21-1 Waves

What is a wave? Put simply, a wave is a disturbance that carries energy from one place to another. Examples include waves on the surface of the ocean, sound waves that carry the sound of chirping birds to your ears on a spring morning, or the waves shown in Figure 21.1.

Figure 21.1: Waves caused by a drop of water hitting the water surface. Photo credit: PhotoDisc, Inc.

There are a number of ways to classify waves. One way is the following:

1. ***Mechanical waves.*** These include water waves, sound waves, and waves on strings, the kind of waves we will investigate in this chapter. Mechanical waves require a medium (such as water, air, or string) through which to travel. There is no net flow of mass through the medium, only energy.

2. ***Electromagnetic waves.*** Such waves include light, x-rays, microwaves, and radio waves. Electromagnetic waves do not need a medium through which to travel, and thus can travel through a vacuum. We will investigate electromagnetic waves in detail in Chapter 22.

3. ***Matter waves.*** These waves are associated with objects we often think of as particles, such as electrons and protons. Quantum physics, which we investigate in Chapter 27, tells us that everything, including ourselves, exhibits wave-particle duality, sometimes acting as a wave and sometimes as a particle.

For this chapter, we will confine ourselves to mechanical waves. Another way to classify waves is the following:

1. ***Transverse waves.*** In these waves, the particles of the medium oscillate in a direction transverse (perpendicular) to the direction the wave travels through the medium. A good example of this is a wave on a string, as shown in Figure 21.2. The various pieces of the string oscillate up and down, while the wave is traveling to the right.

2. ***Longitudinal waves.*** In these waves, the particles of the medium oscillate along the same direction in which the wave is traveling. A sound wave is a good example, in which air molecules oscillate back and forth along the direction the wave is traveling, as is shown in Figure 21.2. The regions of high density (corresponding to higher then average pressure) and low density (lower pressure) propagate to the right, while the air molecules themselves, on average, oscillate back and forth.

Wavelength and Period

To find the wavelength of a wave, we take a snapshot of the entire wave at one particular instant, as is shown in any of the five images of the string in Figure 21.2. The **wavelength** is the distance from, for instance, one peak to the next peak on the displacement versus position graph. Our symbol for wavelength is λ, the Greek letter lambda. The **period**, T, of the wave is the oscillation period for any particular part of the medium. If we focus on one piece of string, such as the piece colored red in Figure 21.2, and plot its displacement from equilibrium as a function of time, the period is the time between neighboring peaks on the displacement versus time graph.

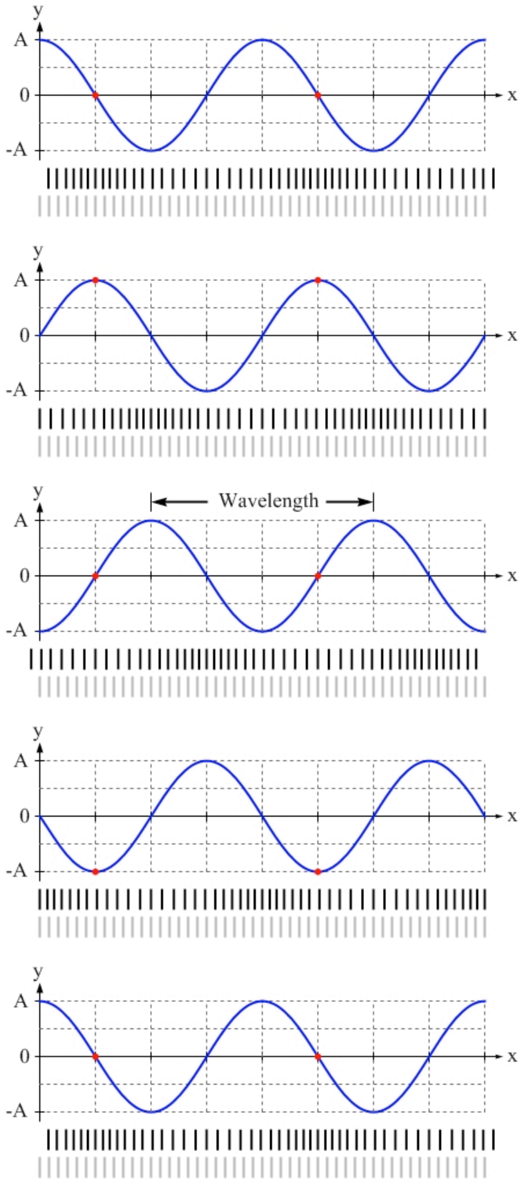

Figure 21.2: The figure shows fives pictures of a string, separated by equal time intervals. The string has a transverse traveling wave on it. Underneath each picture of the string is a representation of a longitudinal wave, such as a sound wave. The black lines represent the position of molecules of the medium as the wave passes, while the gray lines underneath represent the equilibrium position of these molecules. If time increases down the page, the waves are traveling to the right. If time increases up the page, the motion is to the left.

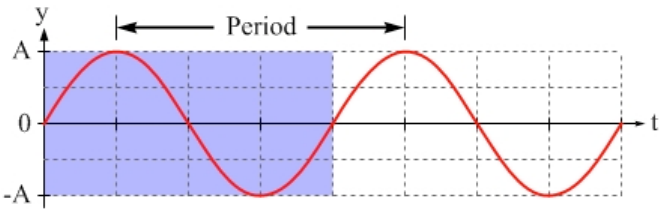

Figure 21.3: A plot of the displacement vs. time for the point on the string that is marked with a dot in Figure 21.2. The shaded region represents the time period covered by the five pictures in Figure 21.2.

Note that we are focusing on a simple kind of wave, a pure sine wave. More complex waves can be built up from sine waves of different wavelength, so our analysis can be generalized to more complicated waveforms.

The wave travels a distance of one wavelength in a time equal to one period. The wave speed is thus the distance over the time, $v = \lambda / T$. Instead of writing the equation in this form, however, we generally use the fact that the frequency, *f*, of the oscillation is the inverse of the period, $f = 1/T$. This leads to the equation in the box below.

In general, the connection between wave speed, frequency, and wavelength is:

$v = f\lambda$.   (Equation 21.1: **Connecting speed, frequency, and wavelength**)

Equation 21.1, in the form it is presented above, gives the impression that the wave speed is determined by the frequency and wavelength. A better way to write the equation is as:

$$\lambda = \frac{v}{f}, \qquad \text{(alternate form of Equation 21.1)}$$

because the wave speed is set by the properties of the medium (such as the mass and tension of a string), and the frequency of the wave is the frequency of whatever is causing a particular part of the medium to oscillate. The wavelength is then determined by the combination of speed and frequency, as is given above in the alternate form of Equation 21.1.

Related End-of-Chapter Exercise: 42.

Essential Question 21.1: Which representation above, the graph of displacement versus position or the graph of displacement versus time, would you use to find the wave speed?