Waves: An Introduction

Basic Ideas

A **wave** can be defined as a disturbance that transfers energy through a medium, without producing net movement in the medium. A **medium** (plural **media**) is the material that a wave travels through.

Waves are generally grouped into two categories:

1. Mechanical Waves
    - these waves require a physical medium (water, air, a spring) through which to travel

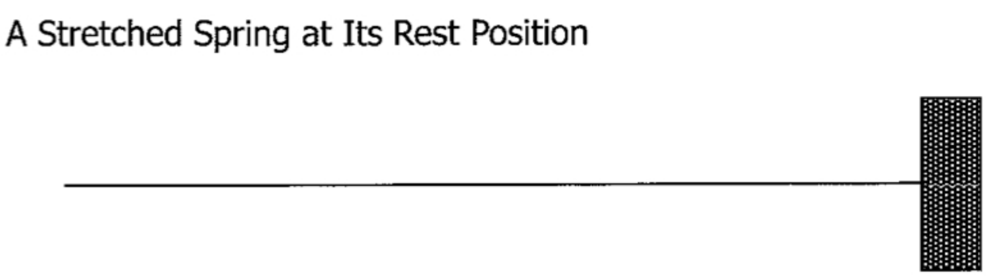
2. Electromagnetic Waves
    - these waves do not require a medium (they can travel through the vacuum of space)

We will work only with mechanical waves until near the end of this unit.

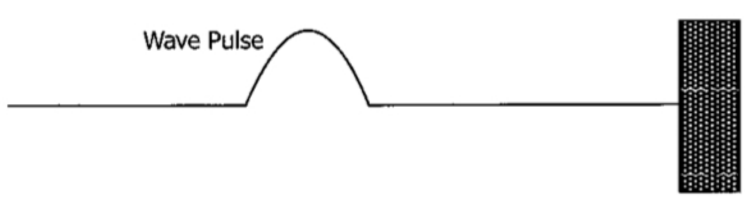
One-Dimensional Waves

A wave that can only travel in a straight line is said to be a **one-dimensional wave**. Such waves are only able to travel either forward or backward along their medium. One very convenient medium for one-dimensional waves is a spring.

The **rest position** (also known as **equilibrium position**) of a spring is the position where each point in the medium is undisturbed.



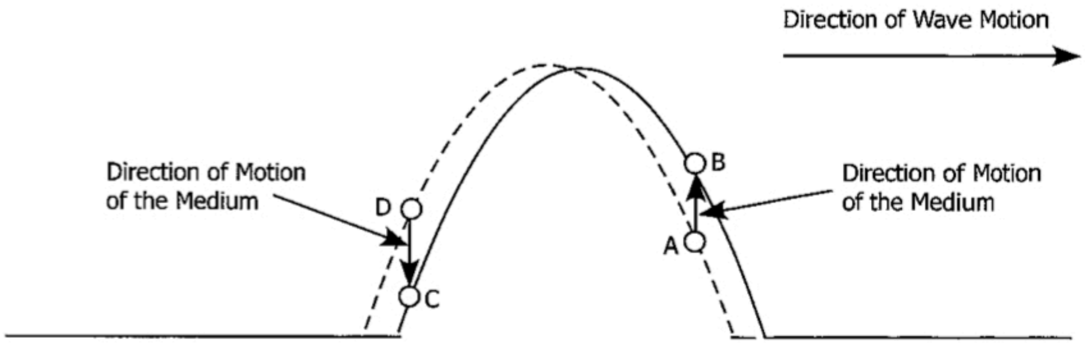
A wave **pulse** is a single disturbance that travels through the medium.



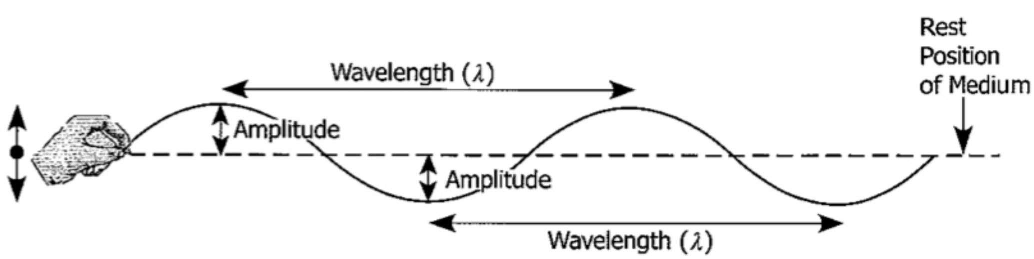
A **continuous wave** (also known as a **periodic wave**) has a series of pulses that are all the same. The **source** of the wave is the object (or person) that starts the wave. Two different types of periodic waves can be generated, depending on how the source disturbs the medium.

Transverse Waves

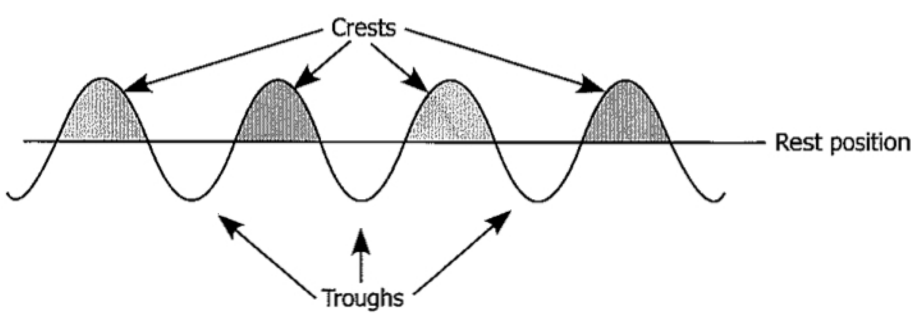
A **transverse wave** is a wave in which the motion of the medium is perpendicular to the direction of the wave motion. Such waves are generated when the source vibrates in a direction that is perpendicular to the direction of wave motion.



There are a number of important characteristics of waves. The diagram below shows a portion of a transverse periodic wave.

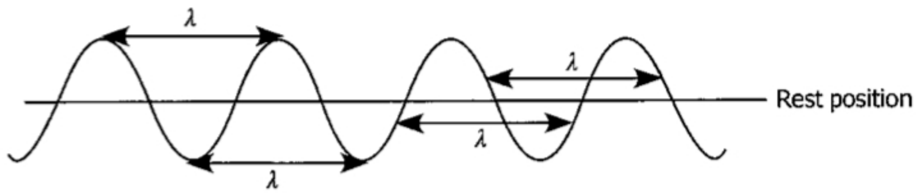


The pulses on one side of the rest position are called **crests**. Those on the other side of the rest position are called **troughs**. For a wave that is vibrating up and down, crests are above the rest position and troughs are below the rest position.

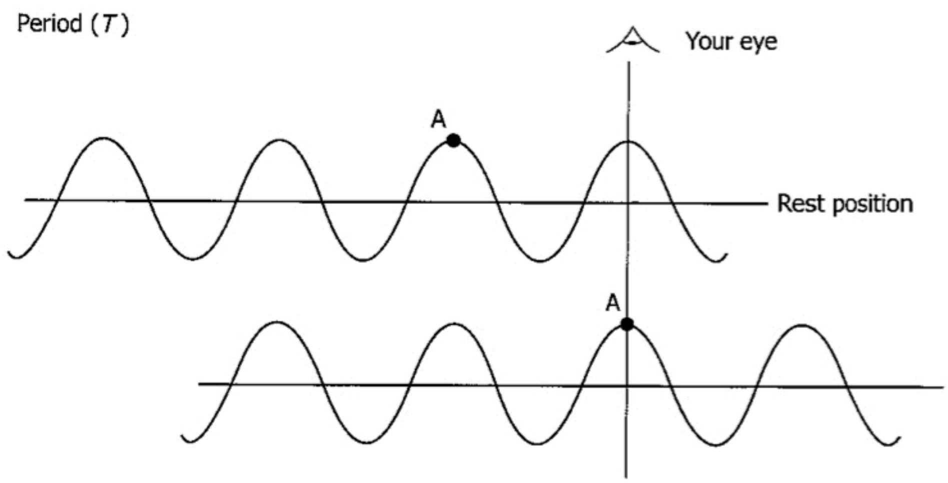


The **amplitude**, A, is the maximum height of a crest, measured from the rest position to the highest point on a crest. The amplitude can also be measured from the rest position to the lowest point on a trough.

One **cycle** of a wave is one complete grouping of a single crest and a single trough. The **wavelength,** λ**,** is the length of one cycle of the wave. Wavelength can also be defined as the distance from one point on a wave to the same point on a successive wave.



The **period**, T, of a wave is the amount of time that the source takes to produce one full cycle (crest and trough). In the diagram below, the point A moves one wavelength to the right. The time it takes the wave to travel one wavelength past your point of view is the period.



Frequency, f, is an indication of how many cycles are produced per second. Frequency is commonly measured in "cycles per second," which is given the name **hertz**, Hz.

Period and frequency are closely related to one another. While period is "how many seconds to complete one cycle," frequency is "how many cycles are completed each second." There is a simple mathematical relationship between period and frequency:

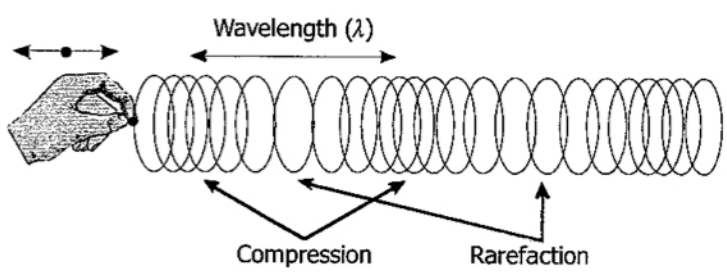
$$T = \frac{1}{f} \qquad\qquad f = \frac{1}{T}$$

Example 1
You are sitting on a dock watching a piece of wood bob up and down on the waves in the water. You notice that as the waves pass by, the wood bobs up and down eight times in 12 seconds. What is the frequency and period of the waves?

Longitudinal Waves

A **longitudinal wave** is a wave in which the motion of the medium is parallel to the direction of the wave motion. Such waves are generated when the source vibrates in a direction that is parallel to the direction of wave motion.

Longitudinal waves do not have crests and troughs. Instead, they have **compressions** (places in which the medium is bunched up, or compressed) and **rarefactions** (also known as **expansions**, which are places in which the medium is relatively spread out).



The wavelength on a longitudinal wave can be measured from the center of one compression to the center of the next compression (for example).

Frequency and period have the same meaning for longitudinal waves as they do for transverse waves.

Amplitude is more complicated for longitudinal waves, and so we will only use it for transverse waves.

Wave Speed

The speed at which a wave travels through a medium can be determined in one of two ways. The first involves simply measuring the distance traveled by a single crest of the wave in a given amount of time. The speed of the wave is then calculated as:

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

The second method uses observable properties of the wave: namely, period and wavelength. In observing the motion of a wave, it becomes apparent that the wave travels a distance of one wavelength in a time interval equal to one period.

This allows us to rewrite the equation for speed in a way that is specific to periodic waves: simply replace the distance with wavelength, and the time with period:

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

Since period and frequency are reciprocals of each other, this equation can be written in terms of frequency instead. This equation, which works for all waves, is known as the universal wave equation:

$$v = f\lambda$$

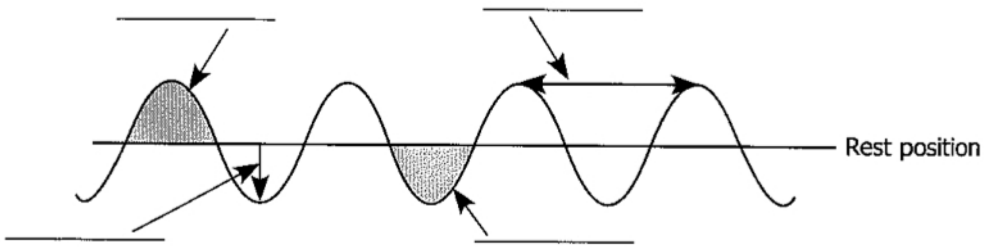
Example 2
Suppose a wave has a wavelength of $5.00\ m$ and that it takes $0.200\ s$ for one wavelength to pass a given point.

a) Determine the frequency of the wave.
b) Determine the speed of the wave.

One important thing to note is that the speed of a wave depends on only one thing: the medium. This means that if the frequency of a wave changes (the source vibrates faster or slower), the speed of the wave will not change at all. In fact, if the frequency of a wave is doubled, the result will be a wave with half the wavelength – the speed would be the same as before.

Waves Worksheet #1

1. Label each part of a transverse wave as indicated.



2. The periodic transverse wave below travels past a point P in $2.75\ s$.

   a) What is the wavelength of this wave? Use a ruler to measure it.
   b) What is the amplitude of this wave? Use a ruler to measure it.
   c) What is the frequency of this wave?
   d) What is the period of this wave?

3. Describe the motion of a point on the medium that occurs in a transverse wave.

4. Describe the motion of a point on the medium that occurs in a longitudinal wave.

5. Define the following terms: crest, trough, compression, rarefaction.

6. What is the frequency of a wave?

7. What is the metric unit of frequency?

8. How is the period of a wave related to its frequency?

9. What is the wavelength of a wave?

10. "Domino toppling" involves lining up a large number of dominoes and then letting them topple, one after the other. It is one entry in the Guinness Book of World Records. If we think about the disturbance that propagates along the line of dominoes, is it transverse, longitudinal, or both?

11. A person standing in the ocean notices that ten wave crests pass by in a time of 100 s. What must be the frequency of the wave?

12. A popular FM radio station is 97.5 on the FM dial. This number refers to the frequency of the radio signal in units of megahertz. This station broadcasts at $97.5\ MHz$. All radio signals travel at the speed of light, $3.00 \times 10^{8}\ m/s$. What is the wavelength of this signal?

13. Porpoises emit sound waves in water in order to navigate. A typical wavelength for such a sound wave might be $2.5\ cm$. The speed of the wave in seawater is typically $1470\ m/s$. What is the period of the wave?

14. A metronome beats 54 times over a 55 s time interval. Determine the frequency and period of its motion.

15. Most butterflies beat their wings between 450 and 650 times per minute. Calculate in hertz the range of typical wing-beating frequencies for butterflies.

16. A watch spring oscillates with a frequency of 3.58 Hz. How long does it take to make 100 vibrations?

17. A child swings back and forth on a swing 12 times in 30.0 s. Determine the frequency and period of the swinging.

18. A longitudinal wave in a 6.0 m long spring has a frequency of 10.0 Hz and a wavelength of 0.75 m. Calculate the speed of the wave and the time it would take to travel the length of the spring.

19. Interstellar hydrogen gas emits radio waves with a wavelength of 21 cm. Given that radio waves travel at 3.00×10^{8} m/s, what is the frequency of this interstellar source of radiation?

20. Tsunamis are fast-moving ocean waves typically caused by underwater earthquakes. One particular tsunami traveled a distance of 3250 km in 4.6 h and its wavelength was determined to be 640 km. What was the frequency of this tsunami?

21. An earthquake wave has a wavelength of 523 m and travels with a speed of 4.60 km/s through a portion of Earth's crust.
    a) What is its frequency?
    b) If it travels into a different portion of Earth's crust, where its speed is 7.50 km/s, what is its new wavelength?
    c) What assumption(s) did you make to answer part (b)?

22. The speed of sound in air at room temperature is 343 m/s. The sound wave produced by striking middle C on a piano has a frequency of 256 Hz.
    a) Calculate the wavelength of this sound.
    b) Calculate the wavelength for the sound produced by high C, one octave higher than middle C, with a frequency of 512 Hz.