HOW THINGS WORK (PHYS 1055)

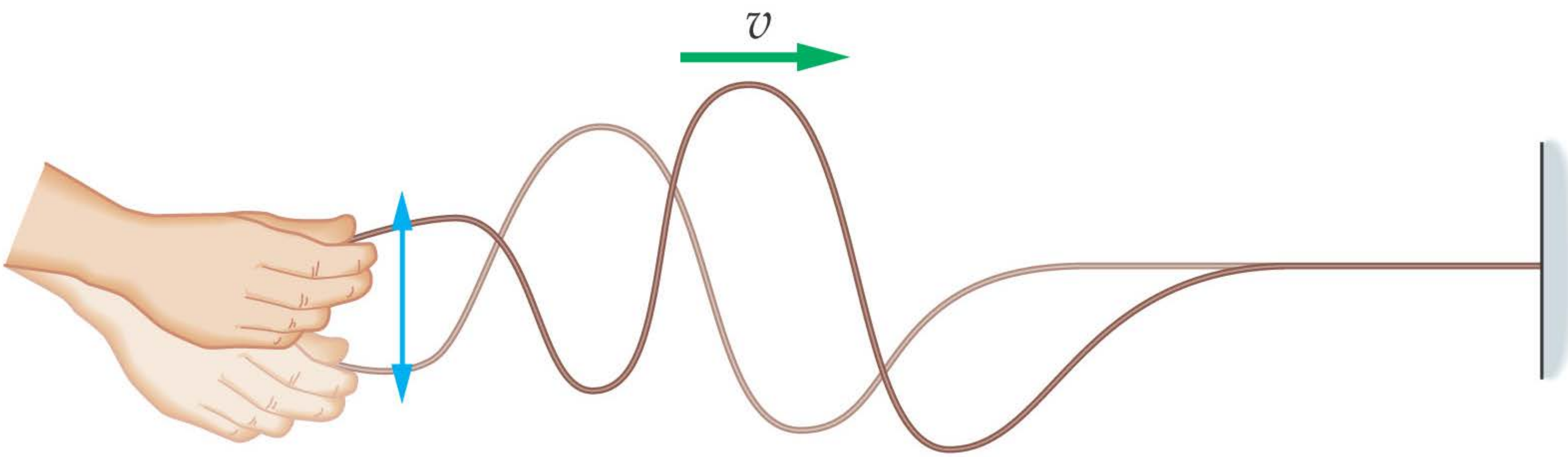
Chapter 7

Waves and Sound

What is wave?

A wave is a disturbance that propagates from one place to another. Or simply, it carries energy from place to place.

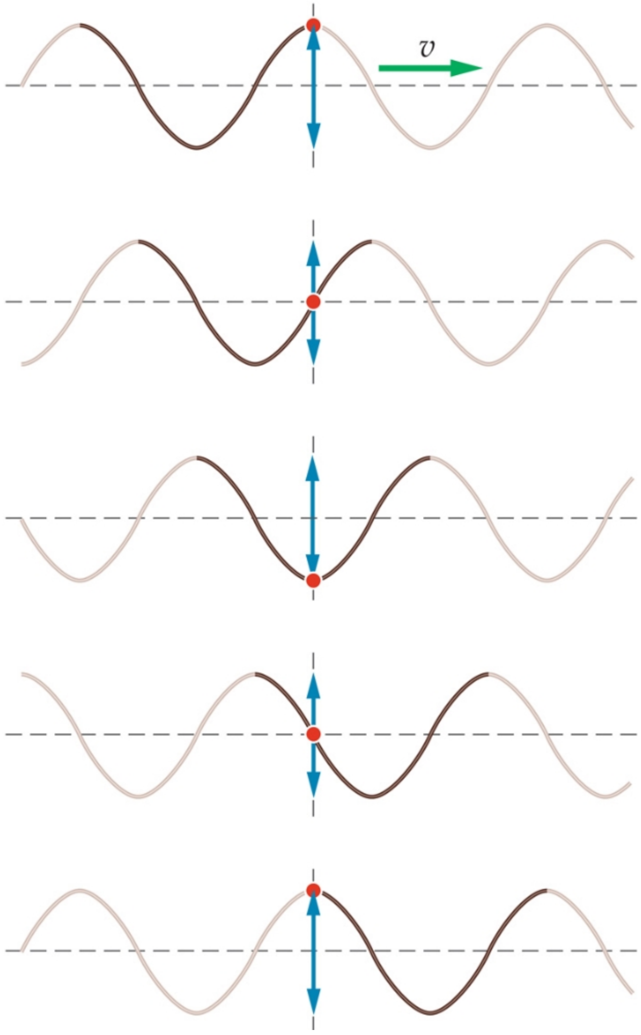
The easiest type of wave to visualize is a transverse wave, where the displacement of the medium is perpendicular to the direction of motion of the wave.



Types of waves

- ***Transverse Wave***

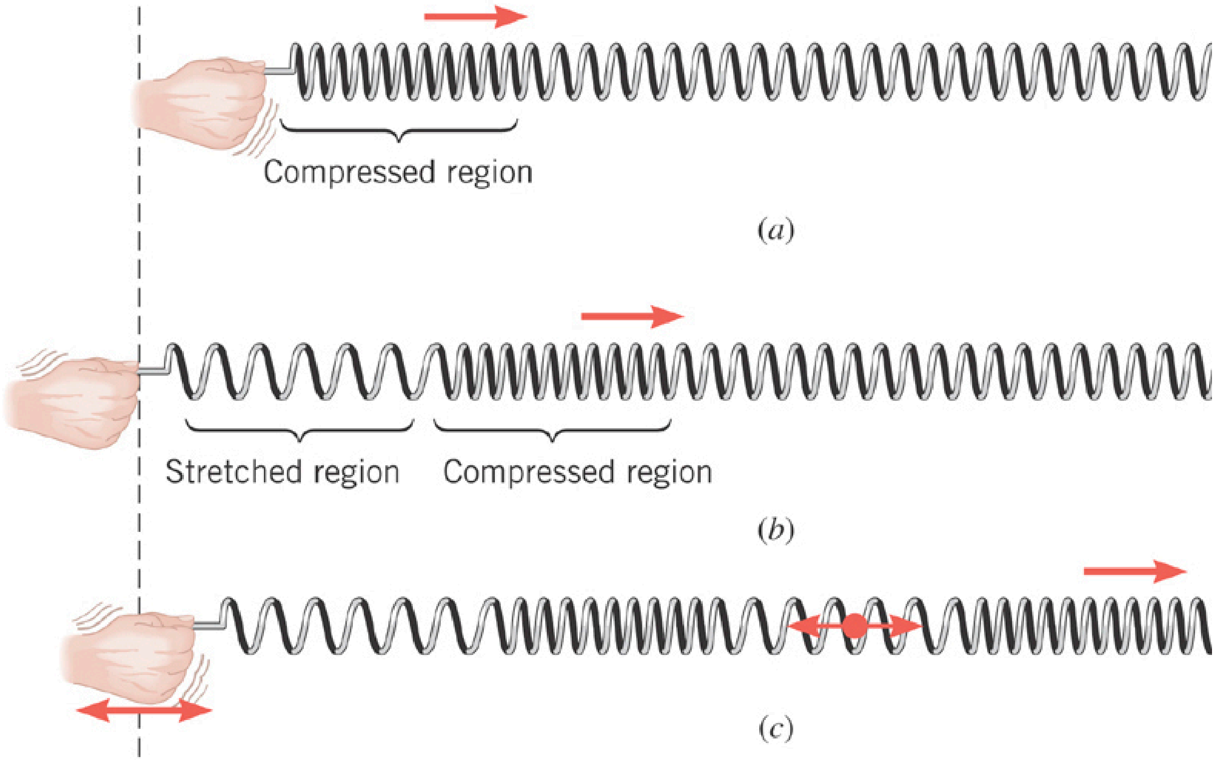
➢ *the displacement of the string element is normal to the direction of wave motion*



Walker, Physics, 3rd edition

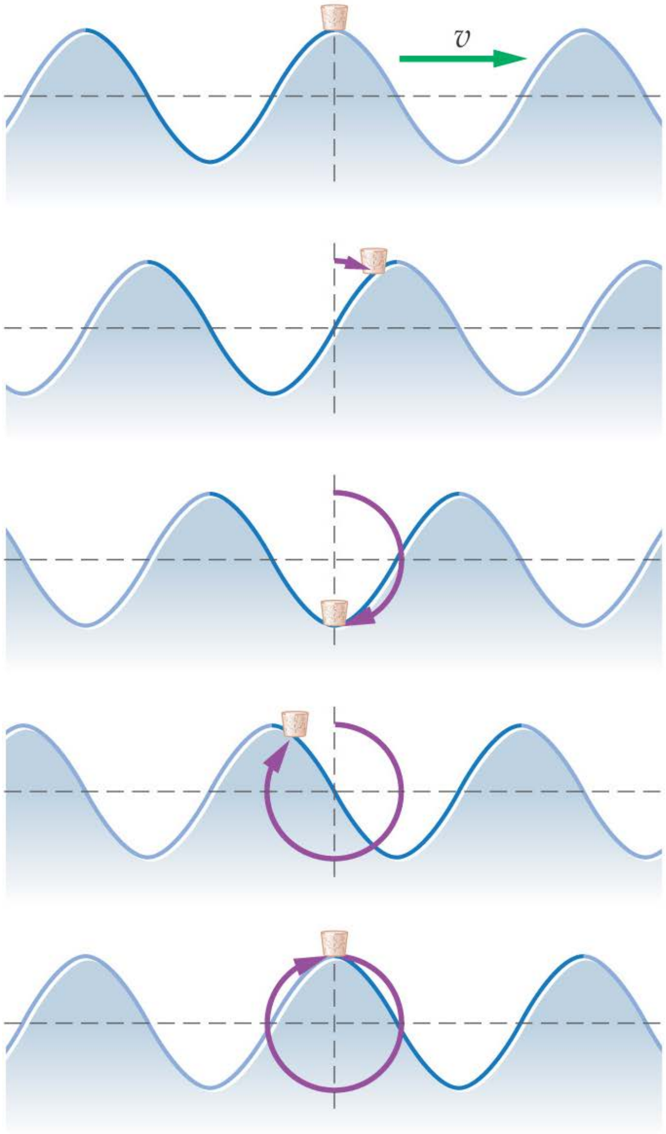
- ***Longitudinal Wave***

> *The displacement of the spring element is along the direction of wave motion*

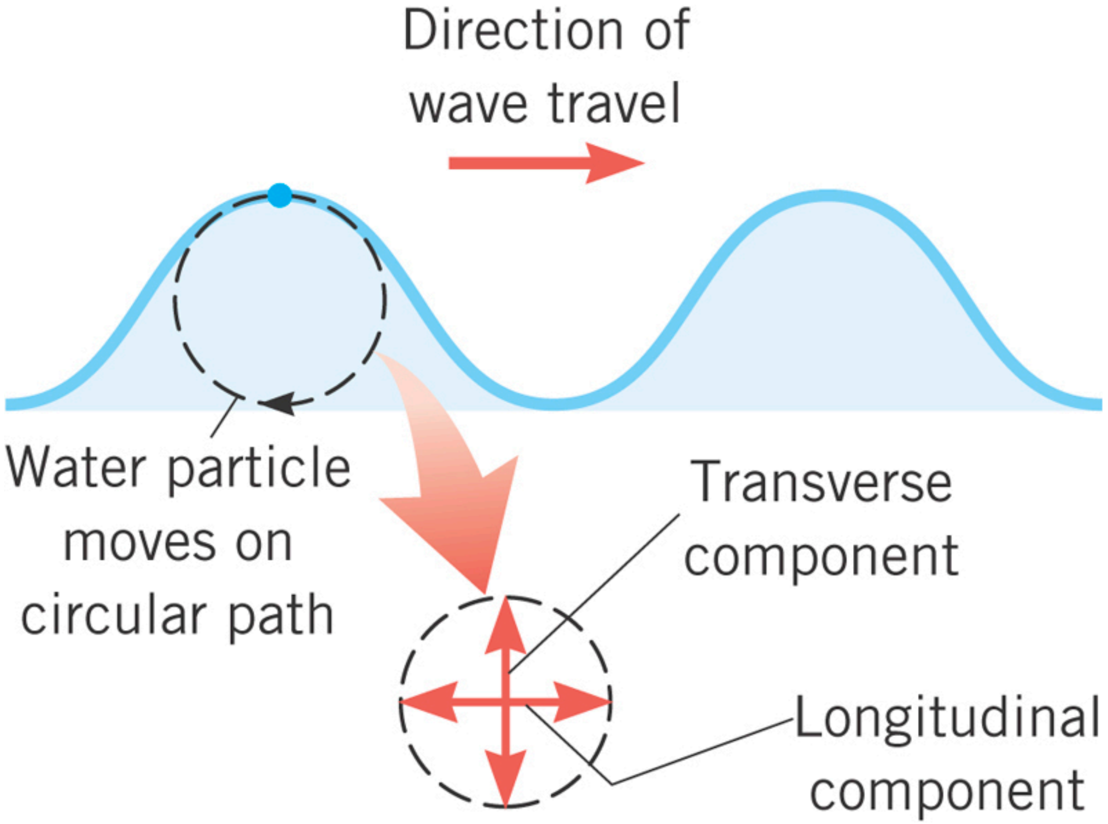


- ***Water waves***

  - Water waves are a combination of transverse and longitudinal waves.

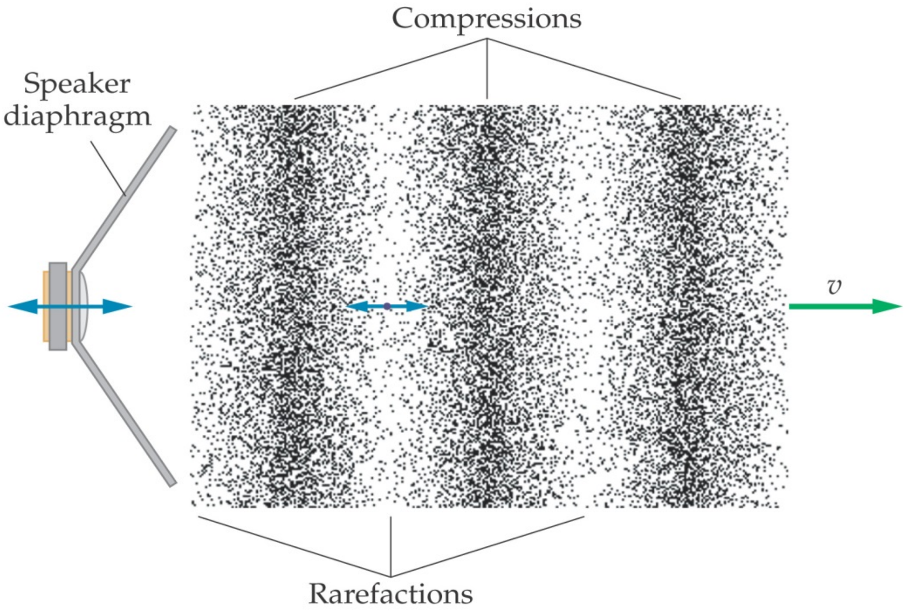


Water waves are partially transverse and partially longitudinal



What is sound?

- Sound is a kind of longitudinal wave that consists of density waves.
- The displacement of particles in the medium is along the direction of wave motion.
- Patterns of compressions and rarefactions that travel outward rapidly from their source.



Sound Waves

- When a sound passes, the air pressure in your ear fluctuates up and down about normal atmospheric pressure.

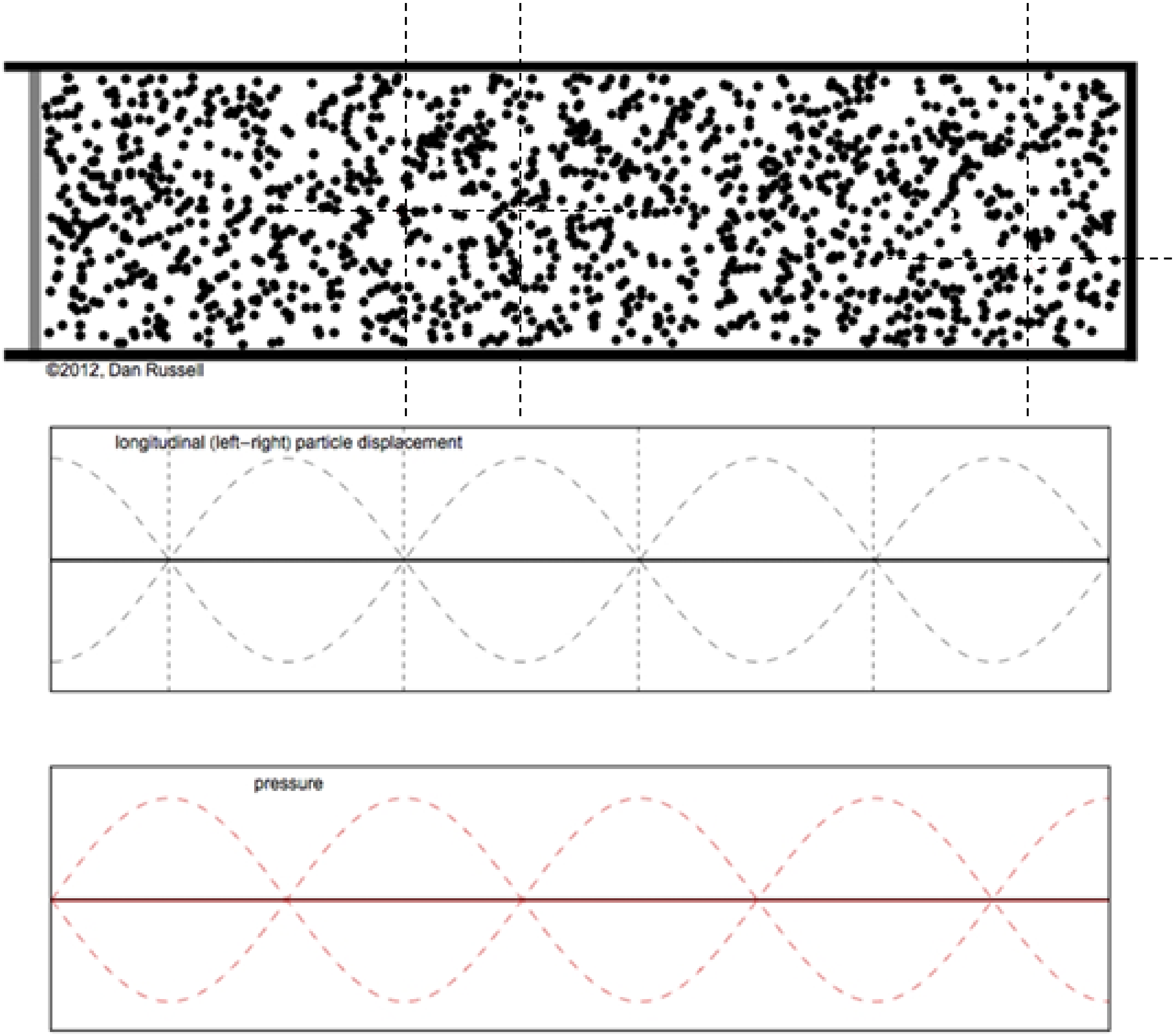
- When the fluctuations are repetitive, you hear a tone with a ***pitch*** equal to the fluctuation's frequency. Strictly speaking, pitch is an auditory sensation to compare the higher and lower frequency.

- Audible frequencies ranging between approximately 20 Hz to 20 000 Hz.

- For some people who have musically trained, are capable of detecting a difference in frequency between two separate sounds that is as little as 2 Hz.

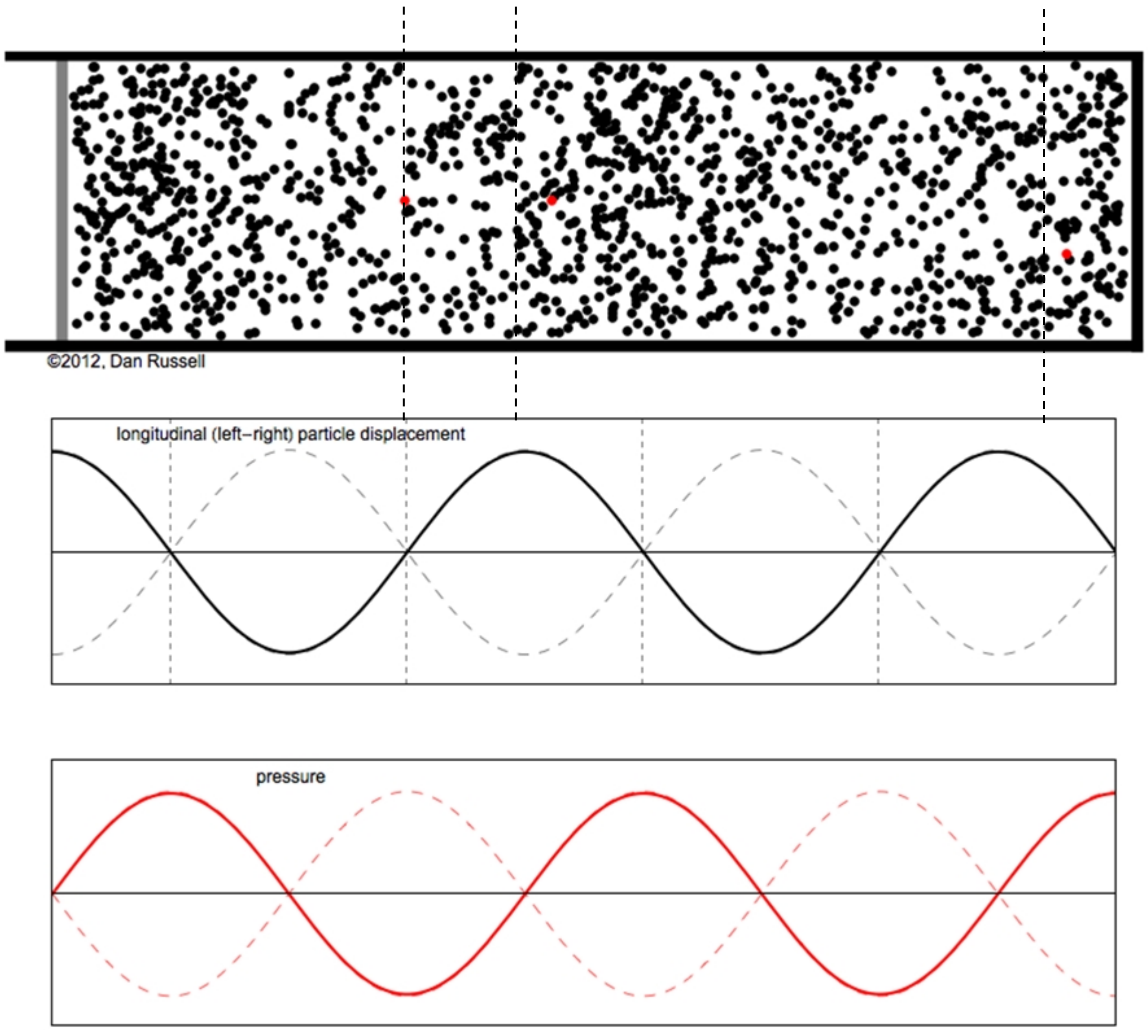
- When two sounds with a frequency difference of greater than 7 Hz are played simultaneously, most people are capable of detecting the presence of a complex wave pattern resulting from them.

Pressure and Density for standing sound wave (1)



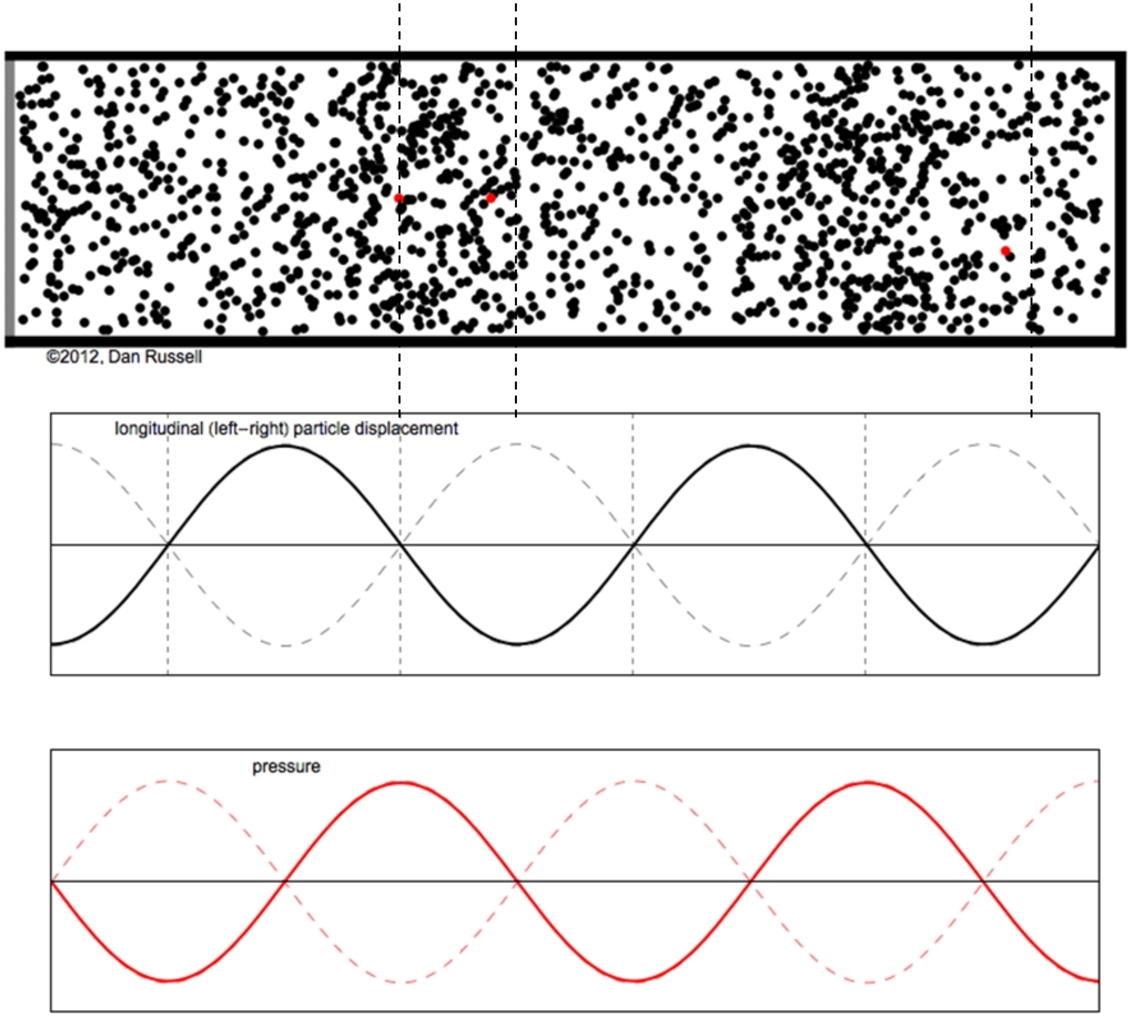
Source: ***http://www.acs.psu.edu/drussell/Demos/StandingWaves/StandingWaves.html***

Pressure and Density for standing sound wave (2)



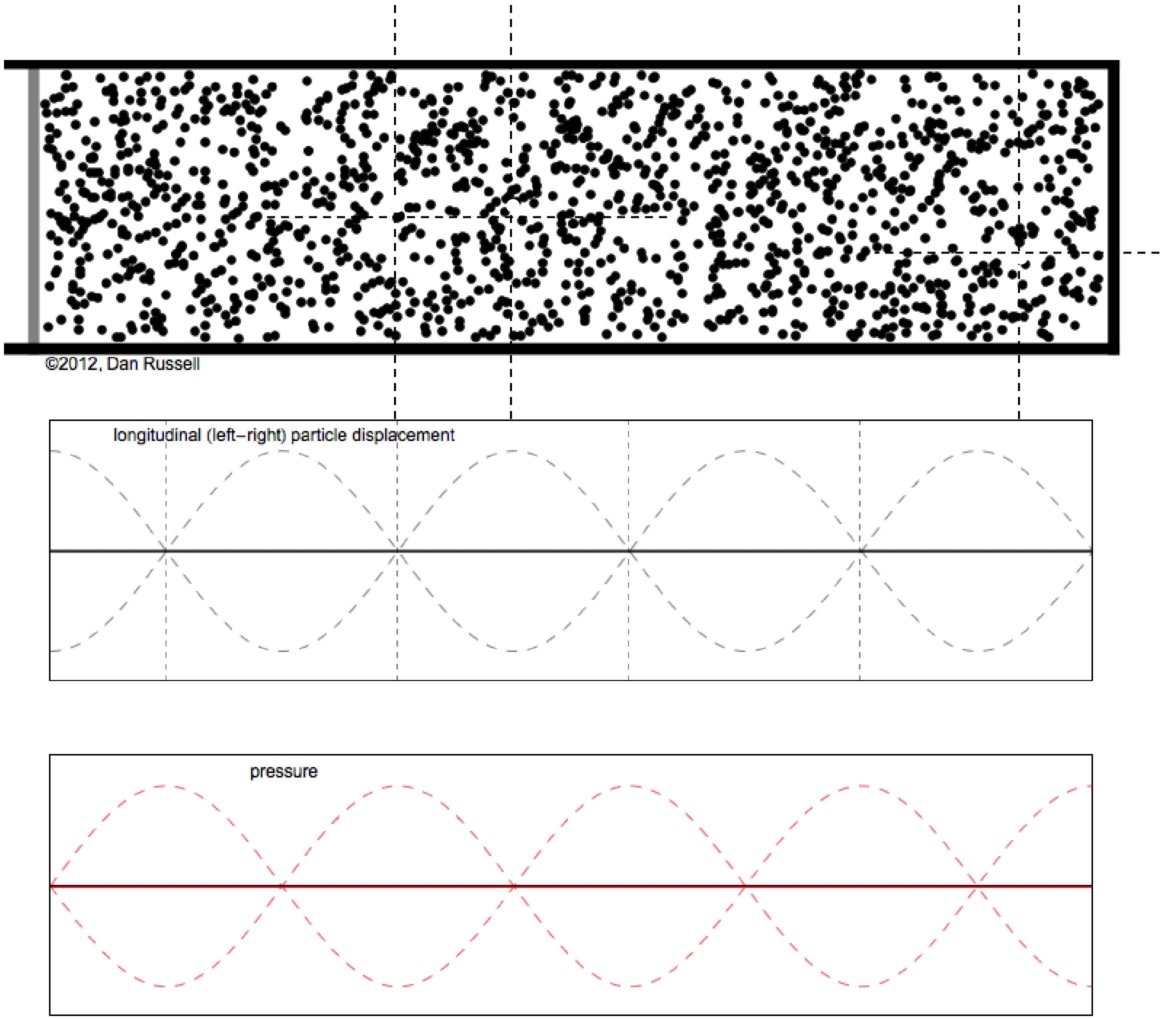
Source: [***http://www.acs.psu.edu/drussell/Demos/StandingWaves/StandingWaves.html***](http://www.acs.psu.edu/drussell/Demos/StandingWaves/StandingWaves.html)

Pressure and Density for standing sound wave (3)



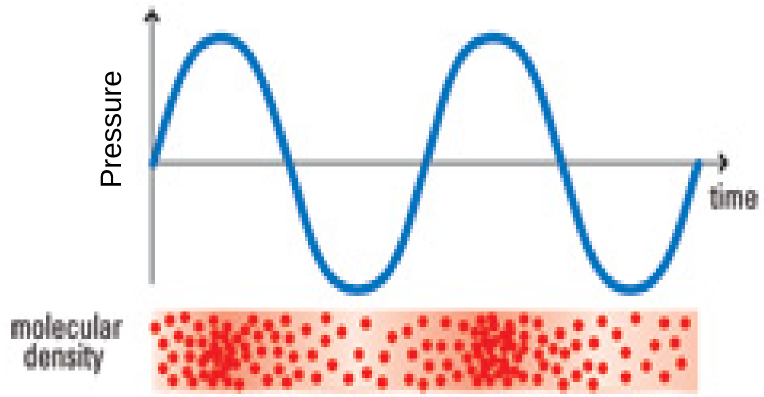
Source: ***http://www.acs.psu.edu/drussell/Demos/StandingWaves/StandingWaves.html***

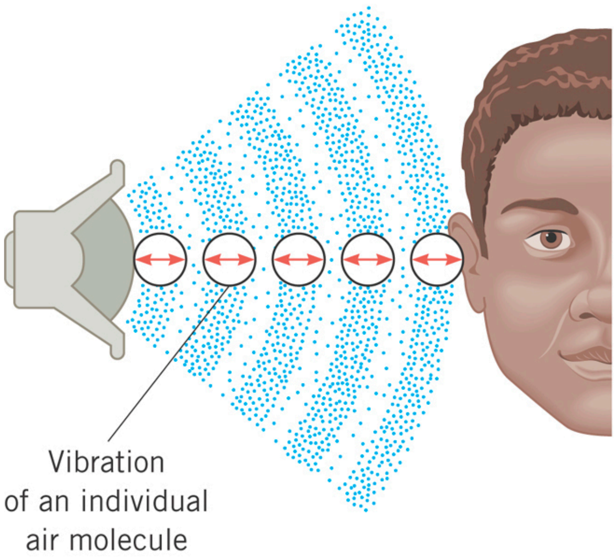
Pressure and Density for standing sound wave (4)

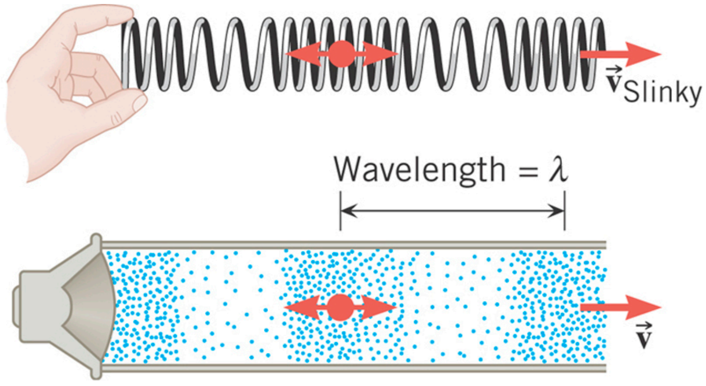


Source: http://www.acs.psu.edu/drussell/Demos/StandingWaves/StandingWaves.html

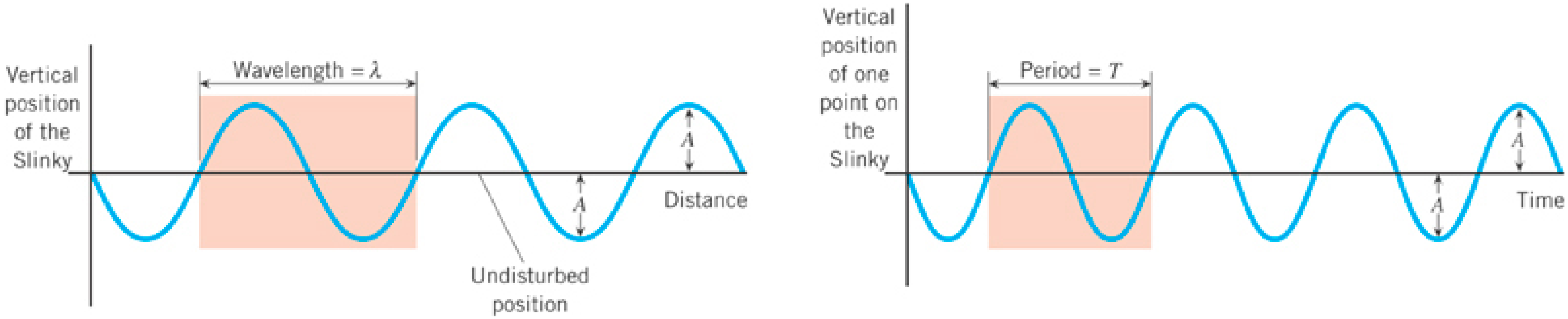
Pressure and Density for sound wave (5)







The distance between adjacent condensations is equal to the wavelength of the sound wave.



(a) At a particular time

(b) At a particular location

In the drawing, one ***cycle*** is shaded in color.

- The ***amplitude*** A is the maximum excursion of a particle of the medium from the particles undisturbed position.
- The ***wavelength*** is the horizontal length of one cycle of the wave.
- The ***period*** is the time required for one complete cycle.
- The ***frequency*** is related to the period and has units of Hz, or s^{-1}.

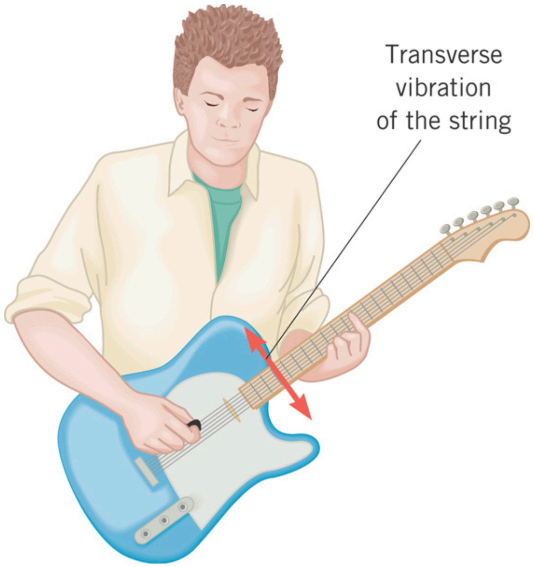
$$f = \frac{1}{T}$$

Waves Traveling on Guitar Strings

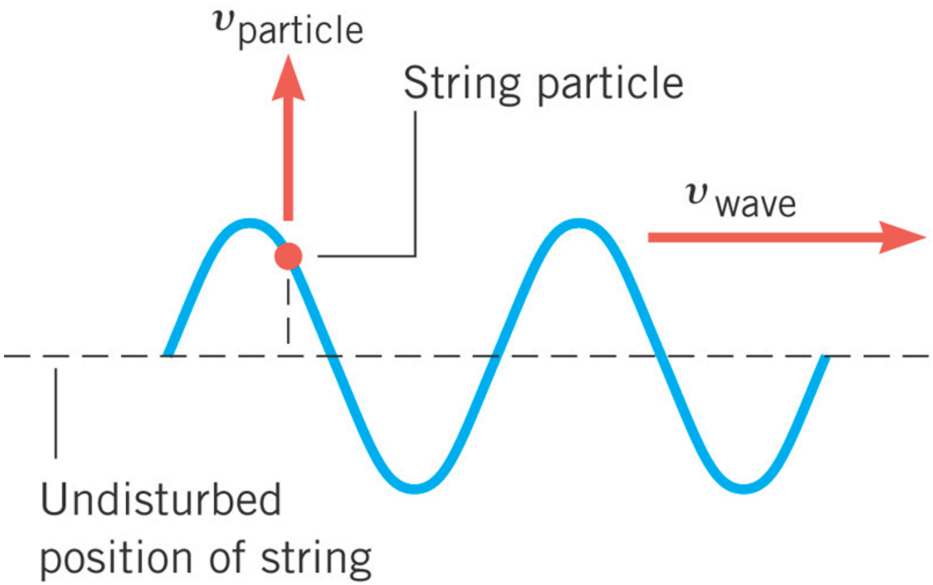
Transverse waves travel on each string of an electric guitar after the string is plucked.

High pitched string
- low density string, i.e. thinner string

Low pitched string
– high density string, i.e. thicker string



Wave Speed Versus Particle Speed

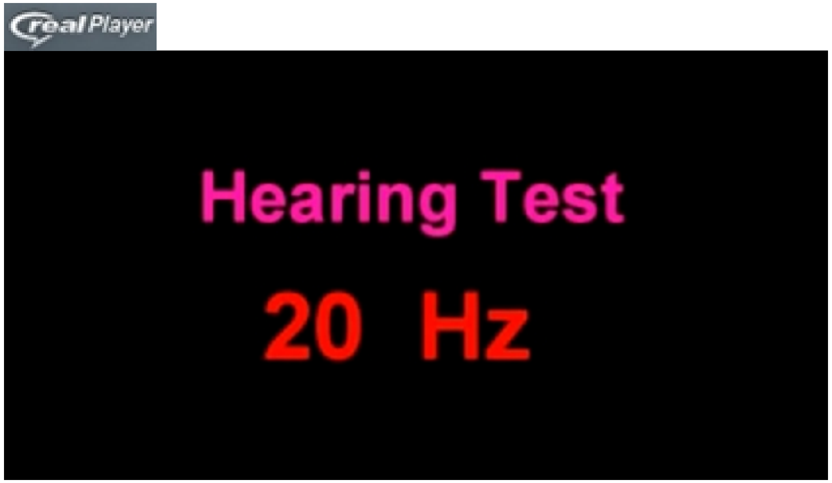


The Frequency of a Sound Wave

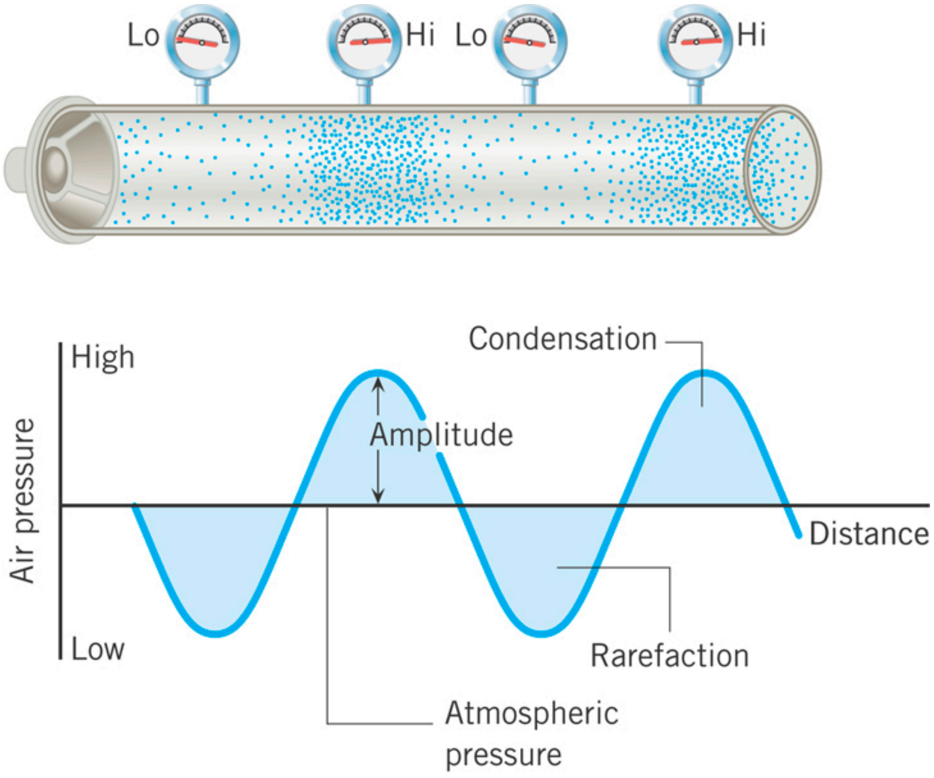
The ***frequency*** is the number of cycles per second.

A sound with a single frequency is called a ***pure tone***.

The brain interprets the frequency in terms of the subjective quality called ***pitch***.



THE PRESSURE AMPLITUDE OF A SOUND WAVE



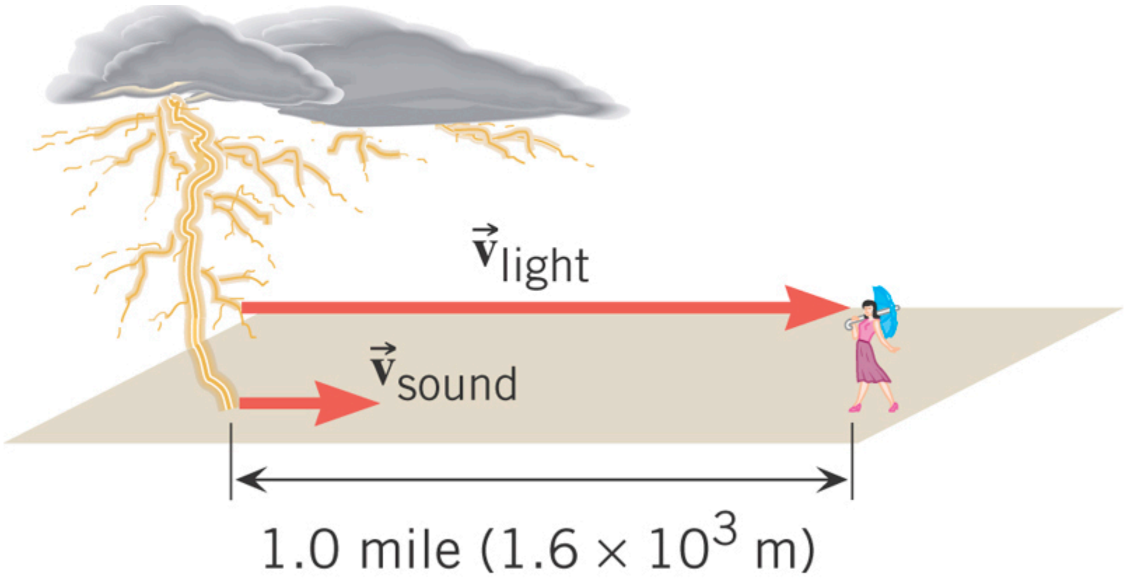
Loudness is an attribute of a sound that depends primarily on the pressure amplitude of the wave. On the other hands, It is subjective. Each individual determines what is loud, depending on the acuteness of his or her hearing.

Speed of Sound in Gases, Liquids, and Solids

Substance	Speed (m/s)
Gases	
Air (0 °C)	331
Air (20 °C)	343
Carbon dioxide (0 °C)	259
Oxygen (0 °C)	316
Helium (0 °C)	965
Liquids	
Chloroform (20 °C)	1004
Ethyl alcohol (20 °C)	1162
Mercury (20 °C)	1450
Fresh water (20 °C)	1482
Seawater (20 °C)	1522
Solids	
Copper	5010
Glass (Pyrex)	5640
Lead	1960
Steel	5960

Lightning, Thunder, and a Rule of Thumb

There is a rule of thumb for estimating how far away a thunderstorm is. After you see a flash of lighting, count off the seconds until the thunder is heard. *Divide the number of seconds by five.* The result gives the approximate distance (in miles) to the thunderstorm. Why does this rule work?

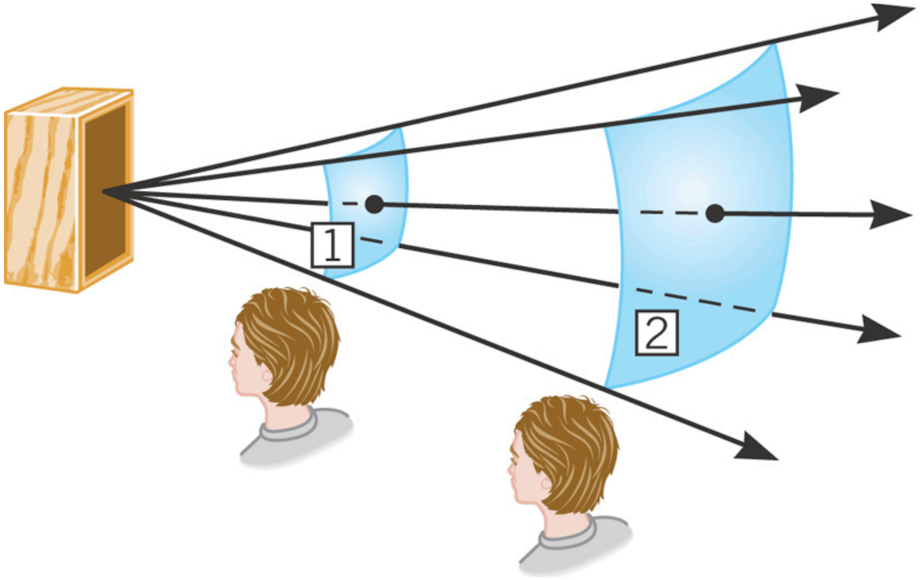


Sound Intensity

Sound waves carry energy that can be used to do work.

The amount of energy transported per second is called the ***power*** of the wave.

The ***sound intensity*** is defined as the power that passes perpendicularly through a surface divided by the area of that surface.

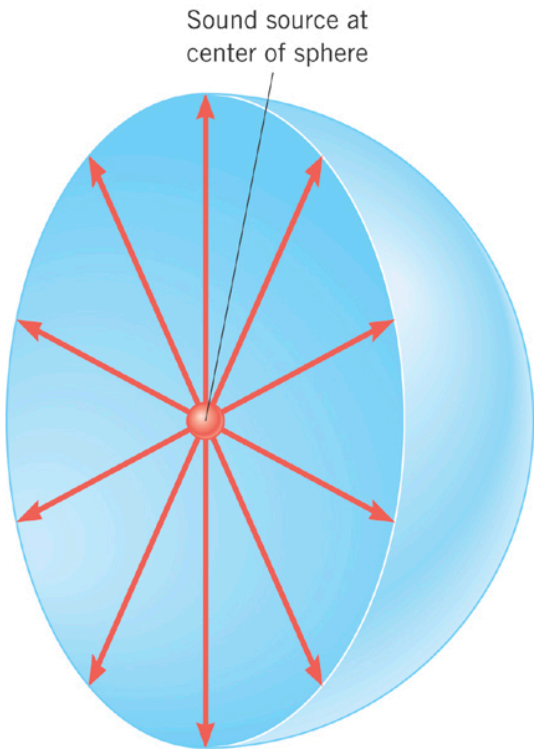


$$I = \frac{P}{A}$$

Sound Intensity

The smallest sound intensity that the human ear can detect is about 1×10^{-12} W/m^2. This intensity is called the ***threshold of hearing***.

On the other extreme, continuous exposure to intensities greater than 1W/m^2 can be painful.



power of sound source

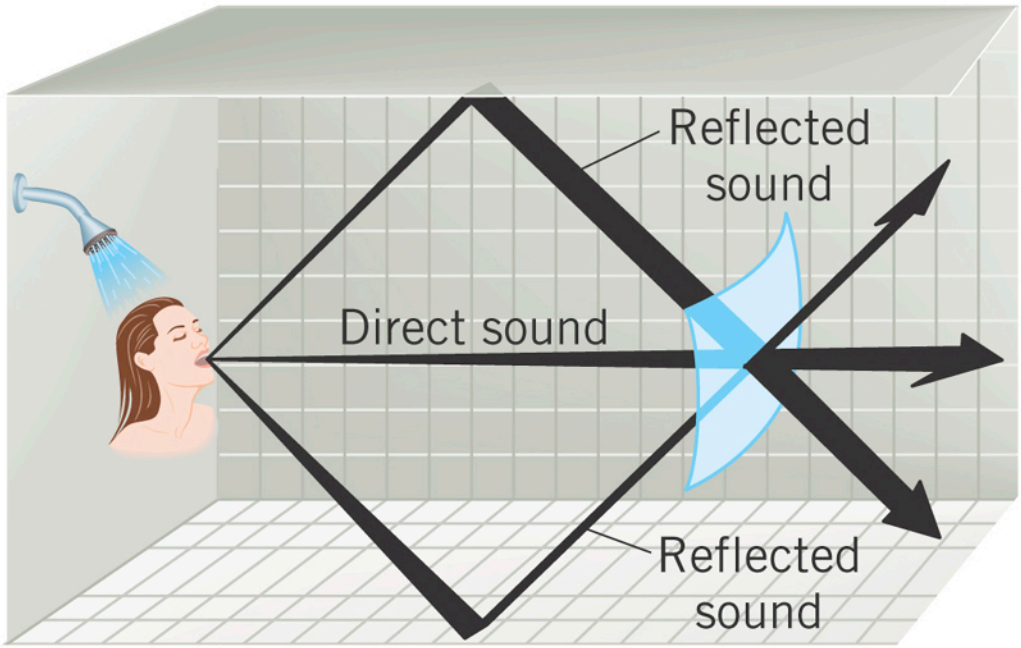
$$I = \frac{P}{4\pi r^2}$$

area of sphere

Reflected Sound and Sound Intensity

Suppose the person singing in the shower produces a sound power. Sound reflects from the surrounding shower stall.

At a distance *r* in front of the person, the sound intensity (power per unit area) is greater because there are reflected sound waves.



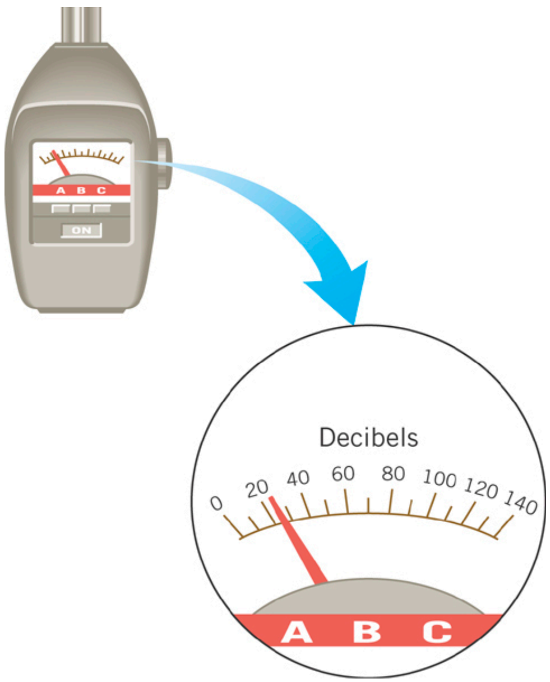
Decibels

The ***decibel*** (dB) is a measurement unit used when comparing two sound intensities.

Because of the way in which the human hearing mechanism responds to intensity, it is appropriate to use a logarithmic scale called the ***intensity level:***

$$\beta = (10\,\mathrm{dB})\log\left(\frac{I}{I_o}\right)$$

$$I_o = 1.00\times 10^{-12}\ \mathrm{W/m^2}$$

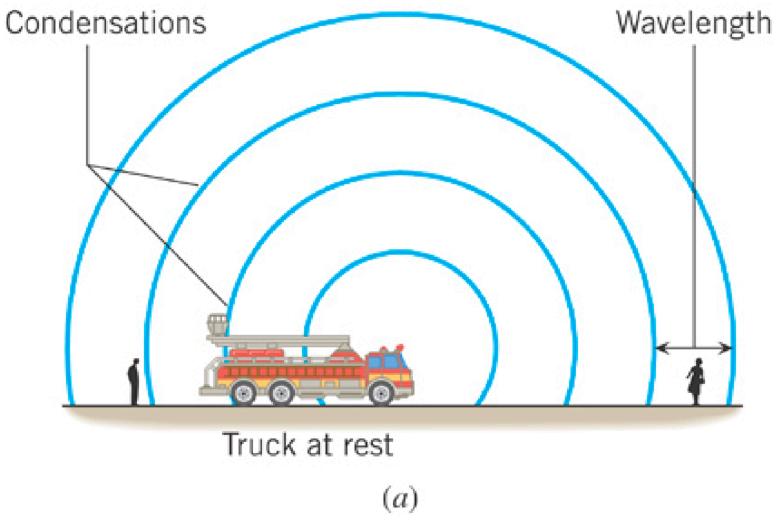


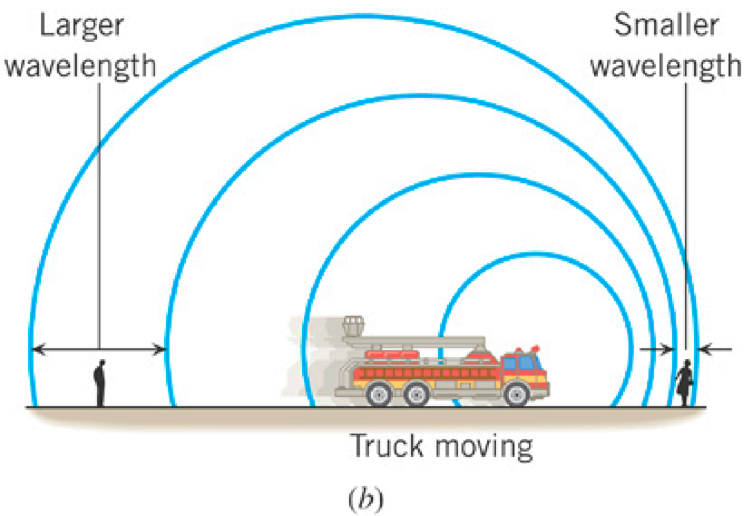
Note that log(1)=0, so when the intensity of the sound is equal to the threshold of hearing, the intensity level is zero.

Typical Sound Intensities and Intensity Levels Relative to the Threshold of Hearing

	Intensity I (W/m^2)	Intensity Level β (dB)
Threshold of hearing	1.0×10^{-12}	0
Rustling leaves	1.0×10^{-11}	10
Whisper	1.0×10^{-10}	20
Normal conversation (1 meter)	3.2×10^{-6}	65
Inside car in city traffic	1.0×10^{-4}	80
Car without muffler	1.0×10^{-2}	100
Live rock concert	1.0	120
Threshold of pain	10	130

The Doppler Effect



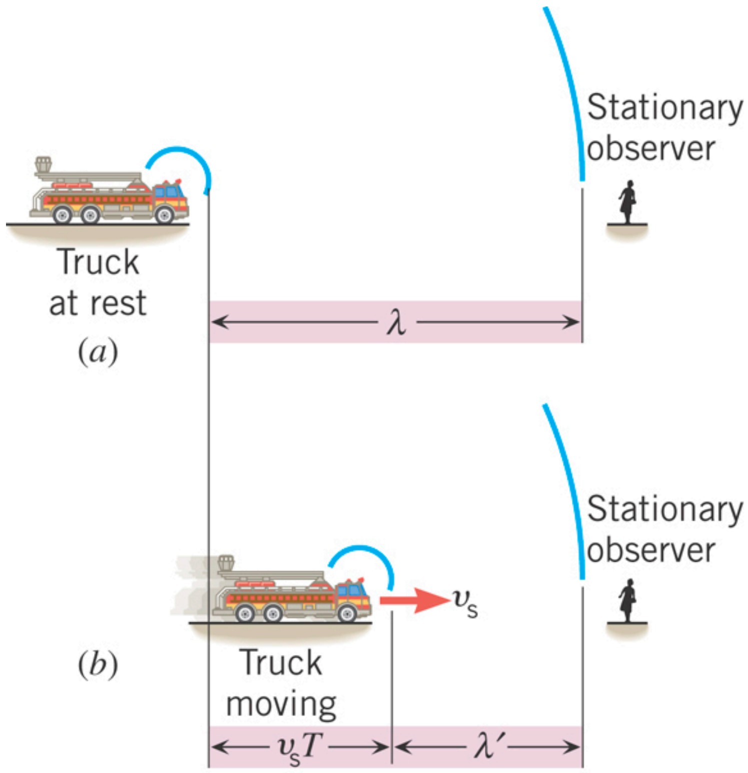


The ***Doppler effect*** is the change in frequency or pitch of the sound detected by an observer because the sound source and the observer have different velocities with respect to the medium of sound propagation.

$$v = f\lambda$$

$$\Rightarrow \qquad f = \frac{v}{\lambda}$$

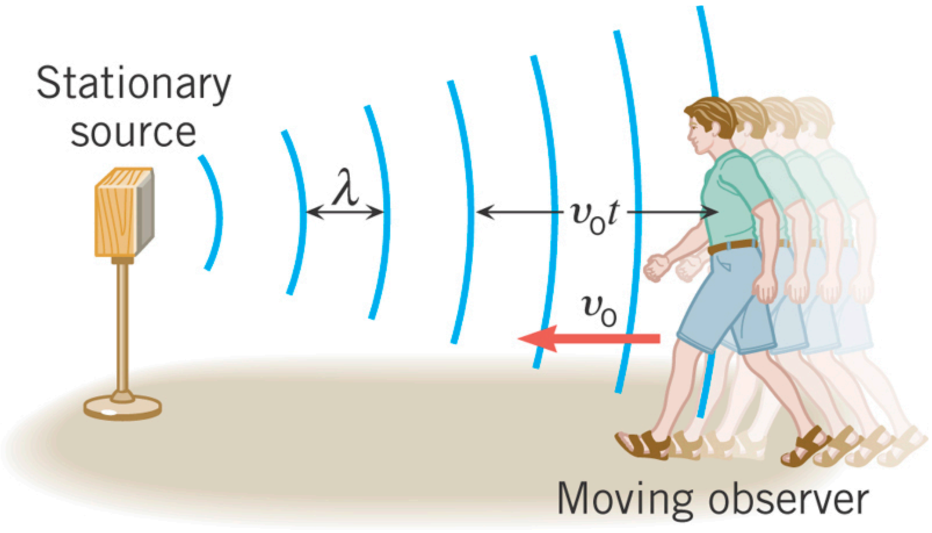
MOVING SOURCE



Source moving toward a stationary observer → ***Higher frequency***

Source moving away from a stationary observer → ***Lower frequency***

MOVING OBSERVER



$$v = f\lambda$$

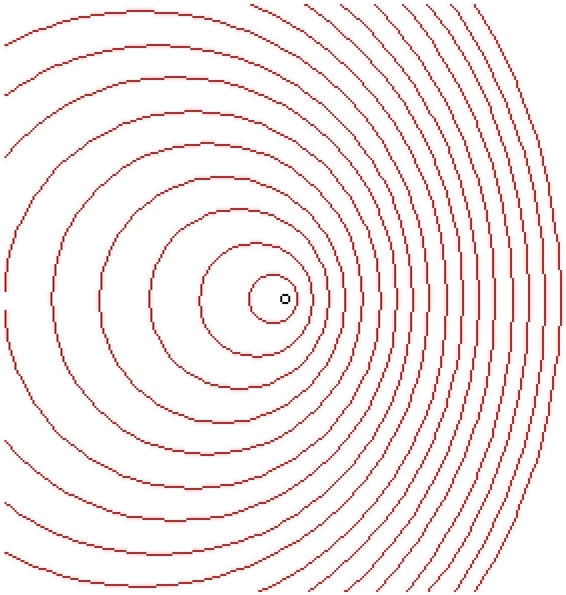
$$\Rightarrow \qquad f = \frac{v}{\lambda}$$

Observer moving towards stationary source → ***Higher frequency***

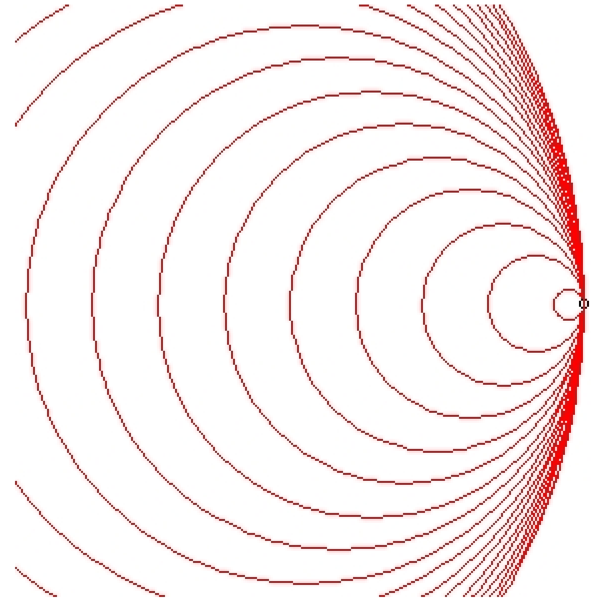
Observer moving away from stationary source → ***Lower frequency***

Sonic Boom

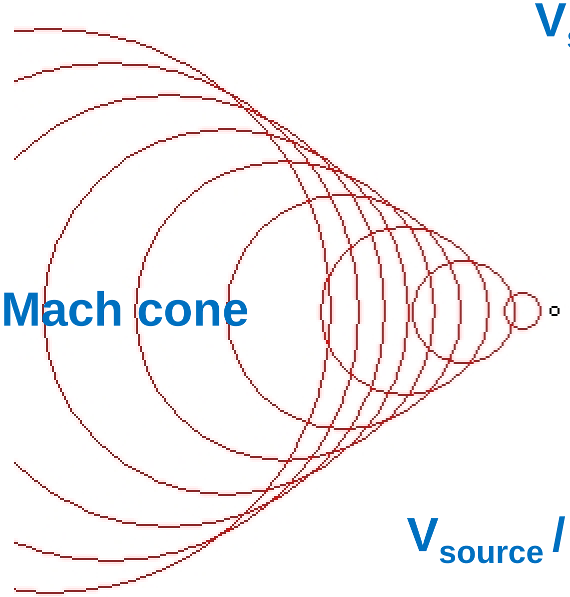
Sonic Boom and Mach Cone



$V_{source} / V_{sound} < 1$

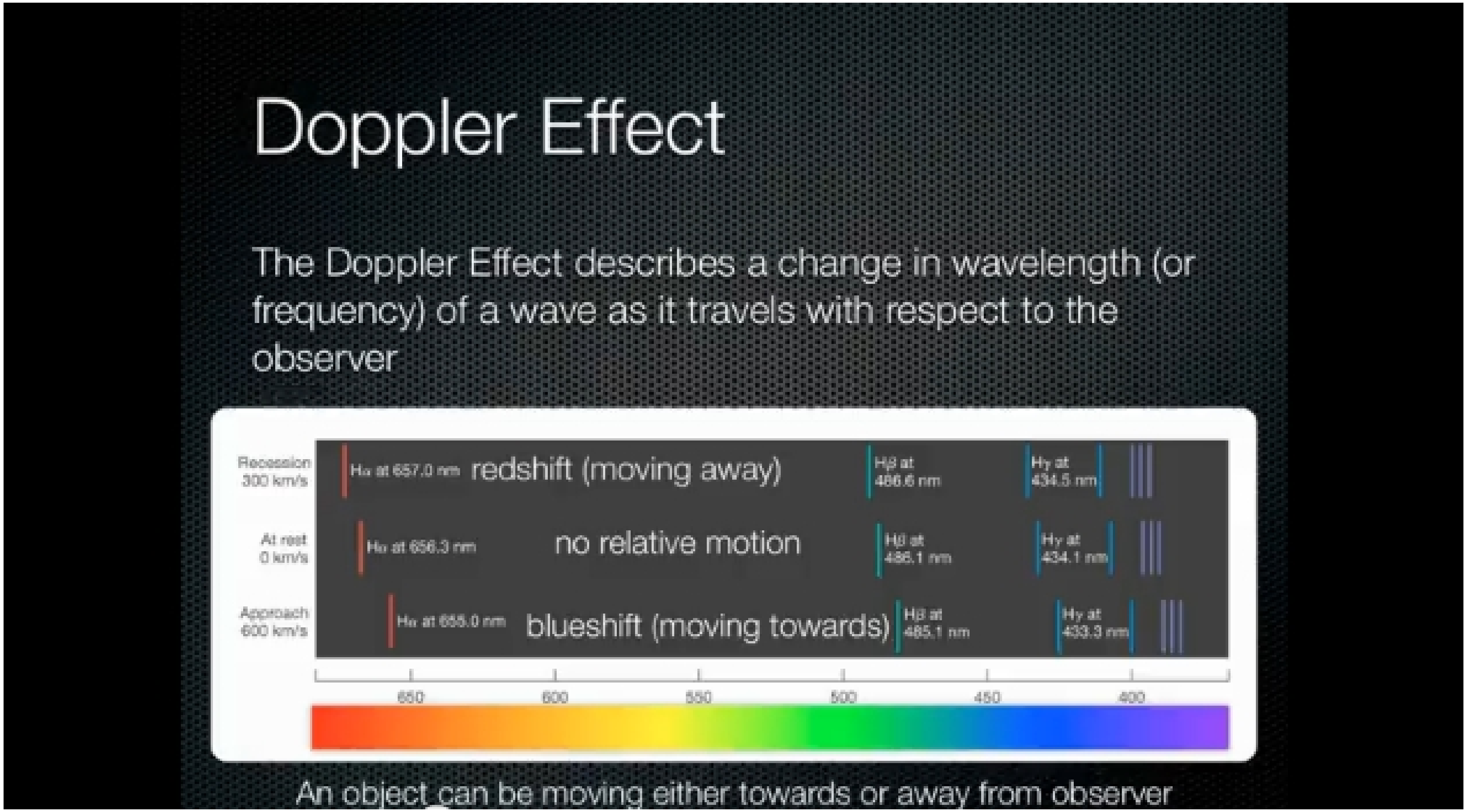


$V_{source} / V_{sound} = 1$

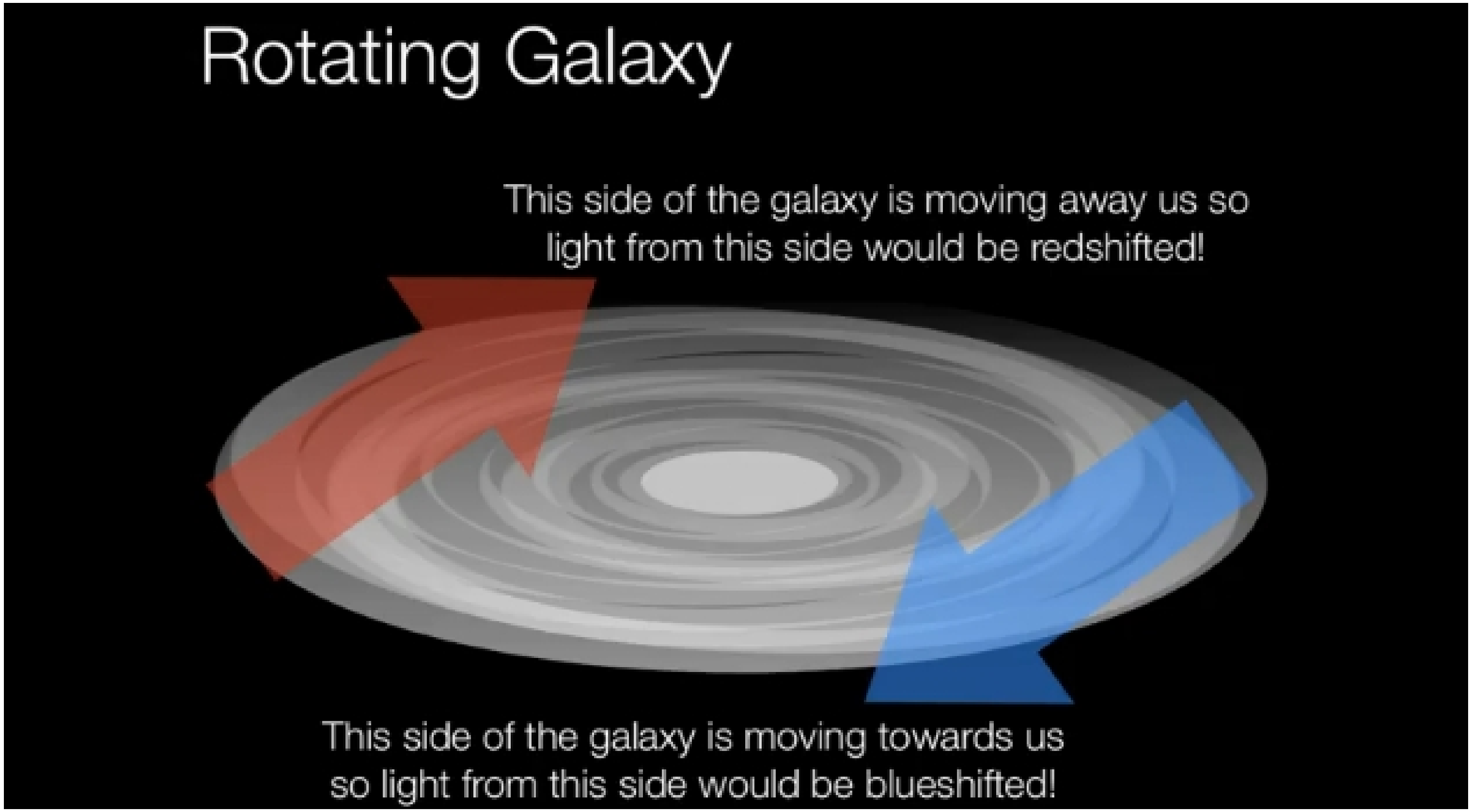


$V_{source} / V_{sound} > 1$

Doppler Effect of Light

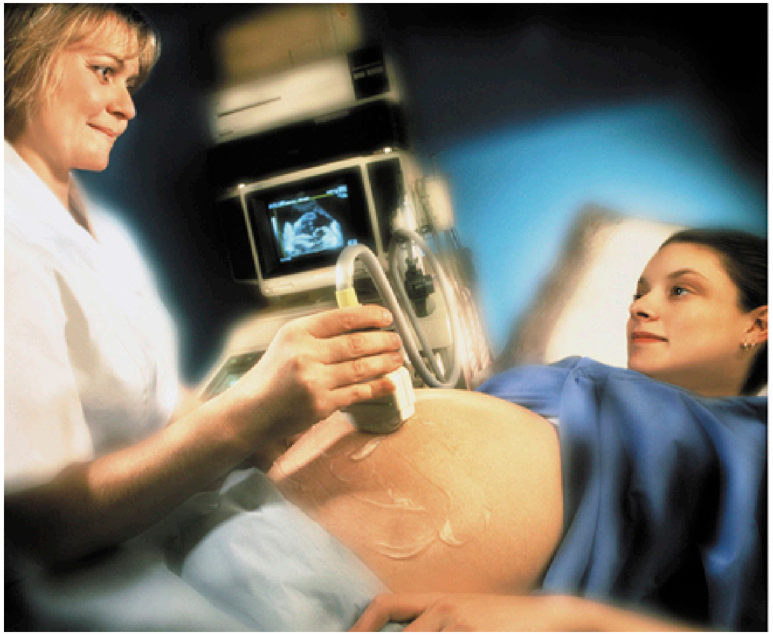


Doppler Effect of Light



Applications of Sound in Medicine

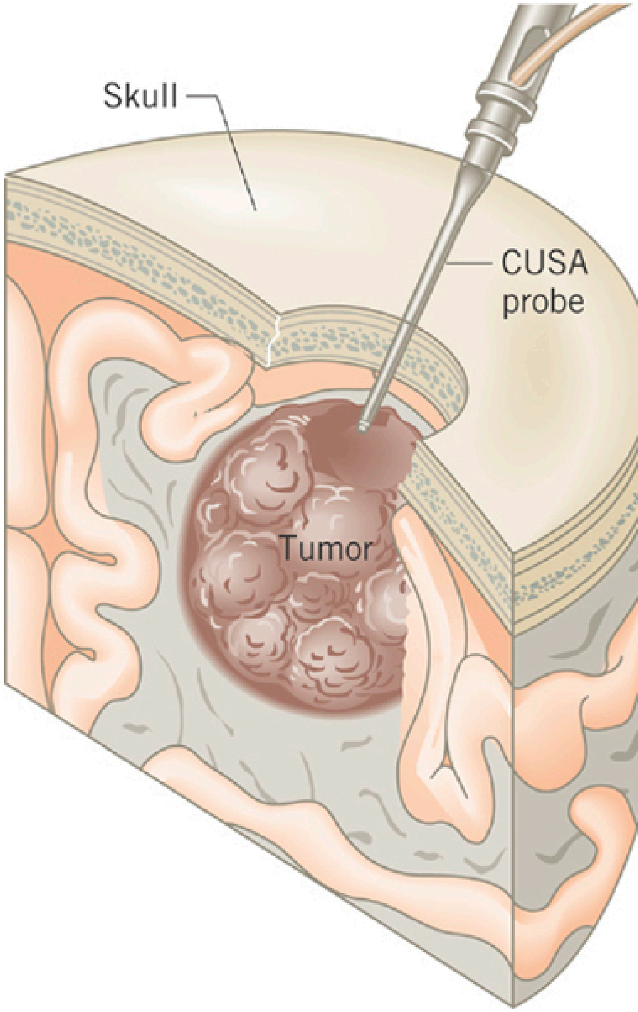
By scanning ultrasonic waves across the body and detecting the echoes from various locations, it is possible to obtain an image.



Cavitron Ultrasonic Surgical Aspirator (CUSA)

Ultrasonic sound waves cause the tip of the probe to vibrate at *23 kHz* and shatter sections of the brain tumor that it touches. The probe is small that it will not damage the surrounding healthy tissue.

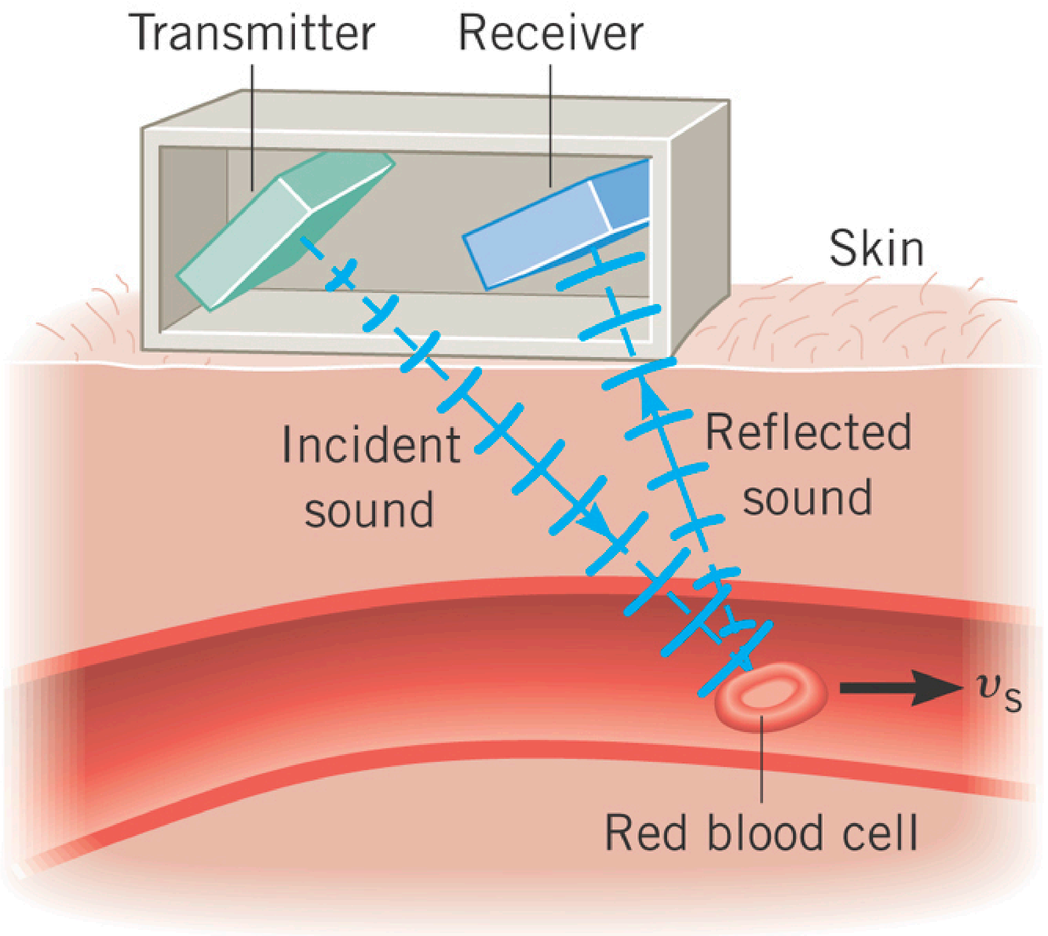
The fragments are flushed out of the brain with a saline solution.



Doppler flow meter

When the sound is reflected from the red blood cells, its frequency is changed in a kind of Doppler effect because the cells are moving.

From the flow speed, it determines the region that the blood vessels has narrowed.



Resonance

During the **resonance**, the amplitude of the oscillation increases dramatically when the frequency of the driven force is near the natural frequency of the system.

The natural frequency is called the **resonance frequency** of the system.

Resonance

Demonstration

Resonance

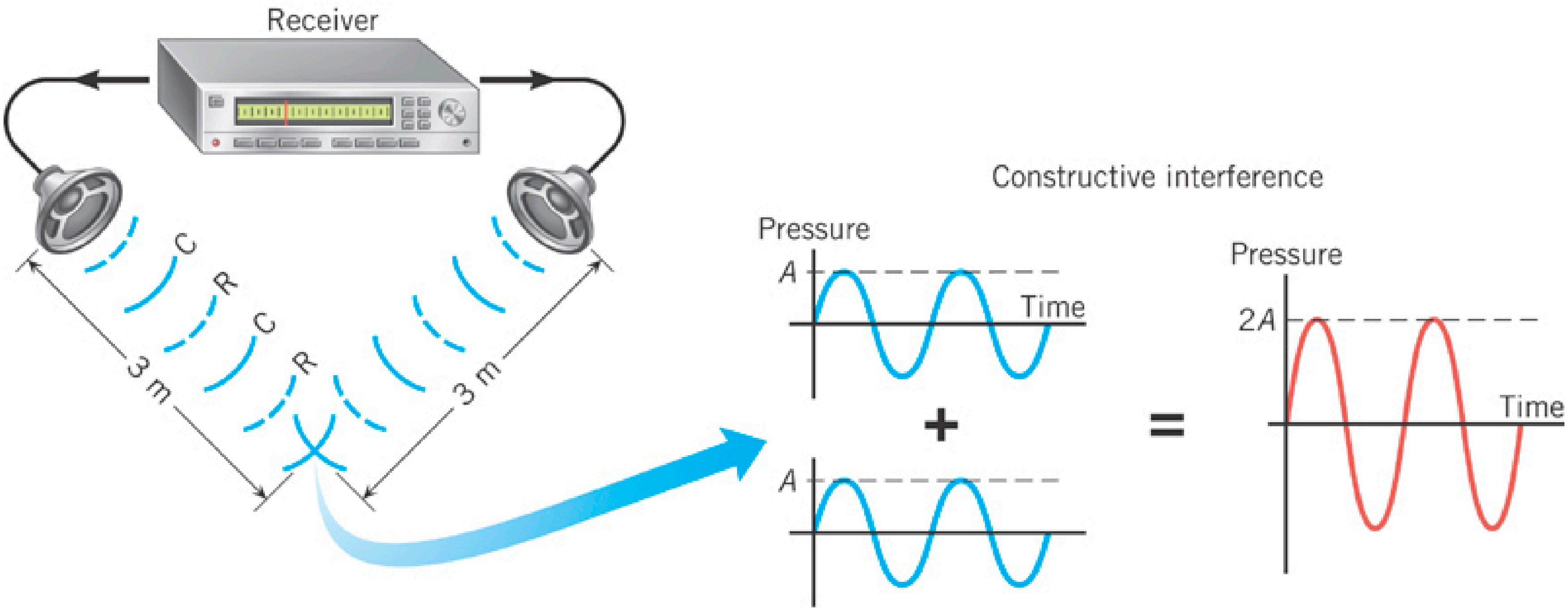
Playing the swing is an example of resonance.

Resonance

Investigate how the player swings to a higher altitude

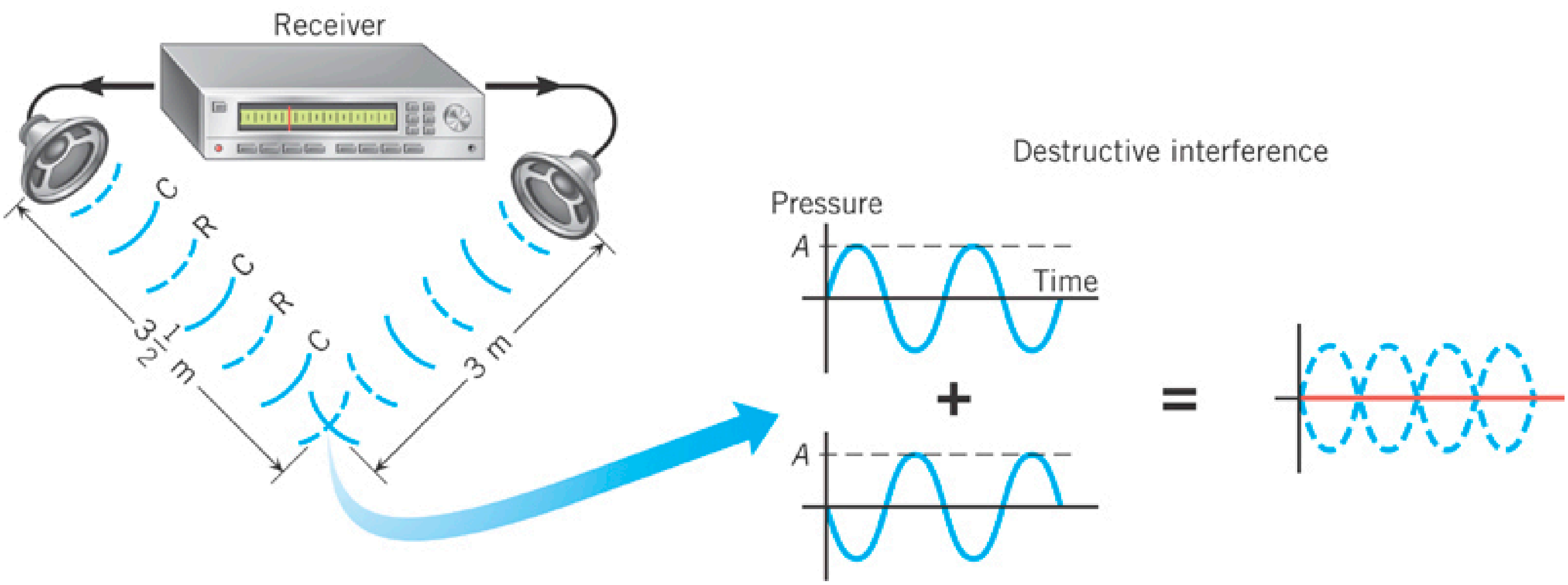
Constructive and Destructive Interference of Sound Waves

When two waves always meet condensation-to-condensation and rarefaction-to-rarefaction, they are said to be ***exactly in phase*** and to exhibit ***constructive interference.***

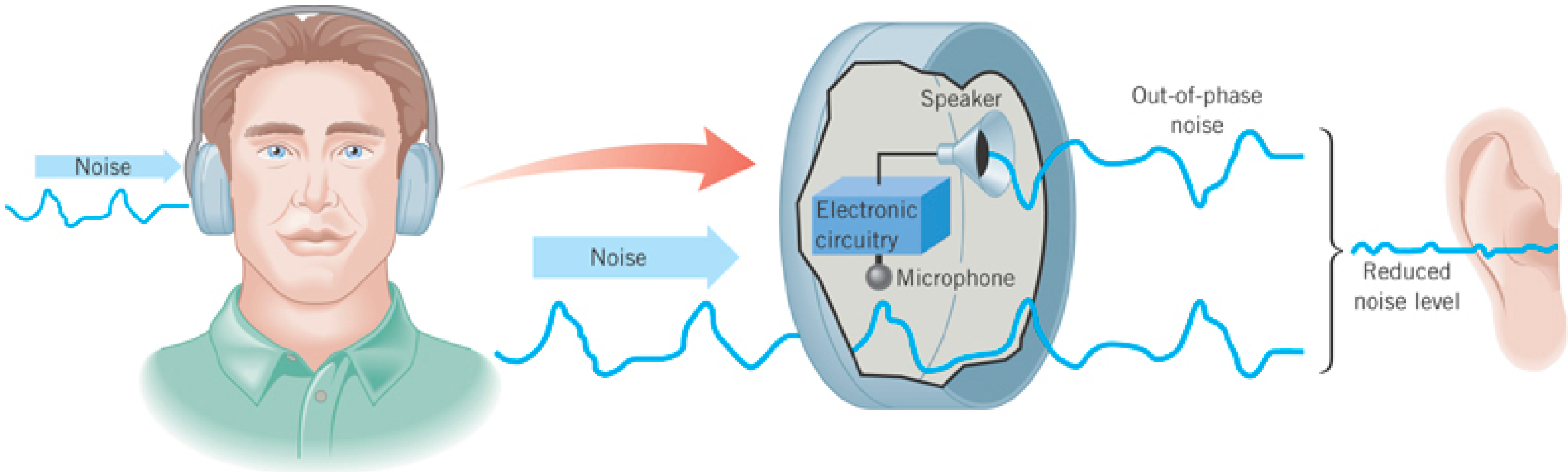


Constructive and Destructive Interference of Sound Waves

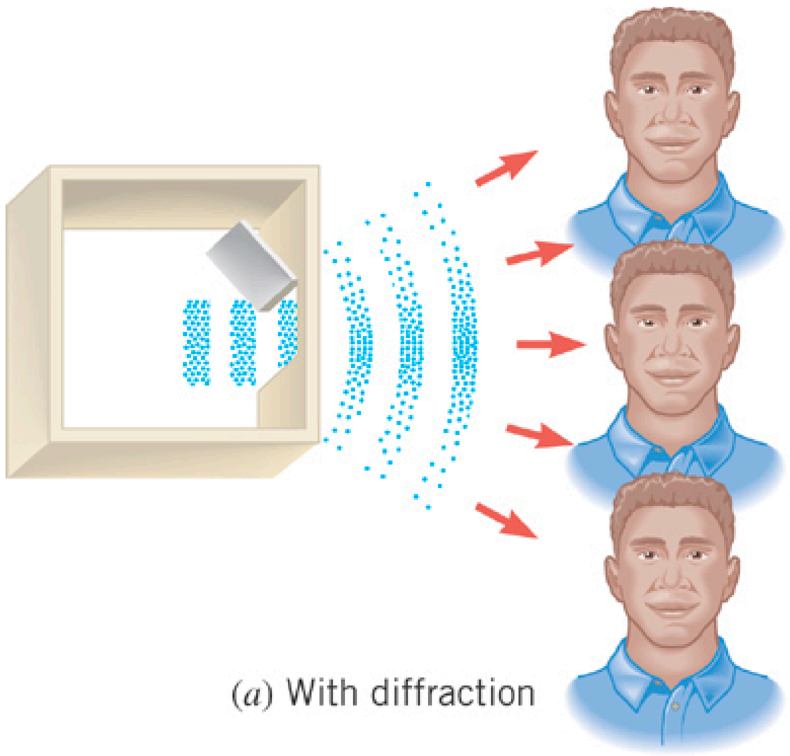
When two waves always meet condensation-to-rarefaction, they are said to be ***exactly out of phase*** and to exhibit ***destructive interference.***

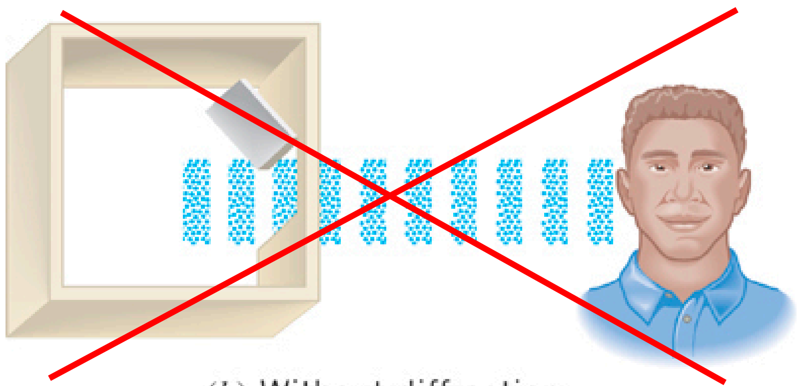


Constructive and Destructive Interference of Sound Waves



Diffraction



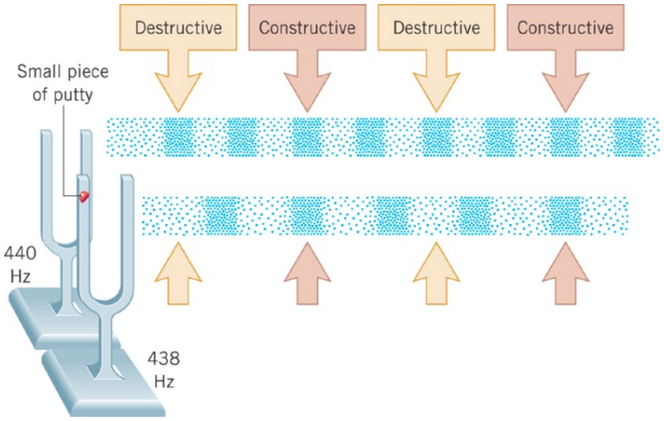


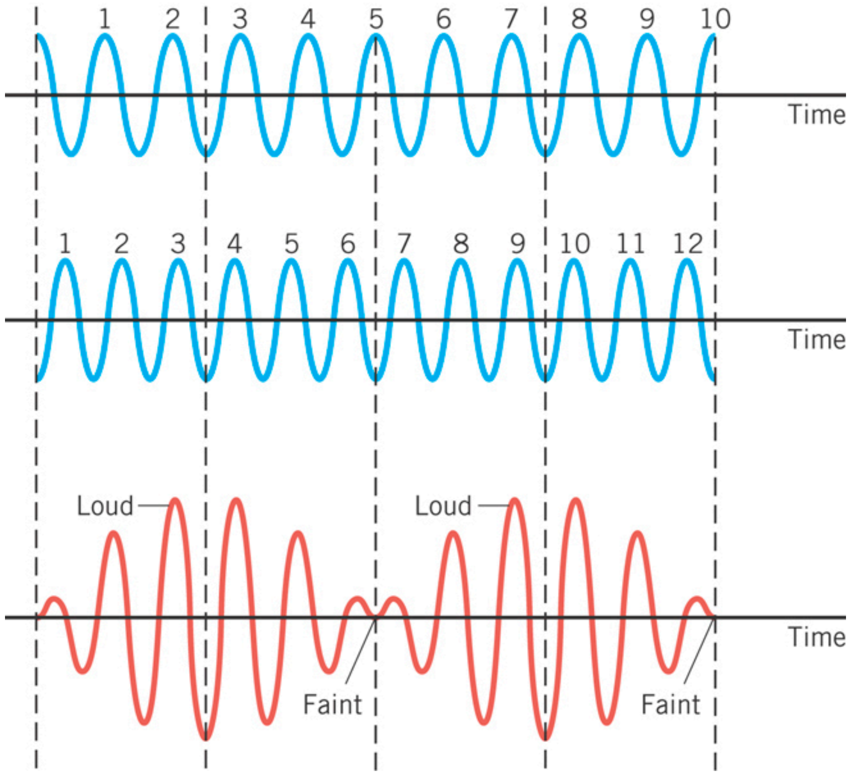
The bending of a wave around an obstacle or the edges of an opening is called ***diffraction***.

For the diffraction of sound, the wavelength of sound and the size of door is comparable.

The listener, who is not staying directly outside the room, can hear the sound.

Beats





The ***beat frequency*** is the ***difference*** between the two sound frequencies.

Beats

The ***beat frequency*** is the ***difference*** between the two sound frequencies.