Suppose the wave is moving to the right with velocity v. After a time t, each part of the wave (indeed, the whole wave "shape") has moved to the right a distance vt. Figure 11–47 shows the wave at $t = 0$ as a solid curve, and at a later time t as a dashed curve. Consider any point on the wave at $t = 0$: say, a crest at some position x. After a time t, that crest will have traveled a distance vt, so its new position is a distance vt greater than its old position. To describe this same point on the wave shape, the argument of the sine function must have the same numerical value, so we replace x in Eq. 11–21 by $(x - vt)$:

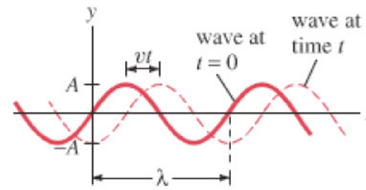

FIGURE 11–47 A traveling wave. In time t, the wave moves a distance vt.

1-D wave, moving in positive x direction

$$y = A\sin\left[\frac{2\pi}{\lambda}(x - vt)\right]. \qquad \textbf{(11–22)}$$

Said another way, if you are on a crest, as t increases, x must increase at the same rate so that $(x - vt)$ remains constant.

For a wave traveling along the x axis to the left, toward decreasing values of x, v becomes $-v$, so

1-D wave, traveling in negative x direction (to the left)

$$y = A\sin\left[\frac{2\pi}{\lambda}(x + vt)\right].$$

Summary

A vibrating object undergoes **simple harmonic motion** (SHM) if the restoring force is proportional to the displacement,

$$F = -kx. \qquad \textbf{(11–1)}$$

The maximum displacement is called the **amplitude**.

The **period**, T, is the time required for one complete cycle (back and forth), and the **frequency**, f, is the number of cycles per second; they are related by

$$f = \frac{1}{T}. \qquad \textbf{(11–2)}$$

The period of vibration for a mass m on the end of a spring is given by

$$T = 2\pi\sqrt{\frac{m}{k}}. \qquad \textbf{(11–7a)}$$

SHM is **sinusoidal**, which means that the displacement as a function of time follows a sine or cosine curve.

During SHM, the total energy

$$E = \tfrac{1}{2}mv^2 + \tfrac{1}{2}kx^2 \qquad \textbf{(11–3)}$$

is continually changing from potential to kinetic and back again.

A **simple pendulum** of length L approximates SHM if its amplitude is small and friction can be ignored. For small amplitudes, its period is then given by

$$T = 2\pi\sqrt{\frac{L}{g}}, \qquad \textbf{(11–11a)}$$

where g is the acceleration of gravity.

When friction is present (for all real springs and pendulums), the motion is said to be **damped**. The maximum displacement decreases in time, and the energy is eventually all transformed to thermal energy.

If an oscillating force is applied to a system capable of vibrating, the system's amplitude of vibration can be very large if the frequency of the applied force matches the **natural** (or **resonant**) **frequency** of the oscillator. This effect is called **resonance**.

Vibrating objects act as sources of **waves** that travel outward from the source. Waves on water and on a string are examples. The wave may be a **pulse** (a single crest), or it may be continuous (many crests and troughs).

The **wavelength** of a continuous sinusoidal wave is the distance between two successive crests.

The **frequency** is the number of wavelengths (or crests) that pass a given point per unit time.

The **amplitude** of a wave is the maximum height of a crest, or depth of a trough, relative to the normal (or equilibrium) level.

The **wave velocity** (how fast a crest moves) is equal to the product of wavelength and frequency,

$$v = \lambda f. \qquad \textbf{(11–12)}$$

In a **transverse wave**, the oscillations are perpendicular to the direction in which the wave travels. An example is a wave on a string.

In a **longitudinal wave**, the oscillations are along (parallel to) the line of travel; sound is an example.

The **intensity** of a wave is the energy per unit time carried across unit area (in watts/m^2). For three-dimensional waves traveling in open space, the intensity decreases inversely as the distance from the source squared:

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

[*Wave intensity is proportional to the amplitude squared and to the frequency squared.]

Waves reflect off objects in their path. When the **wave front** (of a two- or three-dimensional wave) strikes an object, the *angle of reflection* is equal to the *angle of incidence*. When a wave strikes a boundary between two materials in which it can travel, part of the wave is reflected and part is transmitted.