2 Concept-Development Practice Book 29-3, 29-4

29.8 Refraction of Light

A pond or swimming pool both appear shallower than they actually are. A pencil in a glass of water appears bent, the air above a hot stove seems to shimmer, and stars twinkle. These effects are caused by changes in the speed of light as it passes from one medium to another, or through varying temperatures and densities of the same medium—which changes the directions of light rays. In short, these effects are due to the refraction of light.*

Figure 29.17 shows rays and wave fronts of light refracted as they pass from air into water. (The wave fronts would be curved if the source of light were close, just as the wave fronts of water waves near a stone thrown into the water are curved. If we assume that the source of light is the sun, then it is so far away that the wave fronts are practically straight lines.) Note that the left portions of the wave fronts are the first to slow down when they enter the water (or right portion if you look along the direction of travel). The refracted ray of light, which is at right angles to the refracted wave fronts, is closer to the normal than is the incident ray.

Compare the refraction in this case to the bending of the axle's path in Figure 29.13. When light rays enter a medium in which their speed decreases, as when passing from air into water, the rays bend toward the normal. But when light rays enter a medium in which their speed increases, as when passing from water into air, the rays bend away from the normal.

Figure 29.18 shows a laser beam entering a container of water at the left and exiting at the right. The path would be the same if the light entered from the right and exited at the left. The light paths are reversible for both reflection and refraction. If you can see somebody by way of a reflective or refractive device, such as a mirror or a prism, then that person can see you (or your eyes) by looking through the device also.

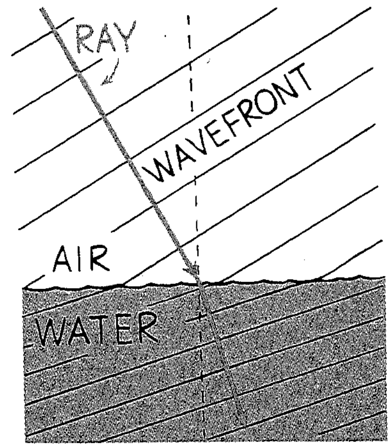

Figure 29.17 ▲
As a light wave passes from air into water, its speed decreases. Note that the refracted ray is closer to the normal than is the incident ray.

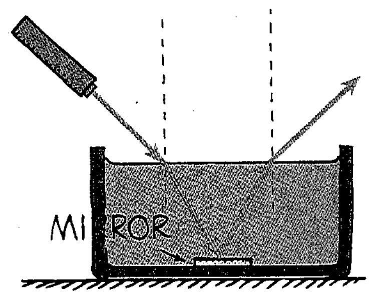

Figure 29.18 ▲
The laser beam bends toward the normal when it enters the water, and away from the normal when it leaves.

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* The ratio n of the speed of light in a vacuum to the speed in a given material is called the *index of refraction* of that material.

$$\text{index of refraction } n = \frac{\text{speed of light in vacuum}}{\text{speed of light in material}}$$

The quantitative law of refraction, called *Snell's law*, was first worked out in 1621 by Willebrod Snell, a Dutch astronomer and mathematician. According to Snell's law,

$$n \sin \theta = n' \sin \theta'$$

where n and n' are the indices of refraction of the media on either side of the boundary, and θ and θ' are the respective angles of incidence and refraction. If three of these values are known, the fourth can be calculated from this relationship.