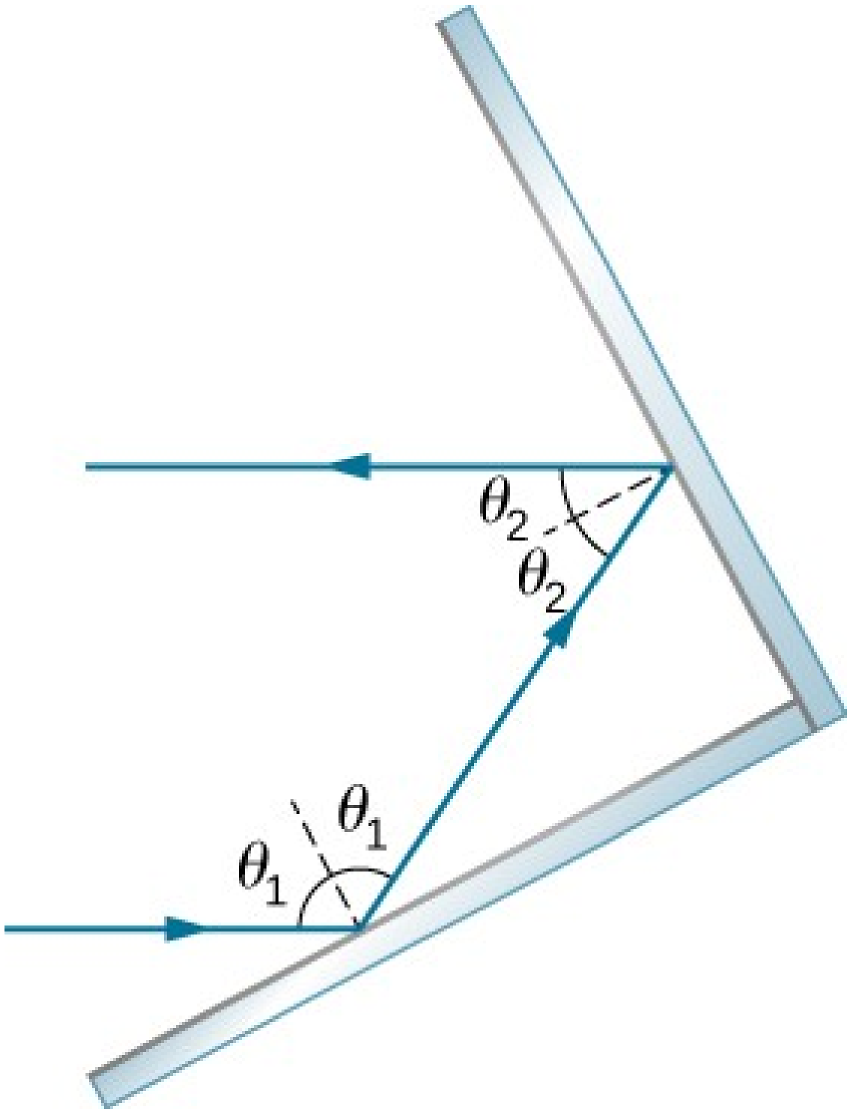
EXERCISE 34



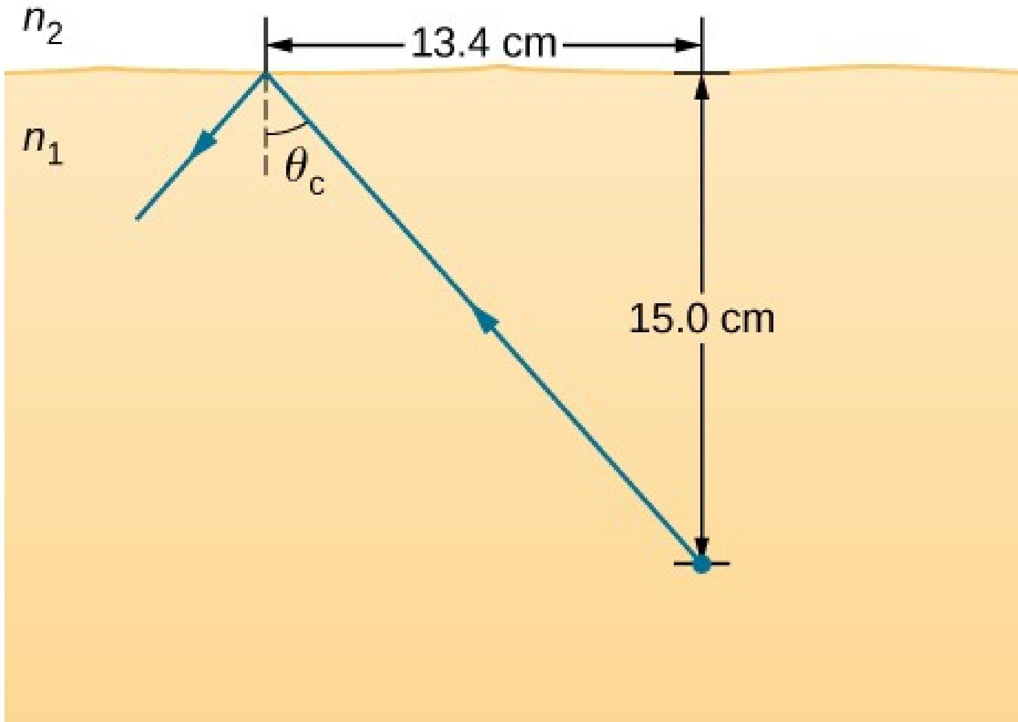
Suppose a man stands in front of a mirror as shown below. His eyes are 1.65 m above the floor and the top of his head is 0.13 m higher. Find the height above the floor of the top and bottom of the smallest mirror in which he can see both the top of his head and his feet. How is this distance related to the man's height?

EXERCISE 35

Show that when light reflects from two mirrors that meet each other at a right angle, the outgoing ray is parallel to the incoming ray, as illustrated below.

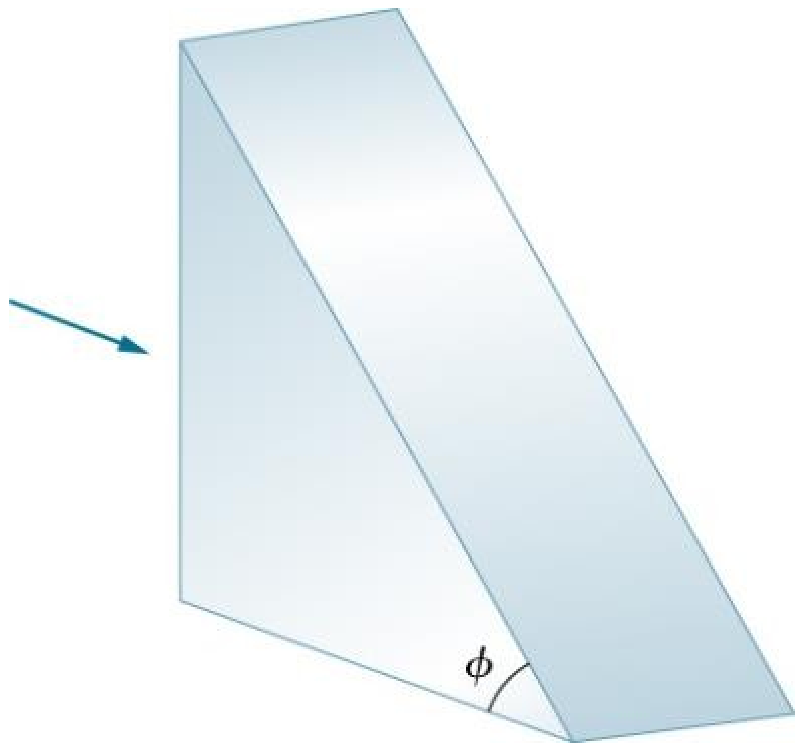


EXERCISE 52



A ray of light, emitted beneath the surface of an unknown liquid with air above it, undergoes total internal reflection as shown below. What is the index of refraction for the liquid and its likely identification?

EXERCISE 53



Light rays fall normally on the vertical surface of the glass prism $(n = 1.50)$ shown below. (a) What is the largest value for ϕ such that the ray is totally reflected at the slanted face? (b) Repeat the calculation of part (a) if the prism is immersed in water.