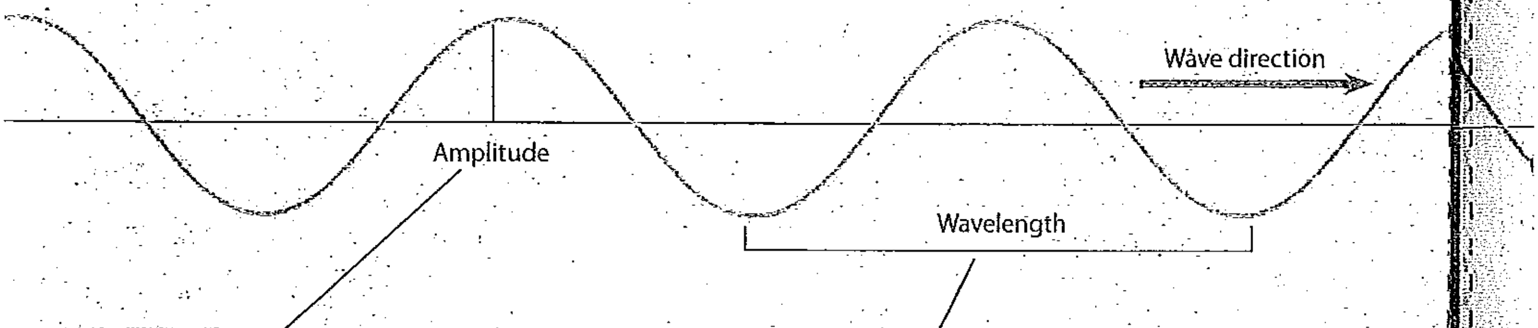
Amp It UP!

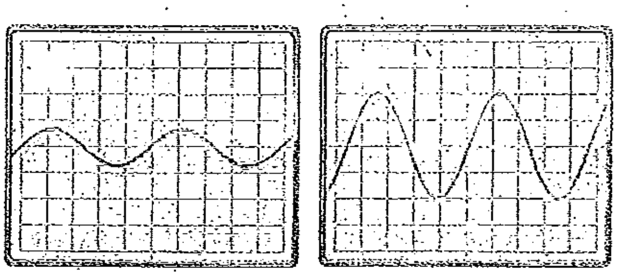
How can we describe a wave?

Suppose you are talking to a friend who had been to the beach. You want to know what the waves were like. Were they big or small? How often did they come? How far apart were they? Were they moving fast? Each of these is a basic property that can be used to describe waves.



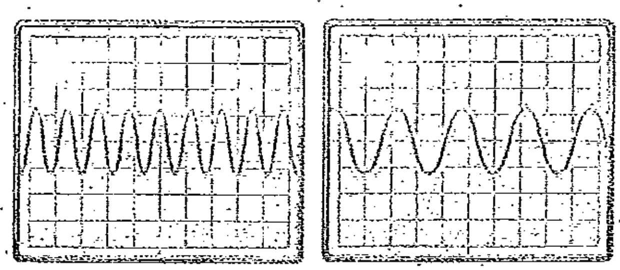
By Its Amplitude

A **wave** is a disturbance that transfers energy from one place to another. As a wave passes, particles in the medium move up and down or back and forth. A wave's **amplitude** is a measure of how far the particles in the medium move away from their normal rest position. The graph above shows a transverse wave. Notice that the amplitude of a wave is also half of the difference between the highest and lowest values.



By Its Wavelength

You can use amplitude to describe the height of an ocean wave, for example. But to describe how long the wave is, you need to know its wavelength. The **wavelength** is the distance from any point on a wave to an identical point on the next wave. For example, wavelength is the distance from one crest to the next, from one trough to the next, or between any other two corresponding points. Wavelength measures the length of one cycle, or repetition.



Visualize It!

5 Label Mark the amplitude in the two graphs above. Which wave has the greater amplitude?

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6 Label Mark the wavelength in the two graphs above. Which wave has the greater wavelength?

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By Its Frequency

Wavelength and amplitude tell you about the size of a wave. Another property tells you how much time a wave takes to repeat. The **wave period** (usually "period") is the time required for one cycle. You can measure the period by finding the time for one full cycle of a wave to pass a given point. For example, you could start timing when one crest passes you and stop when the next crest passes. The time between two crests is the period.

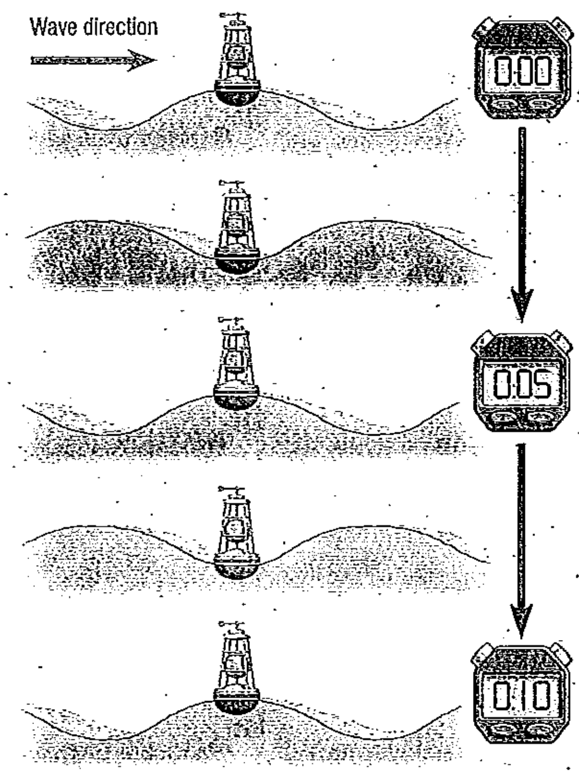
Another way to express the time of a wave's cycle is frequency. The **frequency** of a wave tells how many cycles occur in an amount of time, usually 1 s. Frequency is expressed in **hertz** (Hz). One hertz is equal to one cycle per second. If ten crests pass each second, the frequency is 10 Hz.

Frequency and period are closely related. Frequency is the inverse of period:

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

Suppose the time from one crest to another—the period—is 5 s. The frequency is then $\frac{1}{5}$ Hz, or 0.2 Hz. In other words, one-fifth (0.2) of a wave passes each second.

The buoy moves down and back up every five seconds as waves pass.



Frequency is equal to the number of cycles per unit of time:

$$\text{frequency} = \frac{\text{number of cycles}}{\text{time}}$$

Visualize It!

7 Illustrate On the grid below, draw a wave, and then draw another wave with twice the amplitude.

8 Illustrate On the grid below, draw a wave, and then draw another wave with half the wavelength.

Amp It Down

What affects the energy of a wave?

All waves carry energy from one place to another, but some waves carry more energy than others. A leaf falling on water produces waves so small they are hard to see. An earthquake under the ocean can produce huge waves that cause great destruction.

The Amplitude or The Frequency

For a mechanical wave, amplitude is related to the amount of energy the wave carries. For two similar waves, the wave with greater amplitude carries more energy. For example, sound waves with greater amplitude transfer more energy to your eardrum, so they sound louder.

Greater frequency can also mean greater energy in a given amount of time. If waves hit a barrier three times in a minute, they transfer a certain amount of energy to the barrier. If waves of the same amplitude hit nine times in a minute, they transfer more energy in that minute.

For most electromagnetic (EM) waves, energy is most strongly related to frequency. Very high-frequency EM waves, such as x-rays and gamma rays, carry enough energy to damage human tissue. Lower-frequency EM waves, such as visible light waves, can be absorbed safely by your body.

Active Reading

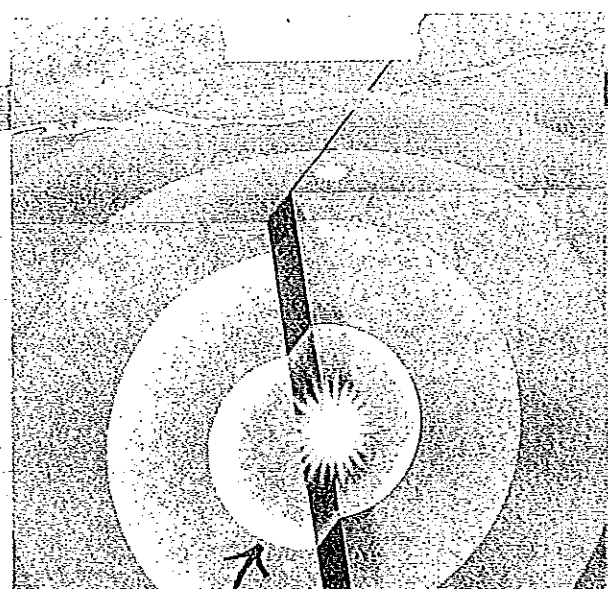
9 Identify As you read, underline the kind of wave whose energy depends mostly on frequency.

10 Apply An echo is the reflection of sound waves as they bounce back after hitting a barrier. How can the design of a building, such as a concert hall, reduce unwanted noises and echoes?

Energy Loss to a Medium

A medium transmits a wave. However, a medium may not transmit all of the wave's energy. As a wave moves through a medium, particles may move in different directions or come to rest in different places. The medium may warm up, shift, or change in other ways. Some of the wave's energy produces these changes. As the wave travels through more of the medium, more energy is lost to the medium.

Often, higher-frequency waves lose energy more readily than lower-frequency waves. For example, when you stand far from a concert, you might hear only the low-frequency (bass) sounds.

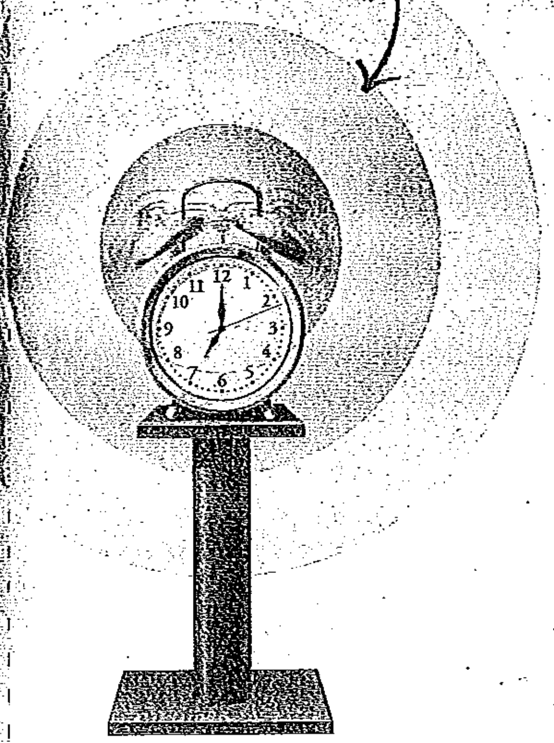


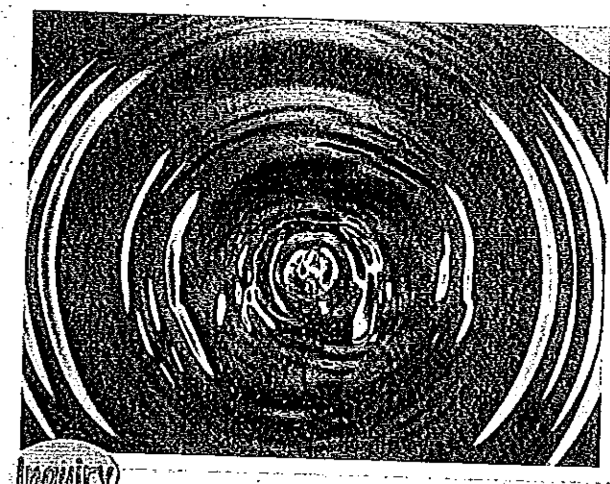
Some of the energy of these earthquake waves is lost to the medium when the ground shifts.

Energy Loss Due to Spreading

So far, we have mostly talked about waves moving in straight lines. But waves usually spread out in more than one dimension. The crests can be drawn as shapes, such as circles or spheres, called *wavefronts*. As each wavefront moves farther from the source, the energy is spread over a greater area. Less energy is available at any one point on the wavefront. If you measure a wave at a point farther from the source, you measure less energy. But the total energy of the wavefront stays the same.

Sound waves expand in three dimensions.





Ripples on a water surface expand in two dimensions.

Inquiry

11 Predict Which type of wave spreading do you think causes faster energy loss—two-dimensional or three-dimensional? Explain.

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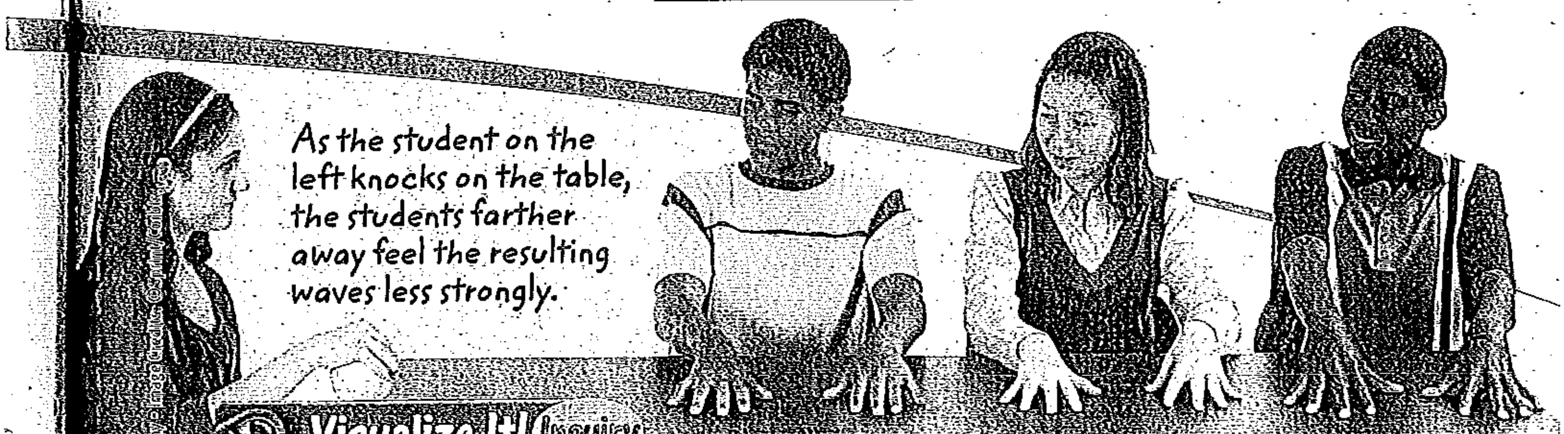

Visualize It! Inquiry

12 Synthesize If these students repeated their experiment using a longer table, what differences would they observe? Explain your answer.

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A Happy Medium

What determines the speed of a wave?

Waves travel at different speeds in different media. For example, sound waves travel at about 340 m/s in air at room temperature, but they travel at nearly 1,500 m/s in water. In a solid, sound waves travel even faster.

The Medium in Which It Travels

The speed at which a wave travels—called **wave speed**—depends on the properties of the medium. Specifically, wave speed depends on the interactions of the atomic particles of the medium. In general, waves travel faster in solids than in liquids and faster in liquids than in gases. Interactions, or collisions, between particles happen faster in solids because the particles are close together.

How fast the wave travels between particles within the medium depends on many factors. For example, wave speed depends on the density of the medium. Waves usually travel slower in the denser of two solids or the denser of two liquids. The more densely packed the particles are, the more they resist motion, so they transfer waves more slowly.

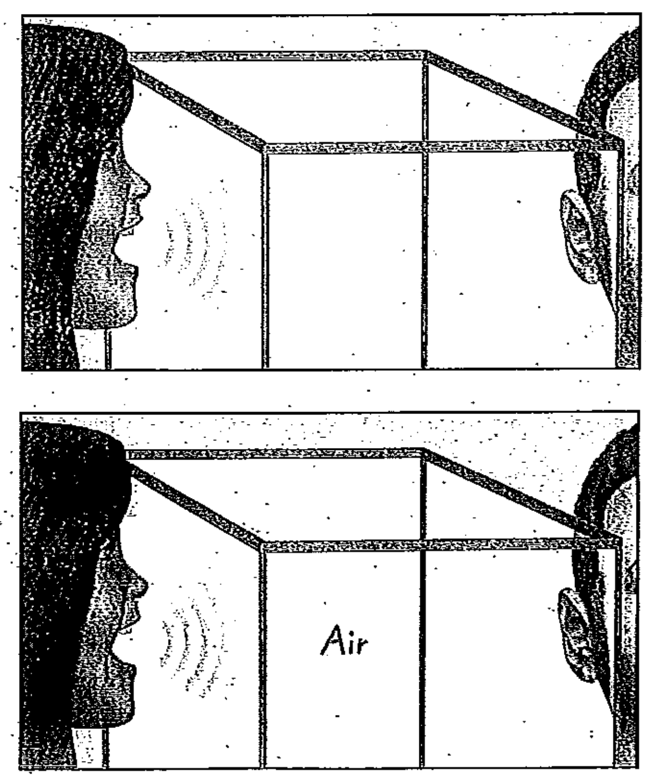
In a gas, wave speed depends on temperature as well as density. Particles in hot air move faster than particles in cold air, so particles in hot air collide more often. This faster interaction allows waves to pass through hot air more quickly than through cold air, even though hot air may be less dense. The speed of sound in air at 20 °C is about 340 m/s. The speed of sound in air at 0 °C is slower, about 330 m/s.

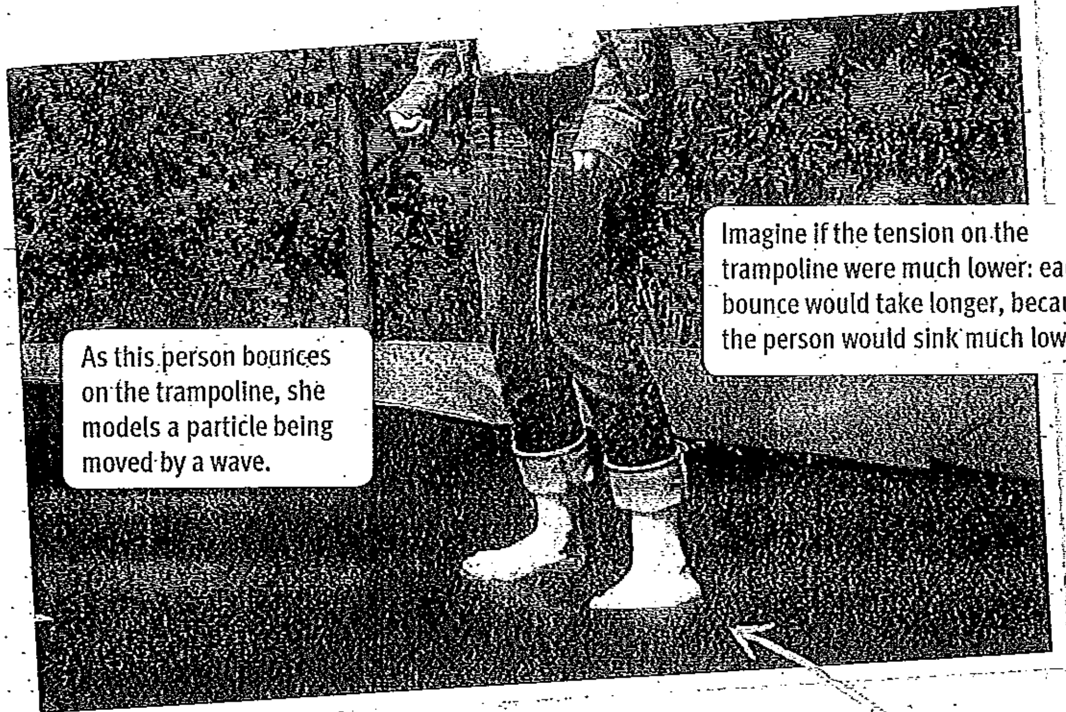
Electromagnetic waves don't require a medium, so they can travel in a vacuum. All electromagnetic waves travel at the same speed in empty space. This speed, called the speed of light, is about 300,000,000 m/s. While passing through a medium such as air or glass, EM waves travel more slowly than they do in a vacuum.

Active Reading **13 Identify** Does sound travel faster or slower when the air gets warmer?

Visualize It!

14 Diagram One diagram shows sound traveling through an air-filled tank. Draw a medium in the second tank in which sound will travel faster than in the air-filled tank.





As a medium becomes more flexible, it carries waves more slowly.

Its Frequency and Wavelength

Wave speed can be calculated from frequency and wavelength. To understand how, it helps to remember that speed is defined as distance divided by time:

$$\text{speed} = \frac{\text{distance}}{\text{time}}$$

So if a runner runs 8 m in 2 s, then the runner's speed is 8 m ÷ 2 s = 4 m/s. For a wave, a crest moves a distance of one wavelength in one cycle. The time for the cycle to occur is one period. Using wavelength and period as the distance and time:

$$\text{wave speed} = \frac{\text{wavelength}}{\text{wave period}}$$

So if a crest moves one wavelength of 8 m in one period of 2 s, the wave speed is calculated just like the runner's speed: 8 m ÷ 2 s = 4 m/s.

Frequency is the inverse of the wave period. So the relationship can be rewritten like this:

$$\text{wave speed} = \text{frequency} \times \text{wavelength}$$

or

$$\text{wavelength} = \frac{\text{wave speed}}{\text{frequency}}$$

If you already know the wave speed, you can use this equation to solve for frequency or wavelength.

Do the Math — You Try It

15 Calculate Complete this table relating wave speed, frequency, and wavelength.

Wave speed (m/s)	Frequency (Hz)	Wavelength (m)
20		5
75	15	
	23	16
625		25
	38	20

Lesson Review

Vocabulary

Fill in the blank with the correct letter.

1 frequency ______

2 wavelength ______

3 wave speed ______

4 wave period ______

5 amplitude ______

A the distance over which a wave's shape repeats

B the maximum distance that particles in a wave's medium vibrate from their rest position

C the time required for one wavelength to pass a point

D the number of wavelengths that pass a point in a given amount of time

E the speed at which a wave travels through a medium

Key Concepts

6 Describe What measures the amount of displacement in a transverse wave?

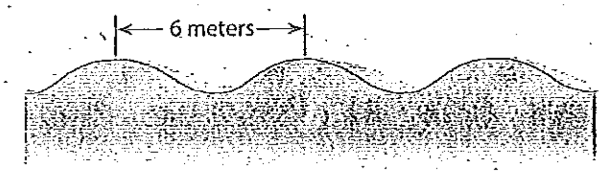
7 Relate How are frequency and wave period related?

8 Provide What does the energy of an electromagnetic wave depend on?

9 Infer Sound travels slower in colder air than it does in warmer air. Why does the speed of sound depend on air temperature?

Critical Thinking

Use this diagram to answer the following questions. The frequency of the wave is 0.5 Hz.



10 Analyze What is the wavelength of these waves?

11 Calculate What is the speed of these waves?

12 Solve If you were sitting in a boat as these waves passed by, how many seconds would pass between wave crests?

13 Infer Why does the energy of a sound wave decrease over time?

14 Infer A wave has a low speed but a high frequency. What can you infer about its wavelength?

15 Predict How do you know the speed of an electromagnetic wave in a vacuum?