9.1 Properties of Waves and Light

If you have ever gone surfing at a water park, or in a lake or an ocean, or watched a news report about a tsunami, you know that water waves can transmit a large amount of energy (**Figure 1**).

Figure 1 Water waves can transmit a large amount of energy.

Other examples of waves are mechanical waves, such as the wave on a vibrating string or the surface of a ringing bell, sound waves such as AM and FM waves, and seismic waves produced by earthquakes. All waves share the same basic properties.

Properties of Waves

periodic wave a wave with a repeated pattern over time or distance

A wave is a moving disturbance that transports energy from one place to another but does not necessarily transport matter. The simplest wave is a periodic wave. A **periodic wave** is a wave that repeats itself at regular intervals.

Figure 2 illustrates one way to generate a mechanical wave. In Figure 2(a), the person's hand exerts a vertical force on the string, creating a wave pulse. Since the force and the resulting pulse act along the length of the string, the force does work on the string. This means that the wave pulse carries energy along the string, from the hand to the wall. In Figure 2(b), as the hand continues to move, the wave becomes periodic. Notice that the points on the strings (matter) do not move horizontally.

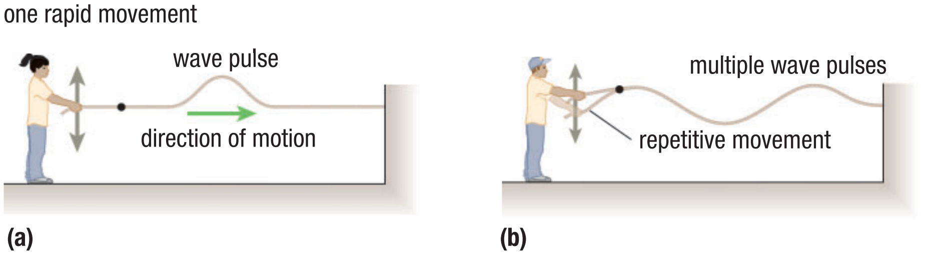

Figure 2 (a) Wave pulse and (b) periodic waves along a string

Suppose that the person is shaking the string such that the string is moving in a periodic fashion in the vertical direction. **Figure 3** shows a snapshot of the wave as it begins to move to the right.

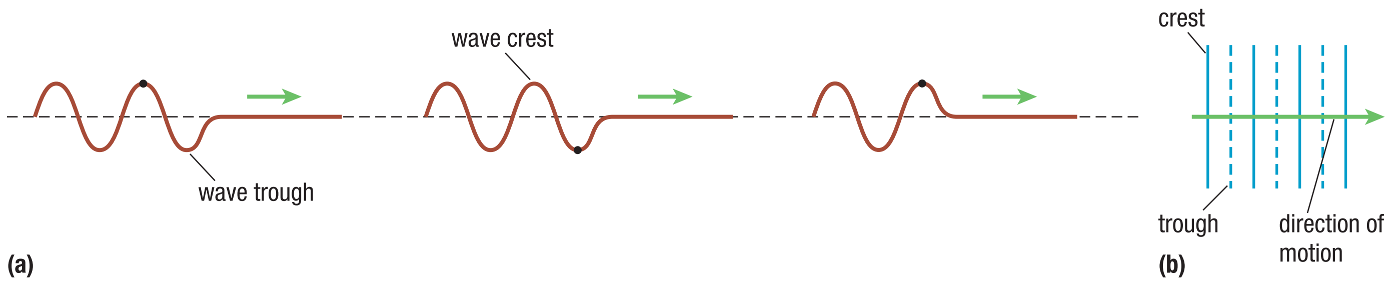

Figure 3 (a) The wave moves to the right. (b) The crests and troughs are shown as waves when viewed from above.

The front edge of a wave is called the **wave front**. The **crest** of the wave is the upper half of the wave. The **trough** of the wave is the lower half of the wave. One complete crest and one complete trough represent one cycle of the wave. The amplitude, A, is the maximum or minimum value of the wave (**Figure 4**). The **wavelength**, λ, of the wave is the distance from one positive amplitude to the next positive amplitude (or one negative amplitude to the next negative amplitude). Two points on a wave that are at the same place in a wave cycle (for example, two successive crests) are said to have the same **phase**. Generally, the phase is the offset of the wave from a reference point. The period, T, of a wave is the time required for one wave cycle to pass a particular point, and the frequency, f, is the number of wave cycles that pass a particular point per unit of time. The SI unit of frequency is the hertz, Hz. One hertz is equal to one cycle per second.

wave front the continuous line or surface at the start of a wave as it travels in time

crest the upper part of a wave

trough the lower part of a wave

wavelength (λ) the distance between one positive amplitude and the next

phase the offset of the wave from a reference point

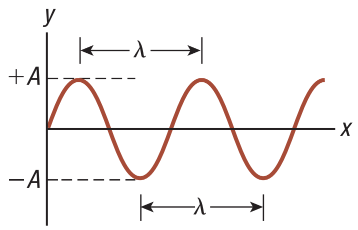

Figure 4 The amplitude is the maximum displacement of a wave. The wavelength is the distance between one positive amplitude, or one negative amplitude, and the next.

How can you use these properties to measure the speed of a wave? Figure 4 shows that the wave moves a distance of $\Delta x = \lambda$ during a period of motion ($\Delta t = T$). The following equation determines the speed of the wave:

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

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

Frequency, f, and period, T, are related according to the following relationships:

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

Substituting the equation for period into the equation for v, you can see that

$$v = \frac{\lambda}{\left(\frac{1}{f}\right)}$$

or

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

This is called the universal wave equation, and it shows that the speed of a periodic wave is related to its frequency and wavelength. A unit analysis of this equation shows that frequency in hertz corresponds to speed in metres per second:

$$v = f\lambda$$

$$\frac{[\mathrm{m}]}{[\mathrm{s}]} = [\mathrm{s}]^{-1}[\mathrm{m}]$$

$$\frac{[\mathrm{m}]}{[\mathrm{s}]} = \frac{[\mathrm{m}]}{[\mathrm{s}]}$$

Reflection

ray approximation treating the propagation of light waves as though they move in straight lines called rays

reflection a change in direction of a light ray when it meets an obstacle where the incoming ray and the outgoing ray are on the same side of the obstacle

In many instances, light travels in straight lines. This model, which treats the propagation of light waves as though they move in straight lines, is called **ray approximation**. **Figure 5(a)** shows the reflection of light modelled by rays. **Reflection** is a change in direction after meeting an obstacle, for example, a mirror, where the original ray and the reflected ray are on the same side of the obstacle, or mirror. **Figure 5(b)** shows the angle of incidence, θ_i, and angle of reflection, θ_r, of one of the rays.

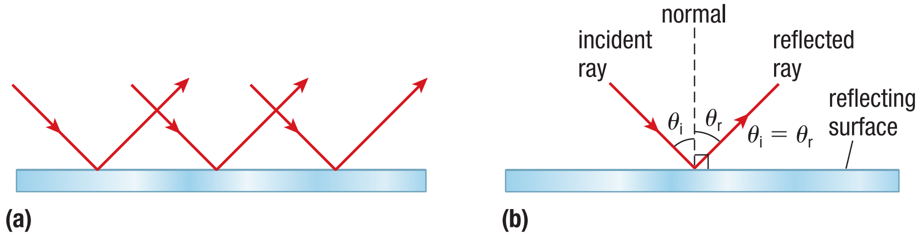

Figure 5 (a) Rays reflecting from a flat surface. Note how the reflected rays are parallel. (b) The angle of incidence is equal to the angle of reflection.

normal the line drawn at a right angle to the boundary at the point where an incident ray strikes the boundary

angle of incidence the angle between the incident ray and the normal

angle of reflection the angle between the reflected ray and the normal

Consider the reflection of light from a flat mirror. The **normal** line is a reference line drawn at a right angle to the surface of the mirror. The **angle of incidence** is the angle between the incoming, or incident, ray and the normal. The **angle of reflection** is the angle between the outgoing, or reflected, ray and the normal. Light, then, behaves according to the **law of reflection**.

Law of Reflection

For reflection from a flat surface, the angle of incidence is always equal to the angle of reflection.

specular reflection the reflection of light from a surface where all the reflected rays are in the same direction

diffuse reflection the reflection of light from a surface where all the reflected rays are directed in many different directions

Reflections from a flat surface, such as the reflecting surface in Figure 5, are called **specular reflections**. If, however, the reflecting surface is rough, as shown in **Figure 6**, then the reflected rays are directed in many different directions as light strikes the different parts of the surface. This is called a **diffuse reflection**.

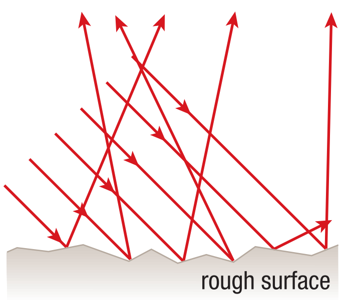

Figure 6 When parallel incident rays reflect from a rough surface, the resulting reflected rays are not parallel. Compare with Figure 5(a).

9.1 Review

Summary

- A wave is a moving disturbance that transports energy from one place to another but does not transport matter.
- The speed of a periodic wave is related to its wavelength and frequency by the universal wave equation, $v = f\lambda$.
- For reflection, we measure the angle between the incident ray and the normal to the reflecting surface, and the reflected ray and the normal to the reflecting surface.
- The law of reflection states that the angle of incidence is equal to the angle of reflection, $\theta_i = \theta_r$.

Questions

1. Explain what determines the frequency of a wave. K/U
2. Explain what determines the speed of a wave. K/U
3. Explain what determines the amplitude of a wave. K/U
4. Explain what determines the wavelength of a wave. K/U
5. A light ray strikes a flat surface making an angle of 10° with the surface. T/I C
   (a) Determine the angle of incidence.
   (b) Calculate the angle of reflection.
   (c) Sketch the path for both the incident and the reflected rays.
6. **Figure 7** shows a wave. The frequency of this wave is 40 Hz. What is the approximate speed of the wave? T/I

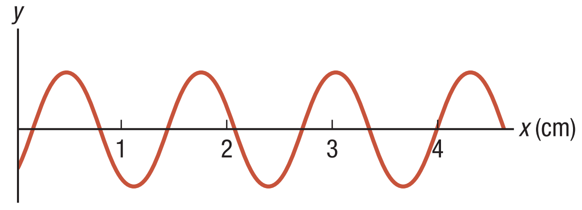

Figure 7

7. A wave travels 0.3 m in 3.5 s and has a frequency of 4.6 Hz. Calculate the wavelength. T/I
8. Determine the frequency of a wave with a period of 0.05 s. T/I A
9. All light waves have a speed of 3.0×10^8 m/s. Calculate the wavelength of light that has a frequency of 5.0×10^{14} Hz. T/I
10. Calculate the frequency of red light waves that have a wavelength of 750 nm. T/I
11. Calculate the wavelength of a violet light with frequency 6.0×10^{14} Hz. T/I
12. A light ray from a source on one wall strikes a flat mirror on the opposite wall. The distance between the walls is 2.5 m. The reflected ray hits the original wall at a point that is 1.2 m below the light source. Determine the angle of incidence, θ_i. T/I
13. Sound waves in water travel at approximately 1.5×10^3 m/s. Calculate the wavelength of a sound wave that has a frequency of 4.4×10^2 Hz. T/I
14. A wave completes one cycle as it moves a distance of 2.0 m at a speed of 20.0 m/s. Calculate the frequency of the wave. T/I
15. A wave has a frequency of 3.1 kHz and a wavelength of 0.13 m. Calculate the speed of the wave. T/I
16. One wavelength of visible radiation has a frequency of 7.9×10^{14} Hz. This radiation has a speed of 3.0×10^8 m/s in air. Determine the wavelength of the radiation. T/I
17. A microwave oven emits microwaves with a frequency of 310 MHz. The speed of microwaves is 3.0×10^8 m/s. Calculate the wavelength of the microwaves. T/I
18. Explain why mirrors can reflect images. K/U
19. Two waves with equal speeds have frequencies that differ by a factor of three. What is the ratio of their wavelengths? K/U A
20. A wave on a string has a frequency of 0.83 Hz and a wavelength of 0.56 m. Determine the wavelength when a new wave of frequency 0.45 Hz is established on this string and the wave speed does not change. T/I A
21. Identify whether the following surfaces cause specular or diffuse reflection, and justify your answer. T/I A
    (a) a flat mirror
    (b) a piece of notebook paper
    (c) the surface of a puddle on a calm day
    (d) the surface of a lake on a windy day