POWER BASICS®

Physics

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UNIT 3

Sound and Light

LESSON 7: Sound Waves

GOAL: To understand the properties of waves; to learn how the properties of waves apply to sound

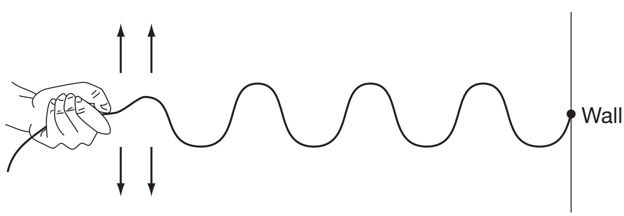
WORDS TO KNOW

amplitude	in phase	rarefaction
compression	infrasonic	redshifted
constructive interference	interference	sonic boom
crest	longitudinal wave	transverse wave
decibels	loudness	trough
destructive interference	medium	ultrasonic
diffraction	natural frequency	vibration
Doppler effect	out of phase	wave
equilibrium point	overtones	wavelength
frequency	period	
hertz	pitch	

Describing Waves

Any repeated back-and-forth motion is called a **vibration.** For example, swinging a pendulum back and forth, or wiggling your hand, are both vibrations.

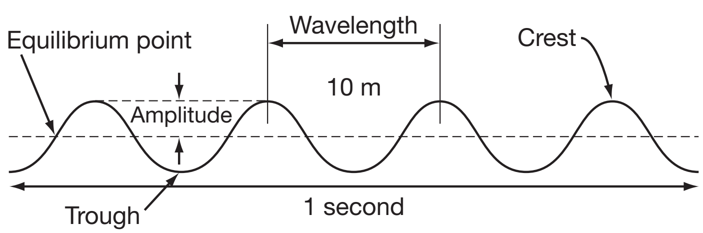
When a vibration moves from one place to another, it is called a **wave.** In the diagram below, the vibration of the hand creates a wave that travels along the rope. When you drop a rock into water, the vibrations in the water spread out across the surface.



An important property of waves is that the vibration travels without any material moving along with it. When you throw a ball, the ball itself moves from one place to another. In the diagram on page 99, when the person shakes the rope, the "wiggle" will move down the rope to the other end. However, the whole rope did not move from one place to another, as happens when you throw a ball. Only the vibration moved. Similarly, when you speak, the air that comes out of your mouth does not travel into other people's ears. Only the vibration of the air molecules is transmitted.

The substance that a wave travels through is called the **medium.** In the preceding diagram, the medium is the rope. For ocean waves, the medium is water. For sound waves, the medium is air. In a wave, the medium does not move from one place to another. Only the energy or disturbance caused by the vibration is transmitted.

There are many terms used to describe waves and vibrations. Several of these are illustrated in the diagram below.



The top of a wave is known as a **crest.** The bottom of a wave is known as a **trough.** The resting position, in between the crest and trough (the dashed line in the diagram above), is known as the **equilibrium point.**

The **amplitude** of a wave describes how big it is. The amplitude is measured as the distance from the equilibrium point to the crest of the wave. The taller the wave, the greater its amplitude.

The **wavelength** describes the length of each wave. The wavelength is usually measured as the distance from one crest to the next. Or, it can be measured as the distance from one trough to the next. It can also be the distance between any two identical points in the wave.

Wavelength and amplitude are both distances. So, they are measured in the same units as length. In the metric system, they can be measured in meters, centimeters, or even nanometers, depending on how big or small the wave is.

You can also measure how quickly waves or vibrations oscillate, or move back and forth. There are two terms to describe this. The **frequency** is the number of complete waves or vibrations that occur in a certain amount of time. High frequency means the waves are occurring very quickly. Low frequency means the waves are being produced infrequently. For example, if you notice that 5 waves hit the beach each minute, the frequency is 5 waves per minute.

The most common unit used to measure frequency is the **hertz** (Hz). Hertz was named after the German scientist Heinrich Hertz. Hertz is the number of waves per second. For example, if you are holding a rope and you shake your hand up and down 3 times each second, the waves in the rope will have a frequency of 3 Hz.

Higher frequencies are usually expressed as kilohertz (kHz) or megahertz (MHz). One kilohertz is one thousand waves per second. One megahertz is one million waves per second.

IN REAL LIFE

The frequency of a radio station is simply the frequency of the radio waves that are carrying the signal. For instance, FM radio stations are in the range of 88 MHz to 108 MHz. If you are listening to 104 FM, it means the radio waves are vibrating 104 million times each second. On the other hand, AM stations are in the kHz range. If you listen to 950 AM, it means the waves are vibrating at 950 kHz, or 950 thousand times each second.

You can also measure how quickly waves are oscillating by the **period.** The period is the length of time it takes for one wave to complete. For example, one wave hits the beach every 10 seconds. This means that the period is 10 seconds. If it takes you 0.2 seconds to shake your hand up and down once, then the period of the waves you will create is 0.2 seconds.

There is a simple relationship between frequency and period. They are inverses, or opposites. If a wave has a high frequency, then each wave does not take much time. So, it has a short period. If each wave takes a lot of time (long period), then there will not be many of them each second. So, the frequency will be low.

This can be summarized in the equations below.

$$\text{Frequency} = \frac{1}{\text{period}}$$

$$\text{Period} = \frac{1}{\text{frequency}}$$

For example, if the frequency of a wave is 5 Hz (5 waves each second), then each wave takes $\frac{1}{5}$ second, making the period $\frac{1}{5}$ second.

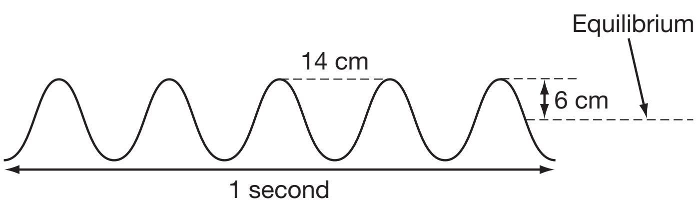
PRACTICE 25: Describing Waves

Circle the correct answer to each of the following questions.

1. What term describes the substance a wave travels through?
- **a.** vibration
- **b.** medium
- **c.** matter

2. What is the top of a wave called?
- **a.** crest
- **b.** trough
- **c.** equilibrium point

3. If a wave oscillates twice each second, what is its period?
- **a.** 2 seconds
- **b.** 2 Hz
- **c.** $\frac{1}{2}$ second



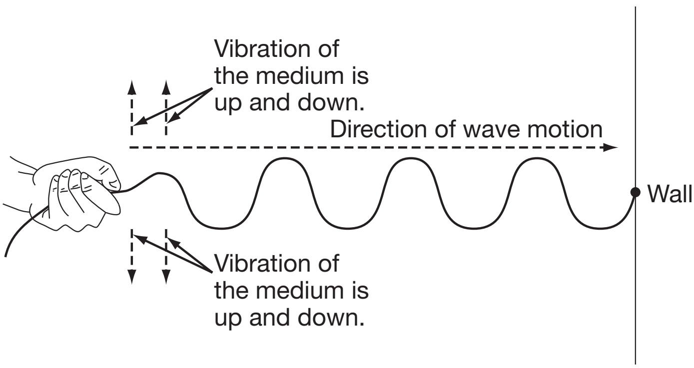
4. What is the amplitude of the wave above?
- **a.** 14 cm
- **b.** 12 cm
- **c.** 6 cm

5. What is the wavelength of the wave on page 102?
   a. 14 cm
   b. 7 cm
   c. 6 cm

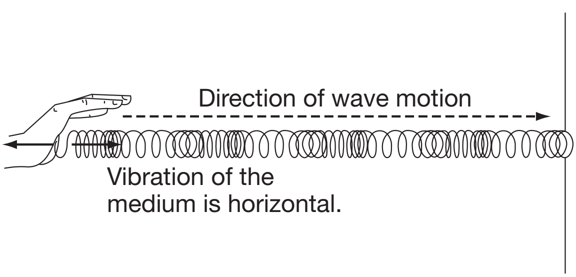
6. What is the frequency of the wave on page 102?
   a. 14 Hz
   b. 5 Hz
   c. 1 Hz

Motion of Waves

In the diagram of the rope below, the rope is vibrating up and down. But the waves are traveling horizontally. Likewise, water waves wiggle up and down. But the waves spread out across the surface. These are known as transverse waves. In a **transverse wave,** the medium vibrates in a different direction than the waves travel.



On the other hand, if you push a coiled spring back and forth, as shown below, the vibrations are horizontal. The wave is traveling horizontally also. The vibration of the medium is in the same direction as the wave is traveling. This is known as a **longitudinal wave.**

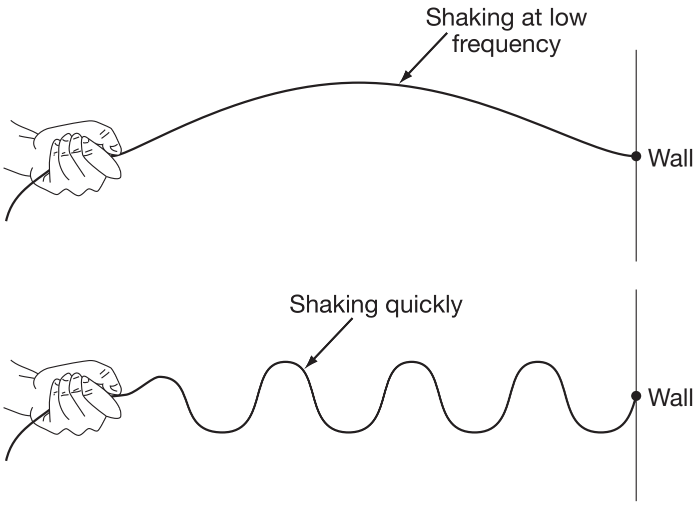


You have already learned about frequency and period, two terms that describe how quickly waves are produced. You can also describe how quickly a wave travels from one place to another. This is the wave's speed. Ocean waves that are moving quickly have a high speed. Slow waves on a pond have a low speed. Just like the speed of any other object, a wave's speed is the distance a wave moves per time. For example, if a wave moves 5 meters in one second, then its speed is 5 m/sec. If you are riding in a boat that is traveling at a rate of 20 km/hr, and the waves are traveling at the same rate as the boat, then the speed of the waves is 20 km/hr.

TIP

It is important to remember the difference between speed and frequency. Frequency is how quickly waves oscillate. If you are watching waves at the beach, the frequency is the number that hit the shore in a certain amount of time. Speed is how quickly the waves move from one place to another. At the beach, the speed of a wave is how fast it moves from a distant point in the ocean to shore.

The speed at which waves move generally depends only on the medium in which it is moving. (You will learn later that light is an exception to this rule.) The speed does not depend on the frequency, wavelength, or amplitude of the waves. For example, large water waves and small water waves travel at the same speed. High-frequency sounds travel at the same speed as low-frequency sounds. And, if you shake the rope shown on the right faster, you will produce more waves. But the waves will not reach the other end of the rope any faster.

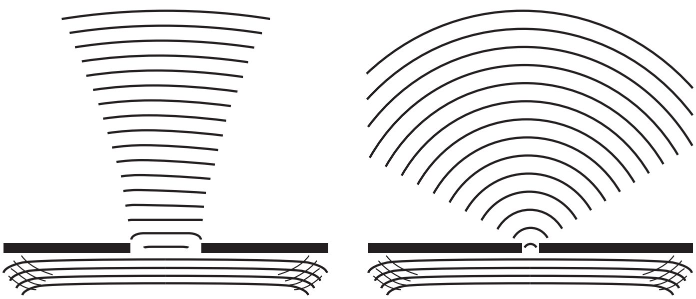


The only way to change the speed that waves travel in a medium is to change something about the medium. For instance, if you stretch the rope tighter, the waves will travel more quickly. Air that is heated transmits sound more quickly than cooler air. This is because the faster moving molecules collide more often, transmitting the sound more quickly.

Shaking the rope faster will not change the speed of the wave. However, it will change the wavelength. As the frequency of the shaking increases, the wavelength becomes shorter. If you shake the rope more slowly, the wavelength becomes longer.

Similarly, if the ocean waves hit the beach often, then the distance between them (wavelength) is small. If the distance between the waves is large, then they will hit at a low frequency. This idea will be very important when you learn how sound is produced.

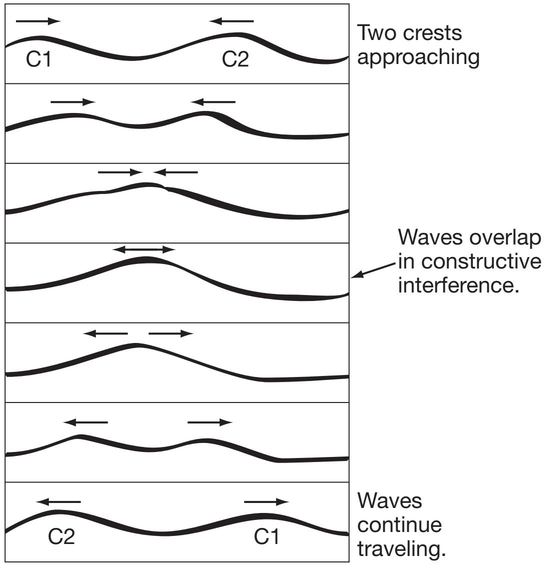
When a wave passes through a narrow opening, it can spread out on the other side. You may have noticed this in water waves. This effect is known as **diffraction.** As shown below, the narrower the opening, the more the waves spread out on the other side.



IN REAL LIFE

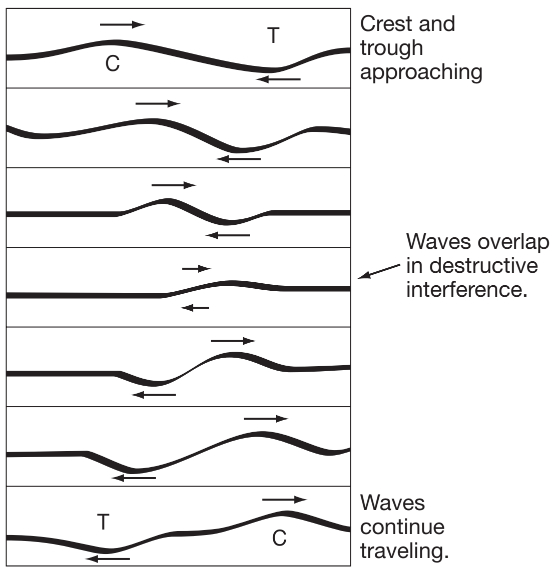
Film camera lenses use the diffraction of light waves to create pictures. Light entering a hole in the lens spreads out to create a picture on the film.

Suppose two people hold opposite ends of a rope. They both shake the rope. As the waves travel down the rope, they will overlap. The point at which the waves overlap is known as **interference.** Similarly, if you drop two rocks at different places in a pond, the waves produced by the rocks will overlap. This creates interference.



Constructive interference (in phase)

When two crests overlap each other, they add up to make an even bigger crest than before. This is known as **constructive interference.** The diagram at the top right illustrates this.



Destructive interference (out of phase)

The same thing would happen if two troughs overlapped. They would make an even larger trough. When two waves are "in step" like this, they are said to be **in phase.** After the waves have passed through each other, they continue traveling normally.

On the other hand, if a crest and a trough overlap, they will momentarily cancel each other out. This is known as **destructive interference**, as shown above. The waves are not actually destroyed by this, however. They continue moving through each other. Once they no longer overlap, they travel as they did before. Two waves in opposite motion like this are called **out of phase.**

TIP

Remember, when two waves meet each other, they are not permanently changed. They undergo interference as they overlap. But then they continue to travel as they did before hitting each other.

PRACTICE 26: Motion of Waves

Decide if each statement that follows is true (**T**) or false (**F**). Write the correct letter on each line.

_____ **1.** In a transverse wave, the medium vibrates in the same direction that the wave moves.

_____ **2.** Ocean waves are transverse waves.

_____ **3.** A wave with a high frequency vibrates very quickly.

_____ **4.** By shaking a rope faster, you can make the waves move down the rope more quickly.

_____ **5.** In order to change the speed of a wave, you must change something about the medium.

_____ **6.** Diffraction is the process in which waves spread out as they pass through an opening.

_____ **7.** The larger the opening a wave passes through, the more the wave will diffract.

_____ **8.** Waves that are matched crest to crest and trough to trough are called "out of phase."

_____ **9.** When two waves interfere destructively, they stop moving completely.