Module 15
Waves: Carriers of Energy

What this module is about

Few experiences are more relaxing than a day at the beach. The sight of waves washing a shore, the sound of good music, and the feel of the sun's rays help us forget about the pressure of examinations and other school projects. What might surprise you is that the phenomenon of waves underlies all of those familiar experiences that will be discussed in this module.

In the previous modules, we have discussed the concepts of energy and how this energy is transferred in the form of work done. In most cases, energy is transferred by mechanical means. We also discussed that heating is another mode of energy transfer. Are there other means of transferring energy?
Another method of energy transfer is by wave motion. Module 16 will give you a detailed discussion on waves.

You will study the following lessons in this module:

- **Lesson 1 - Nature of Waves**
- **Lesson 2 - Types of waves**
- **Lesson 3 - Characteristics of Waves**
- **Lesson 4 - Properties of Waves**

What you are expected to learn

After going through this module, you are expected to:

1. define the nature of waves;
2. explain how waves transfer energy;
3. differentiate wave pulse from wave trains;
4. distinguish between longitudinal and transverse waves;
5. explain the characteristics of waves;
6. solve problems relating frequency, wavelength, and speed of a transverse wave; and,
7. enumerate and explain the properties of waves.

How to learn from this module

Here's a simple guide for you in going about the module.

1. Read the instructions carefully.
2. Follow the instructions very carefully.
3. Answer the pretest in order to determine how much you already know about the lessons in this module.
4. Check your answers against the given answer key at the end of this module.
5. Read each lesson and do activities that are provided for you.
6. Perform all the activities diligently to help and guide you in understanding the topic.
7. Take the self-test after each lesson to determine how much you understood the topic.
8. Answer the posttest to measure how much you have learned from the lessons.
9. Good luck and have fun

What to do before (Pretest)

Encircle the letter of the best answer.

1. Which of the following can be a medium for a wave?
   a. air
   b. water
   c. space
   d. all of the above

2. A medium transfers
   a. air.
   b. matter.
   c. energy.
   d. molecules.

3. An ocean wave is an example of a
   a. standing waves.
   b. stationary wave.
   c. transverse wave.
   d. longitudinal wave.

4. The maximum distance the molecules of a medium are displaced from their rest position is the
    a. speed.
    b. frequency.
    c. amplitude.
    d. wavelength.
5. A large ripple tank with a vibrator working at a frequency of 30 Hz produces 25 complete waves in a distance of 50 cm. The velocity of the wave is
    a. 60 cm/s.
    b. 5/3 cm/s.
    c. 750 cm/s.
    d. 1500 cm/s.

6. A source of frequency 500 Hz emits waves of wavelength 0.2 m. How long does it take the waves to travel 600 m?
    a. 3 s
    b. 6 s
    c. 12 s
    d. 60 s

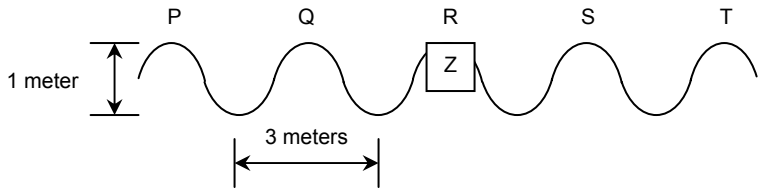
7. Which of the following is an example of longitudinal wave?
    a. blue light
    b. radio waves
    c. water ripples
    d. sound waves

8. The bending of waves around the edge of a barrier is called
    a. reflection.
    b. refraction.
    c. diffraction.
    d. interference.

9. Which of the following describes the effect of water waves passing into shallow water?
    a. wavelength increases, frequency increases, velocity increases
    b. wavelength increases, frequency unchanged, velocity increases
    c. wavelength decreases, frequency increases, velocity unchanged
    d. wavelength decreases, frequency unchanged, velocity decreases

The figure below represents a sea-wave that causes a small cork (Z) to rise up and down through one complete oscillation every 4 seconds.

Refer to this figure for questions 10-13



10. The amplitude of the wave is
    a. 0.5 m
    b. 1.0 m
    c. 1.5 m
    d. 3.0 m

11. The wavelength of the wave is
    a. 0.5 m
    b. 1.0 m
    c. 1.5 m
    d. 3.0 m

12. The horizontal speed of the wave is
    a. 4 m/s
    b. 12 m/s
    c. 0.25 m/s
    d. 0.75 m/s

13. If the wave is moving to the right, after 4 seconds the cork (Z) will be at position
    a. P
    b. Q
    c. R
    d. S

14. Four waves pass a certain point in one second with a speed of 80 cm/s. What is the wavelength?
    a. 0.5 m
    b. 10 cm
    c. 20 cm
    d. 0.05 cm

15. If the frequency of the wave is 2/s and its wavelength is 8 cm, what is the speed of the wave?
    a. 4 cm/s
    b. 6 cm/s
    c. 10 cm/s
    d. 16 cm/s

16. A boat tied to a post is rocked by waves 12 m apart and with a speed of 3 m/s. What is the frequency of the wave?
    a. 4 waves/s
    b. 9 waves/s
    c. 15 wave/s
    d. 0.25 waves/s

17. A wave with amplitude of 4 cm meets another wave of the same wavelength and amplitude. If their high parts meet, what is the amplitude of the resulting wave?
    a. 0
    b. 4 cm
    c. 8 cm
    d. 12 cm

18. Suppose the two waves in question #17 meet such that the high part of one wave meets the low part of the other. What is the amplitude of the resulting wave?
    a. 0
    b. 4 cm
    c. 8 cm
    d. 12 cm

19. Of the following characteristics of a wave, the one that is independent of the others is its
    a. speed.
    b. frequency.
    c. amplitude.
    d. wavelength.

20. The higher the frequency of a wave is,
    a. the lower is its speed.
    b. the longer is its period.
    c. the greater is its amplitude.
    d. the shorter is its wavelength.

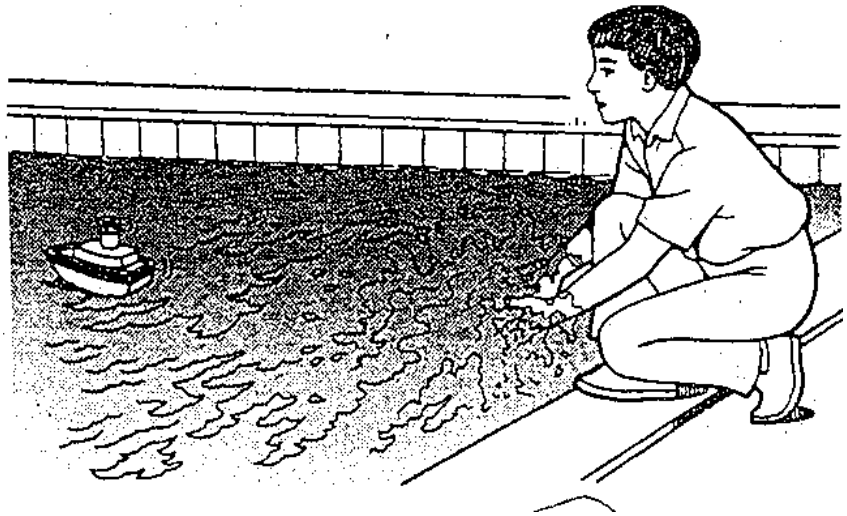
Key to answers on page 19

Lesson 1 The Nature of Waves

Whenever a medium is disturbed, there is a corresponding observable change in it. When you throw a small stone into the river, the water is disturbed and circular waves are formed.

Consider a boy at the side of the river where a toy boat is floating at a distance not within the reach of the boy. The boy wants to move the boat. How will he do that?

One-way to do it is to disturb the water to create waves. The waves will eventually move the boat.



Based on what the boy did in the figure above, what is now your idea of a wave? A *wave* is a disturbance propagated through a medium in which energy is transferred. The medium used in which energy is transferred is water, which is liquid in form. Waves do not transmit matter, but they transmit energy.

We have defined *energy* as the ability to do work and *work* as the product of force and distance. Now consider a transverse pulse moving along a spring toward the person holding the far end. When the pulse reaches him/her, he/she feels a force pulling up or down on his/her hand, and the force will move his/her hand slightly. Thus, it does work on his/her hand. The person who started the wave pulse put energy into the spring, and this energy traveled in the form of a wave to the other end.

Can you generate wave pulse and wave trains along a rope? Then try the succeeding activity.

What you will do

Activity 1.1

1. Get a piece of rope about 2 m long. Fix one end of a rope by tying it around a post or a rod.

2. Have a single disturbance in one end of the rope. What is formed? This time move that same end with a series of disturbances. What did you observe? The single disturbance made in a rope is called *wave pulse* while a series of disturbances are called *wave trains.*

3. How do you differentiate wave pulse from wave trains?

4. What is the medium used in this activity through which wave propagates?

Key to answers on page 19

What you will do

Self-Test 1.1

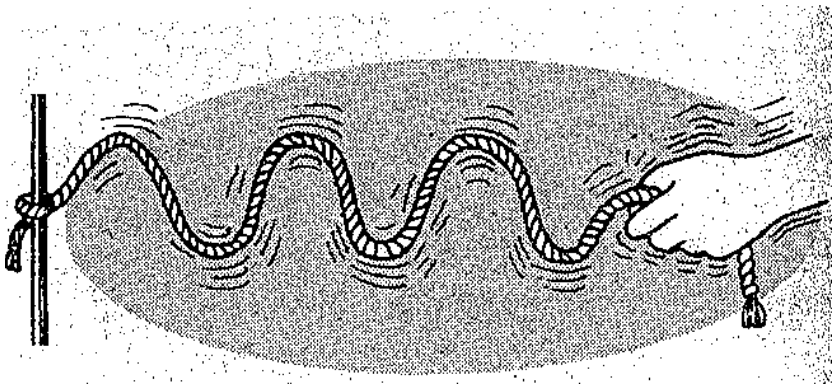
1. In Activity 16.1, how did you generate waves in a rope?
2. What is transferred by waves from one place to another?
3. What is necessary so that energy could be transferred by the waves produced by a rope?

Key to answers on page 19

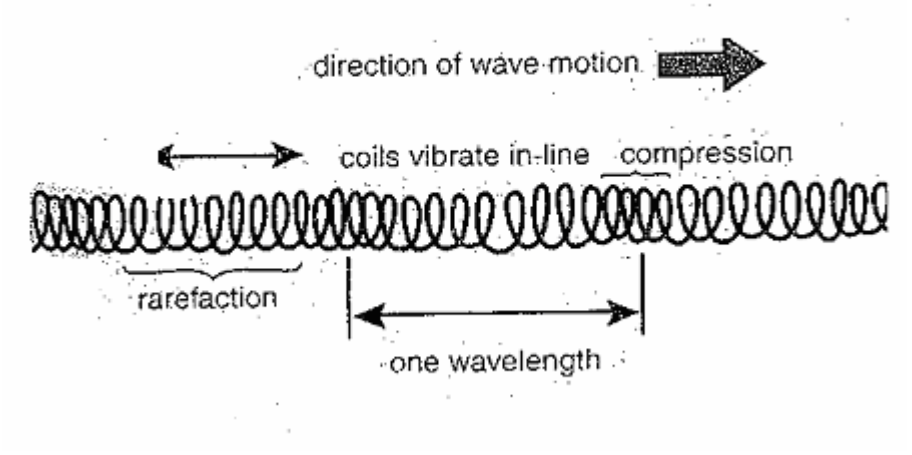
Lesson 2 Types of Waves

There are two types of waves: the *transverse waves* and the *longitudinal waves*. These are *mechanical waves* that require a medium for propagation. Water waves and rope waves are examples of transverse waves. On the other hand, light wave is an example of *electromagnetic wave*, which does not require any medium for propagation. Recall what you did when you generate waves in a rope. When you disturb one end of the rope, how did the rope waves travel with respect to the direction of wave motion? Yes, rope waves travel in a direction perpendicular to the direction of wave motion. This kind of wave is what we call transverse wave.

Below is an illustration of transverse wave.



On the other hand, longitudinal waves are waves which travel in a direction parallel to the direction of wave motion or parallel to the direction of vibration. The figure below illustrates longitudinal waves.



What you will do
Activity 2.1

1. Get a slinky coil in the laboratory or a plastic coil, which is usually played by children. Let a partner hold one end of the coil.

2. Then push and pull the other end. What do you observe? Yes, there are parts in the coil that are compressed and there are parts in the coil that are far apart. This illustrates longitudinal waves.

What you will do
Self-Test 2.1

1. What kind of wave is produced when you flip the edge of the blanket or when you shake the dust from a blanket or rug?
2. Differentiate region of compression from region of rarefaction.

Key to answers on page 20

Lesson 3 Characteristics of Waves

Water waves are easily produced and observed. By touching one point on the surface you can see the peaks of the waves form circles and move outwards from the source of the disturbance.

Some of the characteristics used to describe transverse wave motion are enumerated below:

- The high points are called **crests or peaks** while the low points are called **troughs**.
- The **amplitude** is the maximum displacement from the rest position. It is the height of the crest or depth of a trough measured from the normal undisturbed position.

- The **wavelength, λ**, is the distance between two successive crests or two successive troughs. It is also equal to the distance between any two identical points on successive waves, for example points A and B, and points C and D.
- The frequency, f, is the number of crests or troughs that pass a point per second. This is equivalent to the number of complete waves generated per second. Frequency is measured in terms of hertz (Hz).
- The period, T, is the time taken to generate one complete wave. It is also the time taken for the crests, or any given point on the wave, to move a distance of one wavelength.

$$T = 1/f$$

- The speed, v, of the wave is the distance moved by a wave in one second. Since the wave crest travels a distance of one wavelength in one period, the wave speed,

$$v = \lambda/T \text{ or } v = f\lambda$$

Sample Problem:

The frequency of some approaching ocean waves is 2 Hz and the length between two wave crests is 3 m. What is the speed of the ocean waves moving towards the shore?

Given:
$f = 2$ Hz
$\lambda = 3$ m

Formula: $v = f \lambda$
$= 2$ Hz x 3 m
$= 6$ m/s

What you will do

Activity 3.1

Solve the following exercises:

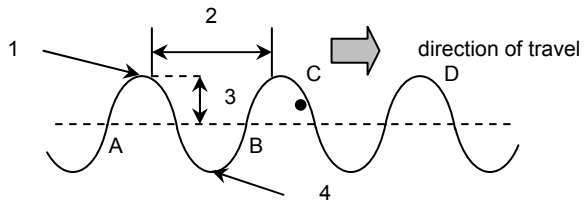
1. A vibration of frequency 5 Hz sends a wave of wavelength 0.8 m down a rope. What is the speed of the wave?
2. A wave of wavelength 1.5 m travels down a rope at a speed of 6 m/s. What is the frequency of the wave?

Key to answers on page 20

What you will do

Self-Test 3.1

A. Below is an illustration of a transverse wave. Identify the characteristic of the wave that is called for in the given item. Write your answer on the space provided below the figure. Refer to the description of each characteristic as mentioned in the early part of Lesson 16.3.



1. _____ 3. _____
2. _____ 4. _____

B. How are the frequency, period and speed of a transverse wave related?

Key to answers on page 20

Lesson 4 Properties of Waves

We can learn more about the behavior of waves by studying water waves. Waves have several common properties. Sound, light, and other types of waves are reflected by barriers in the same way as water waves are reflected.

To show reflection of water waves, try the activity on the next page.

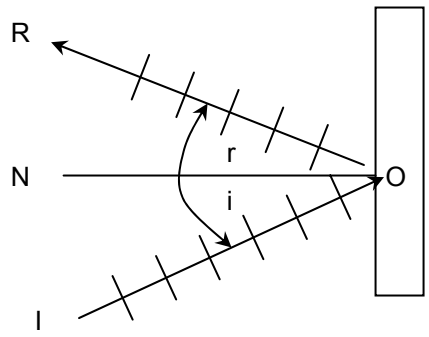
What you will do
Activity 4.1

Prepare a basin with water. Dip your fingertip lightly at the center of the basin. What happens to the wave as it hits the side of the basin?

The preceding activity showed that when water wave hit the side of the basin, the wave turned back. The turning back of wave as it hits a barrier is known as *reflection.* The waves that strike the barrier are called **incident waves** and those waves which turn back after hitting the barrier are called **reflected waves**.

The figure below shows an incident ray represented by IO hitting a barrier at O. ON is normal line perpendicular to the reflecting surface. The angle between the normal line and the incident ray is called the **angle of incidence** and the angle between the normal line and the reflected ray is called the **angle of reflection**.

Angle of incidence is equal to the angle of reflection.



What you will do
Self-Test 4.1

1. What do you think will happen to the waves along the rope when they hit the barrier?
2. Differentiate incident wave from reflected wave.

Key to answers on page 20

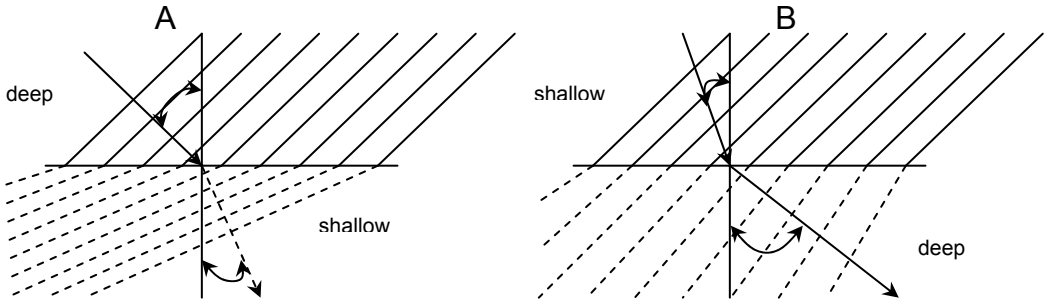
What do you think will happen to the speed of water wave when they moved from the deep to the shallow portions of the river? The wavelength of the waves in the deep part is greater than the wavelength of the waves in the shallow part. Thus, the velocity of the waves in the deep region of the river is greater than the velocity in the shallow portion. This property of waves is what we call *refraction.* The waves change directions as they pass from deep to shallow portions of the water.

What you will do

Activity 4.2

Study Figures A and B in answering the following questions:

1. What happens to the angle of refraction when water waves pass from deep to shallow part of the water?
2. Do the magnitudes of angle of incidence and angle of refraction equal?



Key to answers on page 20

What you will do

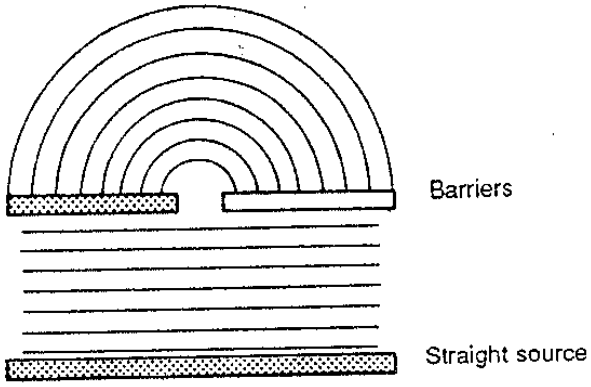
Self-Test 4.2

1. What is refraction?
2. Differentiate angle of incidence from angle of refraction.

Key to answers on page 21

What do you think will happen to the water waves when they pass through openings in a barrier within the same medium? The waves will bend around corners of the barrier. The bending of waves around an obstacle is called **diffraction**.

The figure below shows diffraction of water waves when the opening is small.



Suppose two sets of water waves meet. What would happen? To answer this question, perform the activity that follows.

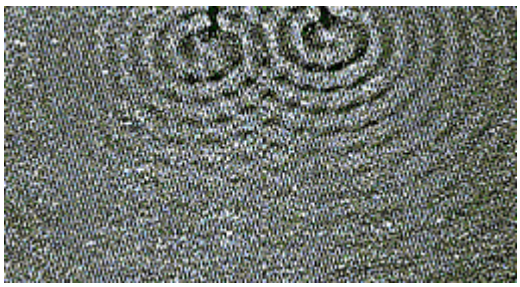
What you will do

Activity 4.3

1. Dip your two fingertips at the center of the basin with water. What happens to the waves produced?

2. Draw your observation.

3. The figures below show constructive interference and destructive interference. Can you differentiate one from the other?



Key to answers on page 21

What you will do

Self-Test 4.3

1. Based on your drawing in the preceding activity, how do you define interference?
2. Suppose a wave with amplitude of 5 cm meets another wave of the same wavelength and amplitude, what is the amplitude of the resulting wave?

Key to answers on page 21

Let's summarize

1. A wave is a disturbance, which travels through a medium in which energy is transferred.
2. A wave pulse is a single disturbance while wave trains are series of disturbances.
3. The two types of waves are transverse waves and longitudinal waves.
4. Transverse waves are waves in which the particles move up and down perpendicular to the direction of the wave motion while longitudinal waves are waves in which the particles move back and forth parallel to the direction of the motion of the wave.
5. The highest points of waves are called crests while the low points are called troughs.
6. The amplitude is the maximum displacement from the rest position.
7. The wavelength is the distance between two successive crests or two successive troughs.
8. The frequency is the number of crests or troughs that pass a point per second. It is measured in hertz (Hz).
9. The period is the time taken to generate one complete wave

$$T = 1/f$$

10. The speed of the wave is the distance moved by a wave in one second.

$$v = \lambda/T$$

11. The properties of waves are reflection, refraction, diffraction, and interference.
12. Reflection is the turning back of waves upon hitting a barrier.
13. Refraction is the change in direction of the waves as they move from one medium to another.
14. Diffraction is the bending of waves as they enter the opening of a barrier
15. Interference is the meeting of two waves at a point.

Posttest

Encircle the letter of the best answer

1. The higher the frequency of the wave is,
    a. the lower is its speed.
    b. the longer is its period.
    c. the greater is its amplitude.
    d. the shorter is its wavelength.

2. Of the following characteristics of a wave, the one that is independent of the others is its
    a. speed.
    b. frequency.
    c. Amplitude.
    d. wavelength.

3. In a transverse wave the individual particles of the medium
    a. move in circles.
    b. move in ellipses.
    c. move parallel to the direction of travel.
    d. move perpendicular to the direction of travel.

4. Water wave is an example of a
    a. standing waves.
    b. stationary wave.
    c. transverse wave.
    d. longitudinal wave.

5. The maximum distance the molecules of a medium are displaced from their rest position is the
    a. speed.
    b. frequency.
    c. amplitude.
    d. wavelength.

6. Two waves meet at a time when one has the instantaneous amplitude A and the other has the instantaneous amplitude B. Their combined amplitude at this time is
    a. A+B.
    b. A- B.
    c. indeterminate.
    d. between A + B and A – B.

7. A source of frequency 500 Hz emits waves of wavelength 0.2 m. How long does it take the waves to travel 600 m?
    a. 3 s
    b. 6 s
    c. 12 s
    d. 60 s

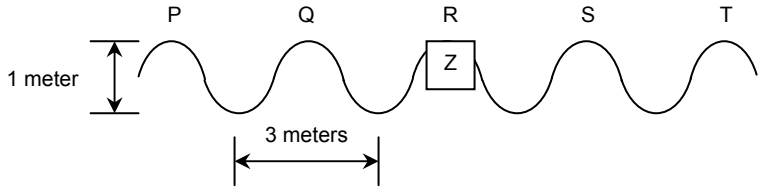
8. All of the following are examples of transverse waves EXCEPT
    a. blue light.
    b. radio waves.
    c. water ripples.
    d. sound waves.

9. The changing of the direction of the wave as it passes from one medium to another medium is called
    a. reflection.
    b. refraction.
    c. diffraction.
    d. interference.

10. Which of the following describes the effect of water waves passing into a shallow water?
    a. wavelength increases, frequency increases, velocity increases
    b. wavelength increases, frequency unchanged, velocity increases
    c. wavelength decreases, frequency increases, velocity unchanged
    d. wavelength decreases, frequency unchanged, velocity decreases

The figure below represents a sea-wave that causes a small cork (Z) to rise up and down through one complete oscillation every 4 seconds.

Refer to this figure for questions 11-14



11. The amplitude of the wave is
    a. 0.5 m
    b. 1.0 m
    c. 1.5 m
    d. 3.0 m

12. The wavelength of the wave is
    a. 0.5 m
    b. 1.0 m
    c. 1.5 m
    d. 3.0 m

13. The horizontal speed of the wave is
    a. 4 m/s
    b. 12 m/s
    c. 0.25 m/s
    d. 0.75 m/s

14. If the wave is moving to the right, after 4 seconds the cork (Z) will be at position
    a. P
    b. Q
    c. R
    d. S

15. Five waves pass a certain point in one second with a speed of 100 cm/s. What is the wavelength?
    a. 10 cm
    b. 20 cm
    c. 0.5 cm
    d. 0.05 cm

16. If the frequency of the wave is 4/s and its wavelength is 10 cm, what is the speed of the wave?
    a. 4 cm/s
    b. 6 cm/s
    c. 10 cm/s
    d. 40 cm/s

17. A boat tied to a post is rocked by waves 12 m apart and with a speed of 3 m/s. What is the frequency of the wave?
    a. 4 waves /s
    b. 9 waves/s
    c. 15 waves/s
    d. 0.25 waves/s

18. A wave with amplitude of 6 cm meets another wave of the same wavelength and amplitude. If their high parts meet, what is the amplitude of the resulting wave?
    a. 0
    b. 4 cm
    c. 8 cm
    d. 12 cm

19. Suppose the two waves in question #17 meet such that the high part of one wave meets the low part of the other. What is the amplitude of the resulting wave?
    a. 0
    b. 4 cm
    c. 8 cm
    d. 12 cm

20. Which one of the following statements is true for both transverse and longitudinal wave?
    a. It can be refracted.
    b. It can travel through a vacuum.
    c. It can have similar wavelengths.
    d. It can travel with the same speed.

Key to answers on page 21

Key to Answers

Pretest

1. d	6. b	11. d	16. d
2. c	7. d	12. d	17. c
3. c	8. c	13. c	18. a
4. c	9. d	14. c	19. c
5. a	10. d	15. d	20. d

Lesson 1

Activity 1.1

1. single wave; series of waves
2. Wave pulse is a single disturbance made in a wave source while wave train is a series of disturbances in a wave source
3. rope which is solid in form

Self-Test 1.1

1. by disturbing one end of the rope
2. energy
3. medium

Lesson 2

Activity 2.1

1. There is a part in the coil where the particles are closest together and there is a part in the coil where the particles are spread apart.

Self-Test 2.1

1. Transverse wave
2. Region of compression is a part in the wire where the particles are compressed while region of rarefaction is a part in the wire where the particles are far apart.

Lesson 3

Activity 3.1

1. 4 m/s
2. 4 Hz

Self-Test 3.1

1. crest or peak
2. one wavelength
3. amplitude
4. trough

Lesson 4

Activity 4.1

1. The waves are reflected back when they hit a barrier.

Self-Test 4.1

1. The rope waves turned back when they hit the barrier.
2. Incident wave is the wave that strikes the barrier while reflected wave is the wave that turned back after hitting the barrier.

Activity 4.2

1. Angle of refraction is lesser than angle of incidence
2. Angle of incidence is not equal to angle of refraction

Self-Test 4.2

1. Refraction is the change in direction of a wave as it moves from one medium to another medium.
2. Angle of incidence is the angle between a normal line and the incident wave while angle of refraction is the angle between the normal line and refracted wave.

Activity 4.3

1. Waves overlap each other.
3. Constructive interference is the meeting of two waves with the same shape and amplitude resulting to a bigger wave while destructive interference is the meeting of two waves with opposite displacements and the sum of their amplitudes is zero.

Self-Test 4.3

1. Interference is the meeting of two waves moving simultaneously in the same direction that pass through the same medium.
2. 10 cm

Posttest

1. d	6. a	11. a	16. d
2. c	7. b	12. d	17. d
3. d	8. d	13. d	18. d
4. c	9. b	14. c	19. a
5. c	10. d	15. b	20. a

-End of Module-

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