24.2 Properties of Waves

In this section, you will apply your understanding of harmonic motion to waves. A **wave** is a traveling oscillation that has frequency, wavelength, and amplitude. Types of waves include water waves, sound, and light. To understand how these waves are alike and different, let's examine the properties of waves.

What is a wave?

Defining a wave If you poke a floating ball, it oscillates up and down. Then the surface of the water oscillates in response, and the oscillation spreads outward from where it started. As you read above, this traveling oscillation is a wave. Waves are a traveling form of energy because they can cause changes in the objects they encounter. As they travel, waves can carry information, such as sound, pictures, or even numbers. For this reason, technology depends on waves. All the information that reaches your eyes and ears comes in waves.

A wave is a traveling form of energy.

Waves are oscillators Like all oscillators, waves have cycles, frequency, and amplitude. The frequency of a wave is a measure of how often it goes up and down at any one place. The frequency of one point on the wave is the frequency of the whole wave. A wave carries its frequency to every place it reaches. Wave frequency is measured in hertz (Hz). A wave with a frequency of one hertz (1 Hz) causes everything it touches to oscillate at one cycle per second.

Wavelength A wave has a moving series of high points called *crests* and low points called *troughs*. The amplitude of a wave is the average distance, or one-half the distance, between the crest and the trough (Figure 24.10). **Wavelength** is the distance from any point on a wave to the same point on the next cycle of the wave (Figure 24.11). For example, the distance between one crest and the next crest is one wavelength. We use the Greek letter *lambda* for wavelength. A *lambda* (λ) looks like an upside-down *y*.

VOCABULARY

wave - a traveling oscillation that has properties of frequency, wavelength, and amplitude.

wavelength - the distance from any point on a wave to the same point on the next cycle of the wave.

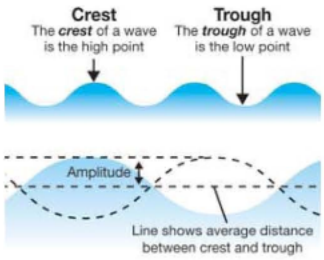


Figure 24.10: *The parts of a wave.*

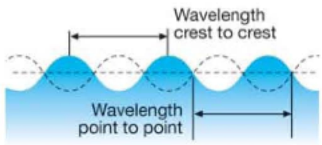
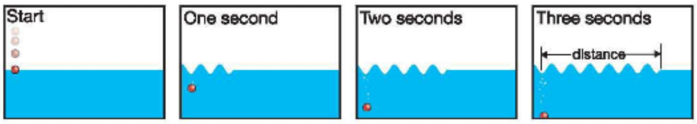


Figure 24.11: *The wavelength can be measured from crest to crest.*

The speed of waves

Waves spread Wave motion is due to the spreading of the wave from where it begins. For a water wave, the water itself stays in the same average place. Therefore, to gauge the speed of a wave, you measure how fast the wave spreads—*not* how fast the water surface moves up and down.

Measuring wave speed The graphic below shows what happens in water when you begin a wave in one location. You can measure the speed of this spreading wave by timing how long it takes the wave to affect a place some distance away. The speed of a typical water wave is about 1 m/s. Light waves are extremely fast—300,000 km/s (or 186,000 mi/s). Sound waves travel at about 1,200 km/hr (or 660 mph).



Speed is frequency times wavelength In one complete cycle, a wave moves one wavelength (Figure 24.12). The speed is the distance traveled (one wavelength) divided by the time it takes (one period). We can also calculate the speed of a wave by multiplying wavelength and frequency. This is mathematically the same because multiplying by the frequency is the same as dividing by the period. These formulas work for all types of waves, including water waves, sound waves, light waves, and even earthquake waves.

WAVE SPEED

$$v = f\lambda$$

Speed (m/s): v; Frequency (Hz or) $\frac{1}{T}$: f; Period (s): T; Wavelength (m): λ

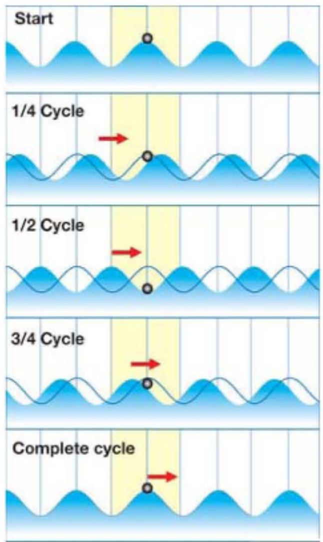


Figure 24.12: *A wave moves one wavelength in each cycle.*

Remember these relationships:

period = T

frequency = $^1/_T$

Speed = wavelength ÷ period

Speed = frequency × wavelength

Solving Problems: Wave Speed

The wavelength of a wave on a string is 1 meter and its speed is 5 m/s. Calculate the frequency and the period of the wave.

1. Looking for: You are asked to find the frequency (f) and period (T) of a wave.

2. Given: You know the wavelength of the wave is 1 meter and its speed is 5 m/s.

3. Relationships: The formulas you know include:

speed = frequency × wavelength

$f = {}^1/_T$ and $T = {}^1/_f$

4. Solution: Solve for frequency.

frequency = speed ÷ wavelength

frequency = 5 m/s ÷ 1 m = 5 Hz

Then solve for period.

period = ${}^1/_f = {}^1/_{5\ \text{Hz}} = 0.20$ s

The frequency of the wave is 5 Hz, and the period is 0.20 second.

Your turn...

a. The wavelength of a wave is 0.5 meter and its period is 2 seconds. What is the speed of this wave?

b. The wavelength of a wave is 100 meters and its frequency is 25 hertz. What is the speed of this wave? What is its period?

c. If the period of a wave is 15 seconds, how many wavelengths pass a certain point in 2 minutes?

SOLVE IT!

Making Waves

Make a harmonic-motion graph of a wave. Place time on the *x*-axis and position on the *y*-axis. The period is 2 seconds and the amplitude is 5 centimeters. On your graph, label a crest, trough, and the wavelength.

SOLVE FIRST LOOK LATER

a. The speed is 0.25 m/s.

b. The speed is 2,500 m/s. The period is 0.04 second.

c. 2 minutes = 120 seconds.
120 s ÷ 15 s/cycle (or wavelengths) = 8 cycles (or wavelengths).
8 wavelengths pass the point.

The four wave interactions

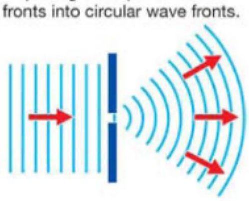
Boundaries Four interactions are possible when a wave encounters a surface—reflection, refraction, diffraction, or absorption. Reflection, refraction, and diffraction usually occur at the boundary between two materials. Absorption also occurs at a boundary, but it happens to a greater extent within the body of a material.

Reflection **Reflection** is the process of a wave bouncing off a surface. A reflected wave is like the original wave, but moving in a new direction. The wavelength and frequency are usually unchanged. An echo is an example of a sound wave reflecting from a distant object or wall. People who design concert halls pay careful attention to the reflection of sound from the walls and ceiling.

Refraction **Refraction** occurs when a wave bends as it crosses a boundary. The process of light refraction through eyeglasses helps people see better. The lenses in a pair of glasses bend, or refract, incoming light waves so that an image is correctly focused within the eye.

Diffraction The process of a wave bending around a corner or passing through an opening is called **diffraction**. Diffraction usually changes the direction and shape of the wave front (the leading edge of a moving wave). You can see this happening in the graphic at the right. Diffraction explains why you can hear sound through a partially closed door. Diffraction causes the sound wave to spread out from any small opening.

Diffraction through a small opening turns parallel wave fronts into circular wave fronts.



Absorption **Absorption** of a wave means that its amplitude gets smaller and smaller as it passes through a material. As this happens, the wave's energy is transferred to the absorbing material. Theaters often use heavy curtains to absorb sound waves so the audience cannot hear backstage noise. The tinted glass or plastic in the lenses of your sunglasses absorbs some of the energy in light waves. Cutting down the energy of light makes your vision more comfortable on a bright, sunny day so you don't have to squint.

VOCABULARY

reflection - the process of a wave bouncing off surfaces.

refraction - the process of a wave bending as it crosses a boundary between two materials.

diffraction - the process of a wave bending around a corner or passing through an opening.

absorption - the process of diminishing the amplitude and energy of a wave as it passes through a material.

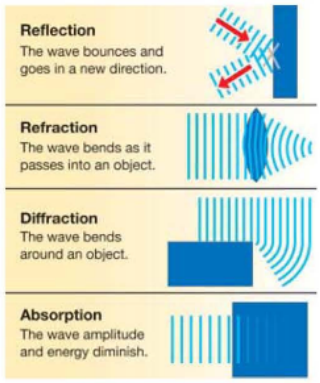


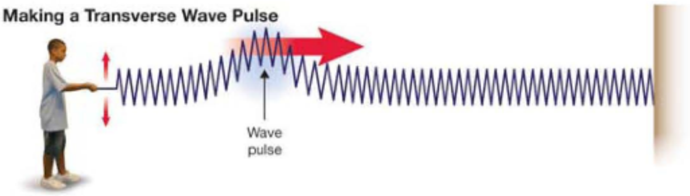
Figure 24.13: *The four wave interactions.*

Transverse and longitudinal waves

Wave pulses A wave *pulse* is a short "burst" of a traveling wave. A pulse can be produced with a single up-down movement. The illustrations below show wave pulses in springs. You can see the difference between the two basic types of waves—transverse and longitudinal—by observing the motion of a wave pulse.

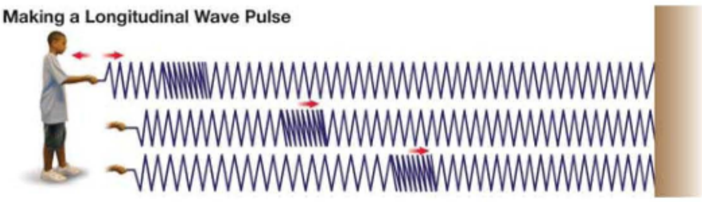
Transverse waves The oscillations of a **transverse wave** *are not* in the direction the wave moves. For example, the wave pulse in the illustration below moves from left to right. The oscillation (caused by the boy's hand) is up and down. Water waves are an example of a transverse wave (Figure 24.14 top).

Making a Transverse Wave Pulse



Longitudinal waves The oscillations of a **longitudinal wave** *are* in the same direction that the wave moves (Figure 24.14 bottom). A sharp push-pull on the end of the spring makes a traveling wave pulse as portions of the spring compress then relax. The direction of the compressions is in the same direction that the wave moves. Sound waves are longitudinal waves.

Making a Longitudinal Wave Pulse



VOCABULARY

transverse wave - a wave is transverse if its oscillations *are not* in the direction it moves.

longitudinal wave - a wave is longitudinal if its oscillations *are* in the direction it moves.

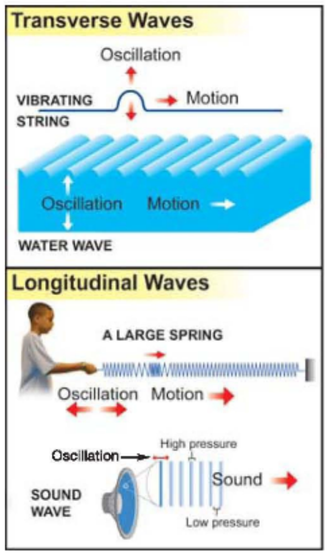
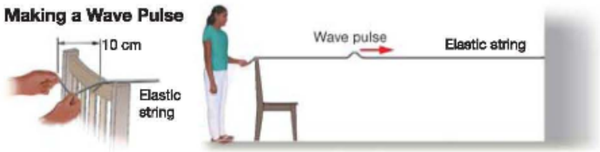


Figure 24.14: *Transverse and longitudinal waves.*

Constructive and destructive interference

Wave pulses If you have a long elastic string attached to a wall, you can make a wave pulse. First, you place the free end of the string over the back of a chair. The string should be straight so that each part of it is in a neutral position. To make the pulse, you pull down a short length of the string behind the chair and let go. The pulse then races away from the chair all the way to the wall. You can see the wave pulse move *on* the string. Each section of string experiences the pulse and returns to the neutral position after the wave pulse has moved past it.



Constructive interference Suppose you make two wave pulses on a stretched string. One comes from the left and the other comes from the right. When the waves meet, they combine to make a single large pulse. **Constructive interference** happens when waves combine to make a larger amplitude (Figure 24.15).

Destructive interference Wave pulses do not always combine to make a larger pulse when they meet. When one pulse is on top of the string and the other is on the bottom, these pulses cancel each other out as they meet in the middle. (Figure 24.16). One pulse pulls the string up and the other pulls it down. The result is that the string flattens and both pulses vanish for a moment. In **destructive interference**, waves add up to make a wave with smaller, or zero, amplitude. After interfering, both wave pulses separate again and travel on their own. This is surprising if you think about it. For a moment, the middle of the string is flat, but a moment later, two wave pulses come out of the flat part and race away from each other. Waves still store energy, even during destructive interference. Noise-canceling headphones are based on technology that uses destructive interference.

VOCABULARY

constructive interference - when waves add up to make a larger amplitude.

destructive interference - when waves add up to make a smaller, or zero, amplitude.

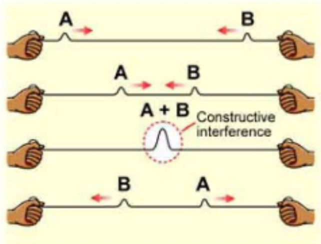


Figure 24.15: *This is an example of constructive interference.*

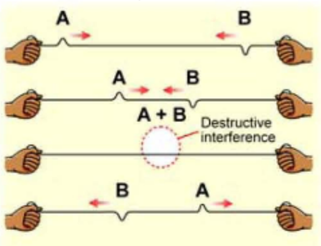


Figure 24.16: *This is an example of destructive interference.*

24.2 Section Review

1. The distance from the crest of a wave to the next crest is 10 centimeters. The distance from a crest of this wave to a trough is 4 centimeters.
   a. What is the amplitude of this wave?
   b. What is the wavelength of this wave?
2. What is the wavelength of the wave shown in this harmonic-motion graph?

3. What is the speed of a wave that has a wavelength of 0.4 meter and a frequency of 10 hertz?
4. A wave has a wavelength of 1 m and a speed of 20 m/s. What is the period of this wave?
5. For each of the examples below, identify whether reflection, refraction, diffraction, or absorption is happening.
   a. The black surface of a parking lot gets hot in the summer when exposed to sunlight.
   b. A straw in a glass of water looks funny (Figure 24.17).
   c. When you look in a mirror, you can see yourself.
   d. Sound seems muffled when it is occurring on the other side of a wall.
   e. Light waves bend when they move from water to air.
   f. The wave front of a wave changes as it passes through an opening.
6. When a wave is being absorbed, what happens to the amplitude of the wave? Use the term *energy* in your explanation.
7. Compare and contrast transverse waves and longitudinal waves.
8. Two waves combine to make a wave that is larger than either wave by itself. Is this constructive or destructive interference?
9. When constructive interference happens between two sound waves, the sound will get louder. What does this tell you about the relationship between amplitude and volume of sound?

TECHNOLOGY

Noise-Canceling Headphones

The graphic below illustrates how noise-canceling headphones work. Study the graphic and write a description that explains why noise-canceling technology is a good way to reduce noise. Verify your description by doing some research about these special headphones.

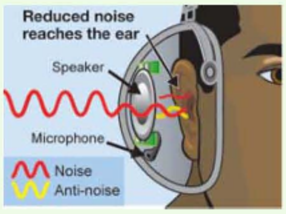


Figure 24.17: *Question 5b.*