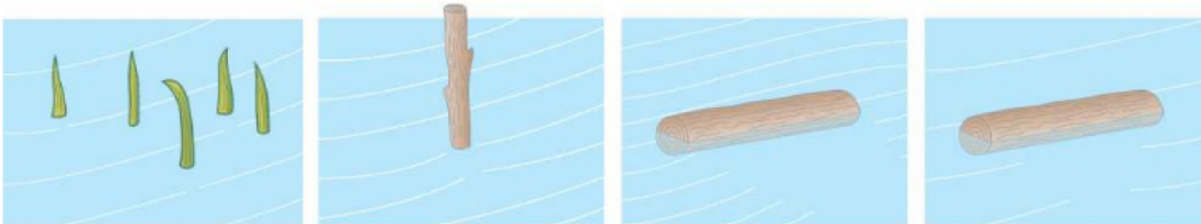


(a) Water waves passing blades of grass (b) Stick in water (c) Short-wavelength waves passing log (d) Long-wavelength waves passing log

FIGURE 11–45 Water waves passing objects of various sizes. Note that the longer the wavelength compared to the size of the object, the more diffraction there is into the "shadow region."

The amount of diffraction depends on the wavelength of the wave and on the size of the obstacle, as shown in Fig. 11–45. If the wavelength is much larger than the object, as with the grass blades of Fig. 11–45a, the wave bends around them almost as if they are not there. For larger objects, parts (b) and (c), there is more of a "shadow" region behind the obstacle where we might not expect the waves to penetrate—but they do, at least a little. Then notice in part (d), where the obstacle is the same as in part (c) but the wavelength is longer, that there is more diffraction into the shadow region. As a rule of thumb, *only if the wavelength is smaller than the size of the object will there be a significant shadow region*. This rule applies to *reflection* from an obstacle as well. Very little of a wave is reflected unless the wavelength is smaller than the size of the obstacle.

A rough guide to the amount of diffraction is

$$\theta(\text{radians}) \approx \frac{\lambda}{L},$$

where θ is roughly the angular spread of waves after they have passed through an opening of width L or around an obstacle of width L.

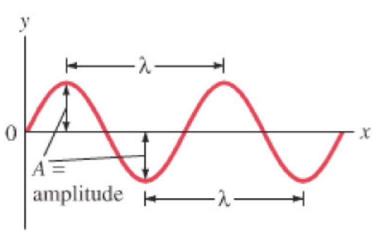
That waves can bend around obstacles, and thus can carry energy to areas behind obstacles, is very different from energy carried by material particles. A clear example is the following: if you are standing around a corner on one side of a building, you can't be hit by a baseball thrown from the other side, but you can hear a shout or other sound because the sound waves diffract around the edges.

CONCEPTUAL EXAMPLE 11–16 **Cell phones.** Cellular phones operate by radio waves with frequencies of about 1 or 2 GHz (1 gigahertz = 10^9 Hz). These waves cannot penetrate objects that conduct electricity, such as a tree trunk or a sheet of metal. The connection is best if the transmitting antenna is within clear view of the handset. Yet it is possible to carry on a phone conversation even if the tower is blocked by trees, or if the handset is inside a car. Why?

RESPONSE If the radio waves have a frequency of about 2 GHz, and the speed of propagation is equal to the speed of light, 3×10^8 m/s (Section 1–5), then the wavelength is $\lambda = v/f = (3 \times 10^8\,\text{m/s})/(2 \times 10^9\,\text{Hz}) = 0.15$ m. The waves can diffract readily around objects 15 cm in diameter or smaller.

* 11–16 Mathematical Representation of a Traveling Wave

FIGURE 11–46 The characteristics of a single-frequency wave at $t = 0$ (just as in Fig. 11–23).



A simple wave with a single frequency, as in Fig. 11–46, is sinusoidal. To express such a wave mathematically, we assume it has a particular wavelength λ and frequency f. At $t = 0$, the wave shape shown is

$$y = A \sin \frac{2\pi}{\lambda} x, \tag{11–21}$$

where y is the **displacement** of the wave (be it a longitudinal or transverse wave) at position x; A is the **amplitude** of the wave, and λ is the wavelength. [Equation 11–21 works because it repeats itself every wavelength: when $x = \lambda$, $y = \sin 2\pi = \sin 0$.]