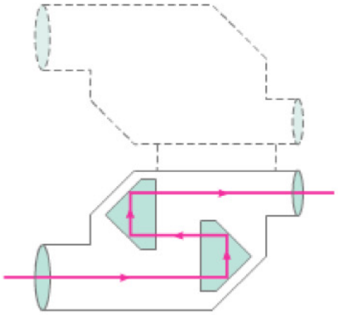


FIGURE 23–26 Total internal reflection of light by prisms in binoculars.

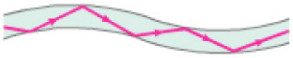
Many optical instruments, such as binoculars, use total internal reflection within a prism to reflect light. The advantage is that very nearly 100% of the light is reflected, whereas even the best mirrors reflect somewhat less than 100%. Thus the image is brighter, especially after several reflections. For glass with $n = 1.50$, $\theta_{\mathrm{C}} = 41.8^\circ$. Therefore, 45° prisms will reflect all the light internally, if oriented as shown in the binoculars of Fig. 23–26.

EXERCISE E If 45° plastic lenses were used in binoculars, what minimum index of refraction must the plastic have?

EXERCISE F What would happen if the 45° glass prisms of Exercise E were immersed in water?

Fiber Optics

FIGURE 23–27 Light reflected totally at the interior surface of a glass or transparent plastic fiber.



Total internal reflection is the principle behind **fiber optics**. Glass and plastic fibers as thin as a few micrometers in diameter are common. A bundle of such tiny fibers is called a **light pipe** or cable, and light[†] can be transmitted along it with almost no loss because of total internal reflection. Figure 23–27 shows how light traveling down a thin fiber makes only glancing collisions with the walls so that total internal reflection occurs. Even if the light pipe is bent into a complicated shape, the critical angle still won't be exceeded, so light is transmitted practically undiminished to the other end. Very small losses do occur, mainly by reflection at the ends and absorption within the fiber.

PHYSICS APPLIED

Fiber optics in communications

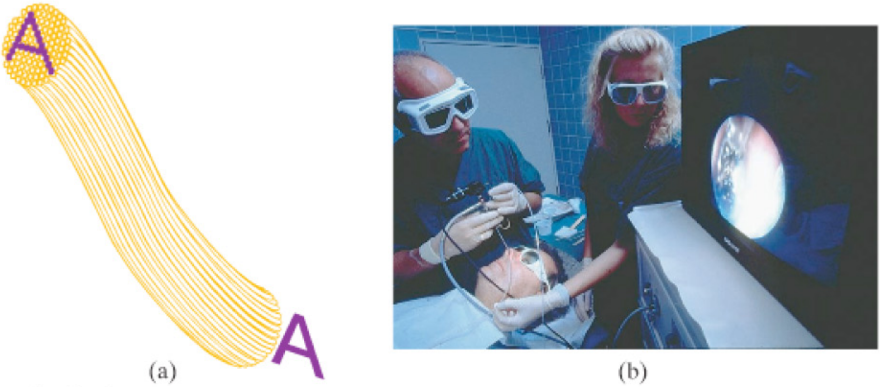
PHYSICS APPLIED

Medicine—bronchoscopes, colonoscopes, endoscopes

Important applications of fiber-optic cables are in communications and medicine. They are used in place of wire to carry telephone calls, video signals, and computer data. The signal is a modulated light beam (a light beam whose intensity can be varied) and data is transmitted at a much higher rate and with less loss and less interference than an electrical signal in a copper wire. Fibers have been developed that can support over one hundred separate wavelengths, each modulated to carry up to 10 gigabits (10^{10} bits) of information per second. That amounts to a terabit (10^{12} bits) per second for the full one hundred wavelengths. The sophisticated use of fiber optics to transmit a clear picture is particularly useful in medicine, Fig. 23–28. For example, a patient's lungs can be examined by inserting a light pipe known as a bronchoscope through the mouth and down the bronchial tube. Light is sent down an outer set of fibers to illuminate the lungs. The reflected light returns up a central core set of fibers. Light directly in front of each fiber travels up that fiber. At the opposite end, a viewer sees a series of bright and dark spots, much like a TV screen—that is, a picture of what lies at the opposite end. Lenses are used at each end: at the object end to bring the rays in parallel, and at the viewing end as a telescope. The image may be viewed directly or on a monitor screen or film. The fibers must be optically insulated from one another, usually by a thin coating of material with index of refraction less than that of the fiber. The more fibers there are, and the smaller they are, the more detailed the picture. Such instruments, including bronchoscopes, colonoscopes (for viewing the colon), and endoscopes (stomach or other organs), are extremely useful for examining hard-to-reach places.

[†] Fiber optics finds use not only with visible light but also with infrared light, ultraviolet light, and microwaves.

FIGURE 23–28 (a) How a fiber-optic image is made. (b) Example of a fiber-optic device inserted through the nose, and the image seen.



(a) (b)