Besides these two types of waves, *surface waves* can travel along the boundary between two materials. A wave on water is actually a surface wave that moves on the boundary between water and air. The motion of each particle of water at the surface is circular or elliptical (Fig. 11–28), so it is a combination of transverse and longitudinal motions. Below the surface, there is also transverse plus longitudinal wave motion, as shown. At the bottom, the motion is only longitudinal. When a wave approaches shore, the water drags at the bottom and is slowed down, while the crests move ahead at higher speed (Fig. 11–29) and "spill" over the top.

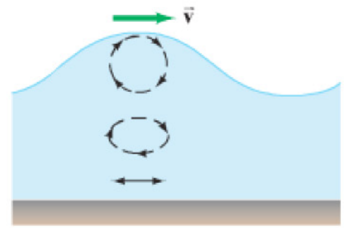
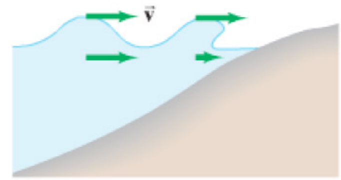


FIGURE 11–28 A water wave is an example of a *surface wave*, which is a combination of transverse and longitudinal wave motions.

Surface waves are also set up on the Earth when an earthquake occurs. The waves that travel along the surface are mainly responsible for the damage caused by earthquakes.

Waves traveling along a line, as on a stretched string, are *one-dimensional waves*. Surface waves, such as the water waves of Fig. 11–20, are *two-dimensional waves*. Waves that move out from a source in all directions in a medium, such as sound from a speaker or earthquake waves through the Earth, are *three-dimensional waves*.

FIGURE 11–29 How a wave breaks. The green arrows represent the local velocity of water molecules.



11–9 Energy Transported by Waves

Waves transport energy from one place to another. As waves travel through a medium, the energy is transferred as vibrational energy from particle to particle of the medium. For a sinusoidal wave of frequency f, the particles move in SHM as a wave passes, so each particle has an energy $E = \frac{1}{2}kA^2$, where A is the amplitude of its motion, either transversely or longitudinally. (See Eq. 11–4a.)

Thus, we have the important result that the **energy transported by a wave is proportional to the square of the amplitude**. The **intensity** I of a wave is defined as the power (energy per unit time) transported across unit area perpendicular to the direction of energy flow:

Wave energy $\propto$ (amplitude)^2

$$I = \frac{\text{energy/time}}{\text{area}} = \frac{\text{power}}{\text{area}}.$$

Intensity (defined)

The SI unit of intensity is watts per square meter $\left(\mathrm{W/m^2}\right)$. Since the energy is proportional to the wave amplitude squared, so too is the intensity:

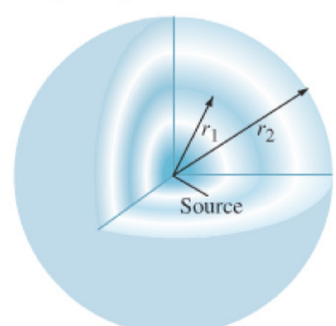
$$I \propto A^2. \qquad \textbf{(11–15)}$$

Intensity $\propto$ (amplitude)^2

If a wave flows out from the source in all directions, it is a three-dimensional wave. Examples are sound traveling in open air, earthquake waves, and light waves. If the medium is isotropic (same in all directions), the wave is a *spherical wave* (Fig. 11–30). As the wave moves outward, the energy it carries is spread over a larger and larger area since the surface area of a sphere of radius r is $4\pi r^2$. Thus the intensity of a spherical wave is

$$I = \frac{\text{power}}{\text{area}} = \frac{P}{4\pi r^2}. \qquad \text{[spherical wave]} \quad \textbf{(11–16a)}$$

FIGURE 11–30 A wave traveling outward in three dimensions from a source is spherical. Two crests (or compressions) are shown, of radii r_1 and r_2.



If the power output P of the source is constant, then the intensity decreases as the inverse square of the distance from the source:

$$I \propto \frac{1}{r^2}. \qquad \textbf{(11–16b)}$$

If we consider two points at distances r_1 and r_2 from the source, as in Fig. 11–30, then $I_1 = P/4\pi r_1^2$ and $I_2 = P/4\pi r_2^2$, so

$$\frac{I_2}{I_1} = \frac{r_1^2}{r_2^2}. \qquad \textbf{(11–16c)}$$

$I \propto \dfrac{1}{r^2}$

Thus, for example, when the distance doubles $(r_2/r_1 = 2)$, the intensity is reduced to $\frac{1}{4}$ its earlier value: $I_2/I_1 = \left(\frac{1}{2}\right)^2 = \frac{1}{4}$.

Sounds are quieter farther from the source