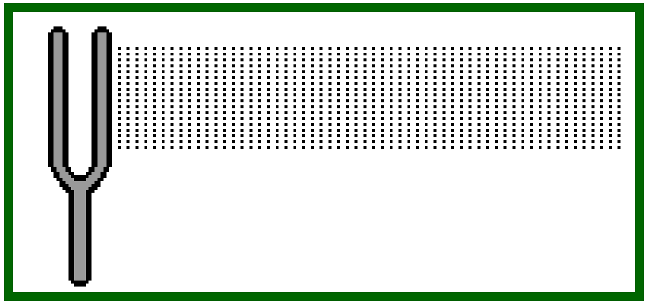
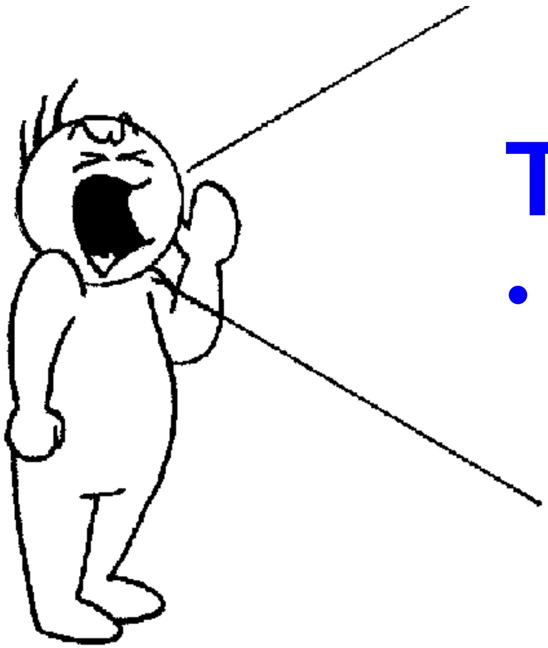
PHYSICS 2204

UNIT 4: Section 1

Fundamental Properties of Waves





Topic 1

- **Introduction to Waves**

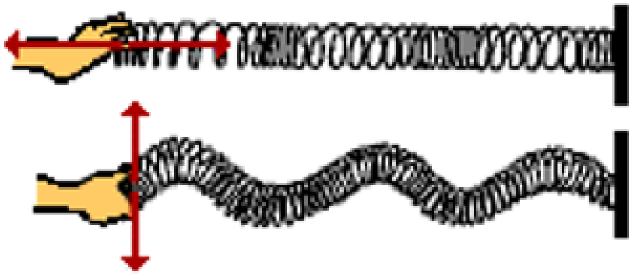
A rock tossed into the water will create a circular disturbance which travels outwards in all directions.

Have you ever seen a wave?

Waves are everywhere. Whether we recognize or not, we encounter waves on a daily basis.

- -Sound waves,
- -visible light waves,
- - radio waves,
- -microwaves,
- -water waves,
- -sine waves, cosine waves,
- -telephone chord waves,
- -stadium waves,
- -earthquake waves,
- -waves on a string,
- -and slinky waves

In addition to waves, there are a variety of phenomenon in our physical world which resemble waves so closely that we can describe them as being wavelike. For example, the motion of a pendulum, a mass suspended by a spring, a child on a swing, or the waving of the hand



Slinky waves can be made by vibrating the first coil back and forth in either a horizontal or a vertical direction.

Why learn about waves?

- Waves carry useful information and energy.

- Waves are all around us:

  - light from the stoplight
  - ripples in a puddle of
  - electricity flowing in wires
  - radio and television and cell phone transmissions

WHAT IS A WAVE?

- **Wave can be described as the transfer of energy, in a form of a disturbance that travels through a medium from one location to another location.**

Waves are classified by what they move through :

1. **Mechanical Waves**

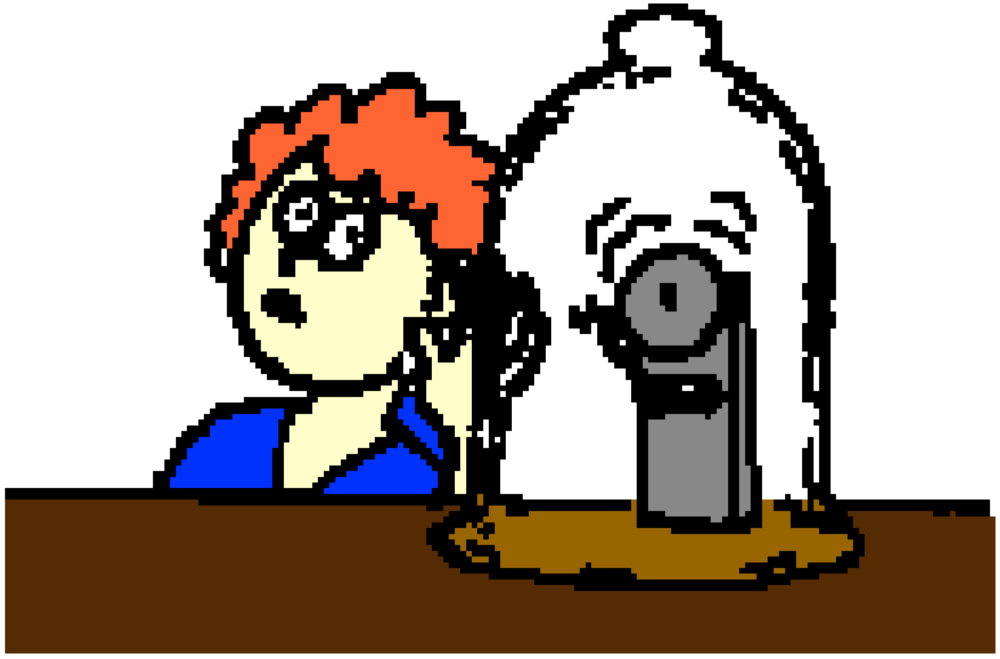
the energy is transferred by vibrations of medium (medium is a substance or material which carries the wave)

example: Sound

2. **Electromagnetic waves (EM Waves)**

the energy moves through disturbances in the electromagnetic field. Can travel through a vacuum.

Example Light



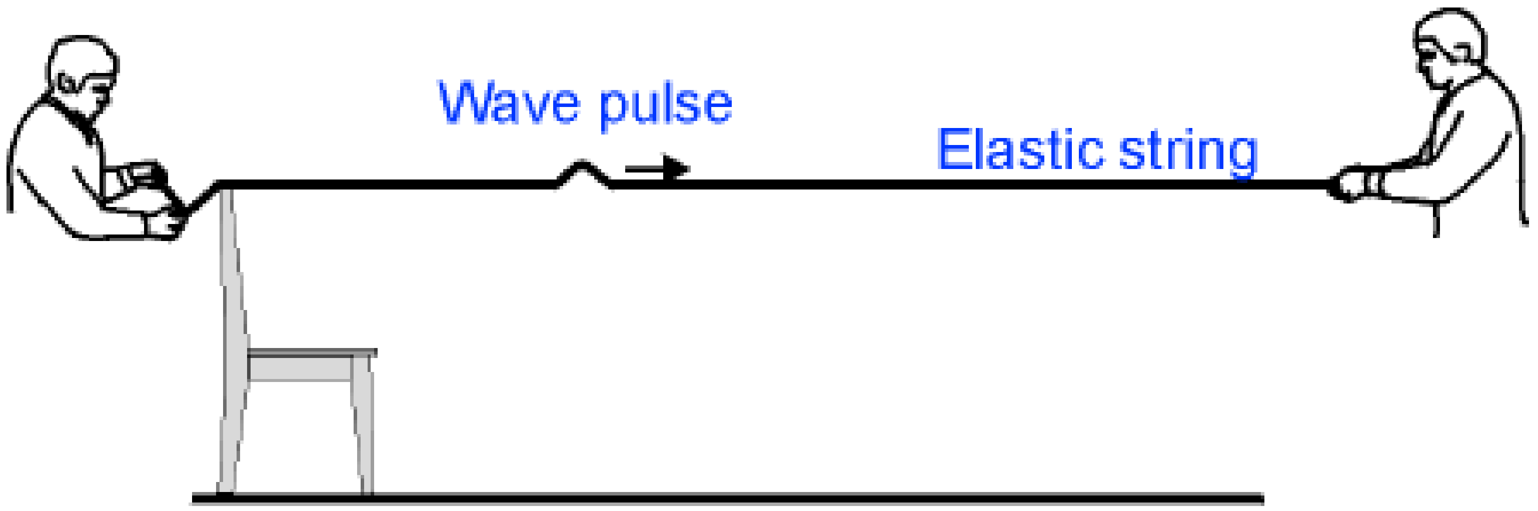
The sound produced by the bell cannot be heard since sound cannot travel through a vacuum.

What causes waves?

- Waves are created when a source of energy causes a medium to vibrate.
- A vibration is a repeated back and forth or up and down motion.

How is a wave formed?

A wave pulse is a short length of wave, often just a single oscillation

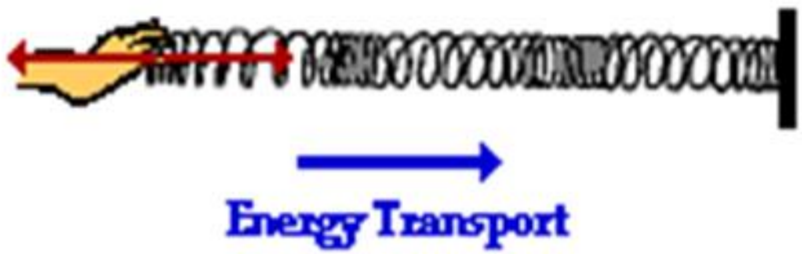


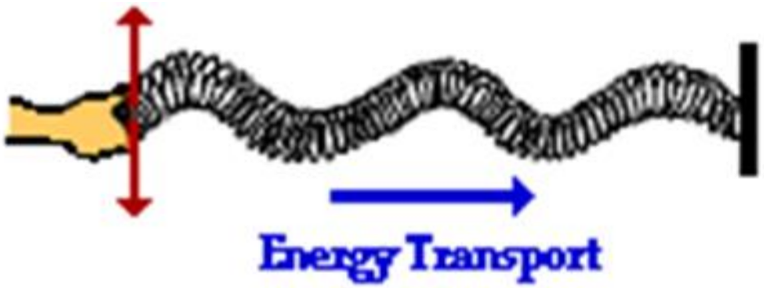
The hand pulls up on one end of the rope, and because the end piece is attached to the adjacent pieces, these also feel the an upward force and they two begin to move upward. As each succeeding piece of rope moves upward, the crest moves outward along the rope.

Meanwhile, the end piece of the rope has been returned to its original position by the hand, and as each succeeding piece of rope reaches its peak position, it too, is pulled back down again by the adjacent section of rope…..

TYPES OF WAVES

- Waves come in many shapes and forms. While all waves share some basic characteristic properties and behaviors, some waves can be distinguished from others based on some very observable (and some non-observable) characteristics



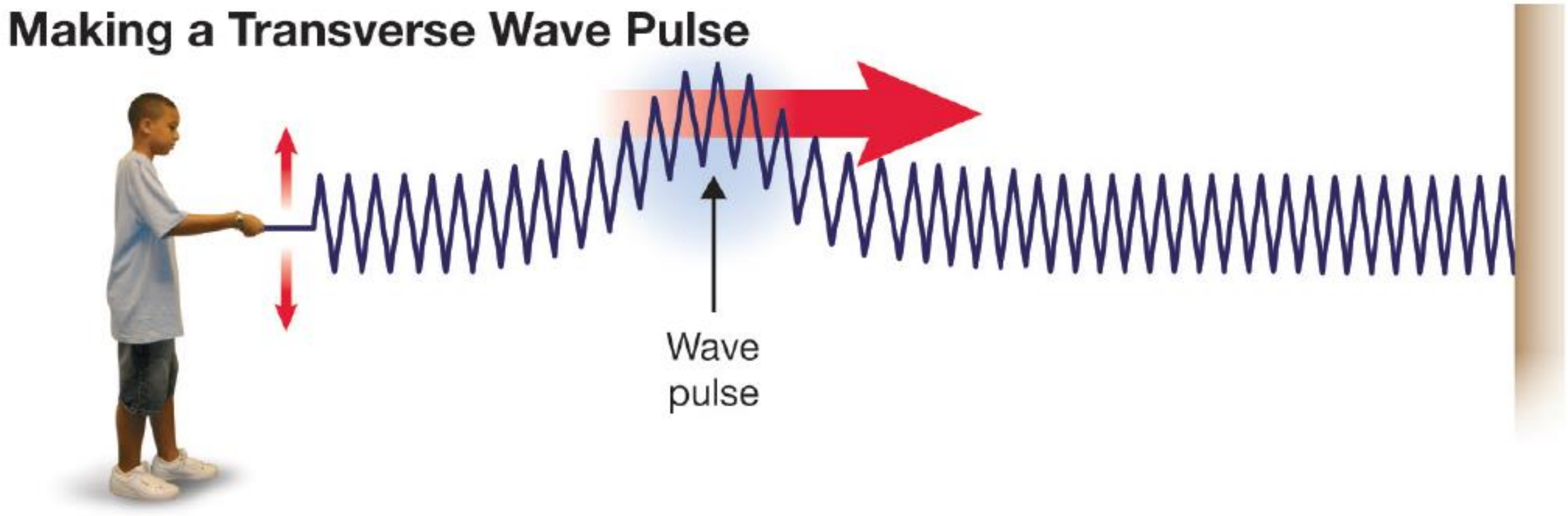


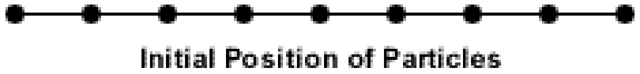
One way to categorize waves is on the basis of the direction of movement of the individual particles of the medium relative to the direction which the waves travel

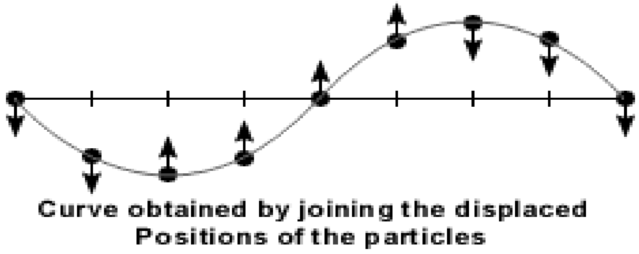
1) **Transverse waves**
2) **Longitudinal wave**

Wave Types

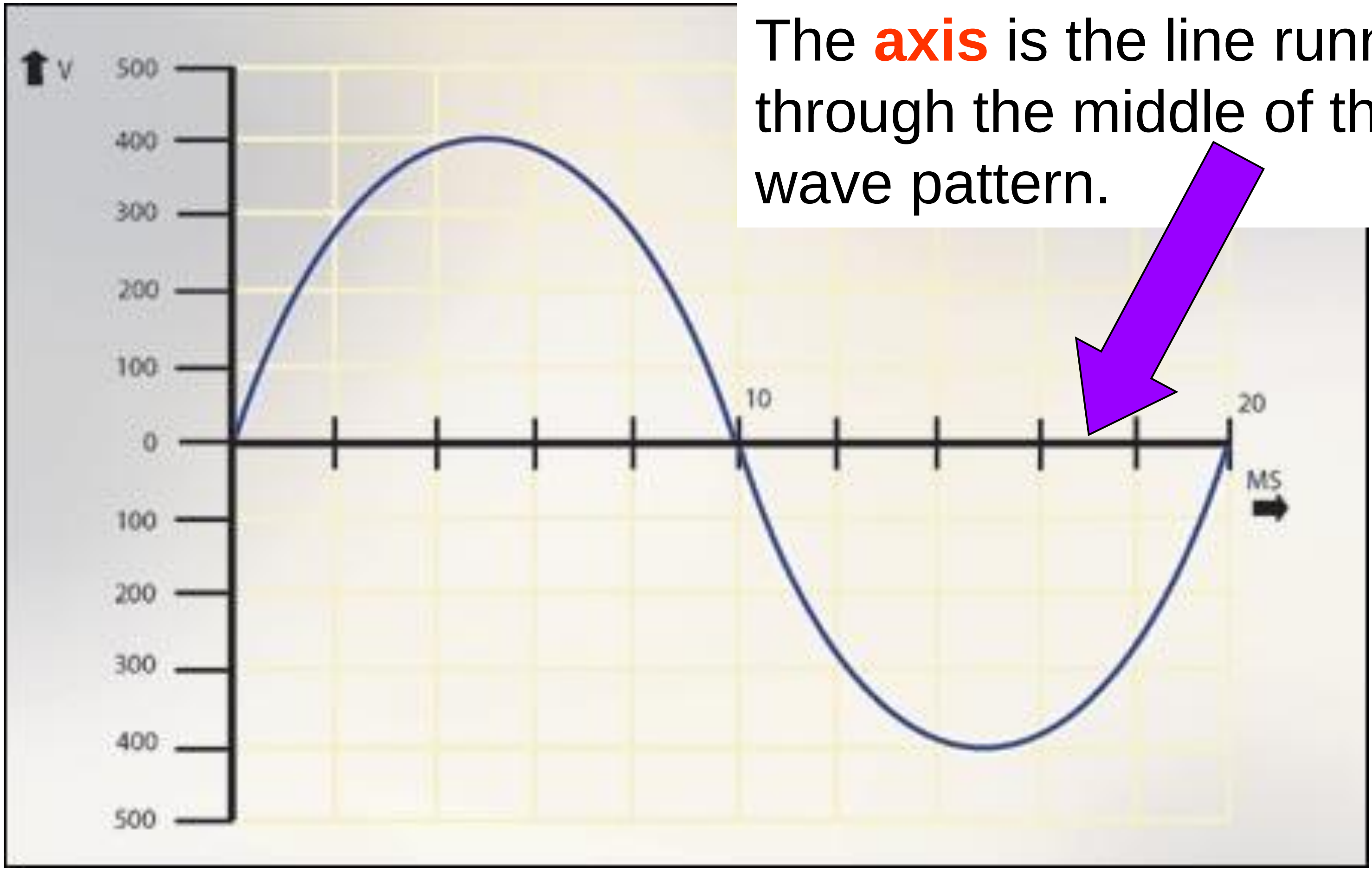
1. **Transverse waves**: Waves in which the medium moves at right angles to the direction of the wave





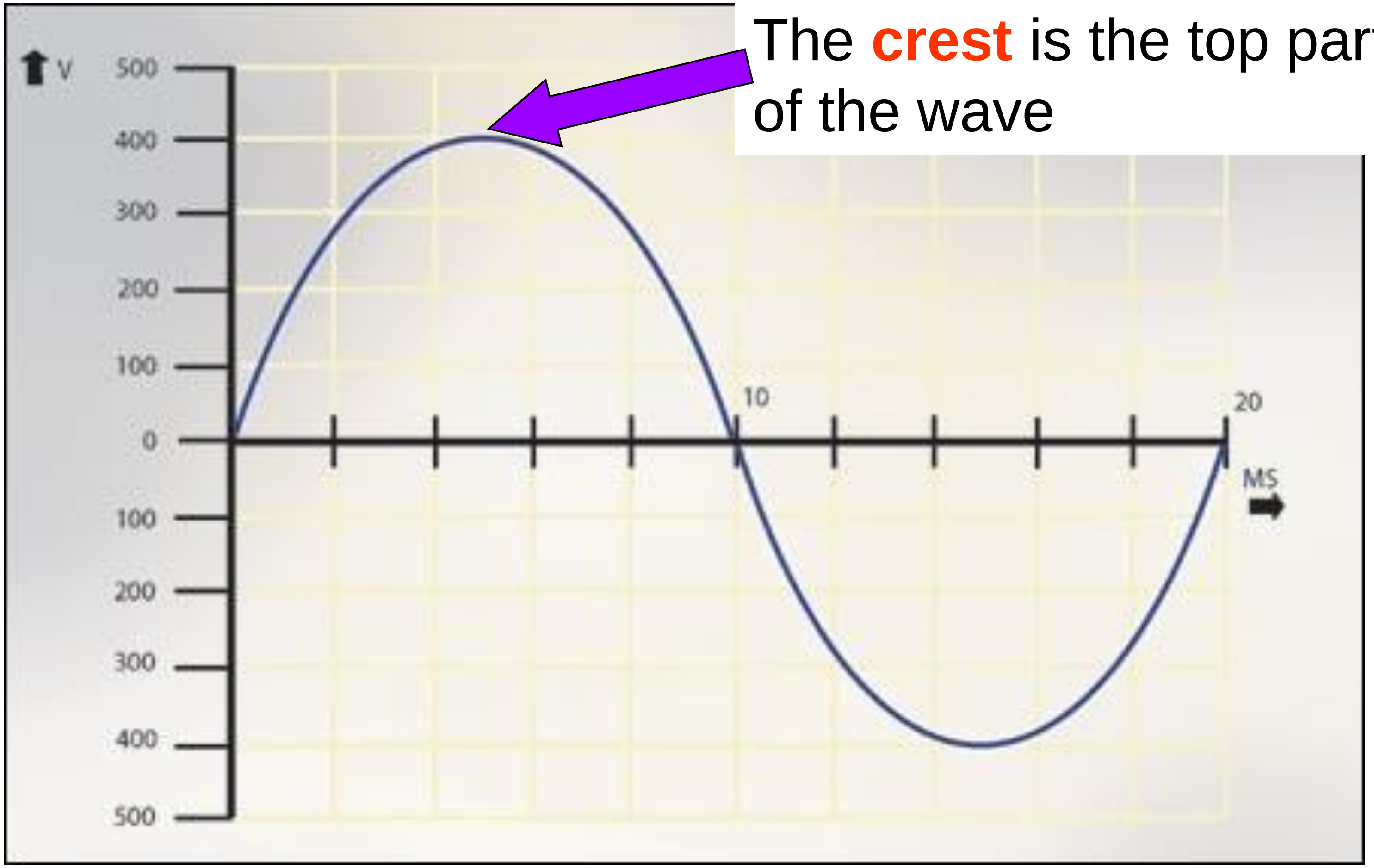


Parts of transverse waves:



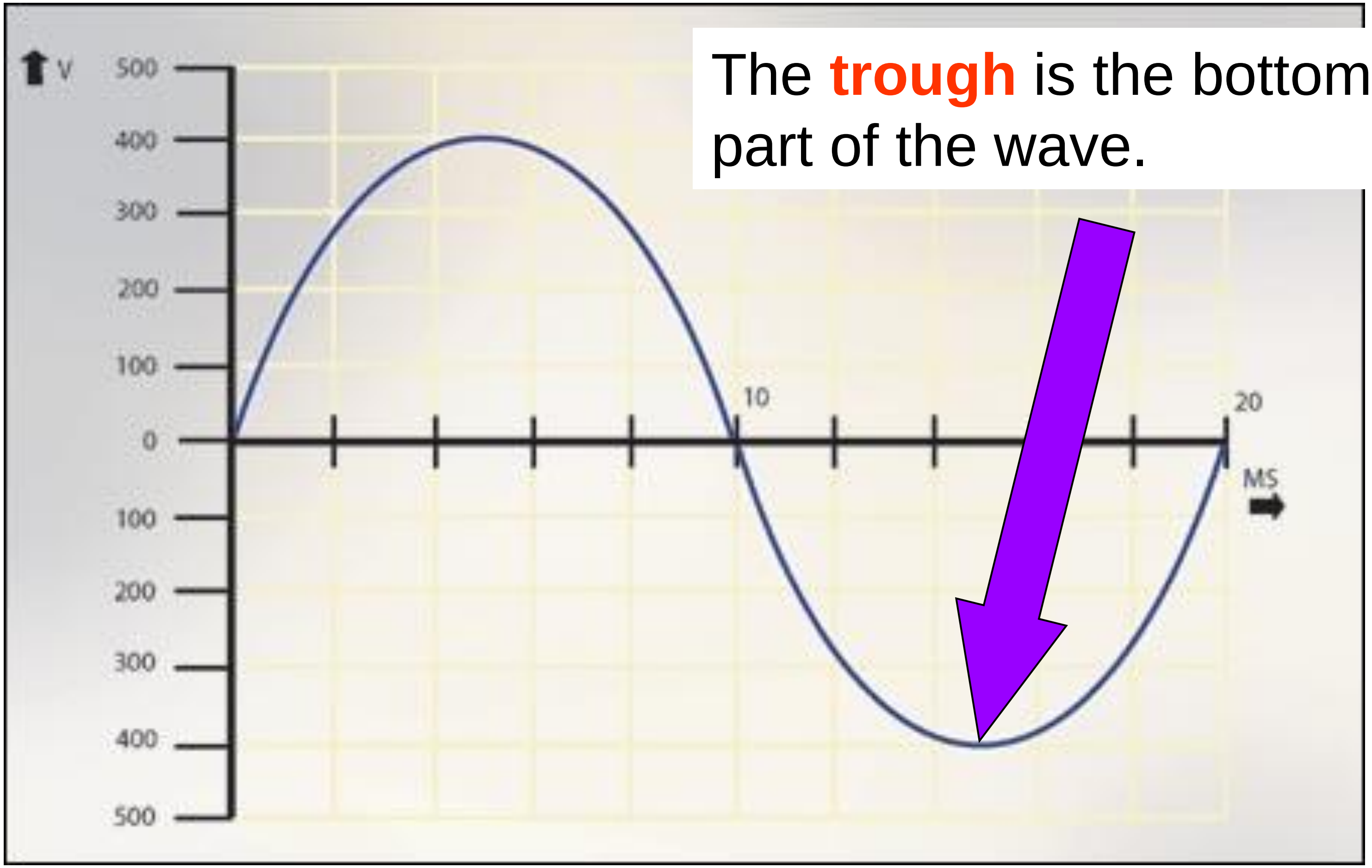
The **axis** is the line running through the middle of the wave pattern.

Parts of transverse waves:



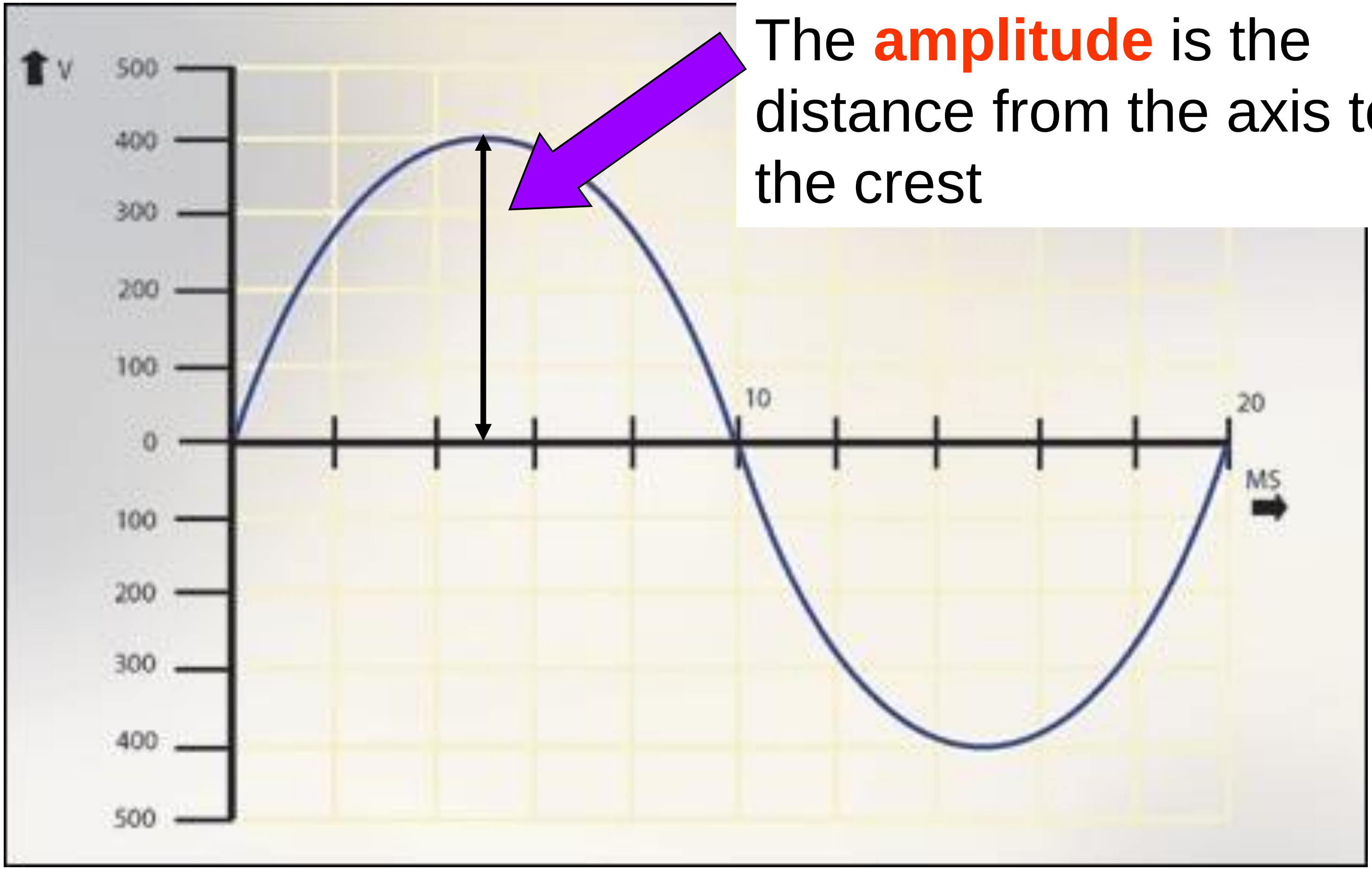
The **crest** is the top part of the wave

Parts of transverse waves:

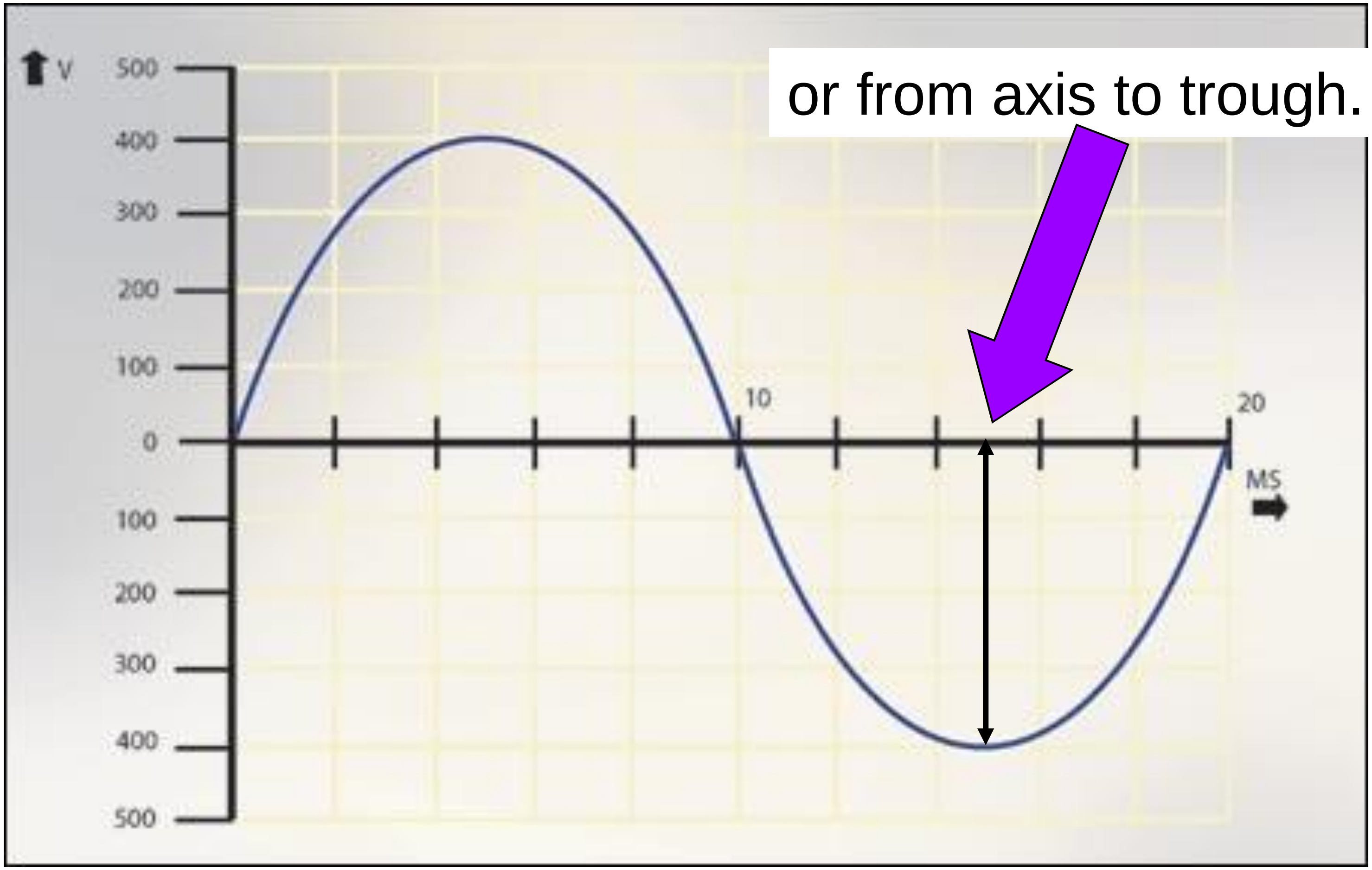


The **trough** is the bottom part of the wave.

Parts of transverse waves:

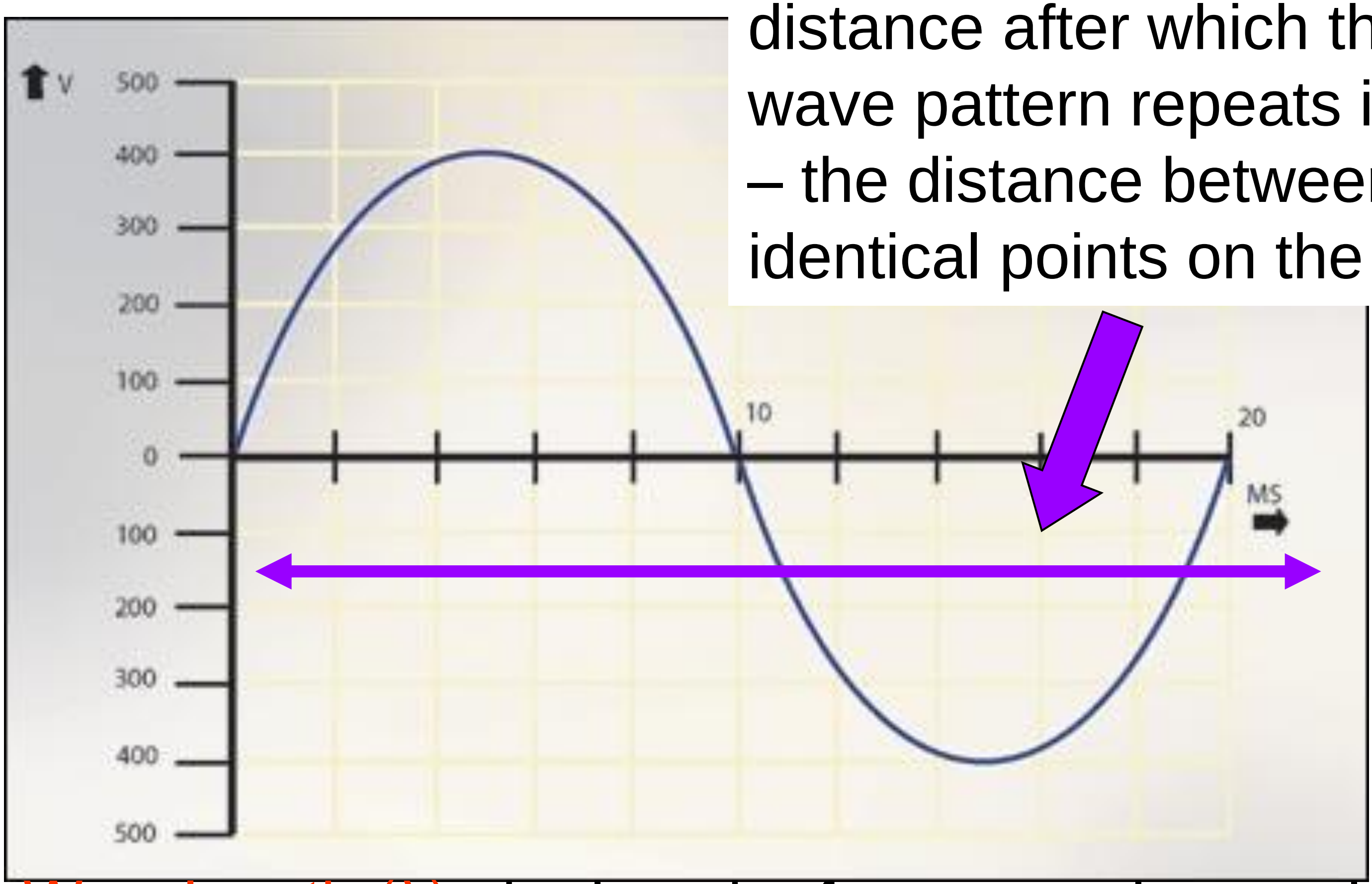


The **amplitude** is the distance from the axis to the crest


or from axis to trough.
V
500
400
300
200
100
0
100
200
300
400
500
10
20
MS

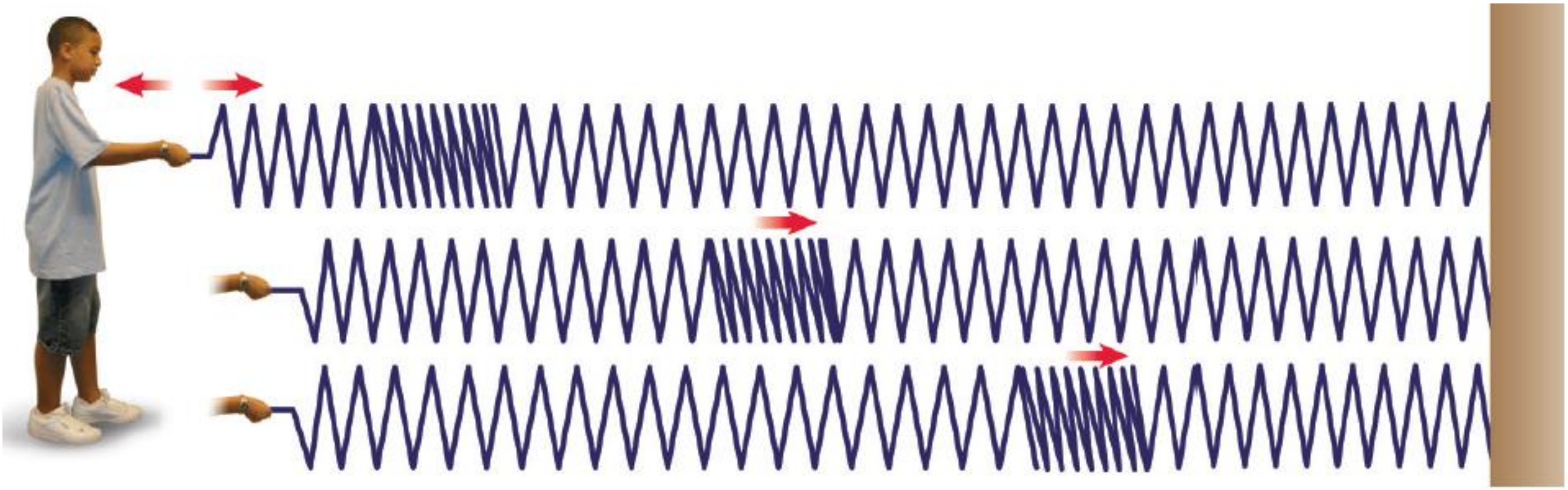
Parts of transverse waves:

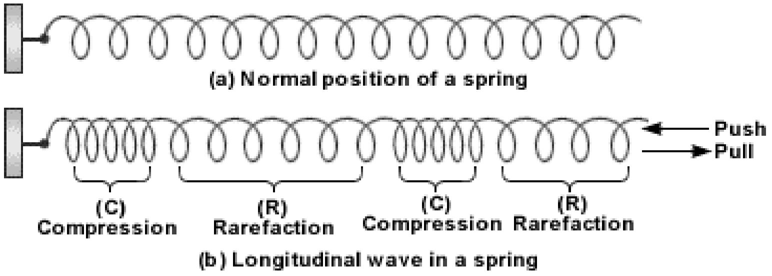
The **wavelength** is the distance after which the wave pattern repeats itself – the distance between two identical points on the wave

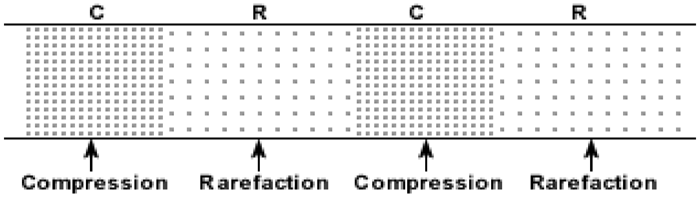


Wavelength (λ): the length of one complete cycle. SI units is (m) and is represented by the greek symbol (λ) lambada,

2. Longitudinal (or) Compressional waves: is one in which the particles of the medium are displaced parallel to the direction in which the energy is traveling in the medium.





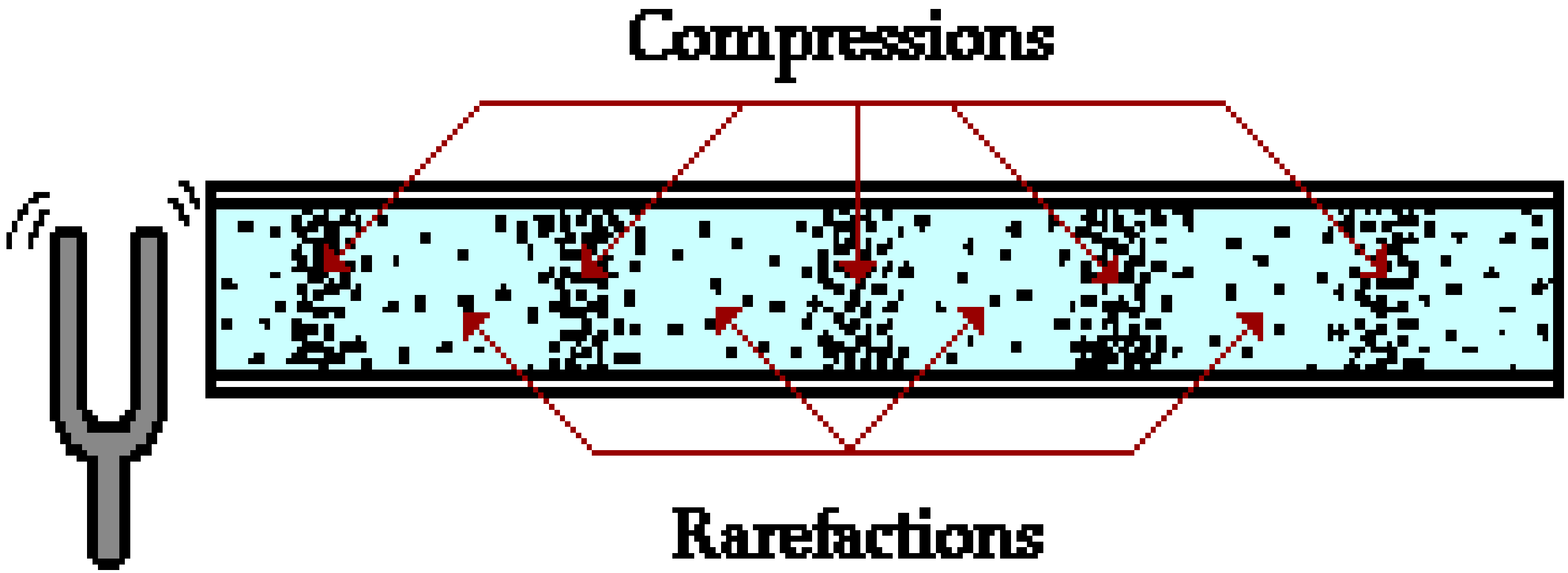


Compressions and rarefactions of a longitudinal wave. Regions marked C are compressions and regions marked R are rarefactions.

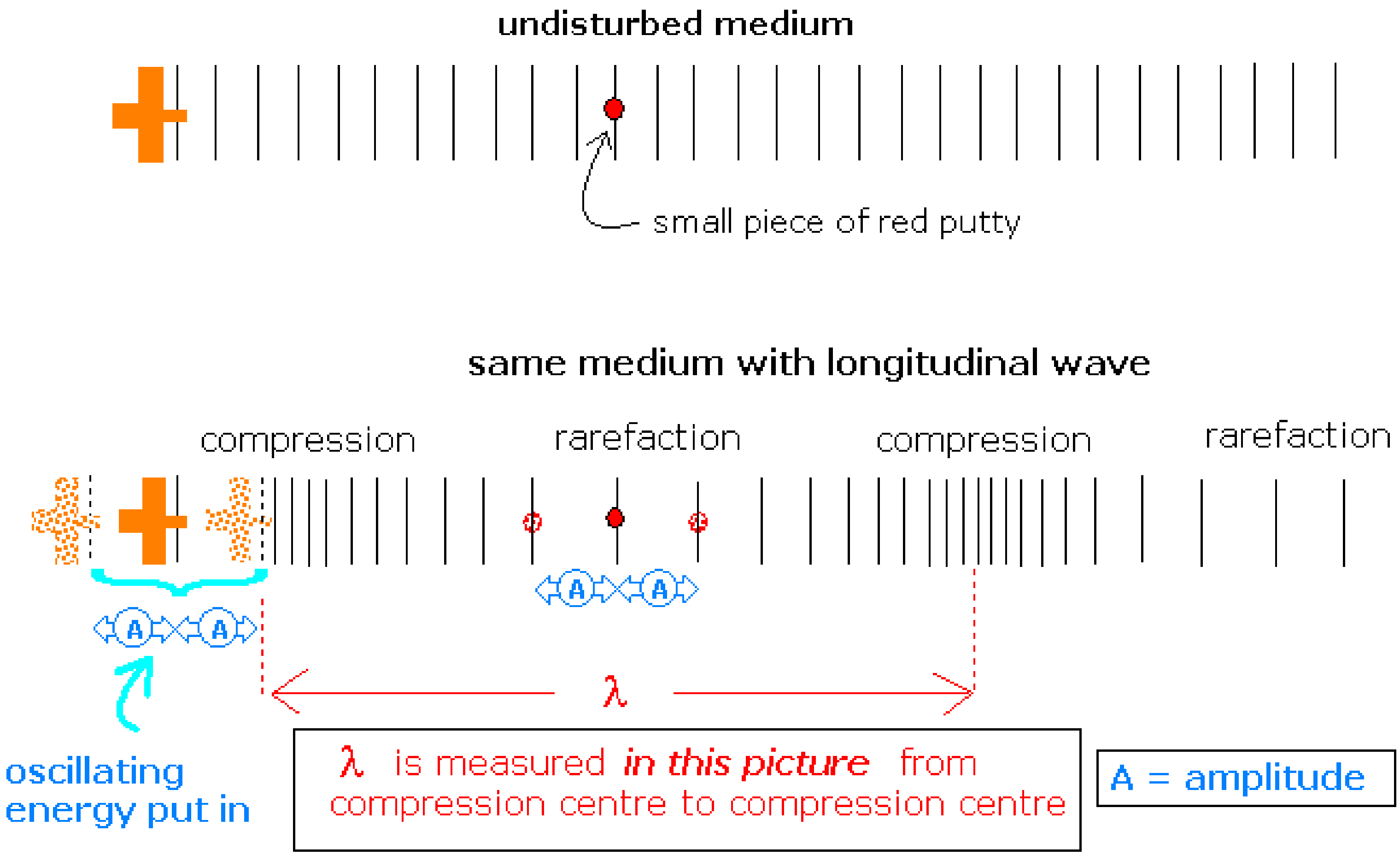
Parts of longitudinal waves:

Compression: where the particles are close together

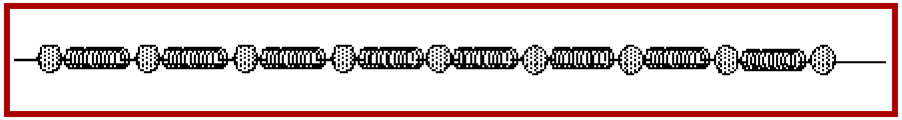
Rarefaction: where the particles are spread apart



Parts of a Longitudinal waves

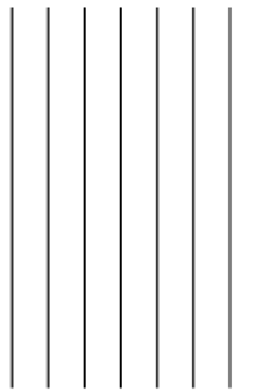


Looking closely at a Longitudinal wave

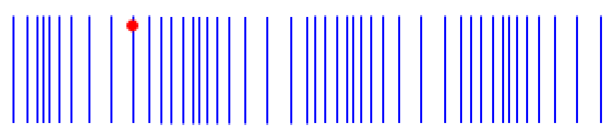


play

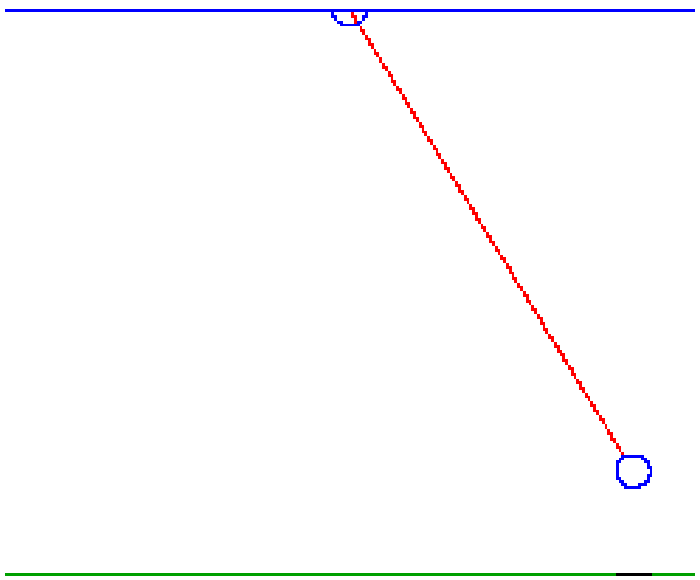
Coils of a slinky



Particles in the slinky



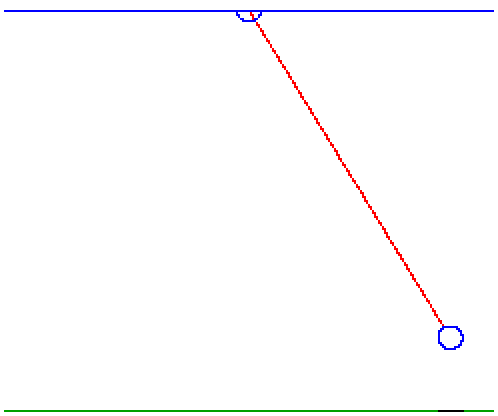
- **Cycle** is the complete path or oscillation as the swinging mass goes through one complete swing and comes back to its starting point.



Period - The period is the amount of time it takes for a vibrating object to go through one oscillation or one cycle. In the case of the pendulum, it is the number of seconds it takes for the swinging mass to go all the way from the extreme left to the extreme right and back again to the left.

The symbol for period is T. The units are seconds.

$$T = \frac{\text{total time}}{\text{\# of cycles}}:$$



- **Frequency** - The term frequency means the number of cycles in one second.

$$f = \frac{\#\ \text{cycles}}{\text{total time}}$$

•There is a special unit for frequency. A "cycle/second" is called a **hertz (Hz)** in honor of Heinrich Hertz (1857-94). Hz may also be written as /s or s-1.

There is a neat relationship between frequency (f) and period (T).

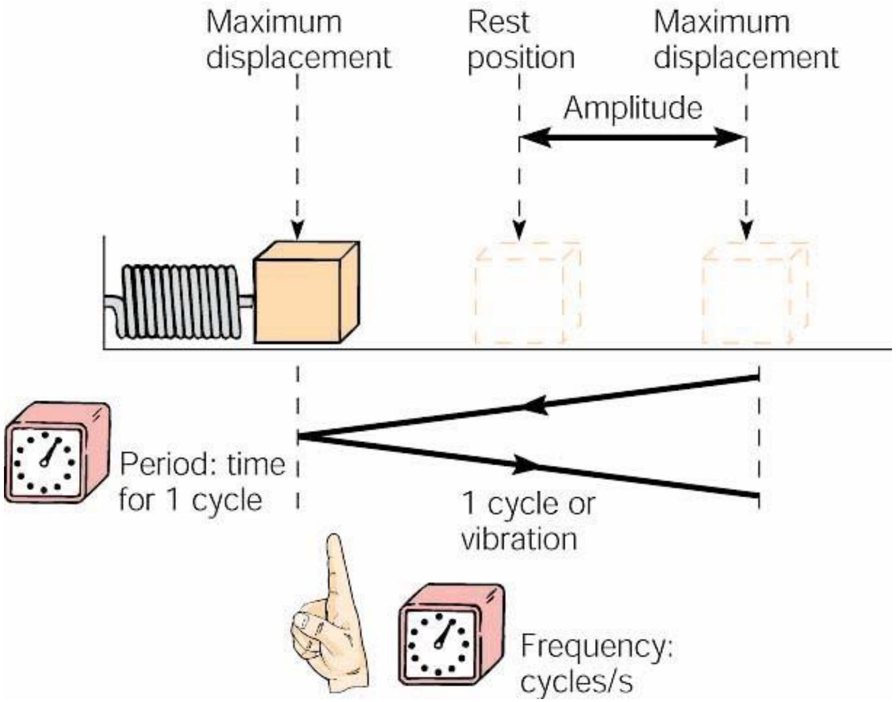
Frequency and period are the inverse of each other.

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

Example 1:

A block in simple harmonic motion completes 20 cycles in 5.0 s.

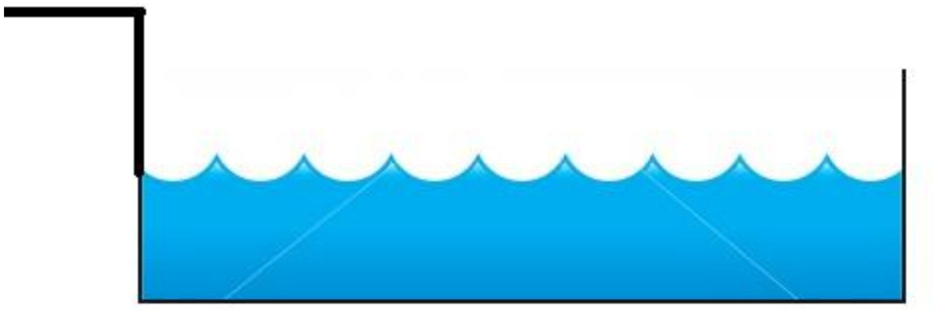
A) Determine the period:



B) Calculate the frequency

Example 2:

If 10 waves pass one dock every 16.0 seconds, determine the period and frequency of the wave:



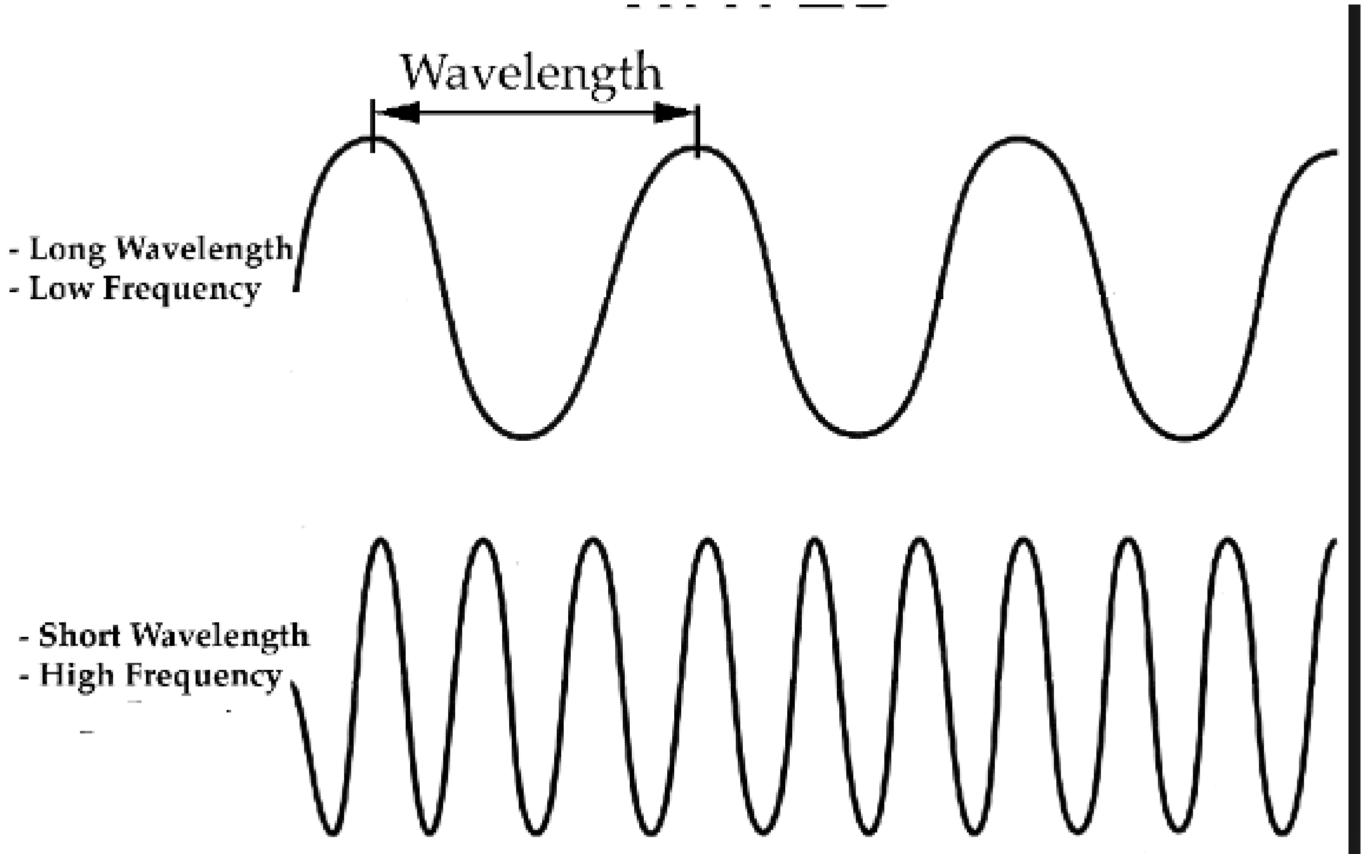
Example 3:

- The center of the boat shown in the diagram is 28 m from the beacon on the buoy. The buoy rocks up and down 45 times in one minute. That is the speed of the waves?

?

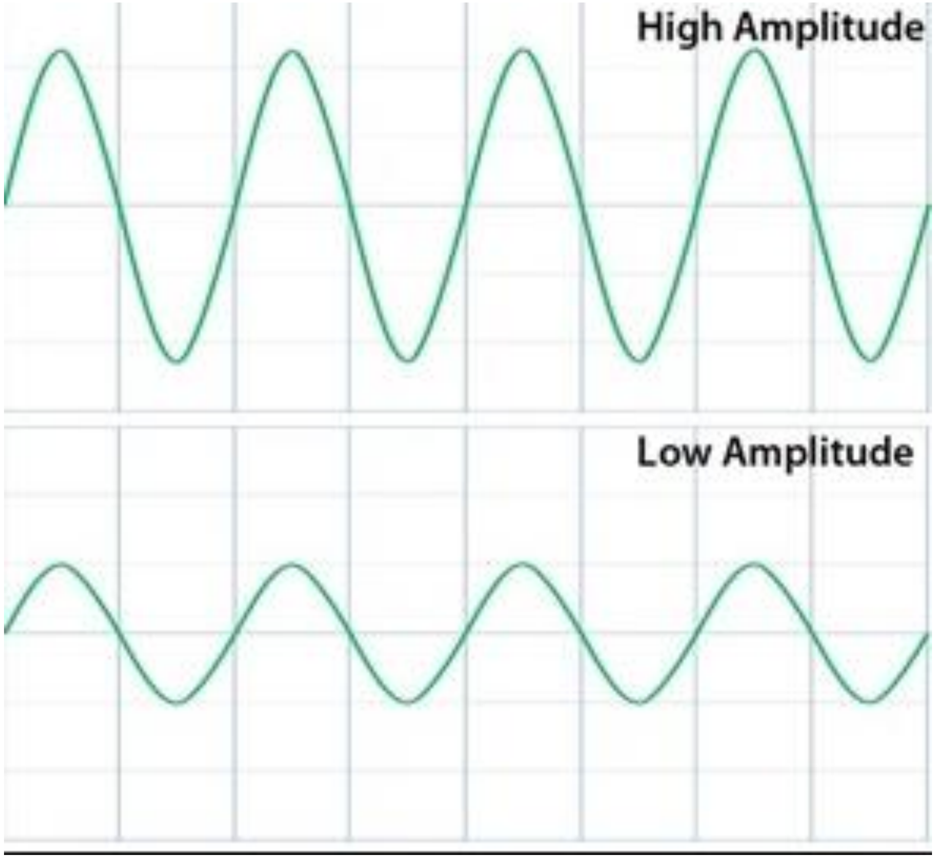
Frequency and Wavelength

The wavelength and frequency of waves are closely related. The higher the frequency, the shorter the wavelength



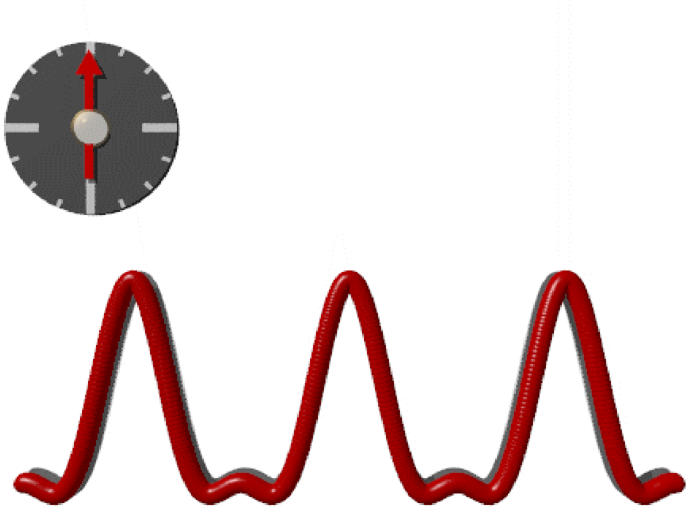
Amplitude and Frequency

Amplitude is merely the 'size' of the wave. So, two signals with different amplitudes, can have the same frequency (and hence wavelength).



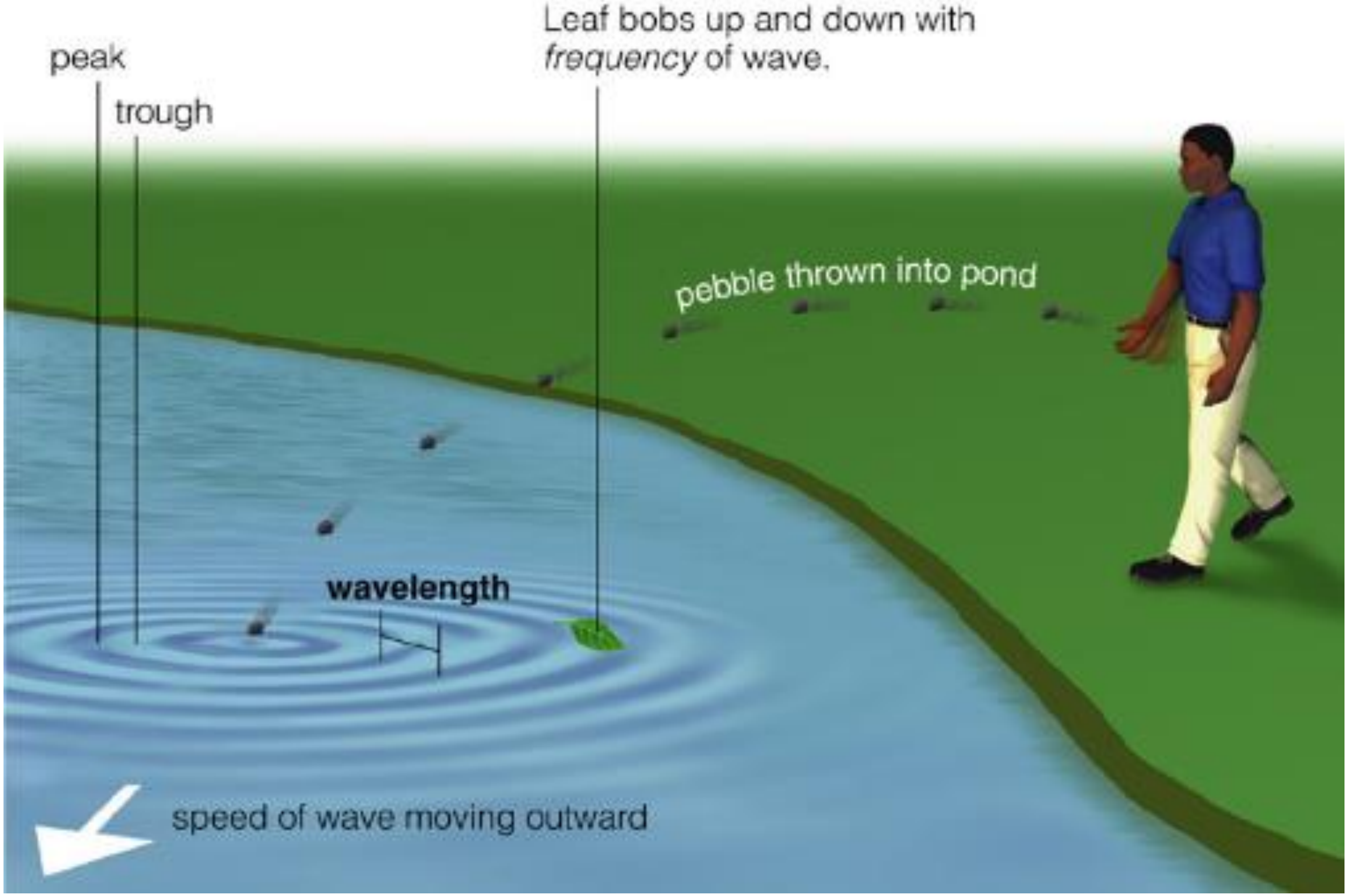
Topic 2

- **Wave Speed**



pavol krivosik, 2008

What determines the speed of the waves?

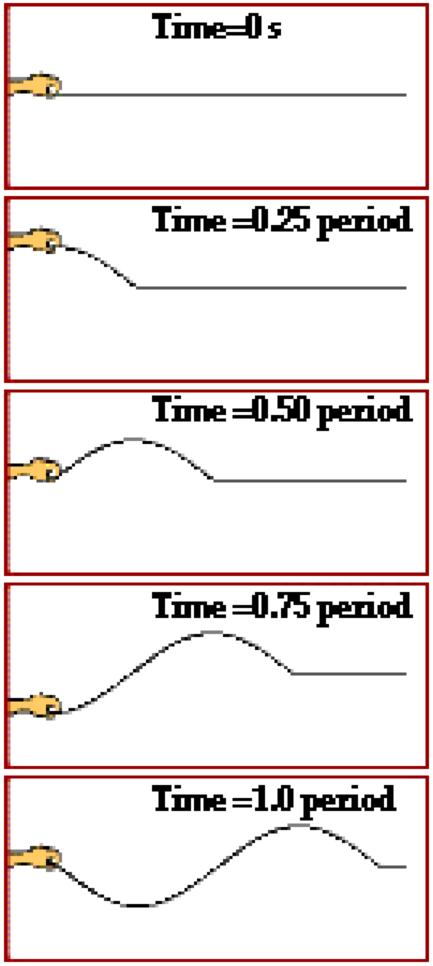


Wave Speed

A wave moves with uniform motion. Therefore, in order to calculate the speed we must start with the formula:

$$\text{speed} = \frac{\text{distance}}{\text{time}}$$

Look at the wave in the diagram. In a time of one period, the wave has moved a distance of one wavelength. Combining this information with the equation for speed (speed=distance/time), it can be said that the speed of a wave is also the wavelength/period



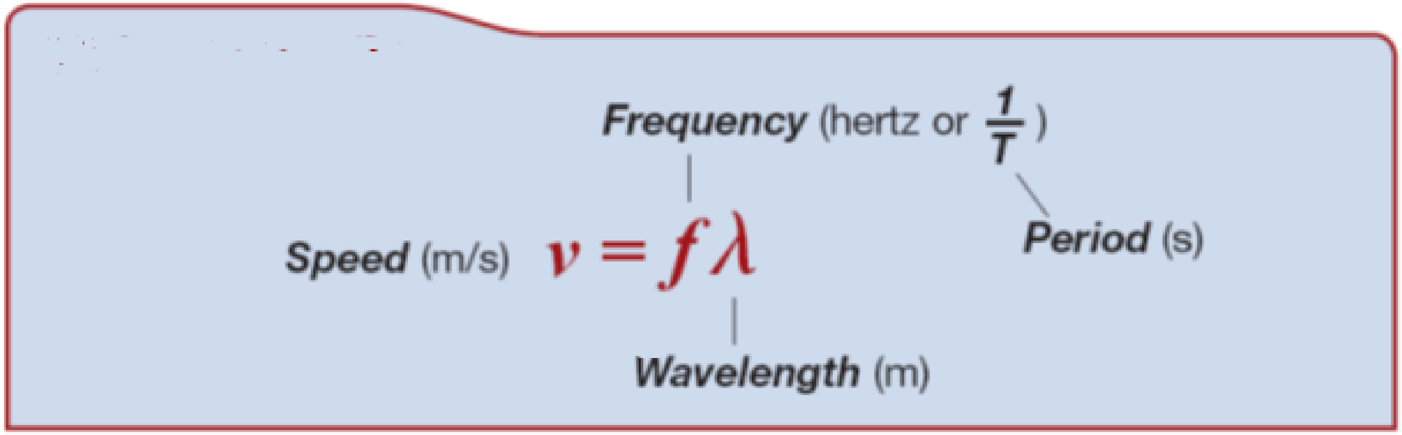
$$\text{Speed} = \frac{\text{Wavelength}}{\text{Period}}$$

OR $v = \lambda / T$

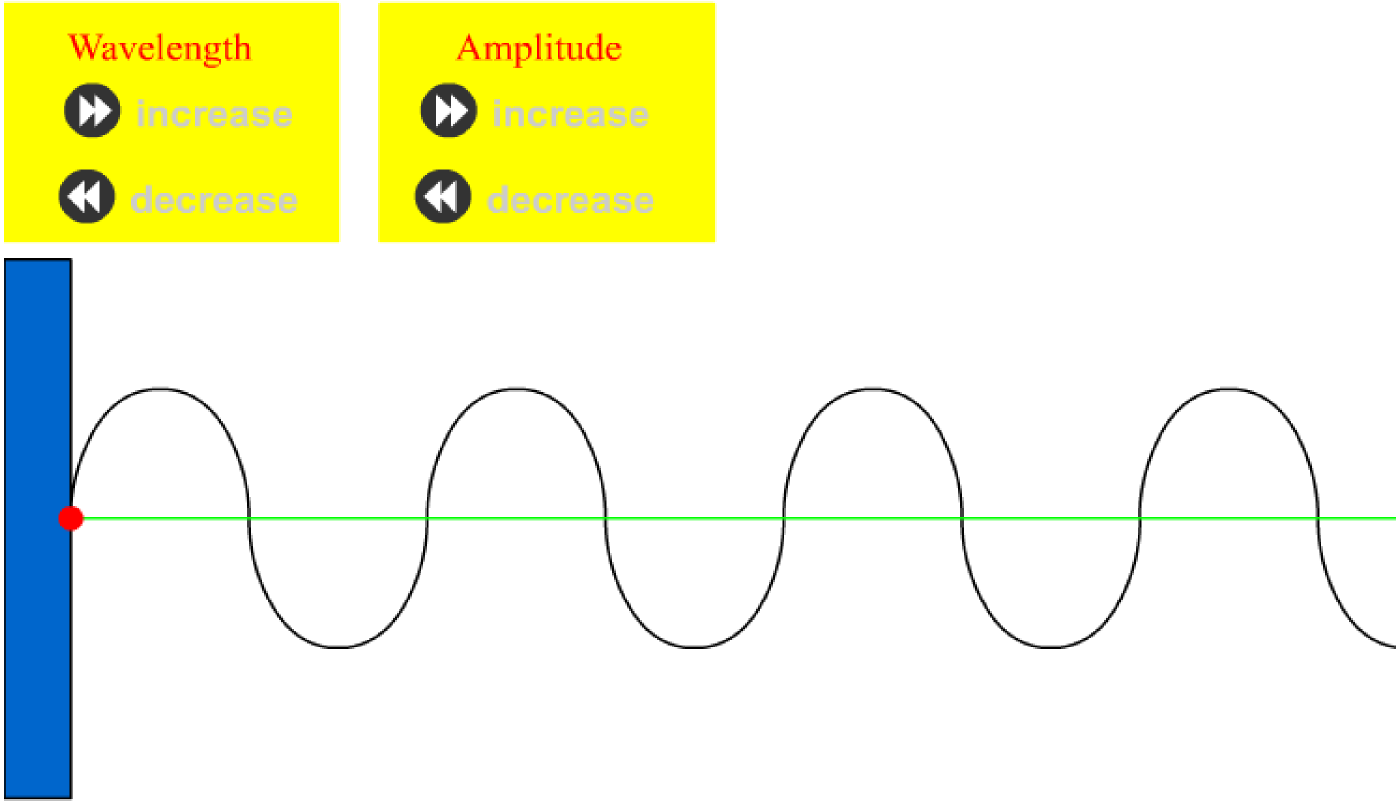
The *speed* is the distance traveled (one wavelength) divided by the time it takes (one period).

$$Speed = \frac{\text{Distance traveled}}{\text{Time taken}} = \frac{\text{Wavelength}}{\text{Period}} = \left(\frac{1}{\text{Period}}\right) \times \text{Wavelength}$$

$$Speed = Frequency \times Wavelength$$



Notice what happens to the wave speed when you change the wavelength and period



The same type of wave moves at the same speed regardless of frequency, wavelength, or amplitude.

Example 1

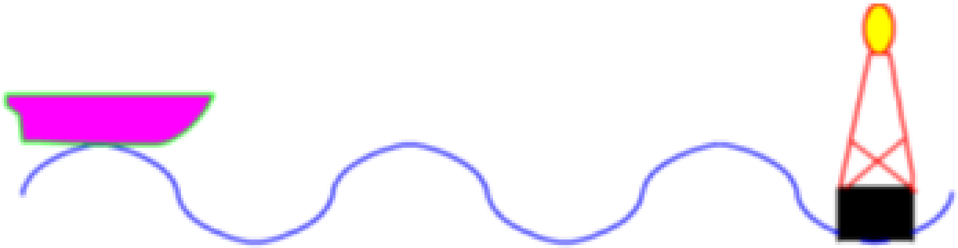
- If you attach one end of a slinky spring to a wall and hold the other end in your hand you can create a traverse wave with side to side movements of your hand. If you do this and produce a 0.70m long wave with a frequency of 3.0 Hz then what is the speed of the wave on the spring?

Example 2:

- Twelve waves are observed to pass by a wharf in a time of 10 seconds. If the wavelength is approximately 1.6 m then what is the speed of the waves?

Example 3:

- Twelve waves are observed to pass by a wharf in a time of 10 seconds. If the wavelength is approximately 1.6 m then what is the speed of the waves?



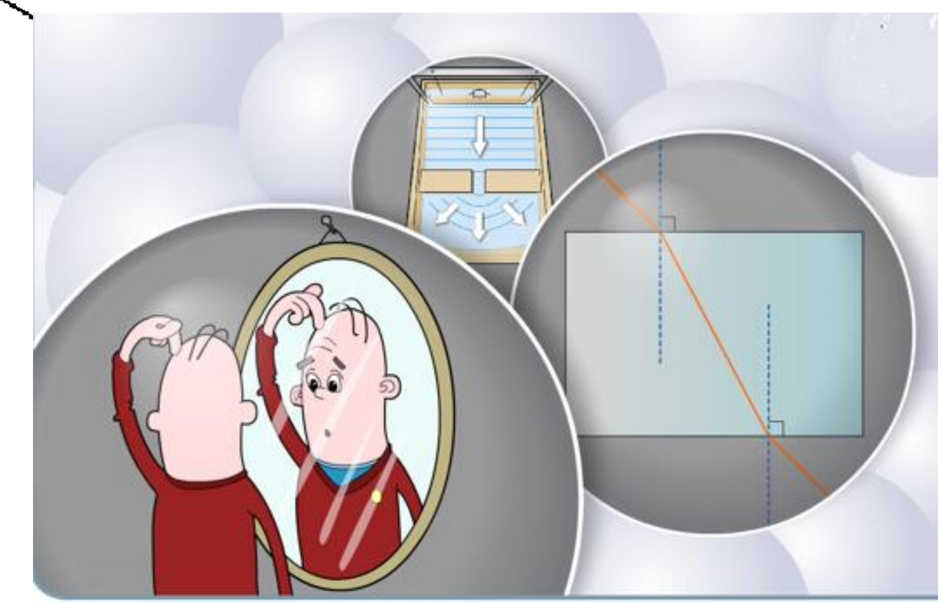
Remember Prefixes

Below are shown the prefixes (factors) used with units in physics,

PREFIXES		
Factor	Prefix	Symbol
10^{12}	tera	T
10^{9}	giga	G
10^{6}	mega	M
10^{3}	kilo	k
10^{-2}	centi	c
10^{-3}	milli	m
10^{-6}	micro	μ
10^{-9}	nano	n
10^{-12}	pico	p

Topic 3

- **Behavior of Waves**

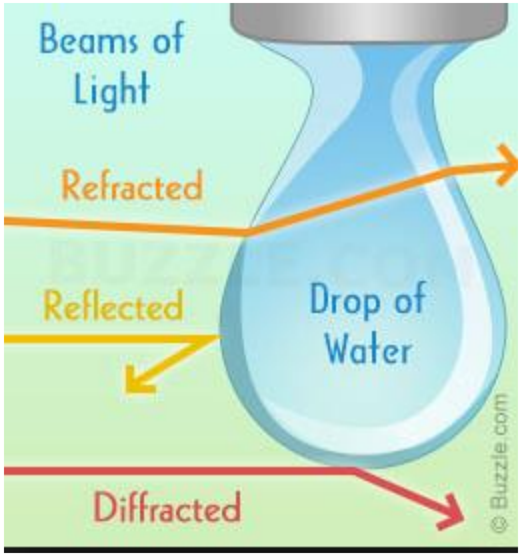


Waves in a Medium

Medium refers to a substance (solid, liquid or gas) that makes possible the transfer of energy from one location to another, especially through waves.

There are three ways wave can interact when passing through a medium:

1) Reflection
2) Refraction
3) Diffraction
4) Interference



1. REFLECTION

Reflection refers to when a wave reaches a boundary between two media, usually some or all of the wave bounces back into the first medium.

REFLECTION – BOUNDRY BEHAVIOUR

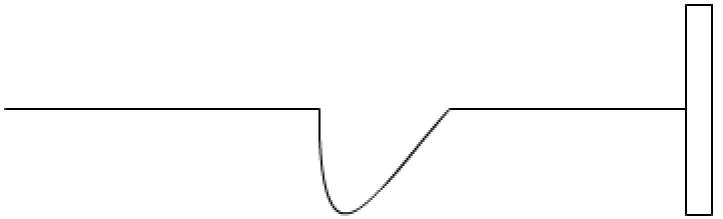
Boundary refers to where on medium ends and another begins

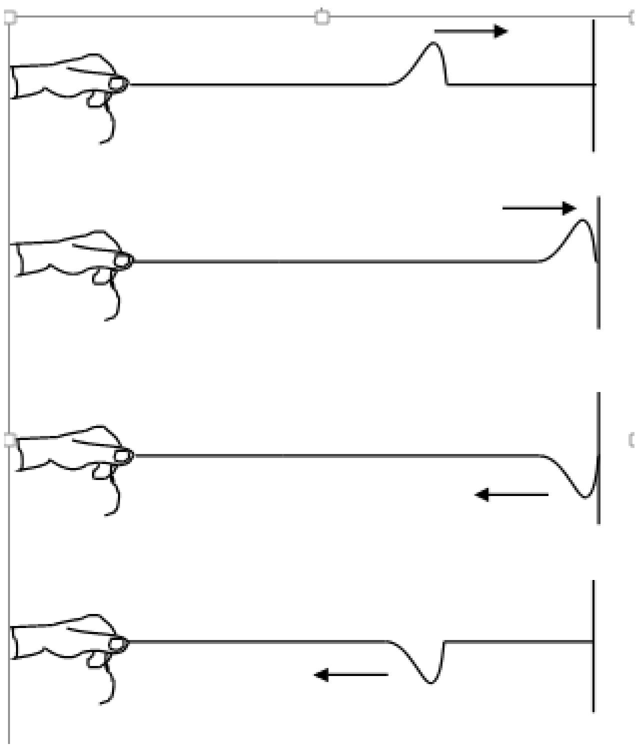
Boundary Behavior refers to the behavior of a wave (or pulse) upon reaching the end of a medium. Lets consider two situations:

1) REFLECTION TO FIXED END

2) REFLECTION TO OPEN END

Reflection - Fixed Ends (Rigid):



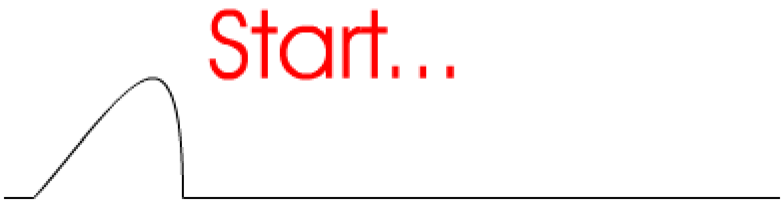


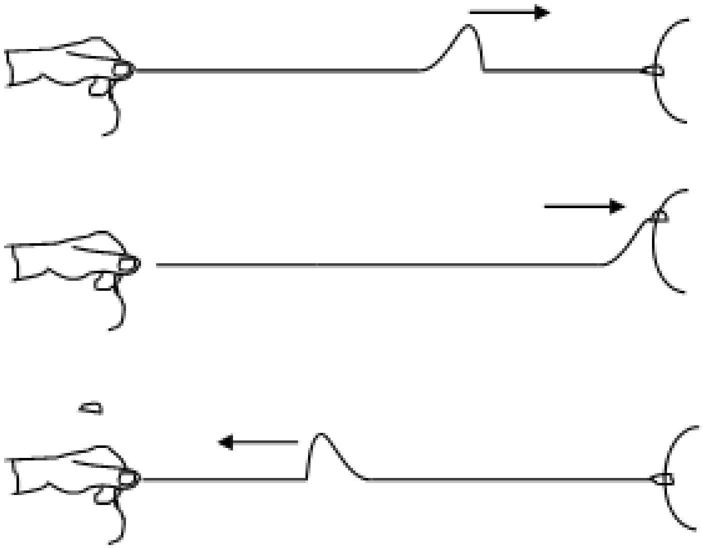
- **Fix End** refers to a reflection from a HARD boundary. For example a slinky fastened tightly to something

- The pulse becomes inverted upon reflecting off the fixed end. The displaced pulse is incident towards a fixed end boundary, it will reflect and return as a downward displaced pulse. This process is referred to as inversion

This phenomena can be explained by newtons 3rd law

Reflection - Open End (Not Rigid)

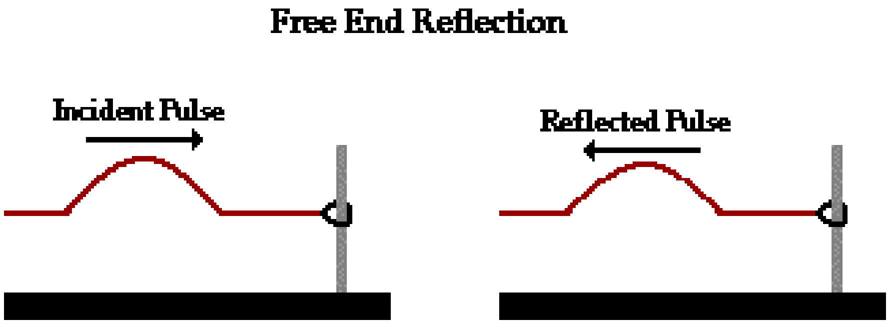




- **OPEN END**: The far end of the medium will be free to move. An open end situation could be accomplished by means of a string tied to the end of the slinky.
- In an open end reflection, the medium is free to move at the boundary. You will see an erect pulse traveling into the boundary came out erect. The pulse is not inverted.

Open End:

The pulse reflects off the free end and returns with the same direction of displacement which it had before reflection.



Other notable characteristics of the reflected pulse include:

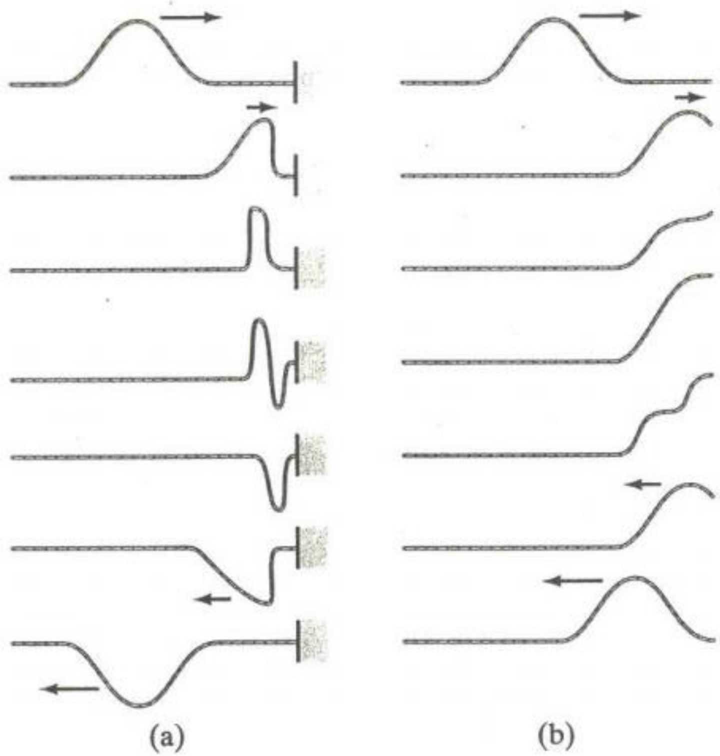


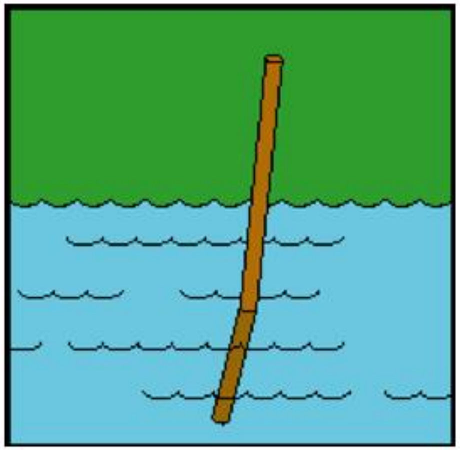
FIGURE 11–31 Reflection of a wave pulse on a cord when the end of the cord is (a) fixed and (b) free.

- the speed of the reflected pulse is the same as the speed of the incident pulse
- the wavelength of the reflected pulse is the same as the wavelength of the incident pulse
- the amplitude of the reflected pulse is less than the amplitude of the incident pulse

2. REFRACTION OF WAVES

Refraction is the bending of waves as it enters a different medium.

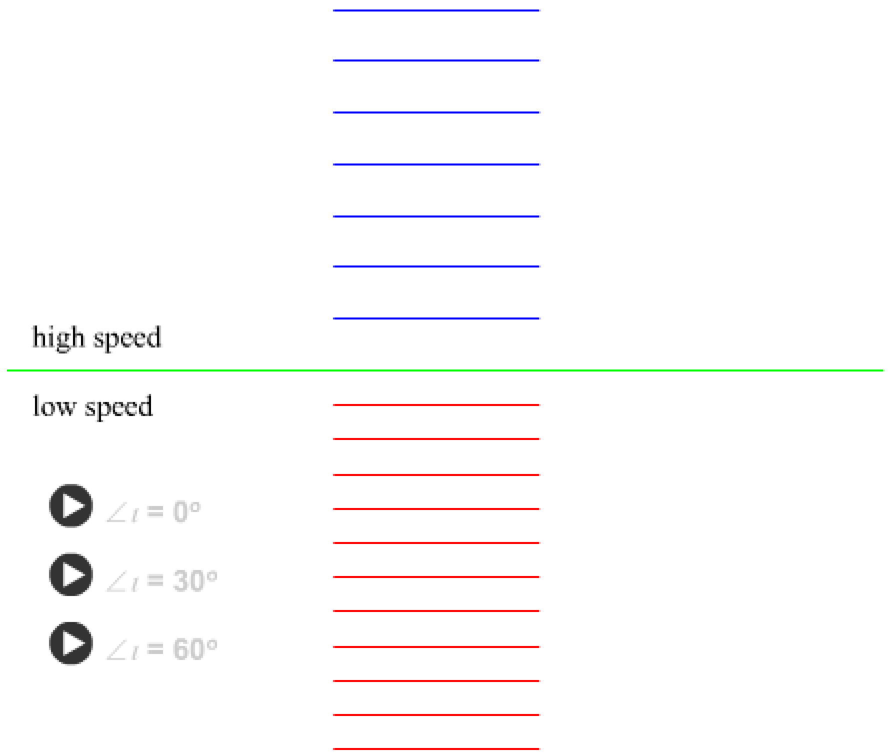
For example a stick appears to bent as it is placed in water. This bending of light is caused by a change in the speed of light when it enters a medium at an angle other than 90 º



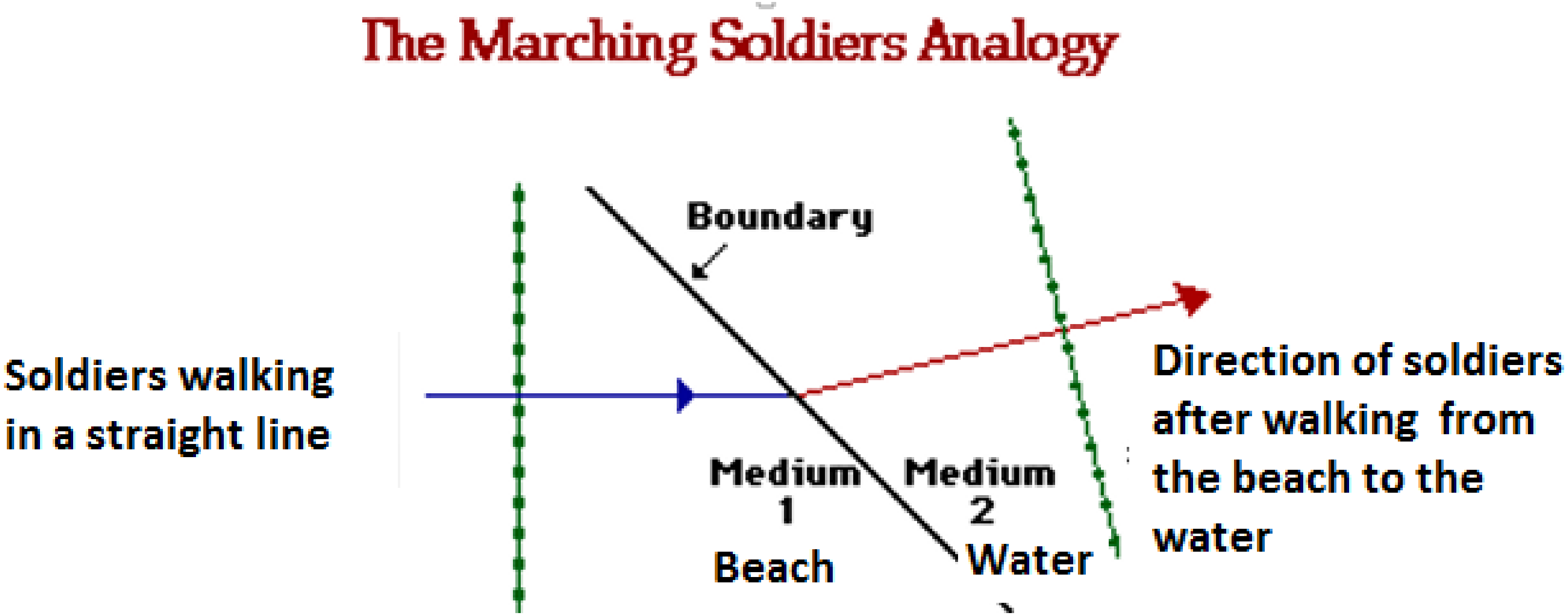
For a water wave the different mediums might be deep water and shallow water; for a sound wave the mediums could be warm air and cold air; for light waves the mediums could be air and glass, or any two transparent materials.

REFRACTION OF WAVES

A wave doesn't just *stop* when it reaches the end of the medium. Notice both the speed and the wavelength decrease. It is also observed to change directions as it crosses the boundary separating the mediums. This bending of the path of light is known as **refraction.**



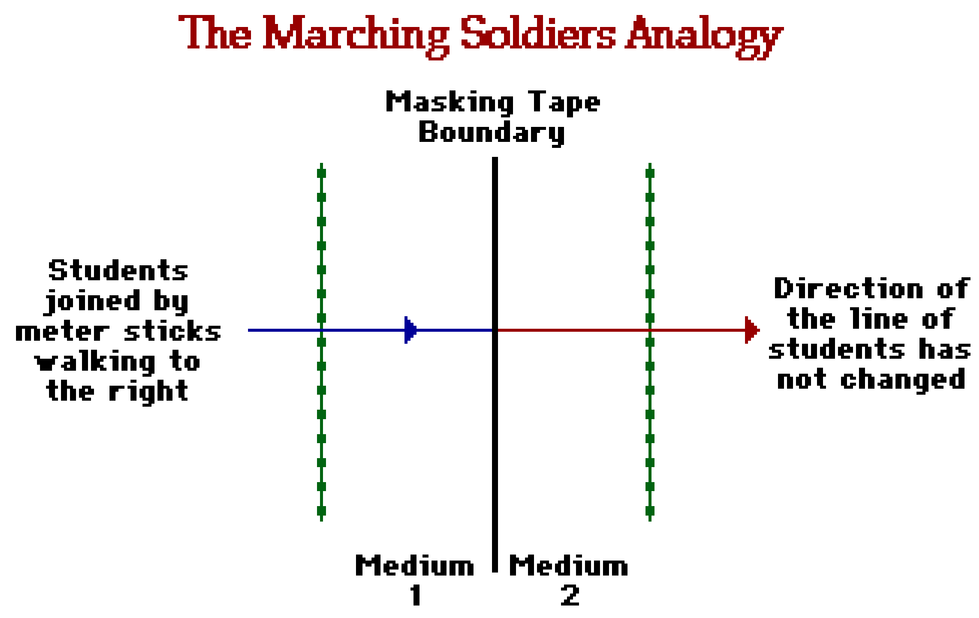
- The analogy of soldiers walking into water can be used to demonstrate why waves bend as they change from one medium to another.



There are two conditions which are required in order to observe the change in direction of the path of the soldiers:

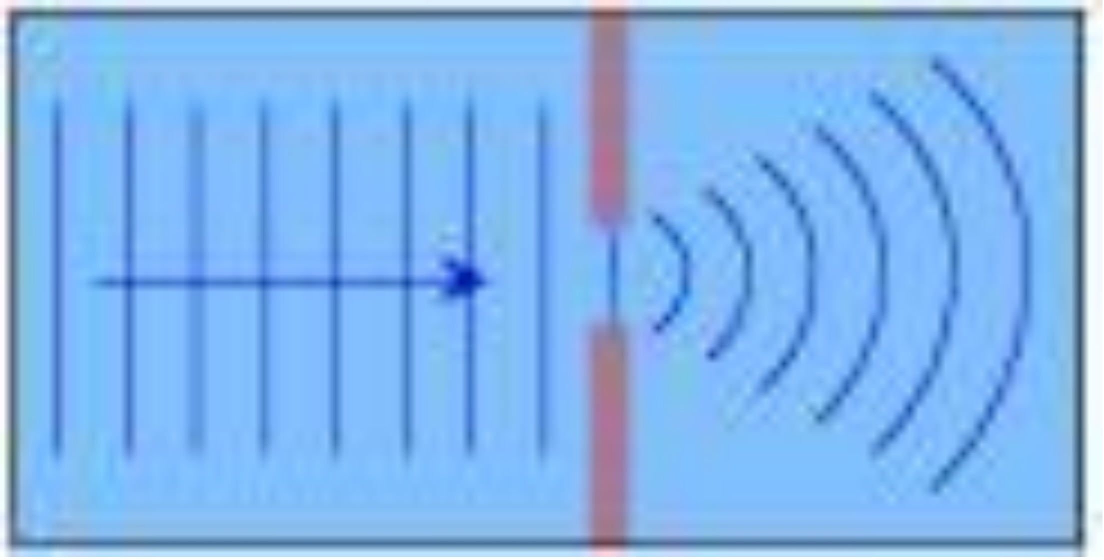
1) As a wave crosses a boundary into a new medium, its speed and wavelength change while its frequency remains the same.

2) The soldiers must approach the boundary at an angle; refraction will not occur when they approach the boundary "head-on" (i.e., heading perpendicular to it).



3. DIFFRACTION OF WAVES

Diffraction means the bending of waves around an obstacle or through an opening



Diffraction Around an Obstacle

- THE LONGER THE WAVE, THE GREATER THE DIFFRACTION EFFECT

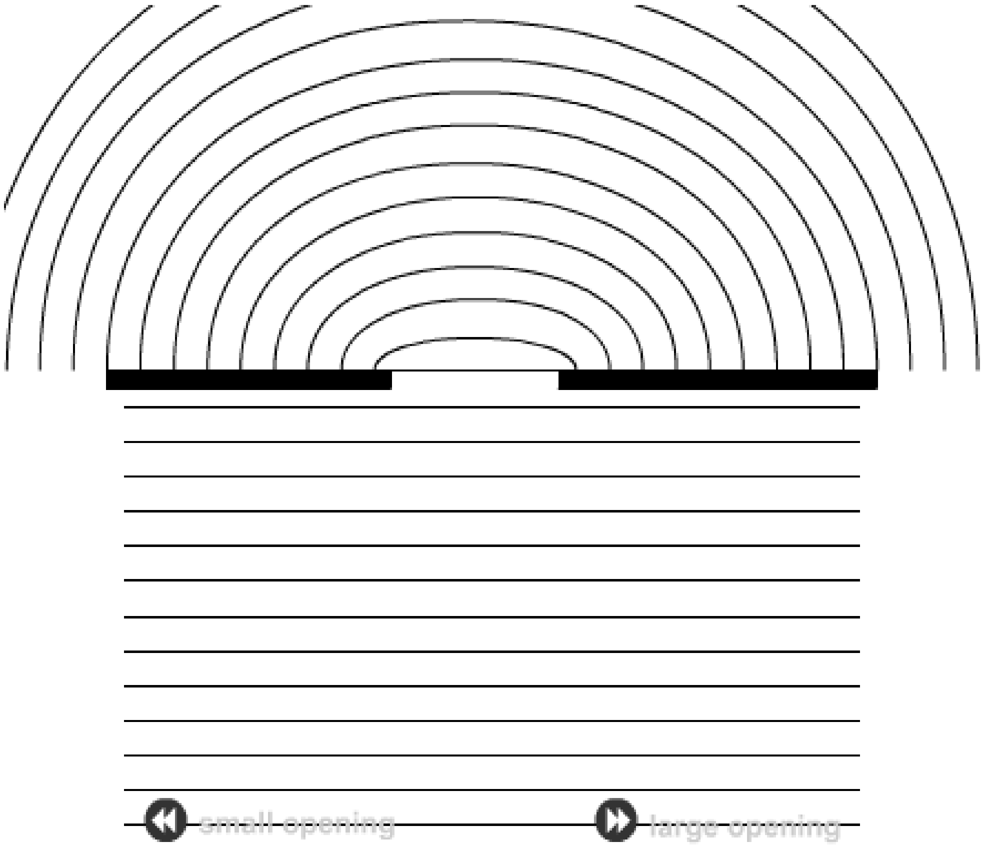
The word "bending" is used in the definitions of both diffraction and refraction. There's an important difference: in **diffraction** there is **only one medium**, and the bending is **caused by a barrier** or obstacle; in **refraction** there are **two mediums** and the bending is **caused by the passage of the wave from one medium to another.**

Diffraction Through an Opening

The diffracted wave will become more and more circular as the opening becomes smaller and smaller

.

The "diffraction will be most pronounced when the opening is smaller than or about the same size as the wavelength

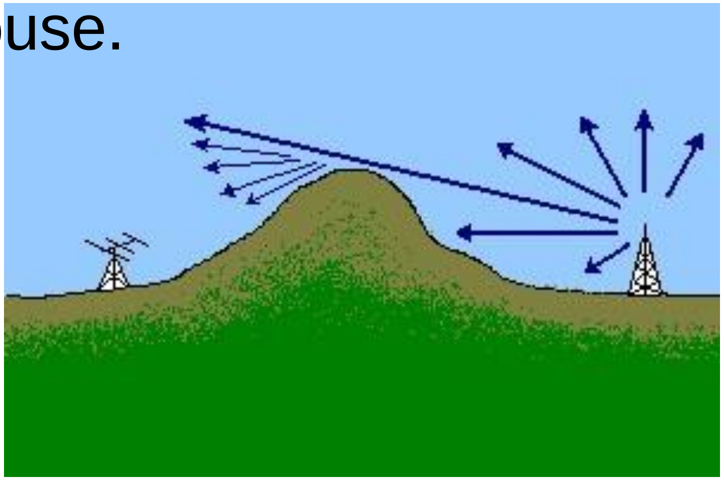


Diffraction of sound waves allows us to hear others who are speaking to us from adjacent rooms.

Many animals take advantage of the diffractive ability of long-wavelength sound waves. Owls for instance are able to communicate across long distances due to the fact that their long-wavelength hoots are able to diffract around forest trees and carry farther than the short-wavelength tweets of song birds.

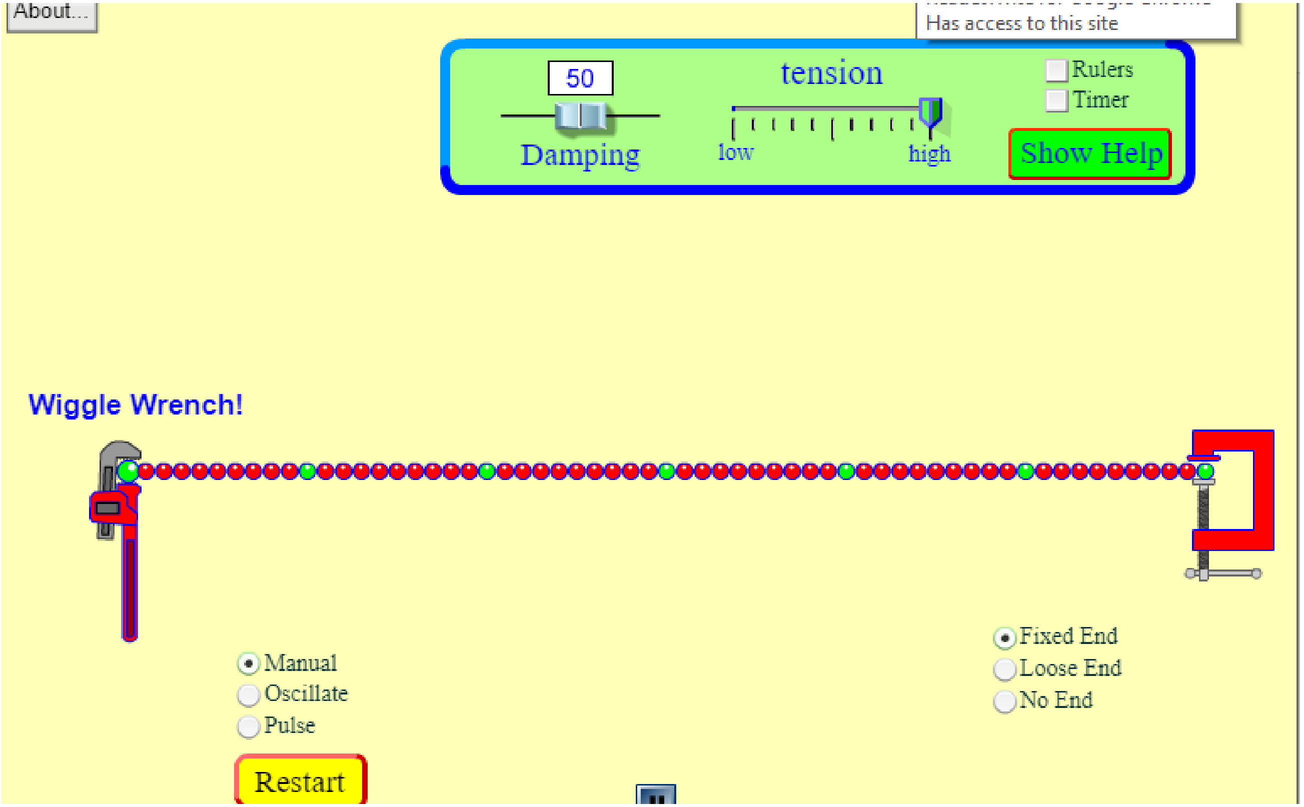
Diffraction of waves also occur with waves that we can't see -sound waves, radio waves and light waves.

If you live a far distance from broadcasting stations, you already know that your AM radio works much better than your TV or FM   This is because AM radio waves are much longer than "TV and FM waves". The longer radio waves more easily diffract over the hills, buildings, landscape, etc. to reach your radio. The TV broadcast waves will not diffract so readily. So, for good TV reception you put your antenna as high as possible, usually on the roof of your house.



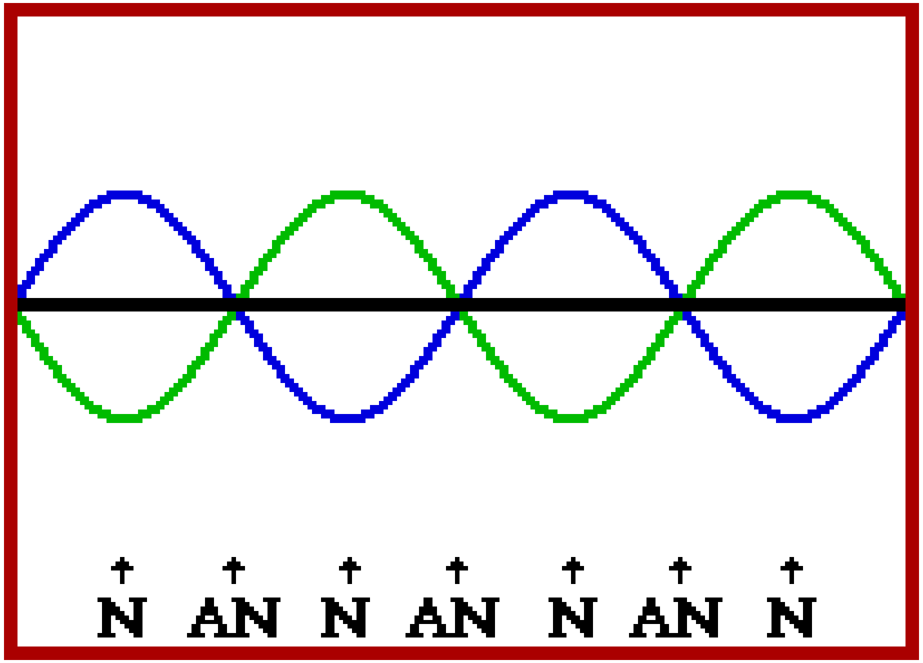
Wave on a String

- (Applet) http://phet.colorado.edu/sims/wave-on-a-string/wave-on-a-string_en.html



4. INTERFERENCE OF WAVES

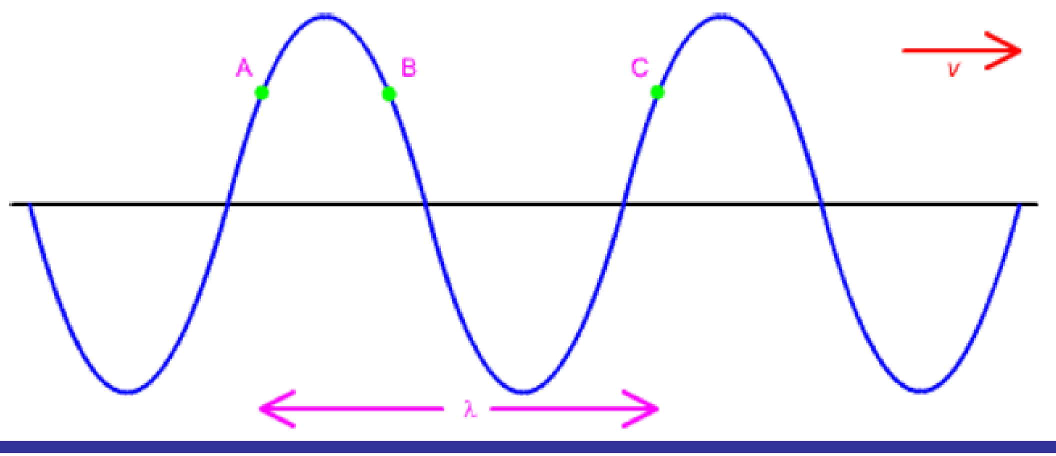
Wave interference is a phenomenon which occurs when two waves meet while traveling along the same medium. The interference of waves causes the medium to take on a shape which results from the net effect of the two individual waves upon the particles of the medium



INTERFERENCE OF WAVES –ONE WAVE

The diagram below shows a wave on a string. Points "A" and "B" have the same displacement above the rest position of the string. But if you look closely, you will see that they are moving in opposite directions. "A" is on the way down and "B" is on the way up. Since points A and B are not exactly alike, we say they are "out of phase“.

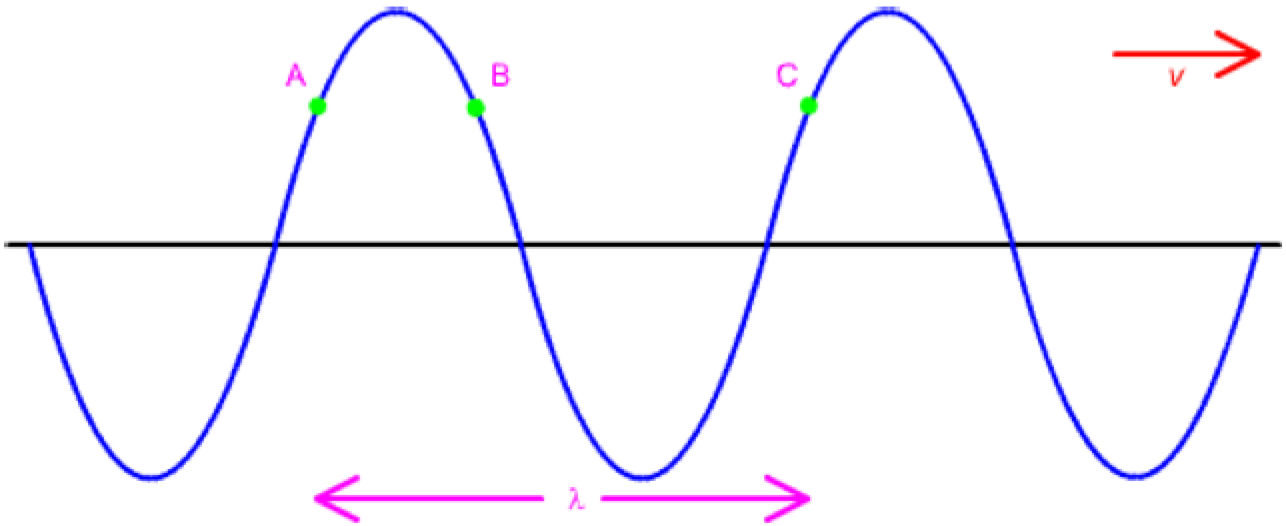
Points A and C are both moving downward. We can say that these two points are "in phase".



Points A and C are in phase because they have the same displacement and are moving in the same direction.

Another way to say this is: Points A and C are in phase because they are a whole number of wavelengths apart.

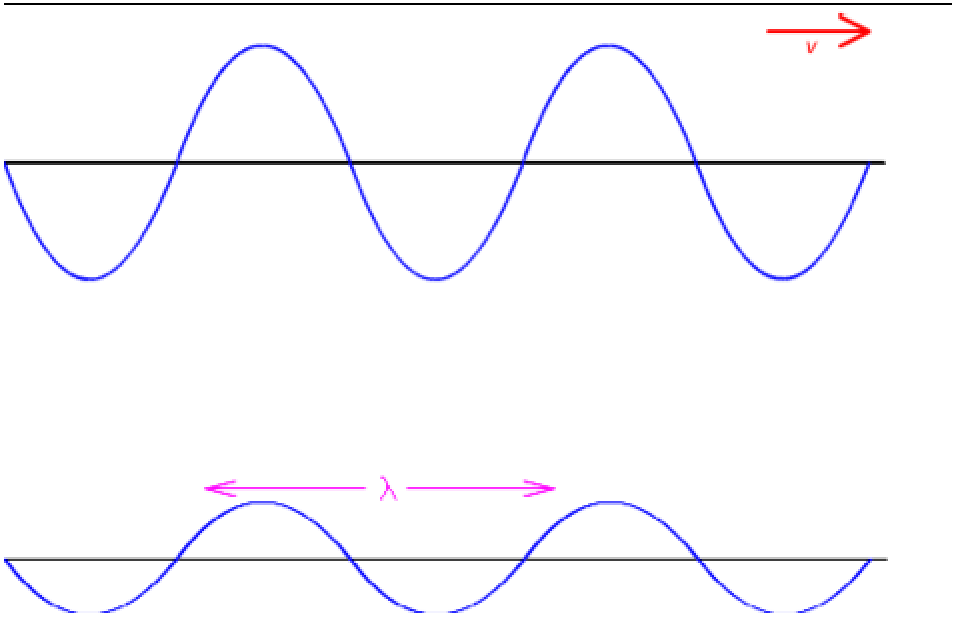
Points which do not satisfy the two conditions (same displacement, same direction) are out of phase.



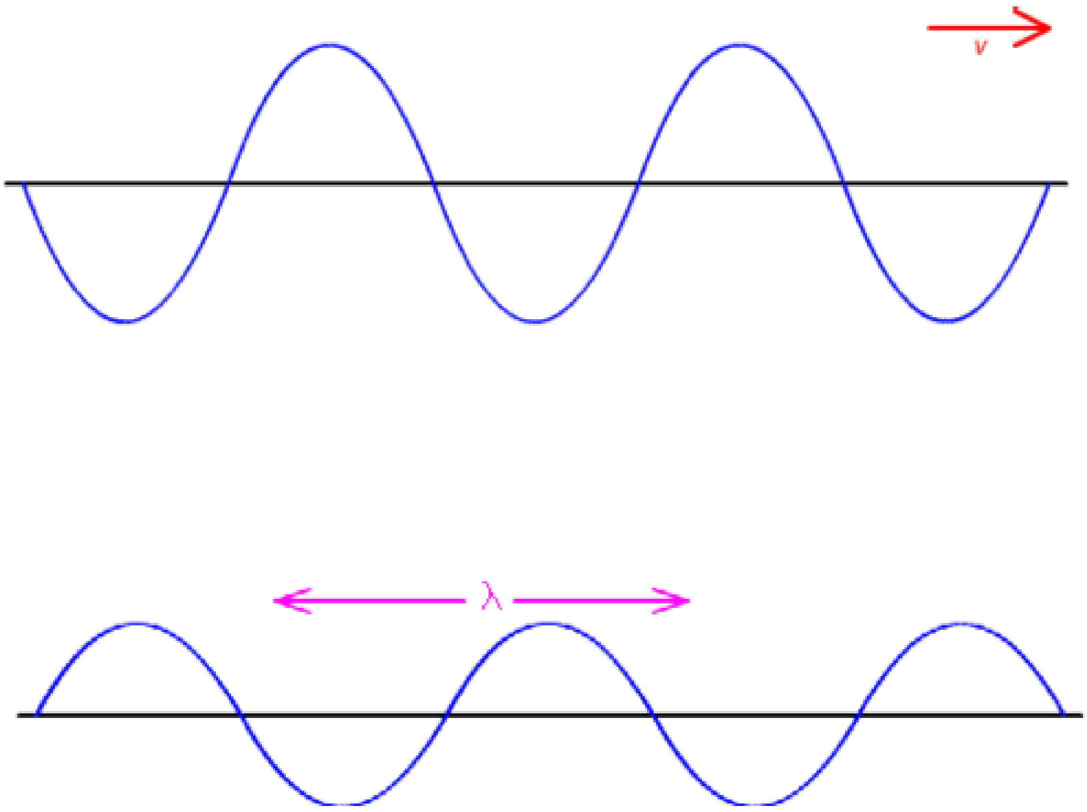
Interference Of Two Waves

The diagram below shows two wave trains in phase with each other.

The two wave trains will be in phase when they have the same wavelength and are positioned on the time axis in identical ways.

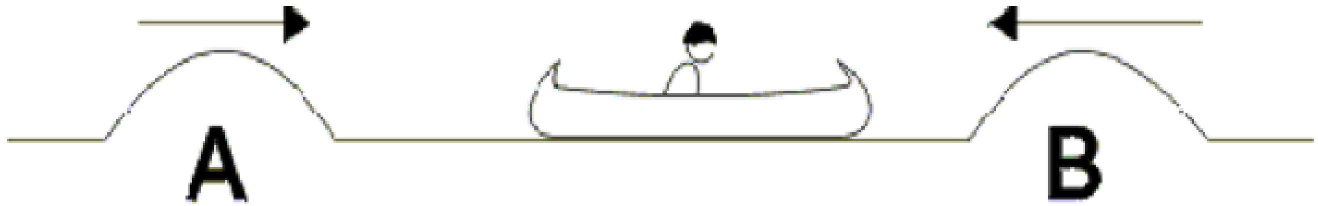


Here, the two waves completely out of phase. To be completely out of phase, two waves must have the same wavelength BUT be positioned on the time axis so that the crest of one matches the trough of the other.

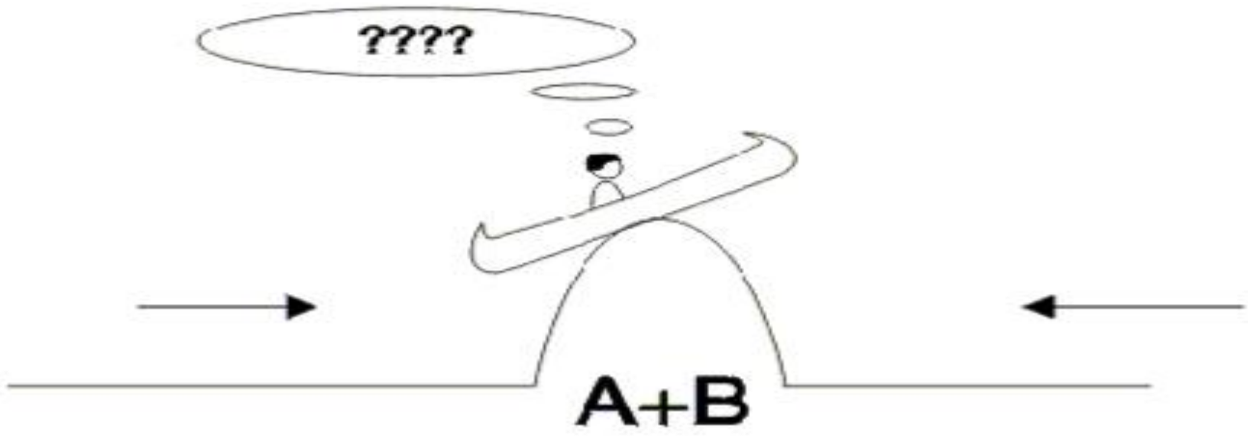


CONSTRUCTIVE INTERFERENCE

The picture below shows a canoeist (minding his own business) on a calm lake. Two speedboats have just passed on either side of the canoe. The speedboats cause two pulses in the water that rapidly move towards the unfortunate canoeist



Look at what happens when they meet



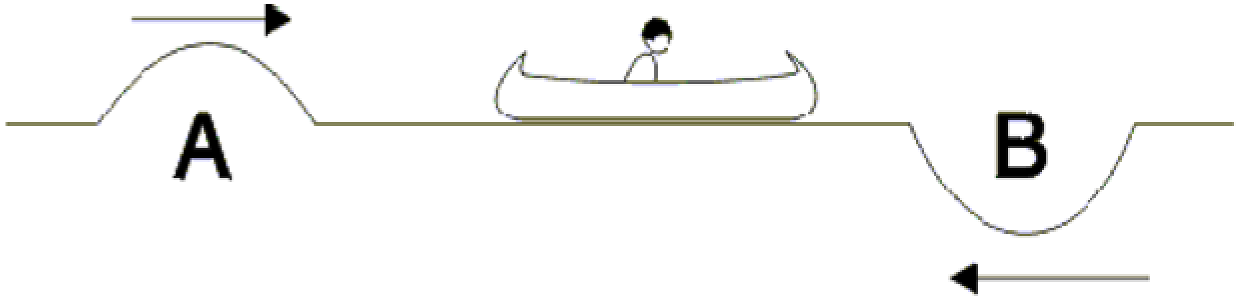
If both pulses reach the canoe at the same time, the pulses will **interfere** **CONSTRUCTIVELY**. They will add together to give a larger pulse which is the SUM of the two original pulses.

How does the pulses affect each other as they interfere constructively.?

They continue to move in their original directions as shown below

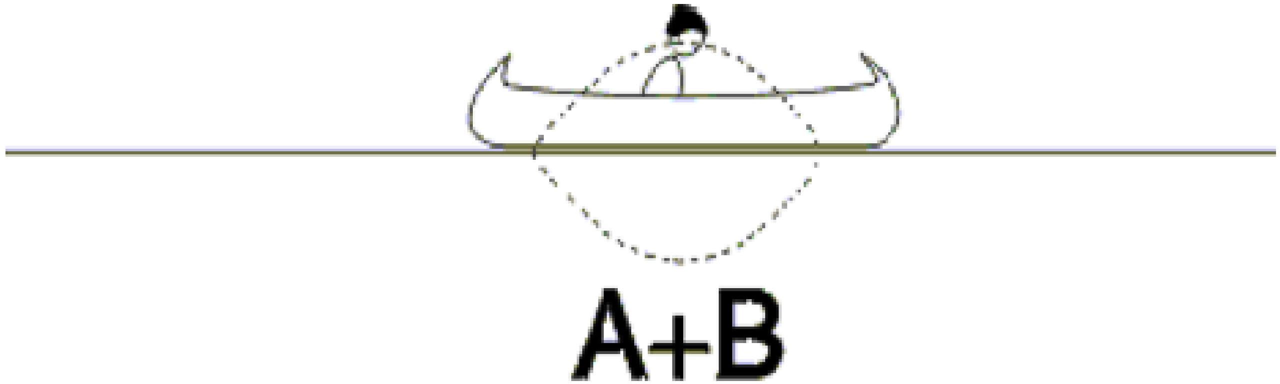
DESTRUCTIVE INTERFERENCE

This time one pulse is a crest while the other is a trough. Here, they are identical in size and both reach the canoe at the same time



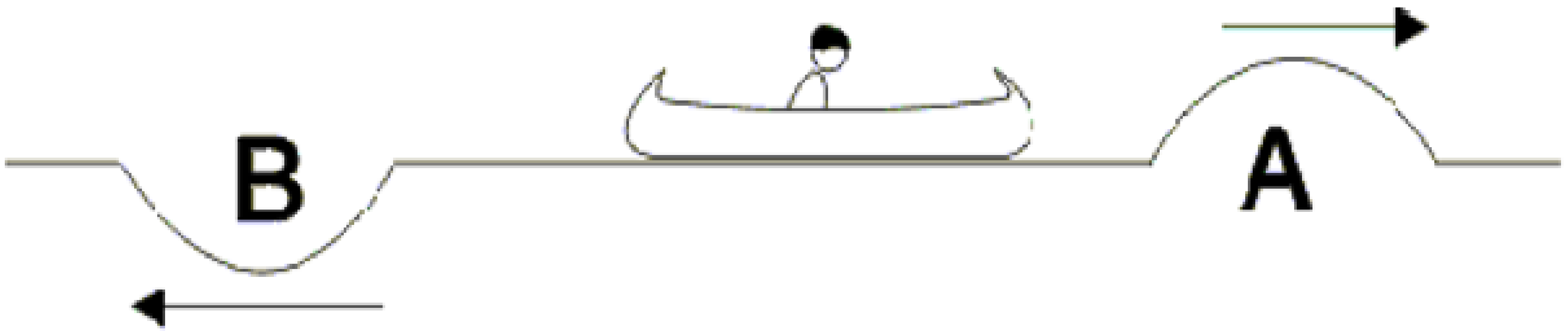
What occurs in this situation?

The pulses are completely out of phase. The canoeist has no need to worry because the pulses **interfere DESTRUCTIVELY** and completely cancel each other.

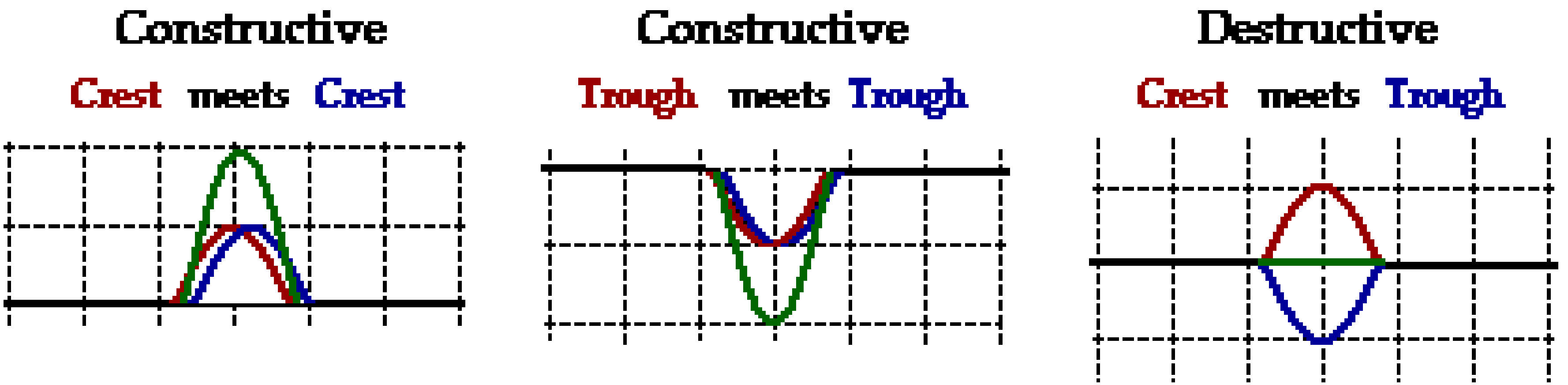


Picture the water of pulse A falling into the empty trough B. For a complete cancellation, they must have the same amplitude.

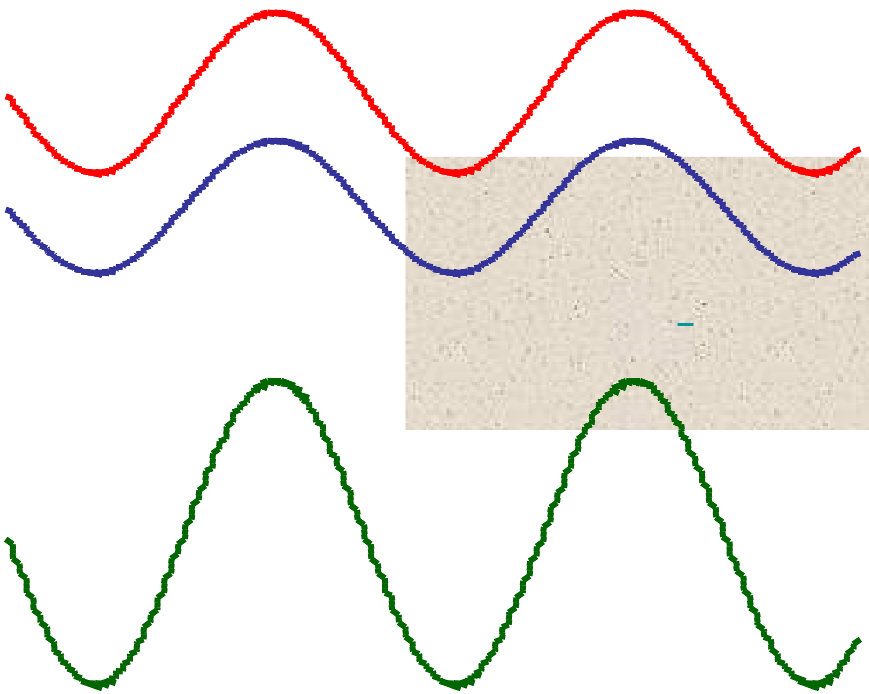
Once again, the pulses "pass through" each other and continue on in their original directions. See picture below.



The diagrams below show two waves - one is blue and the other is red - interfering in such a way to produce a resultant shape in a medium; the resultant is shown in green.

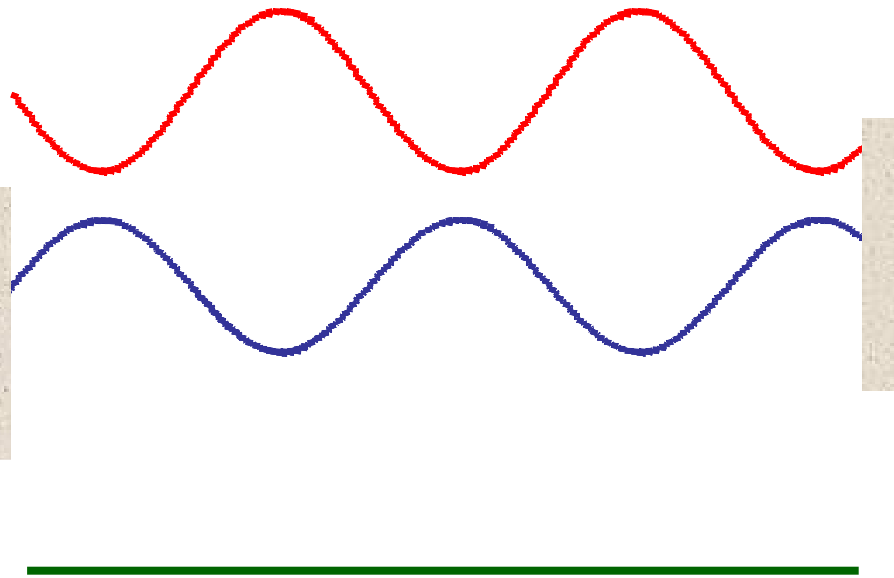


Summary of Interference



Constructive Interference

Waves are “in phase.” By superposition, red + blue = green. If red and blue each have amplitude A, then green has amplitude 2A.

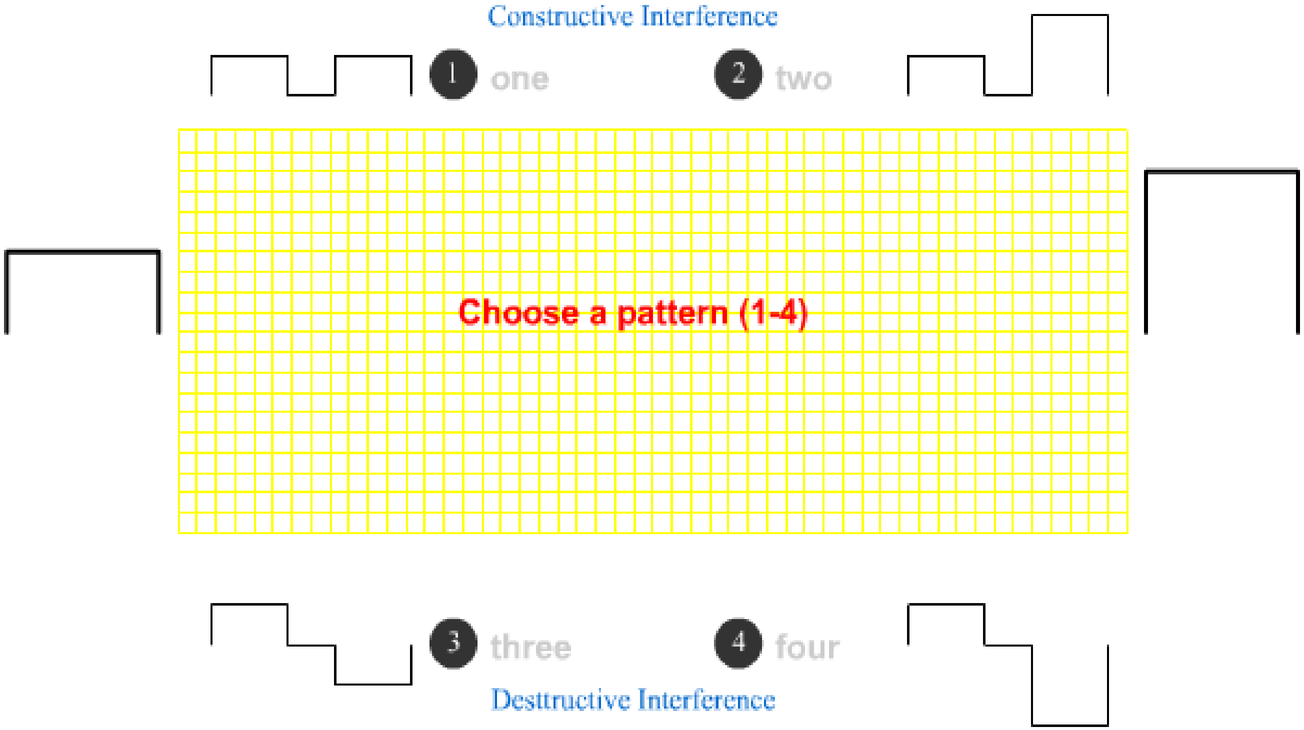


Destructive Interference

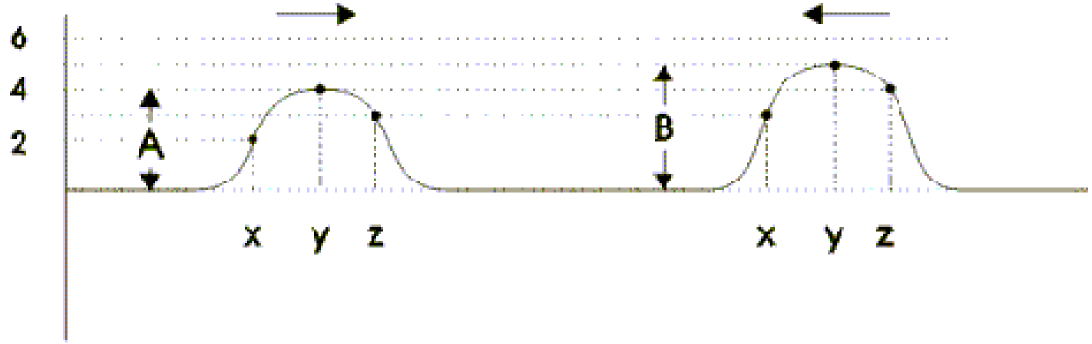
Waves are “out of phase.” By superposition, red and blue completely cancel each other out, if their amplitudes and frequencies are the same.

PRINCIPLE OF SUPERPOSITION

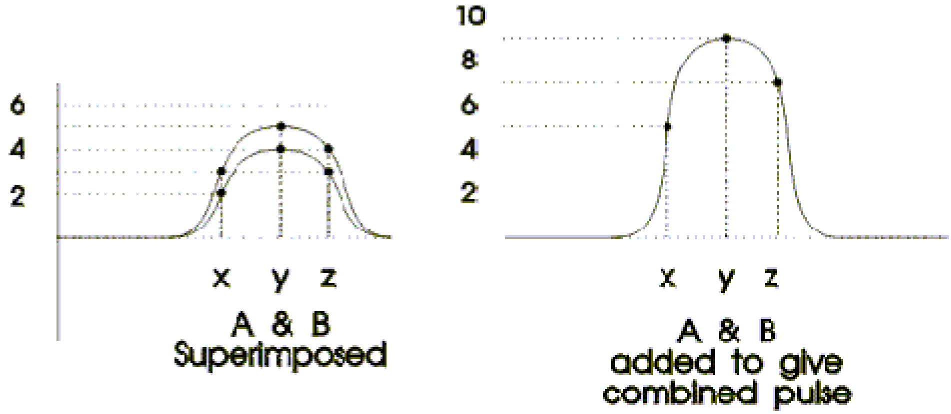
- **Principle of superposition** states that we can find the resultant displacement of a given particle of a medium by finding the sum of the displacements that would be caused by each pulse or wave acting independently.



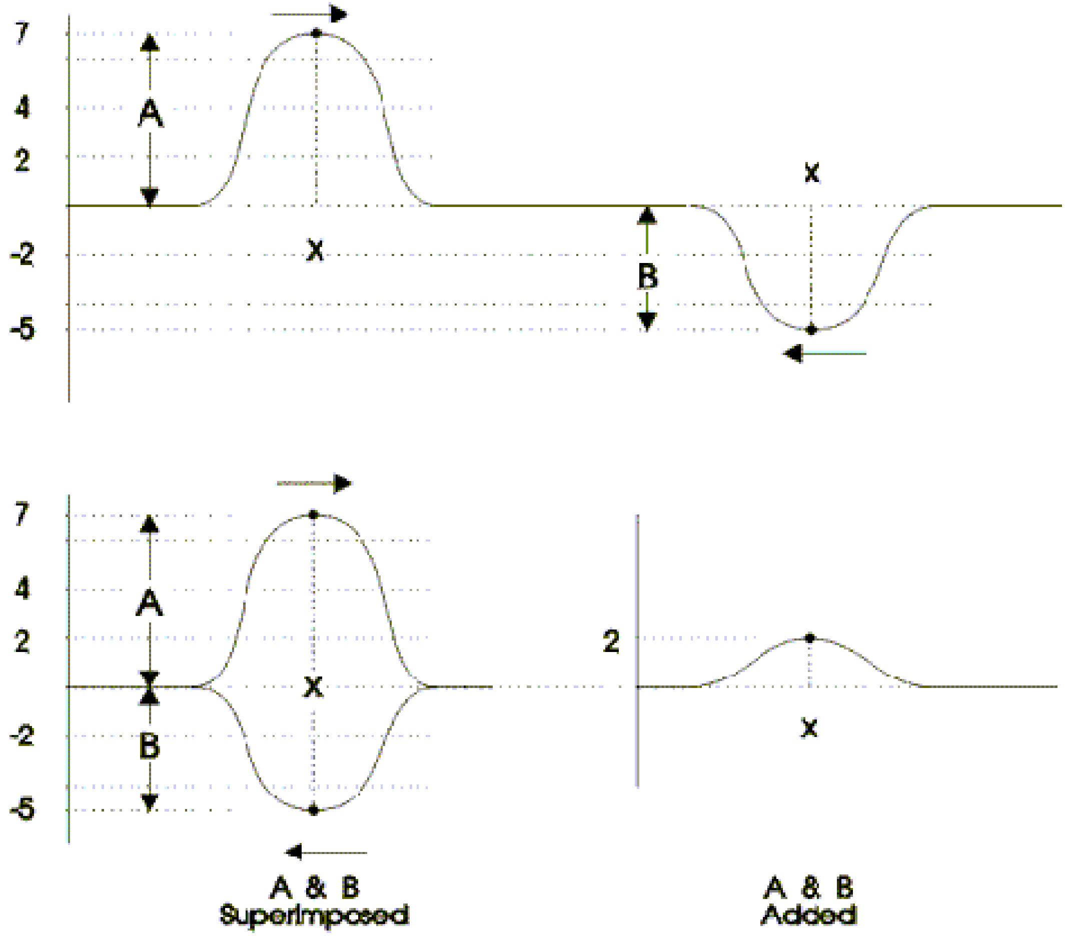
The picture below shows a string (or a slinky) with pulse A traveling to the right and pulse B traveling to the left. To keep the picture simple, the displacements of only three particles (x, y, and z) are shown explicitly.



we apply the superposition principle to find the resultant displacement of x, y, and z by adding together the effects of both pulses. For x we get 5, for y we get 9, and for z we get 7. (constructive interference).



Now, let's use the Superposition principle for two pulses that interfere destructively.



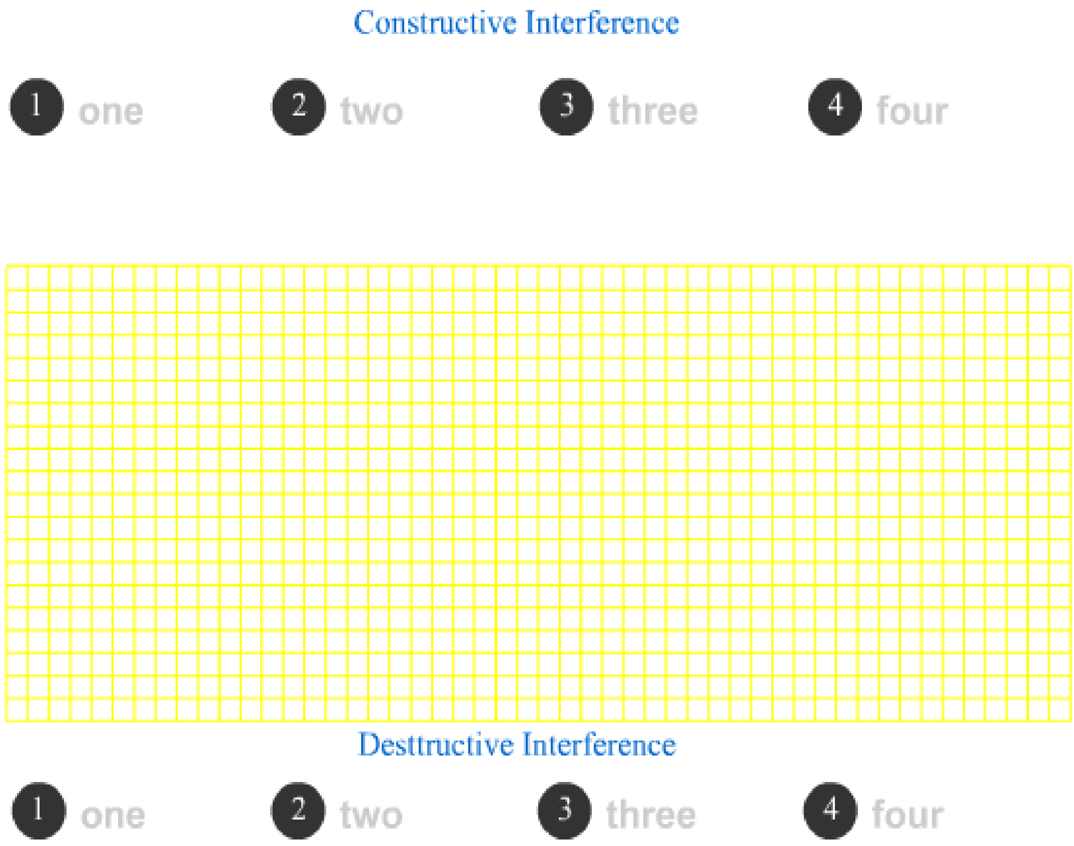
Example 1

1 Constructive Interference

2 Destructive Interference

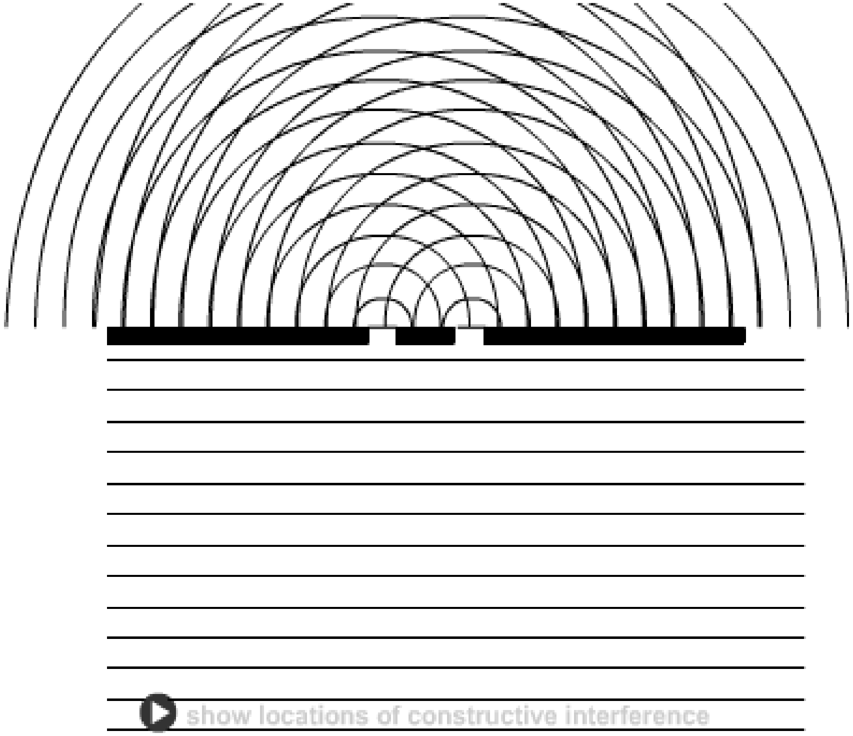
Remember -the patterns that resulted in the above examples are assumed to be things that exist for only a brief instant. They are what the wave looks like at the exact instant the waves overlap.

Example 2


Constructive Interference
1 one
2 two
3 three
4 four
Desttructive Interference
1 one
2 two
3 three
4 four

Interference in 2 Dimensions

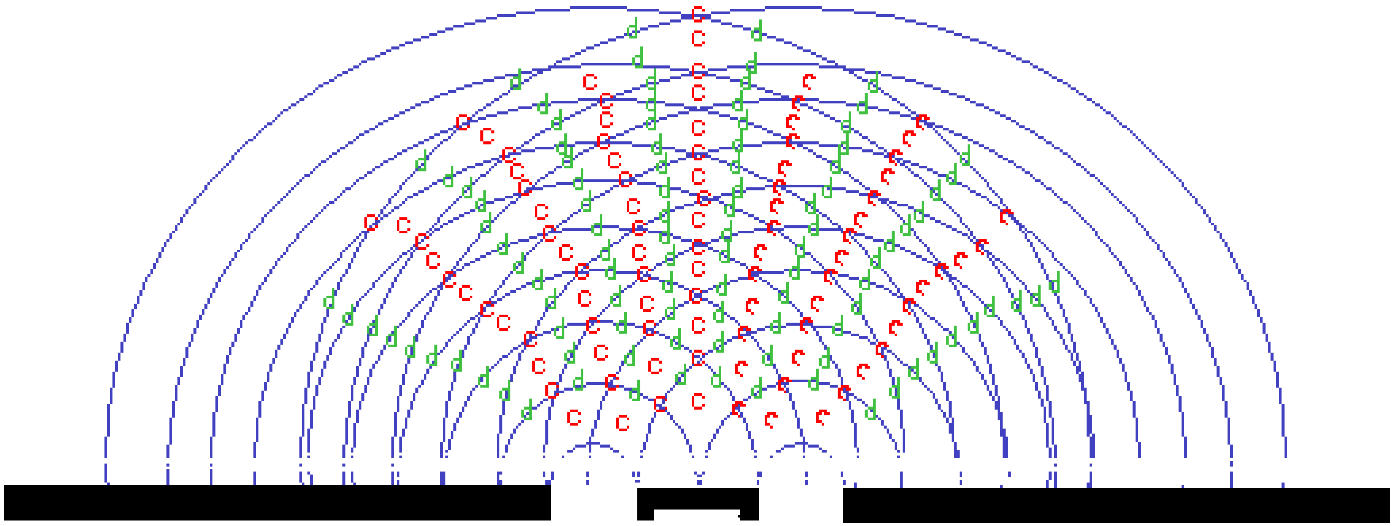
- Interference will only occur when two pulses or wave trains overlap. The picture below shows how this can be done in two dimensions, (ripple tank, or speakers).



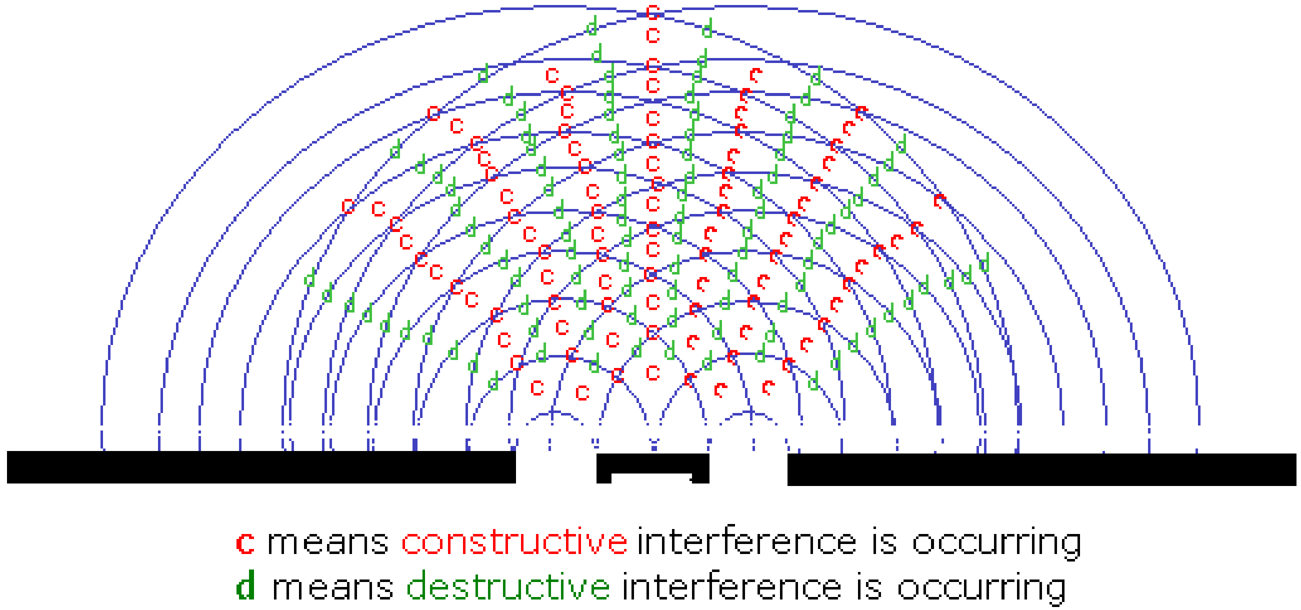
Remember, the blue semi-circular patterns represent the crests of the waves, and the spaces in between the lines are the troughs.

You should be able to see that constructive interference occurs under two conditions: i) when a crest falls on a crest and ii) when a trough falls on a trough.

Similarly, destructive interference occurs when a crest falls on a trough.



c means constructive interference is occurring
d means destructive interference is occurring



Since the waves "destroy" each other at the destructive interference places, the lines formed by destructive interference indicate places where the water is undisturbed. We can call the radiating lines formed by the destructive interference NODAL LINES--the lines of d's in the picture.

The lines formed by the places of maximum disturbance--the constructive inference are called ANTINODAL LINES--are the lines of c's in the picture.

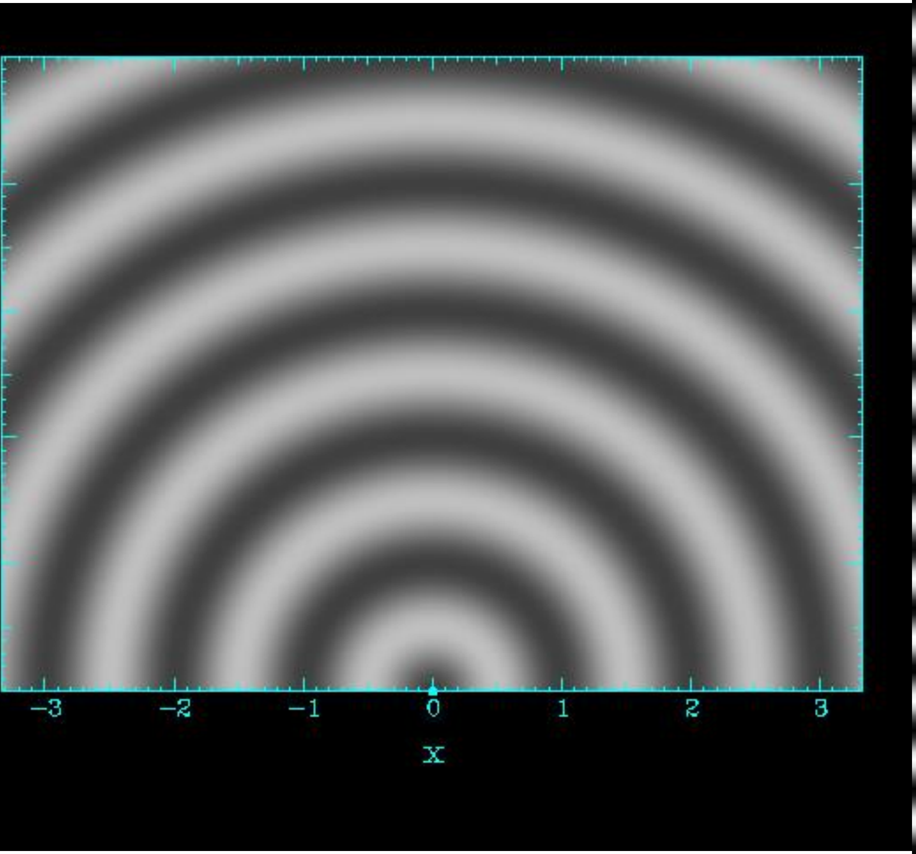
Superposition

- Simulation:

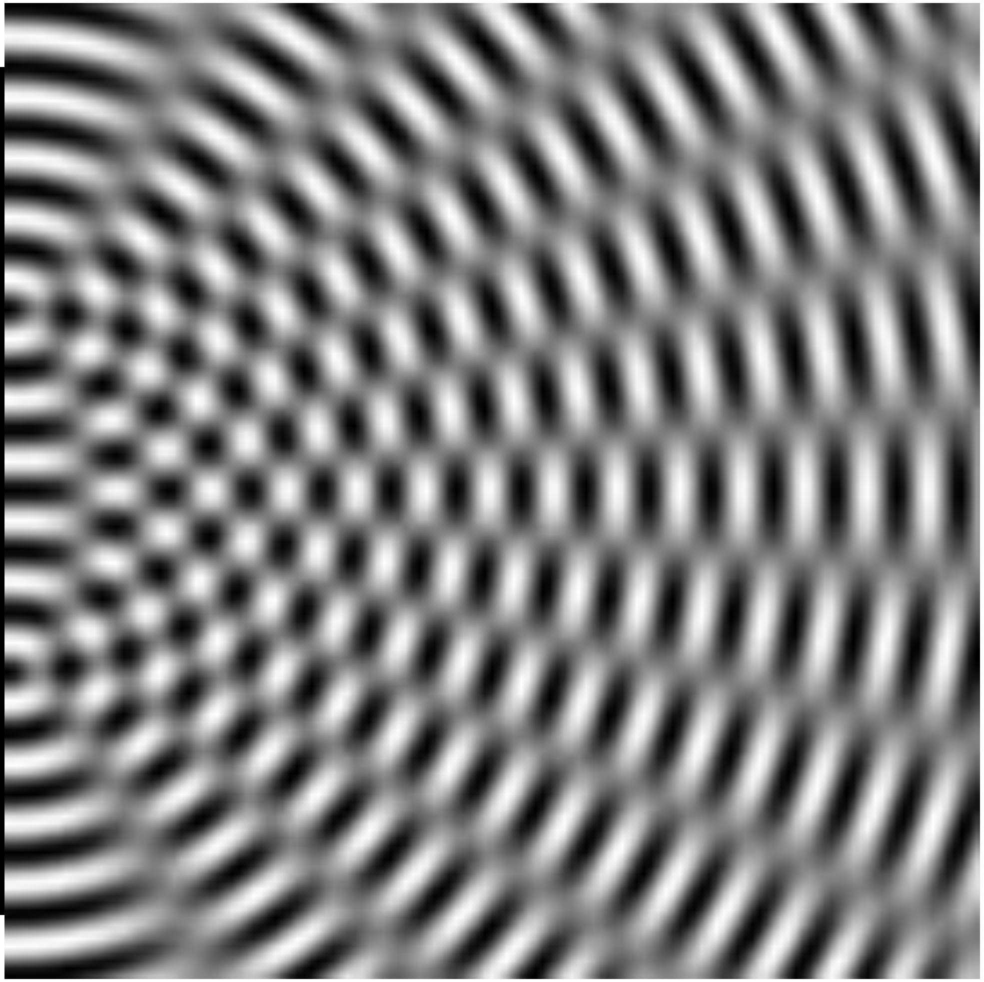
  Constructive and Destructive Interference (string with loose or fixed end)

- http://www3.interscience.wiley.com:8100/legacy/college/halliday/0471320005/simulations6e/index.htm?newwindow=true

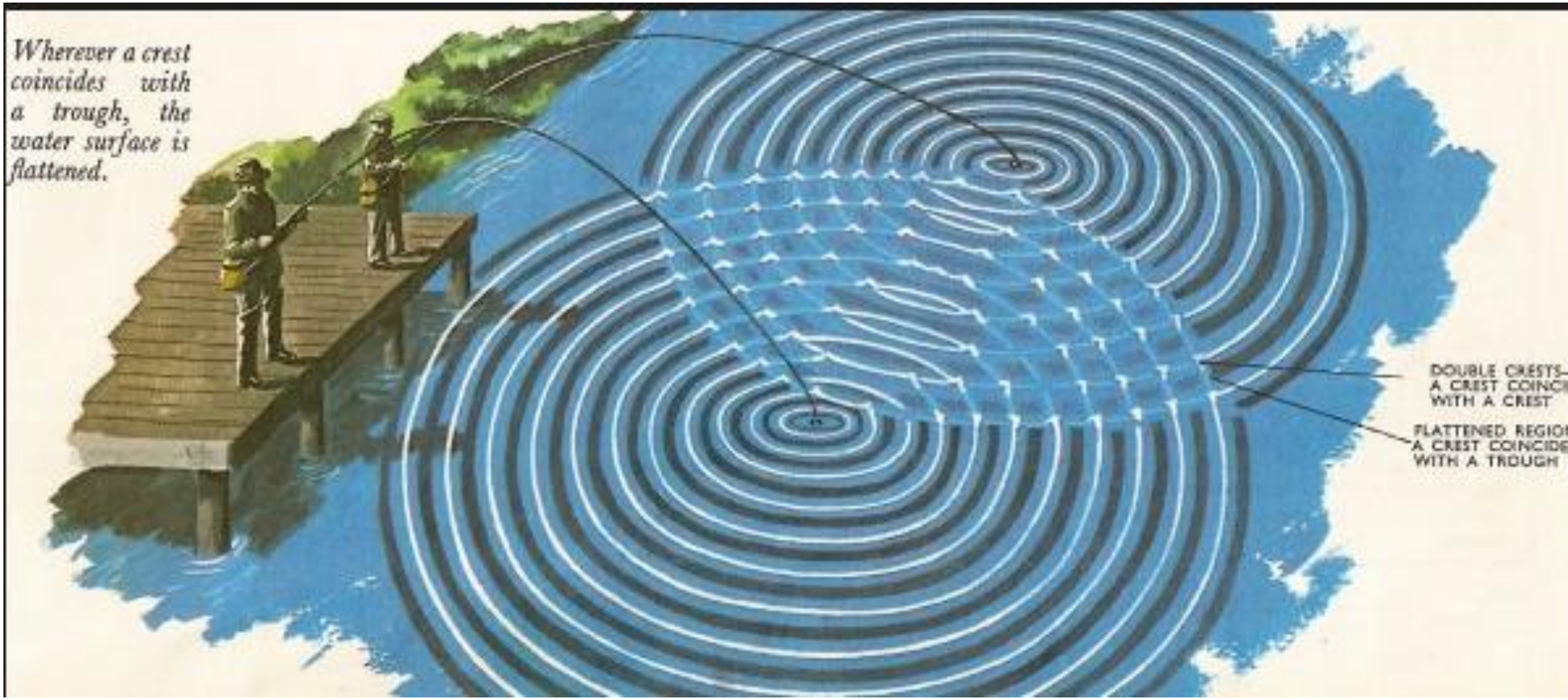
One Wave



Two Waves Interfering

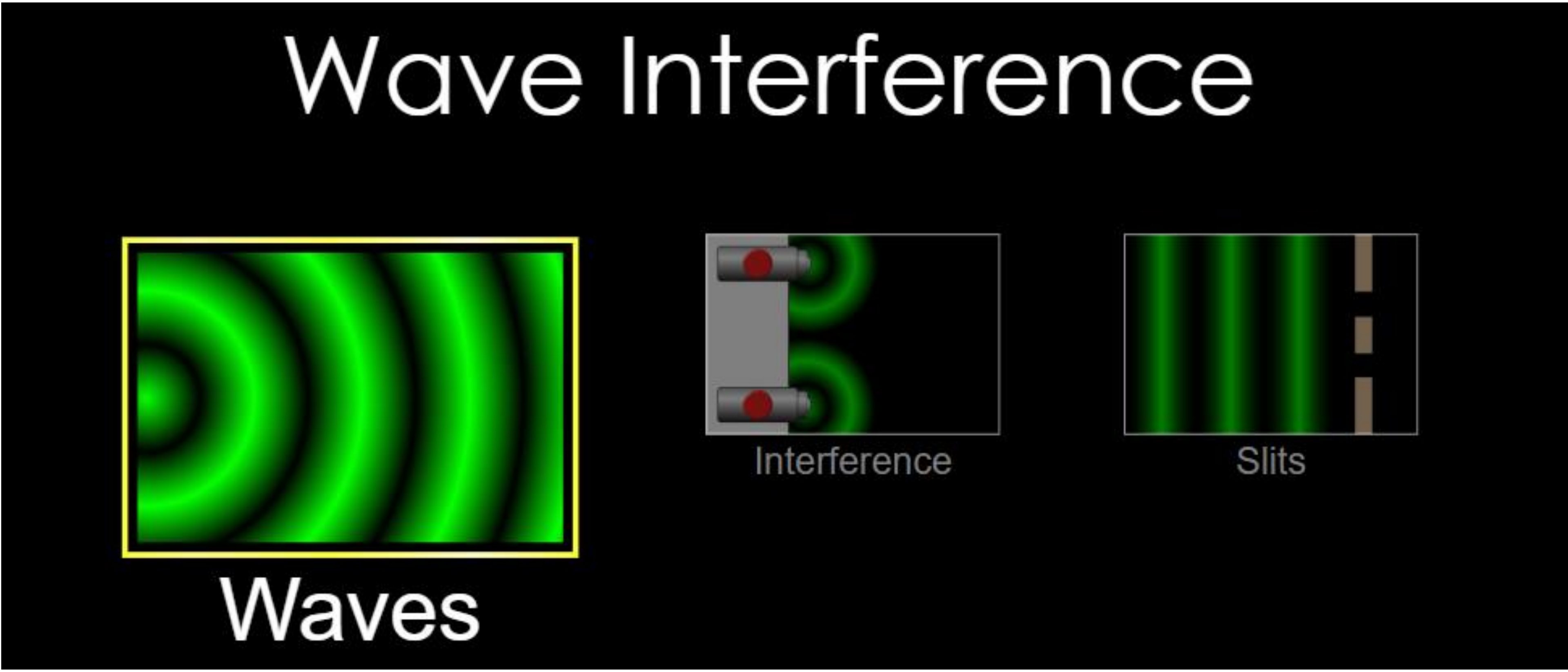


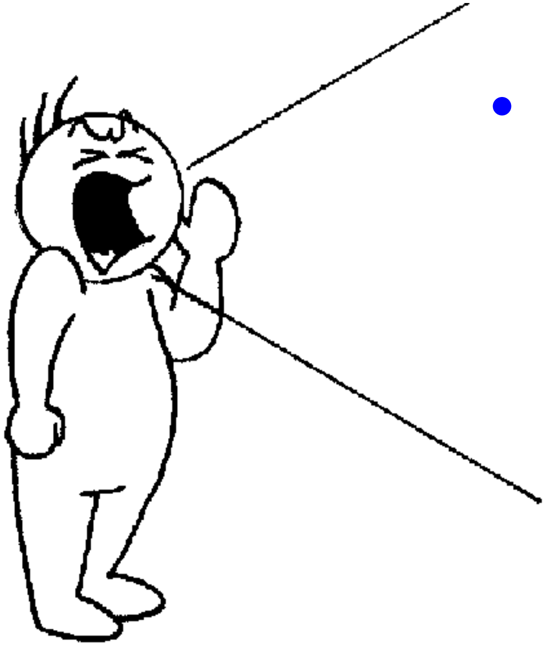
Interference in Water Waves


Wherever a crest coincides with a trough, the water surface is flattened.
DOUBLE CRESTS— A CREST COINCID WITH A CREST
FLATTENED REGION A CREST COINCIDES WITH A TROUGH

Interference Of Waves

https://phet.colorado.edu/sims/html/wave-interference/latest/wave-interference_en.html





Topic 4

- **Introduction to Sound Waves**

What is sound?

Sound:

- Is a wave which is created by vibrating objects and propagated through a medium from one location to another

- A form of energy made by vibrations.

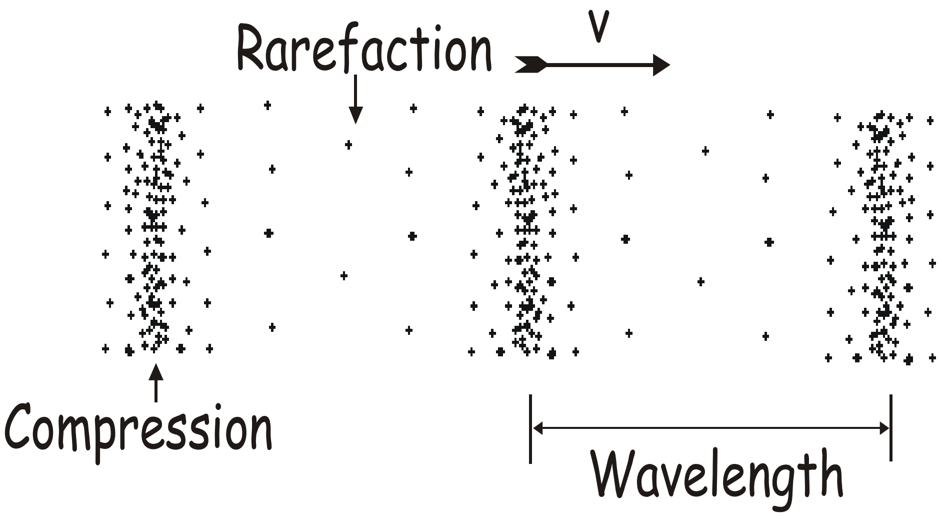
- When an object vibrates it causes the air particles around it to move.

Try This!

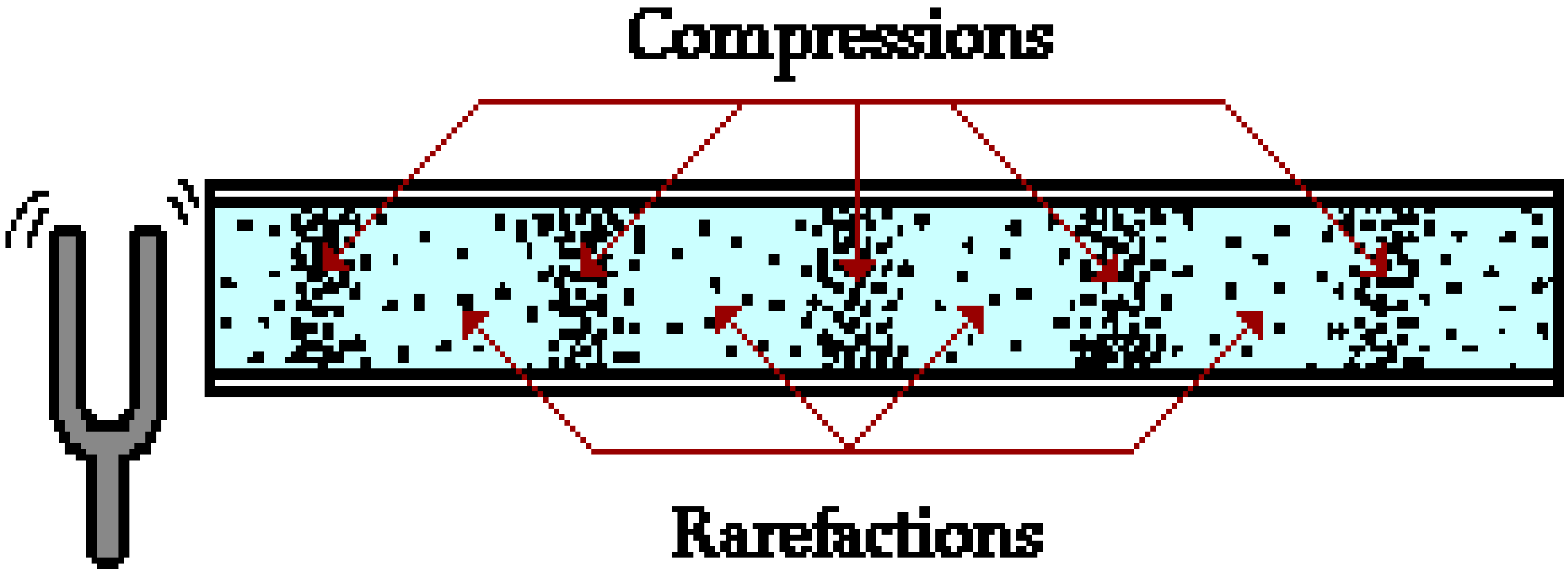
- Put your finger on your neck and say “aah” as loud as you can.
- Now say it as soft as you can.
- You can not only hear the sound, but you can feel the vibration inside your throat

How does sound travel?

- The disturbance which travels through air is the compression of air molecules – they are squeezed together and pulled apart. Sound is a series of traveling high pressure and low pressure fronts.



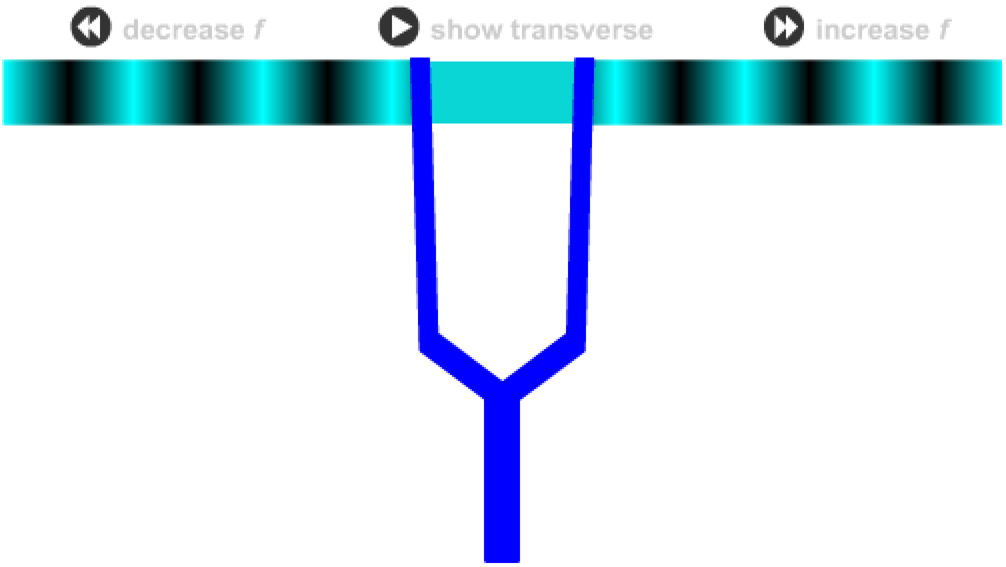
Sound travels as a longitudinal waves:



Compression: where the particles are close together

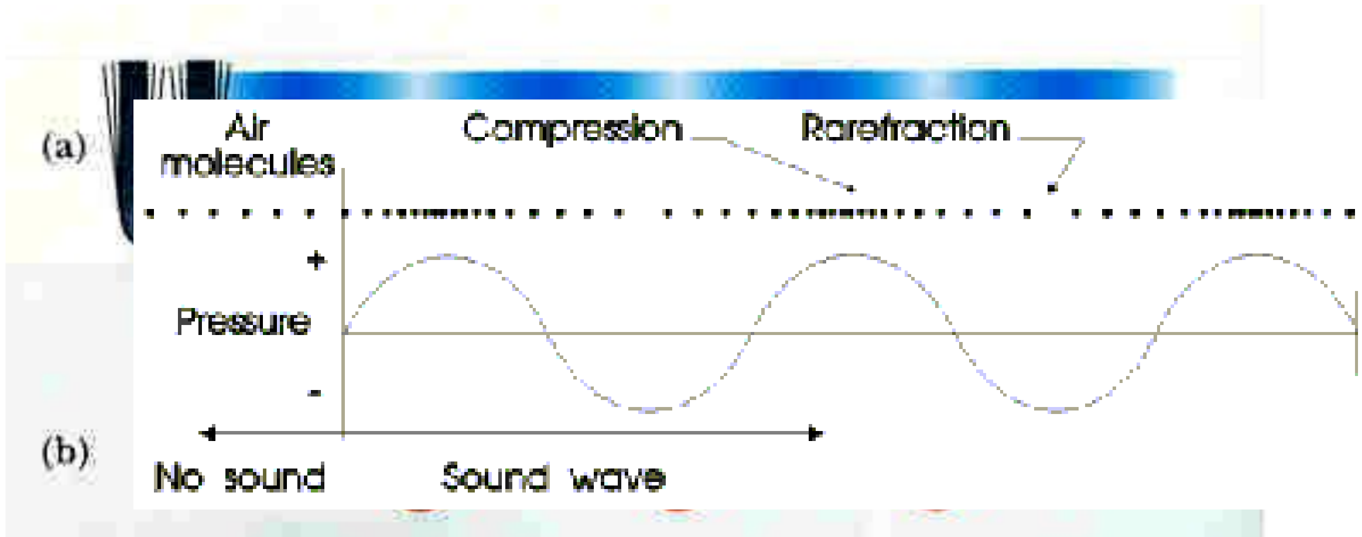
Rarefaction: where the particles are spread apart

The most popular "sound maker" in a physics laboratory is the tuning fork



- As the tines of the tuning forks vibrate back and forth, they begin to disturb surrounding air molecules. A better way to say this is "the air molecules are being compressed into COMPRESSIONS and rarefied into RAREFACTIONS in a regular and rapid way." These disturbances are passed on to adjacent air molecules by the mechanism of particle interaction. The motion of the disturbance, originating at the tines of the tuning fork and traveling through the medium (in this case, air) is what is referred to as a sound wave.

- A sound wave is a longitudinal wave but transverse waves are used because they are a lot easier to draw than are longitudinal waves! Also, it is quite reasonable to use transverse waves to represent sound if we picture sound as a pressure wave.

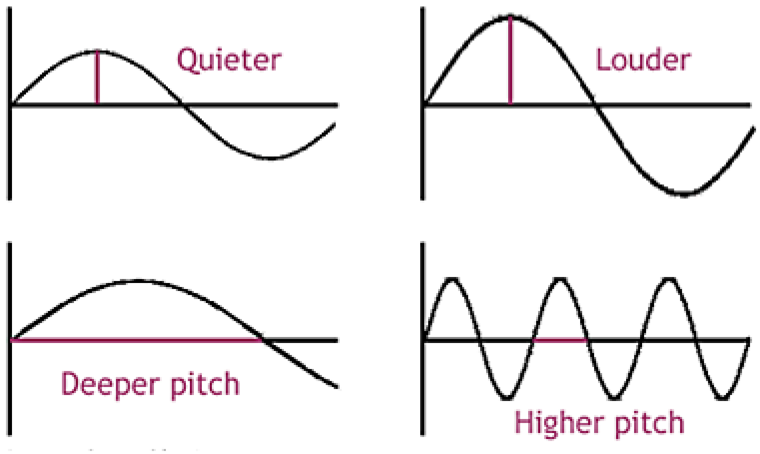


CHARACTERISTICS OF SOUND

• All sounds are not alike.

• There are two key features of a sound wave that make a difference :

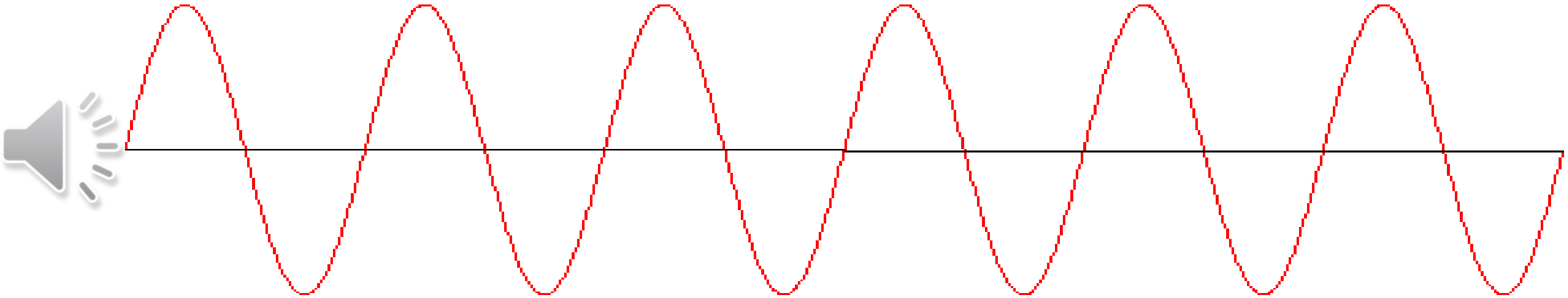
1) PITCH
2) LOUDNESS



1. Pitch is a description of how high or low a sound

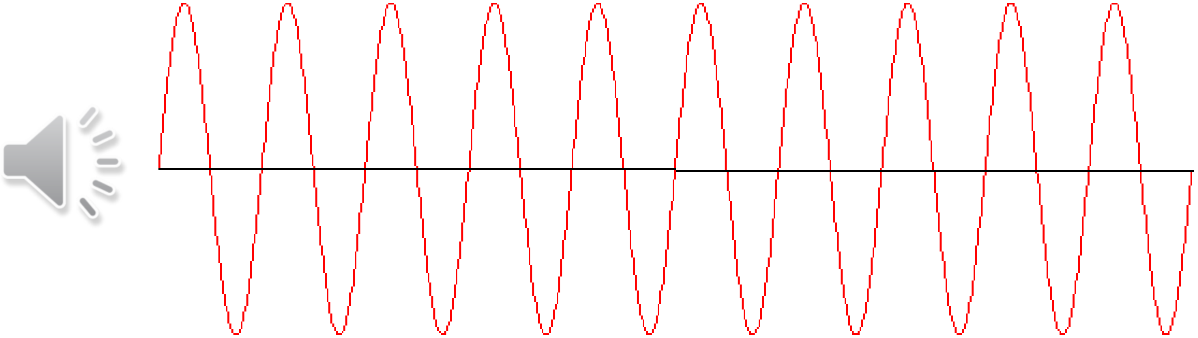
Pitch depends on the frequency of a sound wave

Low frequency sound waves = low pitch



When things vibrate slowly they make a low sound.

High frequency sound waves = high pitch

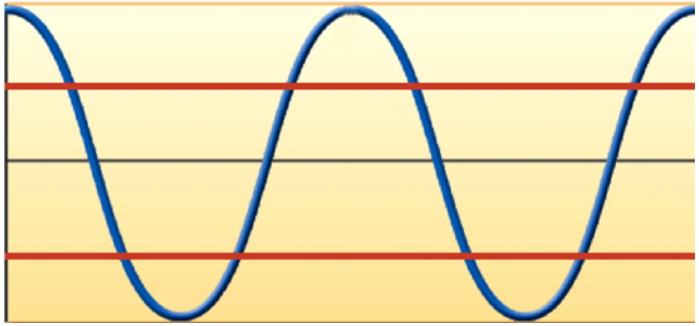


When things vibrate quickly they make a high pitched sound.

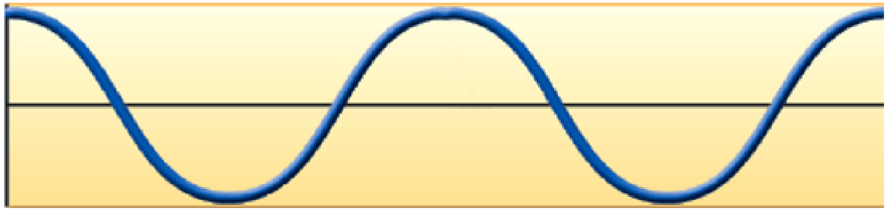
2. Loudness- how loud or soft a sound is perceived to be. It depends on what we actually hear sounds. A sound wave of greater intensity sounds louder

Loudness depends on the amplitude of the wave

A sound wave with a higher amplitude and energy is perceived as a louder sound.



A sound wave with a lower amplitude and energy is perceived as a softer sound.



Measuring Loudness

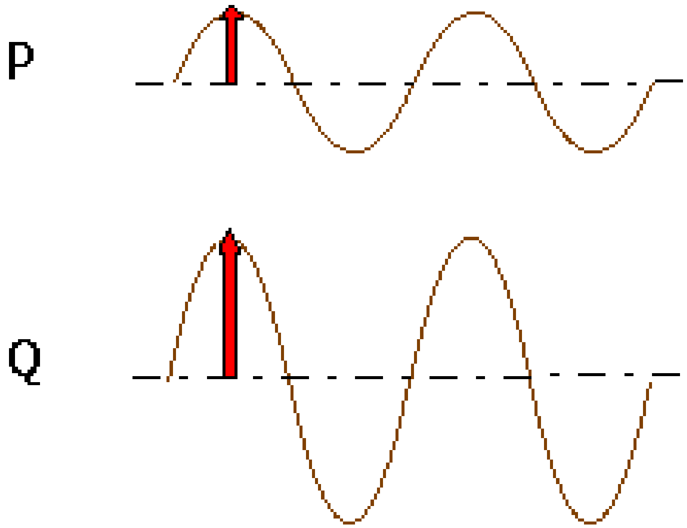
Intensity of a wave is defined as the Power(P) that passes through a surface with an area (A) perpendicular to the wave's direction.

A sound wave of greater intensity sounds louder

Decibels (dB) – measures loudness. A sound you can barely hear is 0 dB. 100dB can damage your ears

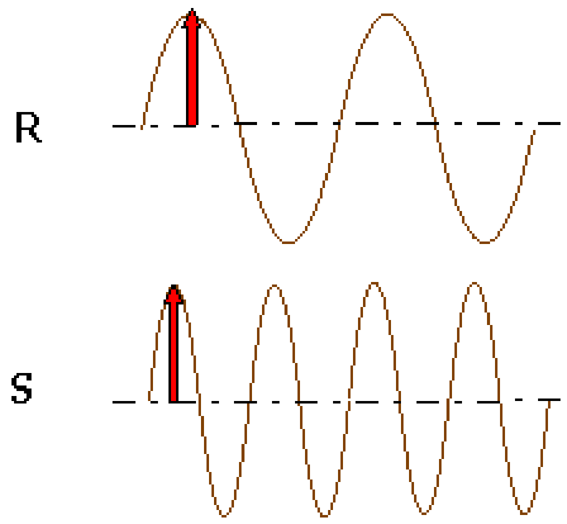
Sound	Decibels
Rustling leaves	**10**
Whisper	**30**
Ambient office noise	**45**
Conversation	**60**
Auto traffic	**80**
Concert	**120**
Jet motor	***140***
Spacecraft launch	***180***

P and Q have the same frequency(just count the wavelengths) but the volume or intensity of Q is twice that of P. (look at the amplitude)



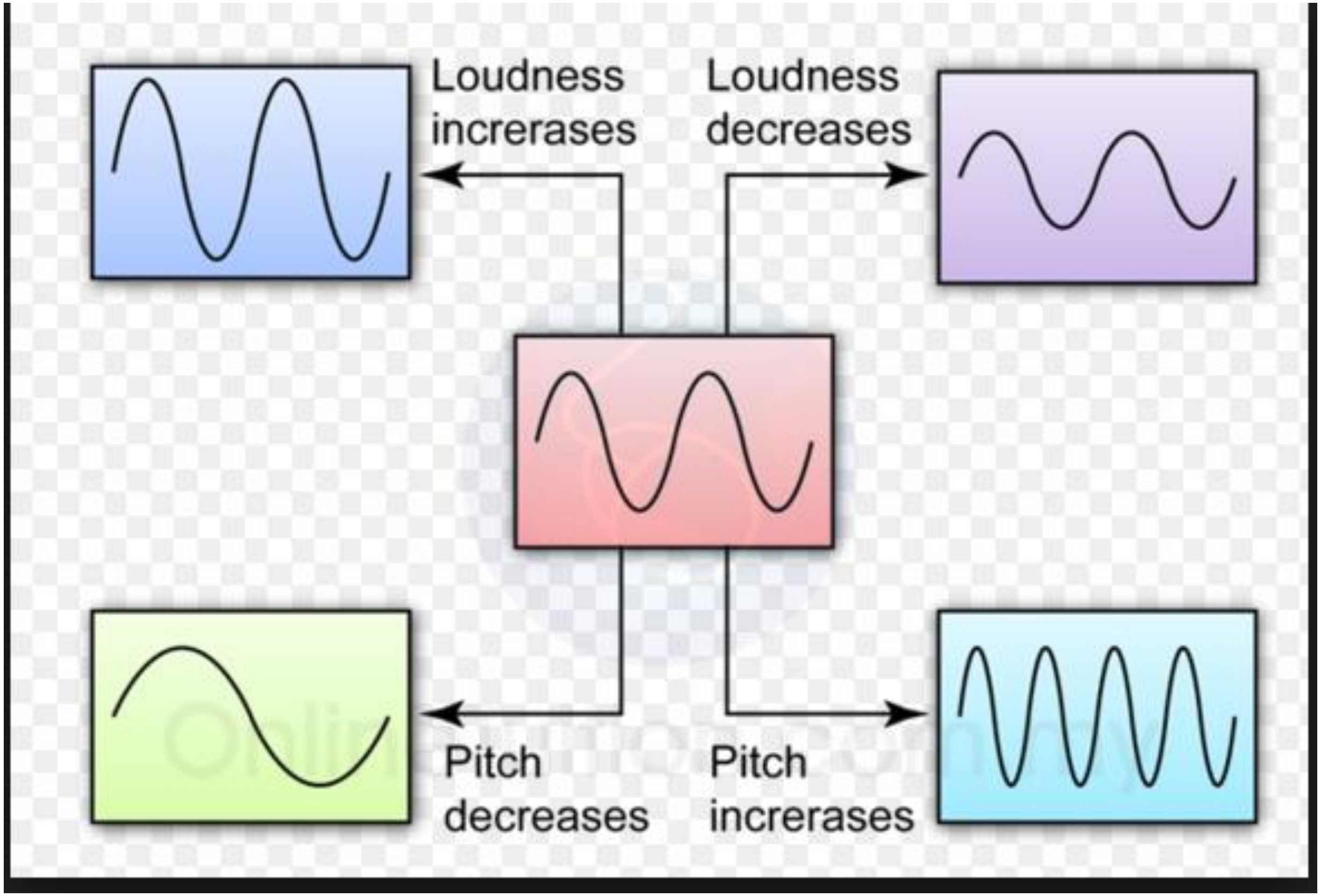
- **This could represent a trumpet playing the same note but Q is much louder**

- Sounds R and S have the same volume or intensity but the frequency if S is twice that of R

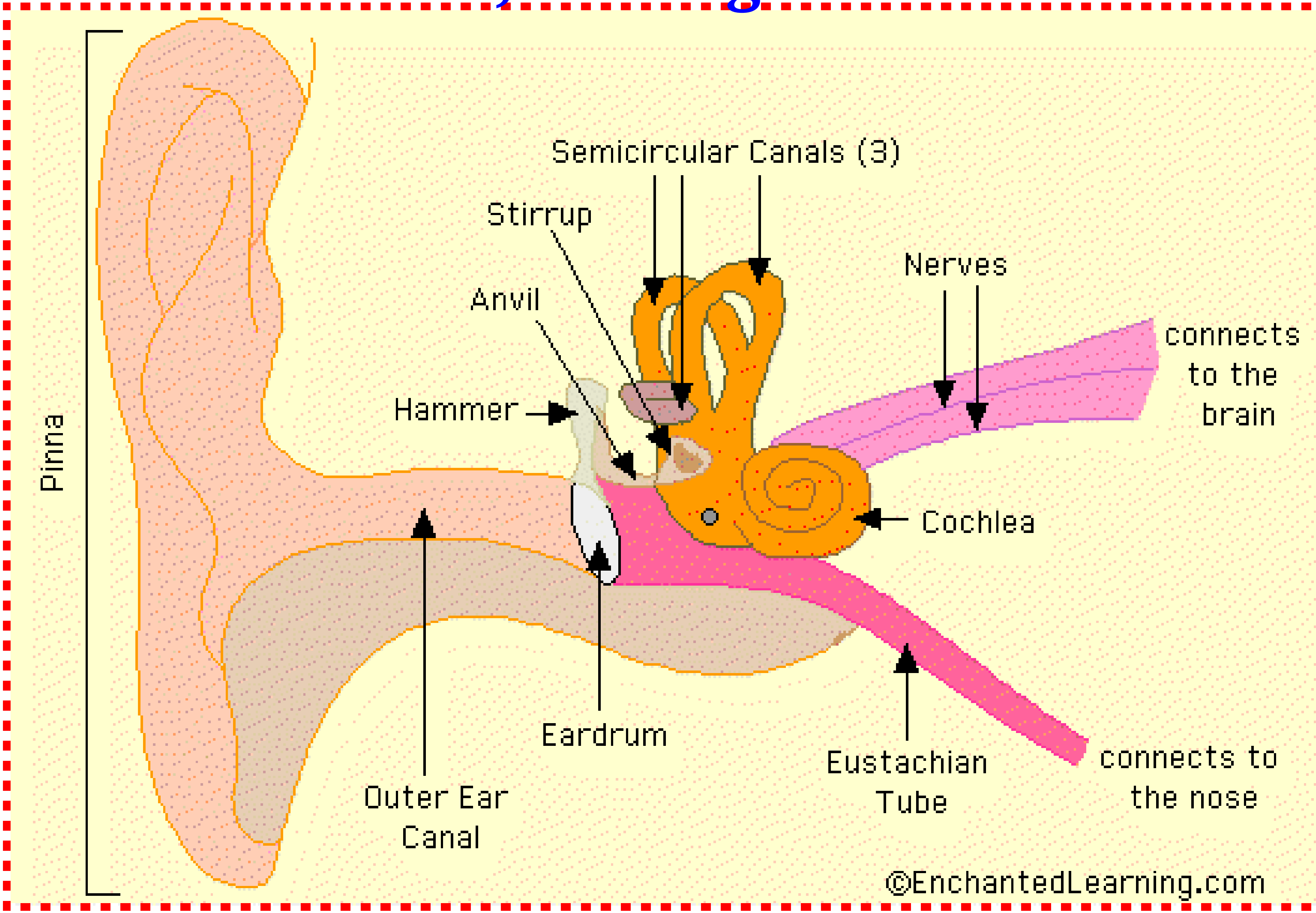


- Sound R could represent a sound from a tuba and sound S could be a sound from a piccolo- they are both being played at the same intensity

Summary of Pitch and Loudness



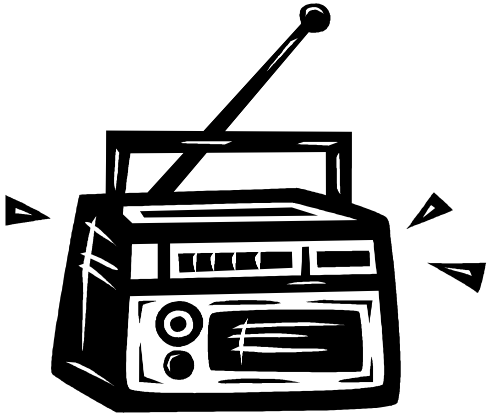
Sound waves, hearing and the ear

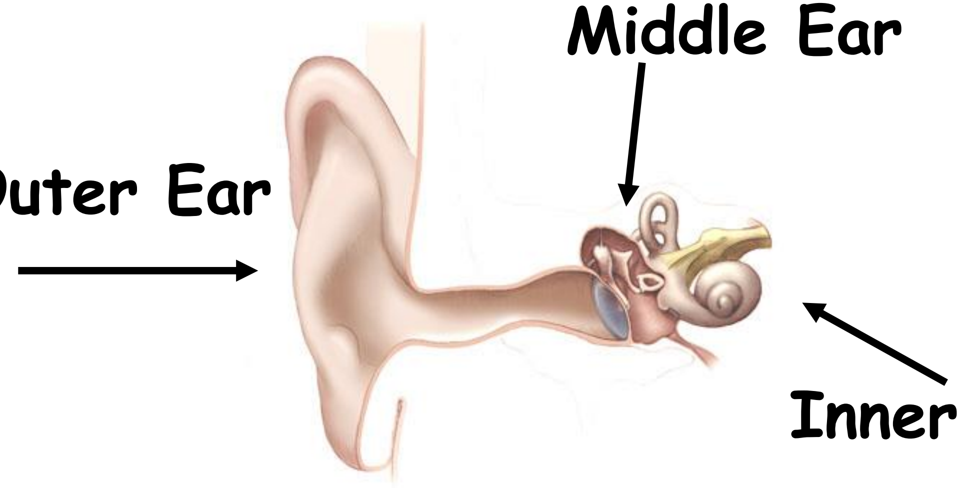


http://www.innerbody.com/anim/ear.html

How does the ear work?

- Sound waves are sent.
- The outer ear "catches the sound waves".
- The middle ear takes the sound waves and "vibrates" the eardrum.
- The inner ear sends the messages to the brain.





- The brain puts it together and hooray! You hear your favorite song on the radio.

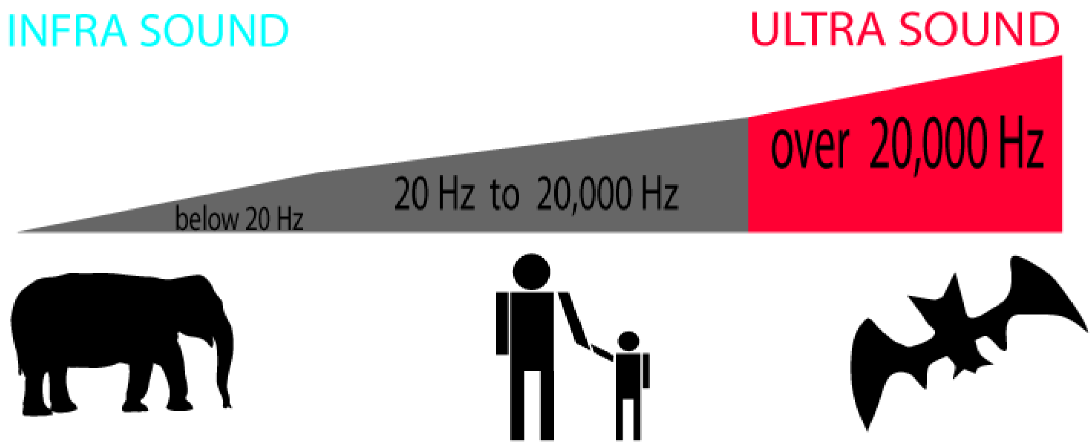
The Audible Range

- The typical frequency range of human hearing is 20 Hz to 20,000 Hz

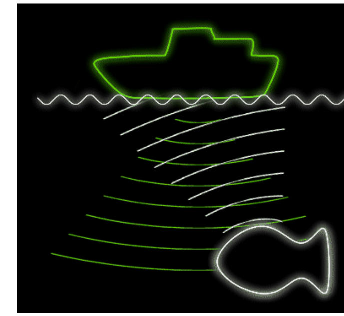
- **Infrasonic frequencies** refers **to** Frequencies lower than 20-25 Hz

- **Ultrasonic frequencies** refers are beyond 20,000 Hz, are called

- Therefere. Humans can not hear **infrasonic** and **ultrasonic frequencies.**

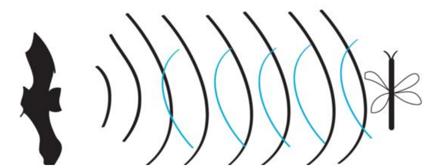


Outside the Audible Range



Sonar stands for SOund NAvigation Ranging. Sonar uses ultrasonic frequencies . To measure water depth, for instance, the transmitter sends out a short pulse of sound, and later, the receiver picks up the reflected sound. The water depth is determined from the time elapsed between the emission of the ultrasonic sound and the reception of its reflection off the sea-floor.

Echolocation is the use of ultrasonic frequencies by certain animals to detect obstacles and food. Some of these animals are bats, porpoises, some kinds of whales, several species of birds, and some shrews.



Ultrasounds refers to ultrasonic frequencies use for imaging fetuses and breaking up kidney stones

Elephants and some whales can communicate over vast distances with infrasonic sound waves too low in pitch for us to hear (**infrasound**).

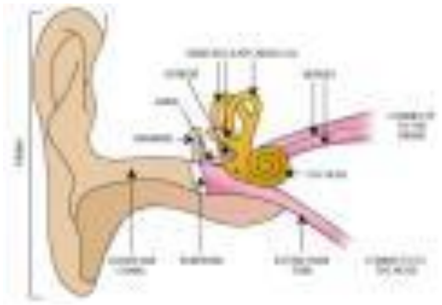
What determines how loud we perceive a sound to be?

- Loudness will depend on the intensity of the sound. However, loudness also depends on the frequency. Frequencies between 1000 Hz and 5000 Hz are perceived to be louder than any other frequencies. This has something to do with the shape of the ear canal leading into our ear drums. The shape of the canal is such that the frequency range 1000 Hz - 5000 Hz is amplified more than any other frequencies.

- For Example, in an orchestra you will perceive the flute to be louder than a tuba. Our ears are more sensitive to the higher frequency sound of the flute than they are to the lower frequency of the tuba (provided, of course, that the frequency of the flute doesn't go beyond 5000 Hz

- **Is it possible to have one sound with a low intensity and another with a high intensity appear to equally loud to us?**

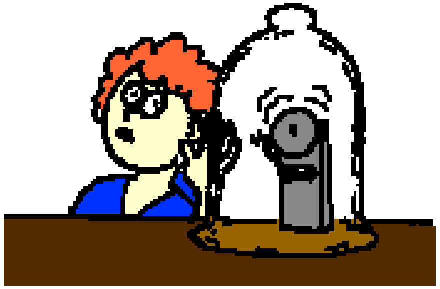
- **Situation 1: The low intensity sound source is closer than the high intensity source and therefore sounds just as loud.**
- **Situation 2: If the sound sources are in exactly the same spot, all that is required is for the low intensity source to be a high frequency source (say, between 1000 Hz and 5000 Hz), and the high intensity source to be a low frequency source. Don't forget, our ears perceive higher frequency sources to be louder.**



Sound Waves and a Medium

- SOUND NEEDS A MEDIUM TO TRAVEL IN. Sound cannot travel through a vacuum.

As with all waves, the speed of sound depends on the medium through which it is traveling. it can be generally said that sound travels fastest in certain solids, less rapidly in many liquids, and quite slowly in most gases.



The sound produced by the bell cannot be heard since sound cannot travel through a vacuum.

Speed of Sound in Some Materials
(normal atmospheric pressure)

air (20^{o} C) 344 m/s	air (0^{o} C) 332 m/s	helium (20^{o} C) 1005 m/s
water (pure) 1440 m/s	water (seawater) 1560 m/s	iron 5000 m/s

- sound travels faster in warm air than in cold air. The molecules of warm air are moving faster (have more kinetic energy), Question: In Star Wars, should you be able to hear the sound?

Sound and Temperature

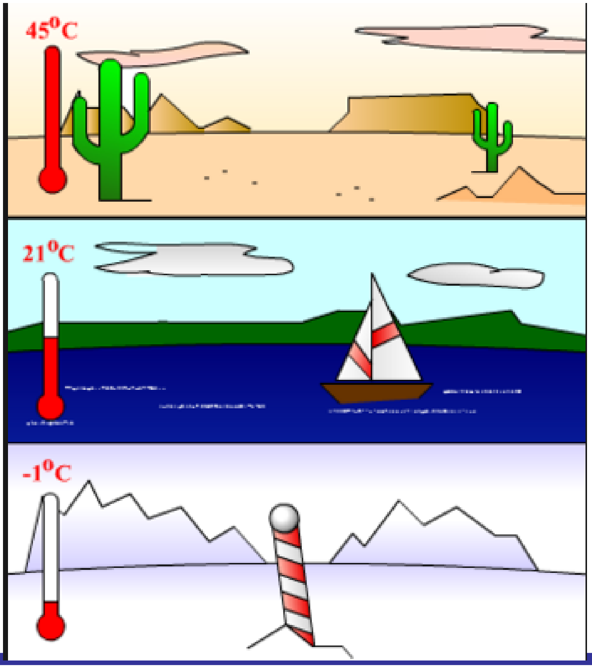
Sound travels faster in warm air than in cold air •

The speed of sound can be determined at ANY temperature, T, by the equation

$$v_{sound} = 332m/s + 0.6(\frac{m/s}{^oC})T$$

V: speed of sound

T : Temperature in degrees Celsius



Example 1:

What would the speed of sound be on a 15 ^{o}C day?

Example 2:

Suppose you measure the speed of sound in air to be 348.8 m/s. What is the temperature of air?

Example 3:

How far away is the thunderstorm if thunder is heard 4.4 s after the lightning is seen? The air temperature is $20^{o}C$

Echoes and Sound

Echoes is a sound or series of sounds caused by the reflection of sound waves from a surface back to the listener.

The formula for speed can be used to make calculations with echoes:

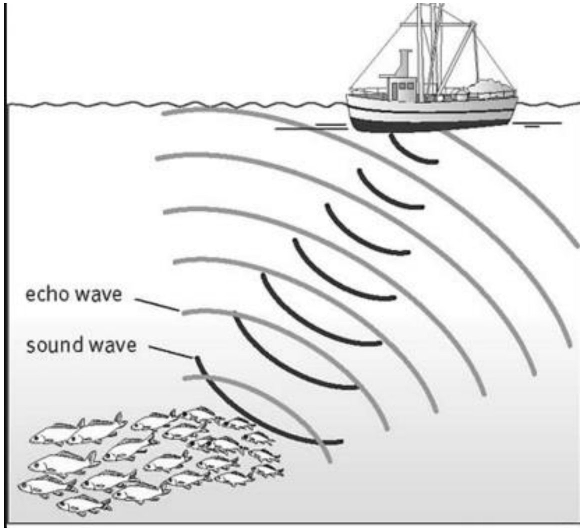
$$v = \frac{d}{t}$$

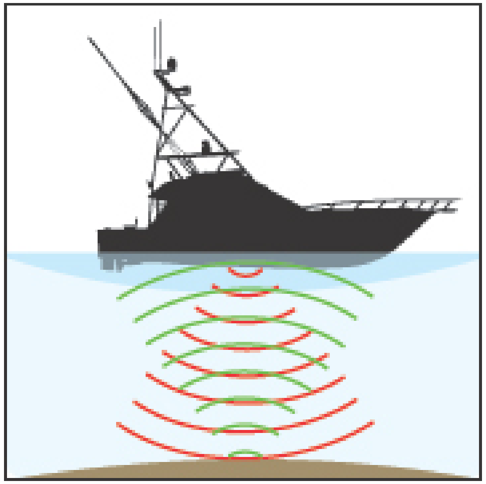
d = the distance the sound wave traveled back and forth,
- v = velocity of sound, and
- t = the time it takes the sound to go back and forth.

Note that the distance was doubled to show the back and forth motion of the sound.)

SONAR

Sound Navigation And Ranging (SONAR) is based on the concept of Echo. The device is attached to the ship at its base. Then the sound wave is originated from the sonar. The sound wave travels to the bed of the sea, and is reflected from the sea bed and is received by the sonar receiver. This distance traveled is equal to the depth of the sea. It is used to see the obstacle also. It consists of a transmitter and a receiver.





Example 4:

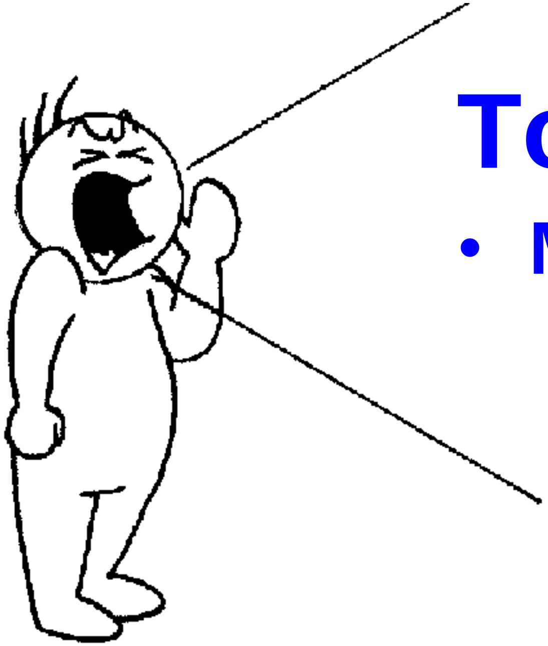
The echo of a ship's foghorn reflected from an iceberg is heard 5.0 seconds after the horn was blown. If the temperature of the air is - 10.0°C, how far away is the iceberg?

Example 5:

How many seconds will it take an echo to reach your ears if you yell toward a mountain 82 m away on a day when the air temperature is $0^{o}C$?

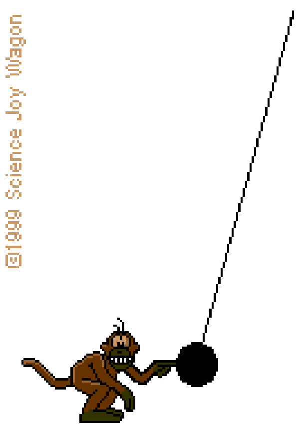
Example 6:

A ship’s horn blasts through the fog. The sound of the echo from an iceberg is heard on the ship 3.8 s later. How far away is the iceberg if the temperature of the air is -12°C?



Topic 5

- **Mechanical Resonance**



Forced Vibrations

Force vibrations occur when we make an object produce a sound.

Ex.

- *Clapping your hands*
- *Hitting a tuning fork*
- *Playing a musical instrument*

Natural Frequency

Natural frequency: The frequency or frequencies at which an object tends to vibrate with when hit, struck, plucked, strummed or somehow disturbed.

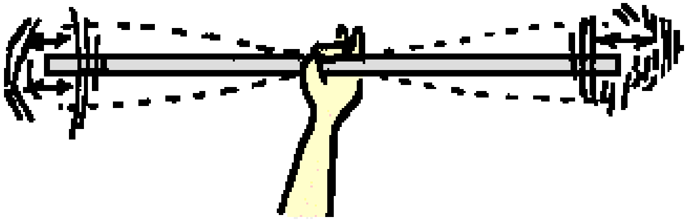
- **The natural frequency of a body depends on its elasticity , shape , & material composition.**

Every object has a natural frequency. It is the frequency with which the object most easily vibrates. It is sometimes called its **resonant frequency**.

Flute	Tuba	Dropped Pencil
200 Hz	200 Hz	197 Hz
	400 Hz	211 Hz
	600 Hz	217 Hz
	800 Hz	219 Hz
	1000 Hz	287 Hz
		311 Hz
		329 Hz
		399 Hz
		407 Hz

Mechanical Resonance

Resonance – when a FORCED vibration matches an object's natural frequency thus producing vibration, and or sound. It occurs when successive impulses are applied to a vibrating object in time with its natural frequency.

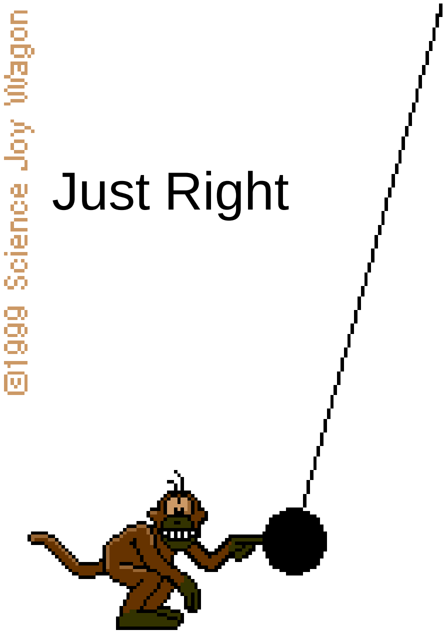


A vibrating metal rod forces the air column inside into vibrations at the same frequency - resonance occurs.

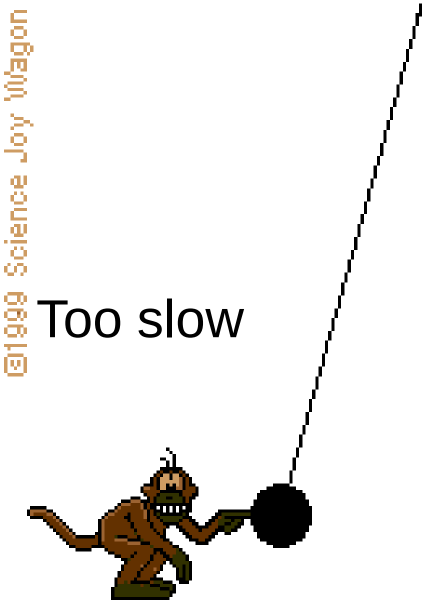
When one object is vibrating and it is put in contact with another object, if the *frequency* of the first object is at the *natural frequency* for the second object, the second object will start vibrating vigorously at its *natural frequency*.

The resulting vibration has a high amplitude and can destroy the body that is vibrating.

Which Monkey best demonstrates resonance?



Just Right



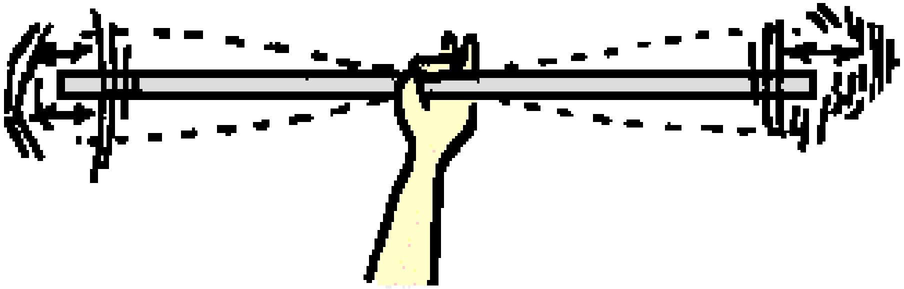
Too slow

Question

Ever wonder why a car sometimes vibrates At a certain speed but not at others?

What is Mechanical Resonance?

Mechanical Resonance : when a FORCED vibration matches an object's natural frequency thus producing vibration, and or sound. It occurs when successive impulses are applied to a vibrating object in time with its natural frequency. The resulting vibration has a high amplitude and can destroy the body that is vibrating



A vibrating metal rod forces the air column inside into vibrations at the same frequency - resonance occurs.

Example 1: Pushing A Swing

The swing has a natural frequency that is determined by its length. If the swing is given a small push at the right time in each cycle, its amplitude gradually increases. This is an example of *resonance.* The swing receives a small amount of energy during each push, but provided this amount is larger than the energy lost during each cycle (due to friction and air drag), the *amplitude* of swing increases.

Example 2: Voice Used to Break A Glass

A wine glass can be broken by a singer finding its resonant frequency

Click the pic to see the MPEG video clip.

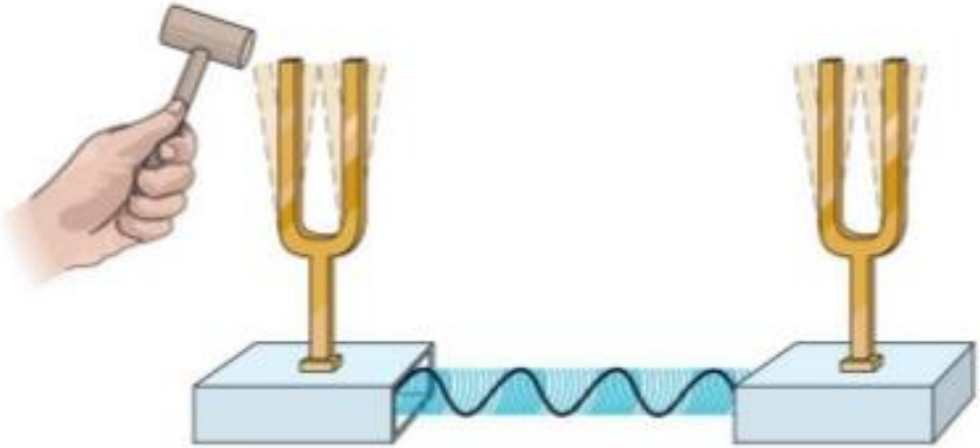
Example 3: Wind Vibrating A Bridge

Even bridges have resonant (natural) frequencies. The Tacoma Narrows bridge in Washington state collapsed due to the complicated effects of wind. One day in 1940 the wind blew at just the right speedfor about an hour. .

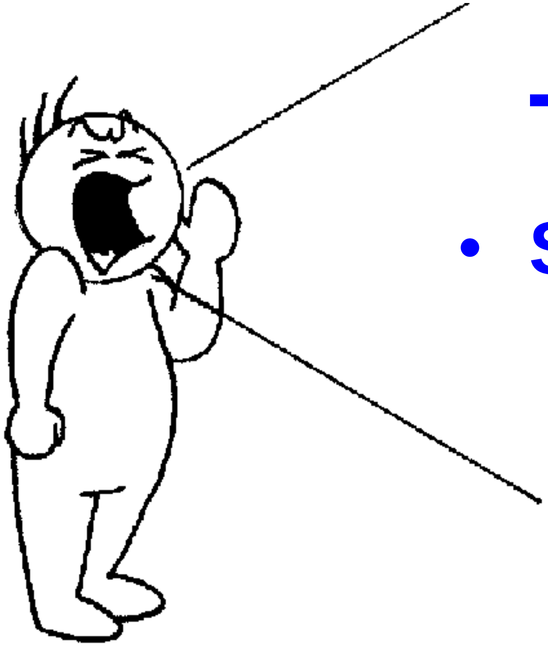
Eventually, the vibrations caused the by wind grew in amplitude until the bridge was destroyed.

Click the pic to see the MPEG video clip.

Example 4: Resonating Tuning Forks

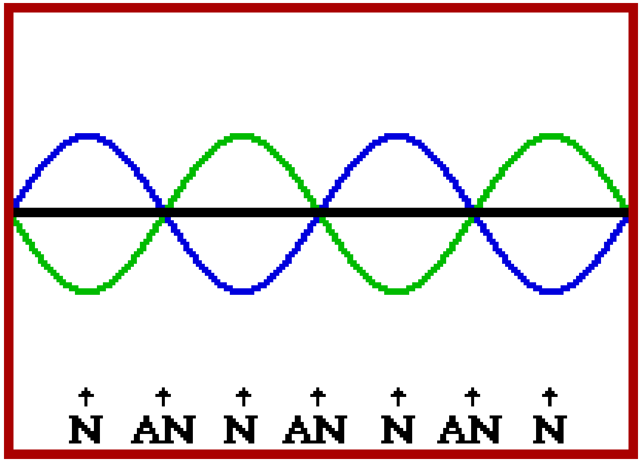


When one tuning fork is struck, the other tuning fork of the same frequency will also vibrate in resonance



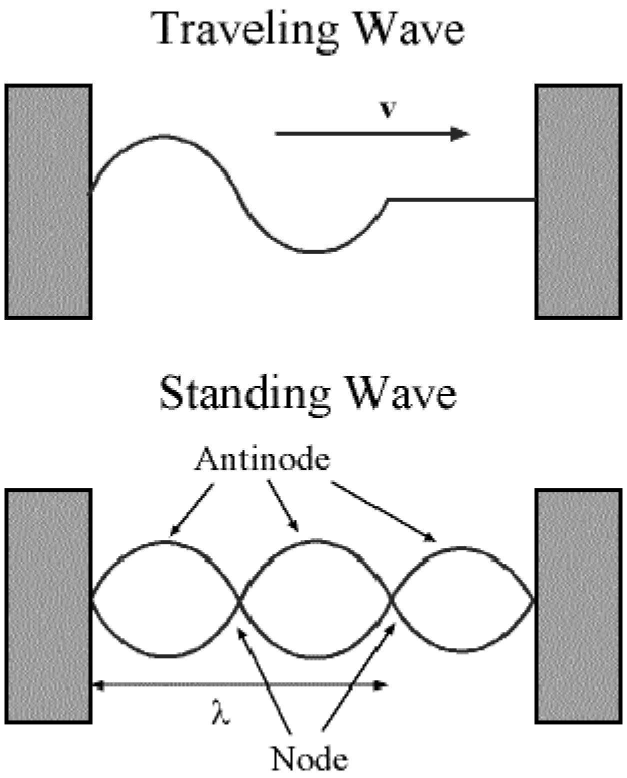
Topic 6

- **Standing Waves**



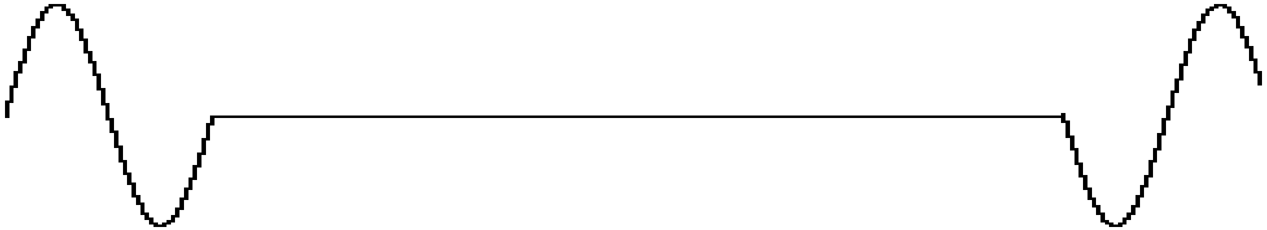
STANDING WAVE

Standing wave : A wave reflects back on itself with the same frequency, wavelength and speed.

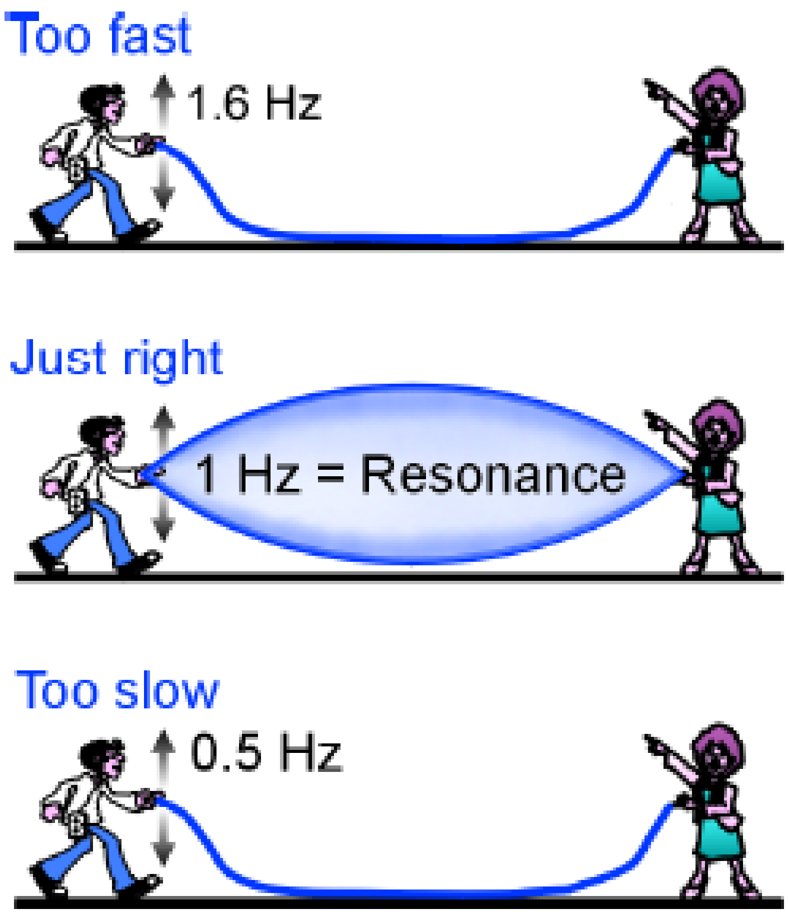


STANDING WAVE

Standing wave is the result of the a wave interfering constructively and destructively with its reflection



- **A standing wave** is confined between boundaries.
- all waves, resonance and natural frequency are dependent on reflections from boundaries of the system containing the wave.



As the waves move through each other, some points never move and some move the most.

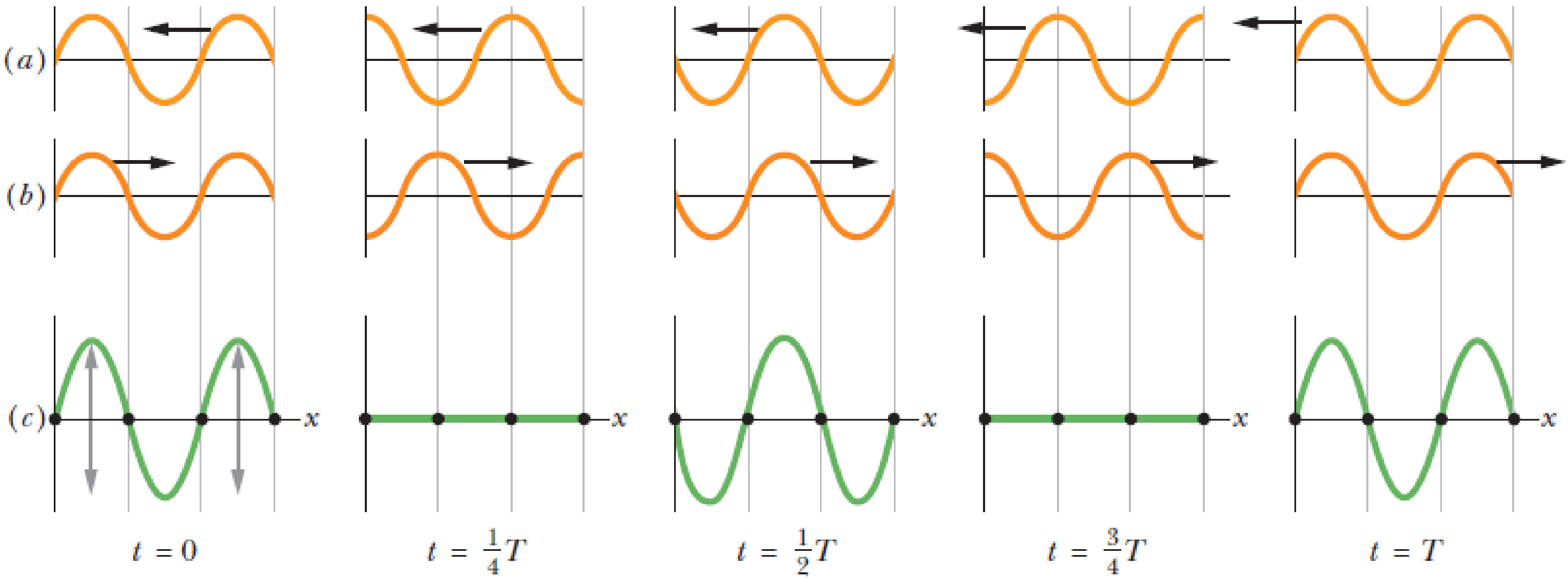
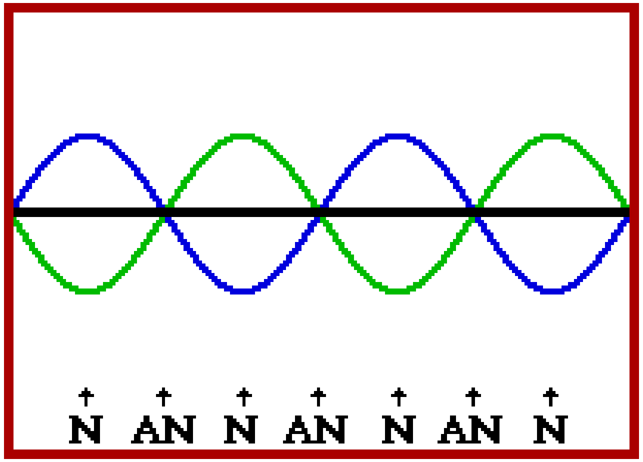


Fig. 16-16 (*a*) Five snapshots of a wave traveling to the left, at the times t indicated below part (*c*) (T is the period of oscillation). (*b*) Five snapshots of a wave identical to that in (*a*) but traveling to the right, at the same times t. (*c*) Corresponding snapshots for the superposition of the two waves on the same string. At $t = 0, \frac{1}{2}T$, and T, fully constructive interference occurs because of the alignment of peaks with peaks and valleys with valleys. At $t = \frac{1}{4}T$ and $\frac{3}{4}T$, fully destructive interference occurs because of the alignment of peaks with valleys. Some points (the nodes, marked with dots) never oscillate; some points (the antinodes) oscillate the most.

Picture below shows two waves moving through a medium in opposite directions. The blue wave is moving to the right and the green wave is moving to the left.   At any given time they are added together in accordance with the principle of superposition.



Nodes are points on the standing wave that remain stationary at all times. It is a place of destructive interference .

Antinodes are points on the standing wave that have the greatest negative and positive displacement. It is a place of constructive interference.

Standing Waves in a String

- Consider a string **fixed at both ends**

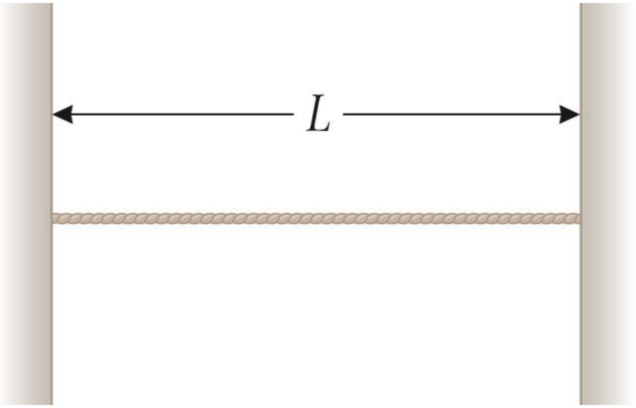
The string has length *L*.

Waves can travel both ways on the string.

Standing waves are set up by a continuous superposition of waves incident on and reflected from the ends.

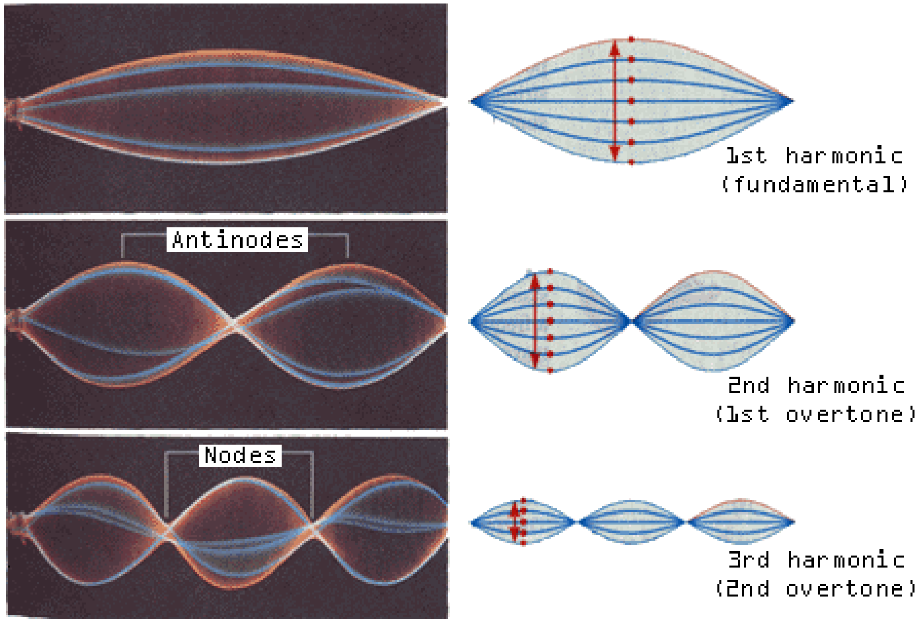
At certain natural or resonance frequencies, standing waves can be produced in which the wave appears to be standing still rather than travelling.

The ends of the strings must necessarily be nodes.



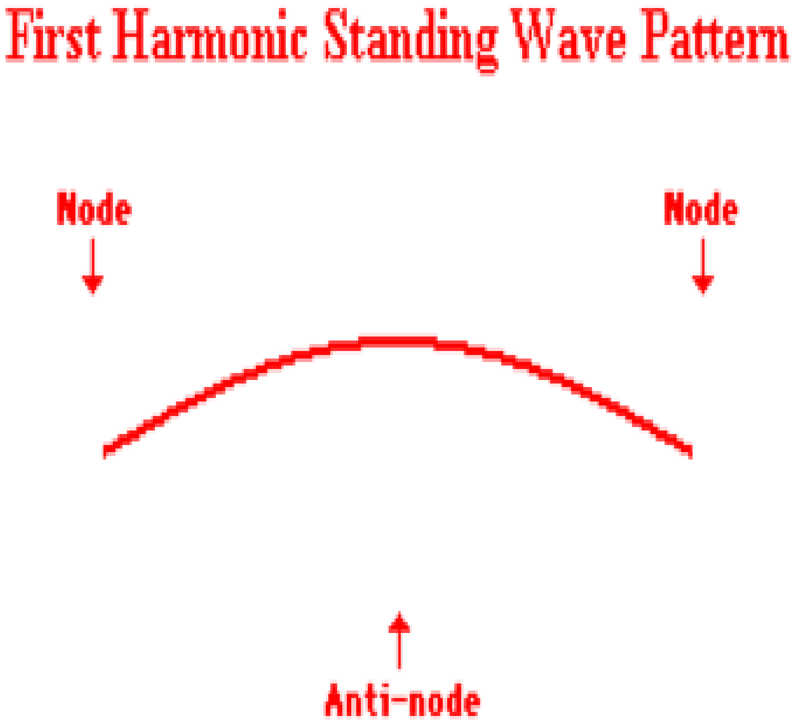
STRING HARMONIC

In a standing wave a variety of actual wave patterns could be produced, with each pattern characterized by a distinctly different number of nodes. Such standing wave patterns can only be produced within the medium when it is vibrated at certain frequencies. Each frequency is associated with a different standing wave pattern. These frequencies and their associated wave patterns are referred to as **harmonics.**



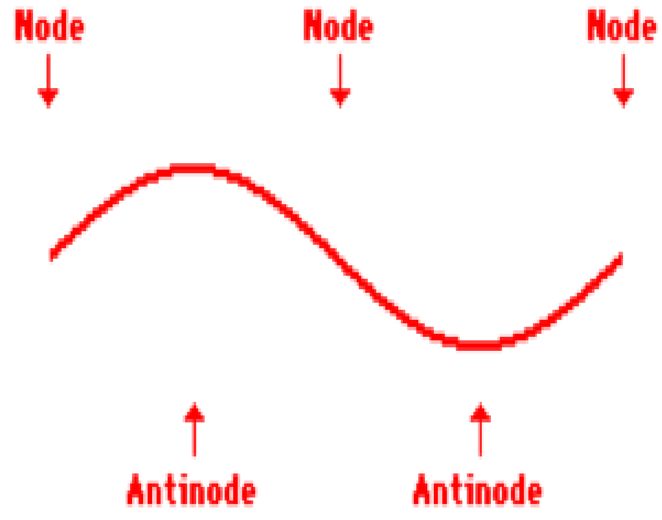
We will look into this in more detail.

1. 1st harmonic
2. 2nd harmonic
3. 3rd harmonic
4. 4th harmonic
5. 5th harmonic
6. 6th harmonic



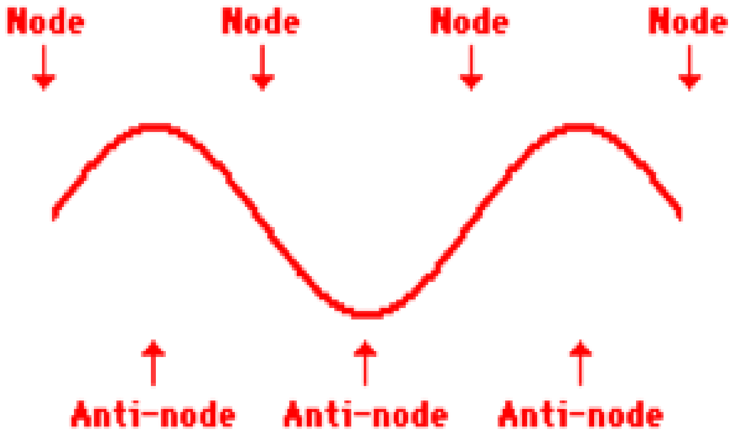
This standing wave pattern is known as the first harmonic. It is the simplest wave pattern and is obtained when introducing vibrations into the end of the medium at low frequencies. Also called the **fundamental frequency** (fo)

Second Harmonic Standing Wave Pattern



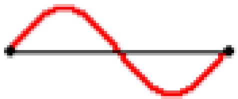
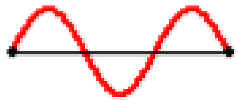
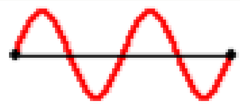
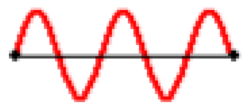
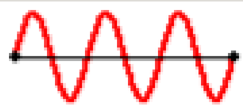
This pattern with three nodes and two antinodes is referred to as the second harmonic

Third Harmonic Standing Wave Pattern



This pattern with four nodes and three antinodes is referred to as the third harmonic

Observe that each consecutive harmonic is characterized by having one additional node and anti-node compared to the previous one. The table below summarizes the features of the standing wave patterns for the first several harmonics.

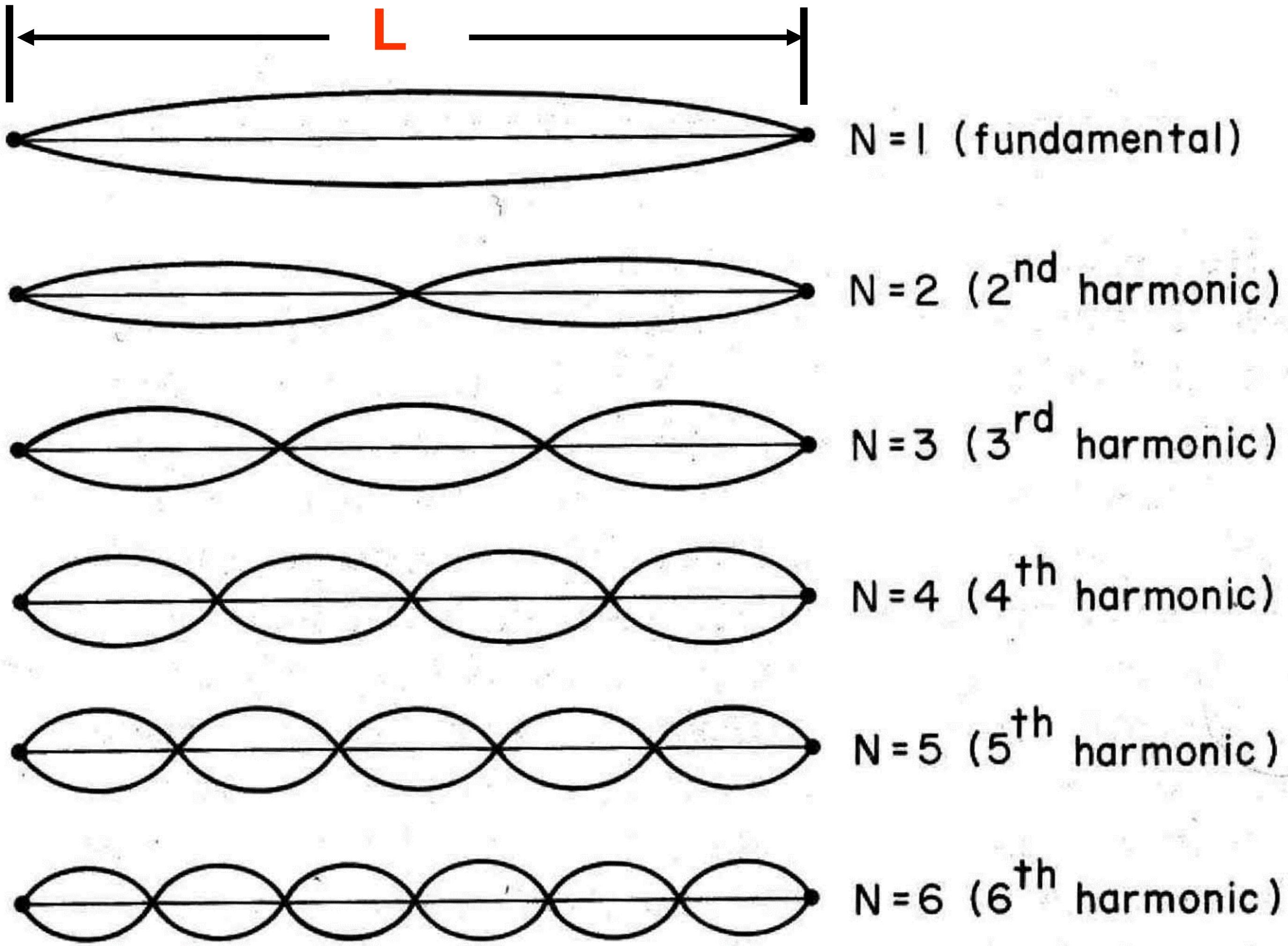
Harmonic	# of Nodes	# of Antinodes	Pattern
1st	2	1	
2nd	3	2	
3rd	4	3	
4th	5	4	
5th	6	5	
6th	7	6	
nth	n + 1	n	--

Fundemental

1st over tone

2nd'overtone

Summary of String Harmonics



frequency

$$f_n = nf_1$$

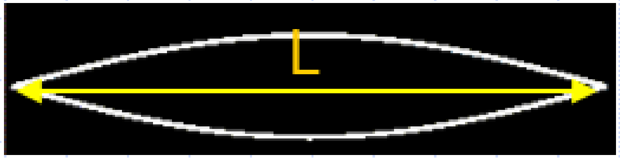
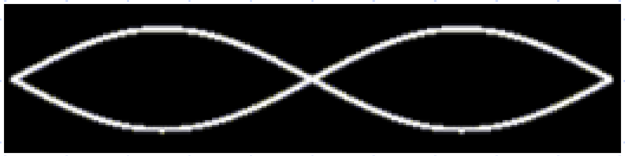
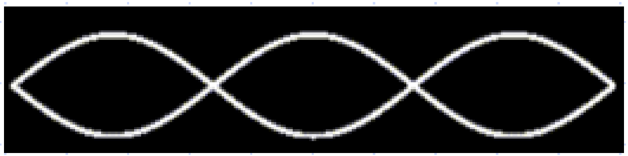
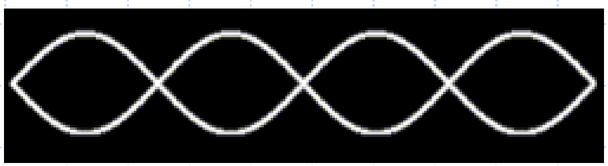
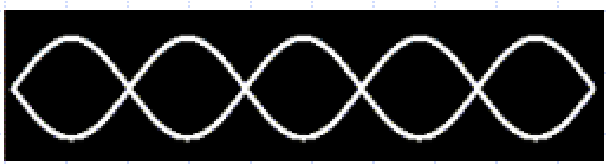
$2f_1$

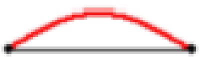
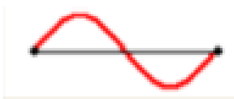
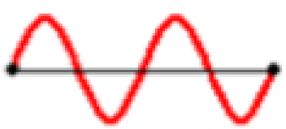
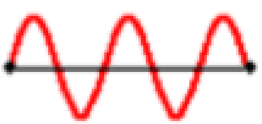
$3f_1$

$4f_1$

$5f_1$

$6f_1$

Picture of Standing Wave	Name	Structure
 $L = \frac{1}{2}\lambda_1$	1st Harmonic or Fundamental	1 Antinode 2 Nodes
 $L = \lambda_2$	2nd Harmonic or 1st Overtone	2 Antinodes 3 Nodes
 $L = 1\frac{1}{2}\lambda_3$	3rd Harmonic or 2nd Overtone	3 Antinodes 4 Nodes
 $L = 2\lambda_4$	4th Harmonic or 3rd Overtone	4 Antinodes 5 Nodes
 $L = 2\frac{1}{2}\lambda_5$	5th Harmonic or 4th Overtone	5 Antinodes 6 Nodes

	#Anitnode	#Nodes	Wavelength	Frequency	Harmonic	Overtone
	1	2	$\frac{1}{2}\lambda$	F_o	1	fund
	2	3	λ	$2F_0$	2	1
	3	4	$1\frac{1}{2}\lambda$	$3F_0$	3	2
	4	5	2λ	$4F_0$	4	3
	5	6	$2\frac{1}{2\lambda}$	$5F_0$	5	4
----	n	n+1	$\frac{n}{2}\lambda$	nF_0	n	n-1

Standing Waves:

- http://www.brightstorm.com/science/physics/vibration-and-waves/standing-waves/

Example1

Complete the chart below for a 60 cm string with a fundamental frequency of 100 Hz

Picture	#Anitnode	#Nodes	Wavelength	Frequency	Harmonic	Overtone
					4	
					6	

Example 2

A string is vibrating in the 3rd harmonic at a frequency of 360 Hz and with a wavelength of 48 cm. What are the wave-length and frequency of the second harmonic, and the speed of each wave?

Given:

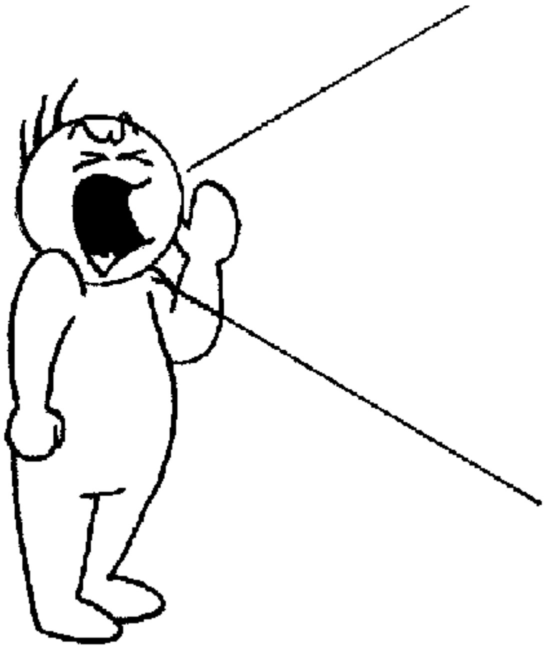
The speed depends only on the medium—not on a particular harmonic.

Example 3

A standing wave in a rope has a frequency of 28 Hz at the second harmonic.

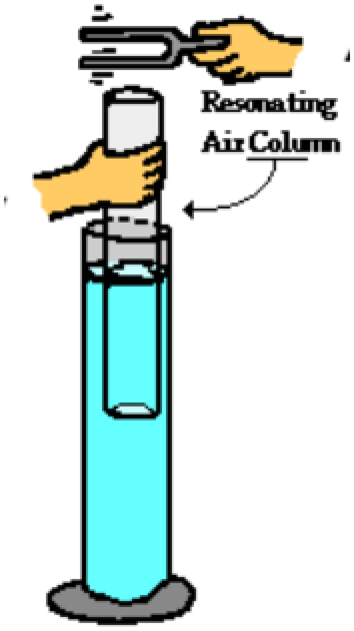
a. If the wavelength is 0.20 m, what is the distance between nodes?

b. What is the speed of the waves that make up the standing wave?



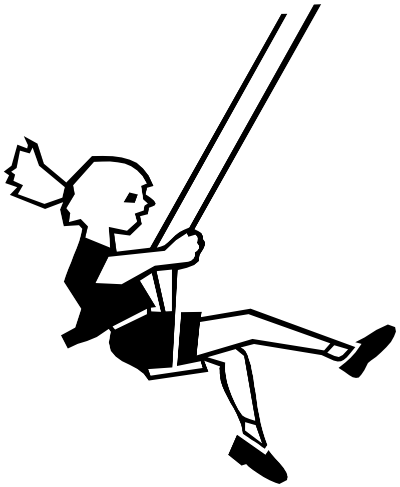
Topic 7

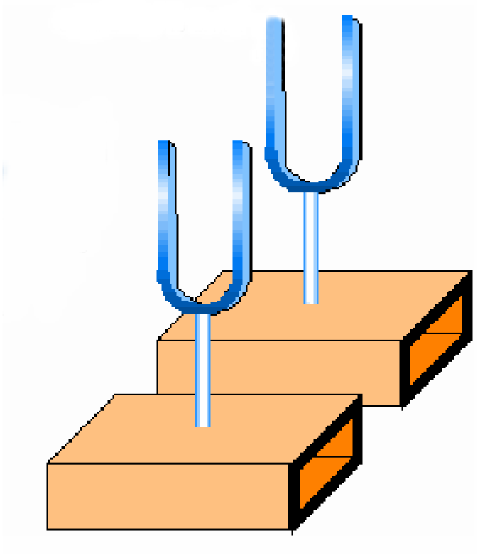
- **Resonance of Sound**



Remembering Resonance of Sound

RESONANCE - the phenomenon when the vibration frequency of object A matches the natural vibration frequency of object B, and object B is caused to vibrate.

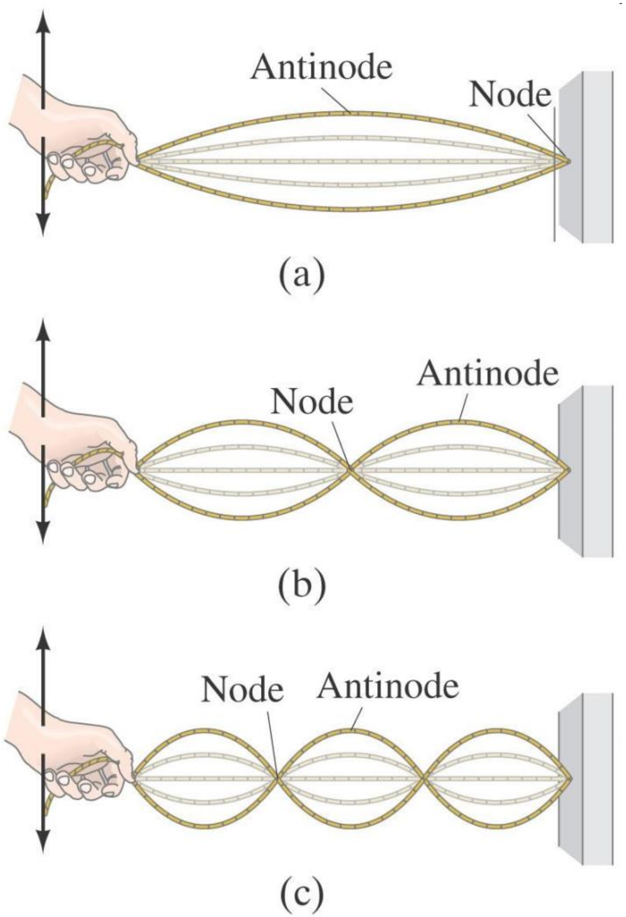




Standing Wave Patterns and Resonance of Sound Waves

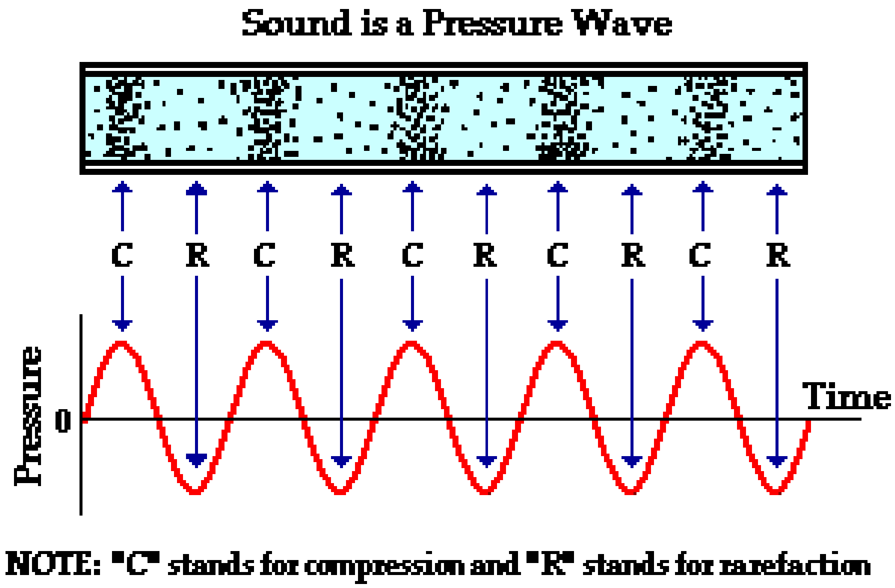
Waves in a string can interfere to produce standing wave patterns. We have given these patterns special Harmonic names and studied them in detail.

-
- When producing standing waves on a rope we could physically change the frequency while the speeds and wavelengths were governed by the frequency and length of the string.



Representing Sound Waves

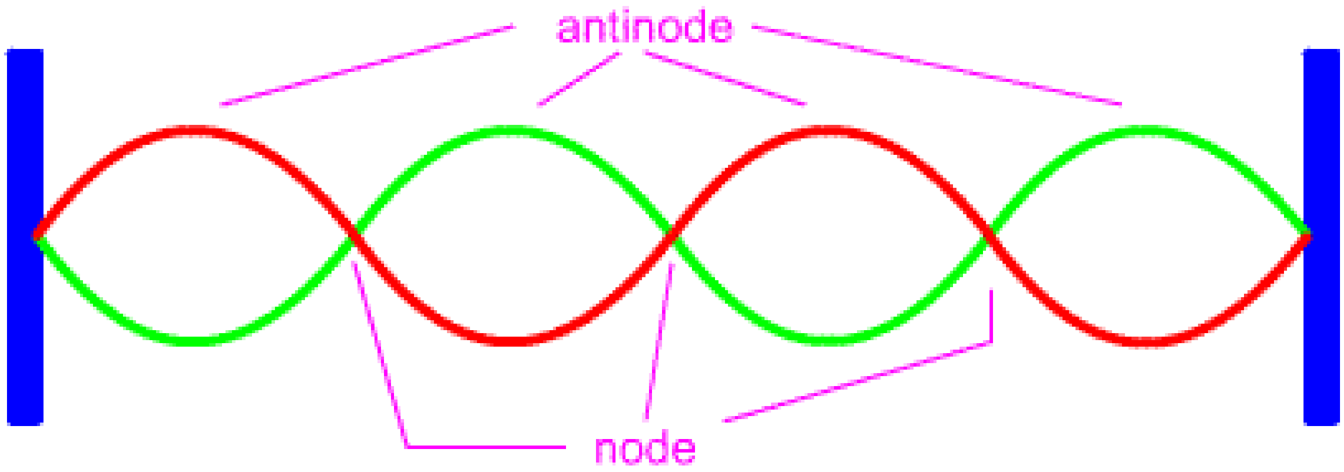
Sound waves are longitudinal and therefore difficult to draw. But that's not a problem - **we can represent the longitudinal sound wave by a transverse pressure wave caused by the sound.**



Standing Waves

- When we have a wave going one way in a rope or spring, it gets interfered with by the reflected wave as it came back from a fixed end to produce a standing wave.

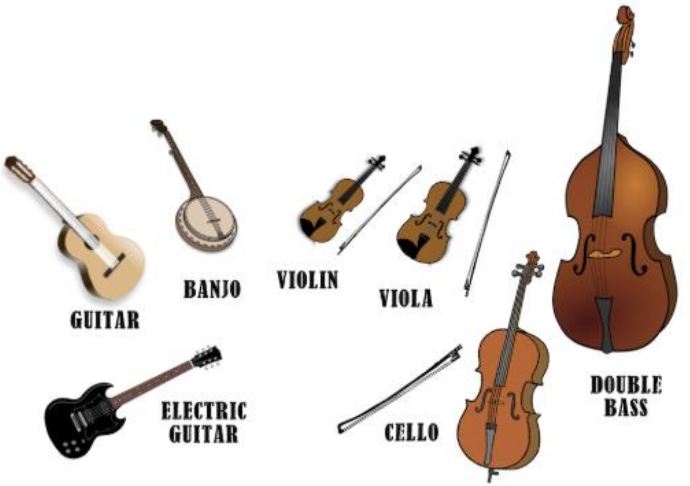
- This resulted in constructive and destructive interference which further resulted in the formation of antinodes (loops) and nodes (zero displacement) in the wave - a standing wave was produced.



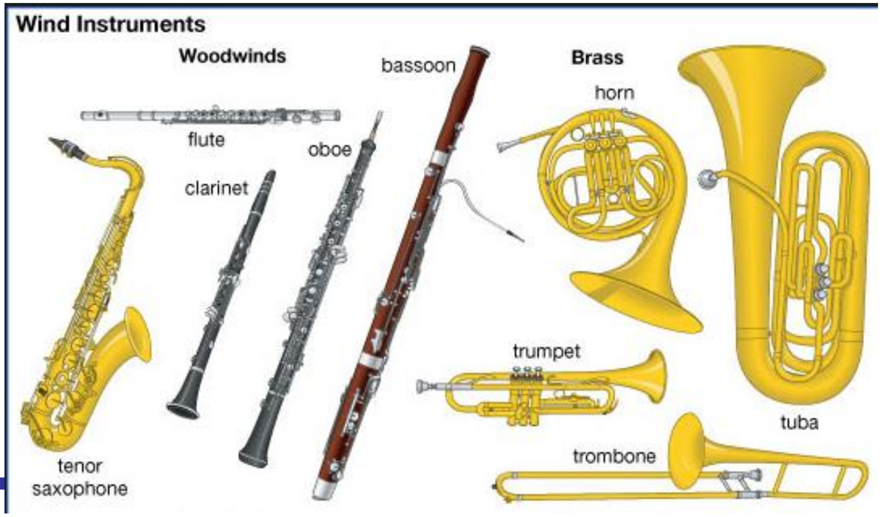
How Musical Sound Is Created?

Musical instruments have two different methods for making sound:

1) Using Vibrating Strings



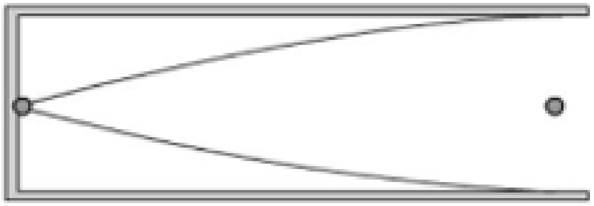
2) Vibrating Air Columns



What Is An Air Column?

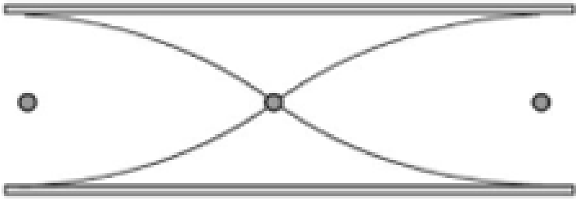
Air Column" refers to air contained inside a tube or pipe. Air columns can be divided into two categories, open ended or closed ended.

Closed air column occurs in a pipe that is closed in one end. Example Clarinet



Closed column

Open air column occurs in a pipe that is opened on both ends. Example: Flute



Open column

Standing Waves In Air Columns

- Just like the standing "transverse" waves produced on a string, standing waves can also be produced by sound in air columns.

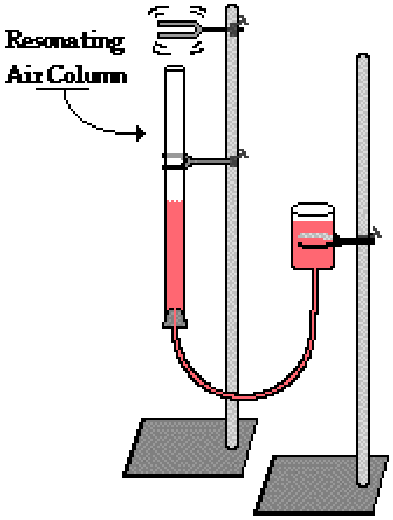
- In air columns we cannot really control the speed since we are dealing with sound and the frequency of our source is usually constant as well so our only hope of producing standing wave is to change the length of the column!

.

Demonstration-
Resonance Of Sound In An Air Column

- Picture a long pipe filled with water which can be drained through a tube in the bottom. Hold a vibrating tuning fork over the mouth of the pipe while at the same time allowing the water to drain from the pipe. At certain points as the water falls, the hum of the tuning fork becomes much louder.

What can be happening?

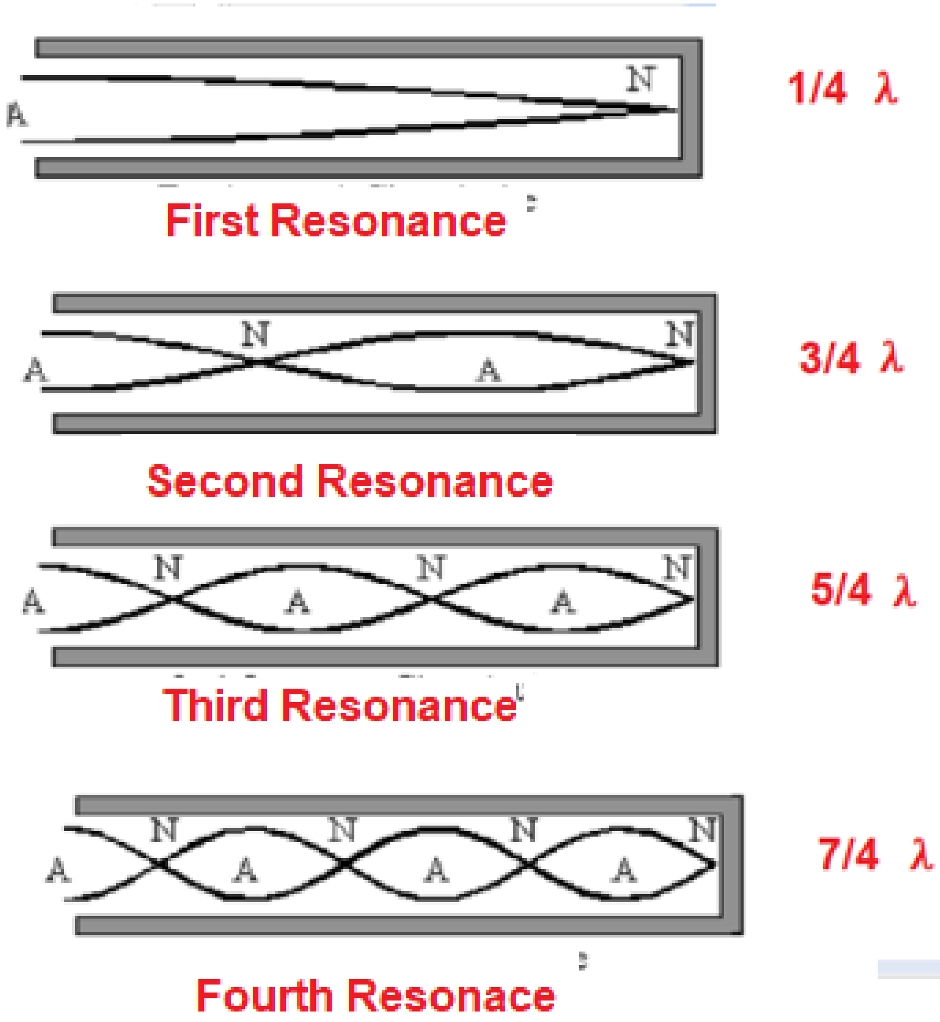


Tuning fork forcing air coumn into resonance

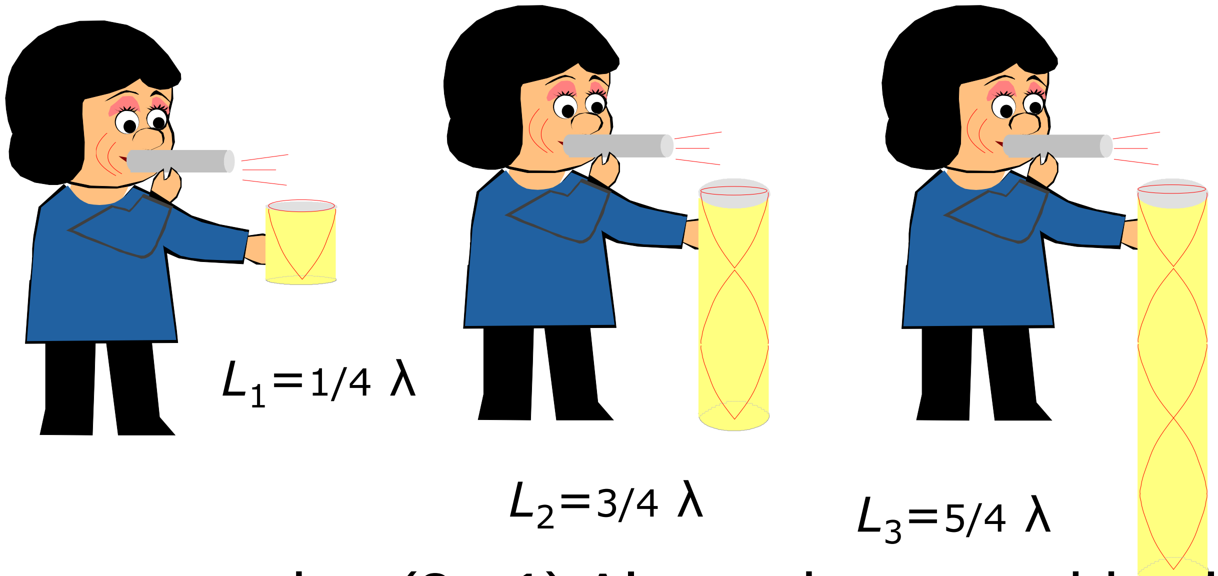
Resonance - Air Column Closed At One End

There is an node at the closed end because the particles are not free to move. An antinode occurs at the open end because the particles are free to move

The fundamental frequency is only a quarter of a wavelength



Mathematical Relationship For Closed at One End Air Column



Note that the expression (2n-1) Always has an odd value for tubes closed at one end.

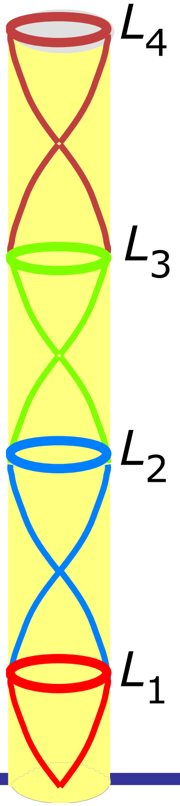
We can use two formula's to determine the length and wavelength for each resonant frequency in a column open at one end:

$$L_n = \frac{2n-1}{4}\lambda \quad \textbf{Or} \quad \lambda = \frac{4L_n}{2n-1}$$

n represents the resonance number

Example 1:

On a nice summer day when the temperature is 23° C, you purse your lips and whistle across the top of an empty pop bottle that is 29 cm tall. What must be the frequency of your whistle to make the air in the bottle vibrate in the fourth resonant length?



Example 2:

You decide to impress Grandpa but showing him how fast sound travels. You have a piece of plastic pipe with an adjustable closed end, and a 312 Hz tuning fork. The piece of pipe resonates in the 2nd resonant length when it is adjusted to a length of 81.0 cm. What is the speed of sound on that day?

$$\lambda = \frac{4L_2}{2n-1}$$

$$= \frac{4 \text{ x } 0.810 \text{ m}}{2\text{x}2 - 1}$$

$$= \frac{3.24 \text{ m}}{3} = 1.08 \text{ m}$$

$$v = f\lambda = 312 \text{ Hz } x \text{ } 1.08 \text{ m}$$

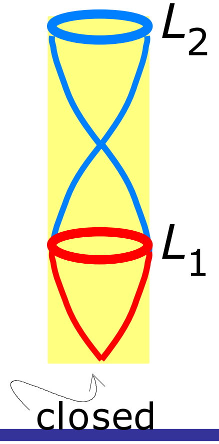
$$= 312 \text{ /s } x \text{ } 1.08 \text{ m} = 337 \text{ m/s}$$

Example 3:

Tell Grandpa you are going to use the piece of plastic pipe in example 2 to measure the air temperature.

Example 4:

On a day when the speed of sound is 345 m/s, a 440 Hz tuning fork causes a tube closed at one end to vibrate in the second resonant length. How long is the tube?

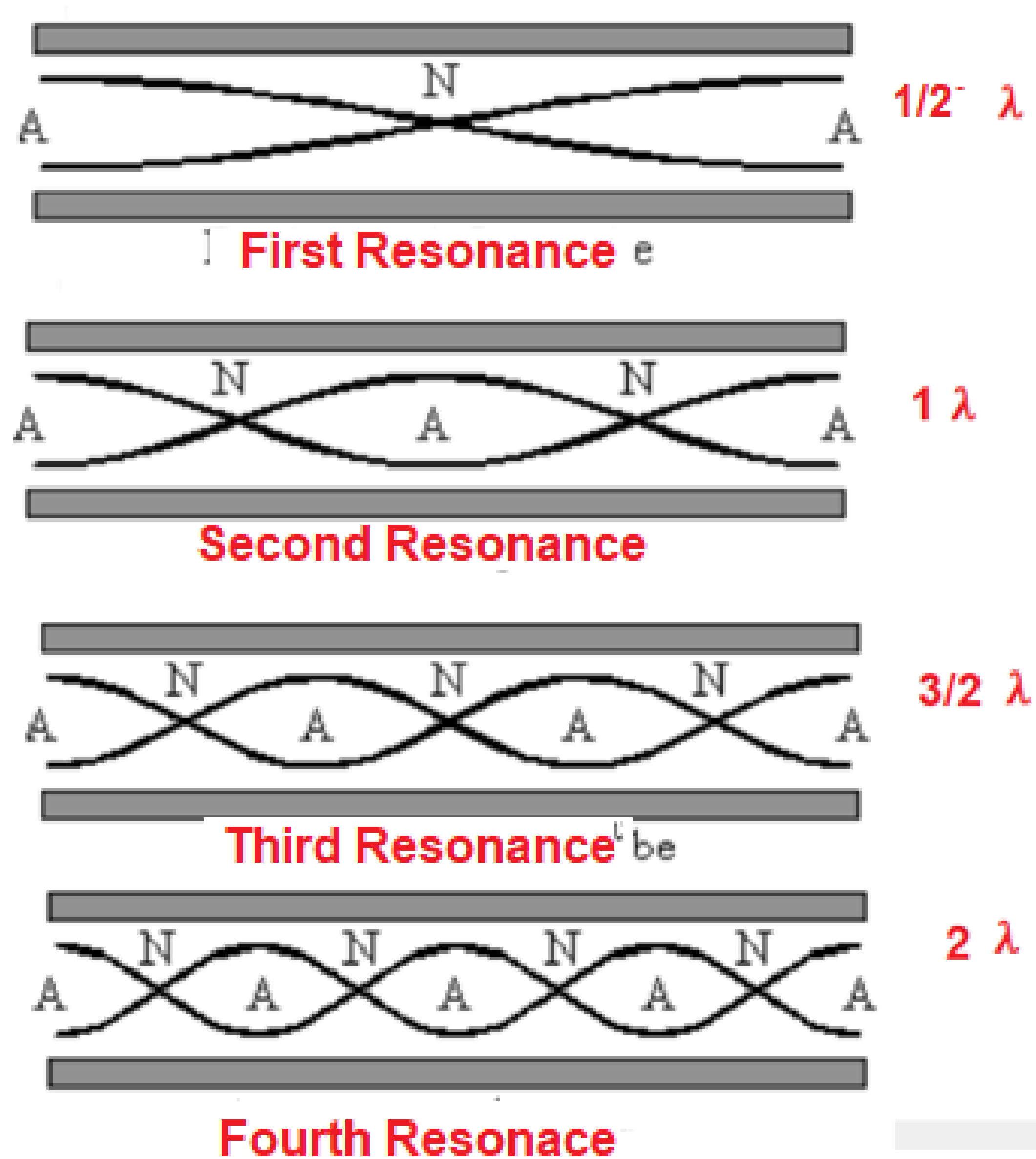


Resonance - Air Column Open At Both Ends

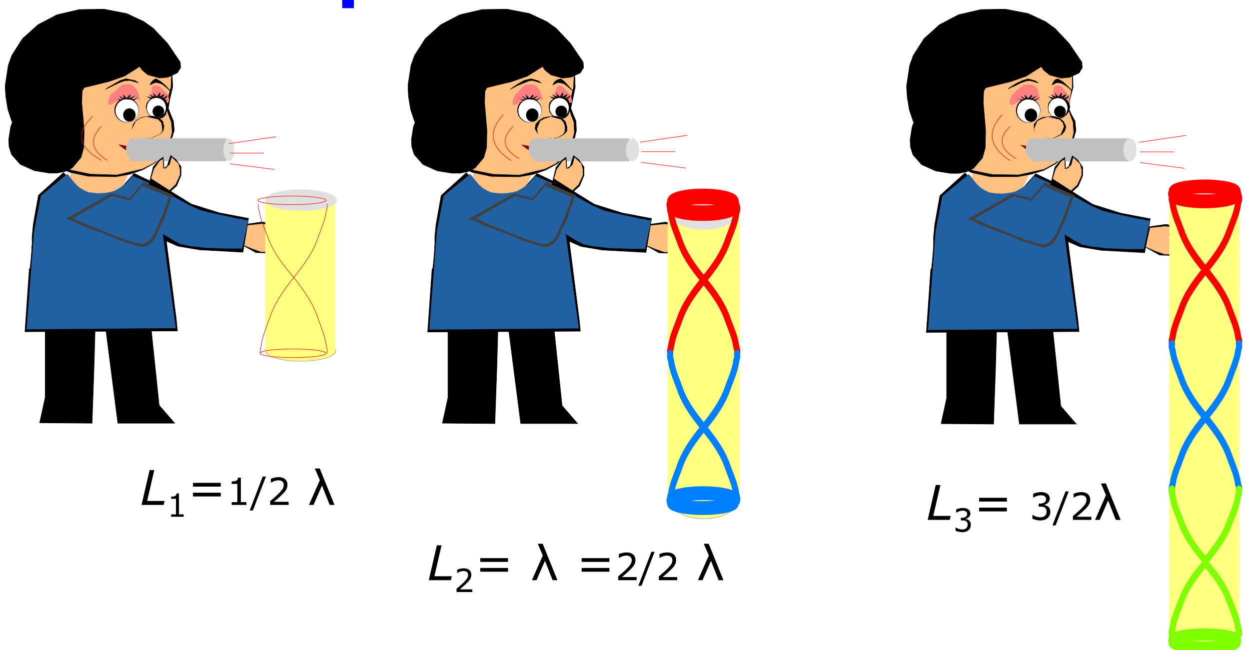
Similar pattern of harmonics as strings.

Each successive harmonic is one half a wavelength greater

The standing wave in an open column is similar tc one in strings. The only difference is that standing waves in open columns have antinodes at the ends instead of node because particles are not fixed.



Mathematical Relationship For Open At Both Ends Air Column



Note that can be any positive whole number for a column open at both ends

We can use two formula's to determine the length and wavelength for each resonant frequency in a column open at both ends:

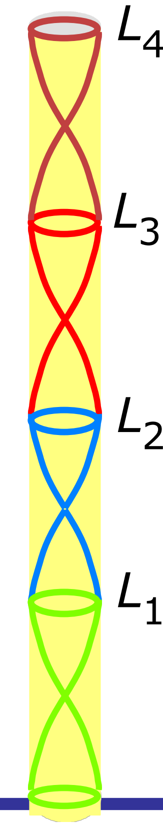
$$L_n = \frac{n}{2}\lambda \quad \textbf{Or} \quad \lambda = \frac{2}{n}L_n$$

n represents the resonance number

Example 5:

On a nice summer day when the temperature is 23^{o} C, you purse your lips and whistle across the top of an empty pop bottle that is 29 cm tall and has NO BOTTOM. What must be the frequency of your whistle to make the air in the bottle vibrate in the fourth resonant length?

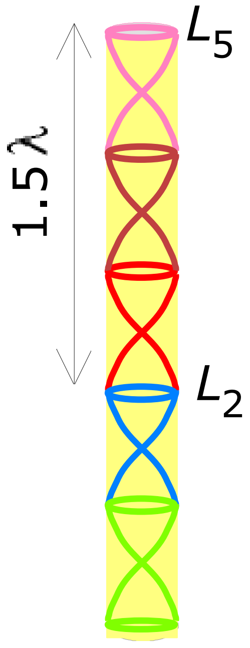
Draw a picture:

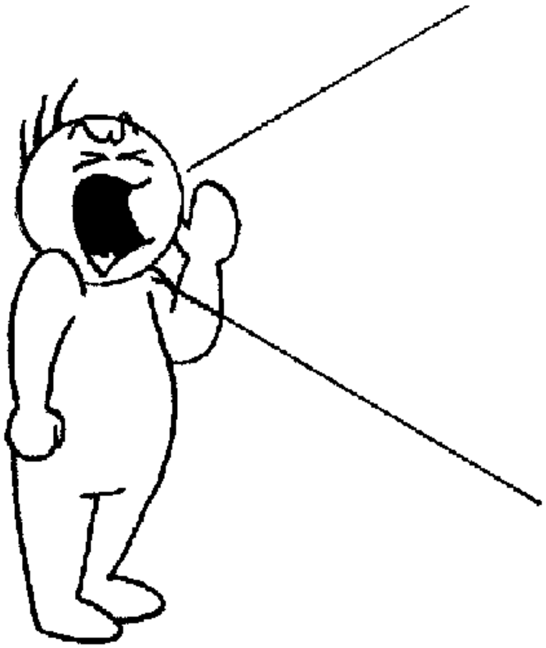


Example 6:

When a 512 Hz tuning fork is sounded near one end of a tube **opened at both** ends, the difference between the 2nd and 5th resonant lengths is found to be 99 cm. What is the temperature of the air in the tube?

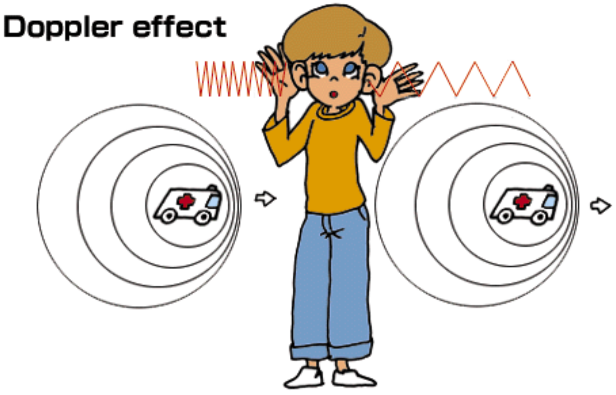
Picture?





Topic 8

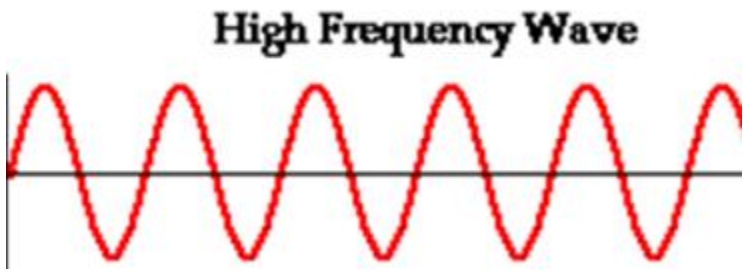
- **The Doppler Effect and Sound**

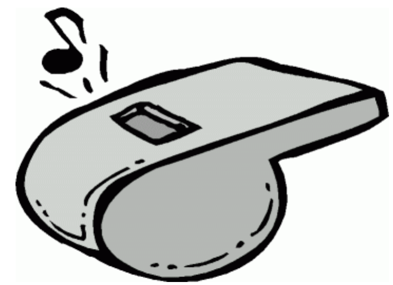


PITCH

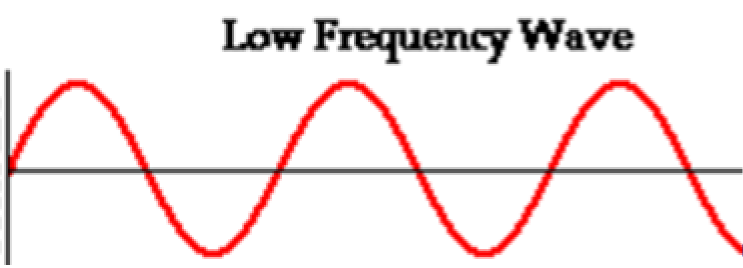
The **pitch** of a sound is how we perceive its **frequency.**
Pitch=frequency

A high pitched sound such as that of a whistle has a relatively high frequency – it sounds “squeaky”.



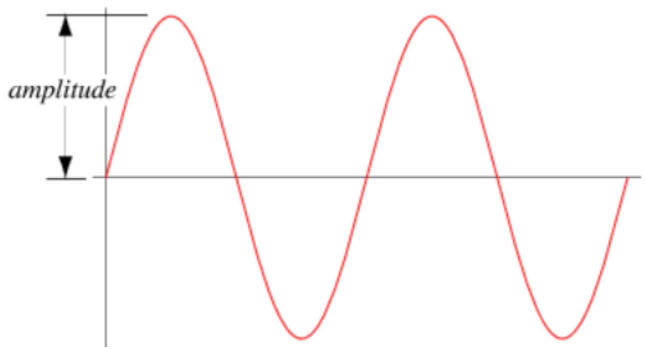


A low pitched sound such as a booming note from a bass guitar has a relatively low frequency – it sc[illegible]



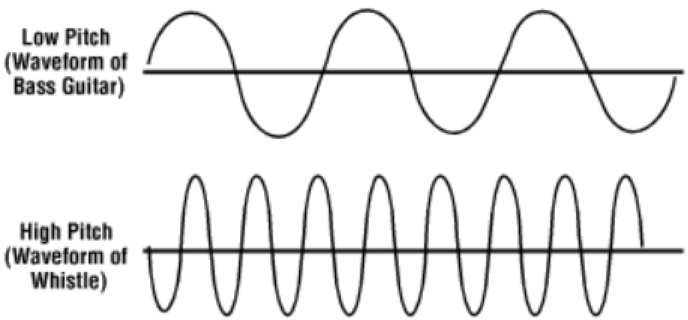
INTENSITY

Intensity is a measure of the **amplitude** of the wave and is the most important factor affecting **loudness**.

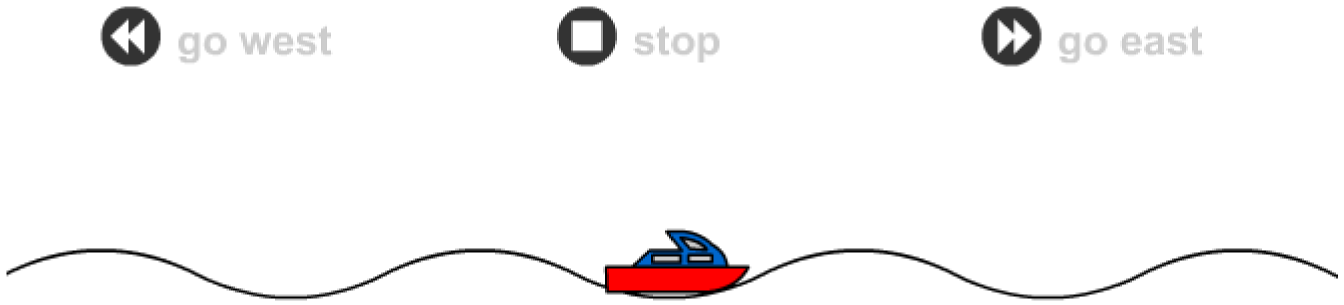


For any given frequency (pitch) an increase in amplitude results in an increase in loudness(intensity).

Which is louder, Guitar or Whistle?



The Doppler Effect and Sound (Activity)

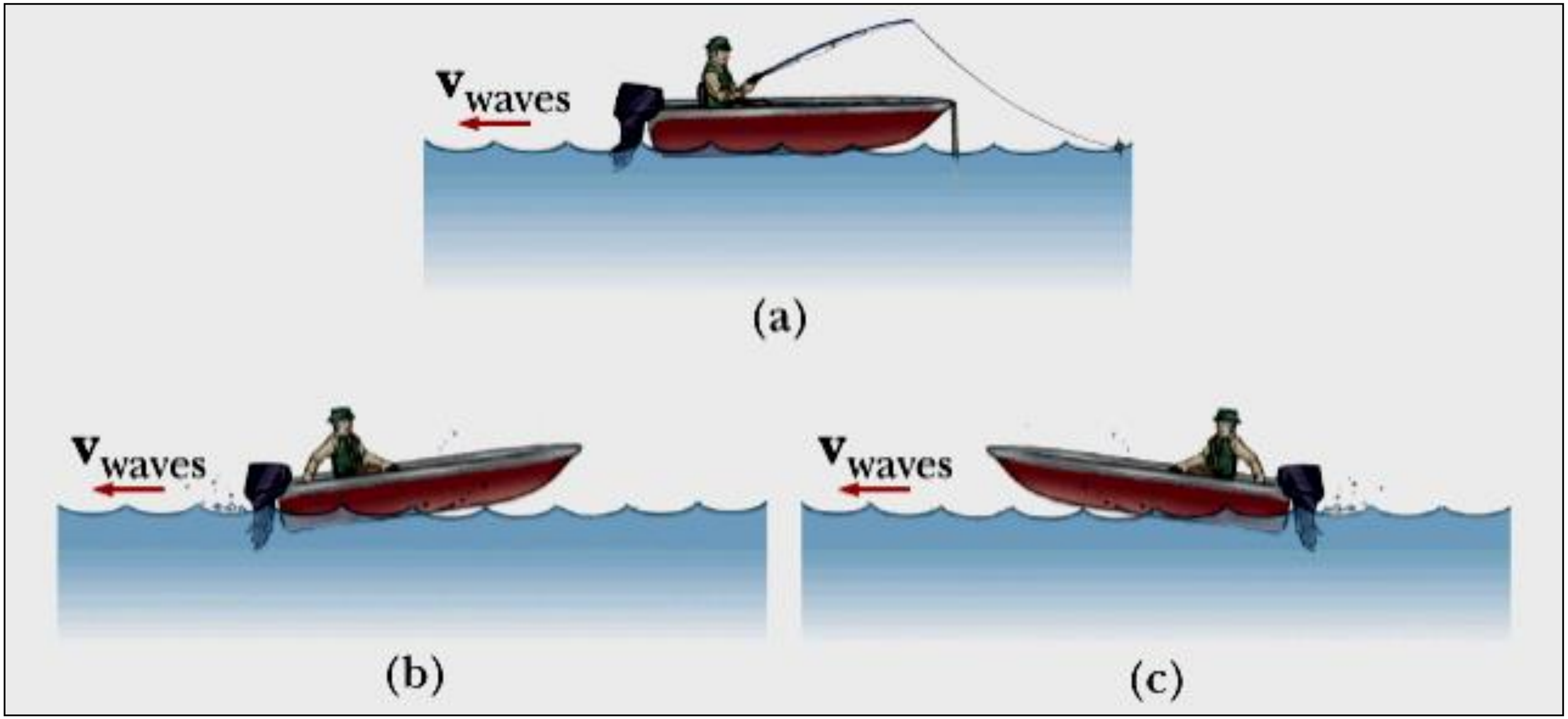


- The apparent (perceived) difference of the wave frequency caused by relative motion between the waves and the observer is called the Doppler Effect. The next page gives an explanation of how this effects sound waves.

Doppler effect

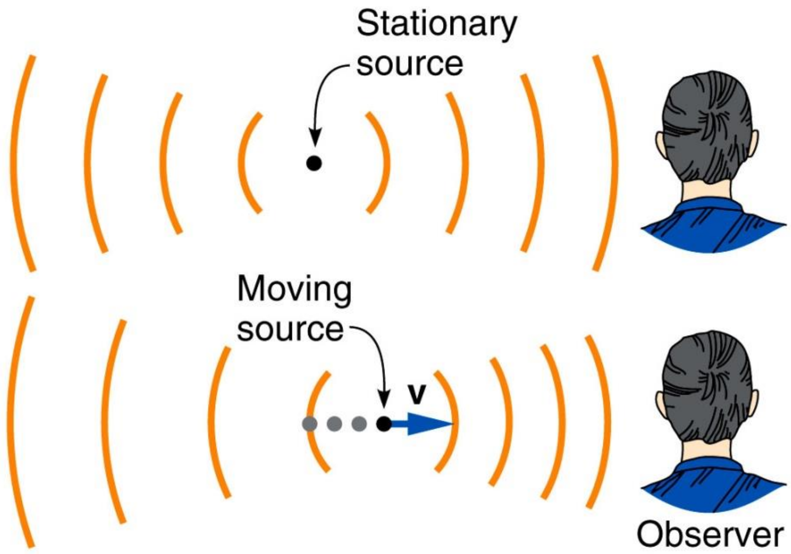
When heading into waves: Frequency becomes higher.

When heading away from waves: Frequency becomes lower.

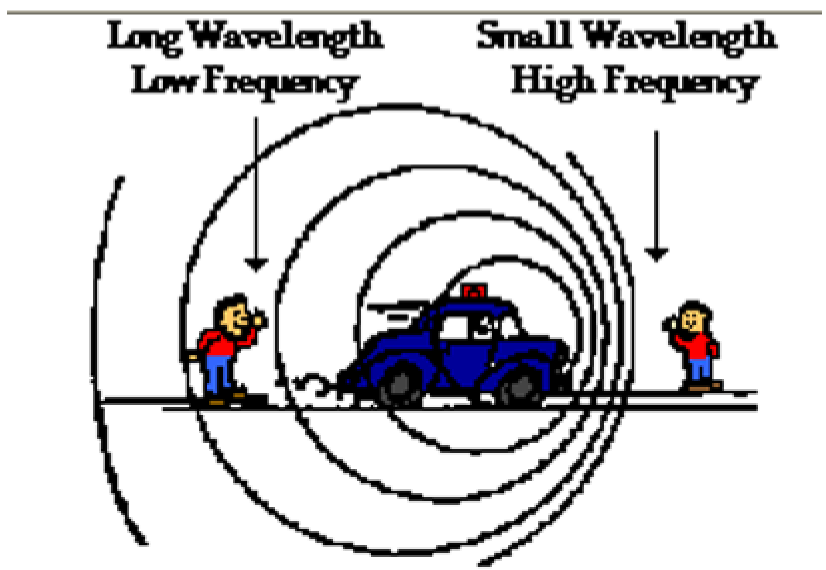


The Doppler Effect and Sound

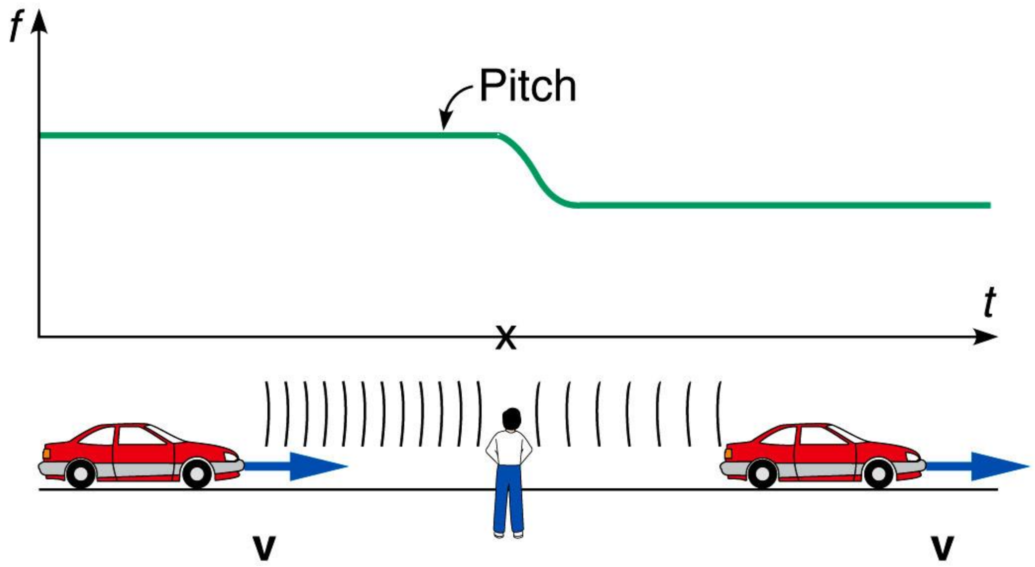
- **Doppler effect** refers to when wave energy like sound or electromagnetic waves travels from two objects, the wavelength can seem to be changed if one or both of them are moving.



- We are most familiar with the Doppler effect because of our experiences with sound waves. Perhaps you recall an instance in which a police car or emergency vehicle was traveling towards you on the highway. As the car approached with its siren blasting, the pitch of the siren sound (a measure of the siren's frequency) was high; and then suddenly after the car passed by, the pitch of the siren sound was low. That was the Doppler effect - an apparent shift in frequency for a sound wave produced by a moving source.



The Doppler Effect for a moving sound source

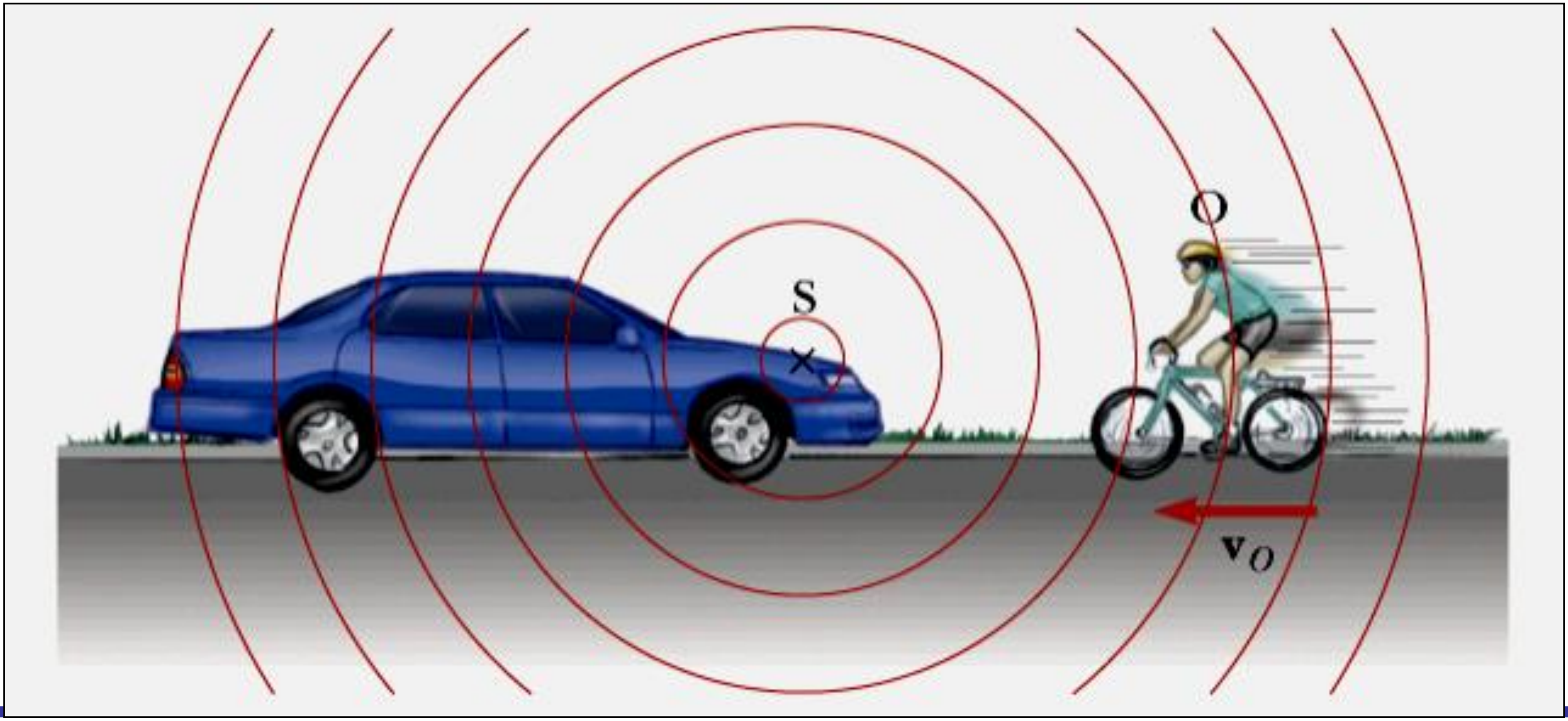


Therefore, for the same period of time, the same number of waves must fit between the source and the observer. if the distance is large, then the waves can be spread apart; but if the distance is small, the waves must be compressed into the smaller distance. For these reasons, if the source is moving towards the observer, the observer perceives sound waves reaching him or her at a more frequent rate (high pitch); and if the source is moving away from the observer, the observer perceives sound waves reaching him or her at a less frequent rate (low pitch).

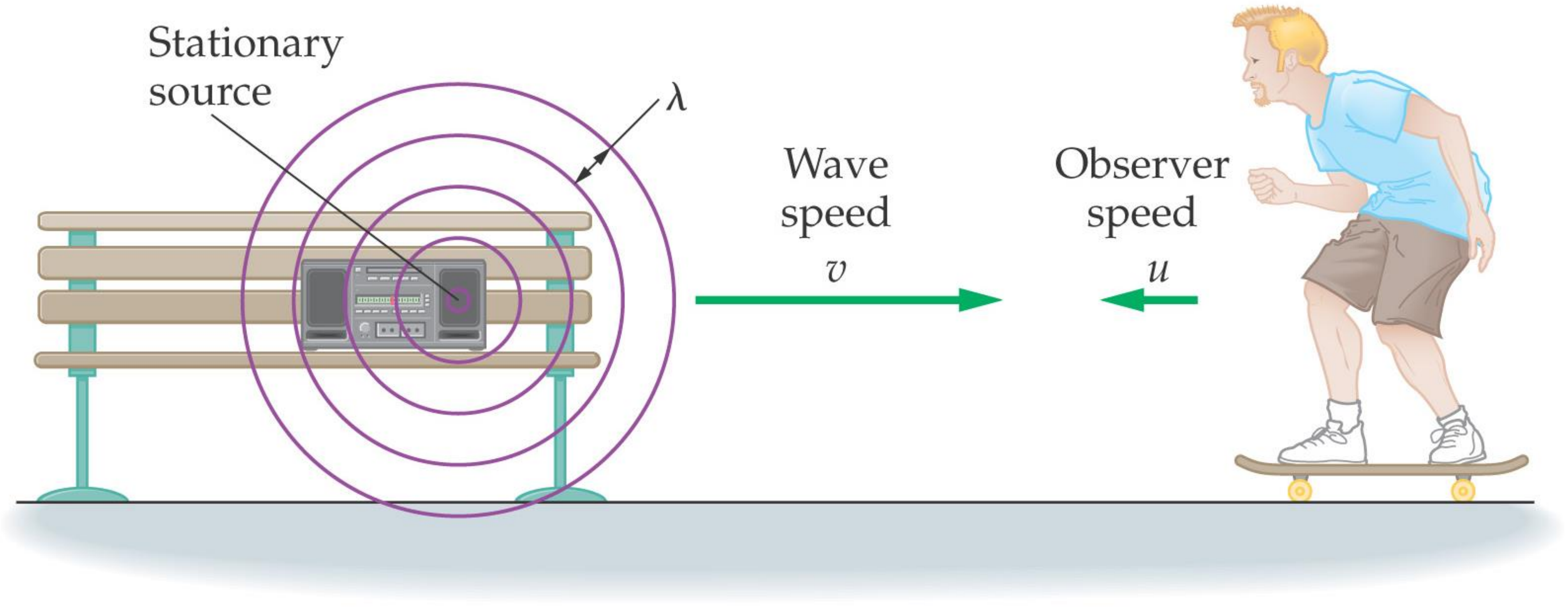
Doppler effect

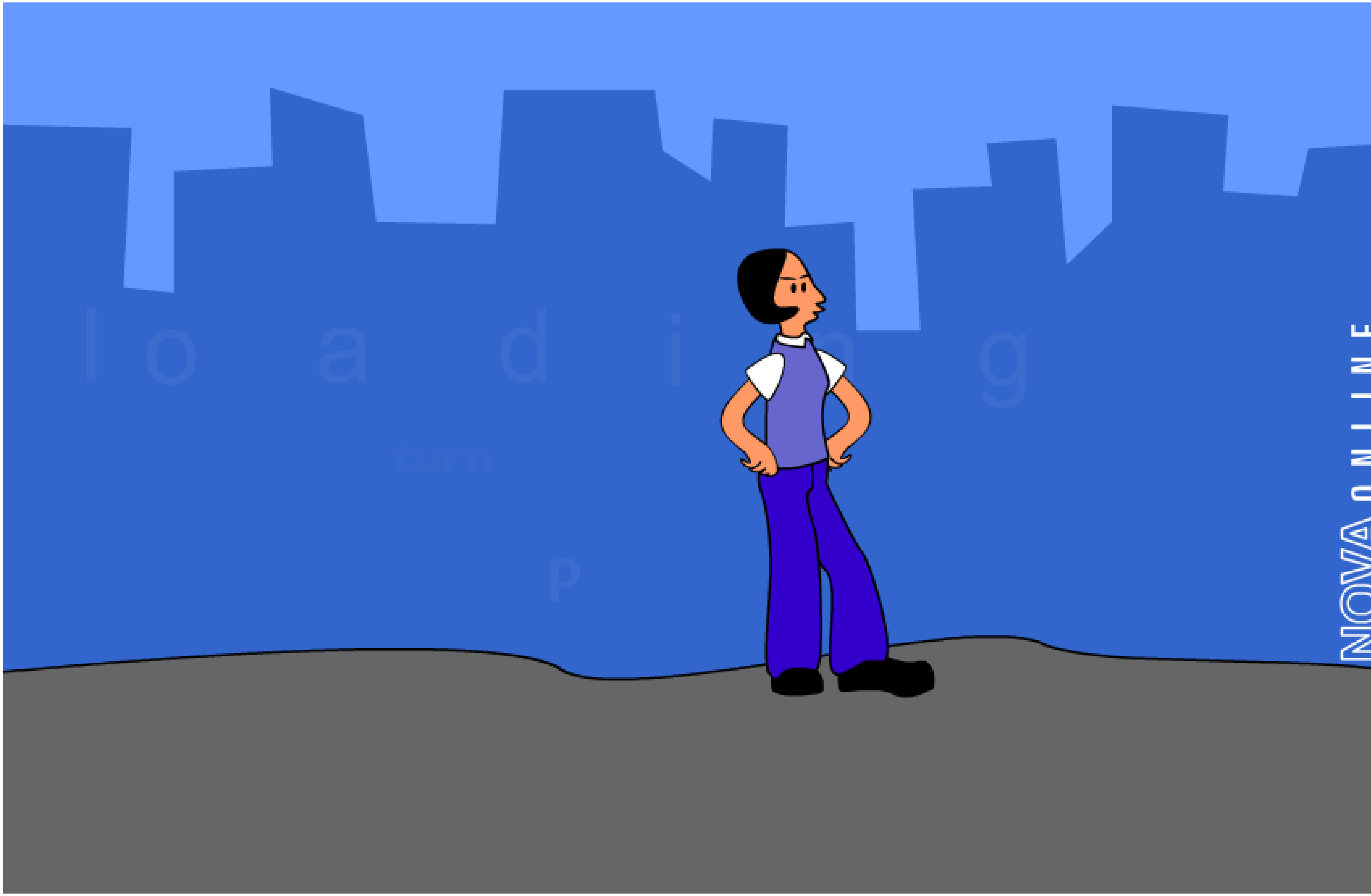
When heading into waves: Frequency becomes higher.

When heading away from waves: Frequency becomes lower.



It is important to note that the effect does not result because of an actual change in the frequency of the source. The source puts out the same frequency; the observer only perceives a different frequency because of the relative motion between them.

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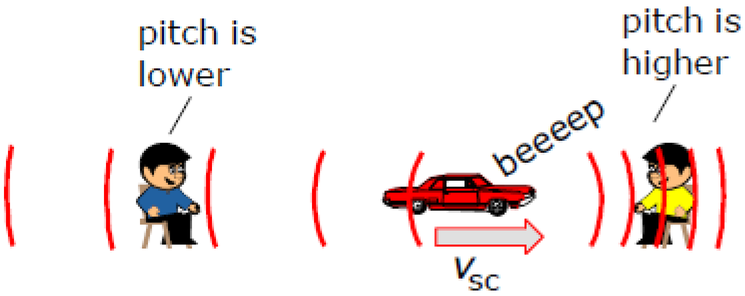
⌗ EQUATIONS FOR PERCEIVED FREQUENCY

Moving Sound Source (Found on formula sheet)

$$f = \frac{f_o v_s}{v_s \pm v_0}$$

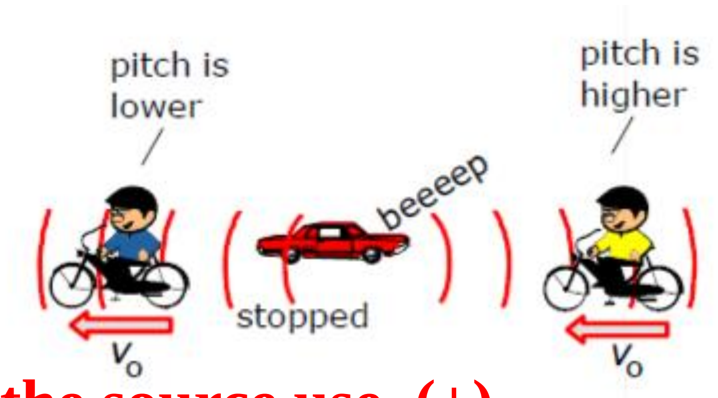


When the source is moving toward the listener it is a (-)
When the source is moving away from the listener it is (+).

f_O = the frequency of the sound at the source
f = the observed frequency according to the Doppler Effect
v_s = Speed of sound
v_o = the speed of source

Equation 2: Moving observer (Not found on formula sheet)

$$f = f_o \frac{(v_s \pm v_o)}{v_s}$$



When the listener is moving toward the source use (+)
When the listener is moving away from the source use (-).

- where

f_O = the frequency of the sound at the source
f = the observed frequency according to the Doppler Effect
v_s = Speed of sound
v_o = the speed of listener

Example 1:

A car passes and moves away from you at 110 km/hr as you stand on the side of the highway in 28^o C weather. The driver gives a long beep on the horn. If the horn makes a 450 Hz sound, what frequency do you hear?

Example 2:

A car is approaching you in in 25° C weather in a 100 km/hr zone. The driver gives a long beep on the horn, which you know from the specifications to be a 450 Hz sound. However, you measure the sound to have a 475 Hz pitch. Is the car speeding?

Given:

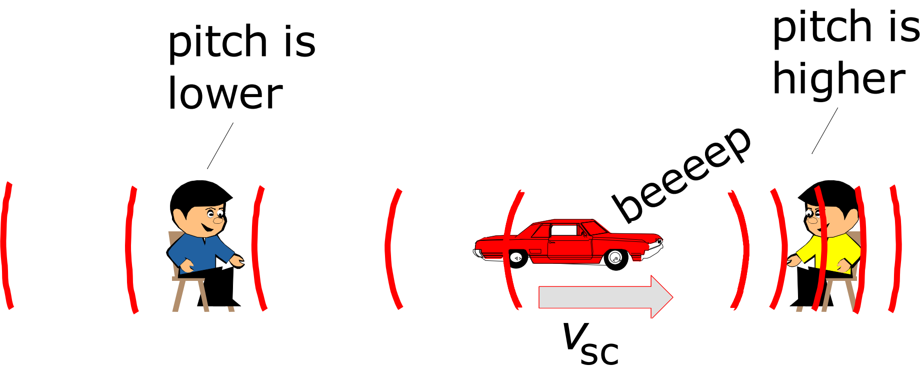
T = 25° C
f_1 = 450 Hz
f_2 = 475 Hz
v_{sc} = ?

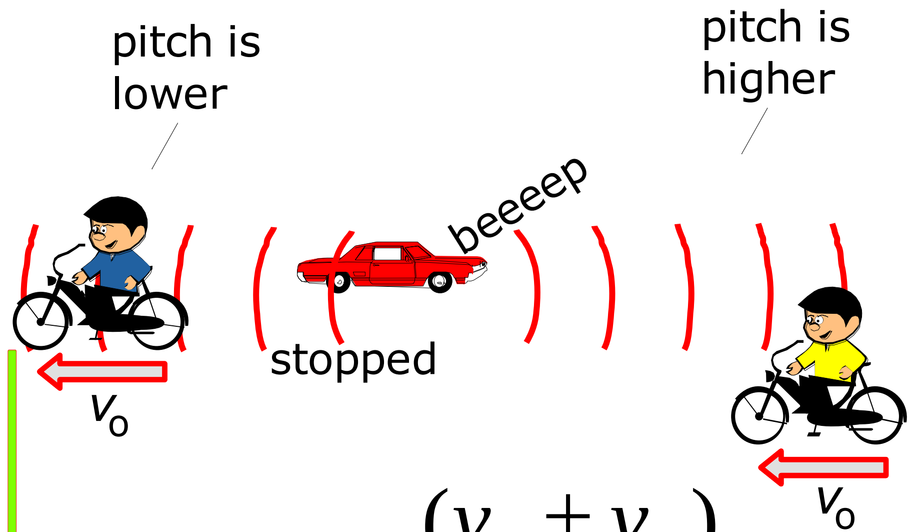
Example 3

A burglar alarm is wailing with a frequency of 1200 hertz on a 20 ^{O}C. What frequency does a cop hear who is driving towards the alarm at a speed of 40.0 m/s?

Review

The Doppler Effect and Sound





$$f = \frac{f_o v_s}{v_s \pm v_0}$$

+… source moving away from listener

- … source moving towards listener

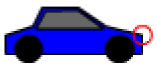
$$f = f_o \frac{(v_s \pm v_o)}{v_s}$$

+… listener moving toward source

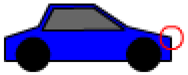
-… listener moving away from source

Sonic Booms

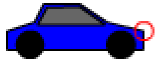
- The picture below show a stationary car with its horn blowing.



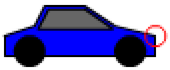
- Next picture shows the wave fronts as the car moves forward. Notice the apparent change in wavelength that will be detected by observers both in front of, and behind, the car. (Doppler Effect)



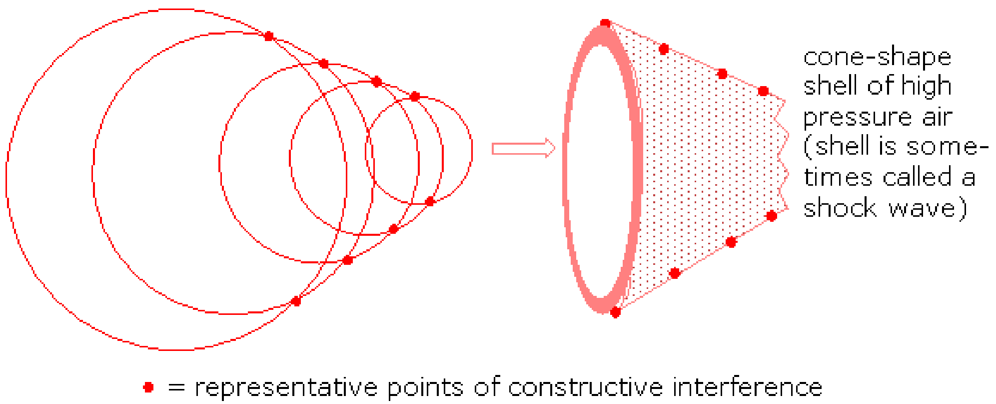
- What is the "supercar" moves at the speed of sound. Notice that, in front of the car, all of the waves are overlapping. This means that, in front of the car, there is a massive amount of constructive interference happening. This result is a region of very high air pressure in front of the car. Such high pressure in front of our supercar causes a resistance to its motion as it approaches the speed of sound. The special name for this resistance is **sound barrier**.



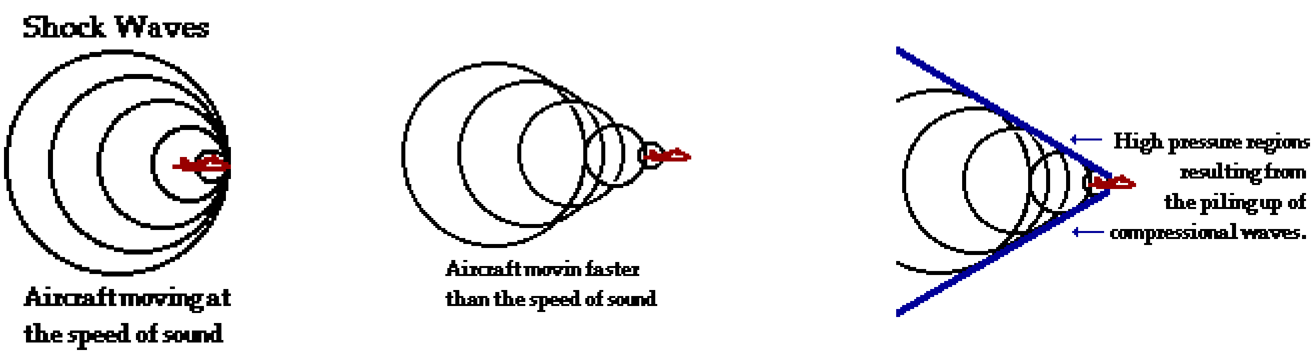
- The next picture shows the car moving faster than the sound that it is making. Because the car is continually going faster than its ripples or wave fronts, the circular patterns (representing pressure wave crests) will have to intersect. At these points of intersection constructive interference will occur.



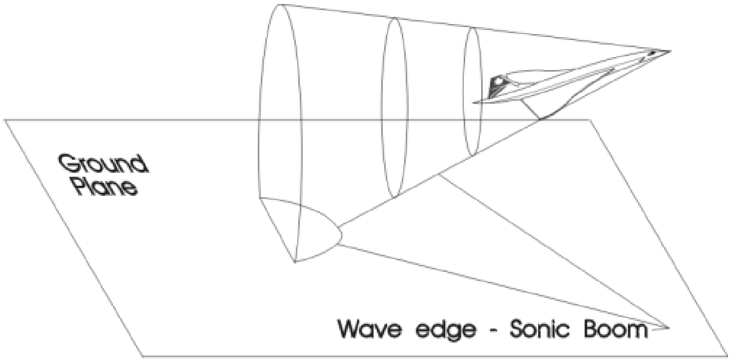
- Countless number of such point result in a cone of constructive interference as shown on the right.

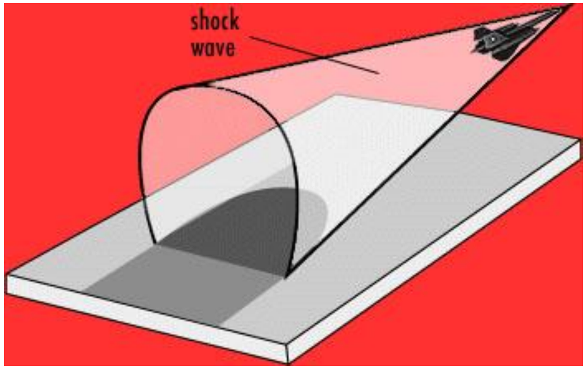


- In reality the supercar would be replaced with an airplane



- For an airplane, 3 dimensions diagram is needed because the plane is in a 3-dimensional "sea of air". Instead of a V-shape wake (like the one behind a speed boat), the plane produces a cone shape wake when it travels faster than the speed of the sound. Because of the constructive interference that takes place in the cone segment, the pressure is very high. When the "shell" of the cone intersects with the ground, the impact of this pressure on our ear drums produces a thunder-like noise that we call a **sonic boom**.





- Chuck Yeager was the first person to break the sound barrier when he flew faster than the speed of sound in the X-1 rocket-powered aircraft on October 14, 1947.

- Every so often, just the right combination of conditions and events occur to create an unbelievable event -- in this case an F/A-18 Hornet passing through the sound barrier. Not only were the water vapor, density and temperature just right, but there just happened to be a camera in the vicinity to capture the moment. The plane is actually in transonic flight, with normal shock waves emanating from behind the canopy and across the wings and fuselage. The condition will last for only an instant, and once supersonic flow exists completely around the aircraft, sharp-angled sonic cones replace the normal shock waves.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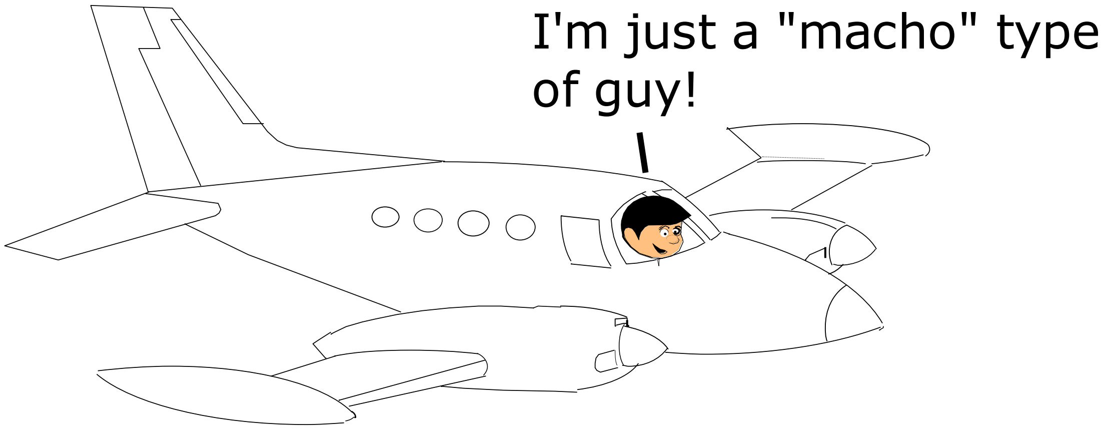
Mach Number and the Sound Barrier

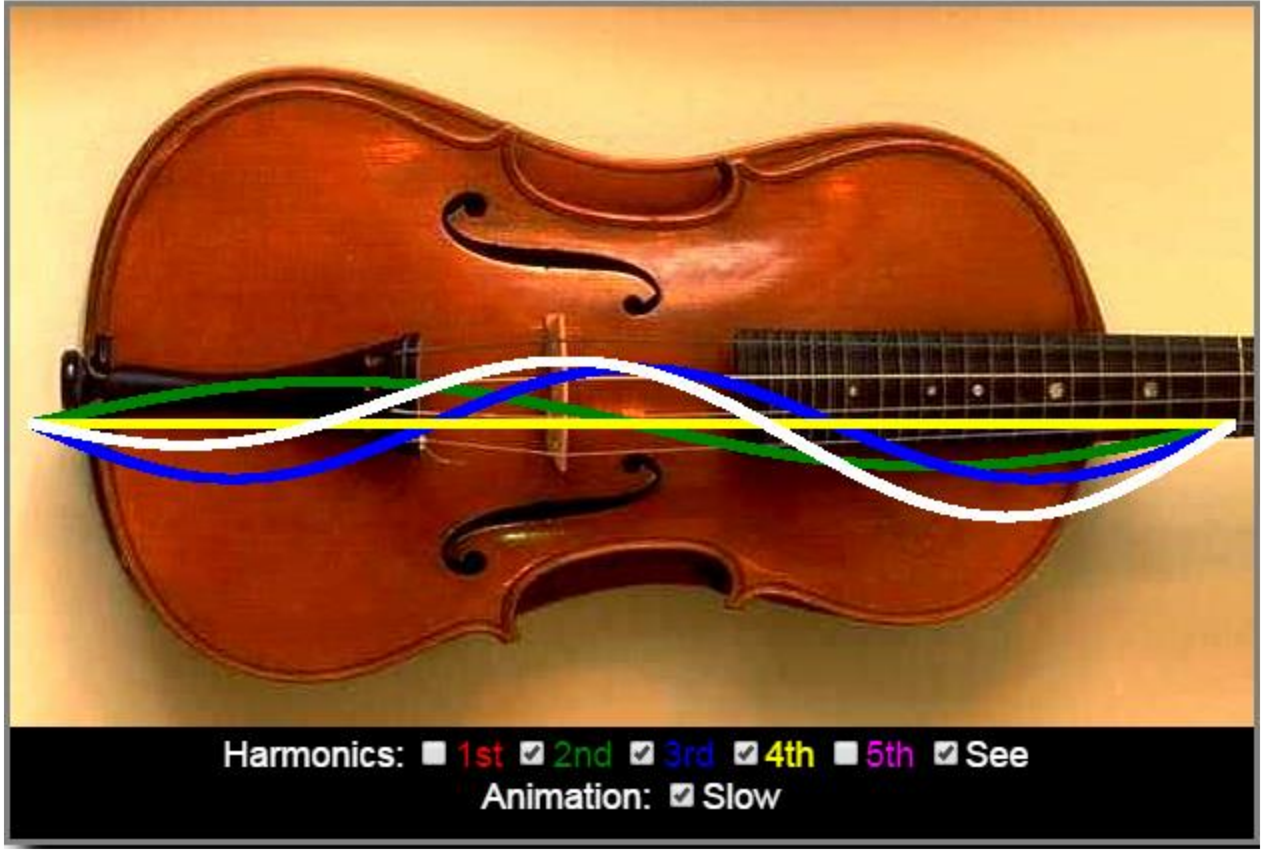
- When airplanes (or supercars) go faster than the speed of sound, a special unit of speed is used--it is the **Mach number**. For example, if on a day when the speed of sound is 340 m/s, a plane is traveling at 680 m/s, its speed is Mach 2.



$$\text{MACH number} = \frac{\text{plane speed}}{\text{sound speed}} = \frac{v_p}{v_{so}} = \frac{v_p}{[332 + 0.6T]_{m/s}}$$

Who Was The First Person To Break The Sound Barrier?

Mach 1



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