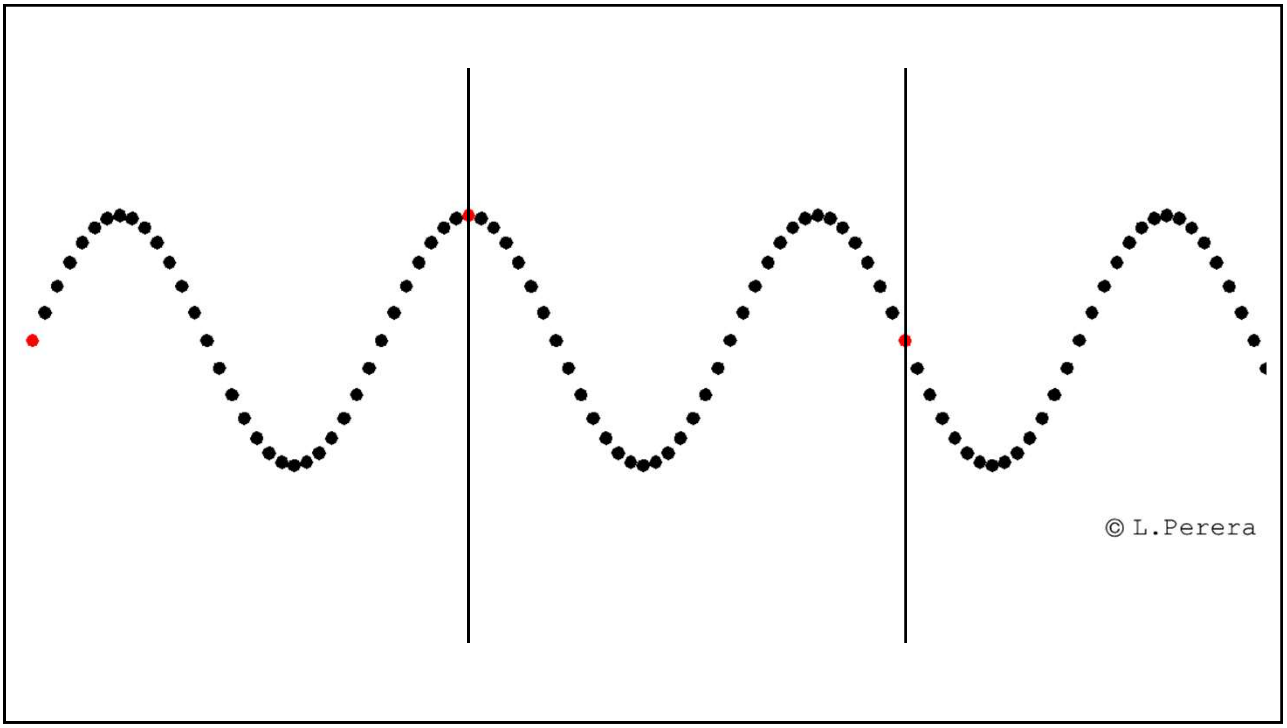
Physics
Unit 6: Waves
(Mechanical Waves)

Slides

What is a wave?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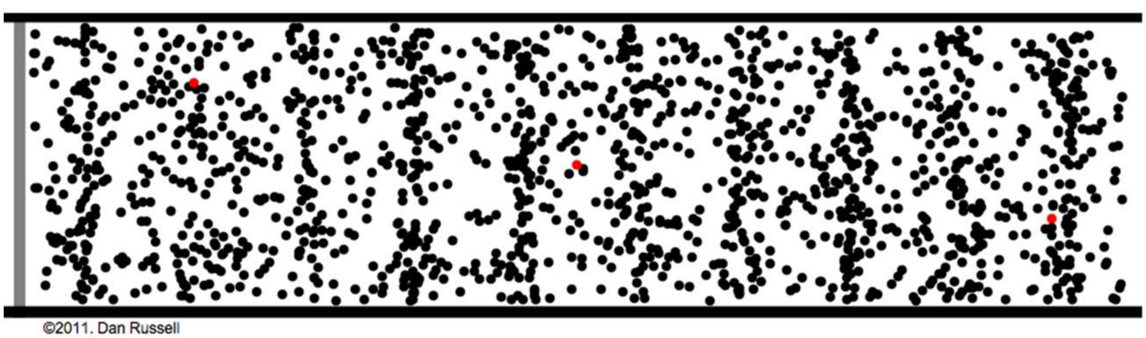
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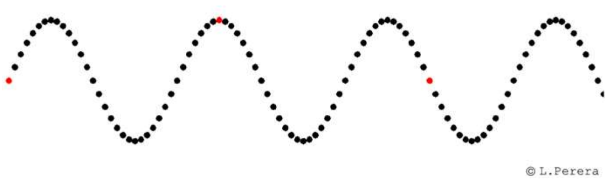
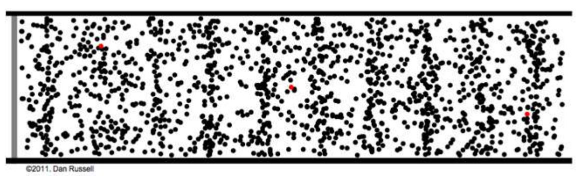
- A mechanical wave is the movement of a disturbance through a medium without net movement of the particles
  - Medium: the material a wave moves through, can be a solid, liquid, or gas
- Waves transfer energy from one place to another without transferring matter

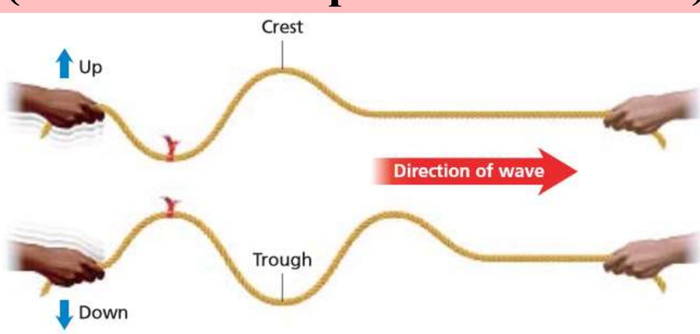
The wave moves in one direction, but the individual particles of the medium only oscillate or vibrate about a fixed point



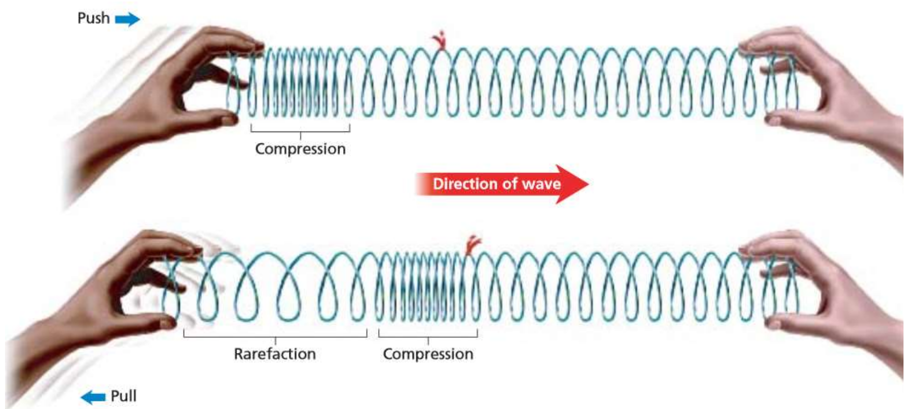


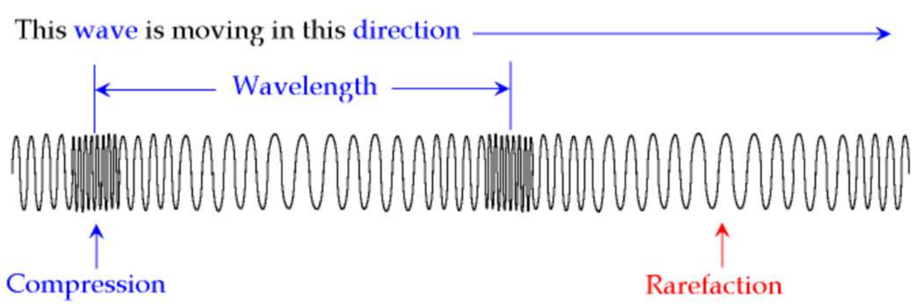
Types of Waves

Transverse Wave
(Sinusoidal or up-and-down wave)



Longitudinal Wave (compression-expansion wave)

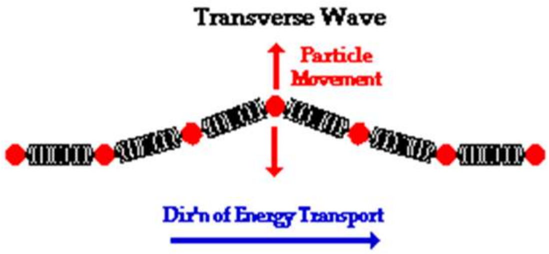


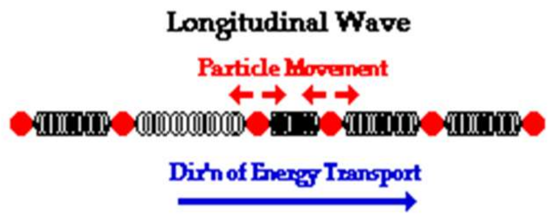


- Molecules are compressed and expanded as the wave passes through the medium.
- The displacement of the medium is **parallel** to the direction of the wave's motion.

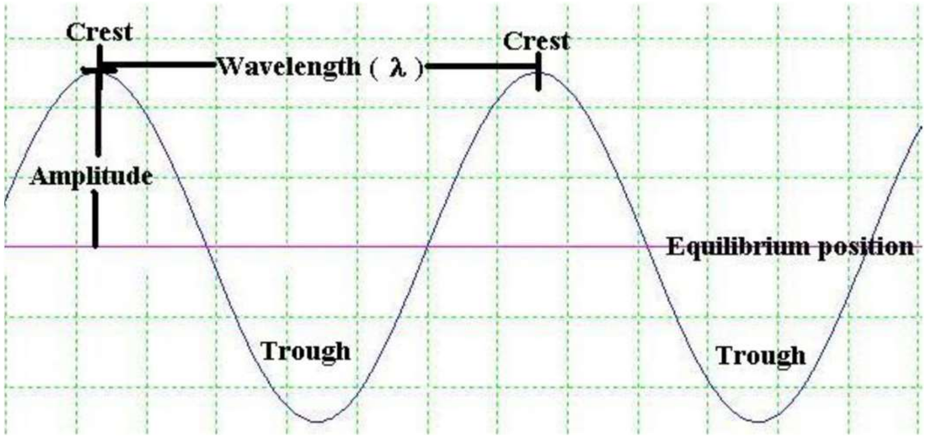
Transverse wave: the oscillation of the medium is perpendicular to the direction the wave travels

Longitudinal wave: the oscillation of the medium is parallel to the direction the wave travels





Parts of a Wave

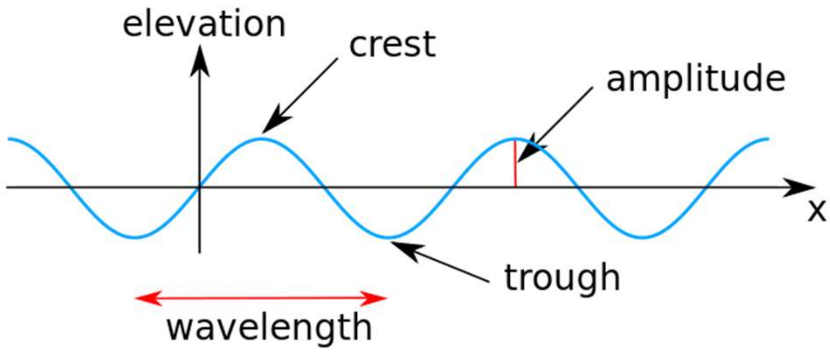


The displacement of the medium is **perpendicular** to the direction of wave motion. As the wave passes through the medium, the medium is moved up and down 90º to the direction of motion.

Equilibrium position: Rest position. The position of particles or spacing of particles in the medium when at rest. Equilibrium position is ½ way between the extremes of the wave.

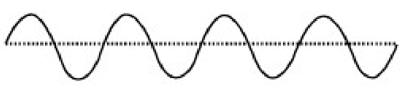
Amplitude (A): The maximum displacement of particles in the medium from their ***equilibrium position*** as the wave passes through.

- Amplitude is independent of all other wave properties except wave energy.
- Amplitude is not affected by frequency or wave speed.

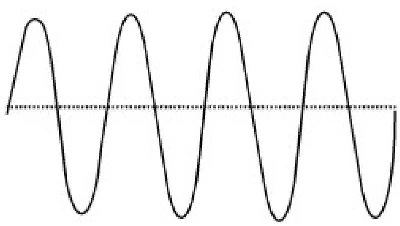


Amplitude
- Height of wave
- Symbol: A
- Unit: meters (m)

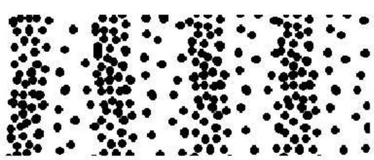
Wavelength
- Length of a cycle
- Symbol: λ ("lambda")
- Unit: meters (m)



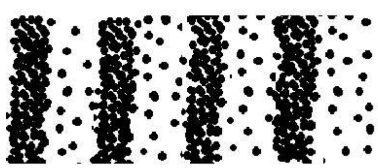
Low amplitude transverse wave (crests & troughs are low)



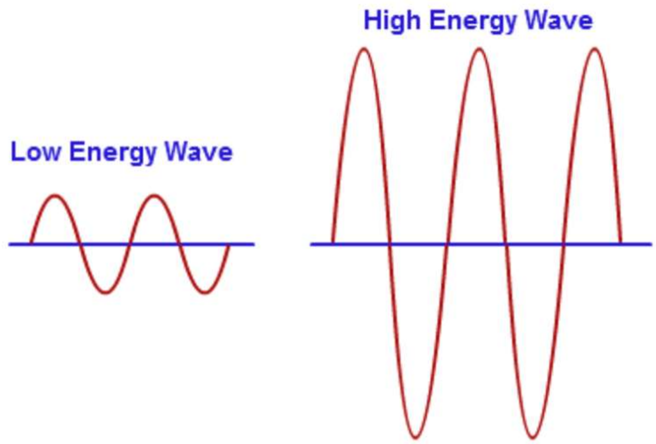
High amplitude transverse wave (crests & troughs are high)



Low amplitude longitudinal wave (condensations are less dense)



High amplitude longitudinal wave (condensations are more dense)



Amplitude is ***proportional*** to the energy of the wave because the wave displaces the medium as it moves through (performs work on the medium).

- Higher amplitude → more work performed by wave.
- Lower amplitude → less work performed by wave.

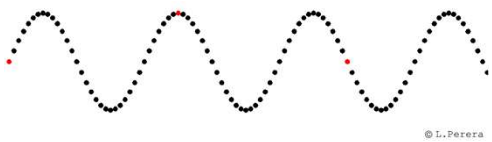
Simple Harmonic Motion

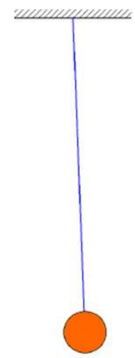
How are waves, pendula, and springs similar?

SIMPLE HARMONIC MOTION

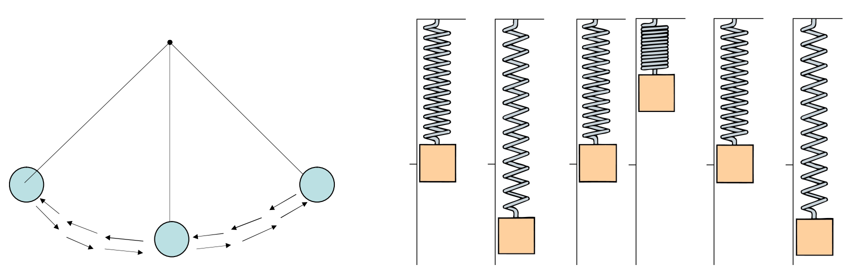
Motion that repeats itself in cycles at a defined time interval.

- **Repetitive up-and-down**
- **Repetitive side-to-side**
- **Repetitive circular motion**
- **Waves**



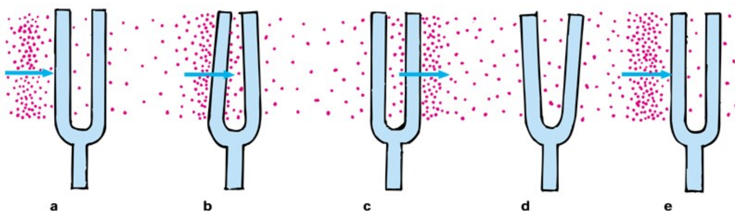


Simple harmonic motion: repetitive motion such as back-and-forth, up-and-down, or in a repeating circular motion.

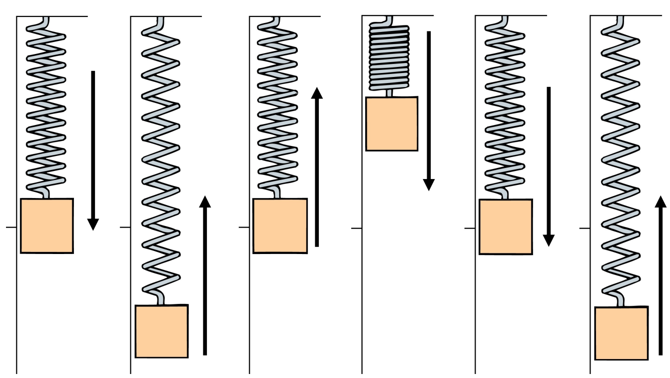


Objects with ***simple harmonic motion*** (like waves) move with a defined **period** and defined **frequency**.

Vibration: Objects rapidly move back-and-forth around a fixed position (e.g., prongs on the tuning fork)



Oscillation: Objects rapidly move up-and-down around a fixed position (e.g., spring stretching and compressing)



Categories of Waves

What types of waves are there?

Categories of Waves

All waves belong to one of three categories:

1. **Mechanical waves**
   - Require a physical medium (solid, liquid, or gas) to travel
   - Examples: sound, ocean waves, earthquakes
2. **Electromagnetic waves**
   - Do not require a physical medium (can travel through vacuum)
   - Examples: light, microwaves, Bluetooth, ultraviolet waves
3. **Gravitational waves**
   - Recently discovered!
   - Medium is spacetime itself

Our focus now (→ Mechanical waves)

Our focus later (→ Electromagnetic waves)

Mechanical Waves

Sound

Earthquakes

Water waves

Electromagnetic Waves

Microwaves

Light

Bluetooth

Frequency & Period

Frequency (*f*): The number of cycles (waves, oscillations, or vibrations) generated per second. Number of waves passing a reference point per second.

"How many per second"

Period (T): The time for one single cycle (vibration, oscillation, or wave). The time to generate one wave, or the time interval between successive waves.

"How much time to form one wave"

Frequency and period are ***inversely proportional*** to each other

- As frequency increases, period decreases
- As frequency decreases, period increases

Period

- Time to complete one cycle
- Symbol: T
- Unit: seconds/cycle (s)

$$T = \frac{\text{time}}{\text{cycles}}$$

Frequency

- Number of cycles in one second
- Symbol: f
- Unit: Hertz (Hz = 1/s)

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

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

Wave Speed

How fast does a wave travel?

$$v = \frac{distance}{time} = \frac{\lambda}{T}$$

$$v = \lambda f$$

Wave Speed Equation

Conclusion:

Wave speed is determined by properties of the medium, not by properties of the wave itself

In other words, to change wave speed, you must change something about the ***medium***, not the wave

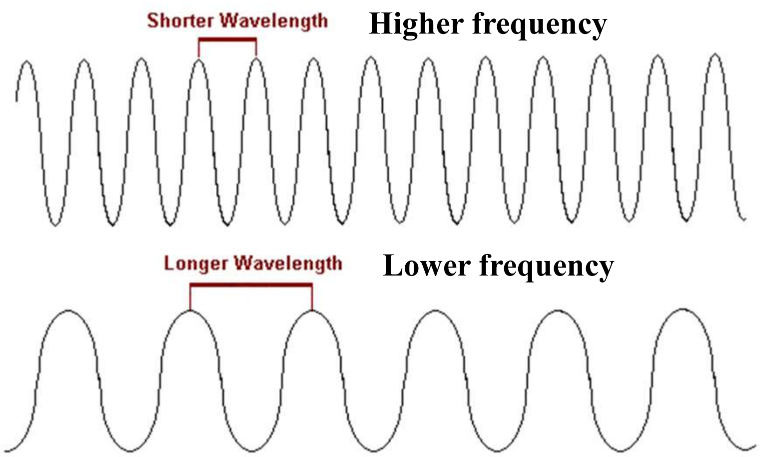
Wave Speed

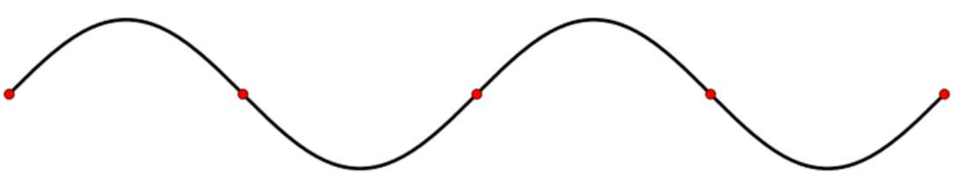
In the same medium, waves will have a constant speed (v)

Therefore, wavelength (λ) and frequency (f) will be **inversely proportional**

$$v = \lambda f$$

Frequency and wavelength are ***inversely proportional*** to each other.
- Higher frequency → Shorter wavelength
- Lower frequency → Longer wavelength



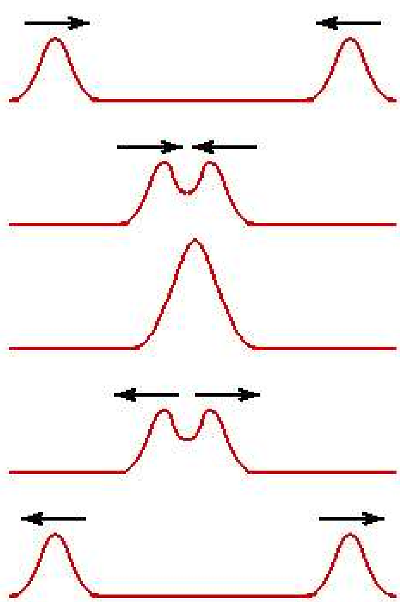


Standing Waves

Principle of Superposition

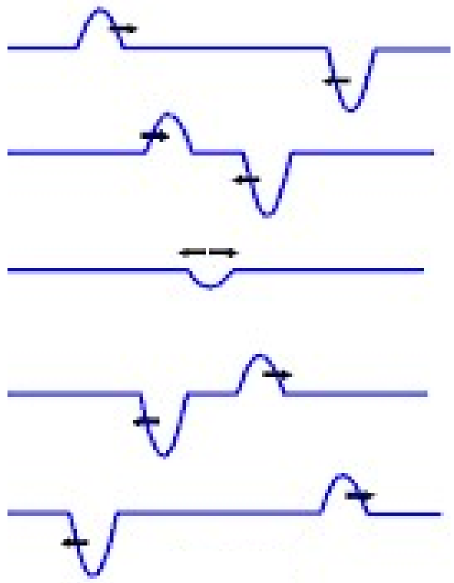
When two waves meet, they will pass through each other. When they overlap, they add together.

- When this adding together strengthens the waves, it is called **constructive interference**
- When this adding together weakens the waves, it is called **destructive interference**



Two crossing wave pulses that produce ***constructive interference***.

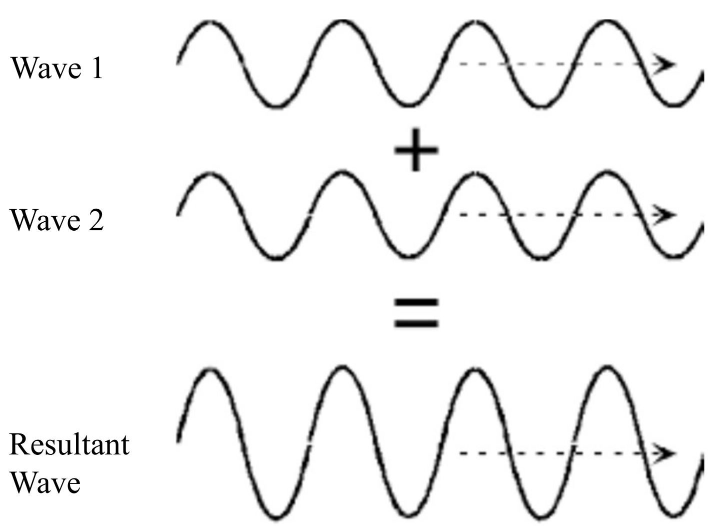
Amplitude of the resultant wave gets bigger—sum of the two smaller waves.



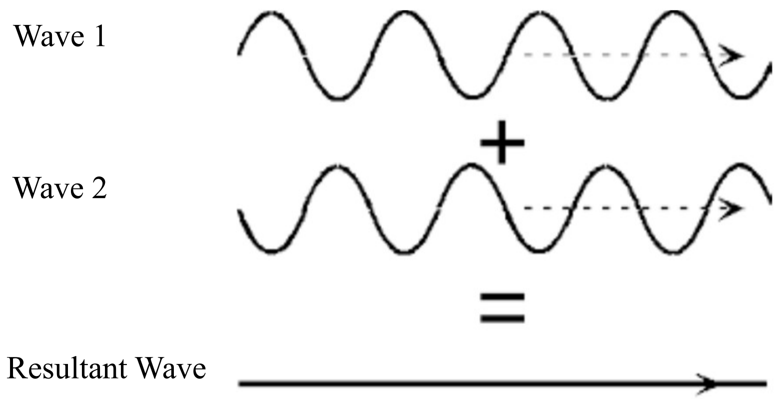
Two crossing wave pulses that produce ***destructive interference***.

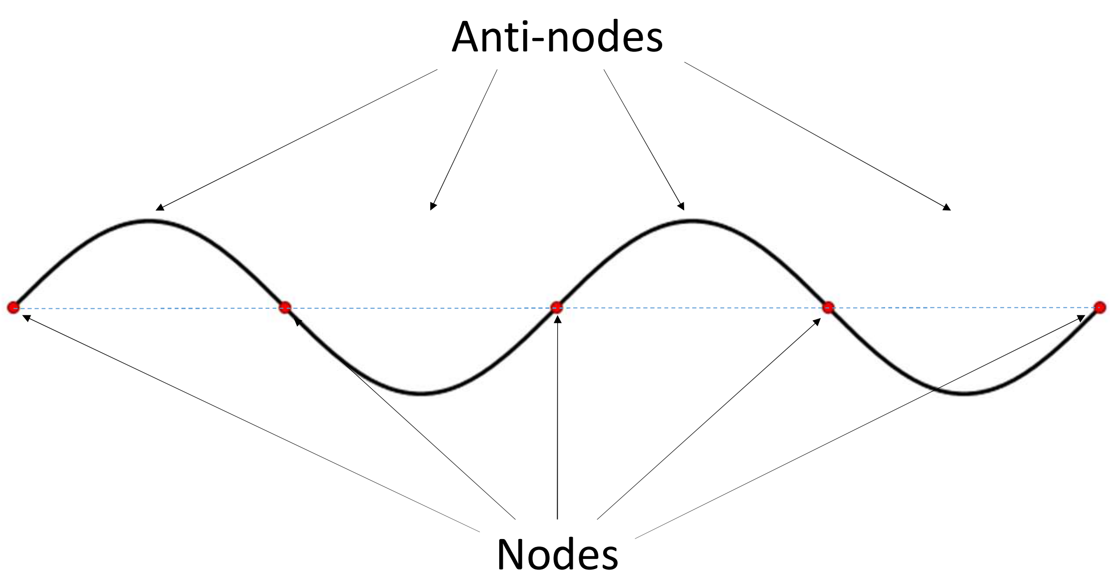
Amplitude of the resultant wave gets smaller—waves partially cancel each other out.

Total Constructive Interference

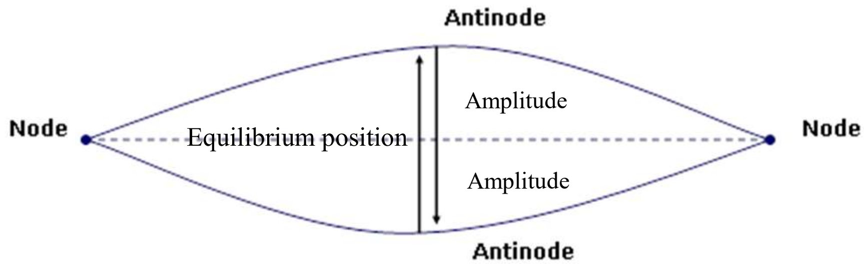


Total Destructive Interference

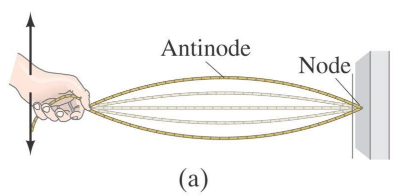




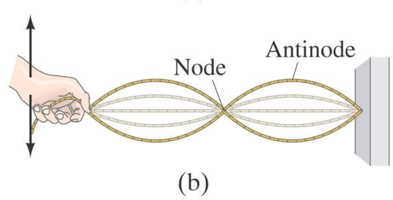
Standing wave



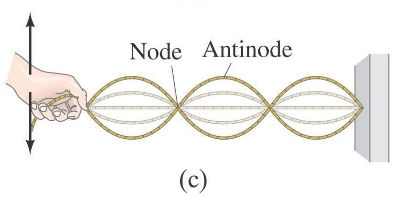
- The wave looks as if it only goes up and down, but has no horizontal movement.
- The oscillation is so fast, the string or wire looks frozen in time at the antinodes.
- Nodes are places of zero amplitude.



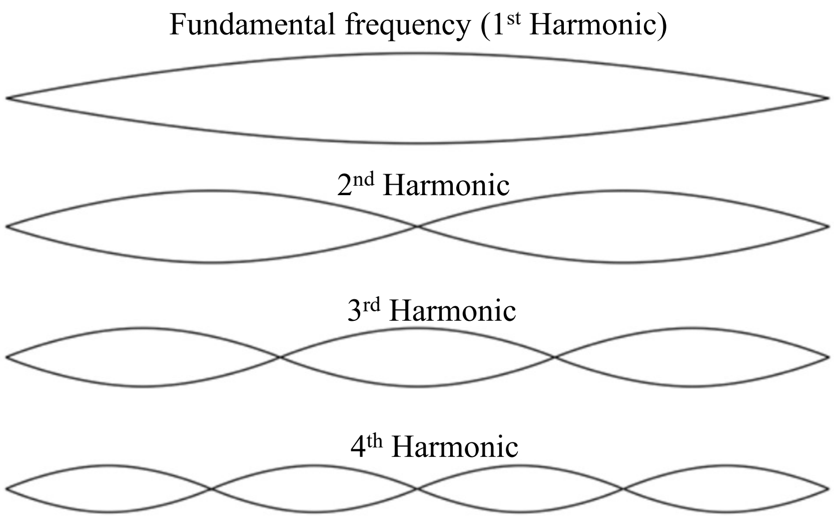
If the wire was vibrated or oscillated at the **fundamental frequency**, the wire will produce the half-wave standing wave.



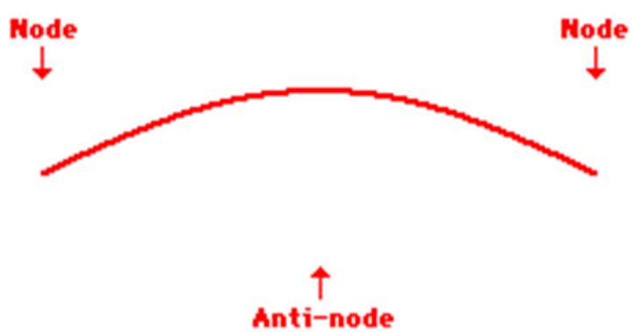
If the wire was vibrated or oscillated at 2-times the fundamental frequency, the wire will produce the **2nd harmonic** (one complete wavelength)

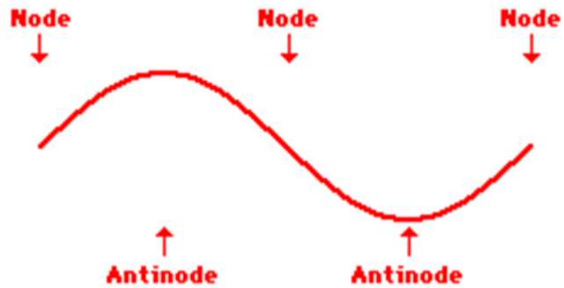


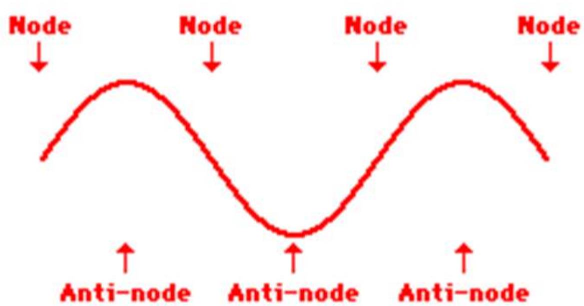
If the wire was vibrated or oscillated at 3-times the fundamental frequency, the wire will produce the **3rd harmonic** (1.5 complete wavelengths)



If the wire or string is fixed at both ends
For each harmonic, **# nodes = # antinodes + 1**




Node
Node
Node
Antinode
Antinode


Node
Node
Node
Node
Anti-node
Anti-node
Anti-node

Standing Wave Lab Debrief

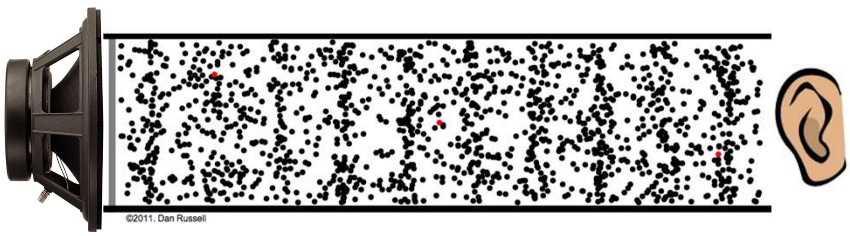
- **The frequency of each harmonic is a multiple of the fundamental frequency**
  - 2nd harmonic is twice the fundamental, 3rd harmonic is three-times the fundamental, etc.

- For example:
  - 1st harmonic (fundamental frequency) = 10 Hz
  - 2nd harmonic = 20 Hz
  - 3rd harmonic = 30 Hz
  - And so on…

Sound

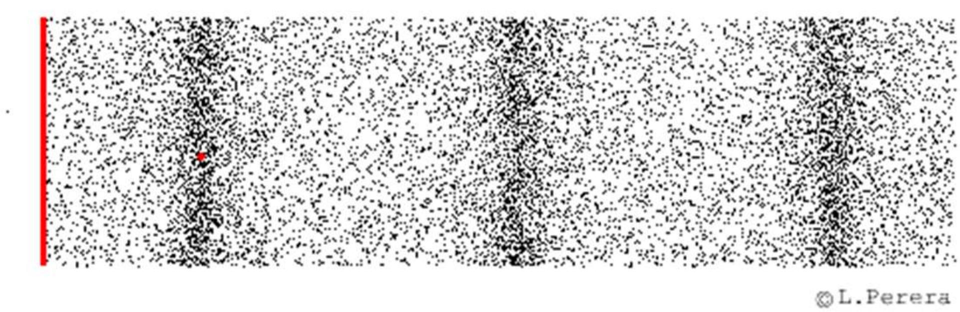
What is sound?

Sound is a longitudinal wave that travels through solid, liquid, and gas media

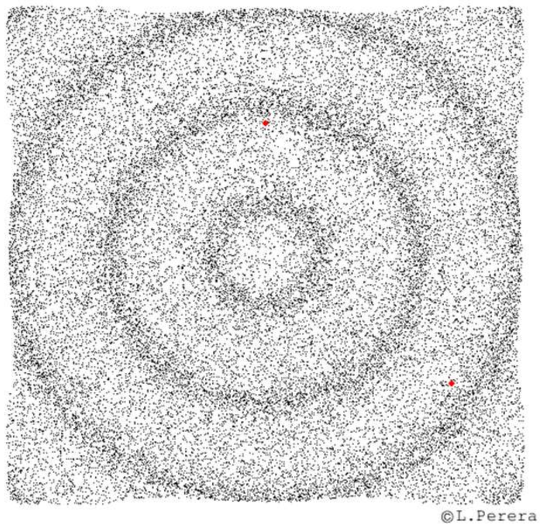


Our ears detect these waves to provide useful information about the world around us

Simple Model

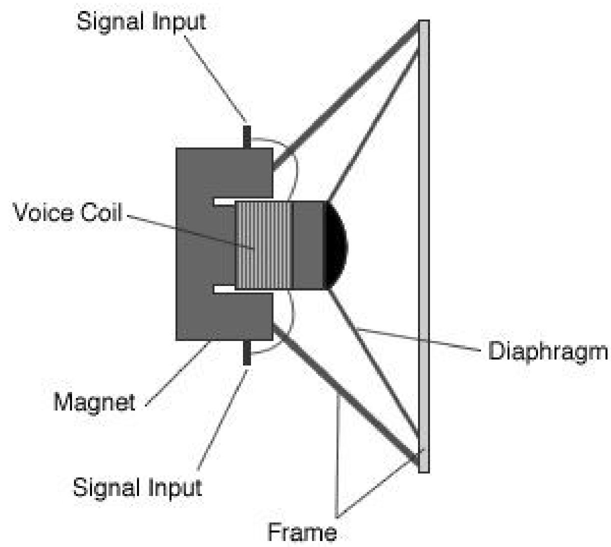


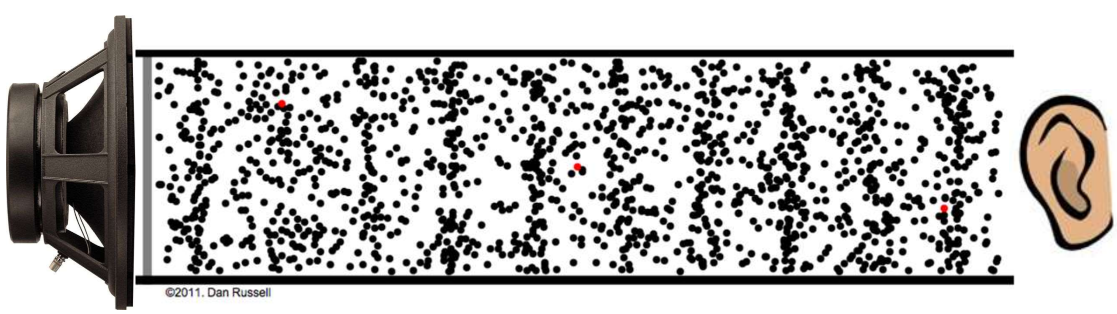
More Realistic Model



Tuning Fork

A **tuning fork** is U-shaped metal fork that, when struck, vibrates at a set frequency, producing a sound wave at that frequency


Signal Input
Voice Coil
Diaphragm
Magnet
Signal Input
Frame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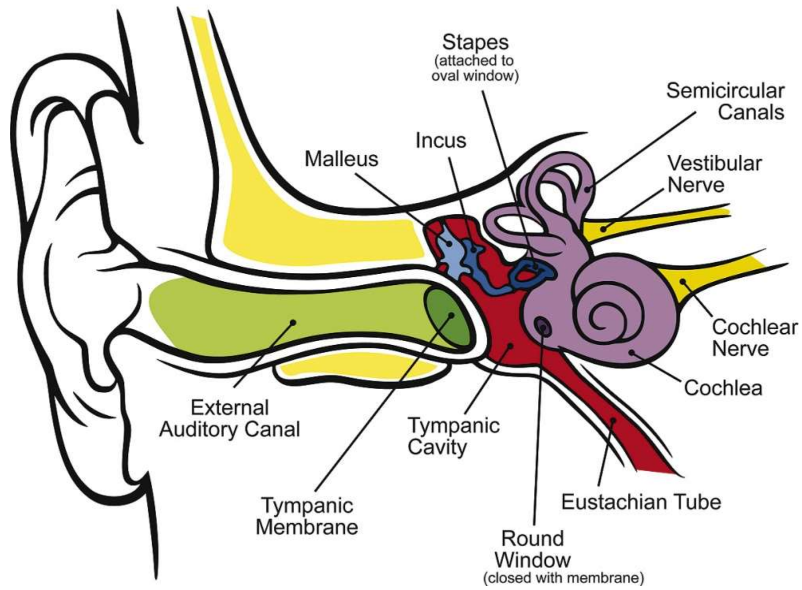


Speed of Sound

Medium	m/s
Carbon dioxide (0°C)	259
Dry air (0°C)	331
Helium (0°C)	965
Hydrogen (0°C)	1,284
Water (25°C)	1,497
Seawater (25°C)	1,530
Lead	1,960
Glass	5,100
Steel	5,940

Speed of sound

Speed of sound is much slower than the speed of light.

Sound must travel through a medium. Sound does not move through a **vacuum**.

- Sound travels fastest through dense solid matter.
- Sound travels slower through fluids.
- Sound travels slowest through gases.

SPEED OF SOUND IN AIR

- **Warmer air temperatures** = faster wave speed.
- **Cooler air temperatures** = slower wave speed.

- Sound waves are traveling pulses of energy that moves through air as wave fronts.
- If air is warm, air molecules have higher kinetic energy—easier to move sound waves through already fast moving air.

Pitch

Pitch: The quality of sounds heard by the human ear. Describes how high or low a sound wave sounds

- Higher frequency = move vibrations = higher pitch
- Lower frequency = fewer vibrations = lower pitch

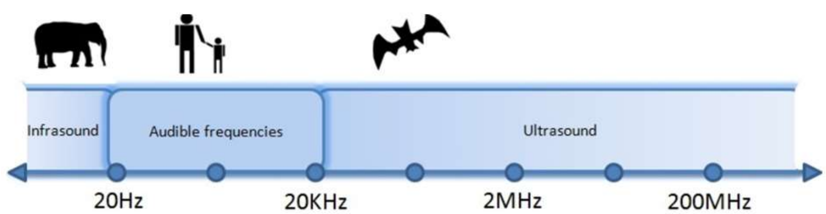
Longer strings produce longer wavelengths and lower frequency with lower pitch notes

Shorter strings produce shorter wavelengths and higher frequency with higher pitch notes

Frequency and Pitch

Human Audible Range: 20-20,000 Hz

- **Infrasonic**: frequencies below the range of human hearing (below 20 Hz)
- **Ultrasonic**: frequencies above the range of human hearing (above 20,000 Hz)



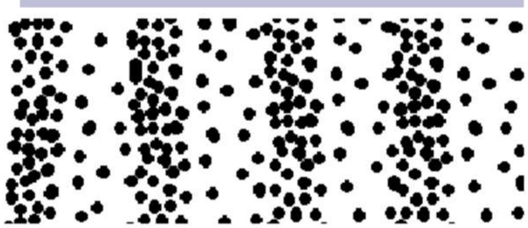
Volume

Volume: The loudness of sound. How loud sound appears to be to the human ear.

Amplitude of longitudinal waves is related to the density of particles/molecules in the compressions (wave fronts).

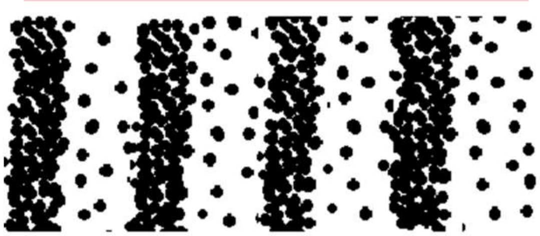
- Greater amplitude = denser with molecules = more wave energy = louder volume
- Lower amplitude = less dense with molecules = less wave energy = softer volume

Low volume sound wave



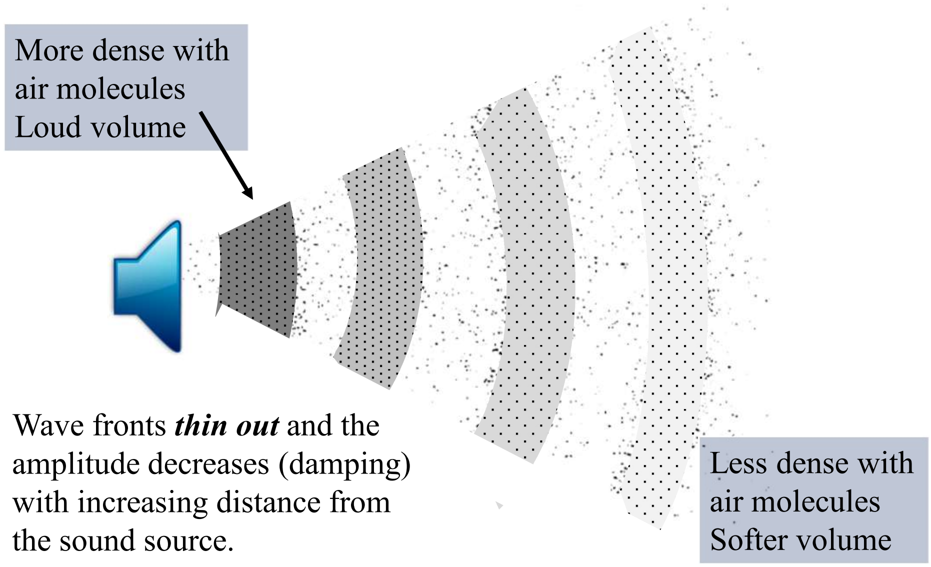
The amplitude is smaller because the wave fronts are not dense with molecules.

High volume sound wave



The amplitude is greater because the wave fronts are denser with compacted molecules

Sound waves (wave fronts, condensations) move outward and away from the source as expanding pulses of energy.



Wave fronts ***thin out*** and the amplitude decreases (damping) with increasing distance from the sound source.

Decibel	Loudness	Object
0	Threshold of hearing	
10	Very faint	Watch ticking
20	Very faint	Whisper
30	Faint	Quiet conversation
40	Faint	Tapping foot
50	Moderate	Normal Conversation
60	Moderate	Normal car engine
70	Loud	Rock music on radio
80	Loud	Alarm clock
90	Very loud	Machines in factory
100	Very loud	Lawn mower
110	Deafening	Train locomotive
120	Deafening	Plane taking off

Beats

Beats

When two waves of slightly different frequencies and wavelengths overlap, they form an alternating pattern of constructive and destructive interference known as **beats**

The listener hears the sound vary in amplitude between zero and a maximum value. The frequency at which this occurs is called the **beat frequency**

Beat frequency = difference in frequency of the two waves

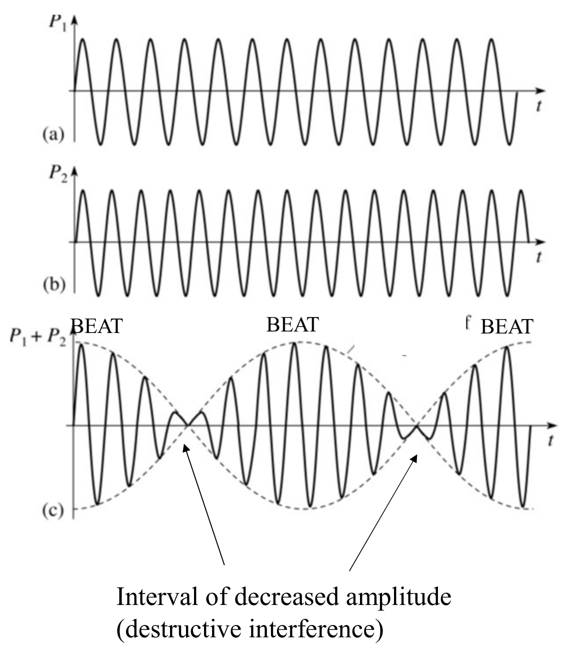
Beats

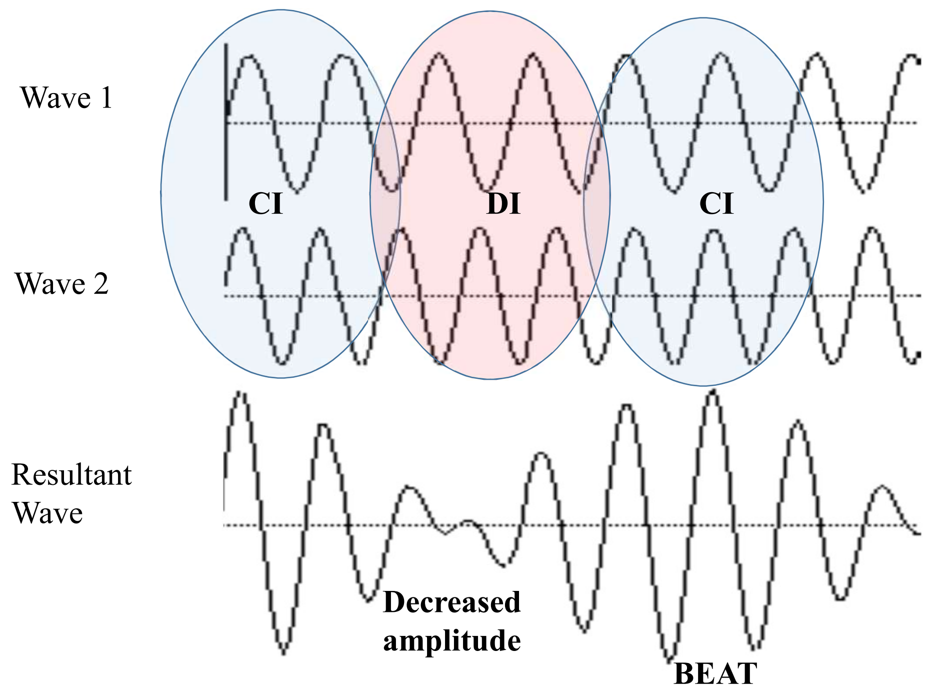
<u>Example:</u>

Wave 1: 1000 Hz

Wave 2: 1002 Hz

Beat frequency = 2 Hz





Doppler Effect

What happens to the sound of a train whistle as it passes you?

Doppler Effect

The **Doppler Effect** is the apparent change in the frequency and wavelength of a wave (sound or light) when the observer and the source of the sound are moving relative to each other

- Apparent – the wave coming from the source never actually changes. It just *appears* to have changed to the observer
- Moving relative to each other – the observer and source are getting closer or farther apart, whether it is the observer, the source, or both that are moving

Doppler Effect

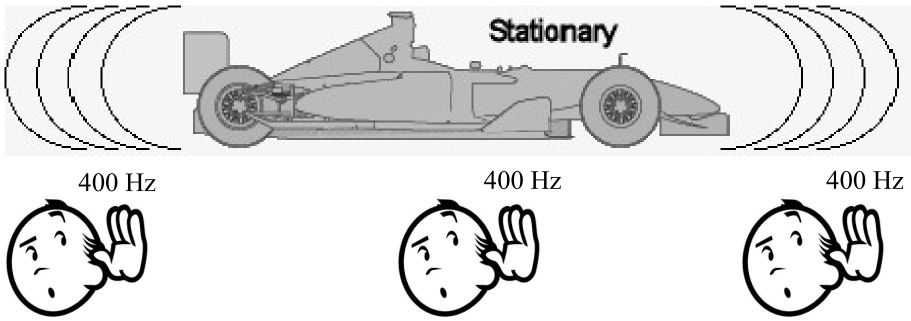
Blue shift: the source is moving towards the observer

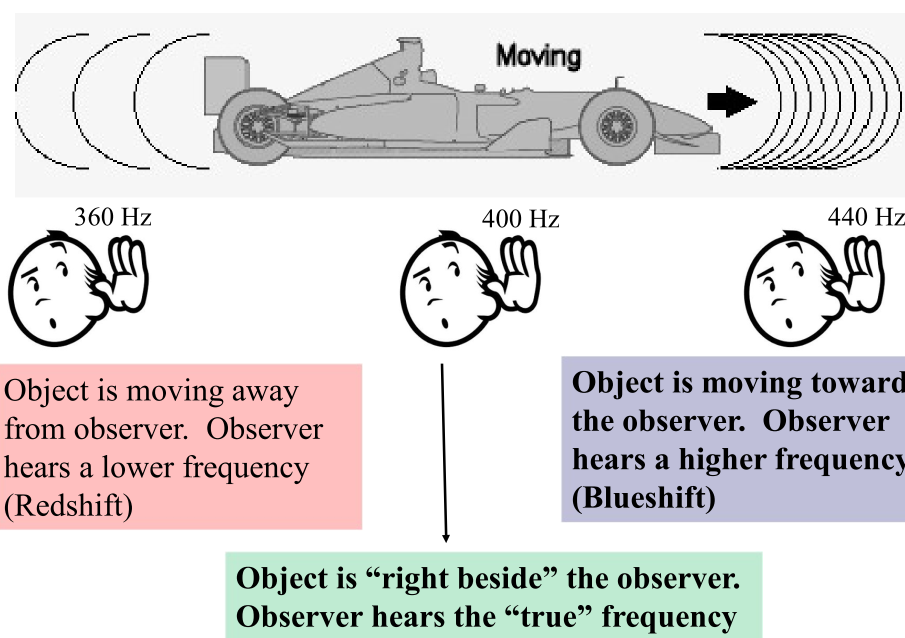
- To the observer, the observed wave has a *higher frequency* and a *smaller wavelength*
- For a sound wave, that means a higher pitch

Red shift: the source is moving away from the observer

- To the observer, the observed wave has a *lower frequency* and a *larger wavelength*
- For a sound wave, that means a lower pitch

Example





Object is moving away from observer. Observer hears a lower frequency (Redshift)

Object is moving toward the observer. Observer hears a higher frequency (Blueshift)

Object is "right beside" the observer. Observer hears the "true" frequency as if the object was not moving.

Doppler Effect Uses

- Astronomy
- Weather radar
- Police radar gun