SUMMARY Transmission and Reflection

- Pulses reflected from a fixed end are inverted.
- Pulses reflected from a free end are not inverted.
- When a pulse enters a new medium, no inversion occurs.
- When a wave enters a slower medium, its wavelength decreases; in a faster medium the wavelength increases.
- When waves strike the boundary between two different media, partial reflection occurs.
- The phase of transmitted waves is unaffected in all partial reflections, but inversion of the reflected wave occurs when the wave passes from a fast medium to a slow medium.

Section 6.4 Questions

Understanding Concepts

1. Copy **Table 1** into your notebook and complete. (Note: + means a crest, – means a trough.)

Table 1

Incident pulse	Reflected pulse	Transmitted pulse	Medium change
+	?	?	fast to slow
+	–	?	?
–	?	?	slow to fast

Applying Inquiry Skills

2. Rope A, rope B, and rope C are made of different materials and are attached to one another in a linear fashion forming one continuous strand. Classify ropes A, B, and C as fast, intermediate, and slow media, based on the following observations:
   - A positive pulse in rope A is reflected as a positive pulse and is transmitted as a positive pulse into rope B.
   - The positive pulse transmitted into rope B is reflected as a positive pulse and is transmitted as a positive pulse into rope C.

6.5 Waves in Two Dimensions

We have been looking at waves in a stretched spring or in a rope to understand some of the basic concepts of wave motion in one dimension. How do waves move in two dimensions?

Using a ripple tank, we can study the behaviour of waves in two dimensions. A ripple tank is a shallow glass-bottomed tank. Light from a source above the tank passes through the water and illuminates a screen on the table below. The light is converged by wave crests and diverged by wave troughs, as shown in **Figure 1**, creating bright and dark areas on the screen. The distance between successive bright areas caused by crests is one wavelength (λ).

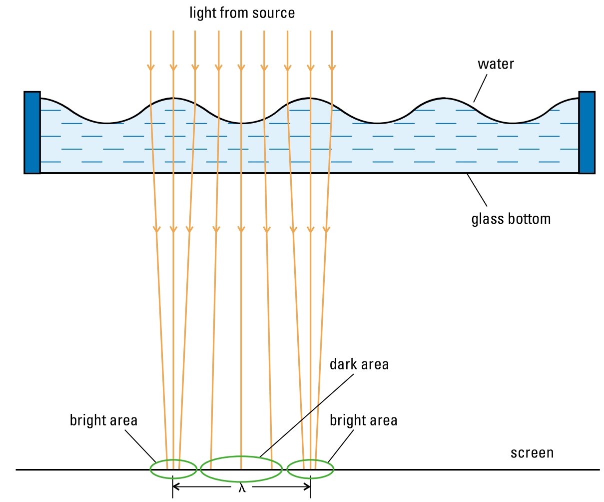

Figure 1
Bright lines occur on the screen where light rays converge.

Figure 2
Periodic circular waves

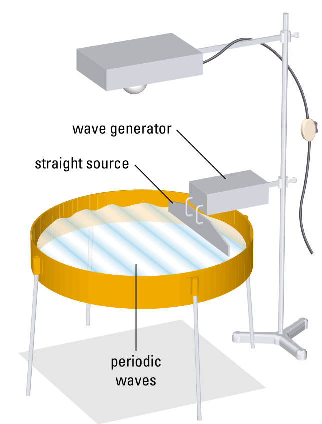

Figure 3
Straight waves

Transmission and Reflection of Water Waves

Water waves coming from a point source in a ripple tank are circular (**Figure 2**), whereas waves from a linear source are straight (**Figure 3**). As a series of periodic waves moves away from its source, the spacing between successive crests and troughs remains the same as long as the speed does not change. That is, the wavelength does not change as long as the speed remains constant. This is predicted by the wave equation ($v = f\lambda$), because when f is constant, $\lambda \propto v$. When the speed decreases, as it does in shallow water, the wavelength also decreases (**Figure 4**).

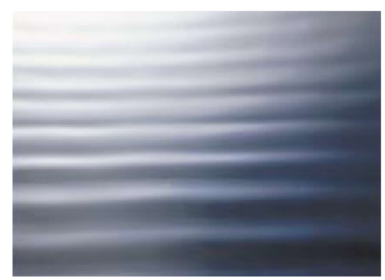

Figure 4
Waves travelling into shallow water have a slower speed and a shorter wavelength.

wavefront: the leading edge of a wave

wave ray: a straight line drawn perpendicular to a wavefront that indicates the direction of transmission

normal: a straight line drawn perpendicular to a barrier struck by a wave

When the frequency of a source is increased, the distance between successive crests becomes smaller. In other words, waves with a higher frequency have a shorter wavelength if their speed remains constant. Although the wavelength and the speed of a wave may change as the wave moves through a medium, the frequency will not change. The frequency can be changed only at the source, and not by the medium.

When waves run into a straight barrier, as shown in **Figure 5**, they are reflected back along their original path. However, if a wave hits a straight barrier obliquely (**Figure 6**), the **wavefront** is also reflected at an angle to the barrier.

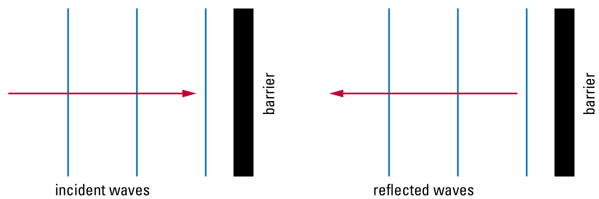

Figure 5
The frequency does not change as a wave moves through a medium.

focal point: a specific place where straight waves are reflected to

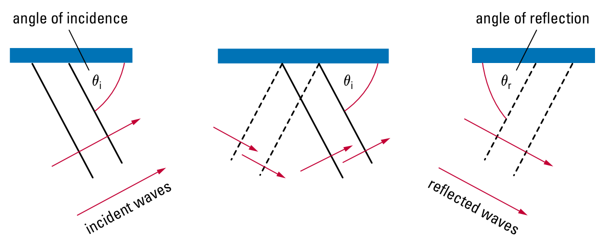

Figure 6
The angle of incidence equals the angle of reflection for a wave that hits a straight barrier obliquely.

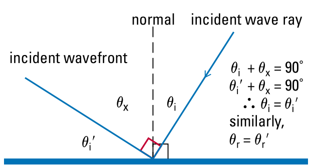

Figure 7

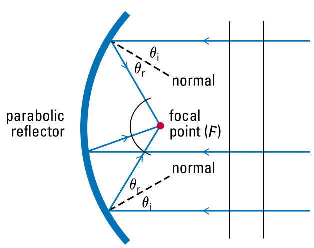

Figure 8

The angles formed by the incident wavefront and the barrier and by the reflected wavefront and the barrier are equal. These angles are called the angle of incidence (θ_i) and the angle of reflection (θ_r), respectively. In neither case does the reflection produce any change in the wavelength or in the speed of the wave.

When describing the reflection of waves, we use the term **wave rays**. Wave rays are straight lines perpendicular to wavefronts indicating the direction of travel. The angles of incidence and reflection for wave rays are measured relative to a straight line perpendicular to the barrier, called the **normal**. This line is constructed at the point where the incident wave ray strikes the reflecting surface. As may be seen from the geometrical analysis shown in **Figure 7**, the angle of incidence has the same value whether wavefronts or wave rays are used to measure it. In both cases the angle of incidence equals the angle of reflection. This is one of the laws of reflection from optics, and is covered in more detail in Unit 4.

Straight waves can be reflected by a parabolic reflector to one point, called the **focal point**. This could have been predicted by means of the laws of reflection using wave rays as shown in **Figure 8**.

When a water wave enters a medium in which it moves more slowly, such as shallow water, its wavelength decreases as well (**Figure 9**). This could have been predicted using the universal wave equation, since we can conclude that $\lambda \propto v$.

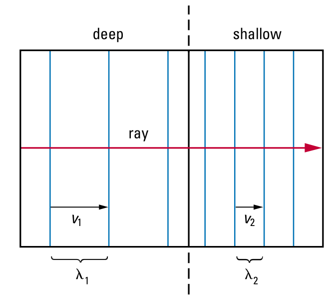

Figure 9

Refraction and Diffraction

When the wave travels from deep to shallow water, in such a way that it crosses the boundary between the two depths straight on, no change in direction occurs. On the other hand, if a wave crosses the boundary at an angle, the direction of travel does change (**Figure 10**). This phenomenon is called **refraction**.

Periodic straight waves travel in a straight line across a ripple tank as long as the depth doesn't change. But if the waves pass by the sharp edge of an obstacle or through a small opening in the obstacle, the waves change direction, as shown in **Figure 11**. This bending is called **diffraction**.

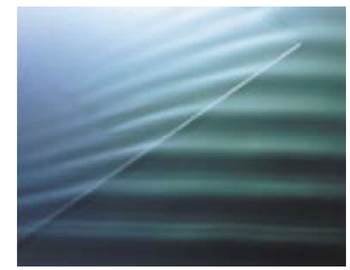

Figure 10
Waves are refracted as they cross a boundary between deep and shallow water if the boundary is at an angle.

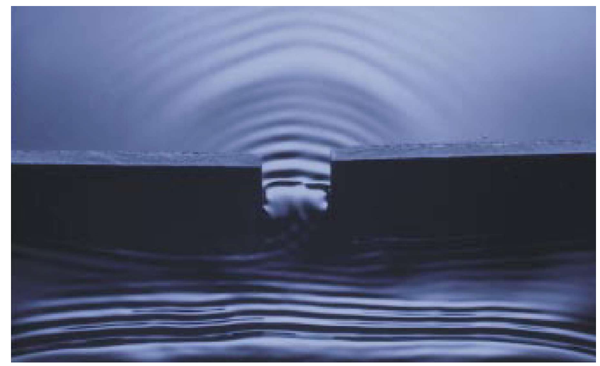

Figure 11
Diffraction of water waves

refraction: the bending effect on a wave's direction that occurs when the wave enters a different medium at an angle

diffraction: the bending effect on a wave's direction as it passes through an opening or by an obstacle

How much the wave bends depends on both the wavelength and the size of the opening in the barrier. For the same opening, long-wavelength waves are diffracted more than short-wavelength waves. Decreasing the size of the opening will increase the amount of diffraction, as shown in **Figure 12**.

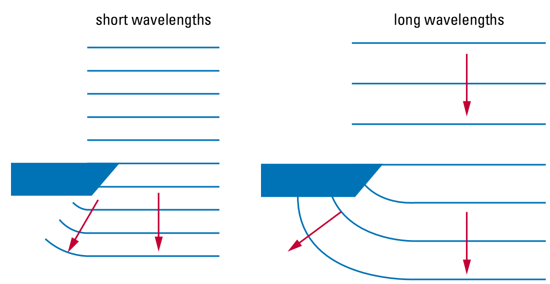

Figure 12

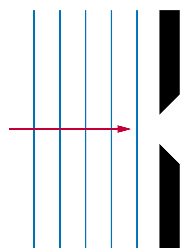

Figure 13
For question 6

Practice

Understanding Concepts

1. (a) Do the bright areas on the screen of a ripple tank represent the crests or troughs of the water waves?
   (b) Are the bright areas formed by converging or diverging rays of light?
2. What happens to the wavelength and the speed of water waves when they reflect off a barrier?
3. When water waves move from deep to shallow water, they slow down. What effect does this have on the wavelength and on the frequency?
4. State the law of reflection as it applies to waves.
5. Distinguish between refraction and diffraction.

Applying Inquiry Skills

6. Predict the shape of the wave fronts that would result if straight periodic water waves went through a very small opening in a barrier. Draw lines to indicate the shape on the right-hand side of **Figure 13**.

SUMMARY Properties of Waves

- A wave ray is a straight line drawn at right angles to the wavefront, indicating the direction of the wave motion.
- When waves are reflected from a solid obstacle, the angle of incidence is always equal to the angle of reflection.
- When a wave enters a medium in which it moves more slowly, its wavelength decreases.
- When a water wave enters a slower medium at an angle, its direction of transmission changes; the wave has undergone refraction.
- When a wave passes by a barrier or through a small opening, it tends to diffract or change direction.

Section 6.5 Questions

Understanding Concepts

1. Draw a sketch illustrating how straight waves behave when
   (a) the frequency of the wave decreases
   (b) the wave encounters a straight barrier straight on
   (c) the wave encounters a straight barrier at an angle
   (d) the wave's speed is reduced
   (e) the wave enters shallow water at an angle
   (f) the wave passes through a small opening
2. What type of sound waves, high frequency (treble) or low frequency (bass), do you predict will diffract better around corners? Explain your answer.

Applying Inquiry Skills

3. Light is transmitted as a high-frequency wave. Predict the size of slit that would be necessary to observe diffraction. Test your prediction by observing a point source of light through a slit plate.

Making Connections

4. Actual water waves do not behave exactly like the ideal transverse waves described in this section. For example, ocean waves increase in amplitude and decrease in wavelength as they approach a beach, but when they near the shore, they "break." Research this issue and, on one page, describe with a diagram how the water particles in a water wave actually move and why this affects their behaviour when waves crash on the beach. Follow the links for Nelson Physics 11, 6.5.

GO TO www.science.nelson.com

6.6 Interference of Waves

Up to this point, we have been dealing with one wave at a time. What happens when two waves meet? Do they bounce off each other? Do they cancel each other out? When pulses travel in opposite directions in a rope or spiral spring, the pulses interfere with each other for an instant and then continue travelling unaffected. This behaviour is common to all types of waves.

Types of Interference

Wave interference occurs when two waves act simultaneously on the same particles of a medium. There are two types of interference: constructive and destructive. For transverse pulses, **destructive interference** occurs when a crest meets a trough. If the crest and trough have equal amplitude and shape, their amplitudes cancel each other for an instant. Then the crest and trough continue in their original directions, as shown in **Figure 1**. For longitudinal pulses, destructive interference occurs when a compression meets a rarefaction.

Constructive interference occurs when pulses build each other up, resulting in a larger amplitude (**Figure 2**). This occurs for transverse pulses when a crest

wave interference: occurs when two or more waves act simultaneously on the same particles of a medium

destructive interference: occurs when waves diminish one another and the amplitude of the medium is less than it would have been for either of the interfering waves acting alone

constructive interference: occurs when waves build each other up, resulting in the medium having a larger amplitude

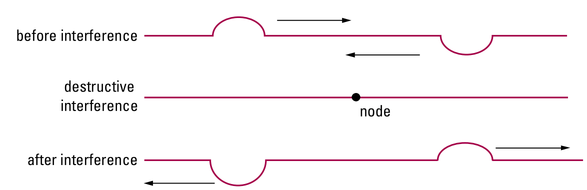

Figure 1
Destructive interference of pulses

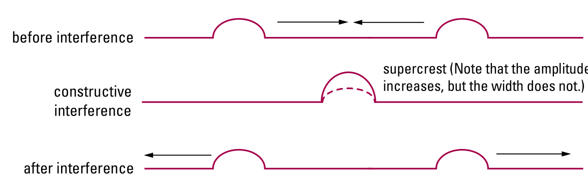

Figure 2
Constructive interference of pulses