

# Mechanical Waves



## Chapter 17



# Investigation

Close your eyes and be absolutely silent for 60 seconds.  
Simply listen.

Write down what you heard up to ten items as specifically  
as possible:

List ways that the sounds were produced:



# Investigation

Close your eyes and be absolutely silent for 60 seconds.  
Simply listen.

Write down what you heard up to ten items as specifically as possible:

- Computer buzz      dog barking      clicking noises
- Humming noise      car driving by

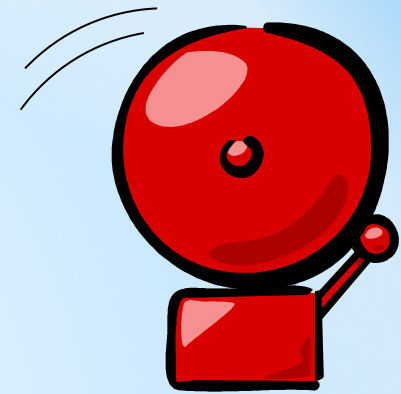
**List ways that the sounds were produced:**

- rubbing/sliding – squeaks, trombone
- knocking/tapping/hitting/clapping – drums, thunder
- blowing – trumpet, wind
- shaking – tambourine
- chemically reacting – explosions

# Try this:

- \*Put your thumb and index finger around your vocal chords and say “aah” pretty loud.
- \*Now say it soft.
- \*You can not only hear the sound, but you can feel the **vibration** inside your throat.

# What is sound?



Sound is

- \* A form of energy made by **vibrations** that can be heard.
- \* When an object vibrates (moves back and forth quickly ... **oscillation**) it causes the air particles around it to move.
- \* These particles collide with particles close to them (**air pressure**) and this continues until they run out of energy.

# Sound is an example of Mechanical Waves?

A **mechanical wave** is a disturbance in matter that carries energy from one place to another.

- The material through which a wave travels is called a **medium**.
- Mechanical waves require a medium to travel through. **Solids, liquids, and gases all can act as mediums.**
- A **vibration** is a repeating back-and-forth motion.

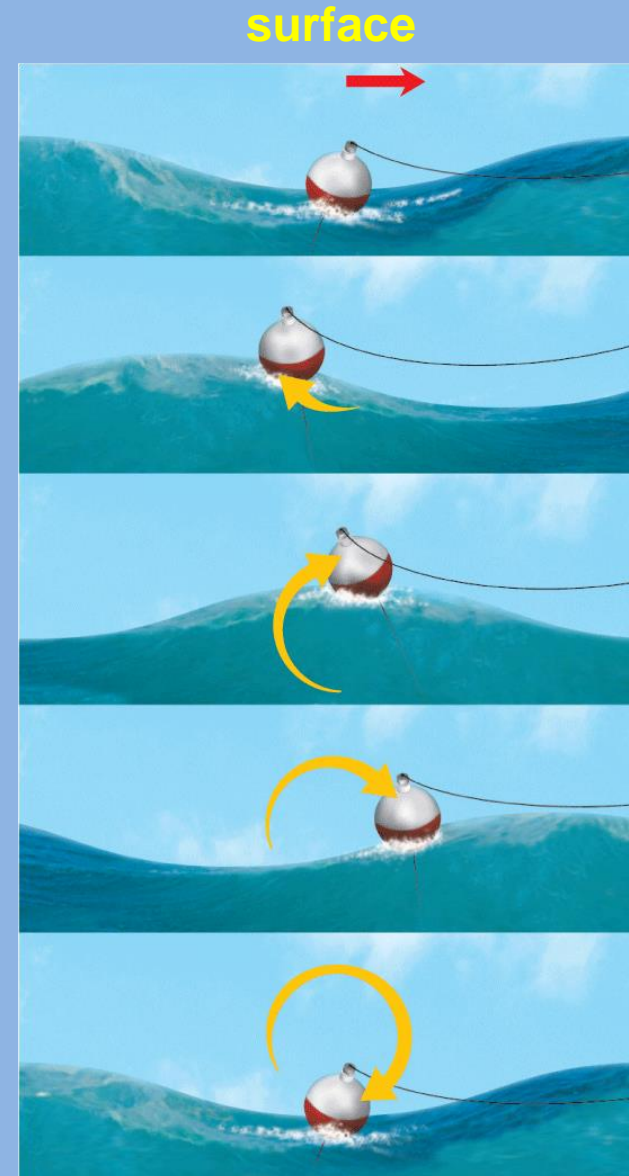
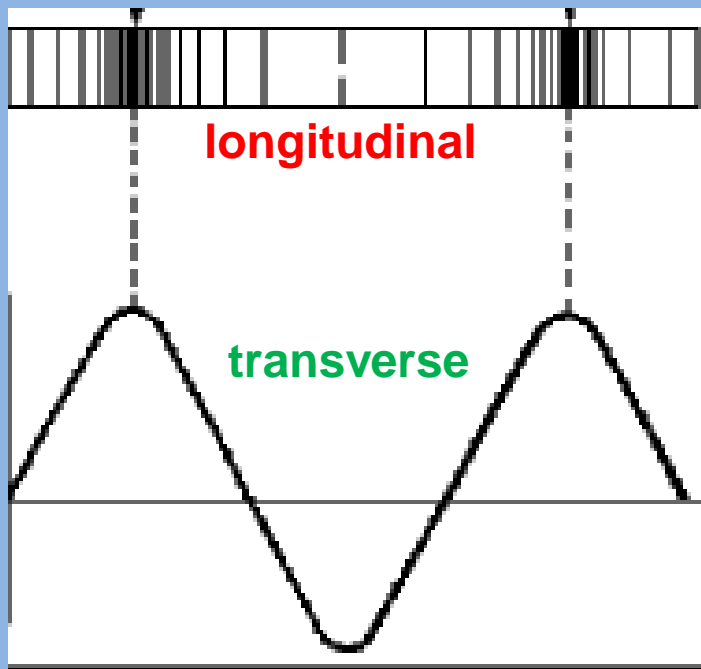
# Focus Questions



1. Define a wave" and describe three types of mechanical waves, especially contrasting transverse & longitudinal waves.
2. Define the properties and components of waves (wavelength, amplitude, crest, trough, period, frequency, speed, interference, standing waves, reflection, refraction).
3. Calculate wave speed, frequency, period, and wavelength.
4. Describe the behavior of waves at a boundary between media (reflection, refraction).

# Types of Mechanical Waves

The three main types of mechanical waves, which are classified by the way they move through a medium.

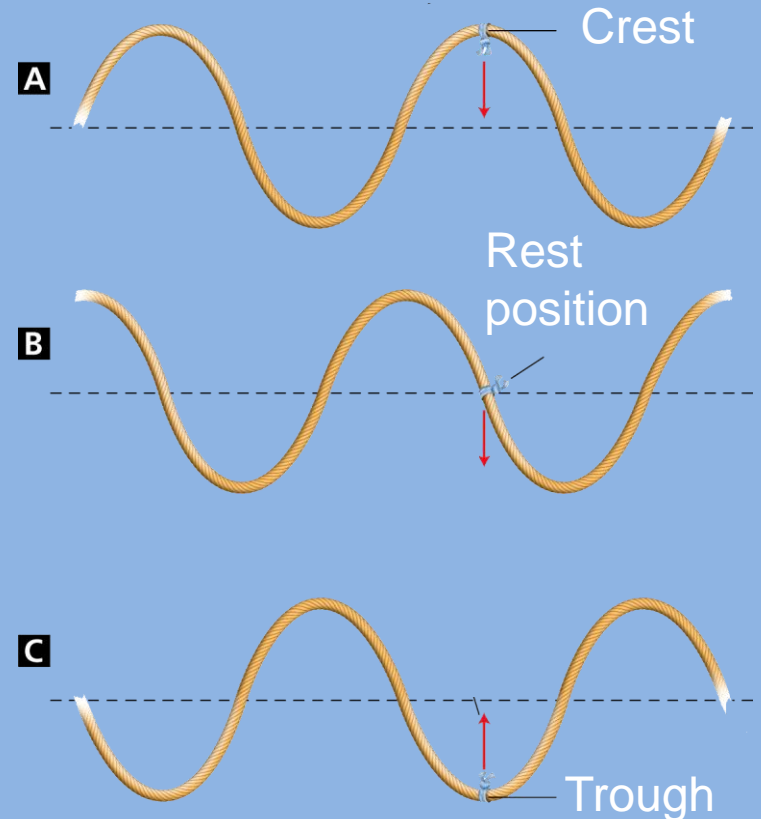




# Transverse Waves

*When you shake one end of a rope up and down, the vibration causes a wave.*

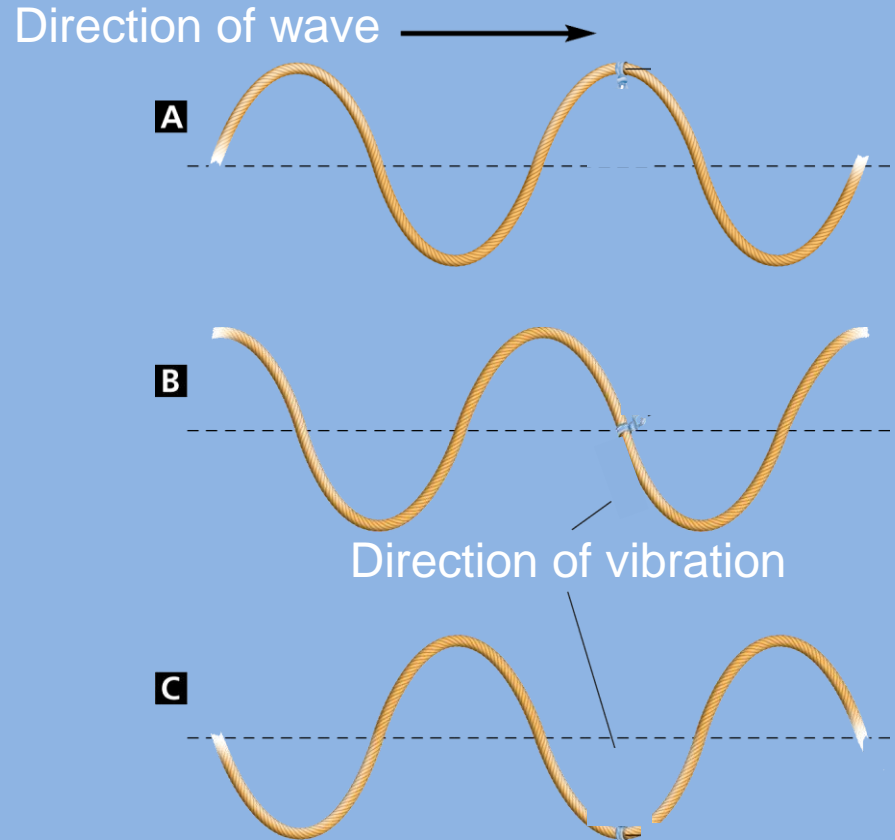
- The highest point of the wave is the **crest**.
- The lowest point of the wave is the **trough**.
- A single point on the rope vibrates up and down between a crest and trough.



## Transverse Waves

A **transverse wave** causes the medium to **vibrate at right angles** to the direction in which the wave travels.

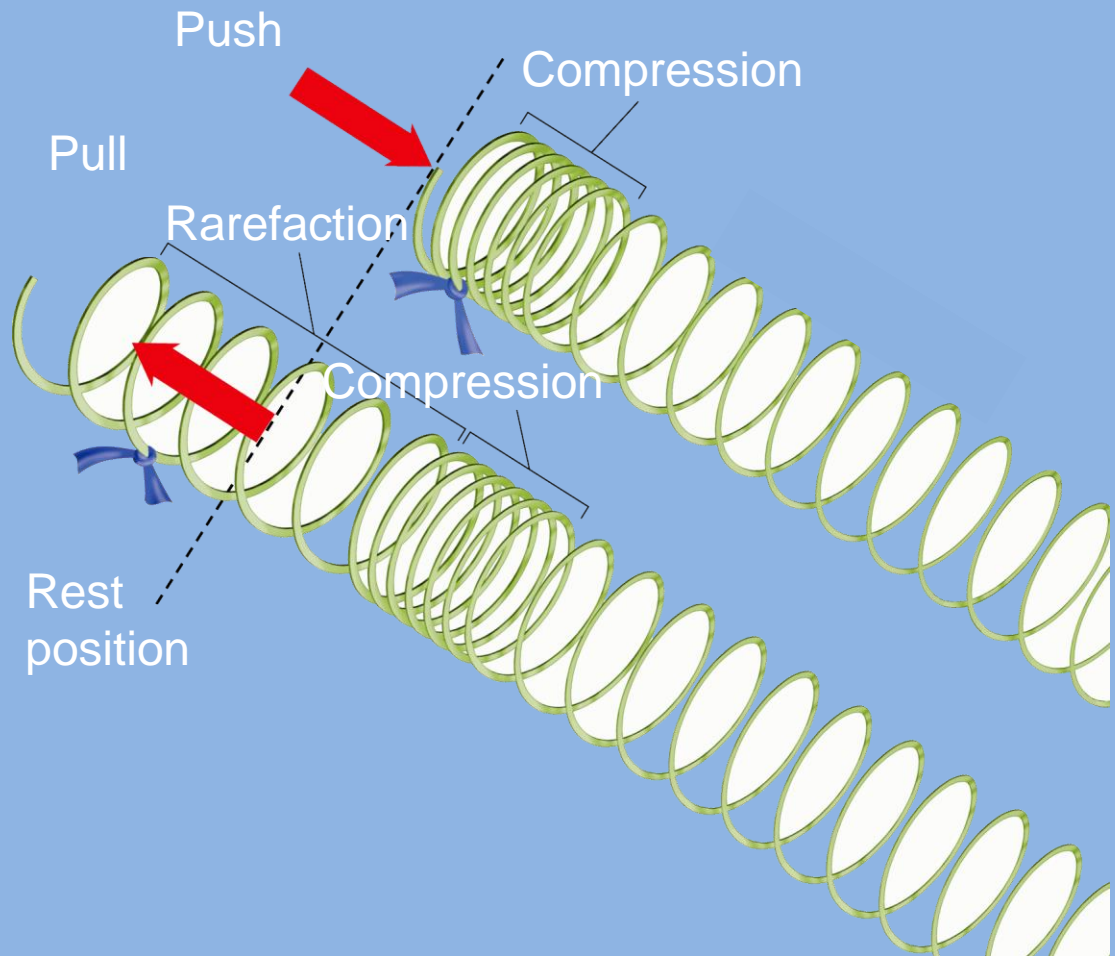
The wave carries energy from left to right, in a direction **perpendicular** to the up-and-down motion of the rope.



# Longitudinal Waves

*In a spring toy, the wave carries energy along the spring.*

- An area where the particles in a medium are spaced close together is called a **compression**.
- An area where the particles in a medium are spread out is called a **rarefaction**.

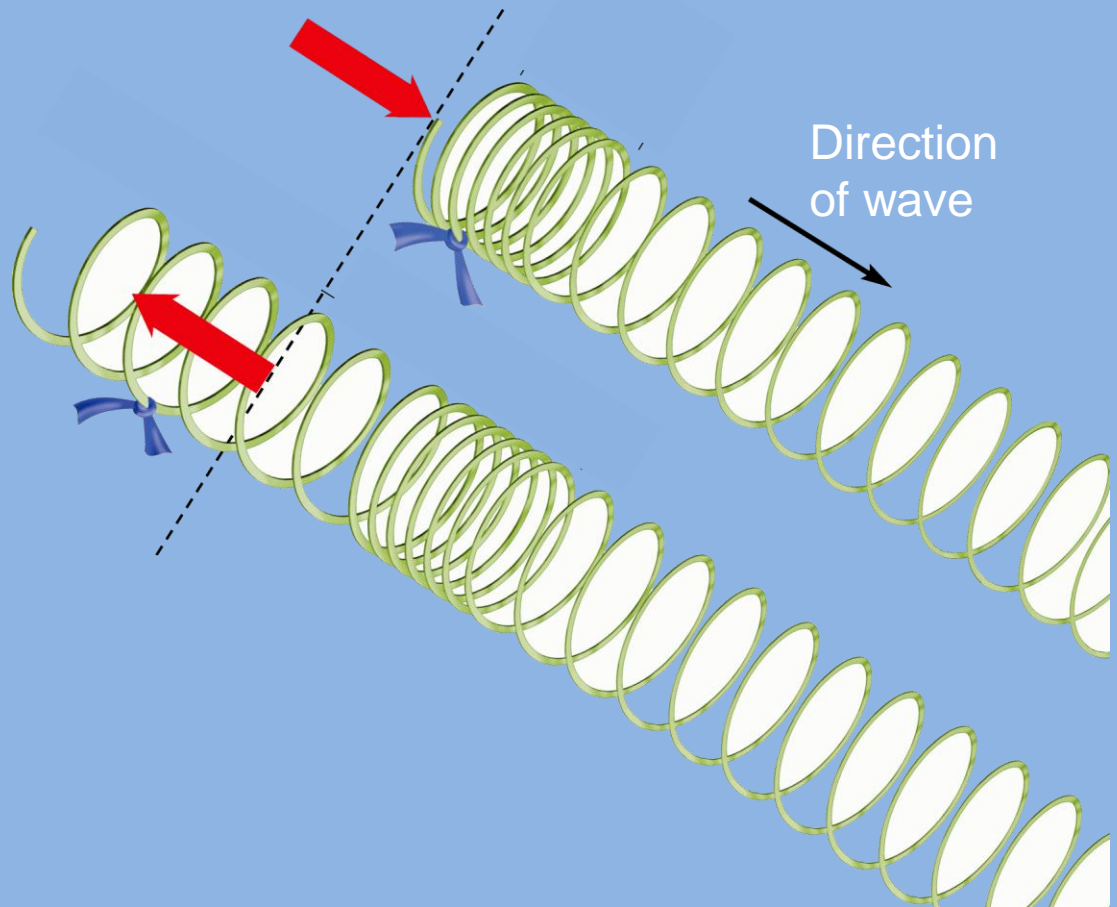


# Longitudinal Waves

*In a spring toy, the wave carries energy along the spring.*

As compressions and rarefactions travel along the spring, each coil vibrates **back and forth** around its rest position.

A **longitudinal wave** is a wave in which the vibration of the medium is **parallel** to the direction the wave travels.



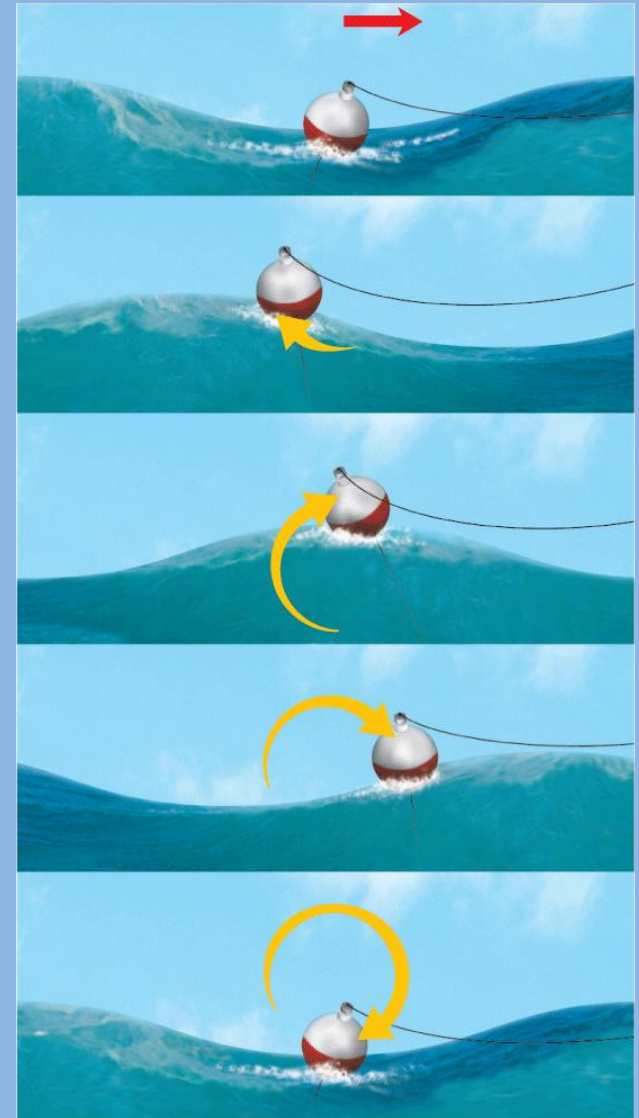
# Surface Waves

## Types of Mechanical Waves

Ocean waves are the most familiar kind of surface waves.

A **surface wave** is a wave that **travels along a surface** separating two media.

As the ocean wave moves to the right, the bobber **moves in a circle**, returning to its original position.



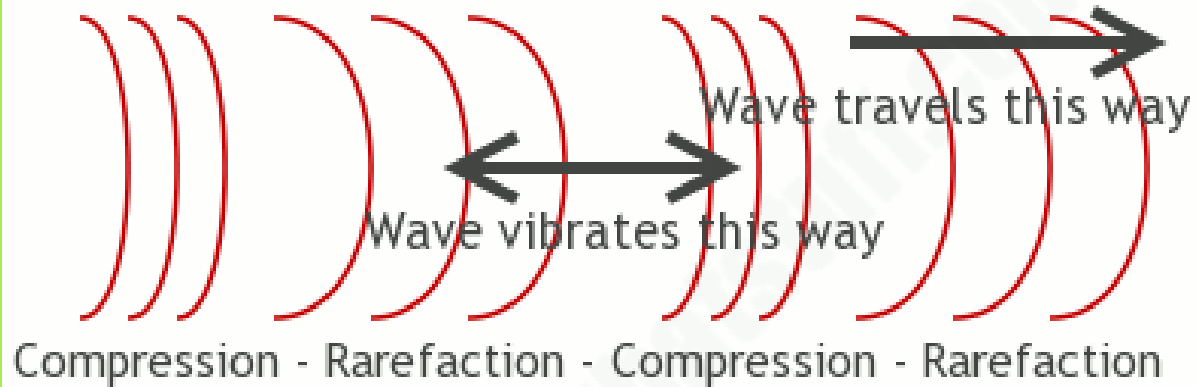
# How do waves travel?

Sound passes through a medium as **longitudinal waves**.

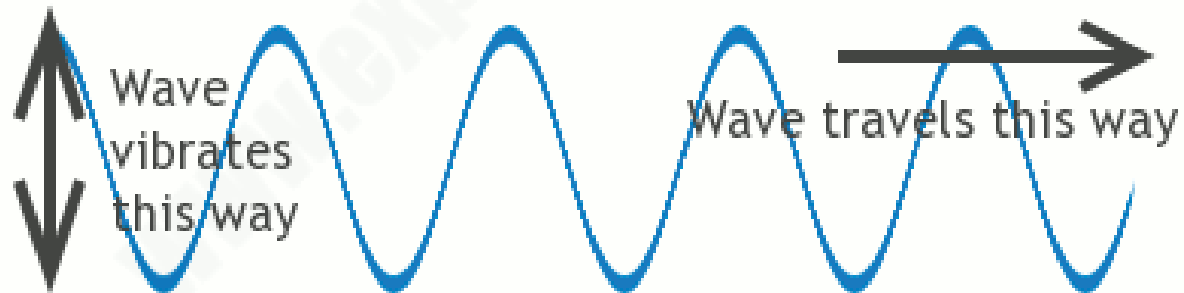
The direction of propagation of a **sound wave** is **parallel** to its direction of oscillation (**back & forth**).

The direction of propagation of a **transverse wave** is **perpendicular** to its direction of oscillation (**up & down**).

Sound wave = longitudinal wave



Ocean wave = transverse wave





A mechanical wave carries energy from one place to another through the

- a. physical transfer of matter.
- b. interaction of electromagnetic fields.
- c. phase changes of a medium.
- d. vibration of a medium.

In what type of wave is the vibration of the medium parallel to the direction in which the wave travels?

- a. transverse wave
- b. longitudinal wave
- c. surface wave
- d. ocean wave



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An example of a transverse wave is a(n)

- a. sound wave traveling through air.
- b. ocean wave far from the shore.
- c. ocean wave as it approaches the shore.
- d. light wave traveling through space.

As a \_\_\_ wave travels across water, molecules of water move in a circular pattern.

longitudinal wave ... surface wave ... transverse wave

A \_\_\_ wave vibrates the medium parallel to the direction the wave travels.

longitudinal wave ... surface wave ... transverse wave



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- a. sound wave traveling through air.
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As a \_\_\_ travels across water, molecules of water move in a circular pattern.

longitudinal wave ... **surface wave** ... transverse wave

A \_\_\_ vibrates the medium parallel to the direction the wave travels.

**longitudinal wave** ... surface wave ... transverse wave

# Simulation Part 1



How is Sound Processed and Received? (1:23)

<http://somup.com/cbeDrkRAG>

- 1) “**Frequency**” will increase from  $\sim 250$  Hz, to  $\sim 500$  Hz, to  $\sim 750$  Hz, and then  $\sim 1000$  Hz. Describe the sound. What happens as frequency changes from low to high?
- 2) Frequency is set to  $\sim 500$  Hz. The “**Amplitude**” will increase. Describe the sound. What happens as amplitude changes from low to high?
- 3) How are the sounds produced in #1 & #2 different?

# Properties of Waves.

<http://somup.com/cbeD3zRBj> (1:24)

Amplitude is set to 0.75 cm and Frequency to 0.75 Hz.

- 1) When that bead reaches its highest point, record the **frequency**:  
\_\_\_\_\_. Wavelength \_\_\_\_\_.
- 2) **Frequency is changed to 1.5 Hz**. Repeat procedure 1. Measure the wavelength \_\_\_\_\_.
- 3) **Frequency is changed to 3.0 Hz**. Repeat procedure 1. Measure the wavelength \_\_\_\_\_.
- 4) What is the relationship between wavelength and frequency?

# Properties of Waves.

<http://somup.com/cbeD3zRBj> (1:24)

Amplitude is set to 0.75 cm and Frequency to 0.75 Hz.

- 1) When that bead reaches its highest point, record the **frequency : 0.75 Hz**. Wavelength 7.5 cm.
- 2) **Frequency is changed to 1.5 Hz**. Repeat procedure 1. Measure the wavelength 4.0 cm.
- 3) **Frequency is changed to 3.0 Hz**. Repeat procedure 1. Measure the wavelength 2.1 cm.
- 4) What is the relationship between wavelength and frequency?  
**Inverse (as  $f$  increases,  $\lambda$  decreases)**

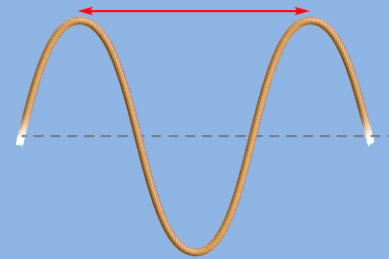
# Frequency and Period

Any motion that repeats at regular time intervals is called **periodic motion**.

- The time required for one cycle is called the **period**.
- Frequency is the number of complete cycles in a given time.
- Frequency is measured in cycles per second, or **hertz** (Hz).

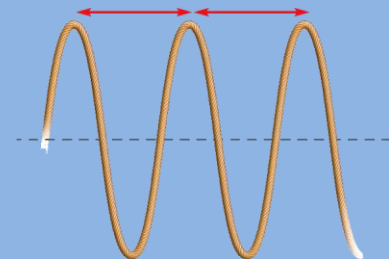
**Frequency = 1.0 hertz**

**A** One cycle per second



**Frequency = 2.0 hertz**

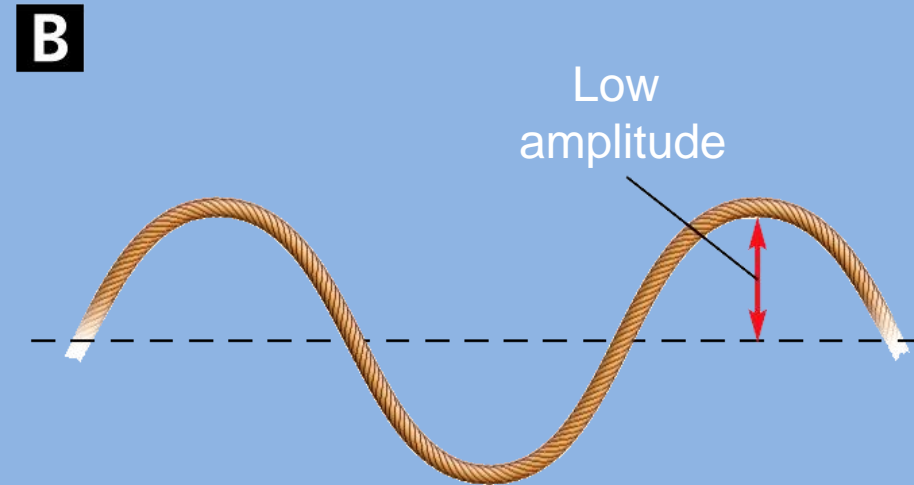
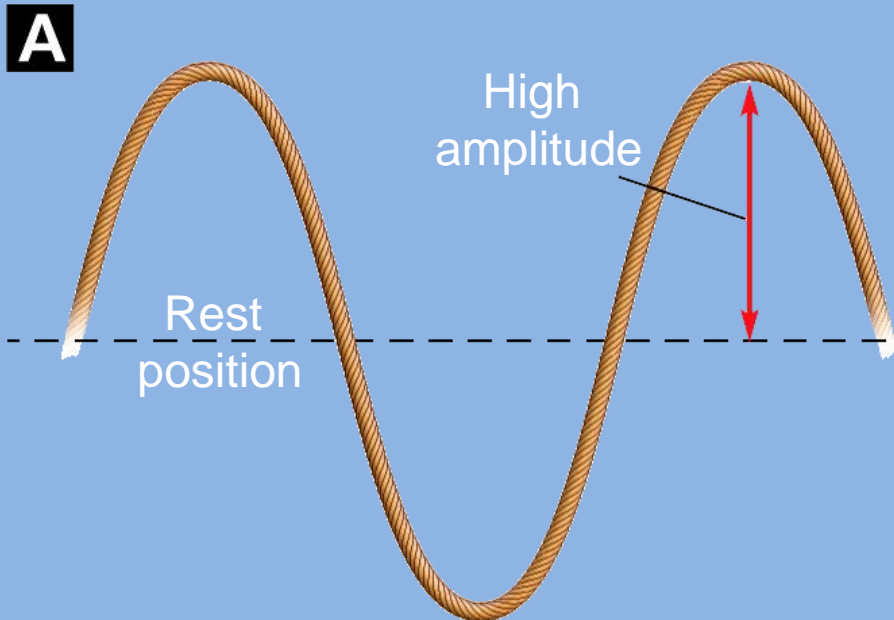
**B** Two cycles per second



# Amplitude

The amplitude of a **transverse** wave is the distance from the rest position to a crest or a trough.

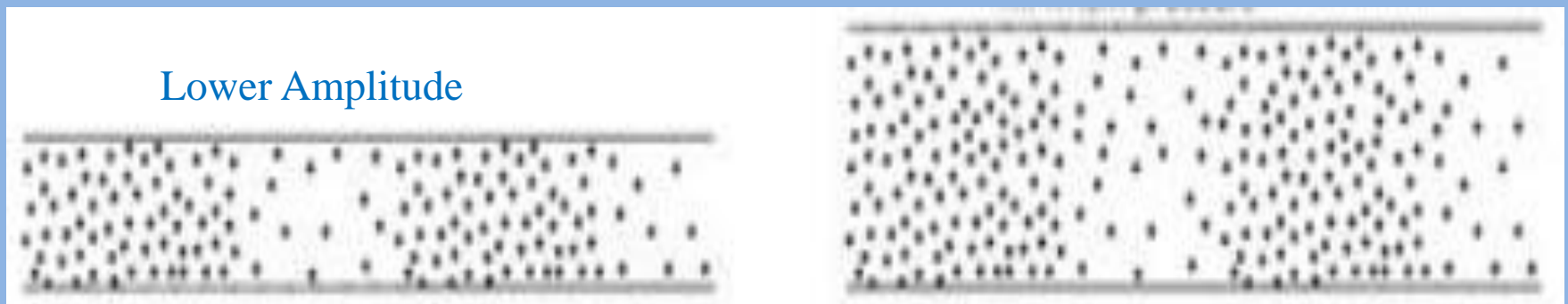
It takes more energy to produce a wave with higher crests and deeper troughs.



# Amplitude

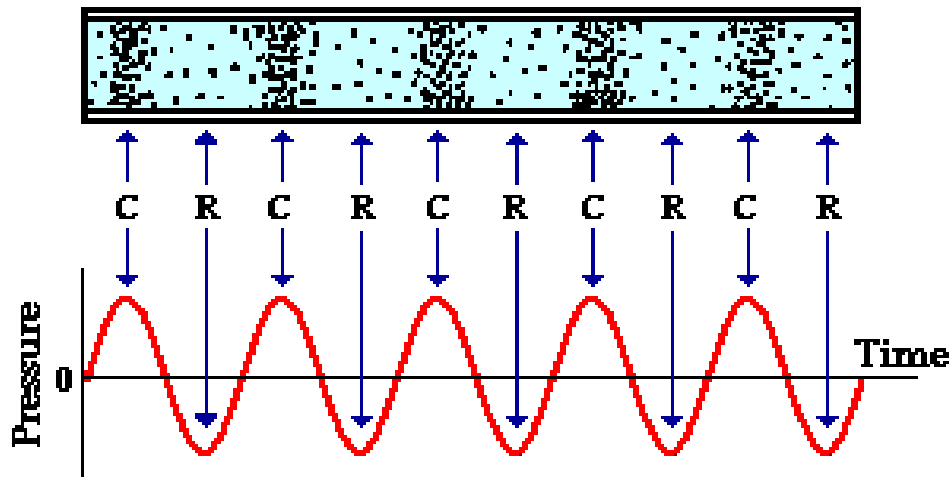
The amplitude of a **longitudinal** wave is the maximum displacement of a point from its rest position.

The more energy the wave has, the more the medium will be compressed or displaced.

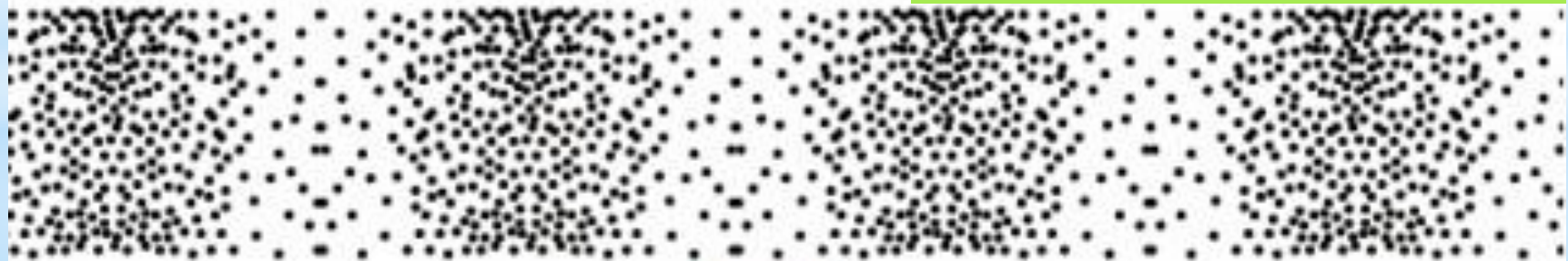
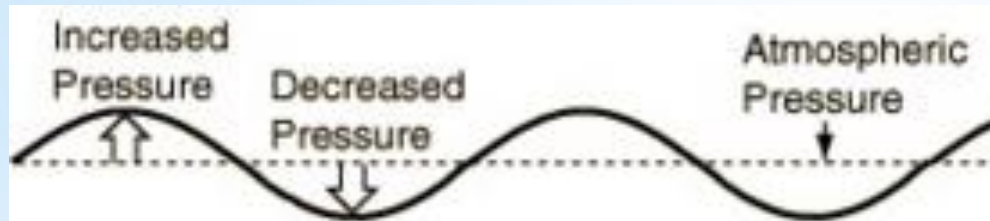




## Sound is a Pressure Wave



NOTE: "C" stands for compression and "R" stands for rarefaction



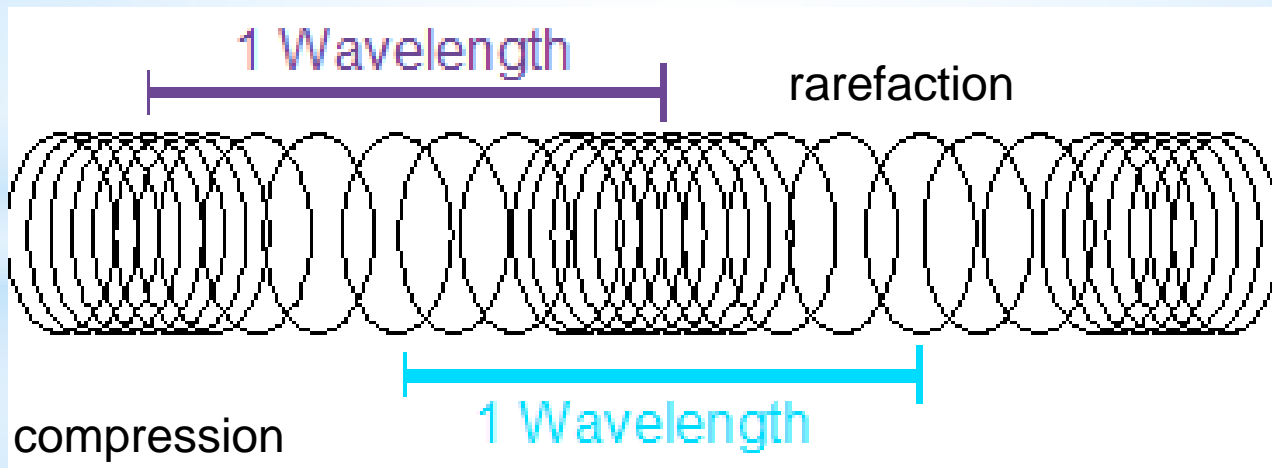
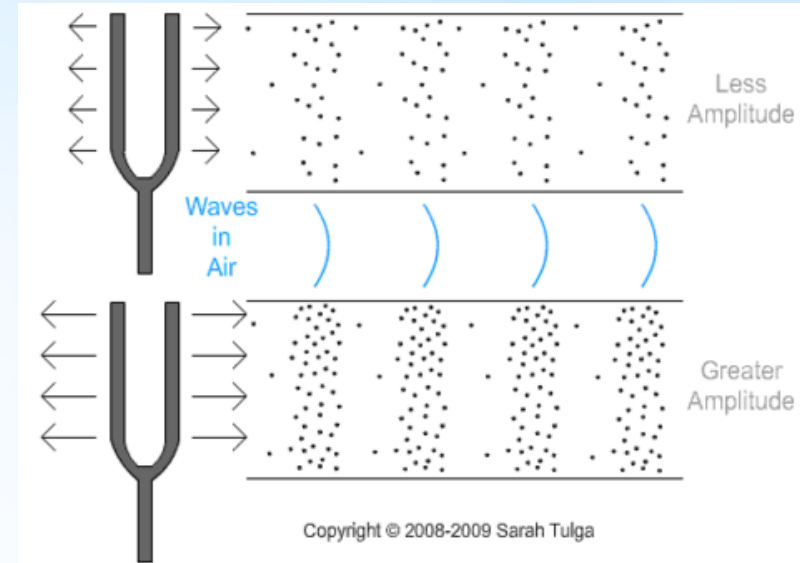
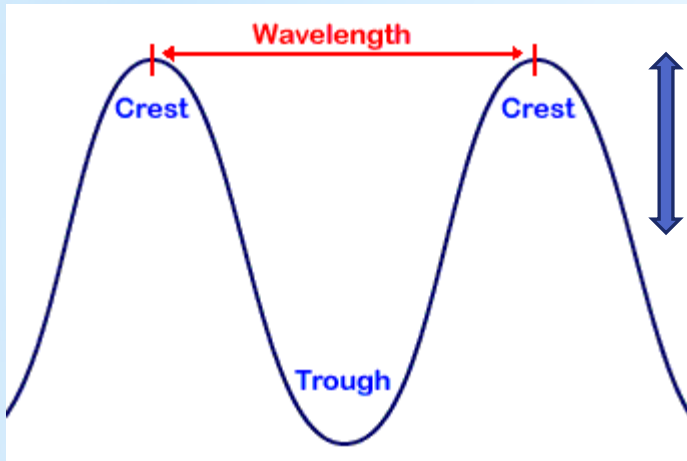
Motion of air molecules associated with sound.

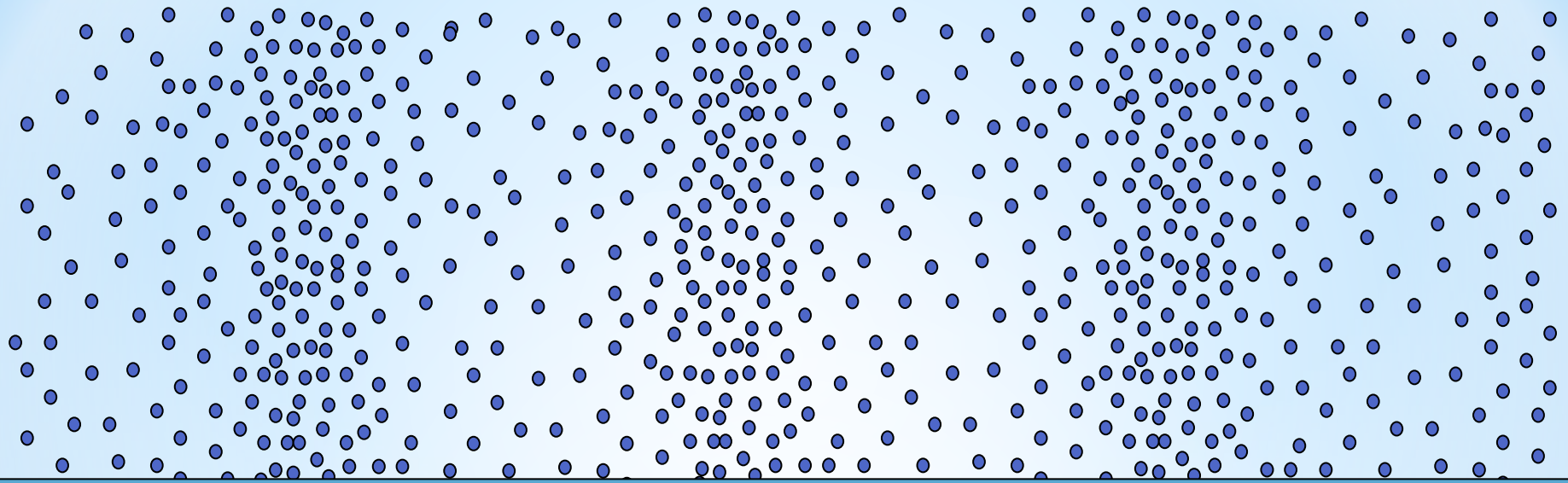
Propagation of sound

# Anatomy of a Wave

The direction of propagation of a sound wave is **parallel** to its direction of oscillation.

# All waves have wavelength.

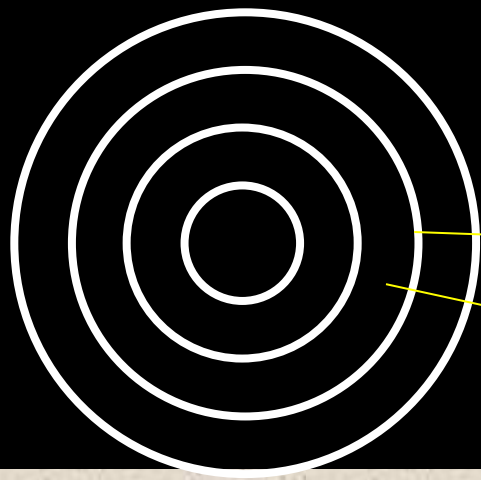




wavelength,  $\lambda$

For a **longitudinal** wave, wavelength is the distance between adjacent compressions or rarefactions.

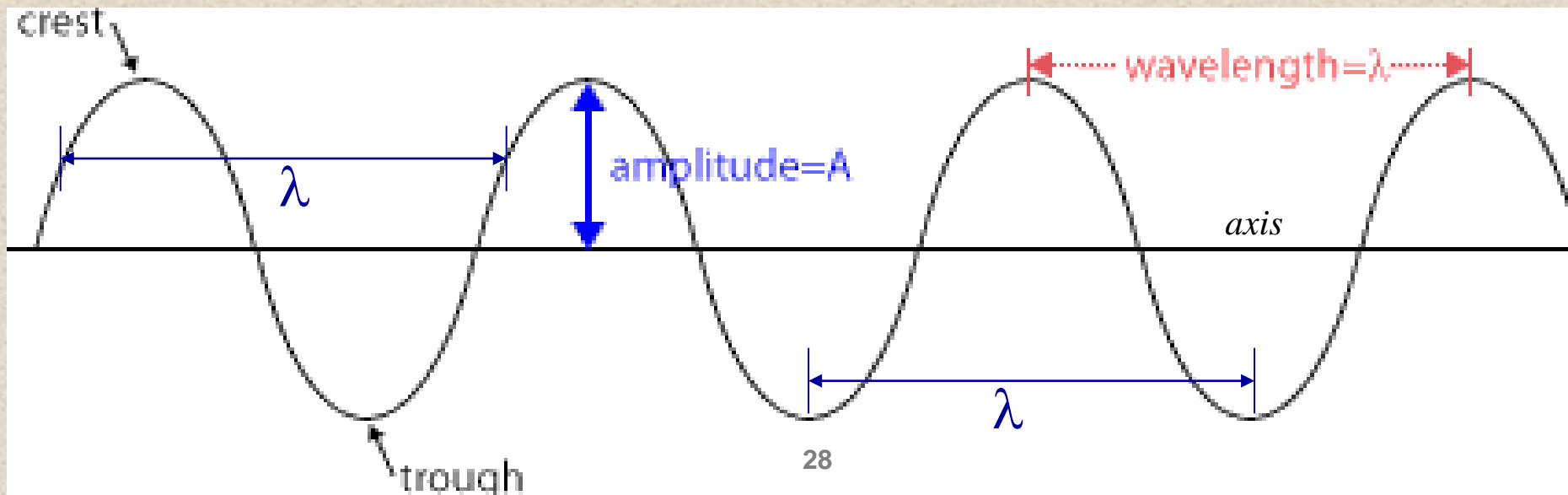
# Wavefronts



crest

trough

For a **transverse** wave, wavelength is measured between adjacent crests or between adjacent troughs.



# Measuring the Speed of Waves

## Wave Velocity

The speed with which a wave crest passes by a particular point in space.

It is measured in meters/second.

### Speed of Waves

$$\text{Speed} = \text{Wavelength} \times \text{Frequency}$$

$$V = f \times \lambda$$

# Speed of Sound

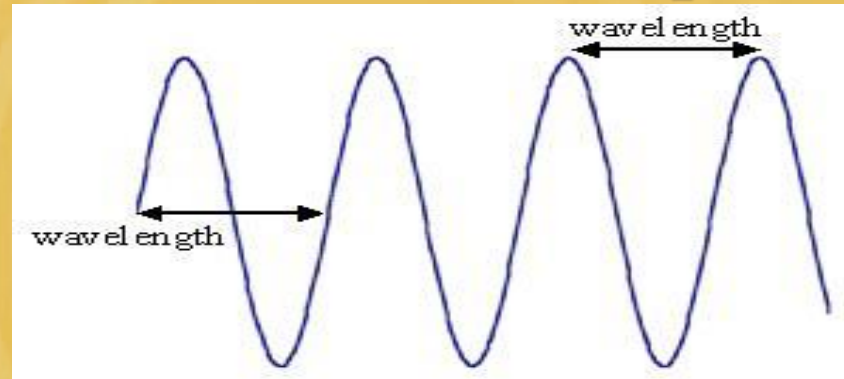
Medium	velocity m/sec
air (20 C)	343
air (0 C)	331
water (25 C)	1493
sea water	1533
diamond	12000
iron	5130
copper	3560
glass	5640

Sound travels 4 times faster through water than through air.

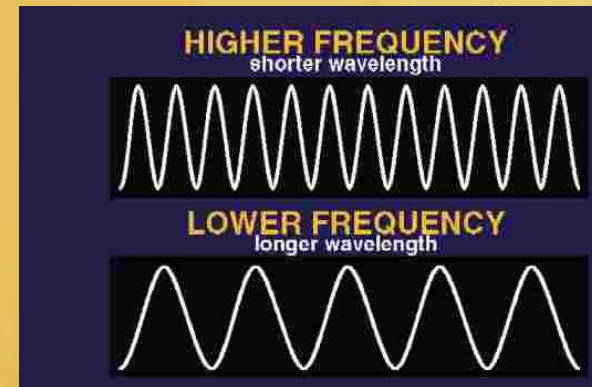
Sound travels 16 times faster through glass than through air.

# Wavelength & Frequency

- **Wavelength** is the distance between one part of a wave and the same part of the next wave



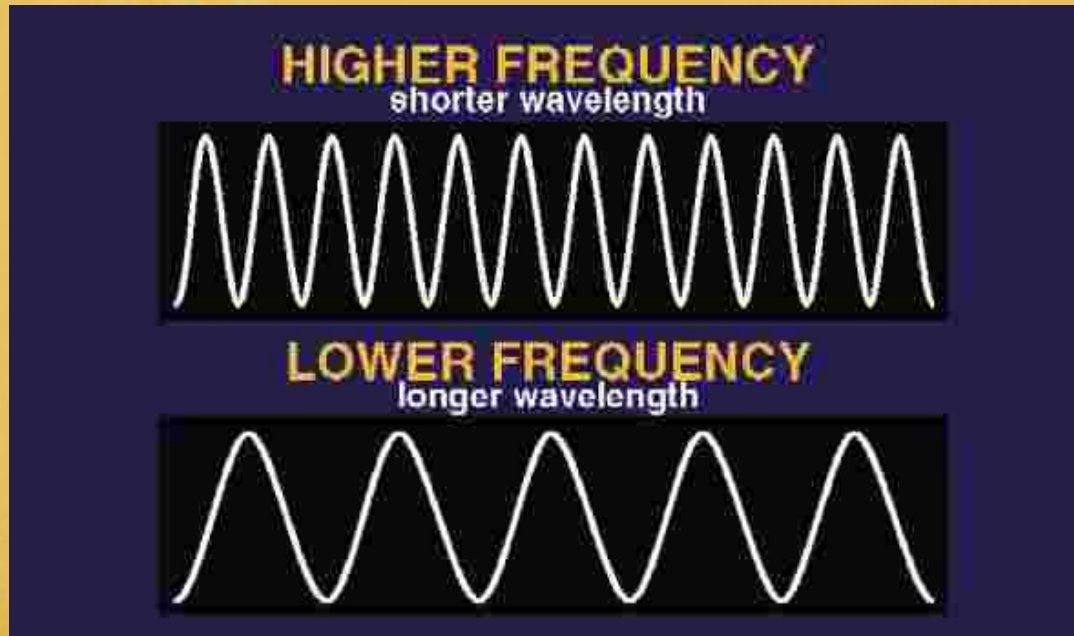
- **Frequency** is the number of waves moving past a point in one second.



# Wavelength & Frequency

$$v = f \lambda$$

What is the relationship between frequency and wavelength?



Sound





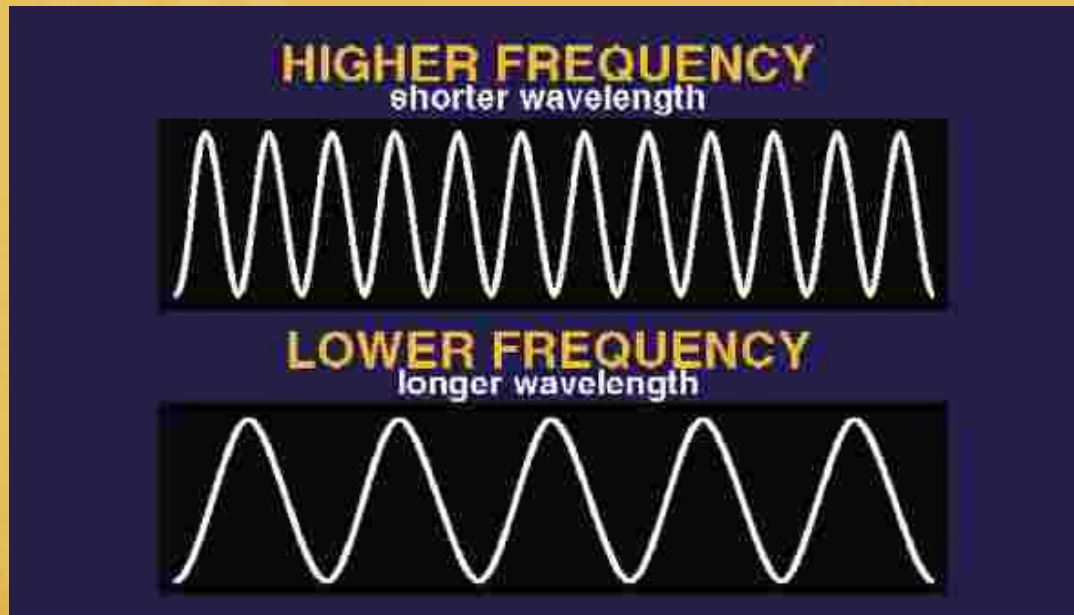
# Wavelength & Frequency

$$v = f \lambda$$

Speed of sound = frequency x wavelength

If the speed of sound is constant, then, frequency and wavelength are **INVERSELY** proportional:  $f \propto 1 / \lambda$

- as frequency (f ) increases, wavelength ( $\lambda$ ) decreases
- as frequency (f ) decreases, wavelength ( $\lambda$ ) increases



Sound

# Wavelength & Frequency

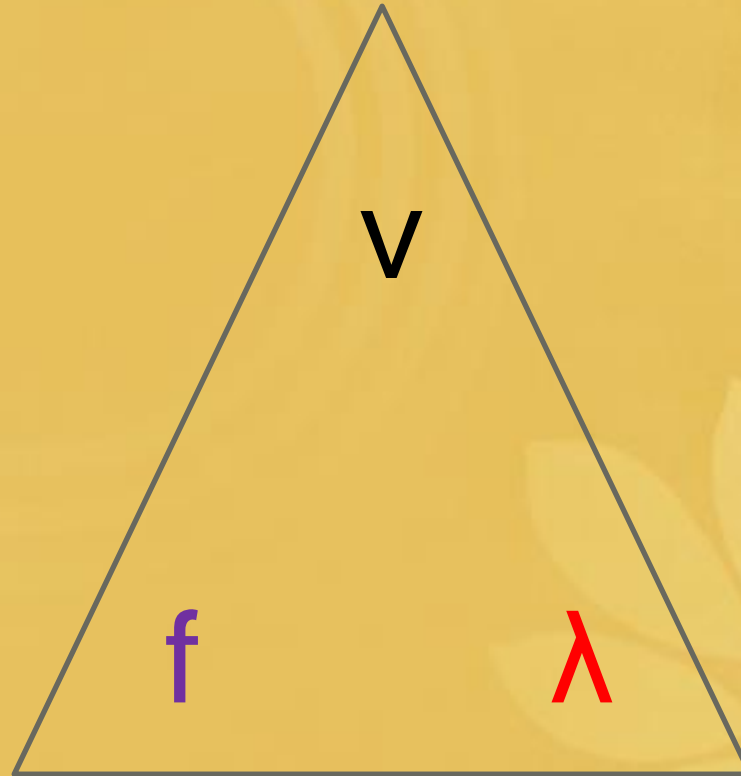


$$v = ?$$

Speed of sound = ? x ?

$$f = ?$$

$$\lambda = ?$$



# Wavelength & Frequency

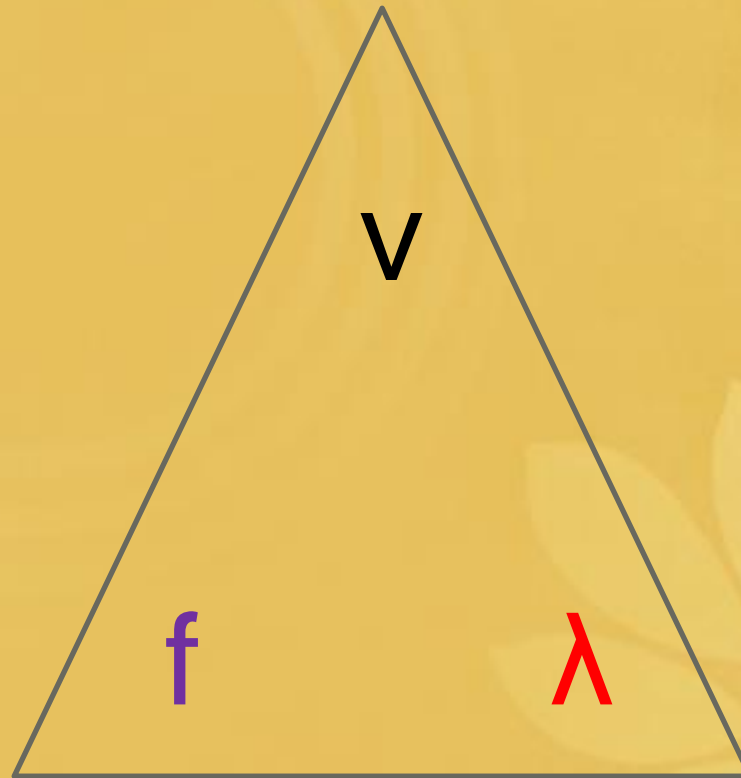
$$v = f \lambda$$



Speed of sound = frequency x wavelength

$$f = v / \lambda$$

$$\lambda = v / f$$



# Wavelength & Frequency



If the wavelength ( $\lambda$ ) of a tuning fork is 1.29 meters and we assume the speed of sound is 330 meters per second, what frequency ( $f$ ) will it produce? SHOW WORK

A  
G  
E  
S

# Wavelength & Frequency



If the wavelength ( $\lambda$ ) of a tuning fork is 1.29 meters and we assume the speed of sound is 330 meters per second, what frequency ( $f$ ) will it produce? SHOW WORK

A frequency

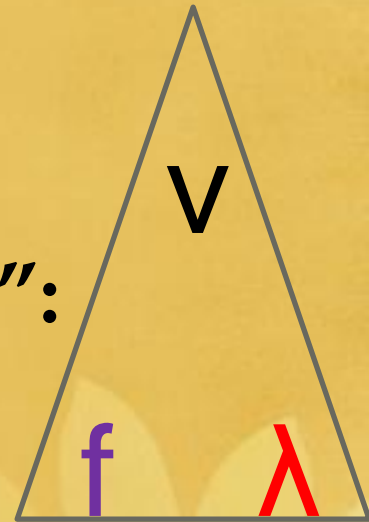
G  $v = 330 \text{ m/s}; \lambda = 1.29 \text{ m}$

E  $v = f \lambda \dots$  rearrange to solve for "f":

$$f = v / \lambda$$

S  $f = 330 \text{ m/s} / 1.29 \text{ m}$

$f = 256 \text{ Hz}$



# Wavelength & Frequency



What is the wavelength ( $\lambda$ ) of the musical note, G, which has a frequency of 767 Hz?

A  
G  
E  
S

# Wavelength & Frequency



What is the wavelength ( $\lambda$ ) of the musical note, G, which has a frequency of 767 Hz?

A wavelength ( $\lambda$ )

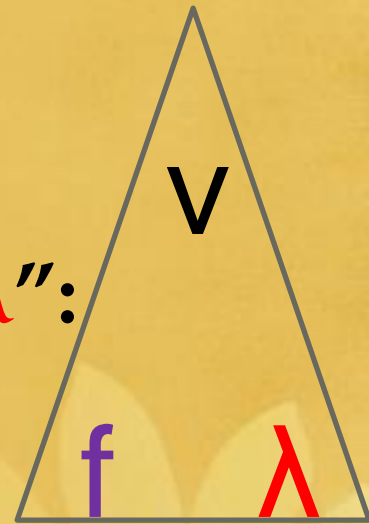
G  $v = 330$  m/s;  $f = 767$  Hz

E  $v = f \lambda$  ... rearrange to solve for " $\lambda$ ":

$$\lambda = v / f$$

S  $\lambda = 330$  m/s / 767 Hz

$$\lambda = 0.43 \text{ m}$$



# *Behavior of Waves*

**“Doppler Effect”**

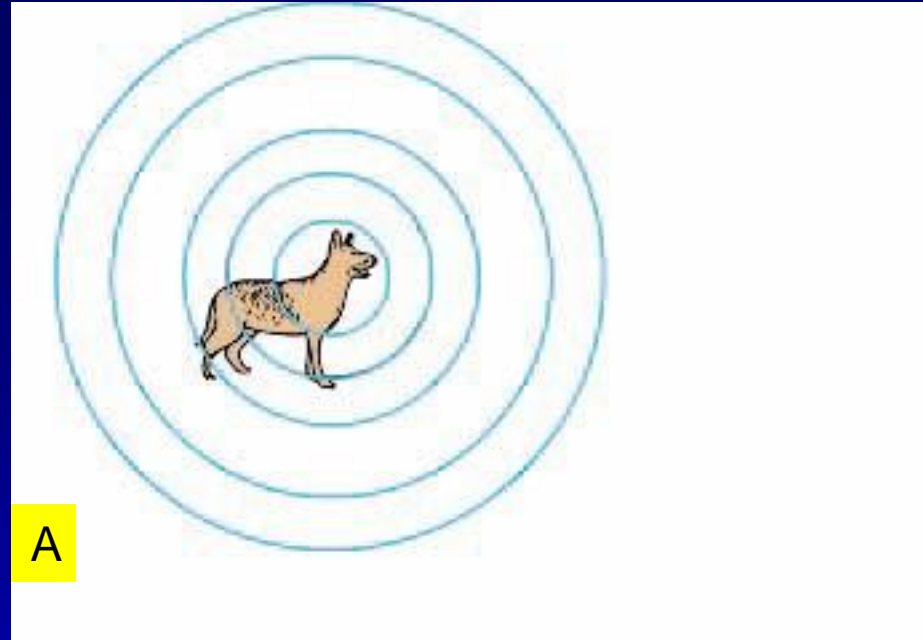
**“Refraction of Sound”**

**“Reflection of Sound”**



Spherical sound waves are produced from a STATIONARY source, spreading out evenly in all directions.

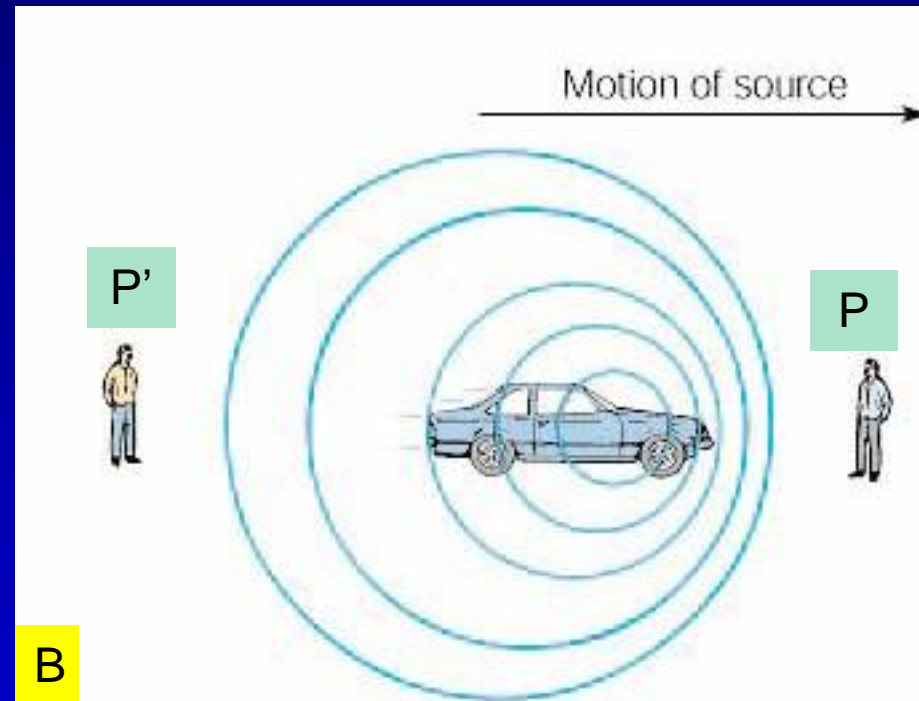
E.g. throw a stone into a calm pond.



# Doppler Effect

If the source is MOVING, an observer at position **P** will experience more wave crests per second than an observer at position **P'**.

The observer at **P** interprets this as a higher pitch.

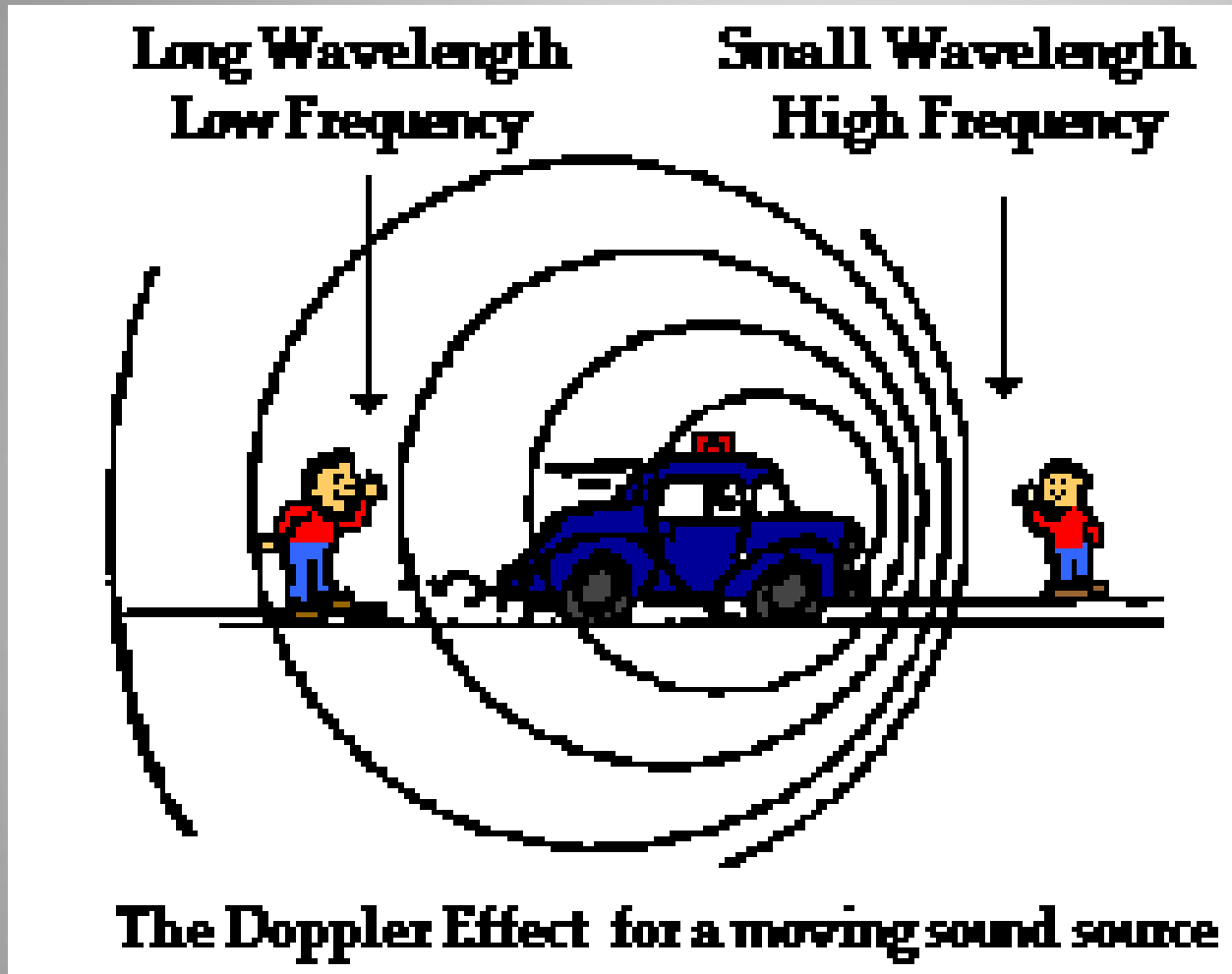


# Doppler Effect

The apparent change in the frequency of a sound caused by the **motion** of either the listener or the source of the sound.



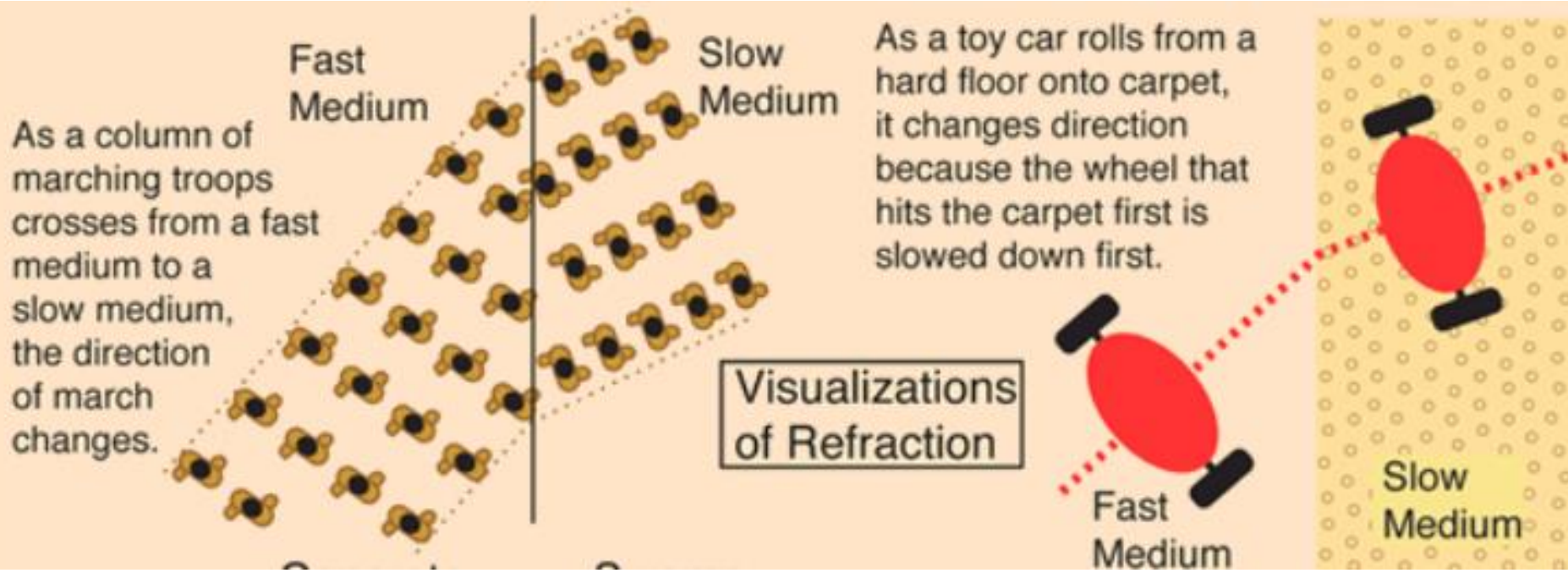
# Doppler Effect



<http://somup.com/cFXoLLnjl> Car Horn (0:13)

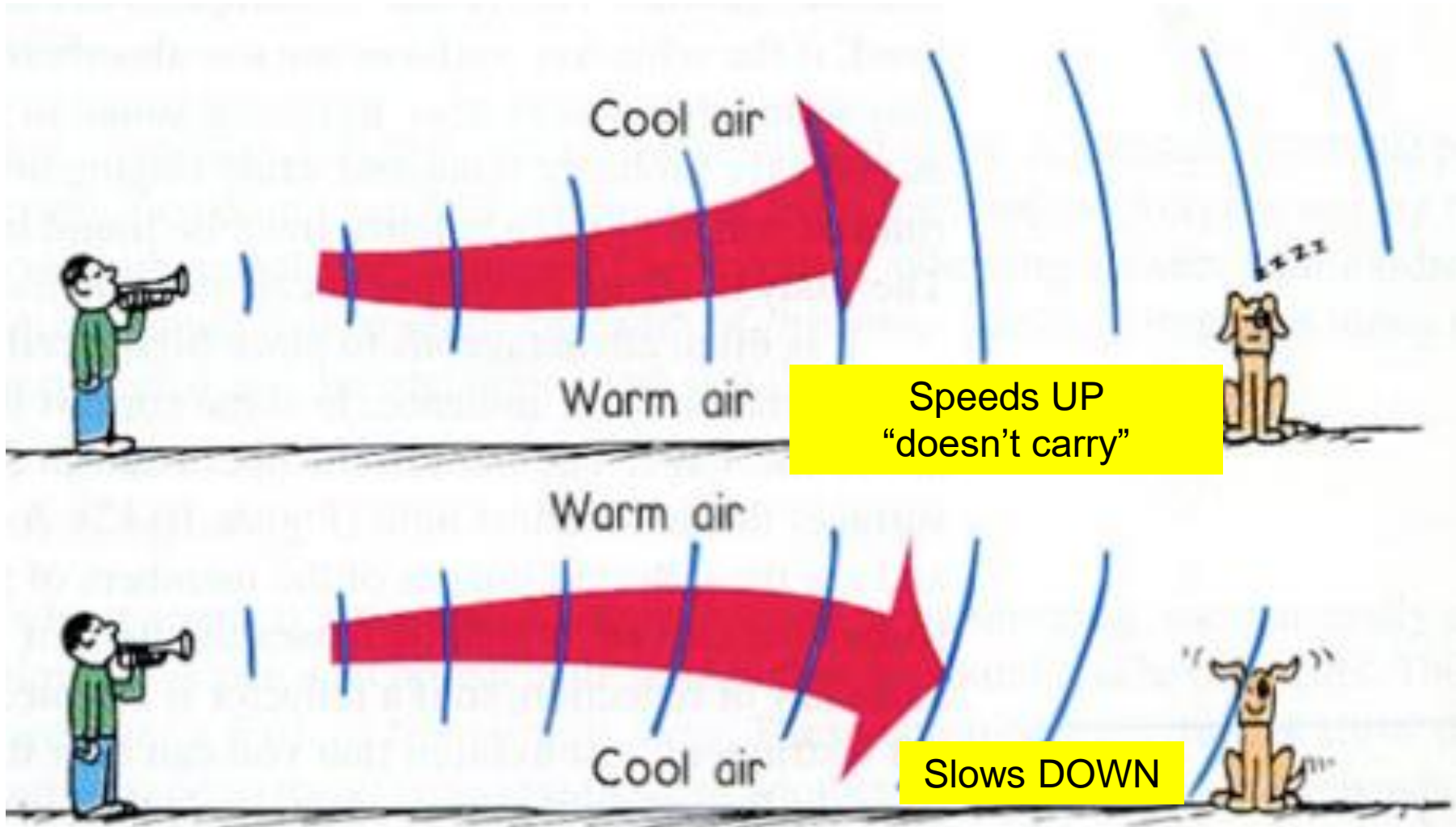
# Refraction

**Refraction** is the bending of a wave as it enters a new medium at an angle (e.g. **waves speed up or slow down**):



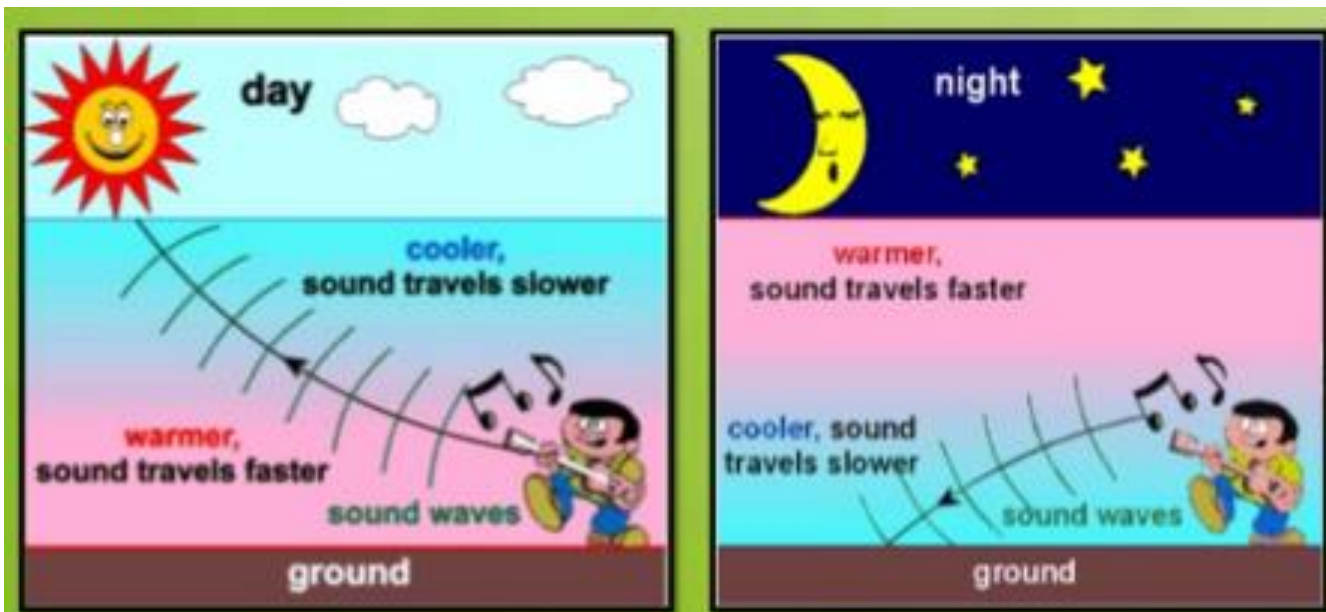
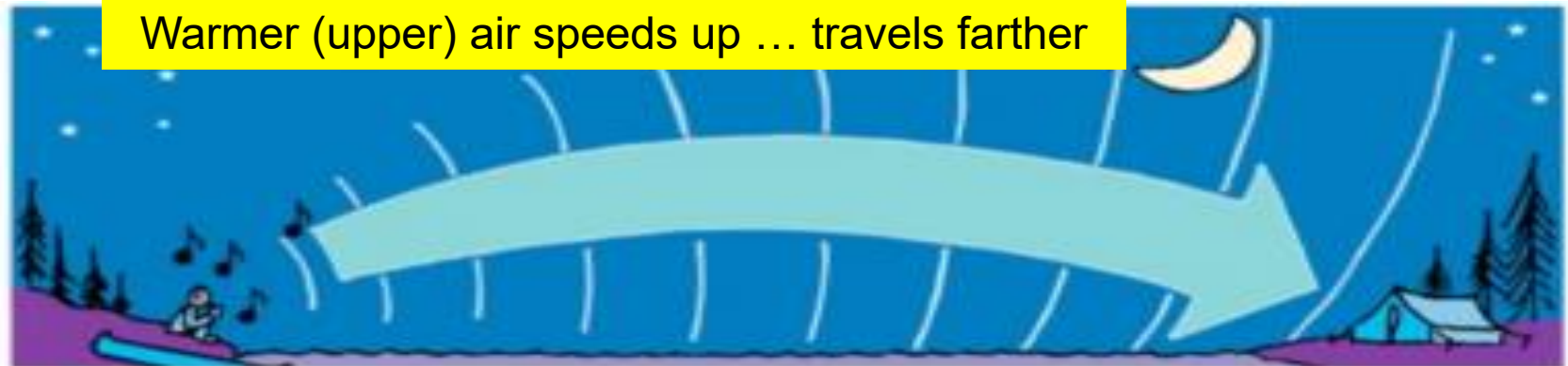
# Refraction

*The temperature of air changes its density and “bends” sound waves (e.g. they speed up or slow down):*



# Refraction

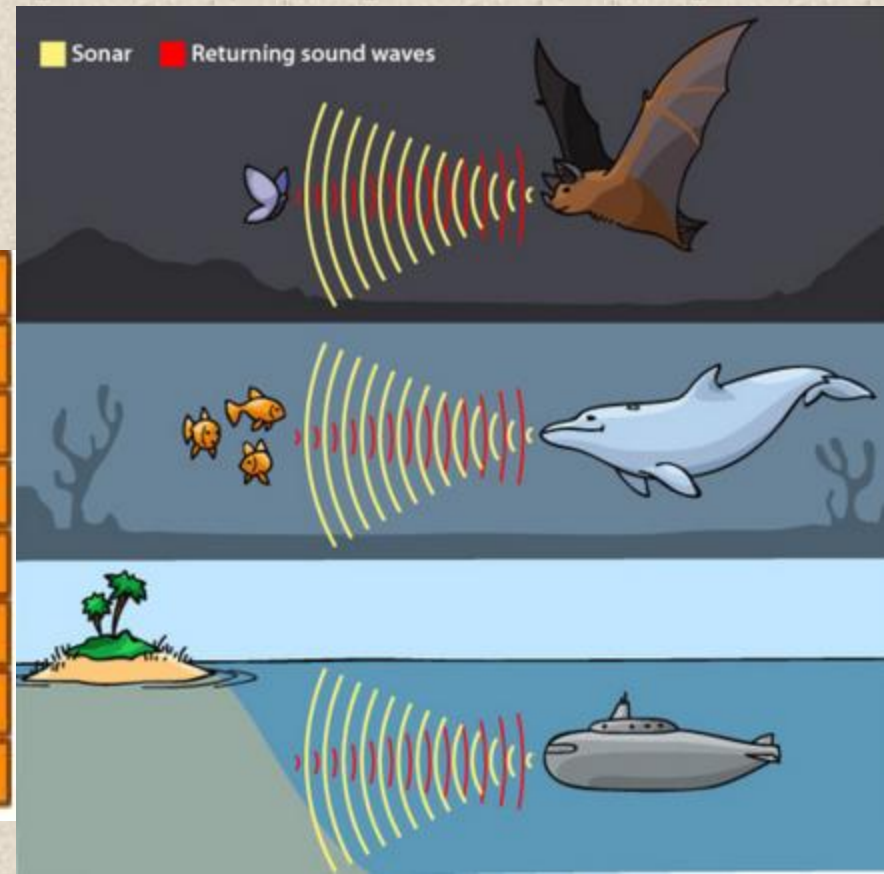
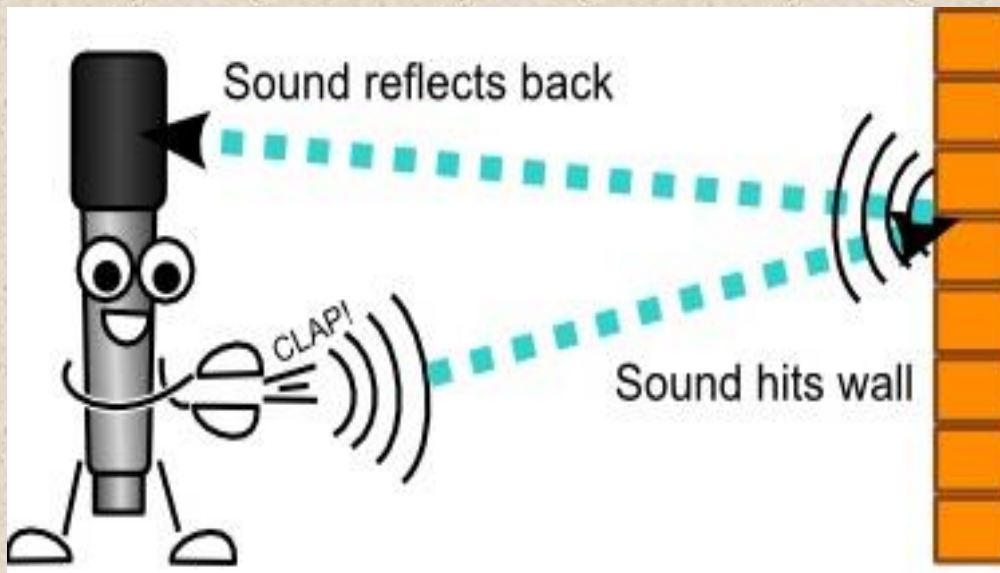
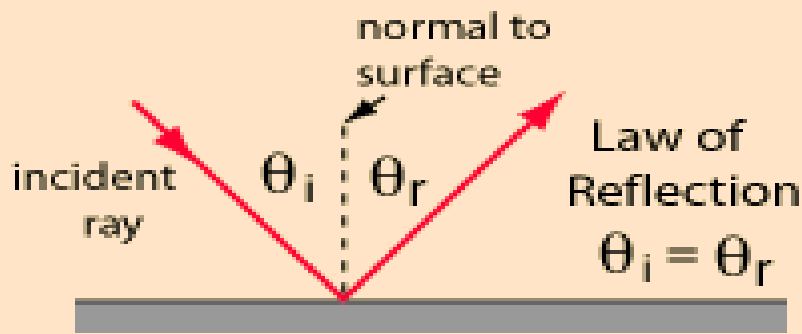
At night, when the air is cooler over the surface of the lake, sound is refracted toward the ground and carries unusually well.



Sound tends to be louder at night

# Reflection

When a sound wave “bounces back” from a surface at the same angle at which it hit the surface. *The angles are typically measured with respect to the “normal” to the surface.*





# Reflection    Echoes & Reverberation

**ECHO** is defined by distinct repetitions of a sound occurring after 30 milliseconds. This is when you can unquestionably hear a distinct echo of a sound coming back to you. Echoes are common in a big canyon or inside a gigantic room. In the world of music production, it's called 'delay'.

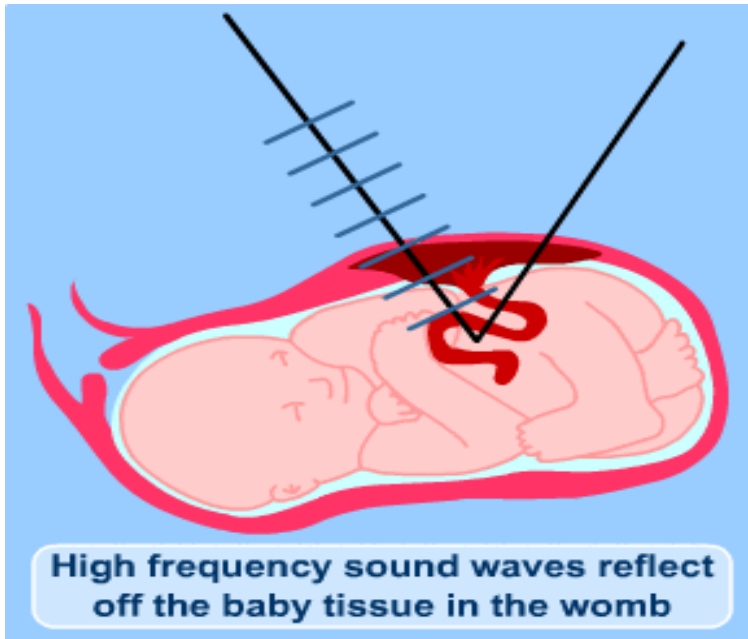
**Reverberation** is characterized as random, blended repetitions of a sound occurring within thirty milliseconds after the sound is made. This is all the sound that immediately bounces off any nearby surfaces before it gets back to your ears. So first you'll hear the original sound and then all the stuff bouncing off the walls, furniture, trees, people, giraffes and even acoustic tiling.

<http://somup.com/cFXoIKnjil> Echo & Reverberation (1:09)

# Reflection

Ultrasound is very, very high frequency sound used to see inside people

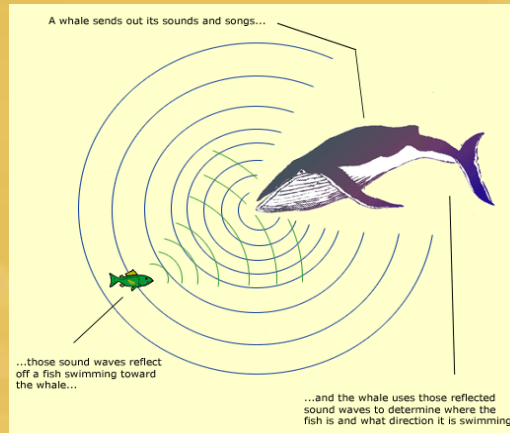
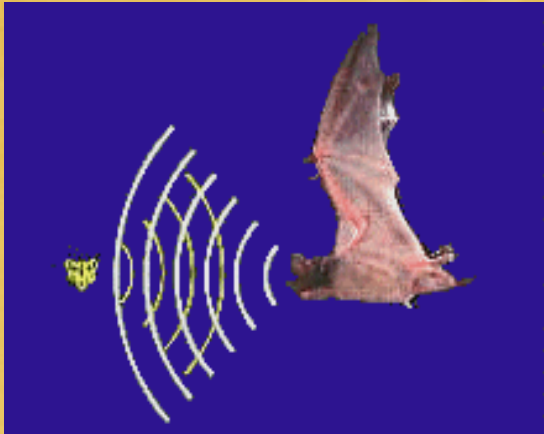
- babies before they are born
- monitor the heart
- blood flow



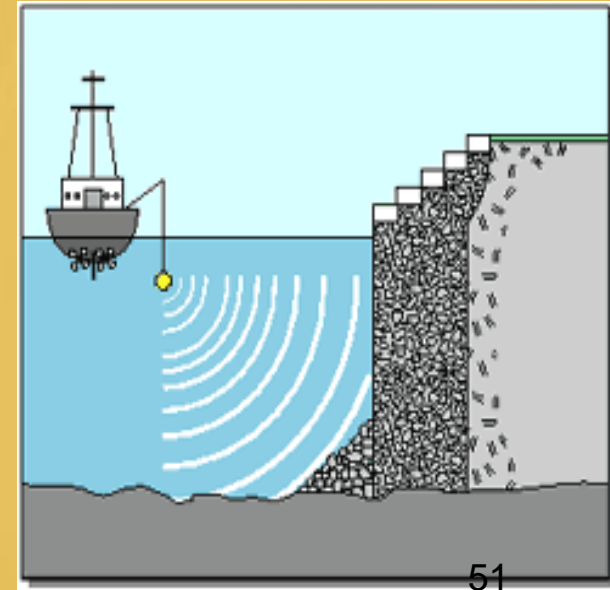
# Sonar

## *Reflection*

- An instrument that uses **reflected sound waves** to find underwater objects.
- **For example,**



Humans use sonar to locate or map objects.



Animals use sonar or echo location to find their prey; these sounds have such a high pitch or frequency that the human ear cannot hear them.



When does refraction of a wave NOT occur?

- a. The wave cannot enter the new medium.
- b. The wave enters a new medium at any angle.
- c. The wave enters a new medium at any angle except  $90^\circ$ .
- d. Part of the wave enters a new medium and part is reflected.

The property of waves that bounce off a surface, that is, cannot pass through, is called

- a. reflection.
- b. refraction.
- c. diffraction.
- d. destructive interference.



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- d. destructive interference.

What is the speed of a wave in a spring if it has a wavelength of 10 cm and a period of 0.2 s?

A  
G  
E  
S

While wading in shallow waters, six waves crash into your legs in a 24-second span. What is the frequency of the waves?

A  
G  
E  
S

What is the speed of a wave in a spring if it has a wavelength of 10 cm and a period of 0.2 s?

A speed

G  $\lambda = 10 \text{ cm}$ ; period (T) = 0.2 s

E  $v = \text{wavelength} / \text{period} = \lambda / T$

S  $v = \lambda / T = 10 \text{ cm} / 0.2 \text{ s} = \mathbf{50 \text{ cm/s}}$

While wading in shallow waters, six waves crash into your legs in a 24-second span. What is the frequency of the waves?

A frequency

G 6 waves in 24 s

E  $f \text{ (Hz)} = \text{waves} / \text{second}$

S  $f \text{ (Hz)} = \text{waves} / \text{second} = 6 \text{ waves} / 24 \text{ s} = \mathbf{0.25 \text{ Hz}}$

## Assessment Questions

1. A mechanical wave carries energy from one place to another through the
  - a. physical transfer of matter.
  - b. interaction of electromagnetic fields.
  - c. phase changes of a medium.
  - d. vibration of a medium.



## Assessment Questions

1. A mechanical wave carries energy from one place to another through the
  - a. physical transfer of matter.
  - b. interaction of electromagnetic fields.
  - c. phase changes of a medium.
  - d. **vibration of a medium.**

ANS: D

## Assessment Questions

2. In what type of wave is the vibration of the medium parallel to the direction in which the wave travels?
- a. transverse wave
  - b. longitudinal wave
  - c. surface wave
  - d. rarefaction

## Assessment Questions

2. In what type of wave is the vibration of the medium parallel to the direction in which the wave travels?
- a. transverse wave
  - b. longitudinal wave**
  - c. surface wave**
  - d. Rarefaction

**e. Two choices apply**

ANS: C & D both apply

## Assessment Questions

3. An example of a transverse wave is a(n)
- sound wave traveling through air.
  - ocean wave far from the shore.
  - ocean wave as it approaches the shore.
  - light wave traveling through space.

## Assessment Questions

3. An example of a transverse wave is a(n)
- a. sound wave traveling through air.
  - b. ocean wave far from the shore.
  - c. ocean wave as it approaches the shore.
  - d. light wave traveling through space.**

ANS: D

## Wave Speed

Math Practice

4. A wave on a rope has a wavelength of 2.0 m and a frequency of 2.0 Hz. What is the speed of the wave?

**A**  
**G**  
**E**  
**S**

## Wave Speed

Math Practice

4. A wave on a rope has a wavelength of 2.0 m and a frequency of 2.0 Hz. What is the speed of the wave?

Answer:  $v = f \lambda$

The speed is  $2.0 \text{ Hz} \times 2.0 \text{ m} = 4.0 \text{ m/s}$

## Wave Speed

Math Practice

5. A motorboat is tied to a dock with its motor running. The spinning propeller makes a surface wave travel at  $0.4 \text{ m/s}$  in the water and a wavelength of  $0.1 \text{ m}$ . What is the frequency of the waves?

**A**  
**G**  
**E**  
**S**



## Wave Speed

Math Practice

5. A motorboat is tied to a dock with its motor running. The spinning propeller makes a surface wave travel at 0.4 m/s in the water and a wavelength of 0.1 m. What is the frequency of the waves?

Answer:  $v = f \lambda$  ... rearrange to solve for “ $\lambda$ ”:

$$f = v / \lambda$$

The frequency is  $0.4 \text{ m/s} / 0.1 \text{ m} = 4 \text{ Hz}$

## Wave Speed

Math Practice

6. What is the wavelength of an earthquake wave if it has a speed of 5 km/s and a frequency of 10 Hz?

A  
G  
E  
S

## Wave Speed

Math Practice

6. What is the wavelength of an earthquake wave if it has a speed of 5 km/s and a frequency of 10 Hz?

Answer:

$v = f \lambda$  ... rearrange to solve for “ $\lambda$ ”:

$$\lambda = v / f$$

The wavelength is  $(5 \text{ km/s})/10 \text{ Hz} = 0.5 \text{ km}$ .

## Assessment Questions

7. The intensity of sound waves is measured in units of
- hertz (Hz).
  - decibels (dB).
  - joules (J).
  - meters (m).

## Assessment Questions

7. The intensity of sound waves is measured in units of
- a. hertz (Hz).
  - b. decibels (dB).**
  - c. joules (J).
  - d. meters (m).

ANS: B