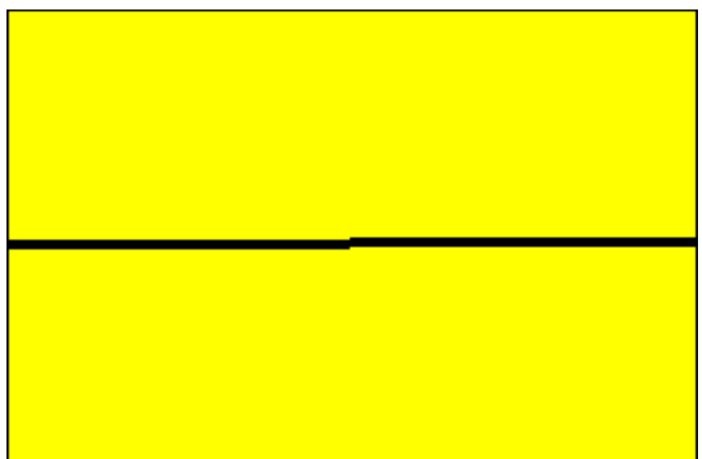
Wave Motion

A *wave* is, in general, a disturbance that moves through a medium.

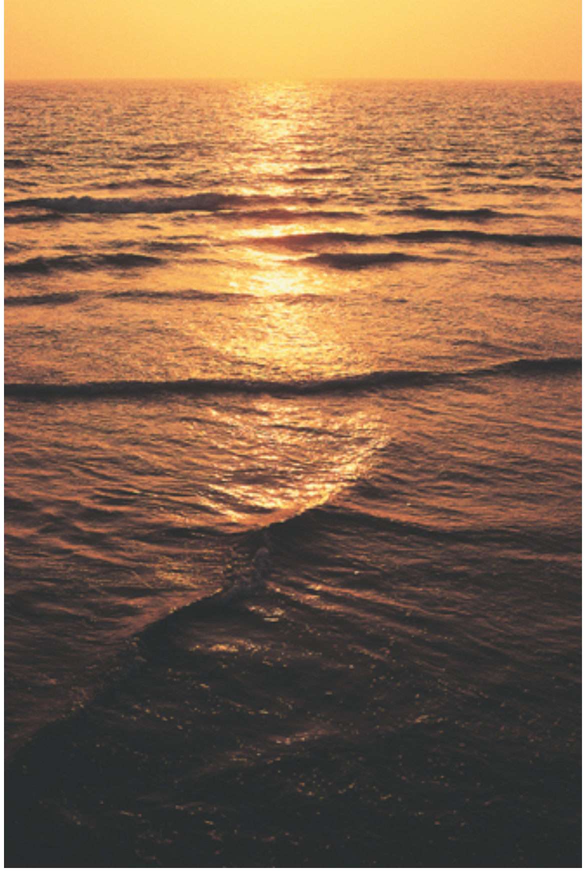


A wave carries ***energy*** **from one location to another without transporting the material of the medium.**

Examples of ***mechanical waves*** **include water waves, waves on a string, and sound waves.**

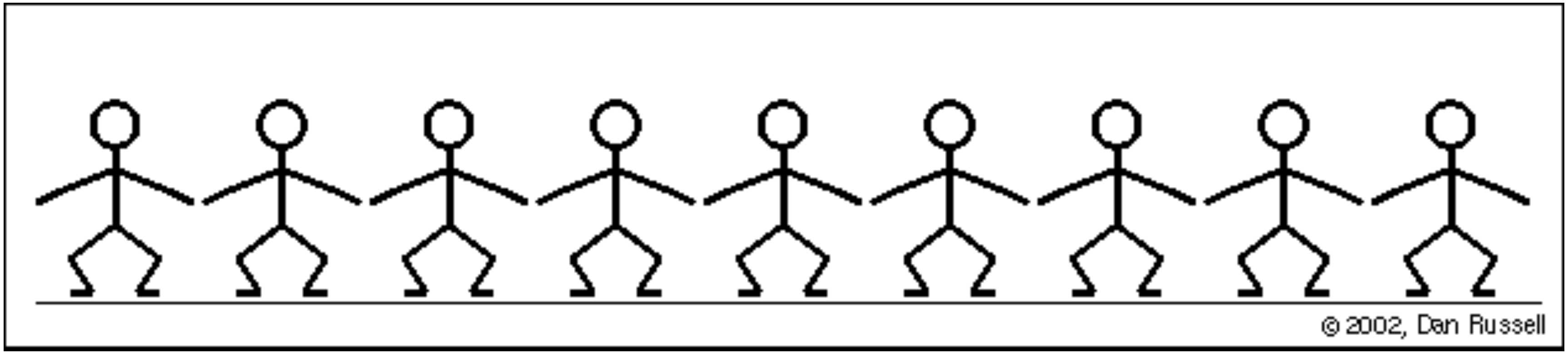
Examples of ***electromagnetic waves*** **include light, microwaves, radio waves, etc. These waves do NOT require a medium to travel through. Why?**

What is the medium?



Water

Slinky



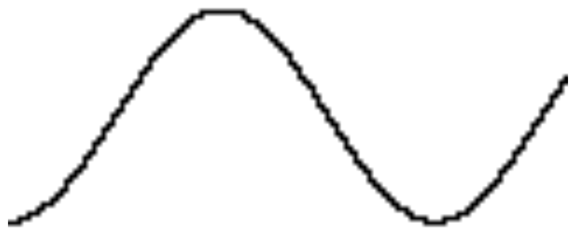
In which direction are the people moving?

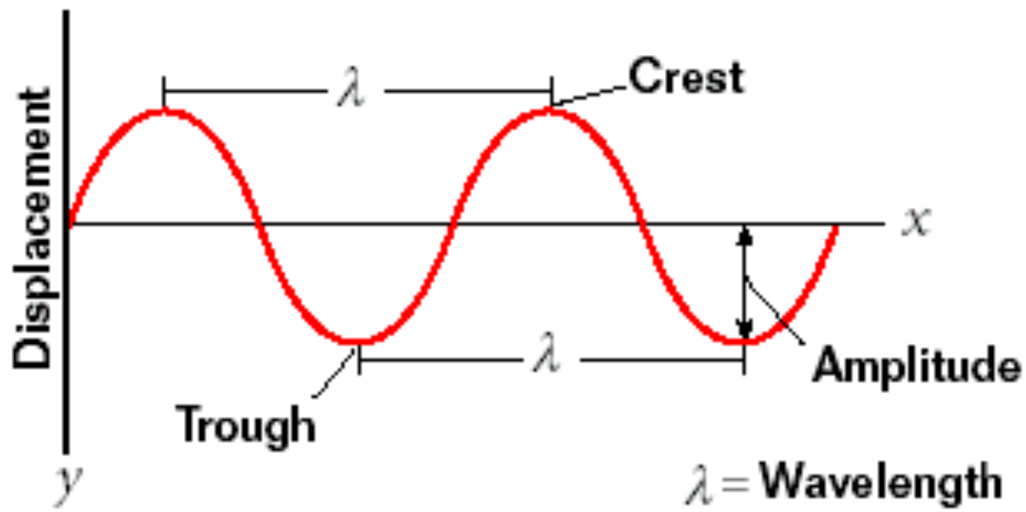
In which direction is the wave moving?

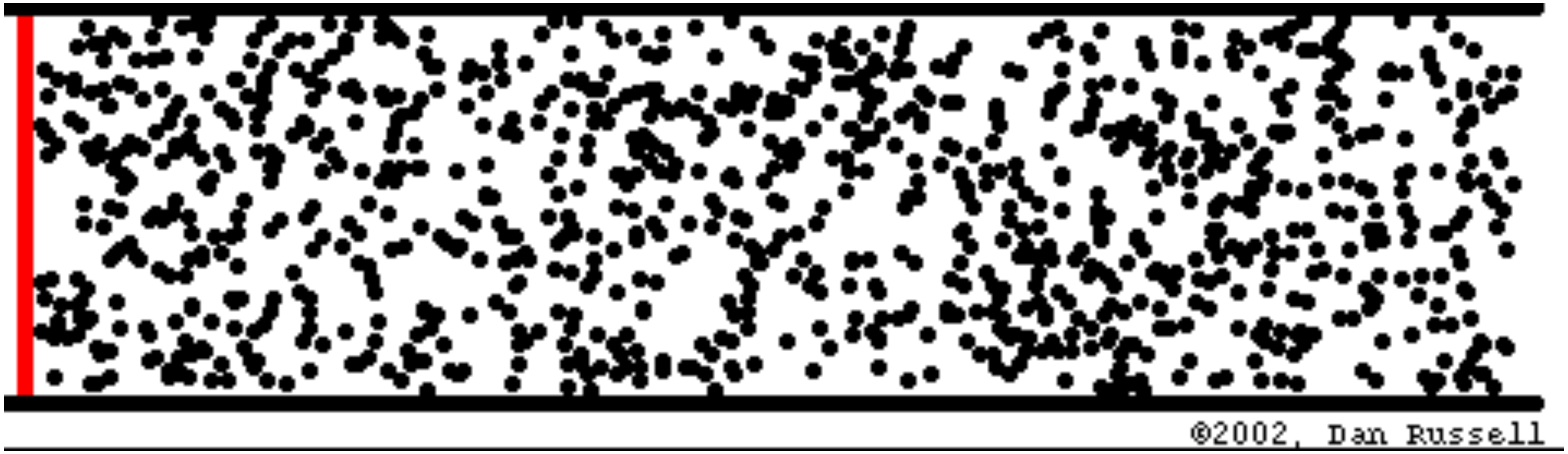
Mechanical Waves

There are two types of mechanical waves:

Transverse waves: The particles of the medium vibrate up and down (perpendicular to the wave).



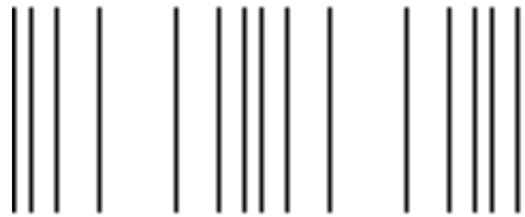


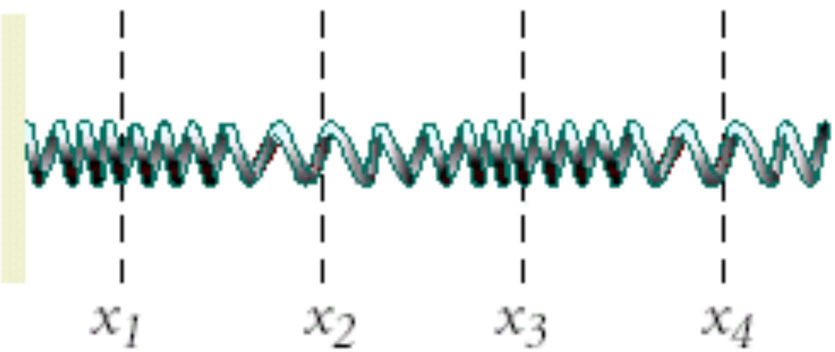


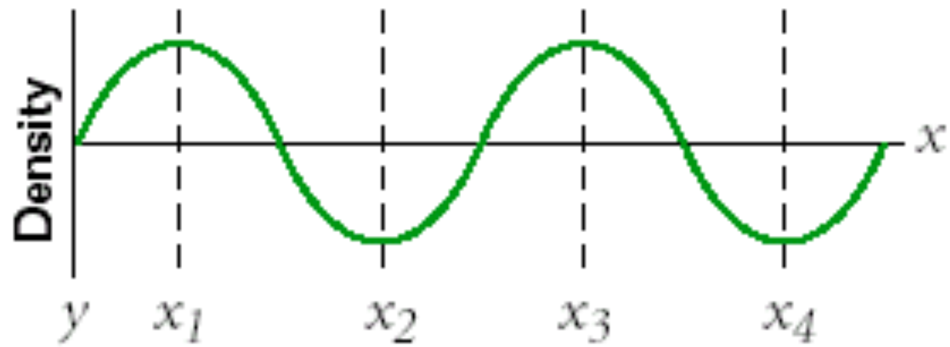
In which direction are the particles moving?

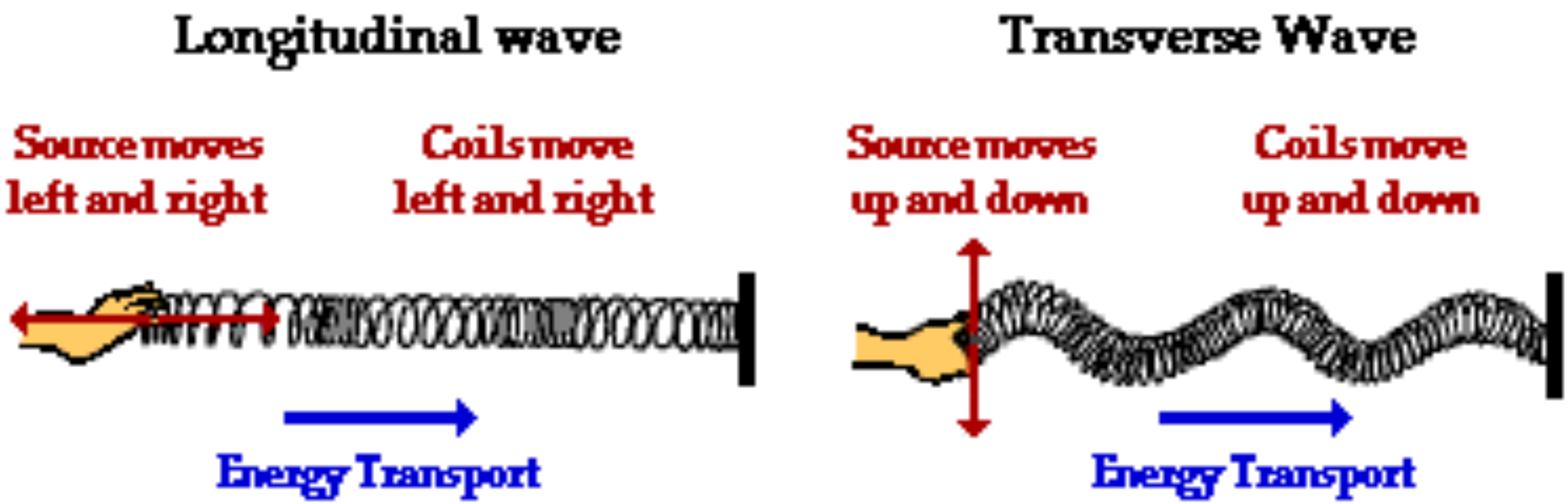
In which direction is the wave moving?

Longitudinal waves: The particles in the medium vibrate along the same direction as the wave (parallel).



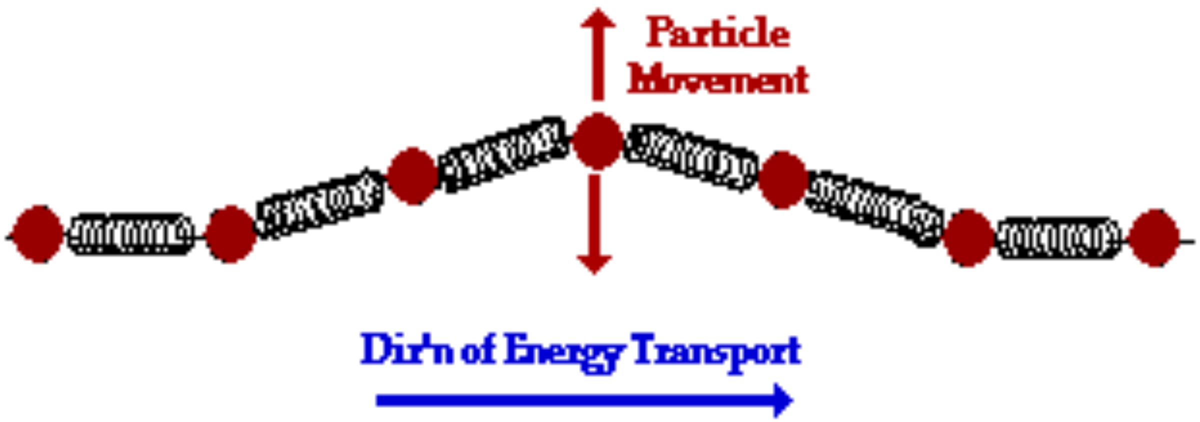




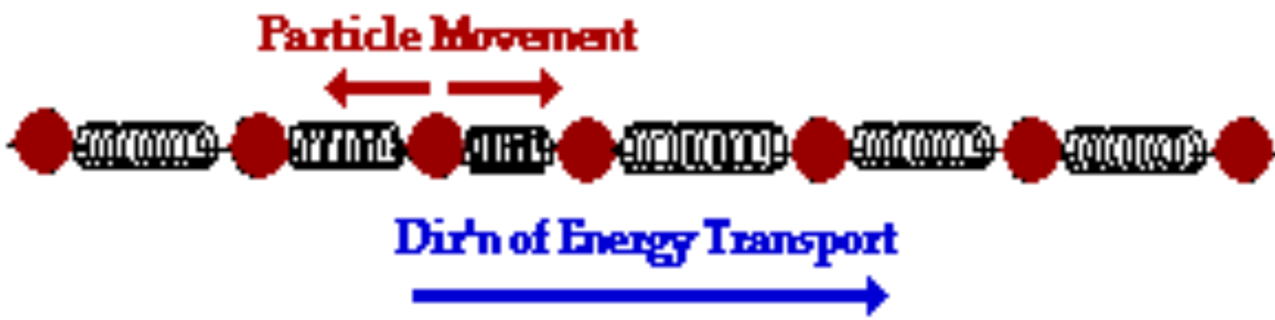


The subsequent direction of motion of individual particles of a medium is the same as the direction of vibration of the source of the disturbance.

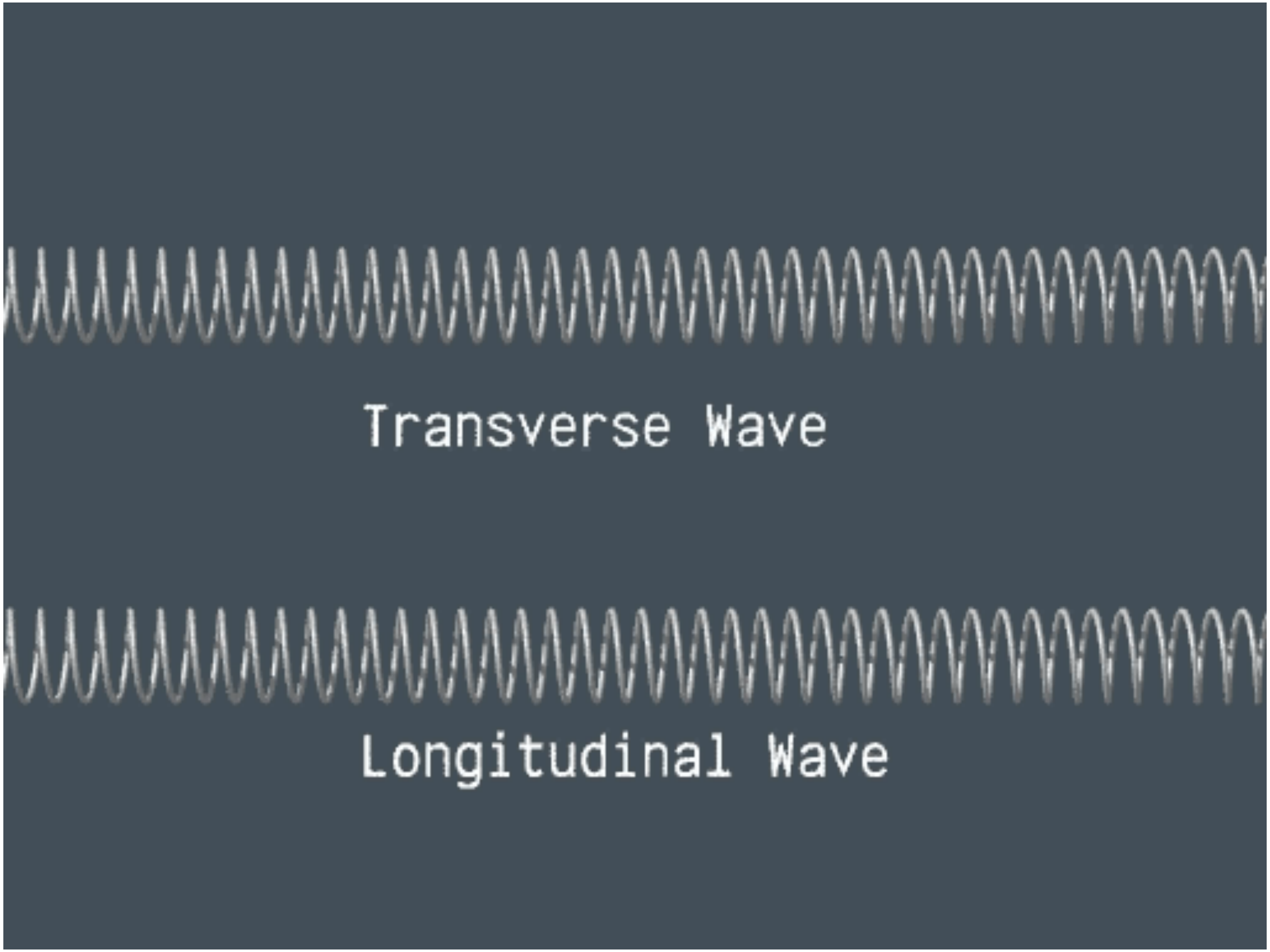
Transverse Wave



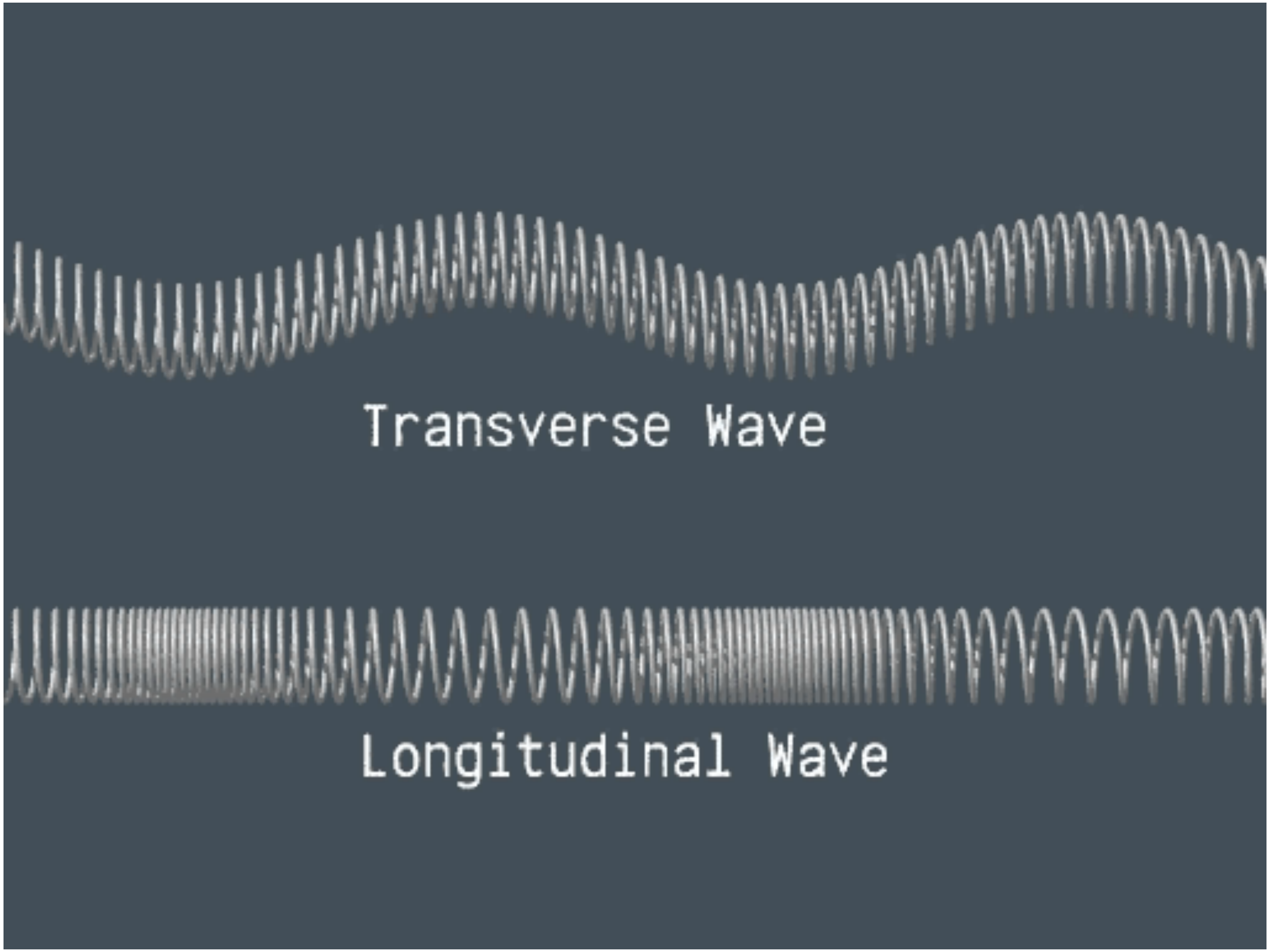
Longitudinal Wave

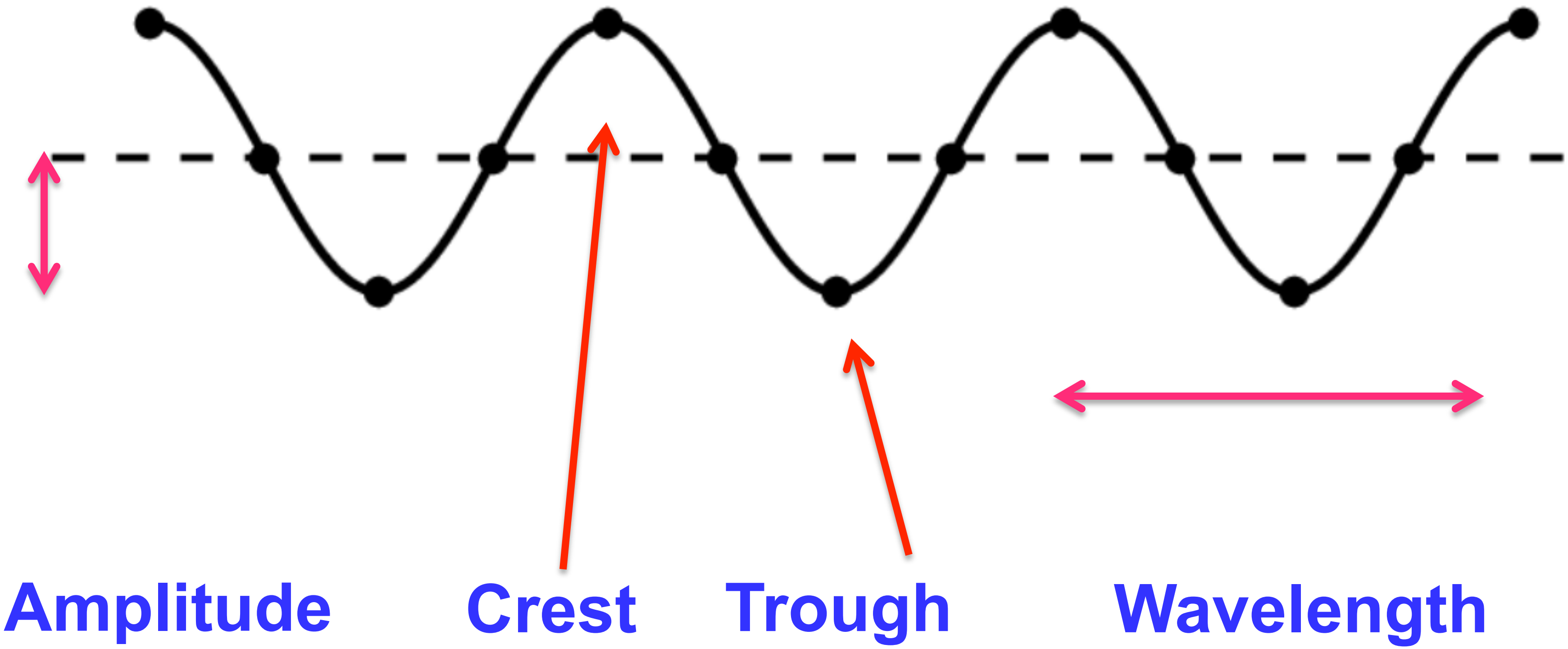


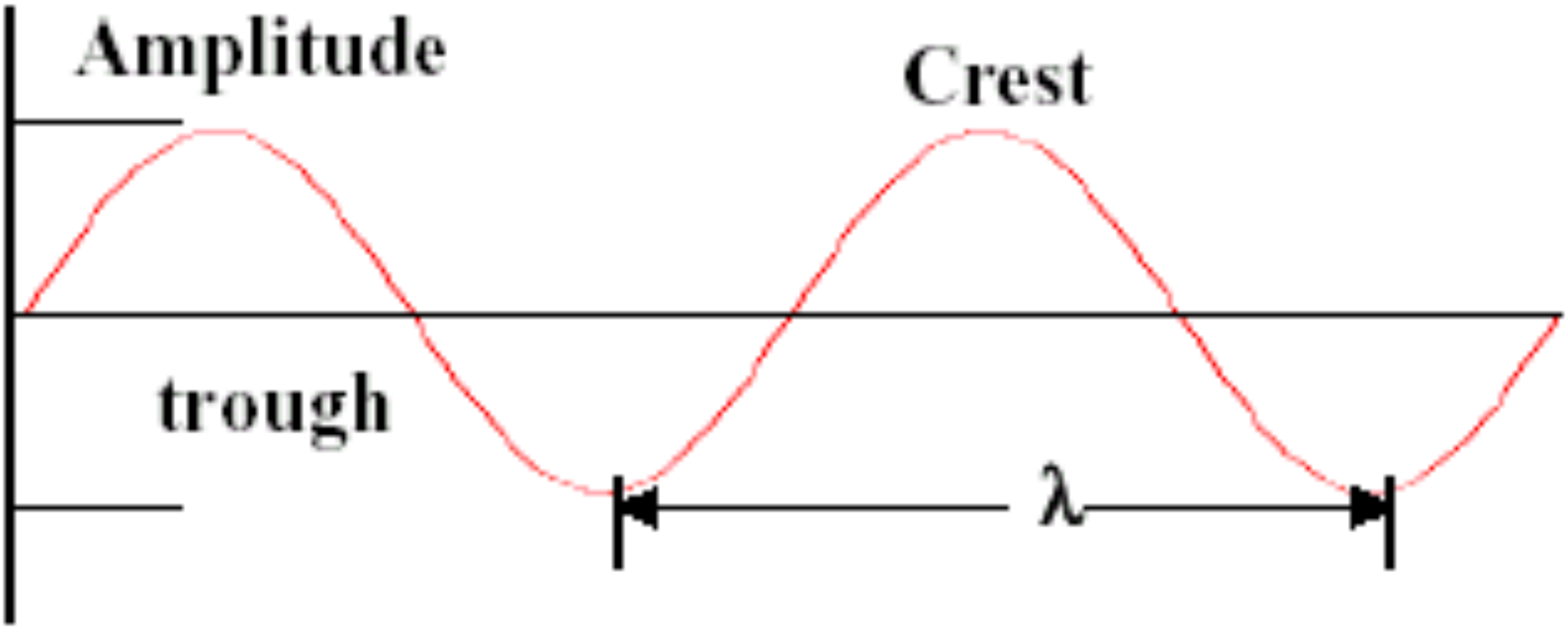
Wave Pulses



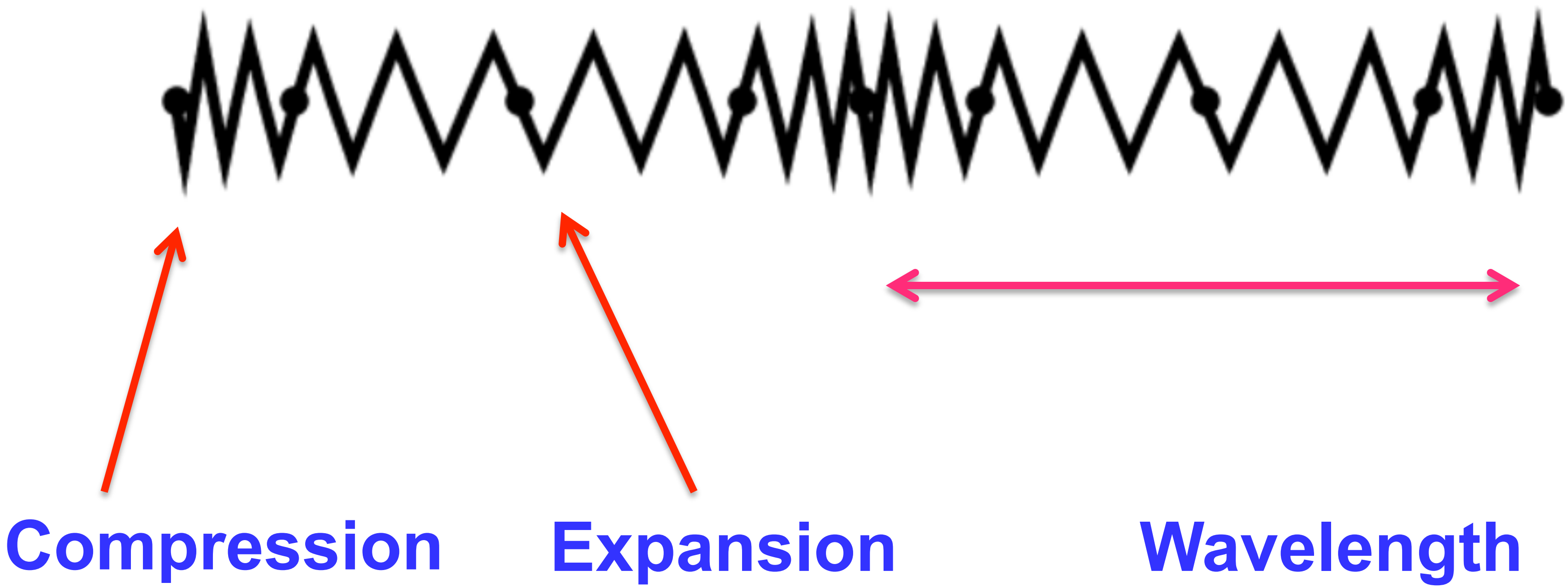
Periodic Wave




Amplitude
Crest
Trough
Wavelength



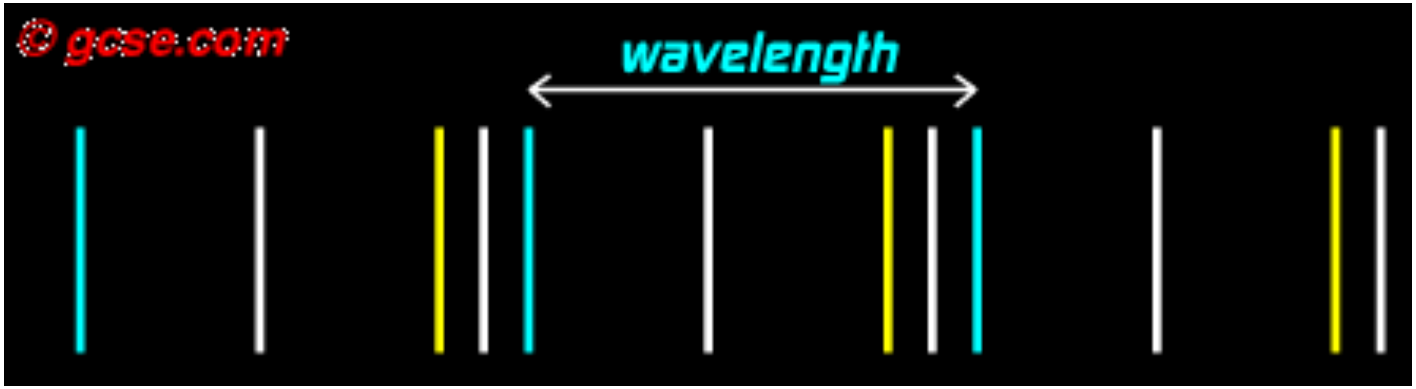
Amplitude: maximum displacement from equilibrium
Crest: Top part of the wave
Trough: Bottom part of the wave
Wavelength: *Length* from crest to crest
or trough to trough


Compression
Expansion
Wavelength

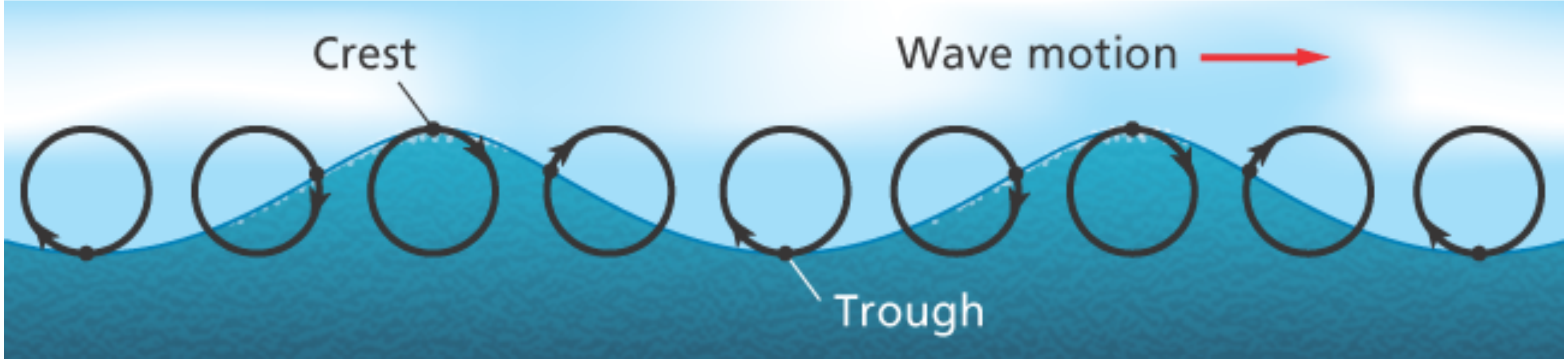
LONGITUDINAL WAVES

The medium undergoes a series of expansions and compressions. The *expansions* are when the coils are far apart and *compressions* are when they are when the coil is close together.

Expansions and compressions are the analogs of the *crests* and *troughs* of a transverse wave.



Surface waves



WAVE MOTION

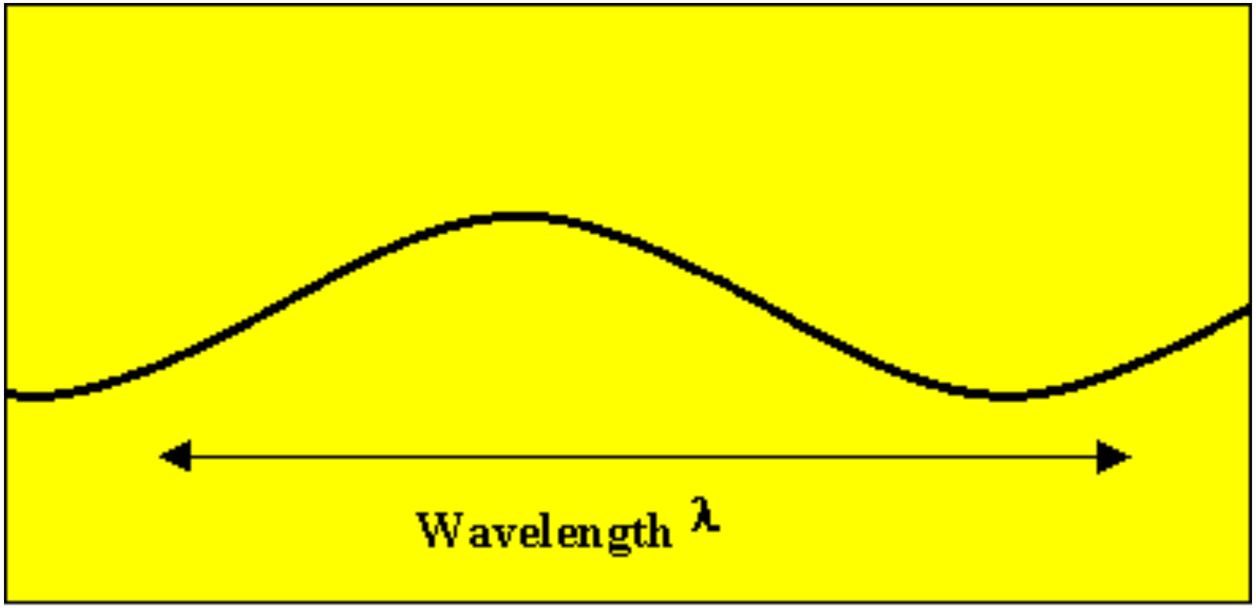
We can find the velocity of a wave by relating it to the velocity equation:

$$v = \frac{x}{t} = \frac{\lambda}{T} = \lambda f$$

Units: m/s

v **= speed (m/s),** ***x*** **= distance (m), and** ***t*** **= time (s),**

λ = wavelength (m), ***f*** **= frequency (Hz) and** ***T*** **= period (s)**



The speed of a mechanical wave is constant in a given medium. The amplitude of a wave does not affect its wavelength, frequency or speed.

8.1 Water waves in a small tank are 6.0 cm long. They pass a given point at the rate of 4.8 waves per second.

a. What is the speed of the water waves?

$\lambda = 0.06$ m

$f = 4.8$ Hz

$$v = f\lambda = 4.8\text{ Hz }(0.06\text{ m}) = 0.29\text{ m/s}$$

b. What is the period of the waves?

$$T = \frac{1}{f} = \frac{1}{4.8\text{ Hz}} = 0.21\text{ s}$$

8.2 Microwaves are electromagnetic waves that travel through space at a speed of $3x10^8$ m/s. Most microwave ovens operate at a frequency of 2450 MHz.

a. What is the period of these microwaves?

$v = 3x10^8$ m/s
$f = 2450x10^6$ Hz

$$T = \frac{1}{f} = \frac{1}{2450x10^6}$$ $= 4.08x10^{-10}$ s

b. How long is the wavelength of these microwaves?

$$v = \lambda f$$

$$\lambda = \frac{v}{f} = \frac{3x10^8}{2450x10^6}$$ $= 0.122$ m

8.3 A sound wave is directed toward a vertical cliff 680 m from the source. A reflected wave is detected 4 s after the wave is produced.

a. What is the speed of sound in air?

x **= 680 m**

t **= 4 s (reflected time)**

t **= 4/2 = 2 s**

$$v = \frac{x}{t} = \frac{680\ \text{m}}{2\ \text{s}} = 340\ \text{m/s}$$

b. The sound has a frequency of 500 Hz. What is its wavelength?

***f* = 500 Hz**

v = 340 m/s

$$v = f\lambda$$

$$\lambda = \frac{v}{f} = \frac{340\ \text{m/s}}{500\ \text{Hz}} = 0.68\ \text{m}$$

c. What is the period of the wave?

$$T = \frac{1}{f} = \frac{1}{500\ \text{Hz}} = 0.002\ \text{s}$$

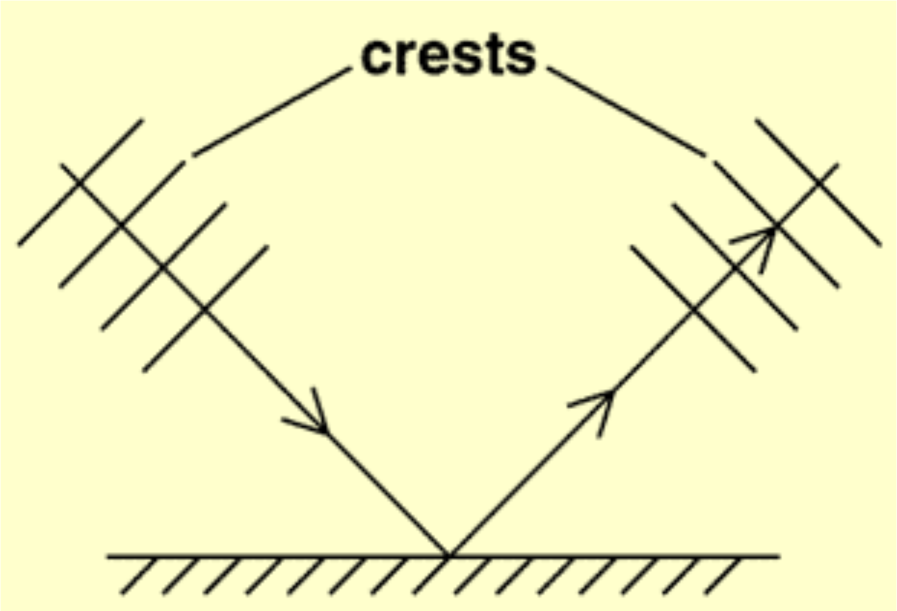
BEHAVIOR OF WAVES

When a wave travels from one medium to another, the wave is both reflected and transmitted.

When a wave passes into a new medium, its speed changes. The wave must have the same frequency in the new medium as in the old medium, thus, the wavelength adjusts.

REFLECTION

Waves bounce off a surface.



PARTIAL REFLECTION

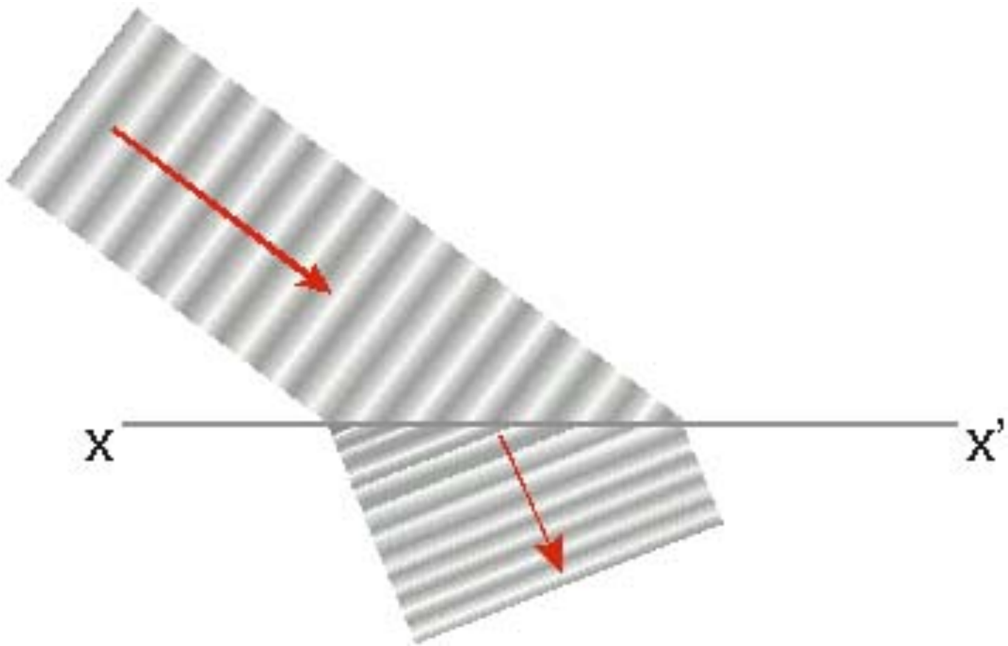
When a wave travels from one medium to another, the wave is both reflected and transmitted.

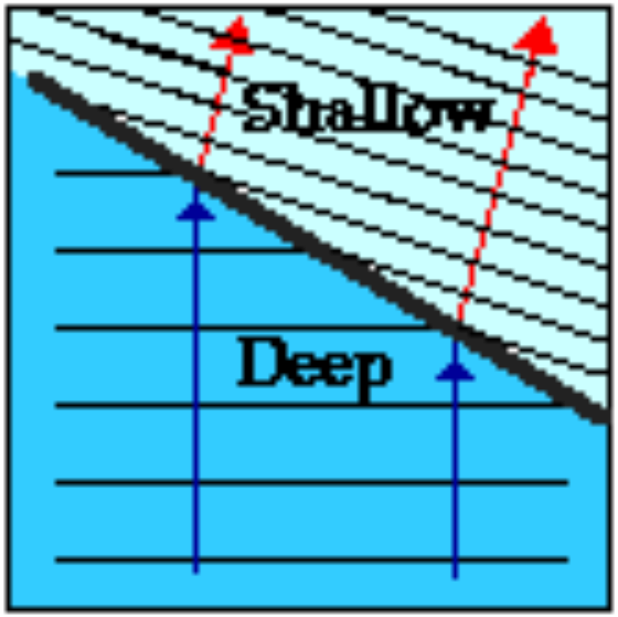
When a wave passes into a new medium, its speed changes. The wave must have the same frequency in the new medium as in the old medium. Thus, the wavelength adjusts.

REFRACTION

A water wave traveling from deep water into shallow water *changes direction*. This phenomenon is known as *refraction.*

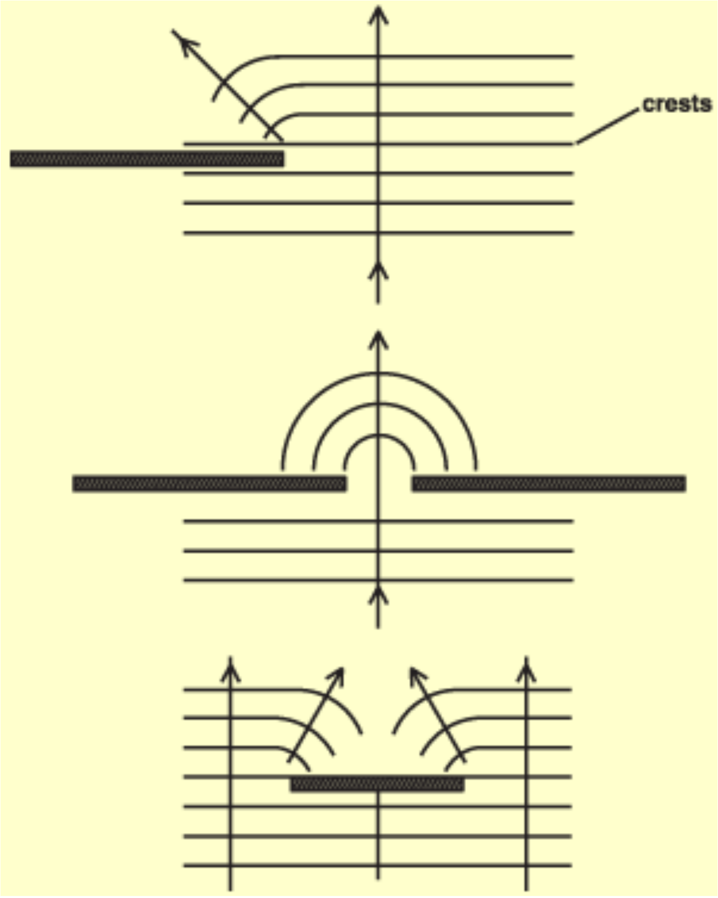
The waves bend when they pass through a boundary.





DIFFRACTION

Waves spread out (bend) as they pass an obstacle: a small opening or around a barrier.



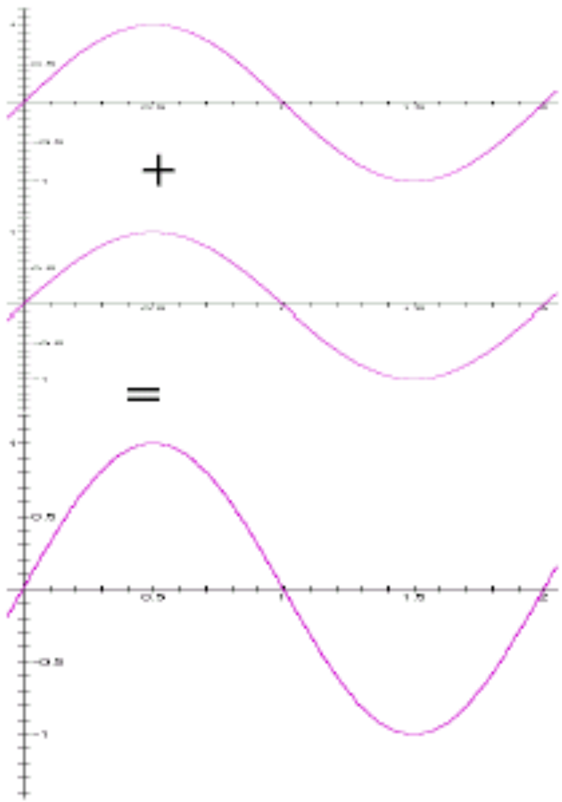
INTERFERENCE

The effect of two or more waves traveling through a medium is called interference.

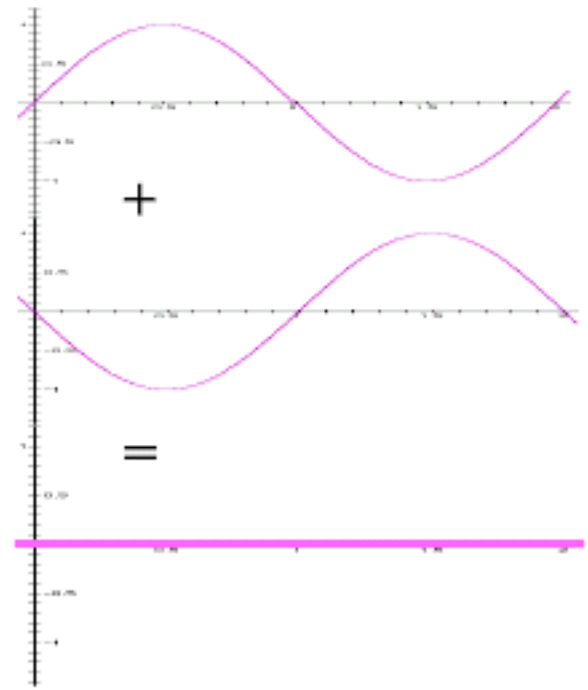
When two or more waves meet their displacements add. This is called superposition. pass through the same region?

When two crests overlap it is called constructive interference. The resultant displacement is larger then the individual ones.

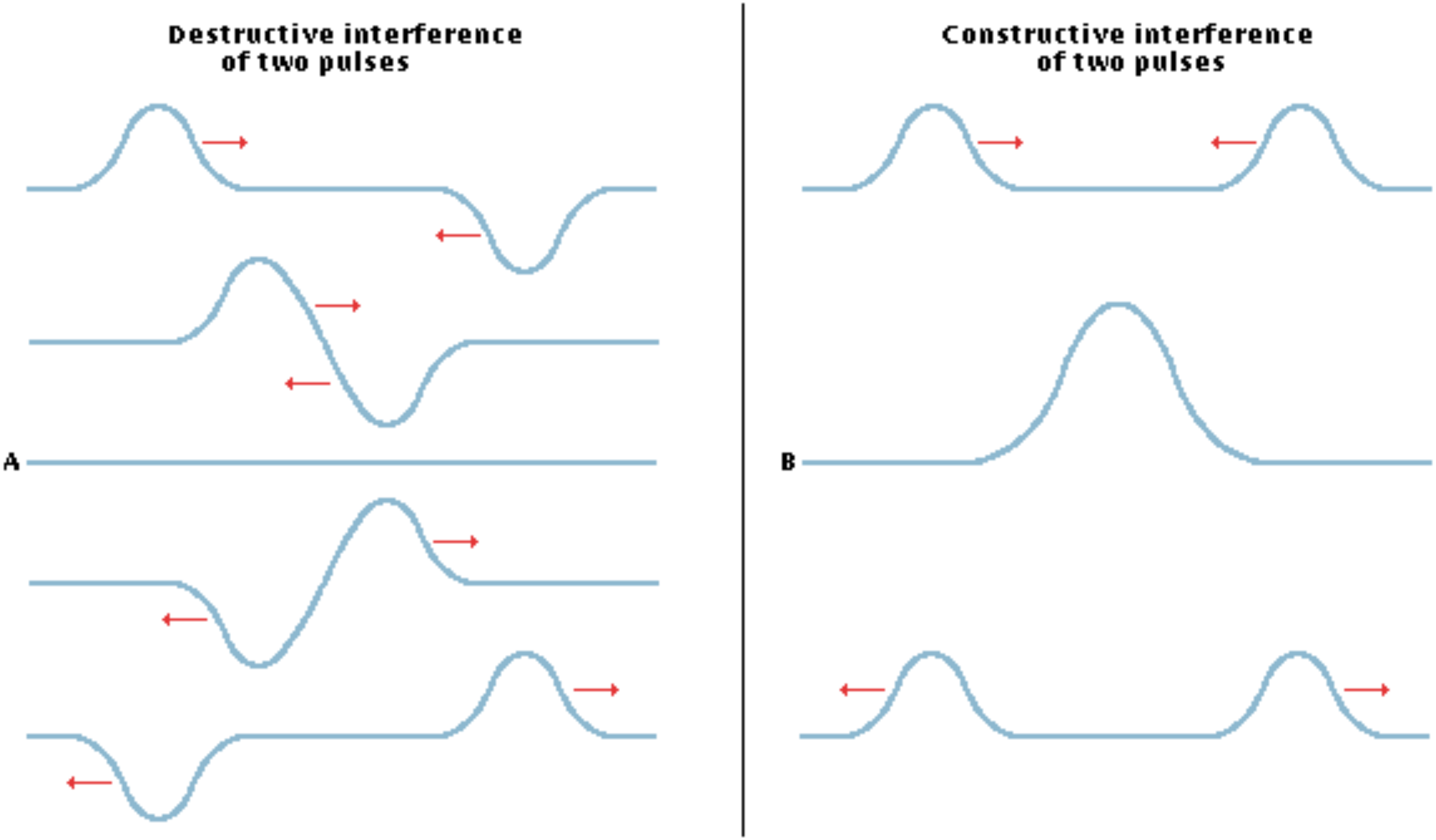
When a crest and a trough interfere, it is called destructive interference. The resultant displacement is smaller.



Constructive interference

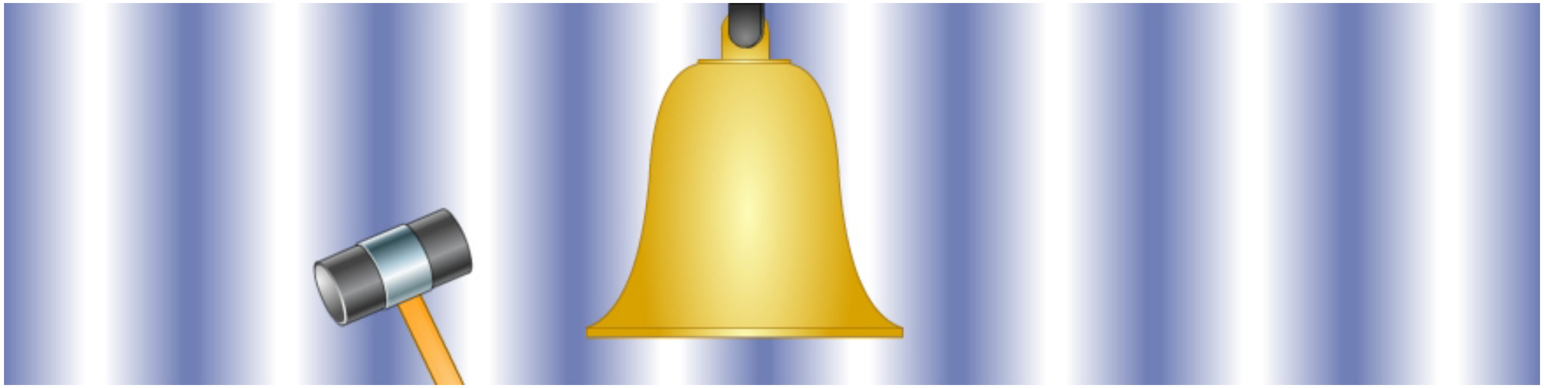


Destructive interference


Destructive interference
of two pulses
A
Constructive interference
of two pulses
B

Sound **is a** ***longitudinal wave*** **produced by a vibration that travels away from the source through solids, liquids, or gases, but not through a vacuum.**

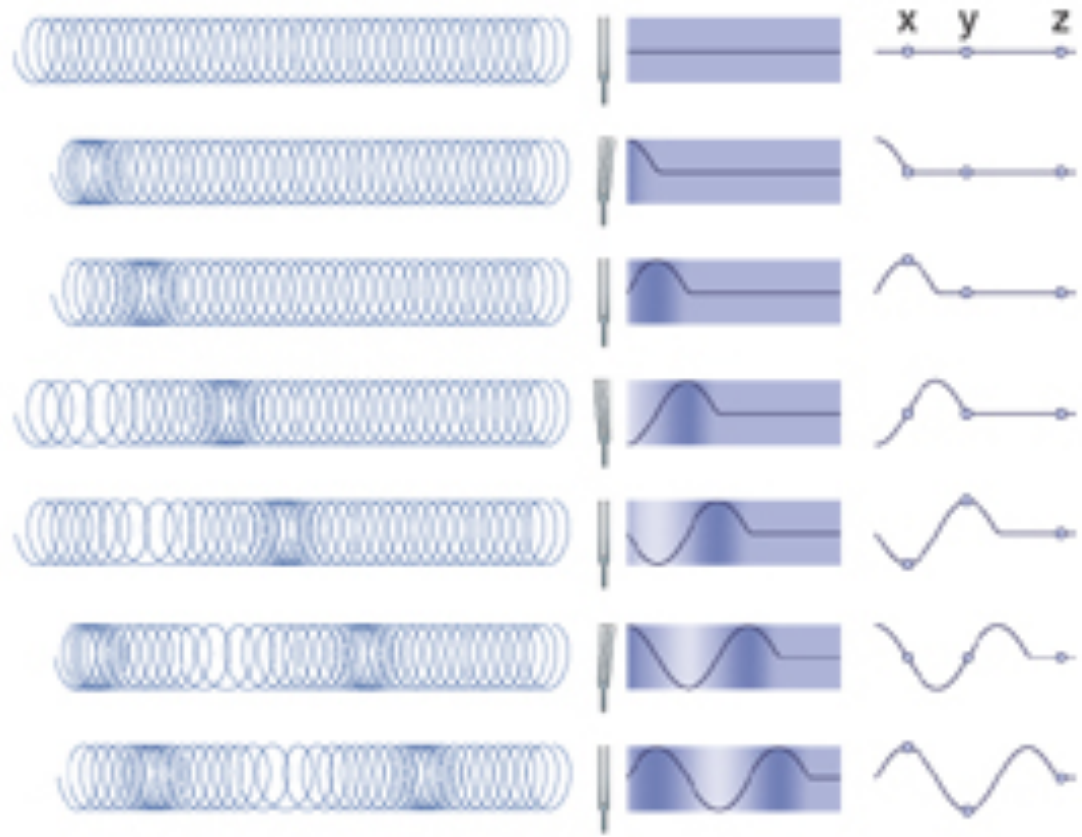
The speed of sound depends on the medium. Sound waves travel faster through solids rather than through gases.



The **frequency** of the wave is the number of oscillations in pressure each second.

The **wavelength** is the distance between successive regions of high or low pressure.

Because the motion of the air particles is parallel to the direction of motion of the wave, sound is a **longitudinal wave.**



Galileo first determined that the pitch we hear depends on the frequency of vibration

Most people cannot hear sounds with frequencies below 20 Hz or above 20,000 Hz.

Older people are less sensitive to frequencies above 10,000 Hz than young people.

By age 70, most people cannot hear sounds with frequencies above 8000 Hz.

We hear frequencies in the range of 20 Hz to 20,000 Hz.

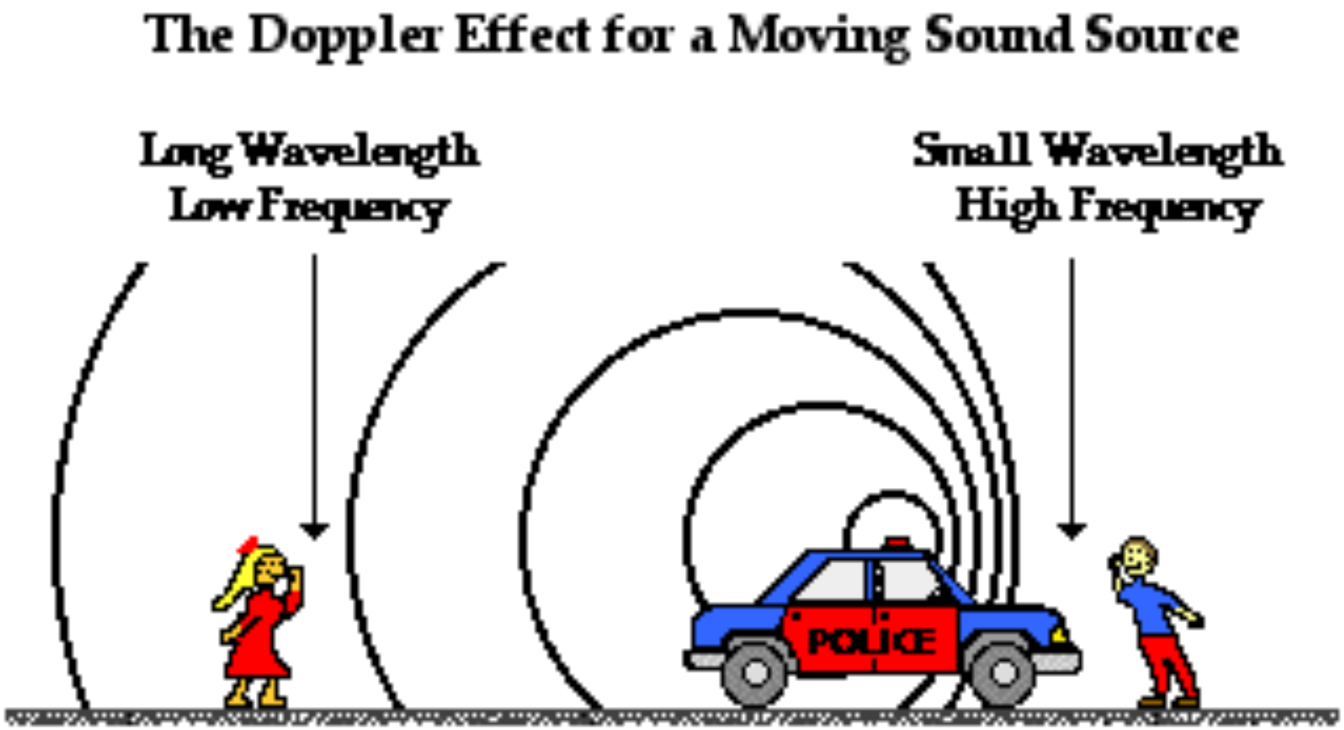
This is called the audible range.

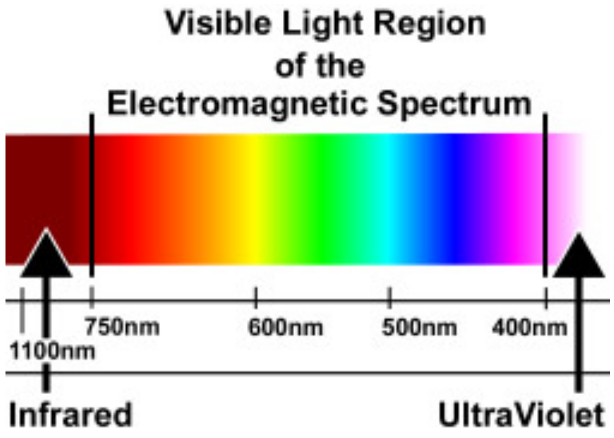
Frequencies above this range are called ultrasonic.

Sound waves whose frequency is lower than the audible range are called infrasonic.

DOPPLER EFFECT

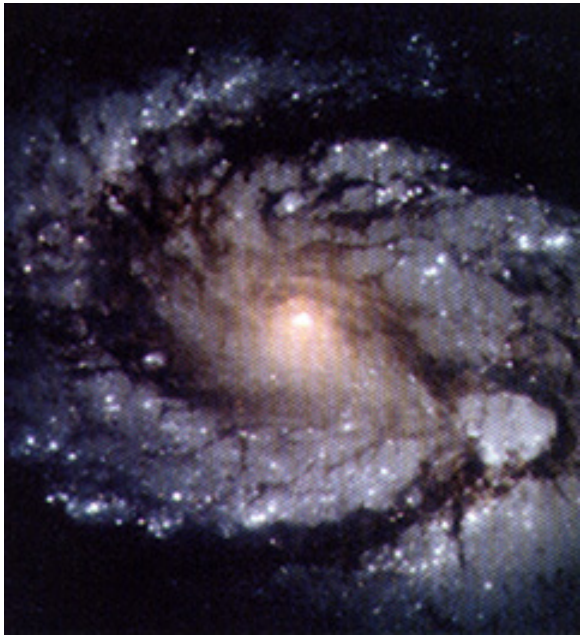
When a source of sound waves and a listener approach one another, the pitch of the sound is increased as compared to the frequency heard if they remain at rest. If the source and the listener recede from one another, the frequency is decreased. This phenomenon is known as the *Doppler effect.*





Light waves also exhibit the Doppler effect. The spectra of stars that are receding from us is shifted toward the longer wavelengths of light. This is known as the ***red shift.***

Measurement of the red shift allows astronomers to calculate the speed at which stars are moving away. Since almost all stars and galaxies exhibit a red shift, it is believed that the universe is **expanding.**



What color might appear if the object was moving away?

DOPPLER EFFECT

f_L : frequency of the listener
f_S : frequency of the source
v : velocity of sound
v_L : velocity of listener
v_S : velocity of source

$$f_L = f_S \frac{v + v_L}{v - v_S}$$

Sign Convention for velocity:

(+) approaching
(-) receding

8.6 A train whistle emits sound at a frequency of 400 Hz on day when the speed of sound is 340 m/s

a. What is the pitch of the sound heard when the train is moving toward a stationary observer at a speed of 20 m/s.

f_s = 400 Hz
v = 340 m/s
v_L = 0
v_S = 20 m/s

$$f_L = f_S \frac{v + v_L}{v - v_S} = 400 \frac{(340 + 0)}{340 - 20} = 425 \text{ Hz}$$

b. **What is the pitch heard when the train is moving away from the observer at this speed?**

$f_s = 400$ Hz

$v = 340$ m/s

$v_L = 0$

$v_S = -20$ m/s

$$f_L = f_S \frac{v + v_L}{v - v_S} = 400 \frac{(340 + 0)}{340 - (-20)} = 377.8 \text{ Hz}$$

8.7 A stationary source of sound has a frequency of 800 Hz on a day when the speed of sound is 340 m/s. What frequency is heard by a person who is moving from the source at 30 m/s?

v_S = 0 m/s
f_s = 800 Hz
v = 340 m/s
v_L = - 30 m/s

$$f_L = f_S \frac{v + v_L}{v - v_S} = 800 \frac{(340 - 30)}{340 - 0}$$ = **729.4 Hz**

SHOCK WAVES AND THE SONIC BOOM

When the speed of a source of sound exceeds the speed of sound, the sound waves in front of the source tend to overlap and constructively interfere. The superposition of the waves produce an extremely large amplitude wave called a *shock wave.*

The shock wave contains a great deal of energy. When the shock wave passes a listener, this energy is heard as a *sonic boom.*

The sonic boom is heard only for a fraction of a second; however, it sounds as if an explosion has occurred and can cause damage.

F-18 jet breaking the sound barrier

F-18 jet breaking the sound barrier

ELECTROMAGNETIC WAVES

Electromagnetic waves are waves that are capable of traveling through a vacuum. They consist of oscillating electric and magnetic fields with different wavelengths. The wave speed equation is: $c = f\lambda$

where c is the speed of light.