CHAPTER 13 Waves and Their Properties



Figure 13.1 Waves in the ocean behave similarly to all other types of waves. (Steve Jurveston, Flickr)

Chapter Outline

13.1 Types of Waves

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

13.3 Wave Interaction: Superposition and Interference

INTRODUCTION Recall from the chapter on Motion in Two Dimensions that oscillations—the back-and-forth movement between two points—involve force and energy. Some oscillations create waves, such as the sound waves created by plucking a guitar string. Other examples of waves include earthquakes and visible light. Even subatomic particles, such as electrons, can behave like waves. You can make water waves in a swimming pool by slapping the water with your hand. Some of these waves, such as water waves, are visible; others, such as sound waves, are not. But every wave is a disturbance that moves from its source and carries energy. In this chapter, we will learn about the different types of waves, their properties, and how they interact with one another.

13.1 Types of Waves

Section Learning Objectives

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

- Define mechanical waves and medium, and relate the two
- Distinguish a pulse wave from a periodic wave
- Distinguish a longitudinal wave from a transverse wave and give examples of such waves

Section Key Terms

longitudinal wave mechanical wave medium wave periodic wave pulse wave transverse wave

Mechanical Waves

What do we mean when we say something is a wave? A **wave** is a disturbance that travels or *propagates* from the place where it was created. Waves transfer energy from one place to another, but they do not necessarily transfer any mass. Light, sound, and waves in the ocean are common examples of waves. Sound and water waves are **mechanical waves**; meaning, they require a medium to travel through. The **medium** may be a solid, a liquid, or a gas, and the speed of the wave depends on the material properties of the medium through which it is traveling. However, light is not a mechanical wave; it can travel through a vacuum such as the empty parts of outer space.

A familiar wave that you can easily imagine is the water wave. For water waves, the disturbance is in the surface of the water, an example of which is the disturbance created by a rock thrown into a pond or by a swimmer splashing the water surface repeatedly. For sound waves, the disturbance is caused by a change in air pressure, an example of which is when the oscillating cone inside a speaker creates a disturbance. For earthquakes, there are several types of disturbances, which include the disturbance of Earth's surface itself and the pressure disturbances under the surface. Even radio waves are most easily understood using an analogy with water waves. Because water waves are common and visible, visualizing water waves may help you in studying other types of waves, especially those that are not visible.

Water waves have characteristics common to all waves, such as amplitude, period, frequency, and energy, which we will discuss in the next section.

Pulse Waves and Periodic Waves

If you drop a pebble into the water, only a few waves may be generated before the disturbance dies down, whereas in a wave pool, the waves are continuous. A **pulse wave** is a sudden disturbance in which only one wave or a few waves are generated, such as in the example of the pebble. Thunder and explosions also create pulse waves. A **periodic wave** repeats the same oscillation for several cycles, such as in the case of the wave pool, and is associated with simple harmonic motion. Each particle in the medium experiences simple harmonic motion in periodic waves by moving back and forth periodically through the same positions.

Consider the simplified water wave in Figure 13.2. This wave is an up-and-down disturbance of the water surface, characterized by a sine wave pattern. The uppermost position is called the *crest* and the lowest is the *trough*. It causes a seagull to move up and down in simple harmonic motion as the wave crests and troughs pass under the bird.



Figure 13.2 An idealized ocean wave passes under a seagull that bobs up and down in simple harmonic motion.

Longitudinal Waves and Transverse Waves

Mechanical waves are categorized by their type of motion and fall into any of two categories: transverse or longitudinal. Note that both transverse and longitudinal waves can be periodic. A **transverse wave** propagates so that the disturbance is perpendicular to the direction of propagation. An example of a transverse wave is shown in <u>Figure 13.3</u>, where a woman moves a toy spring up and down, generating waves that propagate away from herself in the horizontal direction while disturbing the toy spring in the vertical direction.



Figure 13.3 In this example of a transverse wave, the wave propagates horizontally and the disturbance in the toy spring is in the vertical direction.

In contrast, in a **longitudinal wave**, the disturbance is parallel to the direction of propagation. <u>Figure 13.4</u> shows an example of a longitudinal wave, where the woman now creates a disturbance in the horizontal direction—which is the same direction as the wave propagation—by stretching and then compressing the toy spring.



Figure 13.4 In this example of a longitudinal wave, the wave propagates horizontally and the disturbance in the toy spring is also in the horizontal direction.

TIPS FOR SUCCESS

Longitudinal waves are sometimes called *compression waves* or *compressional waves*, and transverse waves are sometimes called *shear waves*.

Waves may be transverse, longitudinal, or *a combination of the two*. The waves on the strings of musical instruments are transverse (as shown in Figure 13.5), and so are electromagnetic waves, such as visible light. Sound waves in air and water are longitudinal. Their disturbances are periodic variations in pressure that are transmitted in fluids.



Figure 13.5 The wave on a guitar string is transverse. However, the sound wave coming out of a speaker rattles a sheet of paper in a direction that shows that such sound wave is longitudinal.

Sound in solids can be both longitudinal and transverse. Essentially, water waves are also a combination of transverse and longitudinal components, although the simplified water wave illustrated in <u>Figure 13.2</u> does not show the longitudinal motion of the bird.

Earthquake waves under Earth's surface have both longitudinal and transverse components as well. The longitudinal waves in an earthquake are called pressure or P-waves, and the transverse waves are called shear or S-waves. These components have important individual characteristics; for example, they propagate at different speeds. Earthquakes also have surface waves that are similar to surface waves on water.

💿 WATCH PHYSICS

Introduction to Waves

This video explains wave propagation in terms of momentum using an example of a wave moving along a rope. It also covers the differences between transverse and longitudinal waves, and between pulse and periodic waves.

Click to view content (https://openstax.org/l/02introtowaves)

GRASP CHECK

In a longitudinal sound wave, after a compression wave moves through a region, the density of molecules briefly decreases. Why is this?

- a. After a compression wave, some molecules move forward temporarily.
- b. After a compression wave, some molecules move backward temporarily.
- c. After a compression wave, some molecules move upward temporarily.
- d. After a compression wave, some molecules move downward temporarily.



The Physics of Surfing

Many people enjoy surfing in the ocean. For some surfers, the bigger the wave, the better. In one area off the coast of central California, waves can reach heights of up to 50 feet in certain times of the year (Figure 13.6).



Figure 13.6 A surfer negotiates a steep take-off on a winter day in California while his friend watches. (Ljsurf, Wikimedia Commons)

How do waves reach such extreme heights? Other than unusual causes, such as when earthquakes produce tsunami waves, most huge waves are caused simply by interactions between the wind and the surface of the water. The wind pushes up against the surface of the water and transfers energy to the water in the process. The stronger the wind, the more energy transferred. As waves start to form, a larger surface area becomes in contact with the wind, and even more energy is transferred from the wind to the water, thus creating higher waves. Intense storms create the fastest winds, kicking up massive waves that travel out from the origin of the storm. Longer-lasting storms and those storms that affect a larger area of the ocean create the biggest waves since they transfer more energy. The cycle of the tides from the Moon's gravitational pull also plays a small role in creating waves.

Actual ocean waves are more complicated than the idealized model of the simple transverse wave with a perfect sinusoidal shape. Ocean waves are examples of *orbital progressive waves*, where water particles at the surface follow a circular path from the crest to the trough of the passing wave, then cycle back again to their original position. This cycle repeats with each passing wave.

As waves reach shore, the water depth decreases and the energy of the wave is compressed into a smaller volume. This creates higher waves—an effect known as *shoaling*.

Since the water particles along the surface move from the crest to the trough, surfers hitch a ride on the cascading water, gliding along the surface. If ocean waves work exactly like the idealized transverse waves, surfing would be much less exciting as it would simply involve standing on a board that bobs up and down in place, just like the seagull in the previous figure.

Additional information and illustrations about the scientific principles behind surfing can be found in the <u>"Using Science to Surf</u> <u>Better!" (http://www.openstax.org/l/28Surf)</u> video.

GRASP CHECK

If we lived in a parallel universe where ocean waves were longitudinal, what would a surfer's motion look like?

- a. The surfer would move side-to-side/back-and-forth vertically with no horizontal motion.
- b. The surfer would forward and backward horizontally with no vertical motion.

Check Your Understanding

- 1. What is a wave?
 - a. A wave is a force that propagates from the place where it was created.
 - b. A wave is a disturbance that propagates from the place where it was created.
 - c. A wave is matter that provides volume to an object.
 - d. A wave is matter that provides mass to an object.
- 2. Do all waves require a medium to travel? Explain.
 - a. No, electromagnetic waves do not require any medium to propagate.
 - b. No, mechanical waves do not require any medium to propagate.
 - c. Yes, both mechanical and electromagnetic waves require a medium to propagate.
 - d. Yes, all transverse waves require a medium to travel.
- 3. What is a pulse wave?
 - a. A pulse wave is a sudden disturbance with only one wave generated.
 - b. A pulse wave is a sudden disturbance with only one or a few waves generated.

- 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

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

or

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

13.1

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

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

or

$$v_w = f\lambda.$$
 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 highfrequency 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.

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 $v_w = f\lambda$.
- b. The relationship between the propagation speed, frequency, and wavelength is $v_{\rm w} = \frac{f}{4}$.
- c. The relationship between the propagation speed, frequency, and wavelength is $v_w = \frac{\lambda}{f}$.

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

Virtual Physics

Wave on a String

Click to view content (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 ($T = 5.00 \ s$) 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 $v_w = \frac{\lambda}{T}$

$$v_w = \frac{10.0 \text{ m}}{5.00 \text{ s}} = 2.00 \text{ m/s}.$$

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 ($f = 2s^{-1}$).

Solution for (a)

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

$$T = \frac{1}{2 \, \mathrm{s}^{-1}} = 0.5 \, \mathrm{s}.$$

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 $v_w = f\lambda$ to find the wave velocity.

Solution for (b)

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

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

Discussion

We could have also used the equation $v_w = \frac{\lambda}{T}$ to solve for the wave velocity since we already know the value of the period (T = 0.5 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. f = Td. $f = (T)^2$
- 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 <u>Figure 13.10</u>, 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.



Figure 13.11 The pure constructive interference of two identical waves produces a wave with twice the amplitude but the same wavelength.

<u>Figure 13.12</u> shows two identical waves that arrive exactly *out* of phase—that is, precisely aligned crest to trough—producing pure **destructive interference**. Because the disturbances are in opposite directions for this superposition, the resulting amplitude is zero for pure destructive interference; that is, the waves completely cancel out each other.



Figure 13.12 The pure destructive interference of two identical waves produces zero amplitude, or complete cancellation.

While pure constructive interference and pure destructive interference can occur, they are not very common because they require precisely aligned identical waves. The superposition of most waves that we see in nature produces a combination of constructive and destructive interferences.

Waves that are not results of pure constructive or destructive interference can vary from place to place and time to time. The sound from a stereo, for example, can be loud in one spot and soft in another. The varying loudness means that the sound waves add partially constructively and partially destructively at different locations. A stereo has at least two speakers that create sound waves, and waves can reflect from walls. All these waves superimpose.

An example of sounds that vary over time from constructive to destructive is found in the combined whine of jet engines heard by a stationary passenger. The volume of the combined sound can fluctuate up and down as the sound from the two engines varies in time from constructive to destructive.

The two previous examples considered waves that are similar—both stereo speakers generate sound waves with the same amplitude and wavelength, as do the jet engines. But what happens when two waves that are not similar, that is, having different amplitudes and wavelengths, are superimposed? An example of the superposition of two dissimilar waves is shown in Figure 13.13. Here again, the disturbances add and subtract, but they produce an even more complicated-looking wave. The resultant wave from the combined disturbances of two dissimilar waves looks much different than the idealized sinusoidal shape of a periodic wave.



Figure 13.13 The superposition of nonidentical waves exhibits both constructive and destructive interferences.

Virtual Physics

Wave Interference

Click to view content (http://www.openstax.org/l/28interference)

In this simulation, make waves with a dripping faucet, an audio speaker, or a laser by switching between the water, sound, and light tabs. Contrast and compare how the different types of waves behave. Try rotating the view from top to side to make observations. Then experiment with adding a second source or a pair of slits to create an interference pattern.

GRASP CHECK

In the water tab, compare the waves generated by one drip versus two drips. What happens to the amplitude of the waves when there are two drips? Is this constructive or destructive interference? Why would this be the case?

- a. The amplitude of the water waves remains same because of the destructive interference as the drips of water hit the surface at the same time.
- b. The amplitude of the water waves is canceled because of the destructive interference as the drips of water hit the surface at the same time.
- c. The amplitude of water waves remains same because of the constructive interference as the drips of water hit the surface at the same time.
- d. The amplitude of water waves doubles because of the constructive interference as the drips of water hit the surface at the same time.

Standing Waves

Sometimes waves do not seem to move and they appear to just stand in place, vibrating. Such waves are called **standing waves** and are formed by the superposition of two or more waves moving in opposite directions. The waves move through each other with their disturbances adding as they go by. If the two waves have the same amplitude and wavelength, then they alternate between constructive and destructive interference. Standing waves created by the superposition of two identical waves moving in opposite directions are illustrated in Figure 13.14.



Figure 13.14 A standing wave is created by the superposition of two identical waves moving in opposite directions. The oscillations are at fixed locations in space and result from alternating constructive and destructive interferences.

As an example, standing waves can be seen on the surface of a glass of milk in a refrigerator. The vibrations from the refrigerator motor create waves on the milk that oscillate up and down but do not seem to move across the surface. The two waves that

produce standing waves may be due to the reflections from the side of the glass.

Earthquakes can create standing waves and cause constructive and destructive interferences. As the earthquake waves travel along the surface of Earth and reflect off denser rocks, constructive interference occurs at certain points. As a result, areas closer to the epicenter are not damaged while areas farther from the epicenter are damaged.

Standing waves are also found on the strings of musical instruments and are due to reflections of waves from the ends of the string. <u>Figure 13.15</u> and <u>Figure 13.16</u> show three standing waves that can be created on a string that is fixed at both ends. When the wave reaches the fixed end, it has nowhere else to go but back where it came from, causing the reflection. The **nodes** are the points where the string does not move; more generally, the nodes are the points where the wave disturbance is zero in a standing wave. The fixed ends of strings must be nodes, too, because the string cannot move there.

The **antinode** is the location of maximum amplitude in standing waves. The standing waves on a string have a frequency that is related to the propagation speed v_w of the disturbance on the string. The wavelength λ is determined by the distance between the points where the string is fixed in place.



Figure 13.15 The figure shows a string oscillating with its maximum disturbance as the antinode.



Figure 13.16 The figure shows a string oscillating with multiple nodes.

Reflection and Refraction of Waves

As we saw in the case of standing waves on the strings of a musical instrument, **reflection** is the change in direction of a wave when it bounces off a barrier, such as a fixed end. When the wave hits the fixed end, it changes direction, returning to its source. As it is reflected, the wave experiences an **inversion**, which means that it flips vertically. If a wave hits the fixed end with a crest, it will return as a trough, and vice versa (Henderson 2015). Refer to Figure 13.17.



Figure 13.17 A wave is inverted after reflection from a fixed end.

TIPS FOR SUCCESS

If the end is not fixed, it is said to be a *free end*, and no inversion occurs. When the end is loosely attached, it reflects without

inversion, and when the end is not attached to anything, it does not reflect at all. You may have noticed this while changing the settings from Fixed End to Loose End to No End in the Waves on a String PhET simulation.

Rather than encountering a fixed end or barrier, waves sometimes pass from one medium into another, for instance, from air into water. Different types of media have different properties, such as density or depth, that affect how a wave travels through them. At the boundary between media, waves experience **refraction**—they change their path of propagation. As the wave bends, it also changes its speed and wavelength upon entering the new medium. Refer to <u>Figure 13.18</u>.



Figure 13.18 A wave refracts as it enters a different medium.

For example, water waves traveling from the deep end to the shallow end of a swimming pool experience refraction. They bend in a path closer to perpendicular to the surface of the water, propagate slower, and decrease in wavelength as they enter shallower water.

Check Your Understanding

- **13**. What is the superposition of waves?
 - a. When a single wave splits into two different waves at a point
 - b. When two waves combine at the same place at the same time
- 14. How do waves superimpose on one another?
 - a. By adding their frequencies
 - b. By adding their wavelengths
 - c. By adding their disturbances
 - d. By adding their speeds
- 15. What is interference of waves?
 - a. Interference is a superposition of two waves to form a resultant wave with higher or lower frequency.
 - b. Interference is a superposition of two waves to form a wave of larger or smaller amplitude.
 - c. Interference is a superposition of two waves to form a resultant wave with higher or lower velocity.
 - d. Interference is a superposition of two waves to form a resultant wave with longer or shorter wavelength.
- 16. Is the following statement true or false? The two types of interference are constructive and destructive interferences.
 - a. True
 - b. False
- 17. What are standing waves?
 - a. Waves that appear to remain in one place and do not seem to move
 - b. Waves that seem to move along a trajectory
- 18. How are standing waves formed?
 - a. Standing waves are formed by the superposition of two or more waves moving in opposite directions.
 - b. Standing waves are formed by the superposition of two or more waves moving in the same direction.
 - c. Standing waves are formed by the superposition of two or more waves moving in perpendicular directions.
 - d. Standing waves are formed by the superposition of two or more waves moving in any arbitrary directions.
- 19. What is the reflection of a wave?
 - a. The reflection of a wave is the change in amplitude of a wave when it bounces off a barrier.
 - b. The reflection of a wave is the change in frequency of a wave when it bounces off a barrier.
 - c. The reflection of a wave is the change in velocity of a wave when it bounces off a barrier.
 - d. The reflection of a wave is the change in direction of a wave when it bounces off a barrier.

20. What is inversion of a wave?

- a. Inversion occurs when a wave reflects off a fixed end, and the wave amplitude changes sign.
- b. Inversion occurs when a wave reflects off a loose end, and the wave amplitude changes sign.
- c. Inversion occurs when a wave reflects off a fixed end without the wave amplitude changing sign.
- d. Inversion occurs when a wave reflects off a loose end without the wave amplitude changing sign.

KEY TERMS

- **antinode** location of maximum amplitude in standing waves
- **constructive interference** when two waves arrive at the same point exactly in phase; that is, the crests of the two waves are precisely aligned, as are the troughs
- **destructive interference** when two identical waves arrive at the same point exactly out of phase that is precisely aligned crest to trough
- **inversion** vertical flipping of a wave after reflection from a fixed end
- **longitudinal wave** wave in which the disturbance is parallel to the direction of propagation
- **mechanical wave** wave that requires a medium through which it can travel
- **medium** solid, liquid, or gas material through which a wave propagates
- **nodes** points where the string does not move; more generally, points where the wave disturbance is zero in a standing wave
- **periodic wave** wave that repeats the same oscillation for several cycles and is associated with simple harmonic

SECTION SUMMARY 13.1 Types of Waves

- A wave is a disturbance that moves from the point of creation and carries energy but not mass.
- Mechanical waves must travel through a medium.
- Sound waves, water waves, and earthquake waves are all examples of mechanical waves.
- Light is not a mechanical wave since it can travel through a vacuum.
- A periodic wave is a wave that repeats for several cycles, whereas a pulse wave has only one crest or a few crests and is associated with a sudden disturbance.
- Periodic waves are associated with simple harmonic motion.
- A transverse wave has a disturbance perpendicular to its direction of propagation, whereas a longitudinal wave has a disturbance parallel to its direction of propagation.

<u>13.2 Wave Properties: Speed,</u> <u>Amplitude, Frequency, and Period</u>

- A wave is a disturbance that moves from the point of creation at a wave velocity *v*_w.
- A wave has a wavelength λ, which is the distance between adjacent identical parts of the wave.
- The wave velocity and the wavelength are related to the wave's frequency and period by $v_w = \frac{\lambda}{T}$ or $v_w = f\lambda$.

motion

- **pulse wave** sudden disturbance with only one wave or a few waves generated
- **reflection** change in direction of a wave at a boundary or fixed end
- **refraction** bending of a wave as it passes from one medium to another medium with a different density

standing wave wave made by the superposition of two waves of the same amplitude and wavelength moving in opposite directions and which appears to vibrate in place

superposition phenomenon that occurs when two or more
waves arrive at the same point

transverse wave wave in which the disturbance is perpendicular to the direction of propagation

wave disturbance that moves from its source and carries energy

wave velocity speed at which the disturbance moves; also called the propagation velocity or propagation speed

- **wavelength** distance between adjacent identical parts of a wave
 - The time for one complete wave cycle is the period *T*.
 - The number of waves per unit time is the frequency f.
 - The wave frequency and the period are inversely related to one another.

<u>13.3 Wave Interaction:</u> <u>Superposition and Interference</u>

- Superposition is the combination of two waves at the same location.
- Constructive interference occurs when two identical waves are superimposed exactly in phase.
- Destructive interference occurs when two identical waves are superimposed exactly out of phase.
- A standing wave is a wave produced by the superposition of two waves. It varies in amplitude but does not propagate.
- The nodes are the points where there is no motion in standing waves.
- An antinode is the location of maximum amplitude of a standing wave.
- Reflection causes a wave to change direction.
- Inversion occurs when a wave reflects from a fixed end.
- Refraction causes a wave's path to bend and occurs when a wave passes from one medium into another medium with a different density.

KEY EQUATIONS

<u>13.2 Wave Properties: Speed,</u> <u>Amplitude, Frequency, and Period</u>

wave velocity $v_{\rm w} = \frac{\lambda}{T}$ or $v_{\rm w} = f\lambda$

CHAPTER REVIEW Concept Items

13.1 Types of Waves

- 1. Do water waves push water from one place to another? Explain.
 - a. No, water waves transfer only energy from one place to another.
 - b. Yes, water waves transfer water from one place to another.
- 2. With reference to waves, what is a trough?
 - a. the lowermost position of a wave
 - b. the uppermost position of a wave
 - c. the final position of a wave
 - d. the initial position of the wave
- 3. Give an example of longitudinal waves.
 - a. light waves
 - b. water waves in a lake
 - c. sound waves in air
 - d. seismic waves in Earth's surface
- 4. What does the speed of a mechanical wave depend on?
 - a. the properties of the material through which it travels
 - b. the shape of the material through which it travels
 - c. the size of the material through which it travels
 - d. the color of the material through which it travels

<u>13.2 Wave Properties: Speed, Amplitude,</u> <u>Frequency, and Period</u>

- **5**. Which characteristic of a transverse wave is measured along the direction of propagation?
 - a. The amplitude of a transverse wave is measured along the direction of propagation.
 - b. The amplitude and the wavelength of a transverse wave are measured along the direction of propagation.
 - c. The wavelength of a transverse wave is measured along the direction of propagation.
 - d. The displacement of the particles of the medium in a transverse wave is measured along the direction of propagation.
- 6. Which kind of seismic waves cannot travel through

liquid?

period

- a. compressional waves
- b. P-waves
- c. longitudinal waves
- d. S-waves
- 7. What is the period of a wave?
 - a. the time that a wave takes to complete a half cycle
 - b. the time that a wave takes to complete one cycle
 - c. the time that a wave takes to complete two cycles
 - d. the time that a wave takes to complete four cycles
- 8. When the period of a wave increases, what happens to its frequency?
 - a. Its frequency decreases.
 - b. Its frequency increases.
 - c. Its frequency remains the same.

13.3 Wave Interaction: Superposition and Interference

- **9**. Is this statement true or false? The amplitudes of waves add up only if they are propagating in the same line.
 - a. True
 - b. False
- **10.** Why is sound from a stereo louder in one part of the room and softer in another?
 - a. Sound is louder in parts of the room where the density is greatest. Sound is softer in parts of the room where density is smallest.
 - b. Sound is louder in parts of the room where the density is smallest. Sound is softer in parts of the room where density is greatest.
 - c. Sound is louder in parts of the room where constructive interference occurs and softer in parts where destructive interference occurs.
 - d. Sound is louder in parts of the room where destructive interference occurs and softer in parts where constructive interference occurs.
- **11**. In standing waves on a string, what does the frequency depend on?
 - a. The frequency depends on the propagation speed and the density of the string.

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

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J
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frequency f = \frac{1}{T}
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- b. The frequency depends on the propagation speed and the length of the string.
- c. The frequency depends on the density and the length of the string.
- d. The frequency depends on the propagation speed, the density, and the length of the string.
- **12**. Is the following statement true or false? Refraction is useful in fiber optic cables for transmitting signals.
 - a. False
 - b. True
- 13. What is refraction?

Critical Thinking Items

13.1 Types of Waves

- **14**. Give an example of a wave that propagates only through a solid.
 - a. Light wave
 - b. Sound wave
 - c. Seismic wave
 - d. Surface wave
- 15. Can mechanical waves be periodic waves?
 - a. No, mechanical waves cannot be periodic waves.
 - b. Yes, mechanical waves can be periodic.
- **16**. In a sound wave, which parameter of the medium varies with every cycle?
 - a. The density of the medium varies with every cycle.
 - b. The mass of the medium varies with every cycle.
 - c. The resistivity of the medium varies with every cycle.
 - d. The volume of the medium varies with every cycle.
- 17. What is a transverse wave in an earthquake called?
 - a. L-wave
 - b. P-wave
 - c. S-wave
 - d. R-wave

<u>13.2 Wave Properties: Speed, Amplitude,</u> <u>Frequency, and Period</u>

- 18. If the horizontal distance, that is, the distance in the direction of propagation, between a crest and the adjacent trough of a sine wave is 1 m, what is the wavelength of the wave?
 - a. 0.5 m
 - b. 1 m
 - c. 2 m
 - d. 4 m
- **19**. How is the distance to the epicenter of an earthquake determined?

- a. Refraction is the phenomenon in which waves change their path of propagation at the interface of two media with different densities.
- b. Refraction is the phenomenon in which waves change their path of propagation at the interface of two media with the same density.
- c. Refraction is the phenomenon in which waves become non-periodic at the boundary of two media with different densities.
- d. Refraction is the phenomenon in which waves become non-periodic at the boundary of two media with the same density.
- a. The wavelength difference between P-waves and Swaves is used to measure the distance to the epicenter.
- b. The time difference between P-waves and S-waves is used to measure the distance to the epicenter.
- c. The frequency difference between P-waves and Swaves is used to measure the distance to the epicenter.
- d. The phase difference between P-waves and S-waves is used to measure the distance to the epicenter.
- **20**. Two identical waves superimpose in pure constructive interference. What is the height of the resultant wave if the amplitude of each of the waves is 1 m?
 - a. 1 m
 - b. 2 m
 - c. 3 m
 - d. 4 m

<u>13.3 Wave Interaction: Superposition and Interference</u>

- 21. Two identical waves with an amplitude X superimpose in a way that pure constructive interference occurs. What is the amplitude of the resultant wave?
 - a. $\frac{X}{2}$
 - b. *X*
 - c. 2X
 - d. X^2
- **22**. In which kind of wave is the amplitude at each point constant?
 - a. Seismic waves
 - b. Pulse wave
 - c. Standing waves
 - d. Electromagnetic waves
- 23. Which property of a medium causes refraction?
 - a. Conductivity
 - b. Opacity
 - c. Ductility

- d. Density
- 24. What is added together when two waves superimpose?a. Amplitudes

Problems

<u>13.2 Wave Properties: Speed, Amplitude,</u> <u>Frequency, and Period</u>

- **25**. If a seagull sitting in water bobs up and down once every 2 seconds and the distance between two crests of the water wave is 3 m, what is the velocity of the wave?
 - a. 1.5 m/s
 - b. 3 m/s
 - c. 6 m/s

Performance Task

<u>13.3 Wave Interaction: Superposition and</u> Interference

27. Ocean waves repeatedly crash against beaches and coasts. Their energy can lead to erosion and collapse of land. Scientists and engineers need to study how waves interact with beaches in order to assess threats to coastal communities and construct breakwater systems. In this task, you will construct a wave tank and fill it with water. Simulate a beach by placing sand at one end. Create waves by moving a piece of wood or plastic up and down in the water. Measure or estimate the

TEST PREP Multiple Choice

Multiple choice

13.1 Types of Waves

- 28. What kind of waves are sound waves?
 - a. Mechanical waves
 - b. Electromagnetic waves
- 29. What kind of a wave does a tuning fork create?
 - a. Pulse wave
 - b. Periodic wave
 - c. Electromagnetic wave
- 30. What kind of waves are electromagnetic waves?
 - a. Longitudinal waves
 - b. Transverse waves
 - c. Mechanical waves
 - d. P-waves
- 31. With reference to waves, what is a *disturbance*?
 - a. It refers to the resistance produced by some particles of a material.
 - b. It refers to an oscillation produced by some energy

- b. Wavelengths
- c. Velocities
- d. 12 m/s
- **26**. A boat in the trough of a wave takes 3 seconds to reach the highest point of the wave. The velocity of the wave is 5 m/s. What is its wavelength?
 - a. 0.83 m
 - b. 15 m
 - c. 30 m
 - d. 180 m

wavelength, period, frequency, and amplitude of the wave, and observe the effect of the wave on the sand. Produce waves of different amplitudes and frequencies, and record your observations each time. Use mathematical representations to demonstrate the relationships between different wave properties. Change the position of the sand to create a steeper beach and record your observations. Give a qualitative analysis of the effects of the waves on the beach. What kind of wave causes the most damage? At what height, wavelength, and frequency do waves *break*? How does the steepness of the beach affect the waves?

that creates a wave.

- c. It refers to the wavelength of the wave.
- d. It refers to the speed of the wave.

<u>13.2 Wave Properties: Speed, Amplitude,</u> <u>Frequency, and Period</u>

- 32. Which of these is not a characteristic of a wave?
 - a. amplitude
 - b. period
 - c. mass
 - d. velocity
- **33.** If you are in a boat at a resting position, how much will your height change when you are hit by the peak of a wave with a height of 2 m?
 - a. om
 - b. 1 m
 - c. 2 m
 - d. 4 m
- 34. What is the period of a wave with a frequency of 0.5 Hz?

- a. 0.5 s
- b. 1s
- c. 2 s
- d. 3 s
- **35**. What is the relation between the amplitude of a wave and its speed?
 - a. The amplitude of a wave is independent of its speed.
 - b. The amplitude of a wave is directly proportional to its speed.
 - c. The amplitude of a wave is directly proportional to the square of the inverse of its speed.
 - d. The amplitude of a wave is directly proportional to the inverse of its speed.
- 36. What does the speed of seismic waves depend on?
 - a. The speed of seismic waves depends on the size of the medium.
 - b. The speed of seismic waves depends on the shape of the medium.
 - c. The speed of seismic waves depends on the rigidity of the medium.

13.3 Wave Interaction: Superposition and Interference

- 37. What is added together when two waves superimpose?
 - a. amplitudes
 - b. wavelengths
 - c. velocities
- **38**. Pure constructive interference occurs between two waves when they have the same _____.

Short Answer

13.1 Types of Waves

- **43**. Give an example of a non-mechanical wave.
 - a. A radio wave is an example of a nonmechanical wave.
 - b. A sound wave is an example of a nonmechanical wave.
 - c. A surface wave is an example of a nonmechanical wave.
 - d. A seismic wave is an example of a nonmechanical wave.
- 44. How is sound produced by an electronic speaker?
 - a. The cone of a speaker vibrates to create small changes in the temperature of the air.
 - b. The cone of a speaker vibrates to create small changes in the pressure of the air.
 - c. The cone of a speaker vibrates to create small changes in the volume of the air.

- a. frequency and are in phase
- b. frequency and are out of phase
- c. amplitude and are in phase
- d. amplitude and are out of phase
- **39.** What kind(s) of interference can occur between two identical waves moving in opposite directions?
 - a. Constructive interference only
 - b. Destructive interference only
 - c. Both constructive and destructive interference
 - d. Neither constructive nor destructive interference
- **40**. What term refers to the bending of light at the junction of two media?
 - a. interference
 - b. diffraction
 - c. scattering
 - d. refraction
- **41**. Which parameter of a wave gets affected after superposition?
 - a. wavelength
 - b. direction
 - c. amplitude
 - d. frequency
- 42. When do the amplitudes of two waves get added?
 - a. When their amplitudes are the same
 - b. When their amplitudes are different
 - c. When they propagate in perpendicular directions
 - d. When they are propagating along the same line in opposite directions
 - d. The cone of a speaker vibrates to create small changes in the resistance of the air.
- 45. What kind of wave is thunder?
 - a. Transverse wave
 - b. Pulse wave
 - c. R-wave
 - d. P-wave
- 46. Are all ocean waves perfectly sinusoidal?
 - a. No, all ocean waves are not perfectly sinusoidal.
 - b. Yes, all ocean waves are perfectly sinusoidal.
- 47. What are orbital progressive waves?
 - a. Waves that force the particles of the medium to follow a linear path from the crest to the trough
 - b. Waves that force the particles of the medium to follow a circular path from the crest to the trough
 - c. Waves that force the particles of the medium to follow a zigzag path from the crest to the trough
 - d. Waves that force the particles of the medium to

follow a random path from the crest to the trough

- **48**. Give an example of orbital progressive waves.
 - a. light waves
 - b. ocean waves
 - c. sound waves
 - d. seismic waves

<u>13.2 Wave Properties: Speed, Amplitude,</u> <u>Frequency, and Period</u>

- **49.** What is the relation between the amplitude and height of a transverse wave?
 - a. The height of a wave is half of its amplitude.
 - b. The height of a wave is equal to its amplitude.
 - c. The height of a wave is twice its amplitude.
 - d. The height of a wave is four times its amplitude.
- 50. If the amplitude of a water wave is 0.2 m and its frequency is 2 Hz, how much distance would a bird sitting on the water's surface move with every wave? How many times will it do this every second?
 - a. The bird will go up and down a distance of 0.4 m. It will do this twice per second.
 - b. The bird will go up and down a distance of 0.2 m. It will do this twice per second.
 - c. The bird will go up and down a distance of 0.4 m. It will do this once per second.
 - d. The bird will go up and down a distance of 0.2 m. It will do this once per second.
- **51**. What is the relation between the amplitude and the frequency of a wave?
 - a. The amplitude and the frequency of a wave are independent of each other.
 - b. The amplitude and the frequency of a wave are equal.
 - c. The amplitude decreases with an increase in the frequency of a wave.
 - d. The amplitude increases with an increase in the frequency of a wave.
- **52.** What is the relation between a wave's energy and its amplitude?
 - a. There is no relation between the energy and the amplitude of a wave.
 - b. The magnitude of the energy is equal to the magnitude of the amplitude of a wave.
 - c. The energy of a wave increases with an increase in the amplitude of the wave.
 - d. The energy of a wave decreases with an increase in the amplitude of a wave.
- **53.** A wave travels 2 m every 2 cycles. What is its wavelength?
 - a. 4 m

- b. 2 m
- c. 0.5 m
- d. 1 m
- **54**. A water wave propagates in a river at 6 m/s. If the river moves in the opposite direction at 3 m/s, what is the effective velocity of the wave?
 - a. 3 m/s
 - b. 6 m/s
 - c. 9 m/s
 - d. 18 m/s

13.3 Wave Interaction: Superposition and Interference

- **55.** Is this statement true or false? Spherical waves can superimpose.
 - a. True
 - b. False
- **56.** Is this statement true or false? Waves can superimpose if their frequencies are different.
 - a. True
 - b. False
- 57. When does pure destructive interference occur?
 - a. When two waves with equal frequencies that are perfectly in phase and propagating along the same line superimpose.
 - b. When two waves with unequal frequencies that are perfectly in phase and propagating along the same line superimpose.
 - c. When two waves with unequal frequencies that are perfectly out of phase and propagating along the same line superimpose.
 - d. When two waves with equal frequencies that are perfectly out of phase and propagating along the same line superimpose.
- **58**. Is this statement true or false? The amplitude of one wave is affected by the amplitude of another wave only when they are precisely aligned.
 - a. True
 - b. False
- **59**. Why does a standing wave form on a guitar string?
 - a. due to superposition with the reflected waves from the ends of the string
 - b. due to superposition with the reflected waves from the walls of the room
 - c. due to superposition with waves generated from the body of the guitar
- **60**. Is the following statement true or false? A standing wave is a superposition of two identical waves that are in phase and propagating in the same direction.

- a. True
- b. False
- **61**. Why do water waves traveling from the deep end to the shallow end of a swimming pool experience refraction?
 - a. Because the pressure of water at the two ends of the pool is same
 - b. Because the pressures of water at the two ends of the pool are different

Extended Response

13.1 Types of Waves

- **63**. Why can light travel through outer space while sound cannot?
 - a. Sound waves are mechanical waves and require a medium to propagate. Light waves can travel through a vacuum.
 - b. Sound waves are electromagnetic waves and require a medium to propagate. Light waves can travel through a vacuum.
 - c. Light waves are mechanical waves and do not require a medium to propagate; sound waves require a medium to propagate.
 - d. Light waves are longitudinal waves and do not require a medium to propagate; sound waves require a medium to propagate.
- 64. Do periodic waves require a medium to travel through?
 - a. No, the requirement of a medium for propagation does not depend on whether the waves are pulse waves or periodic waves.
 - b. Yes, the requirement of a medium for propagation depends on whether the waves are pulse waves or periodic waves.
- **65.** How is the propagation of sound in solids different from that in air?
 - a. Sound waves in solids are transverse, whereas in air, they are longitudinal.
 - b. Sound waves in solids are longitudinal, whereas in air, they are transverse.
 - c. Sound waves in solids can be both longitudinal and transverse, whereas in air, they are longitudinal.
 - d. Sound waves in solids are longitudinal, whereas in air, they can be both longitudinal and transverse.

<u>13.2 Wave Properties: Speed, Amplitude,</u> <u>Frequency, and Period</u>

- **66.** A seagull is sitting in the water surface and a simple water wave passes under it. What sort of motion does the gull experience? Why?
 - a. The gull experiences mostly side-to-side motion

- c. Because the density of water at the two ends of the pool is same
- d. Because the density of water at the two ends of the pool is different
- **62.** Is the statement true or false? Waves propagate faster in a less dense medium if the stiffness is the same.
 - a. True
 - b. False

and moves with the wave in its direction.

- b. The gull experiences mostly side-to-side motion but does not move with the wave in its direction.
- c. The gull experiences mostly up-and-down motion and moves with the wave in its direction.
- d. The gull experiences mostly up-and-down motion but does not move in the direction of the wave.
- **67**. Why does a good-quality speaker have a woofer and a tweeter?
 - a. In a good-quality speaker, sounds with high frequencies or short wavelengths are reproduced accurately by woofers, while sounds with low frequencies or long wavelengths are reproduced accurately by tweeters.
 - b. Sounds with high frequencies or short wavelengths are reproduced more accurately by tweeters, while sounds with low frequencies or long wavelengths are reproduced more accurately by woofers.
- 68. The time difference between a 2 km/s S-wave and a 6 km/s P-wave recorded at a certain point is 10 seconds. How far is the epicenter of the earthquake from that point?
 - a. 15 m
 - b. 30 m
 - c. 15 km
 - d. 30 km

13.3 Wave Interaction: Superposition and Interference

- **69.** Why do water waves sometimes appear like a complex criss-cross pattern?
 - a. The crests and the troughs of waves traveling in the same direction combine to form a criss-cross pattern.
 - b. The crests and the troughs of waves traveling in different directions combine to form a criss-cross pattern.
- 70. What happens when two dissimilar waves interfere?
 - a. pure constructive interference
 - b. pure destructive interference
 - c. a combination of constructive and destructive

interference

- **71**. Occasionally, during earthquakes, areas near the epicenter are not damaged while those farther away are damaged. Why could this occur?
 - a. Destructive interference results in waves with greater amplitudes being formed in places farther away from the epicenter.
 - b. Constructive interference results in waves with greater amplitudes being formed in places farther away from the epicenter.
 - c. The standing waves of great amplitudes are formed in places farther away from the epicenter.
 - d. The pulse waves of great amplitude are formed in places farther away from the epicenter.
- **72**. Why does an object appear to be distorted when you

view it through a glass of water?

- a. The glass and the water reflect the light in different directions. Hence, the object appears to be distorted.
- b. The glass and the water absorb the light by different amounts. Hence, the object appears to be distorted.
- c. Water, air, and glass are media with different densities. Light rays refract and bend when they pass from one medium to another. Hence, the object appears to be distorted.
- d. The glass and the water disperse the light into its components. Hence, the object appears to be distorted.

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