POWER BASICS®

Physics

Robert Taggart

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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

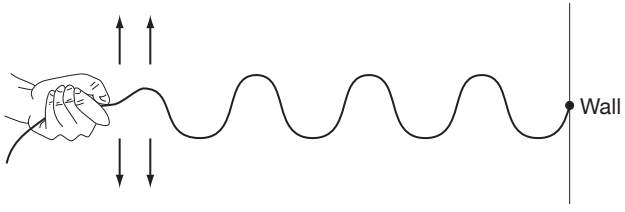
WORDS TO KNOW

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.

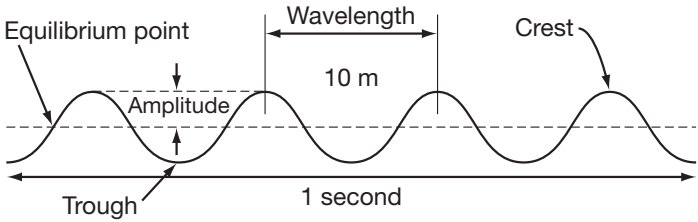
When a vibration moves from one place to another, it is called a **wave.** In the diagram below, the vibration of the hand creates a wave that travels along the rope. When you drop a rock into water, the vibrations in the water spread out across the surface.



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.

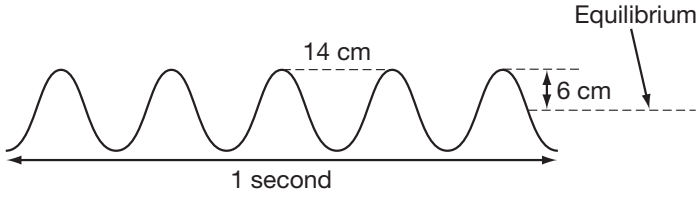
PRACTICE 25: Describing Waves

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



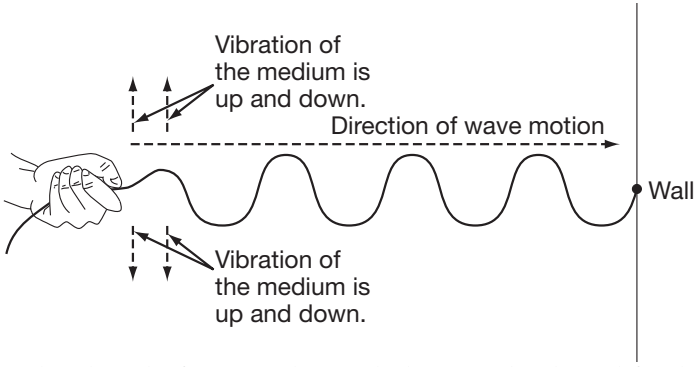
4. What is the amplitude of the wave above?
   - **a.** 14 cm
   - **b.** 12 cm
   - **c.** 6 cm

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

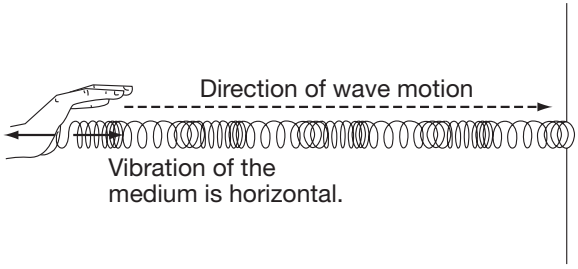
6. What is the frequency of the wave on page 102?
   a. 14 Hz
   b. 5 Hz
   c. 1 Hz

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.**

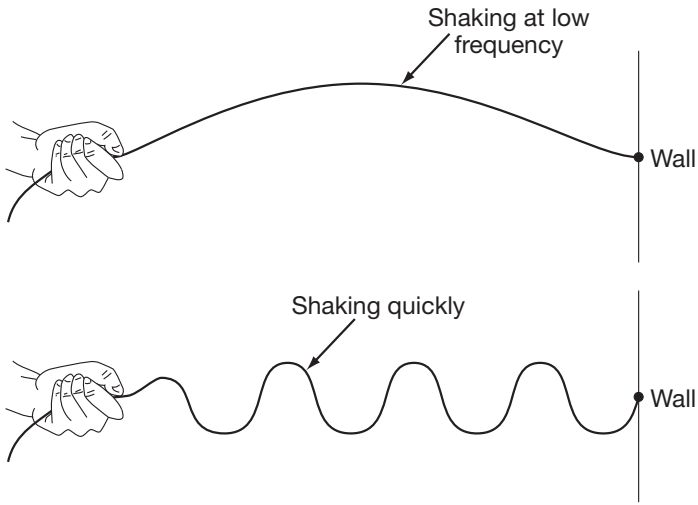


You have already learned about frequency and period, two terms that describe how quickly waves are produced. You can also describe how quickly a wave travels from one place to another. This is the wave's speed. Ocean waves that are moving quickly have a high speed. Slow waves on a pond have a low speed. 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.

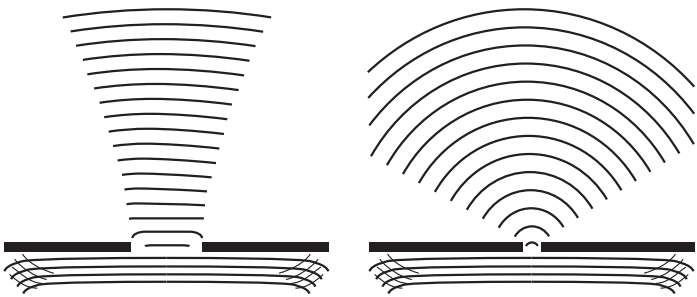


The only way to change the speed that waves travel in a medium is to change something about the medium. For instance, if you stretch the rope tighter, the waves will travel more quickly. Air that is heated transmits sound more quickly than cooler air. This is because the faster moving molecules collide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

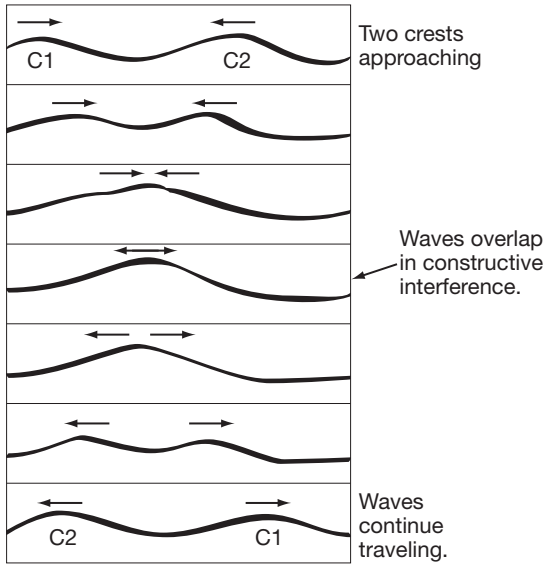
When a wave passes through a narrow opening, it can spread out on the other side. You may have noticed this in water waves. This effect is known as **diffraction.** As shown below, the narrower the opening, the more the waves spread out on the other side.



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.

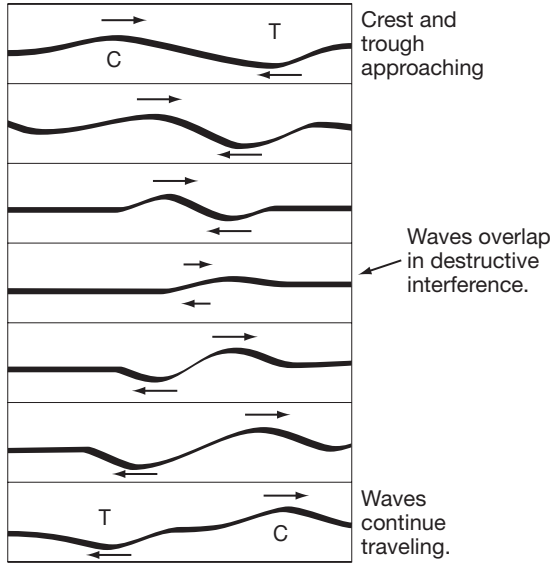
Suppose two people hold opposite ends of a rope. They both shake the rope. As the waves travel down the rope, they will overlap. The point at which the waves overlap is known as **interference.** Similarly, if you drop two rocks at different places in a pond, the waves produced by the rocks will overlap.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

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.



Destructive interference (out of phase)

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.

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Physics

Teacher's Guide

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Unit 3: Sound and Light

In this unit, students will look at waves—sound waves, light waves, and the nature and behavior of waves. Lesson 7 helps students understand the properties of waves. They will learn how the properties of waves apply to sound. In Lesson 8, students will explore the properties of light as both waves and particles. Lesson 9 discusses how light travels and interacts with objects.

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

Lesson 8—The Nature of Light

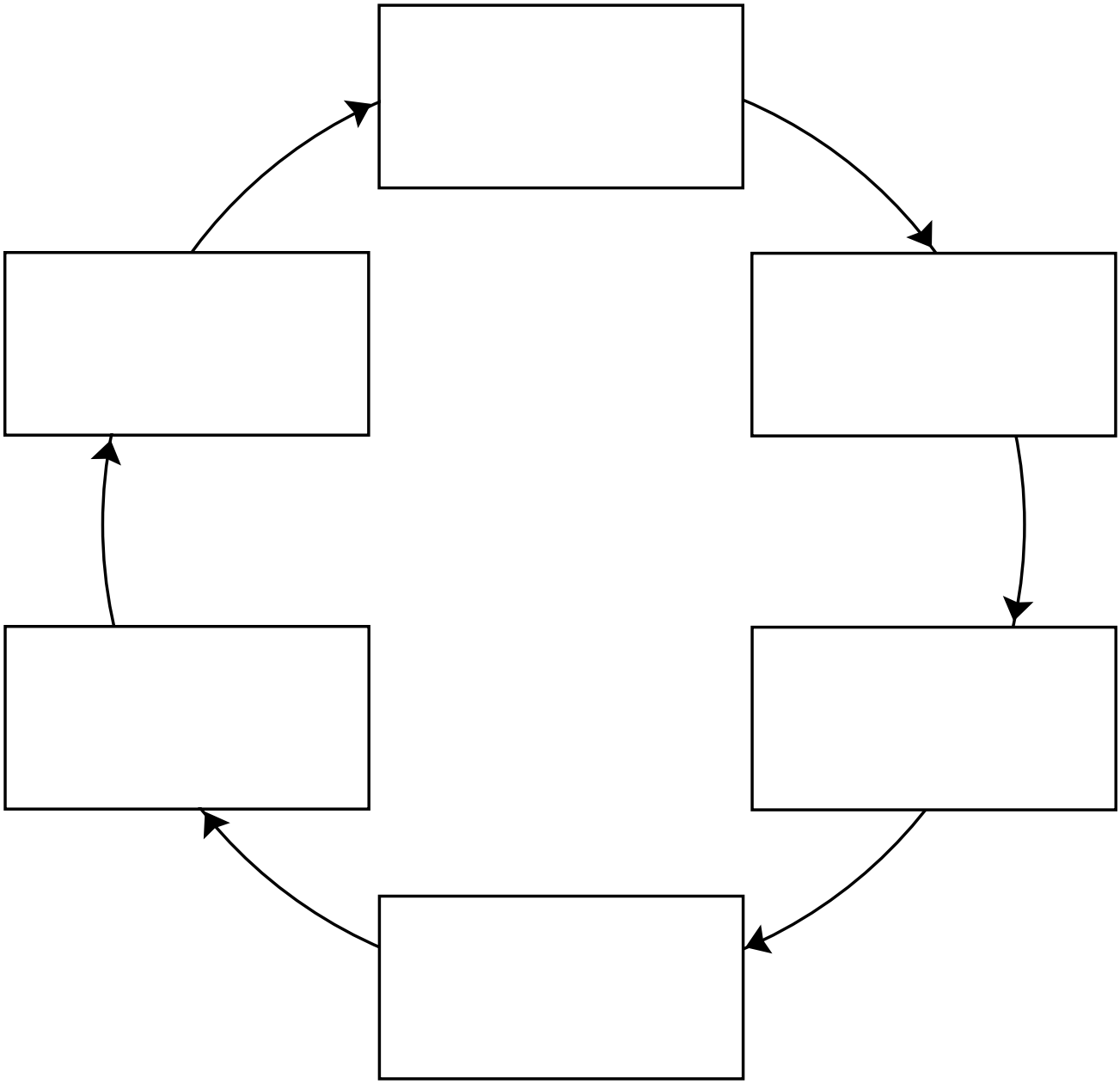
Goal: To understand the properties of light as both waves and particles

WORDS TO KNOW

additive
additive primary colors
coherent light
cones
electric field
electromagnetic radiation
incoherent light
magnetic field
optical fibers
orbits
photons
prism
spectrum
subtractive
subtractive primary colors
wave-particle duality

Cycle

Write the important stages of the cycle in the boxes. Add or delete boxes as needed.



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Physics

Workbook

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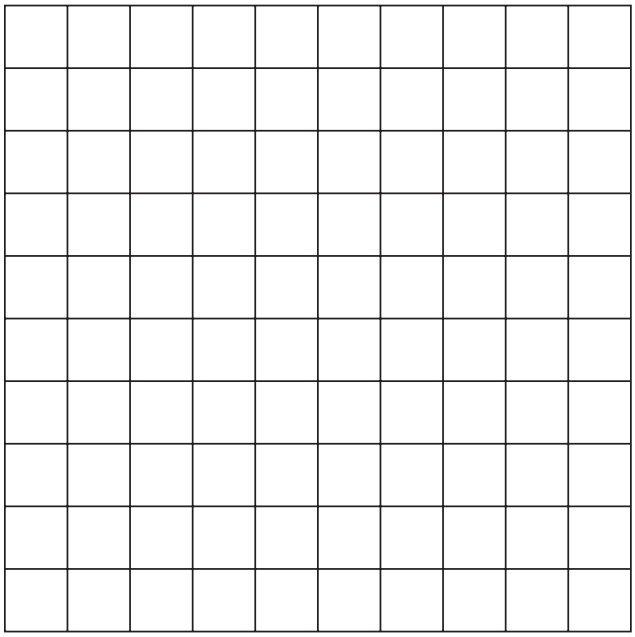
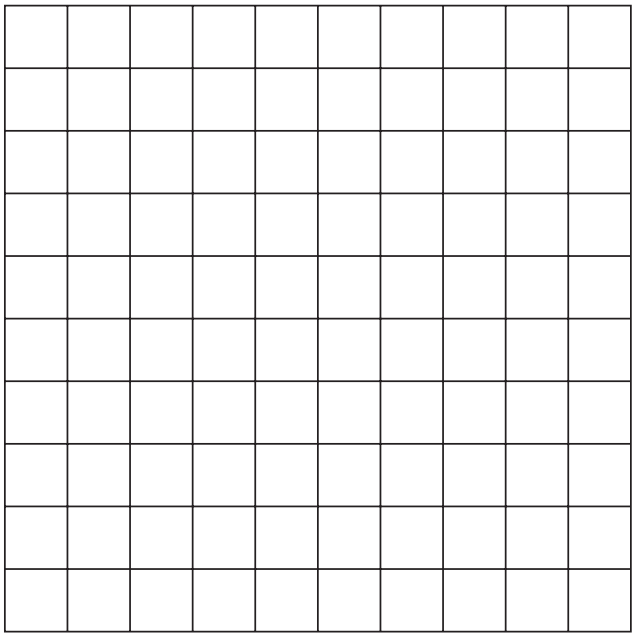
UNIT 3 • ACTIVITY 48
Descriptions of Waves

Read the two descriptions of waves below. Use the information to draw each wave on the grid that follows. Each square on the grid is 1 unit by 1 unit.

1. The wavelength is 4 units.
   The amplitude is 2 units.



2. The wavelength is 5 units.
   The amplitude is 1 unit.



NAME:

UNIT 3 • ACTIVITY 49
Frequency and Period

Circle the answer that best completes each sentence below.

1. Suppose that a flag flutters 5 times per second on a windy day. The period of each individual flutter is _____.
   - **a.** 5 seconds
   - **b.** 0.5 seconds
   - **c.** 0.2 seconds
   - **d.** 0.02 seconds

2. A pendulum swings back and forth once every 2 seconds. The frequency of each complete swing of the pendulum is _____.
   - **a.** 0.5 Hz
   - **b.** 1 Hz
   - **c.** 2 Hz
   - **d.** 5 Hz

3. The period of the swing of the same pendulum is _____.
   - **a.** 0.5 seconds
   - **b.** 1 second
   - **c.** 2 seconds
   - **d.** 5 seconds

4. As the frequency of a wave increases, the period of the wave _____.
   - **a.** decreases
   - **b.** remains the same
   - **c.** increases
   - **d.** approaches infinity

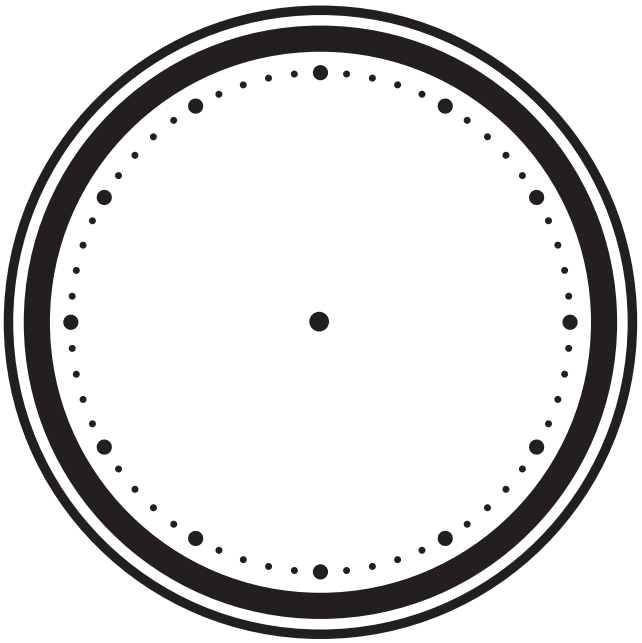
NAME:

UNIT 3 • ACTIVITY 50
Measuring in Hertz

In your student text, you learned that the most common unit used to measure frequency is the hertz. Hertz is the number of waves per second.

In this activity, you will measure the frequency of the hands of a clock in hertz.

Draw in the numbers (1 to 12) on the clock below. Then draw in the second hand, the minute hand, and the hour hand.



Now think about how often each hand moves around the clock, and answer the following three questions. Be sure to write your answer in hertz!

1. What is the frequency (in hertz) of the second hand? (*Hint:* It takes the second hand 60 seconds to move all the way around the clock.)

   _____

2. What is the frequency (in hertz) of the minute hand?

   _____

3. What is the frequency (in hertz) of the hour hand?

   _____

NAME:

UNIT 3 • ACTIVITY 52
Motion of Waves

Circle the answer that best completes each sentence below.

1. The frequency of a wave is _____.
   a. how quickly the wave moves from one place to another
   b. the density of the medium through which the wave travels
   c. how quickly the wave oscillates
   d. the direction the wave is traveling

2. One way to increase the speed of a wave traveling along a rope is to _____.
   a. shake the rope slower
   b. shake the rope faster
   c. stretch the rope tighter
   d. None of the above. There is no way to increase the speed of a wave.

3. When the crests of two different waves overlap and create an even bigger crest, it is called _____.
   a. destructive interference
   b. constructive interference
   c. diffraction
   d. a longitudinal wave

4. Suppose a transverse wave is traveling through a medium left to right. The particles of the medium will move _____.
   a. from left to right only
   b. both left and right
   c. both up and down
   d. up, down, left, and right

NAME:

UNIT 3 • ACTIVITY 51
Transverse Waves and Longitudinal Waves

Remember that a transverse wave is the kind of wave in which the medium moves perpendicular to the direction the wave travels. Imagine that several of your friends or family members are standing in a line in front of you. It is your job to instruct them how to create one big transverse wave. The medium is the line of people. The wave should travel all the way from one end of the line to the other.

1. What would you say to your friends or family members to make them understand how to move to produce the transverse wave? Write your instructions on the lines below.

2. Next you decide to ask the group to produce a longitudinal wave. Remember that a longitudinal wave is the kind of wave in which the vibration of the medium is in the same direction as the wave is traveling. What would you say to the line of people to explain how to create a longitudinal wave? Write your instructions on the lines below.

3. Which wave do you think would be the most difficult for the group to create? Why?

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PHYSICS • PRETEST

Circle the letter of the correct answer to each of the following questions.

1. How can an object change its velocity without changing its speed?
   a. by balancing changes in acceleration with changes in velocity
   b. by changing its acceleration
   c. by changing its direction
   d. This is impossible.

---

2. What is the term for the imaginary line around which an object spins?
   a. the angular displacement
   b. the angular velocity
   c. the axis of rotation
   d. the axis of displacement

---

3. When an object makes one complete rotation, what is its angular displacement?
   a. 90°
   b. 180°
   c. 270°
   d. 360°

---

4. What does the principle of inertia state?
   a. that friction will always overcome velocity
   b. that the natural position of an object is at rest
   c. that the natural position of an object is in motion
   d. that the velocity of an object does not change unless a force acts upon it

---

5. What is the term for an inward perpendicular force that causes an object to move in a circle?
   a. centrifugal force
   b. centripetal force
   c. circular force
   d. rotary force

UNIT 3 TEST • SOUND AND LIGHT

Circle the letter of the correct answer to each of the following questions.

1. What is the term for the top of a wave?
   a. crest
   b. curl
   c. equilibrium point
   d. trough

---

2. When calculating wavelength, where must you measure?
   a. from crest to crest
   b. from equilibrium point to equilibrium point
   c. from trough to trough
   d. between any two identical points of the wave

---

3. What is the term for the substance through which a wave travels?
   a. aether
   b. bearer
   c. medium
   d. vibratory receptor

---

4. Which of the following measurements describes the size of a wave?
   a. amplitude
   b. frequency
   c. pulse
   d. wavelength

---

5. A wave hits the beach every 10 seconds. What is its frequency?
   a. 0.10 Hz
   b. 1.0 Hz
   c. 10.0 Hz
   d. 100.0 Hz

6. What happens in a transverse wave?
   a. The medium blocks the wave from traveling.
   b. The medium vibrates in a different direction from the direction the wave travels.
   c. The medium vibrates in the same direction that the wave travels.
   d. The wave travels without a medium.

---

7. What happens when the crests of two different waves overlap?
   a. constructive interference
   b. destructive interference
   c. maximum interference
   d. minimum interference

---

8. What does the pitch of a sound wave depend upon?
   a. frequency
   b. loudness
   c. speed
   d. wavelength

---

9. At what air temperature does sound travel the fastest?
   a. 0°F
   b. 10°F
   c. 75°F
   d. 100°F

---

10. The side of a mountain is 340 meters away. If you shout loudly enough, about how long will it take before you hear your echo?
   a. 1 second
   b. 1.5 seconds
   c. 2 seconds
   d. 2.5 seconds

11. What is the term for a bundle of light energy?

    a. electron

    b. neutron

    c. photon

    d. proton

---

12. Which of the following types of light is not really a color, but rather a combination of all colors?

    a. blue

    b. green

    c. red

    d. white

---

13. Which of the following is NOT one of the subtractive primary colors?

    a. blue

    b. cyan

    c. magenta

    d. yellow

---

14. If you mix red paint and green paint in equal proportions, and both paints are very pure, what color will you get?

    a. black

    b. gray

    c. white

    d. yellow

---

15. What is the term for the set of frequencies emitted by a certain type of atom?

    a. bandwidth

    b. laser

    c. prism

    d. spectrum

16. Which of the following is true of laser light?
    a. All its light is of the same wavelength.
    b. It cannot be concentrated as well as ordinary light.
    c. It contains more frequencies than ordinary light.
    d. It is faster than ordinary light.

---

17. Why does red paint appear red?
    a. because it absorbs all colors except red
    b. because it absorbs red
    c. because it reflects all colors except red
    d. because it transmits all colors except red

---

18. When light bounces off a surface, what is the term for the angle at which it bounces off?
    a. the angle of incidence
    b. the angle of reflection
    c. the angle of refraction
    d. the normal

---

19. What condition is necessary for a specular reflection?
    a. The surface must be close to room temperature.
    b. The surface must be very hard.
    c. The surface must be very light in color.
    d. The surface must be very smooth.

---

20. Light passes from one layer of air to a slightly denser layer (which will slightly slow it down). How will the light bend?
    a. a great deal away from the normal
    b. a great deal toward the normal
    c. slightly away from the normal
    d. slightly toward the normal

21. What is the term for the point to which a converging lens brings together parallel beams of light?

- **a.** cluster
- **b.** "eye"
- **c.** focal point
- **d.** node

---

22. In people with normal vision, onto what part of the eye is light focused?

- **a.** iris
- **b.** lens
- **c.** pupil
- **d.** retina

---

23. Which of the following is NOT one of the types of cones in the eye?

- **a.** blue cones
- **b.** green cones
- **c.** red cones
- **d.** yellow cones

---

24. Why does the sky appear blue on a clear day?

- **a.** because the short wavelength of blue light is closest to the size of air molecules, so blue light is scattered the most widely
- **b.** because blue is the natural color of nitrogen
- **c.** because blue is the natural color of oxygen
- **d.** because blue light reaches Earth in higher proportions than other colors of light

---

25. All the waves in a beam of light are precisely horizontal. What is the term for this type of light?

- **a.** diffracted
- **b.** ionized
- **c.** iridescent
- **d.** polarized

Circle the letter of the correct answer to each of the following questions.

1. What do you need to know to determine the displacement of an object?
   a. the direction an object has moved
   b. the distance an object has moved
   c. the direction and distance an object has moved
   d. the distance and speed an object has moved

---

2. What is the term for the imaginary line around which an object spins?
   a. the angular displacement
   b. the angular velocity
   c. the axis of rotation
   d. the axis of displacement

---

3. When a car makes a quick turn, what acts on the passengers to push them toward the outside?
   a. friction
   b. gravity
   c. inertia
   d. velocity

---

4. Four people, all wearing roller skates, throw the same size basketball. Each of them is pushed backward in reaction. Who will move the least?
   a. Amy, who has a mass of 50 kilograms
   b. Julia, who has a mass of 55 kilograms
   c. Hiroshi, who has a mass of 70 kilograms
   d. Jamal, who has a mass of 80 kilograms

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5. Who formulated the law of falling objects?
   a. Copernicus
   b. Einstein
   c. Galileo
   d. Newton