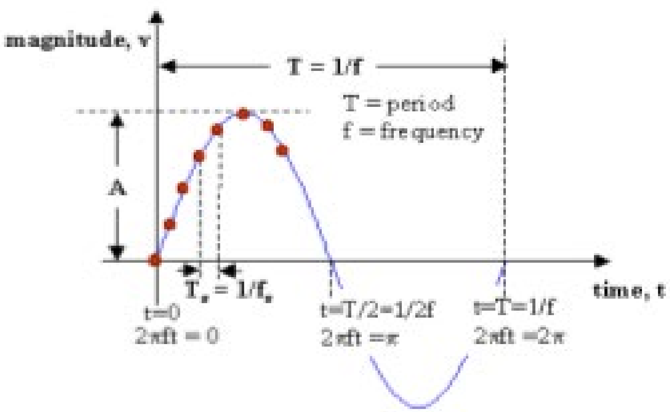
Introduction to Wave Theory



SHM Quick Review

What you need to know:

1. Period and Frequency

Period: the amount of time to make one cycle

Frequency: the number of cycles per second (Hz)

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

2. Simple Harmonic Motion (SHM)

- when a force acts opposite of a displacement to keep an object oscillating
- horizontal/vertical mass-spring system and pendulum: know the diagrams

- horizontal mass-spring system: restoring (spring) force is zero at equilibrium
- vertical mass-spring system: $F_g = F_{spring}$ at equilibrium
- pendulum: $F_{restoring} = F_g \sin(\theta)$

3. Eqns of SHM

- mass-spring system (either kind)

$$\vec{a} = \frac{-k\vec{x}}{m}$$

$$\vec{v} = \sqrt{\frac{k\vec{x}^2}{m}}$$

$$T = 2\pi\sqrt{\frac{m}{k}}$$

comes from:

$\vec{F}_g = \vec{F}_{spring}$

comes from:

$\vec{F} = \vec{F}_{spring}$

comes from:

$PE_s = KE$

On formula sheet

- pendulum

ma = kx

$$T = 2\pi\sqrt{\frac{L}{g}}$$

On formula sheet

4. Resonance / Force Frequency

What does the word

Waves

mean to you?

Definition of a Wave

The regular transportation of energy without the permanent displacement of matter.

- waves are **regular** because the particles which make them up oscillate in SHM, returning to their equilibrium positions

- waves transport energy (i.e. heat energy in light, sound energy, energy in water waves)

- waves don't displace matter (as the particles eventually return to equilibrium)

Two Main Types of Waves:

1. Mechanical Waves (P20)
- water waves
- waves on strings/springs
- sound
-
-

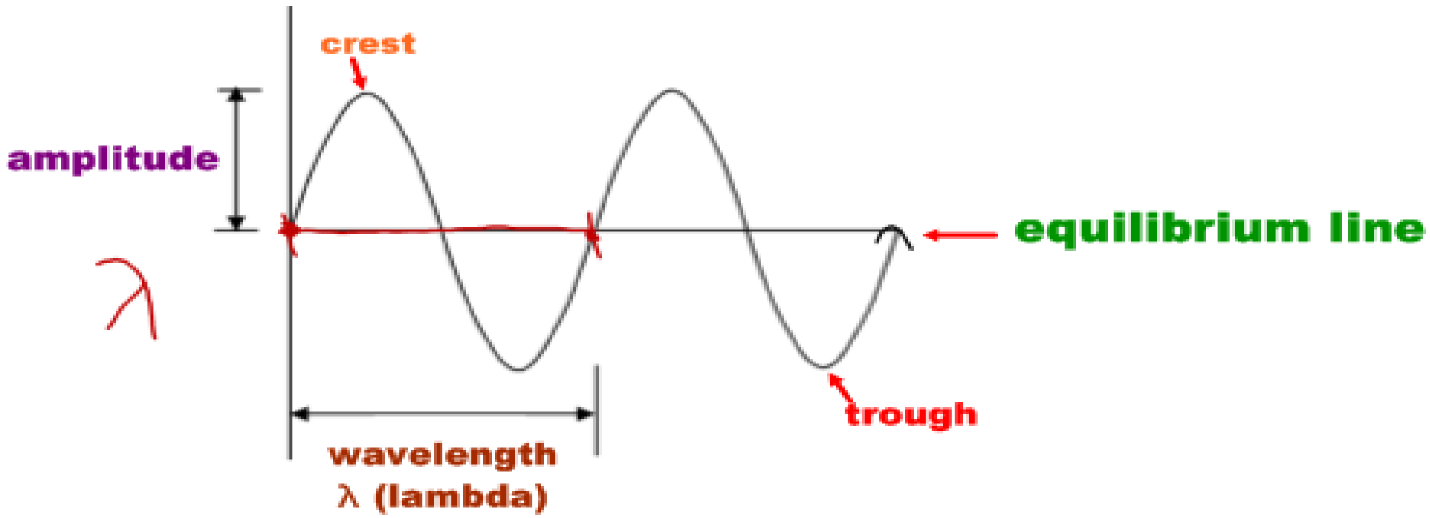
Need a medium to travel through (i.e. water, air, string).

2. Electromagnetic Waves (P30)
- light
- radio/tv/satellite rays
- microwaves
-
-

Don't need a medium to travel through (can go through the vacuum of space).

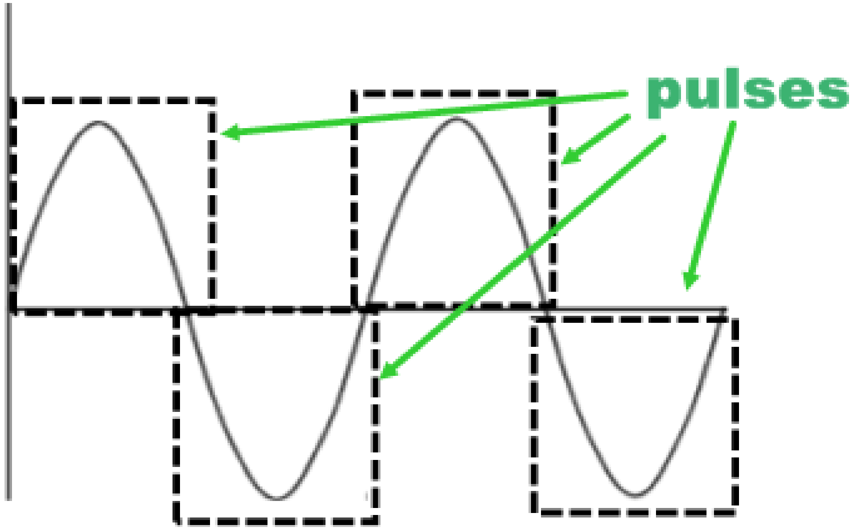
Description of Waves

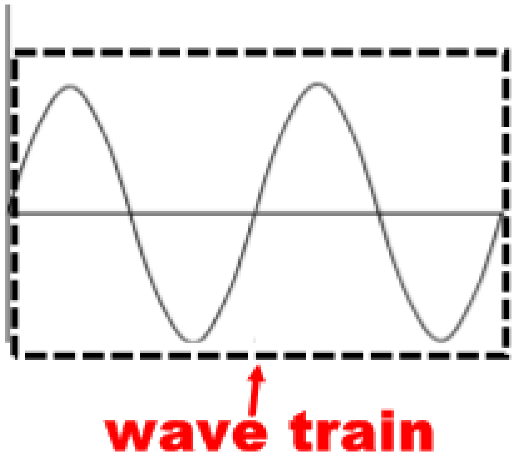
A wave can be drawn using a sinusoidal curve:



Terms:

- **equilibrium: the initial position of the medium**
- **crest: the portion of the wave above equilibrium**
- **trough: the portion of the wave below equilibrium**
- **amplitude: the distance between the crest and equilibrium or between the trough and equilibrium (m).**
- **wavelength: the distance between two repeating parts of the wave. Symbol: λ (m).**





The diagram shows a collection of pulses: individual crests and troughs, that make up a wave train.

The wave train is moving horizontally. We call the overall movement of a wave the propagation of the wave.

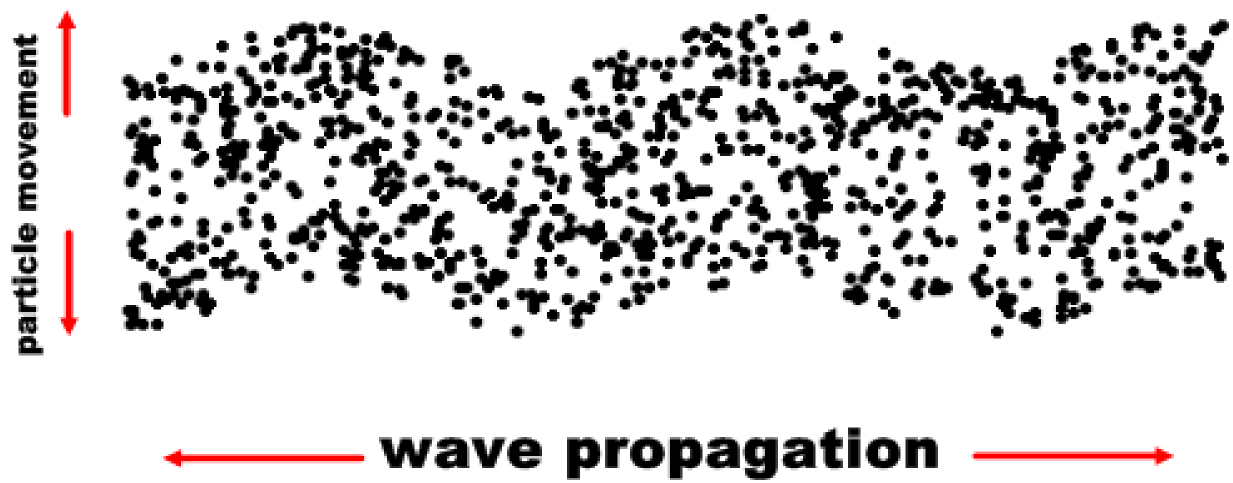
Transverse and Longitudinal Waves

- We will study two types of wave motion in P20:

Transverse Waves: a wave where the particles vibrate in a direction perpendicular to the propagation of the wave.

Longitudinal Waves: a wave where particles vibrate in a direction parallel to the propagation of the wave.

In a transverse wave, particles move up and down when the wave moves right to left.



Java Applet

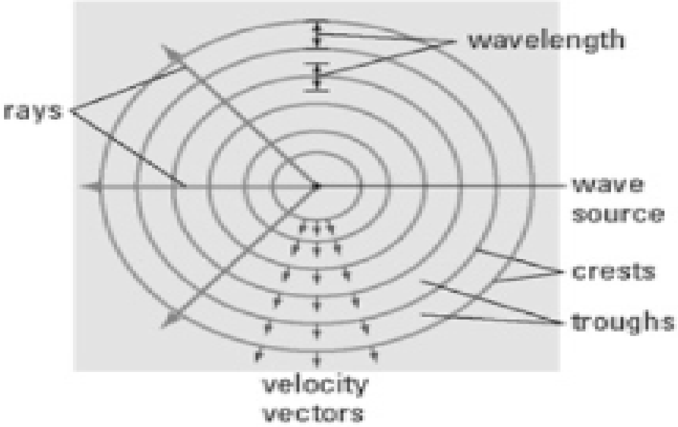
This animation

Examples:

- waves in strings
- ripples on water
- electromagnetic waves
- crowd "waves"

When a disturbance is made in a pond, a wave is produced.

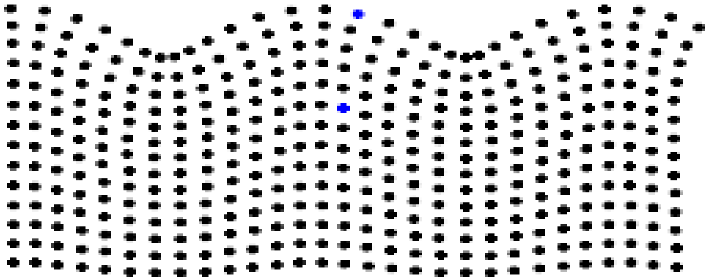
The movement of the water particles is up and down, but the direction of propagation is away from the source. This is a transverse wave.



This movement can be represented with a line called a ray.

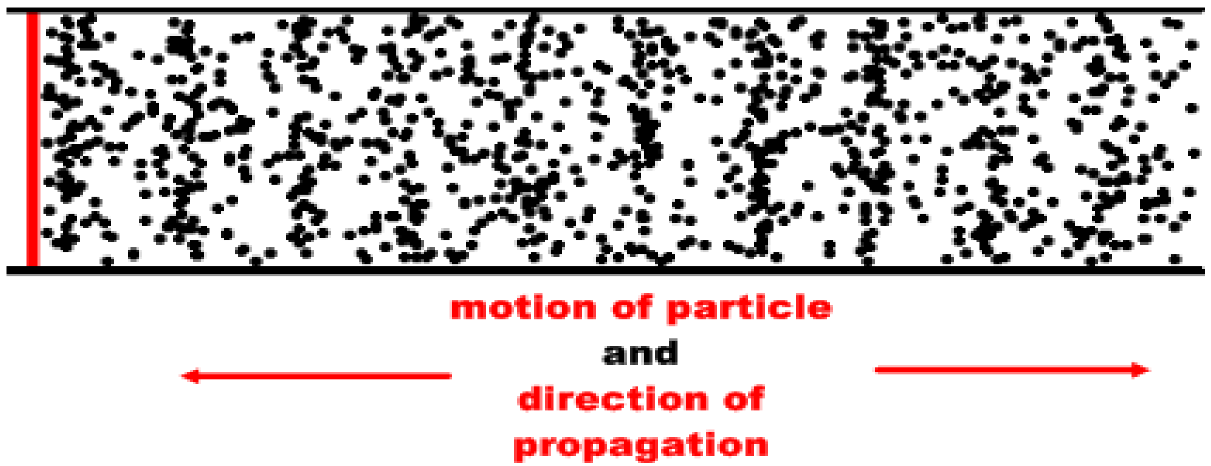
Rays are perpendicular to the crests of the wave.

A more detailed look at a water wave shows circular motion of particles (but transverse motion is a good approximation).



Rayleigh Surface Waves

In longitudinal waves, the particles move left and right when the wave moves left and right.



Longitudinal waves are made up of areas of high particle density (compressions) and low particle density (rarefactions).

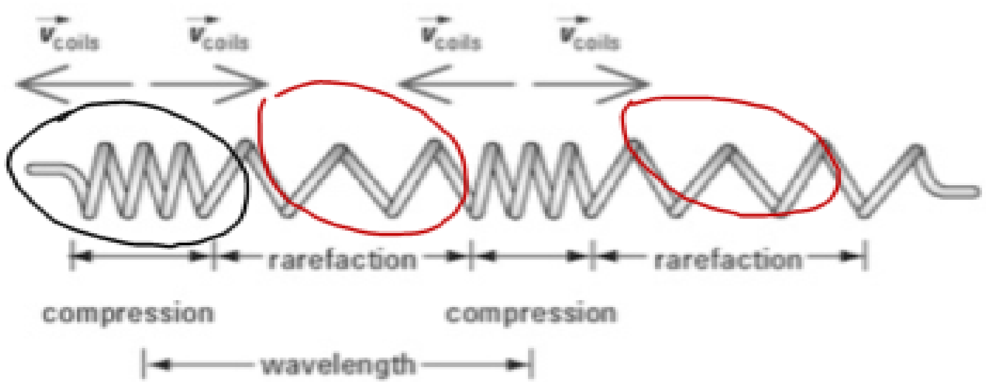
Examples:

- sound waves

-

-

[Earthquakes]



Wave Properties

Waves have the ability to:

- **reflect (P20)**
- **refract (P30)**
- **superimpose (P20)**
- **diffract (P30)**
- **travel in perfectly straight lines (P30)**
- **disperse (?)**

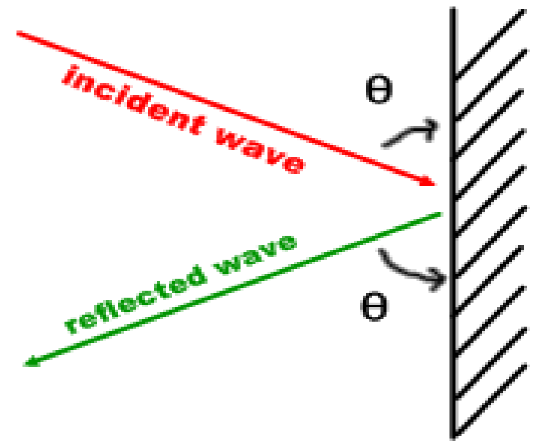
Like other matter, they also have a speed dependent on time and displacement.

Reflection

When a wave pulse hits a barrier of different density, it will reflect.

Light rays are perhaps the best example of this, but all waves reflect.

In a reflection, all properties of the wave (λ, $\vec{v}$, T) stay the same: only the direction changes.



We call the wave an incident wave before it strikes the boundary and a reflected wave afterwards.

Whatsmore, the angle the incident wave hits the boundary at is always the same as the angle the reflected wave bounces off the boundary at.

In a wave reflection,
Initial Angle = Reflected Angle

Speed of a Wave

The same wave will travel at different speeds through different mediums.

Waves travel more quickly through more dense mediums (such as solids) and move slowly through less dense mediums (such as fluids).

Speed of Sound in Various Materials

solids	v (m/s)
aluminum	6420
beryllium	12,890
brass	4700
brick	3650
copper	4760
cork	500
glass, crown	5100
glass, flint	3980
glass, pyrex	5640
gold	3240
granite	5950
iron	5950
lead	2160
lucite	2680
marble	3810
rubber, butyl	1830
rubber, vulcanized	54
silver	3650
steel, mild	5960
steel, stainless	5790
titanium	6070
wood, ash	4670
wood, elm	4120
wood, maple	4110
wood, oak	3850

liquids	v (m/s)
alcohol, ethyl	1207
alcohol, methyl	1103
mercury	1450
water, distilled	1497
water, sea	1531

gases (STP)	v (m/s)
air, 000 °C	331
air, 020 °C	343
argon	319
carbon dioxide	259
helium	965
hydrogen (H_2)	1284
neon	435
nitrogen	334
nitrous oxide	263
oxygen (O_2)	316
water vapor, 134 °C	494

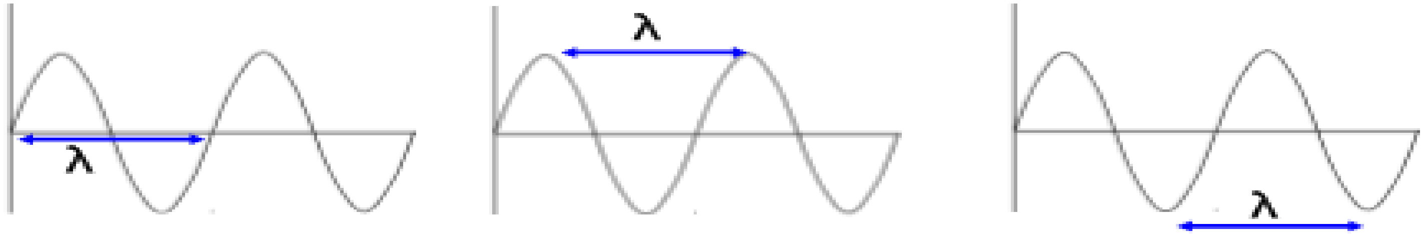
biological materials	v (m/s)
soft tissues	1540

Universal Wave Formula

In P20, waves will move in straight lines at constant velocities. This means we can describe the motion of a line with good old:

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

But what is the displacement and time of a wave?



For displacement, we measure the wavelength, λ, of the wave. This is the distance, in m, between any two repeating parts of the wave.

For time, we will use period, T, the amount of time it takes for the wave pattern to repeat.

So:

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

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

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

the Universal Wave Eqn.

where:
v = velocity (m/s)
f = frequency (Hz or s^{-1})
λ = wavelength (m)

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

the Universal Wave Eqn.

This equation applies to any wave, mechanical or electromagnetic.

ex) The speed of sound in air at 0^{o} C is 331 m/s. The speed of the same sound increases in air at 20^{o} C to 343 m/s. If the frequency of the sound is 2.50×10^{3} Hz, what is the difference in wavelength

ex) While floating in a tube on a lake, you notice that you bob up and down 4.0 times every 5.0 minutes. You estimate that the distance between the crests is 4.0 m. What is the estimated speed of the water?