SPH3U-C

UNIT 1

Waves and Sound

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Introduction

In this unit, you will learn how sound travels in waves and how the properties of wave motion are a factor in everything, from how musical instruments are designed, to how skyscrapers are built.

Overall Expectations

After completing this unit, you will be able to

- identify and describe different types of waves
- solve problems related to the wave equation
- explain why the speed of sound varies from one medium to another
- determine the properties of waves as they interfere with each other
- analyze the negative impact of noise on society and the environment
- predict and analyze the conditions needed to produce resonance
- explain how resonance is involved in musical instruments

SPH3U-C

Lesson 1

Characteristics of Waves

Introduction

You might be sitting peacefully in your living room, when a truck rumbles by or a jet thunders overhead. The windows may rattle and the floor might shake. Even though the truck or jet is far away, you hear the noise and may even feel it. These are common examples of what are called mechanical waves.

Waves play an important part in our lives. For example, we obtain information about our environment from sound waves; however, not all sound waves are appreciated. When we listen to music the sound waves can be pleasant, but loud noises, like the ones created by a truck, can disrupt our environment.

Planning Your Study

You may find this time grid helpful in planning when and how you will work through the lesson.

Suggested Timing for This Lesson (Hours)	
What Is a Wave?	1
Types of Waves	1
The Wave Equation	1
Reflecting Waves	1
Key Questions	½

What You Will Learn

After completing this lesson, you will be able to

- calculate both the period and frequency for periodic motion
- identify and describe different types of waves
- investigate and solve problems related to the wave equation
- describe the reflection of waves for mediums with both fixed and free ends
- explain the impact of noise pollution

What Is a Wave?

Imagine you are sitting in a large stadium (such as the Rogers Centre in Toronto) watching a major league sporting event. You notice a ripple as the fans in the seats across the field create a "wave." What exactly is happening? If you look closely, you will see that one of the fans gets excited and then stands up, arms extended) and then sits down. This excitement or energy is then passed on to the fan in the next seat, who repeats the process.

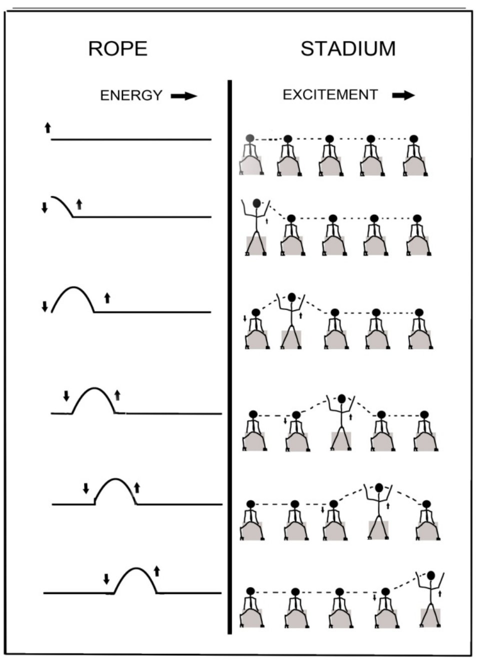


Figure 1.1

From a distance, you cannot distinguish the individual fans. All you can see is the ripple/excitement/energy moving across the row. Note that the fans keep their positions and only the energy moves.

The same effect can be seen if you have a stretched rope and you rapidly move one end up and down to create a pulse. The energy will be transferred from particle to particle along the rope. Again, the rope particles stay in place and only the energy moves.

The particles that transfer the energy of the wave make up what is called the "medium." In the examples, the mediums were sports fans and rope particles.

A wave, then, is a disturbance that transfers energy from particle to particle along a medium.

A child moving back and forth on a swing can be described in many of the same ways as wave motion. A playground swing is like a pendulum, which is just a mass tied to a string that is swinging back and forth. Waves are often produced by this type of periodic motion. Periodic motion, like vibration or oscillation, is motion that repeats itself over and over again in equally spaced time intervals.

For the child on the swing, one complete vibration, or cycle, would require them to swing from the top of one side, down to the bottom, then to the top on the other side, back to the bottom, and then back to where they started. The distance in either direction from the equilibrium, or rest position (when the mass is at rest, hanging vertically), to the maximum displacement (when the mass is at maximum deflection) is called the amplitude.

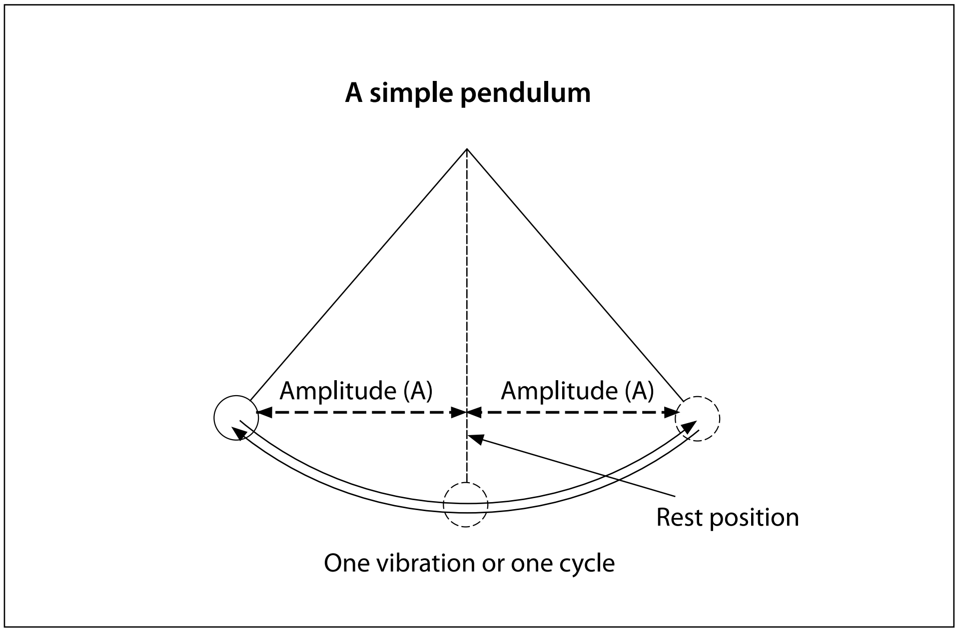


Figure 1.2

As the pendulum swings back and forth, it repeats each cycle in the same amount of time. The time for one complete cycle for any periodic motion is called the period (T). The period can be calculated using the following equation:

$$T = \frac{\text{total time}}{\text{number of cycles}} \quad \text{or} \quad T = \frac{\Delta t}{N}$$

Example

The pendulum in Figure 1.2 makes 20 cycles in 5.0 seconds. What is the time needed to complete one cycle?

$$T = \frac{\text{total time}}{\text{no. of cycles}} = \frac{5.0 \text{ s}}{20 \text{ cycles}} = 0.25 \text{ s (1/4 second)}$$

The period is usually measured in seconds, but larger units of time can be used for convenience if the period is very long.

The number of cycles per second is called frequency (f). The unit of frequency is the hertz (Hz). Frequency can be calculated using the following equation:

$$f = \frac{\text{number of cycles}}{\text{total time}} \quad \text{or} \quad f = \frac{N}{\Delta t}$$

1 Hz = 1 cycle/s

10 Hz = 10 cycles/s

1000 Hz = 1000 cycles/s

Note that 1000 Hz can also be called 1 kilohertz (kHz)

25 kHz = 25 000 cycles/s

Example

What is the frequency of the pendulum in the previous example?

$$f = \frac{\text{number of cycles}}{\text{total time}} = \frac{20 \text{ cycles}}{5.0 \text{ s}} = \frac{4.0 \text{ cycles}}{\text{s}} = 4.0 \text{ Hz}$$

Notice that the two answers for period and frequency are reciprocals of each other. Therefore, if you divide 1 by the period, you will get frequency or vice versa:

$$f = \frac{1}{T} \quad \text{or} \quad T = \frac{1}{f}$$

Example

A mass on a string vibrates 22 times in 11 s. Find the period and the frequency.

Solution

$N = 22, \ \Delta t = 11 \text{ s}$

$$T = \frac{\Delta t}{N}$$

$$T = \frac{11 \text{ s}}{22} = 0.50 \text{ s}$$

$$f = \frac{1}{T} = \frac{1}{0.50 \text{ s}} = 2.0 \text{ Hz}$$

The period is 0.50 s and the frequency is 2.0 Hz.

Example

A child is sitting on a swing, going back and forth with a constant amplitude of 1.4 m. Find the total horizontal distance that the child moves through in five cycles.

Solution

In one cycle, the child moves through four amplitudes. There is a total of five cycles; therefore, the total distance = 4 × (1.4 m) × 5 = 28 m.

The child moves a total horizontal distance of 28 m.

Two identical pendulums are said to be in phase if they have the same period and pass through the rest position at the same time, as well as if they move together (as shown in Figure 1.3). If you watched them side by side, they would swing back and forth together. Each would reach the maximum amplitude, as well as the rest position, at the same time. Pendulums are vibrating out of phase if they do not have the same period or do not pass through the rest position at the same time.

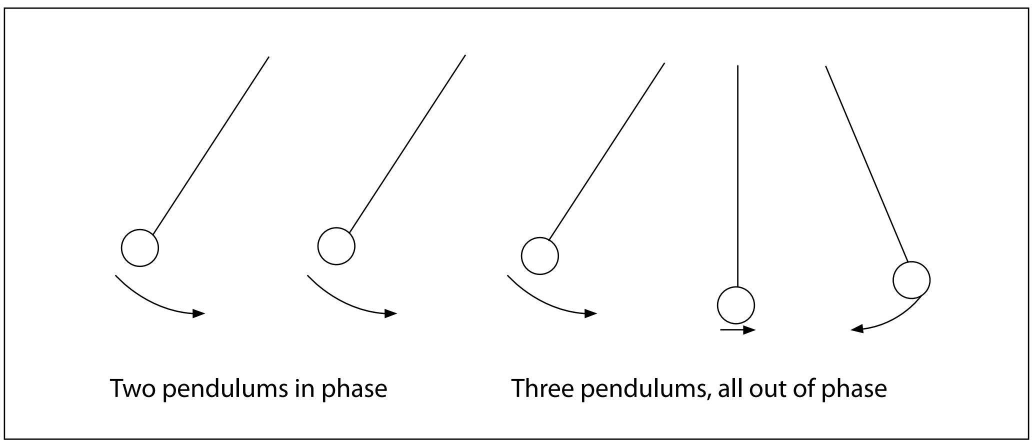


Figure 1.3

A pendulum is not the only example of periodic motion. Others include a boat bobbing up and down as waves pass by, a mass on a spring moving back and forth, and the second hand on a clock. The number of other examples of periodic motion are too numerous to mention. In this unit, you will concentrate on sound, and methods of producing sound, as the main type of periodic motion.

Support Questions

Be sure to try the Support Questions on your own before looking at the suggested answers provided. Click on each "Suggested answer" button to check your work.

1. Find the frequency and the period for each of the following:

a) A light bulb turns on and off 60 times in 1 s.

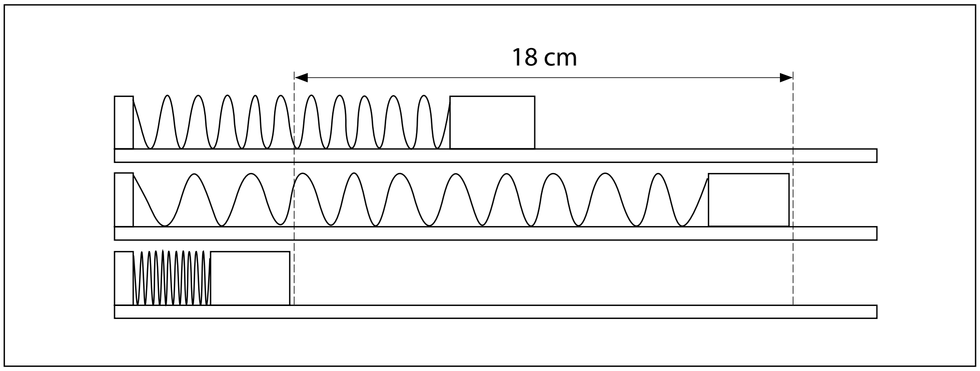
b) A bird flaps its wings 120 times in 6 s.

Suggested answer

2. Consider the second hand of a typical clock. It moves around in a circle with a constant period and frequency. State the period. Explain your reasoning.

Suggested answer

3. The following diagram shows a single mass moving back and forth, while attached to a spring. It takes the mass 6.0 s to move through three cycles.



a) Find the amplitude.

b) How far does the mass move in three cycles?

c) What is the frequency?

d) Find the period.

Suggested answer

Types of Waves

You may already have noticed that there are different types of waves. These waves share many similar qualities, such as periodic motion and constant period and frequency, but they often look quite different. In this section, you will study two different types of wave motion and learn how to recognize them.

To explore the development of waves, look at Wave Creation.

Transverse Waves

Review the Rogers Centre and rope wave examples earlier in this lesson. Recall that the particles of the medium (the fans) move up and down while the energy excitement of the wave moves across. The same happens in the rope. These waves are both examples of a transverse wave.

In a transverse wave, the motion of the particles and the direction of the energy are at right angles (perpendicular) to each other. Only the energy moves across; the particles remain at their location as they transfer energy from one to the next.

Figure 1.4 shows the creation of a transverse wave as the end of a rope is moved through one complete up-and-down cycle or vibration. Notice, that, after completing one cycle, the energy has reached only point E on the rope. The distance the wave has travelled after the source has made one vibration is called a wavelength. This is given the symbol λ (the Greek letter lambda).

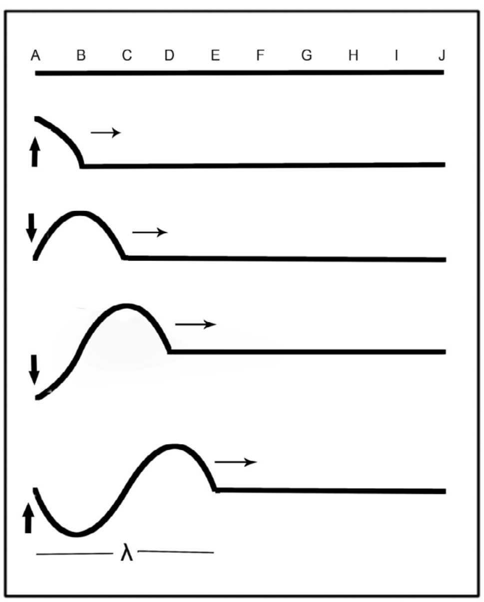


Figure 1.4

The high section of the wave is called a crest and the low section is called a trough. The crest is also called a positive pulse because the amplitude is above the rest position. Troughs are also called negative pulses because their amplitude is below the rest position.

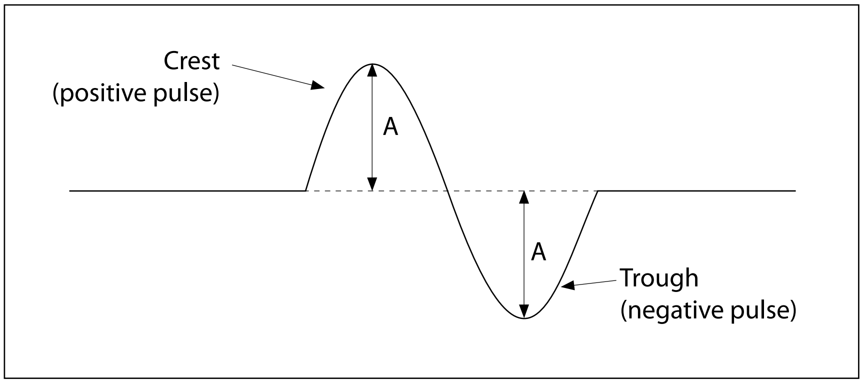


Figure 1.5

If a periodic vibration is used to produce a transverse wave in a rope, then a series of crests and troughs will be visible in the rope at one time. To produce this type of wave motion, your hand would have to move with a constant frequency (period) up and down, as shown in Figure 1.6. All of the crests and troughs would have equal amplitudes and lengths. Notice that the pattern of the waves is repetitive. The wavelength (the distance across one crest and one trough) remains constant. It is usually measured in metres or centimetres. Several examples showing how to measure wavelength are shown in the diagram.

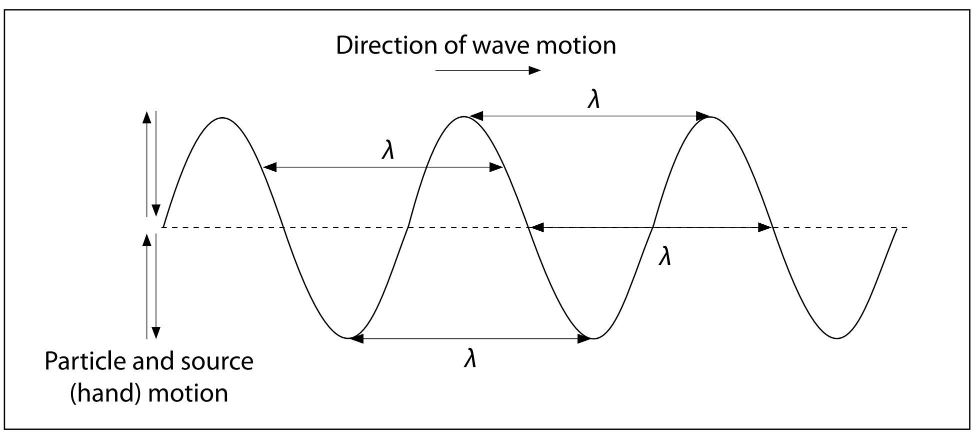


Figure 1.6

Real waves in ropes must pass through the air or rub against a surface, as they move along the rope. In such cases, friction often reduces the amplitude of the wave as it moves through the medium. You will also see that the amplitude of the wave gradually decreases as it moves through the medium, but the wavelength does not change.

Longitudinal Waves

When the particles in the medium vibrate parallel to the direction of wave motion, the wave is called a longitudinal wave. The most common longitudinal waves are sound waves. You will learn more about sound waves later in this unit.

One way to visualize longitudinal sound waves is to use a “slinky” spring. To produce a longitudinal wave in a slinky, tie one end to a fixed position and hold the other end in your hand. With the slinky stretched out to a reasonable length you can move the end you are holding towards the slinky and then back again, parallel to the length of the slinky.

This periodic motion will produce compressions in the slinky when you are pushing towards it. In this case, the slinky’s coils will get bunched together. You will produce rarefactions when your hand moves away from the slinky. In this case, the coils of the slinky will spread further apart. These compressions and rarefactions will move down through the length of the slinky, parallel to the direction of wave motion. In general, a compression occurs when the particles of the medium in a longitudinal wave are closer together than normal, and a rarefaction is when the particles are further apart than normal.

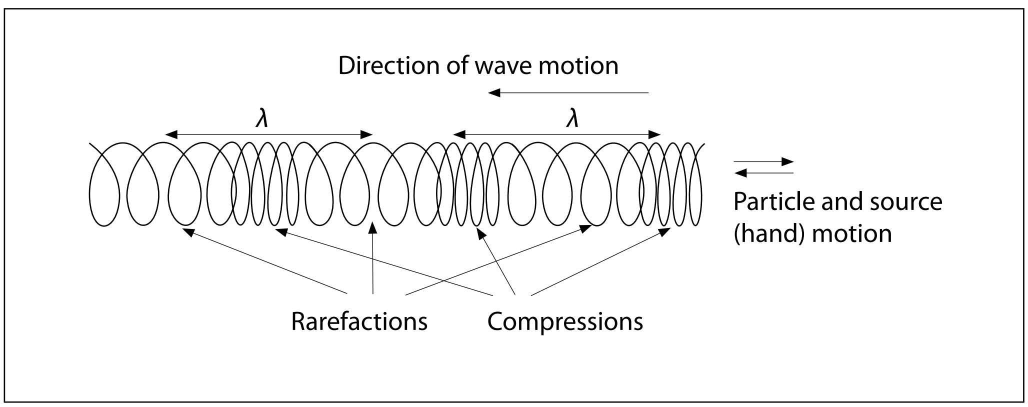


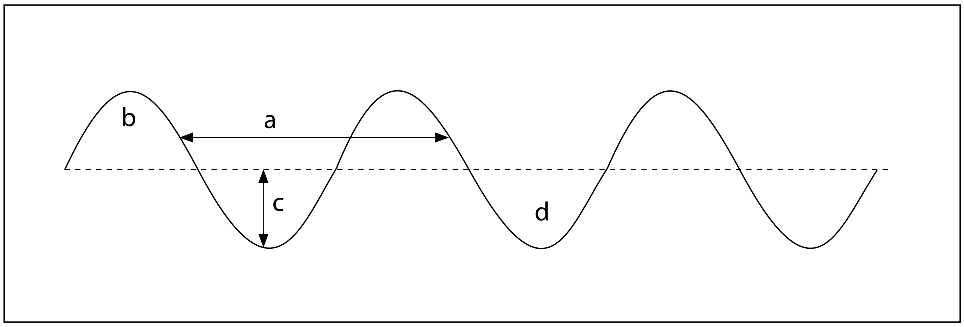
Figure 1.7

If you tie a ribbon to the slinky, you will see the ribbon move back and forth, parallel to the wave motion, as shown on the right-hand side of Figure 1.7. For a longitudinal wave, a wavelength is measured from the centres of two successive compressions or rarefactions, as shown in the diagram. As with transverse waves, the maximum displacement of the particles from the rest position is the amplitude. In one cycle, these particles will move a distance of four times the amplitude.

Support Questions

4. Explain the difference between a transverse wave and a longitudinal wave. Suggested answer

5. Which type of wave is shown in the following diagram? Name all of the parts of the wave labelled by the letters in this diagram.



Suggested answer

The Wave Equation

In this section, you will consider the motion of a wave through a rope and derive an equation for the speed of a wave. Imagine that the rope is tied to a secure position at one end, while you hold the other end in your hand. To make a crest, you would first move your hand rapidly up and then back down to the rest position, followed by moving your hand down and then back up to the rest position to make a trough. As you make this periodic motion, the wave will move through the rope (medium), as shown in Figure 1.8. Remember that each time the source makes one cycle, the wave advances one wavelength.

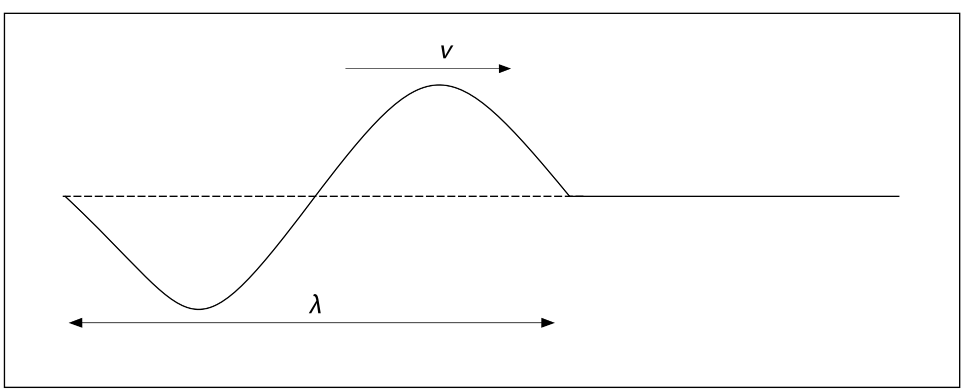


Figure 1.8

Figure 1.9 represents a rope that vibrates at a frequency of 2.0 Hz. That means that in one second the end of the rope goes though two complete vibrations and creates two compete waves. The wavelength is 3.0 m. After each complete vibration, the source pushes the wave another 3.0 m along the medium.

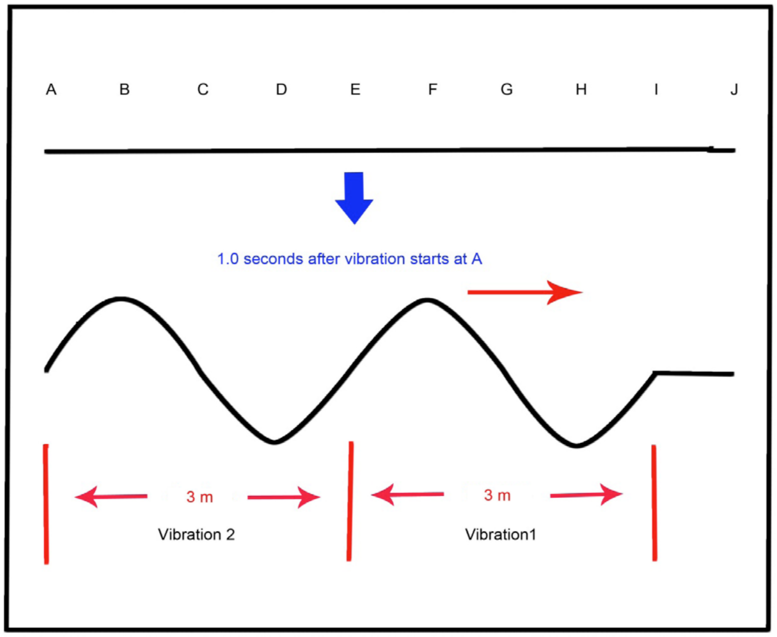


Figure 1.9

Exactly 1.0 seconds after the vibration starts, the wave has travelled 6.0 m.

Since speed = distance/time, or $\boldsymbol{v} = \boldsymbol{\Delta d/\Delta t}$ the speed of this wave is 6.0 m/1 s

v = 6 m/s

The speed of a wave can also be represented by the equation $v = f\lambda$

v = (2 waves/s)(3 m/wave) = 6 m/s

Example

The wavelength of a water wave in a swimming pool is 4.0 m. The wave travels 6.0 m in 2.7 s. Find the frequency of the wave.

Solution

$\lambda = 4.0$ m, $\Delta d = 6.0$ m, $\Delta t = 2.7$ s

First, find the speed of the waves.

$$v = \frac{\Delta d}{\Delta t}$$

$$v = \frac{6.0 \text{ m}}{2.7 \text{ s}} = 2.2 \text{ m/s}$$

$$v = f\lambda$$

$$f = \frac{v}{\lambda}$$

$$f = \frac{2.2 \text{ m/s}}{4.0 \text{ m}} = 0.55 \text{ Hz}$$

The frequency is 0.55 Hz.

Now, complete the following digital activity to reinforce many of the concepts you have learned about waves, as well as finding out about some new ones.

Digital Activity: Properties of Waves

Have a look at the activity Properties of Waves.

Part 1: Simulating Transverse and Longitudinal Waves

Run the simulation of two slinkies placed parallel to each other. A source makes one complete cycle in each slinky. Observe the waves moving through the slinkies for several seconds. Pay special attention to the motion of the medium as the wave passes through it.

This simulation would be more effective if the student could stop the clock and freeze the wave when it has travelled 1 m.

Questions

a) How can you tell which one is a longitudinal wave and which one is a transverse wave?

b) How does the source move to produce the waves for each slinky?

c) How can you identify a compression? How can you identify a rarefaction?

d) How can you identify a crest? How can you identify a trough?

Suggested answer

Part 2: The Speed of a Wave

Select Part 2: "The Speed of a Wave" from the menu at the bottom left of the activity. Run the simulation once for each frequency. Observe the wave as it travels along the medium. Measure the distance the wave has travelled and the time it took to move through the medium. Also measure the wavelength of the wave. Record the information, using the following as a model.

A: f = 2.0 Hz

Δd = ______________ Δt = ________________ λ = _______________

Find the speed of the wave using two different methods and compare the results.

B: f = 1.0 Hz

Δd = ______________ Δt = ________________ λ = _______________

Find the speed of the wave using two different methods and compare the results.

C: f = 4.0 Hz

Δd = ______________ Δt = ________________ λ = _______________

Find the speed of the wave using two different methods and compare the results.

Suggested answer

Questions

a) What evidence do you have from this activity that the wave equation $v = f\lambda$ is correct?

b) What effect does changing the frequency of the wave have on the

i) wavelength?

ii) speed of the wave?

Suggested answer

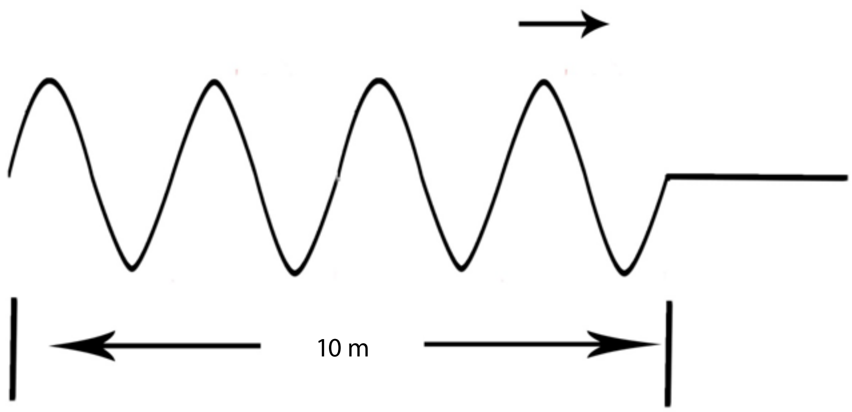
In the activity you observed several things, but the most important idea was that the frequency of the source did not affect the speed of the wave in a given medium. In fact, the speed of a wave moving through a uniform medium is constant. If the frequency increases, then the wavelength decreases proportionally and the product of the two quantities remains constant. Then, according to the wave equation, $v = f\lambda$, the speed will also remain constant. Obviously, if the medium is changed, the speed of a wave can also change. However, for any given medium, the speed at which a wave travels will not change, no matter what the source that is producing the wave does.

Support Questions

6. A wave takes 4.2 s to travel 10.5 m through a rope. If the waves are 0.60 m long, find the frequency of the source. Suggested answer

7. A student watches a boat bob up and down 12 times in 24 s. The water waves travel 24 m in 8.0 s. Find the wavelength of the water waves. Suggested answer

8. Exactly 1.0 seconds after a wave is created in a rope, the following image is captured.



a) Find the speed of the wave.

b) What is the frequency?

c) What is the wavelength.

d) Show that $v = f\lambda$ also works here. Suggested answer

Reflecting Waves

When a wave travelling through one medium runs into another medium, it can reflect off the new medium and head back the way it came. This can occur when a sound wave in the air hits a wall, when an ocean wave hits a cliff, and when a transverse wave in a slinky hits the end of the slinky. Examples of this, such as echoes and the properties of sound that make musical instruments work, will be studied in this unit. Applications such as anti-reflective coatings for eyeglasses and CDs/DVDs/Blu-ray Discs™ will be studied in more advanced courses.

To keep this concept as simple as possible, first consider one end of a rope tied to a fixed position. The end that is tied is called the fixed end because it cannot move. If a transverse pulse moves towards this fixed end it will push on the fixed end, but, as stated before, this point will not move. The fixed end will actually push back on the medium in the opposite direction. The result will cause the reflected pulse to be inverted vertically. In other words, a crest will be reflected as a trough, and vice versa. In addition, since the front of the pulse will interact with the fixed end first, it will be reflected first, while the back of the pulse will be reflected later, because it reaches the fixed end later. This will cause the pulse to be inverted horizontally as well. The following diagram shows how a strange-looking triangular pulse will be reflected from a fixed end.

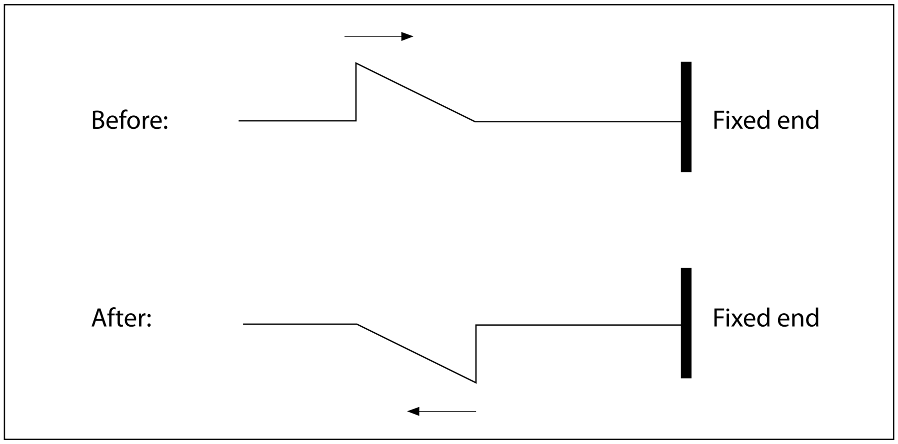


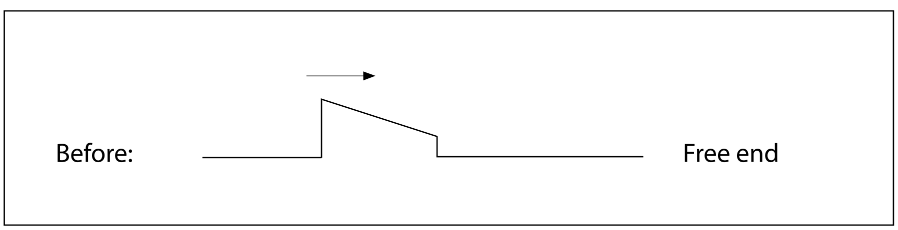
Figure 1.10

Notice that the wavelength, frequency, and speed of the pulse are unchanged. The pulse is still in the same medium, so the only thing that switches is its orientation.

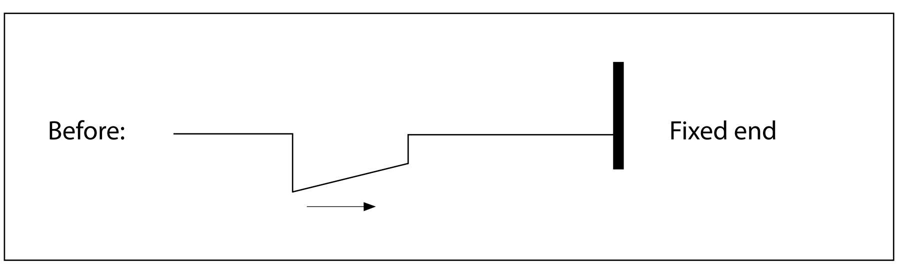
Support Questions

9. Each of the following diagrams shows an incident pulse travelling towards one end of a rope. Draw a diagram showing the reflected pulse for each one.

a)



b)



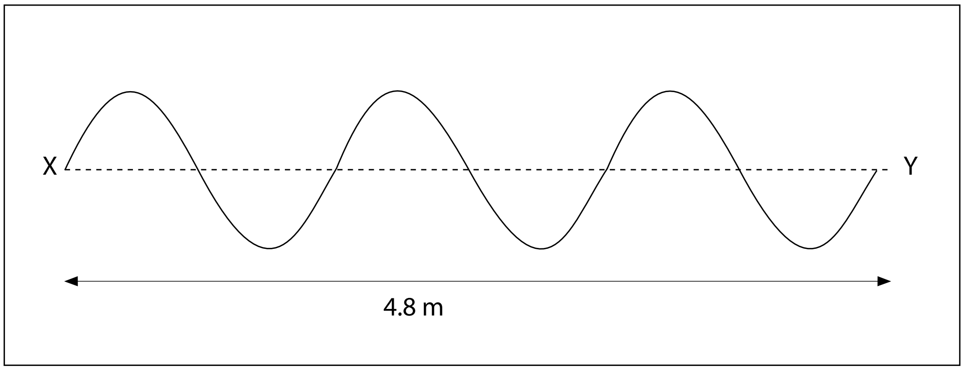
Suggested answer

Key Questions

Now work on your Key Questions in the online submission tool. You may continue to work at this task over several sessions, but be sure to save your work each time. When you have answered all the unit's Key Questions, submit your work to the ILC.

(26 marks)

1. Look at this diagram of a wave in a rope.

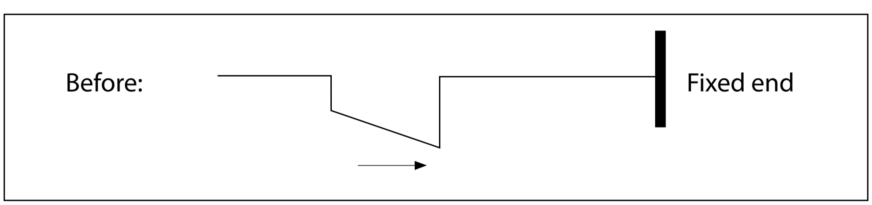


- explain how the amplitude and one wavelength are measured
- find the wavelength in metres
- if the time that the wave takes to move from point X to point Y is 6.0 s, determine the speed of the wave and its frequency
- find the speed and wavelength if the frequency of the source changed to 2.0 Hz and explain your reasoning

(12 marks)

2. Explain the differences and similarities between transverse and longitudinal waves **and** the difference between wavelength and amplitude **and** the difference between period and frequency. **(6 marks)**

3. The diagram shows an incident pulse travelling towards one end of a rope. Draw a diagram showing the *reflected* pulse. **(2 marks)**



4. A pendulum swings back and forth, completing 16 cycles in 8.0 s. Find the period of the pendulum **and** the frequency of the pendulum **and** how long it would take the pendulum to complete 5.0 cycles. **(6 marks)**

Save your answers to the Key Questions in the online submission tool. You'll be able to submit them when you've finished all the Key Questions for this unit. Now go on to Lesson 2!