Waves: Defined as a transfer of energy, in the form of a temporary disturbance of a medium, where the medium itself does not move.

Three Classifications of waves:

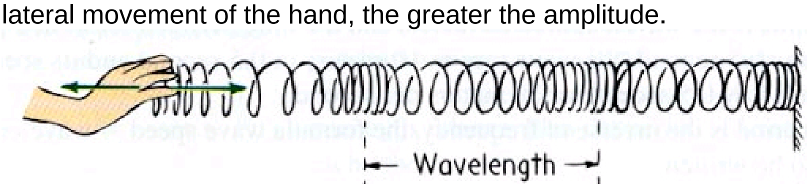
1. **Mechanical waves**: These are waves that are governed by Newton's laws. Examples are sound, seismic, water waves. These types of waves require a medium and can be longitudinal, transversal or torsional (rotational)
2. **Electromagnetic waves:** These are waves do not require a medium. These types of waves have both a magnetic and electrical component to them. Electromagnetic waves are always transversal and travel at or near the speed of light.
3. **Matter waves:** Refer to the behaviour of many subatomic particles, such as electrons, protons, neutrons, etc., which at times behave like waves at other times like particles.

Three Oscillation Modes of Waves: Longitudinal, Transversal and Rotational

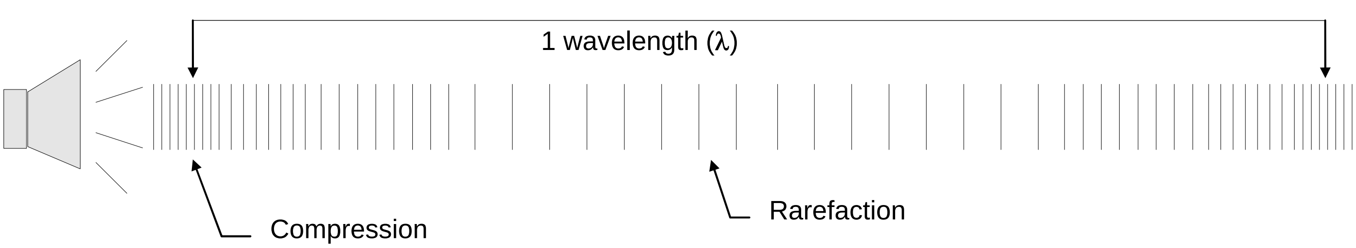
All waves fall into one of three categories, longitudinal, transversal, torsional waves. This describes how the wave oscillates and hence, how it transmits its energy. The direction of a wave is defined as the direction of which the wave energy moves (in English… direction the actual wave goes). Where the disturbance is defined as the way in which the medium is temporarily disturbed (en Anglais... what the actual wave looks like).

Longitudinal waves:

- Types of waves where the disturbance is in the same direction as the motion of the wave. (like a spring or sound)
- The amplitude of the wave is measured by how much the medium is temporarily displaced from equilibrium. In the diagram below, the motion of the hand is a measure of the amplitude. The greater lateral movement of the hand, the greater the amplitude.

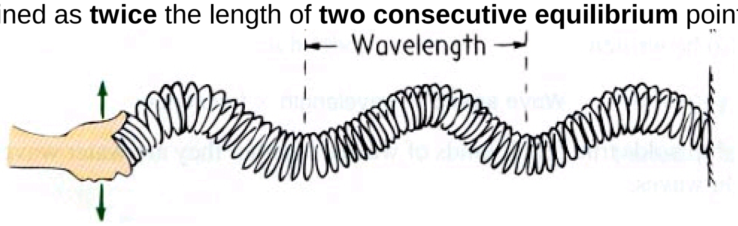


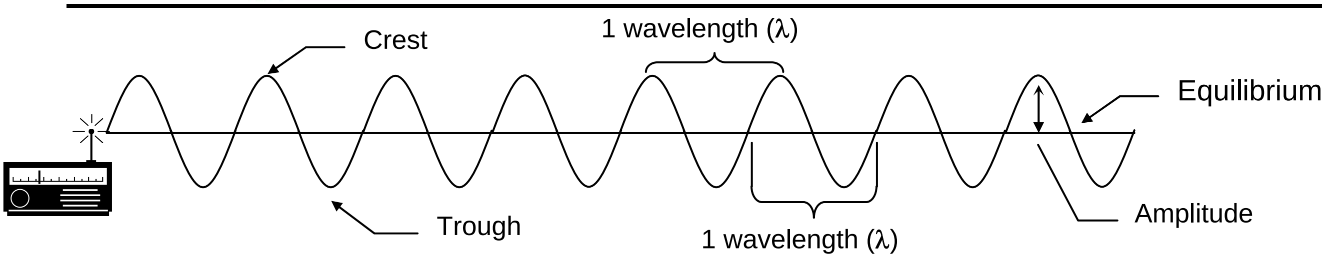
- During the transmission of the wave, the medium will experience sections of high and low density / pressure. These areas of high density / pressure are called **compressions** and areas of low density are called **rarefactions**.
- The **wavelength** of a longitudinal wave is defined as the distance between two consecutive compressions or rarefactions.



Transverse Wave

- Types of waves were the disturbance is perpendicular to the direction of the wave (like water waves and guitar strings).
- The **amplitude** of a transverse wave is measured by how much the **medium** is **displaced**, **perpendicular** to the motion of the wave. For example water waves; the taller the wave, the greater the amplitude.
- The **wavelength** is defined as the distance between **two** consecutive **crests** or **troughs**. It is also defined as **twice** the length of **two consecutive equilibrium** points

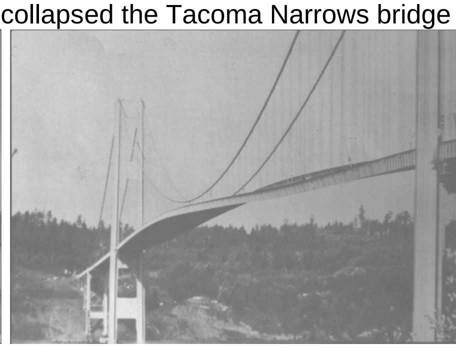




Rotational Waves

- Types of waves were the disturbance rotates perpendicular to the direction of the wave. These types of waves are often experienced in earthquakes.

- The **amplitude** of a transverse wave is measured by how much the **medium** is **rotated**, **perpendicular** to the motion of the wave. For example the rotational bending of the ground during an earthquake, or the dramatic torsional standing wave that collapsed the Tacoma Narrows bridge on Nov 7, 1940.

The wave equations

1) $f = \frac{cycles}{time}$ is the basic frequency equation which defines the Hertz (Hz) as the number of cycles, or oscillations, per second.

2) $f = \frac{1}{T}$ which can be re-written as $T = \frac{1}{f}$, where T is the period in seconds and f is the frequency in Hertz (Hz).

3) $v = f\lambda$ where v is the velocity in m/s, f is the frequency in Hz and λ is the wave length in meters.

example 1 – A wheel rotates 120 times in 30s.

$$f = \frac{cycles}{time} = \frac{120}{30} = 4Hz$$

example 2 – a radio wave has a wavelength of 2.887m. What is its frequency? Note, radio waves travel at the speed of light 3.0×10^8m/s.

$$v = f\lambda$$

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

$$f = \frac{3.00 \times 10^8}{2.887}$$

$$= 1.039 \times 10^8 \, Hz$$

$$= 103.9 \times 10^6 \, Hz$$

$$= 103.9MHz$$

(or more commonly known as *"The Hawk"*.)

Example:

1. A child on a swing takes 0.5 seconds to move from the maximum forward position to the maximum reverse position. What is the frequency of the swing?

2. If the child's displacement from max forward to max reverse is 3m, what is the amplitude of the wave?

3. A tone generator is hooked up to a speaker. The generator is set to 50Hz. If the generator is on for 5 minutes, how many cycles has the speaker experienced?

4. If the speaker in 3. has an amplitude of 2cm, what is the total distance traveled by the speaker in the 5 minutes?

5. The only decent radio station in London broadcasts at a frequency of 94.9 MHz. How many wavelengths separate the transmitter in London from Woodstock? Assume a distance of 50km.

6. You're sitting on a boat in the middle of the lake hanging out with your friend when you notice an interesting physical phenomenon. A buoy, 30m away, is bobbing up and down in the complete opposite fashion to your boat. You also notice that there are 10 crests separating your boat and the buoy. What is the wave speed in the water if the frequency is 1.0Hz?

Transmission of Waves

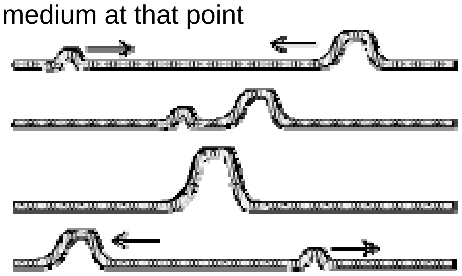
Single Medium: The transmission of waves through a medium can be characterized by the following.

- Passing waves will cause a temporary disturbance within the medium, after which the medium returns to its normal state.

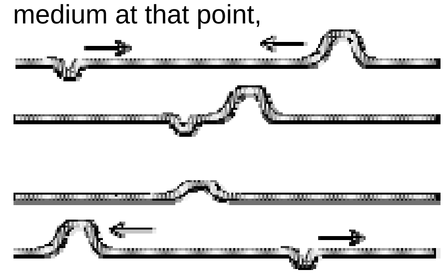
- The speed of a wave is dependent on the medium. Some factors that can affect wave speed are **density**, **rigidity**, **state**, and **viscosity**.

- Two waves on a collision course will pass through each other without any permanent effect on either wave. At the point of collision, the **amplitudes** of the two waves will **mathematically add** to form a temporary waveform called a **superposition**.

  Constructive Interference occurs when to colliding waves produce a wave form that increases the overall amplitude of the medium at that point

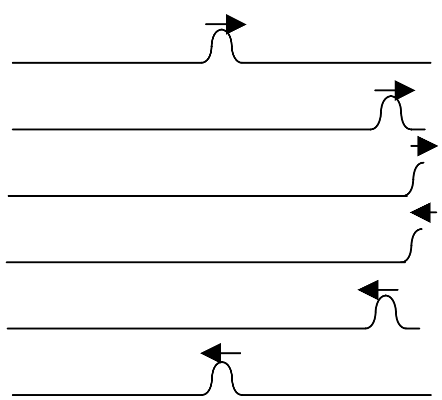
  

  Destructive Interference occurs when to colliding waves produce a wave form that decreases the overall amplitude of the medium at that point,

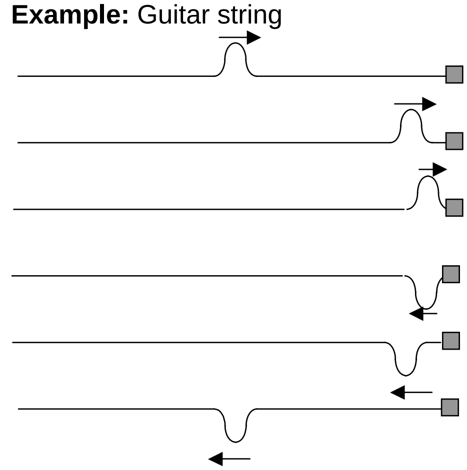
  

- **Reflection:** waves will reflect at the boundaries of their media. This why we can see walls and hear echoes. In fact most barriers reflect some amount of energy.

  Free-end reflections: Waves that reach the boundary of a medium, where the medium is free to move, will reflect a pulse back at the same speed, amplitude and orientation.
  Example: Water waves

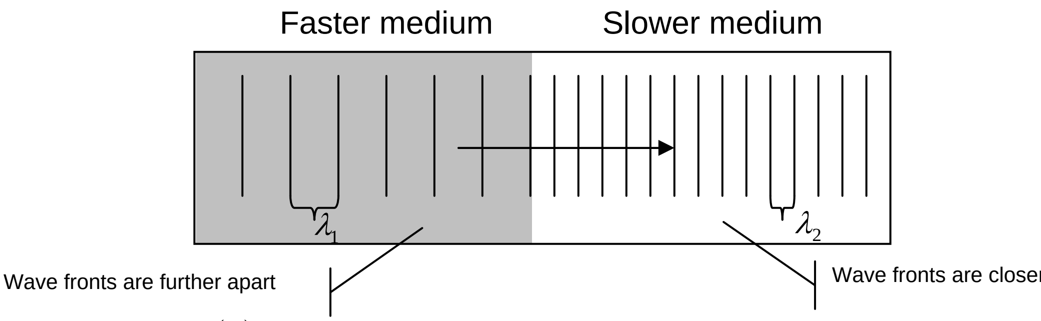
  

  Fixed-end reflections: Waves that reach the boundary of a medium, where the medium is not free to move, will reflect a pulse back at the same speed and amplitude but inverted.
  Example: Guitar string

Two Media: The transmission of waves from one medium to another are characterized by the following

- The **frequency** (f) of a wave remains constant when passing from on medium to another

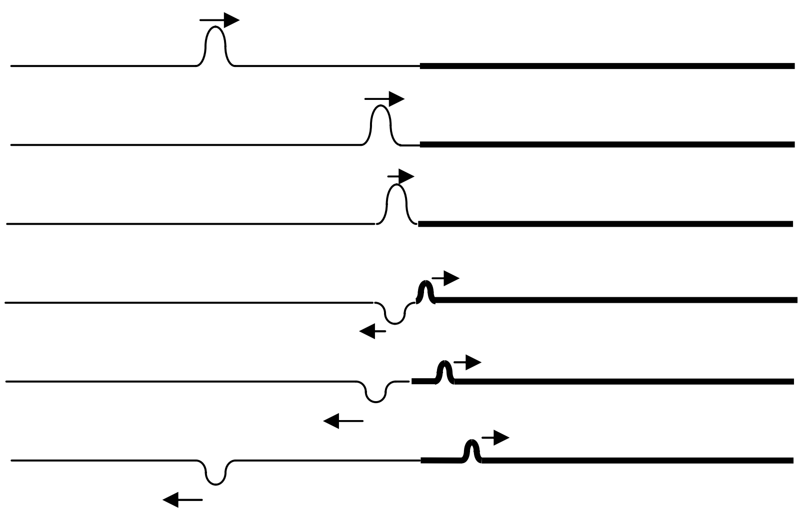


- The **wavelength** (λ) of the wave varies depending on the **wave speed** with in the medium, the **slower the medium** the **shorter the wavelength** for any given frequency.

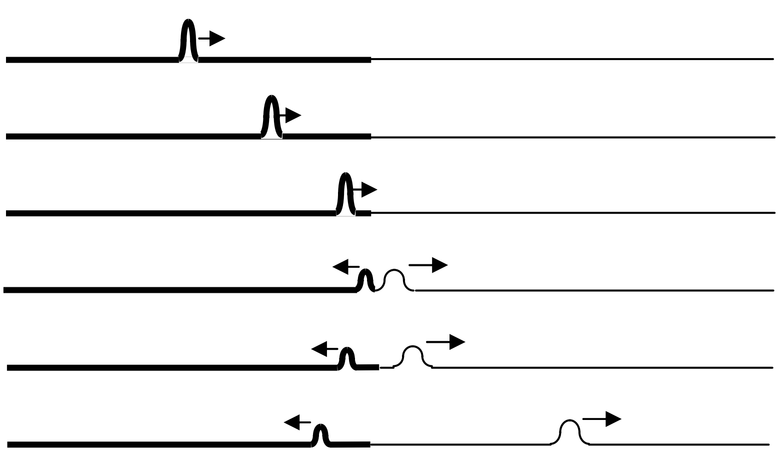
- Waves that encounter boundary between two media will experience both **transmission** and **reflection**. **Two dimensional** waves will also experience **refraction**.

One-dimensional waves:

Waves moving from a **fast** medium to a **slow** medium will experience a reflection as illustrated below. The pulse traveling from the faster medium sees the boundary as a ***fixed-end*** and reflects accordingly.



Waves moving from a **slow** medium to a **fast** medium will experience a reflection as illustrated below. The pulse traveling from the faster medium sees the boundary as a ***free-end*** and reflects accordingly

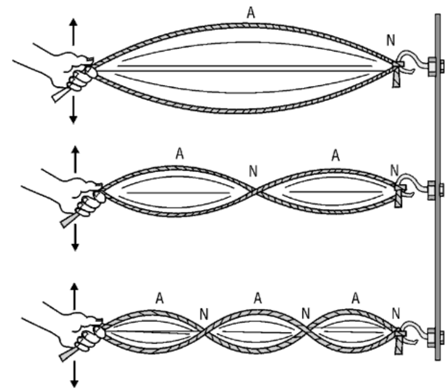


Resonance and the Natural Resonant Frequency

Any oscillating system has one frequency in which the system oscillates most easily. This frequency is called the **natural resonance frequency**, which is defined as that frequency which results in a maximum energy output from a minimum energy input.

Examples:
- The low rumble of thunder causing a window to vibrate in your home.
- A Honda Civic with an over-the-top sound system causes coin tray to rattle in the car beside it
- Crazy lasso tricks
- A hula-hoop
- The wonderfully grating sound of guitar feedback

Standing Waves:

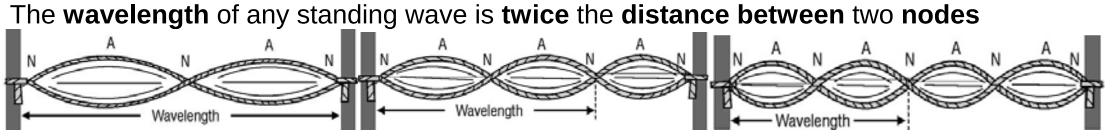


- Standing waves are a type of natural resonance.
- Standing waves occur when a wave, traveling through a medium, reflects off a boundary in such a way that the reflected wave and the incident wave line up precisely to produce a pattern that does not appear to move. In reality, two waves, moving in opposite directions produce the pattern.
- Standing waves are dependent on the **frequency of the wave** and the **speed within the medium**
- Standing waves consist of two regions; **Nodes** and **Antinodes**

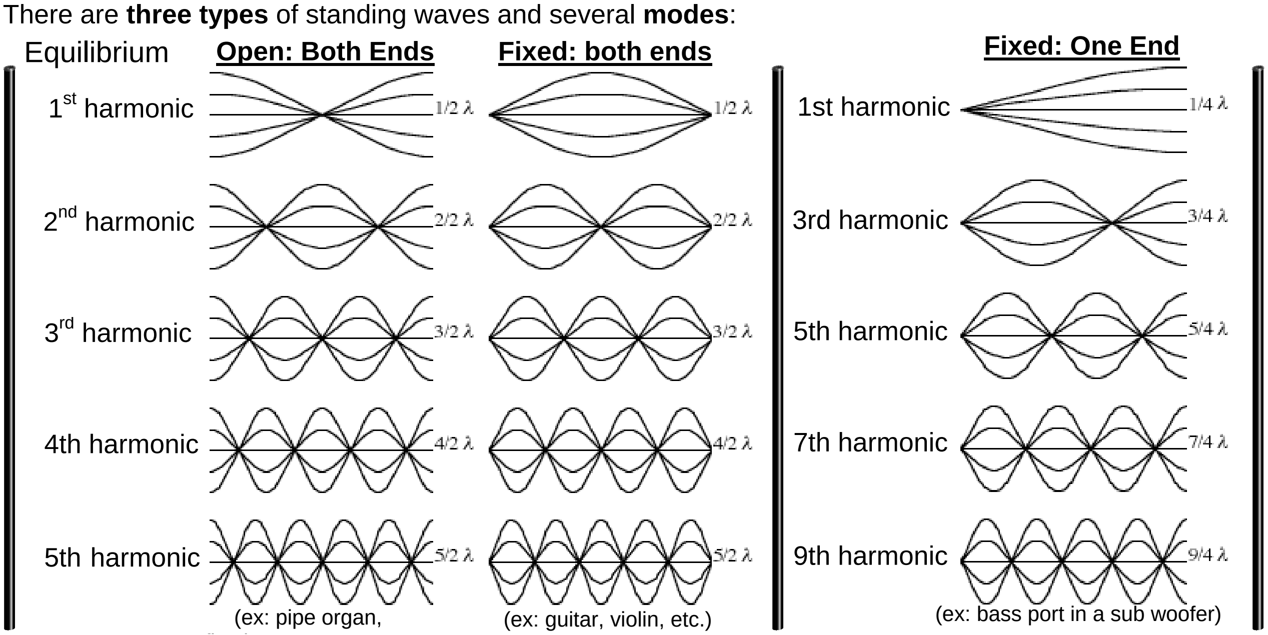
  Nodes: Are regions where there is always **destructive** interference. At these points, the medium does not move.

  Antinodes: Are regions where the **super crests** and **super troughs** occur. These regions always experience **constructive interference**

- The **wavelength** of any standing wave is **twice** the **distance between** two **nodes**



- There are **three types** of standing waves and several **modes**:



Modes: 1st Harmonic (fundamental): lowest mode of resonance in any system
2nd Harmonic (1st overtone): second mode of resonance in any system (not applicable to **fixed: one end**)
3rd Harmonic (2nd overtone): Third mode of resonance in any system

Examples:

1. A standing wave with a frequency of 30Hz is generated in a string that is 10cm, fixed at both ends. One antinode is observed in the standing wave. Find the velocity of the wave.

2. A piece of PVC pipe can often be used as a speaker port in a homemade subwoofer box. What minimum length of pipe is required in order to have the system resonate at 50Hz. (assume $v_{sound} = 340m/s$)

3. What would be the next two resonant frequencies of the system in 3)?

4. Two 50.00 cm lengths of pipe are setup two ways. The first pipe is open at both ends but the second pipe is fixed at one end. (assume $v_{sound} = 340m/s$)
   a) Determine the fundamental frequency for each pipe.
   b) Determine the frequency of the 2nd overtone for each pipe.