c. A pulse wave is a gradual disturbance with only one or a few waves generated.
d. A pulse wave is a gradual disturbance with only one wave generated.

4. Is the following statement true or false? A pebble dropped in water is an example of a pulse wave.
   a. False
   b. True

5. What are the categories of mechanical waves based on the type of motion?
   a. Both transverse and longitudinal waves
   b. Only longitudinal waves
   c. Only transverse waves
   d. Only surface waves

6. In which direction do the particles of the medium oscillate in a transverse wave?
   a. Perpendicular to the direction of propagation of the transverse wave
   b. Parallel to the direction of propagation of the transverse wave

13.2 Wave Properties: Speed, Amplitude, Frequency, and Period

Section Learning Objectives

By the end of this section, you will be able to do the following:

- Define amplitude, frequency, period, wavelength, and velocity of a wave
- Relate wave frequency, period, wavelength, and velocity
- Solve problems involving wave properties

Section Key Terms

wavelength	wave velocity

Wave Variables

In the chapter on motion in two dimensions, we defined the following variables to describe harmonic motion:

- Amplitude—maximum displacement from the equilibrium position of an object oscillating around such equilibrium position
- Frequency—number of events per unit of time
- Period—time it takes to complete one oscillation

For waves, these variables have the same basic meaning. However, it is helpful to word the definitions in a more specific way that applies directly to waves:

- Amplitude—distance between the resting position and the maximum displacement of the wave
- Frequency—number of waves passing by a specific point per second
- Period—time it takes for one wave cycle to complete

In addition to amplitude, frequency, and period, their wavelength and wave velocity also characterize waves. The **wavelength** λ is the distance between adjacent identical parts of a wave, parallel to the direction of propagation. The **wave velocity** v_w is the speed at which the disturbance moves.

TIPS FOR SUCCESS

Wave velocity is sometimes also called the *propagation velocity* or *propagation speed* because the disturbance propagates from one location to another.

Consider the periodic water wave in Figure 13.7. Its wavelength is the distance from crest to crest or from trough to trough. The wavelength can also be thought of as the distance a wave has traveled after one complete cycle—or one period. The time for one complete up-and-down motion is the simple water wave's period T. In the figure, the wave itself moves to the right with a wave velocity v_w. Its amplitude X is the distance between the resting position and the maximum displacement—either the crest or the trough—of the wave. It is important to note that this movement of the wave is actually the *disturbance* moving to the right, not the water itself; otherwise, the bird would move to the right. Instead, the seagull bobs up and down in place as waves pass underneath, traveling a total distance of $2X$ in one cycle. However, as mentioned in the text feature on surfing, actual ocean waves are more complex than this simplified example.

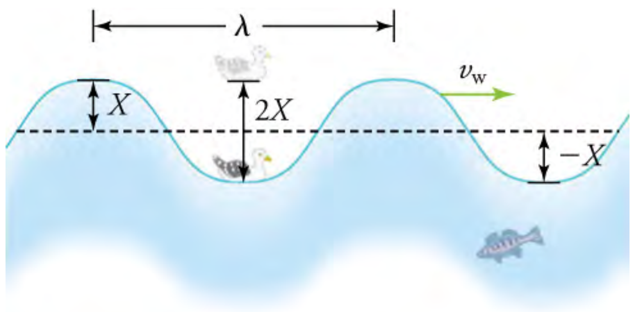

Figure 13.7 The wave has a wavelength λ, which is the distance between adjacent identical parts of the wave. The up-and-down disturbance of the surface propagates parallel to the surface at a speed v_w.

WATCH PHYSICS

Amplitude, Period, Frequency, and Wavelength of Periodic Waves

This video is a continuation of the video "Introduction to Waves" from the "Types of Waves" section. It discusses the properties of a periodic wave: amplitude, period, frequency, wavelength, and wave velocity.

Click to view content (https://www.openstax.org/l/28wavepro)

TIPS FOR SUCCESS

The crest of a wave is sometimes also called the *peak*.

GRASP CHECK

If you are on a boat in the trough of a wave on the ocean, and the wave amplitude is 1 m, what is the wave height from your position?

a. 1 m
b. 2 m
c. 4 m
d. 8 m

The Relationship between Wave Frequency, Period, Wavelength, and Velocity

Since wave frequency is the number of waves per second, and the period is essentially the number of seconds per wave, the relationship between frequency and period is

$$f = \frac{1}{T} \tag{13.1}$$

or

$$T = \frac{1}{f}, \tag{13.2}$$

just as in the case of harmonic motion of an object. We can see from this relationship that a higher frequency means a shorter period. Recall that the unit for frequency is hertz (Hz), and that 1 Hz is one cycle—or one wave—per second.

The speed of propagation v_w is the distance the wave travels in a given time, which is one wavelength in a time of one period. In equation form, it is written as

$$v_w = \frac{\lambda}{T} \tag{13.3}$$

or

$$v_w = f\lambda. \tag{13.4}$$

From this relationship, we see that in a medium where v_w is constant, the higher the frequency, the smaller the wavelength. See Figure 13.8.

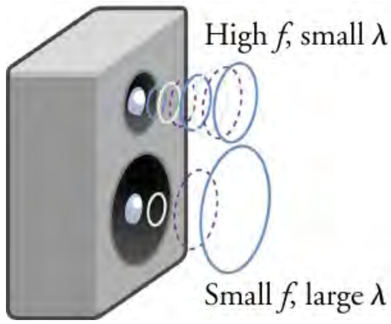

Figure 13.8 Because they travel at the same speed in a given medium, low-frequency sounds must have a greater wavelength than high-frequency sounds. Here, the lower-frequency sounds are emitted by the large speaker, called a woofer, while the higher-frequency sounds are emitted by the small speaker, called a tweeter.

These fundamental relationships hold true for all types of waves. As an example, for water waves, v_w is the speed of a surface wave; for sound, v_w is the speed of sound; and for visible light, v_w is the speed of light. The amplitude X is completely independent of the speed of propagation v_w and depends only on the amount of energy in the wave.

Snap Lab

Waves in a Bowl

In this lab, you will take measurements to determine how the amplitude and the period of waves are affected by the transfer of energy from a cork dropped into the water. The cork initially has some potential energy when it is held above the water—the greater the height, the higher the potential energy. When it is dropped, such potential energy is converted to kinetic energy as the cork falls. When the cork hits the water, that energy travels through the water in waves.

- Large bowl or basin
- Water
- Cork (or ping pong ball)
- Stopwatch
- Measuring tape

Instructions

Procedure

1. Fill a large bowl or basin with water and wait for the water to settle so there are no ripples.
2. Gently drop a cork into the middle of the bowl.
3. Estimate the wavelength and the period of oscillation of the water wave that propagates away from the cork. You can estimate the period by counting the number of ripples from the center to the edge of the bowl while your partner times it. This information, combined with the bowl measurement, will give you the wavelength when the correct formula is used.
4. Remove the cork from the bowl and wait for the water to settle again.
5. Gently drop the cork at a height that is different from the first drop.
6. Repeat Steps 3 to 5 to collect a second and third set of data, dropping the cork from different heights and recording the resulting wavelengths and periods.

7. Interpret your results.

GRASP CHECK

A cork is dropped into a pool of water creating waves. Does the wavelength depend upon the height above the water from which the cork is dropped?

a. No, only the amplitude is affected.
b. Yes, the wavelength is affected.

LINKS TO PHYSICS

Geology: Physics of Seismic Waves

Figure 13.9 The destructive effect of an earthquake is a palpable evidence of the energy carried in the earthquake waves. The Richter scale rating of earthquakes is related to both their amplitude and the energy they carry. (Petty Officer 2nd Class Candice Villarreal, U.S. Navy)

Geologists rely heavily on physics to study earthquakes since earthquakes involve several types of wave disturbances, including disturbance of Earth's surface and pressure disturbances under the surface. Surface earthquake waves are similar to surface waves on water. The waves under Earth's surface have both longitudinal and transverse components. The longitudinal waves in an earthquake are called pressure waves (P-waves) and the transverse waves are called shear waves (S-waves). These two types of waves propagate at different speeds, and the speed at which they travel depends on the rigidity of the medium through which they are traveling. During earthquakes, the speed of P-waves in granite is significantly higher than the speed of S-waves. Both components of earthquakes travel more slowly in less rigid materials, such as sediments. P-waves have speeds of 4 to 7 km/s, and S-waves have speeds of 2 to 5 km/s, but both are faster in more rigid materials. The P-wave gets progressively farther ahead of the S-wave as they travel through Earth's crust. For that reason, the time difference between the P- and S-waves is used to determine the distance to their source, the epicenter of the earthquake.

We know from seismic waves produced by earthquakes that parts of the interior of Earth are liquid. Shear or transverse waves cannot travel through a liquid and are not transmitted through Earth's core. In contrast, compression or longitudinal waves can pass through a liquid and they do go through the core.

All waves carry energy, and the energy of earthquake waves is easy to observe based on the amount of damage left behind after the ground has stopped moving. Earthquakes can shake whole cities to the ground, performing the work of thousands of wrecking balls. The amount of energy in a wave is related to its amplitude. Large-amplitude earthquakes produce large ground displacements and greater damage. As earthquake waves spread out, their amplitude decreases, so there is less damage the farther they get from the source.

GRASP CHECK

What is the relationship between the propagation speed, frequency, and wavelength of the S-waves in an earthquake?

a. The relationship between the propagation speed, frequency, and wavelength is $v_\mathrm{w} = f\lambda$.
b. The relationship between the propagation speed, frequency, and wavelength is $v_\mathrm{w} = \frac{f}{\lambda}$.
c. The relationship between the propagation speed, frequency, and wavelength is $v_\mathrm{w} = \frac{\lambda}{f}$.

d. The relationship between the propagation speed, frequency, and wavelength is $v_{\text{w}} = \sqrt{f\lambda}$.

Virtual Physics

Wave on a String

[Click to view content (http://www.openstax.org/l/28wavestring)](http://www.openstax.org/l/28wavestring)

In this animation, watch how a string vibrates in slow motion by choosing the Slow Motion setting. Select the No End and Manual options, and wiggle the end of the string to make waves yourself. Then switch to the Oscillate setting to generate waves automatically. Adjust the frequency and the amplitude of the oscillations to see what happens. Then experiment with adjusting the damping and the tension.

GRASP CHECK

Which of the settings—amplitude, frequency, damping, or tension—changes the amplitude of the wave as it propagates? What does it do to the amplitude?

a. Frequency; it decreases the amplitude of the wave as it propagates.
b. Frequency; it increases the amplitude of the wave as it propagates.
c. Damping; it decreases the amplitude of the wave as it propagates.
d. Damping; it increases the amplitude of the wave as it propagates.

Solving Wave Problems

WORKED EXAMPLE

Calculate the Velocity of Wave Propagation: Gull in the Ocean

Calculate the wave velocity of the ocean wave in the previous figure if the distance between wave crests is 10.0 m and the time for a seagull to bob up and down is 5.00 s.

STRATEGY

The values for the wavelength ($\lambda = 10.0 \ \ m$) and the period ($T = 5.00 \ \ \text{s}$) are given and we are asked to find v_w Therefore, we can use $v_w = \frac{\lambda}{T}$ to find the wave velocity.

Solution

Enter the known values into $v_w = \frac{\lambda}{T}$

$$v_w = \frac{10.0 \text{ m}}{5.00 \text{ s}} = 2.\ 00 \text{ m/s}. \tag{13.5}$$

Discussion

This slow speed seems reasonable for an ocean wave. Note that in the figure, the wave moves to the right at this speed, which is different from the varying speed at which the seagull bobs up and down.

WORKED EXAMPLE

Calculate the Period and the Wave Velocity of a Toy Spring

The woman in creates two waves every second by shaking the toy spring up and down. (a)What is the period of each wave? (b) If each wave travels 0.9 meters after one complete wave cycle, what is the velocity of wave propagation?

STRATEGY FOR (A)

To find the period, we solve for $T = \frac{1}{f}$, given the value of the frequency ($f = 2\text{s}^{-1}$).

Solution for (a)

Enter the known value into $T = \frac{1}{f}$

$$T = \frac{1}{2\ \text{s}^{-1}} = 0.5\ \text{s}. \tag{13.6}$$

STRATEGY FOR (B)

Since one definition of wavelength is the distance a wave has traveled after one complete cycle—or one period—the values for the wavelength ($\lambda = 0.9\ \ m$) as well as the frequency are given. Therefore, we can use $v_\text{w} = f\lambda$ to find the wave velocity.

Solution for (b)

Enter the known values into $v_\text{w} = f\lambda$

$v_\text{w} = f\lambda = (2\ \text{s}^{-1})(0.9\ \text{m}) = 1.8\ \text{m/s}.$

Discussion

We could have also used the equation $v_\text{w} = \frac{\lambda}{T}$ to solve for the wave velocity since we already know the value of the period ($T = 0.5\ \text{s}$) from our calculation in part (a), and we would come up with the same answer.

Practice Problems

7. The frequency of a wave is 10 Hz. What is its period?
   a. The period of the wave is 100 s.
   b. The period of the wave is 10 s.
   c. The period of the wave is 0.01 s.
   d. The period of the wave is 0.1 s.

8. What is the velocity of a wave whose wavelength is 2 m and whose frequency is 5 Hz?
   a. 20 m/s
   b. 2.5 m/s
   c. 0.4 m/s
   d. 10 m/s

Check Your Understanding

9. What is the amplitude of a wave?
   a. A quarter of the total height of the wave
   b. Half of the total height of the wave
   c. Two times the total height of the wave
   d. Four times the total height of the wave

10. What is meant by the wavelength of a wave?
    a. The wavelength is the distance between adjacent identical parts of a wave, parallel to the direction of propagation.
    b. The wavelength is the distance between adjacent identical parts of a wave, perpendicular to the direction of propagation.
    c. The wavelength is the distance between a crest and the adjacent trough of a wave, parallel to the direction of propagation.
    d. The wavelength is the distance between a crest and the adjacent trough of a wave, perpendicular to the direction of propagation.

11. How can you mathematically express wave frequency in terms of wave period?
    a. $f = \frac{1}{T}$
    b. $f = \left(\frac{1}{T}\right)^2$
    c. $\text{f} = \text{T}$
    d. $f = (T)^2$

12. When is the wavelength directly proportional to the period of a wave?

a. When the velocity of the wave is halved
b. When the velocity of the wave is constant
c. When the velocity of the wave is doubled
d. When the velocity of the wave is tripled

13.3 Wave Interaction: Superposition and Interference

Section Learning Objectives

By the end of this section, you will be able to do the following:

- Describe superposition of waves
- Describe interference of waves and distinguish between constructive and destructive interference of waves
- Describe the characteristics of standing waves
- Distinguish reflection from refraction of waves

Section Key Terms

antinode	constructive interference	destructive interference	inversion	nodes
reflection	refraction	standing wave	superposition	

Superposition of Waves

Most waves do not look very simple. They look more like the waves in Figure 13.10, rather than the simple water wave considered in the previous sections, which has a perfect sinusoidal shape.

Figure 13.10 These waves result from the superposition of several waves from different sources, producing a complex pattern. (Waterborough, Wikimedia Commons)

Most waves appear complex because they result from two or more simple waves that combine as they come together at the same place at the same time—a phenomenon called **superposition**.

Waves superimpose by adding their disturbances; each disturbance corresponds to a force, and all the forces add. If the disturbances are along the same line, then the resulting wave is a simple addition of the disturbances of the individual waves, that is, their amplitudes add.

Wave Interference

The two special cases of superposition that produce the simplest results are pure constructive interference and pure destructive interference.

Pure **constructive interference** occurs when two identical waves arrive at the same point exactly in phase. When waves are exactly in phase, the crests of the two waves are precisely aligned, as are the troughs. Refer to Figure 13.11. Because the disturbances add, the pure constructive interference of two waves with the same amplitude produces a wave that has twice the amplitude of the two individual waves, but has the same wavelength.