## Properties of Sound

Sound waves are caused by vibrations and carry energy through a medium.

In air, sound waves spread out in all directions away from the source.

**sound wave:** a longitudinal wave that is caused by vibrations and that travels through a material medium

1

## Speed of Sound

The speed of sound depends on the medium.

The speed of sound in a particular medium depends on how well the particles can transmit the motions of sound waves.

Sound waves travel faster through liquids and solids than through gases.

2

## Speed of Sound in Various Mediums

| **Solids (m/s)** | | **Liquids at 25°C (m/s)** | | **Gases (m/s)** | |
|---|---|---|---|---|---|
| Diamond | 12000 | Glycerol | 1904 | Hydrogen (0°C) | 1286 |
| Pyrex glass | 5640 | Sea water | 1533 | Helium (0°C) | 972 |
| Iron (25°C) | 5130 | Water | 1493 | Oxygen (0°C) | 317 |
| Aluminum | 5100 | Mercury | 1450 | Air (0°C) | 331 |
| Brass | 4700 | Kerosene | 1324 | Air (20°C) | 343 |
| Copper (25°C) | 3560 | Methyl alcohol | 1143 | Air (100°C) | 386 |
| Gold | 3240 | Carbon tetrachloride | 926 | | |
| Lucite | 2680 | | | | |
| Lead | 1322 | | | | |
| Rubber | 1600 | | | | |

3

## Speed of Sound in Air

The speed of sound in air depends on temperature.

$$v_{sound} = 331.3\,m/s + 0.606 \cdot T$$

T = Temperature in Celsius!

4

### Ultrasound and Sonar

Sonar is used to locate objects underwater.

**Sonar: s**ound **n**avigation **a**nd **r**anging, a system that uses acoustic signals and echo returns to determine the location of objects or to communicate.

A sonar system determines distance by measuring the time it takes for sound waves to be reflected back from a surface.

$$d = vt$$

*d* is distance
*v* is the average speed of the sound waves in water
*t* is time

5

### Ultrasound and Sonar, *continued*

Ultrasound imaging is used in medicine.

The echoes of very high frequency ultrasound waves, between 1 million and 15 million Hz, are used to produce computerized images called *sonograms*.

Some ultrasound waves are reflected at boundaries.

Some sound waves are reflected when they pass from one type of material into another.

How much sound is reflected depends on the density of the materials at each boundary.

The reflected waves can be made into a computer image called a *sonogram.*

6

## The Doppler Effect

Motion between the source of waves and the observer creates a change in observed frequency.

Pitch is determined by the frequency of sound waves.

The *pitch* of a sound (how high or low it is) is determined by the frequency at which sound waves strike the eardrum in your ear.

A higher-pitched sound is caused by sound waves of higher frequency.

7

## The Doppler Effect, *continued*

Pitch is determined by the frequency of sound waves.

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A higher-pitched sound is caused by sound waves of higher frequency.

8

## The Doppler Effect, *continued*

Frequency changes when the source of waves is moving.

– **Doppler effect:** an observed change in the frequency of a wave when the source or observer is moving

– The Doppler effect occurs for many types of waves, including sound waves and light waves.

9

## The Doppler Equation

$$f_d = f_s\left(\frac{v - v_d}{v - v_s}\right)$$

$V_d$ = velocity of detector (listener)

**$V_d$: toward is – , away is +**

$V_s$ = velocity of sound output (disturbance)

**$V_s$: toward is + , away is –**

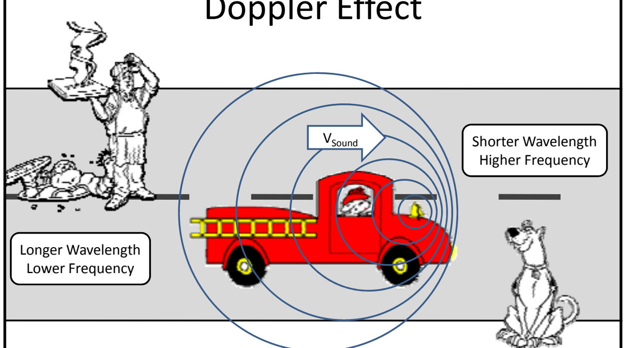
V = speed of wave at given temperature

$f_s$ = frequency of sound

$f_d$ = frequency listener hears

10

## Doppler Effect




11

## Hearing and the Ear

The human ear is a sensitive organ that senses vibrations in the air, amplifies them, and then transmits signals to the brain.

Vibrations pass through three regions in the ear.

Your ear is divided into three regions —outer, middle, and inner.

12

## Hearing and the Ear, *continued*

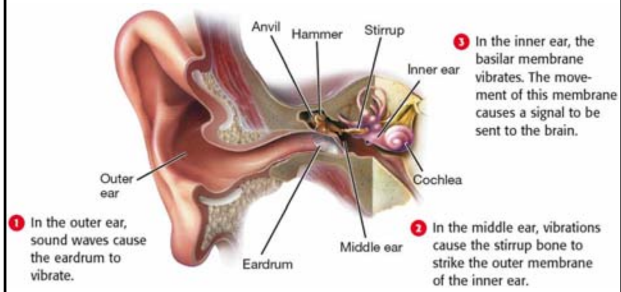
Resonance occurs in the inner ear.

A wave of a particular frequency causes a specific part of the basilar membrane to vibrate.

Hair cells near the part of the membrane that vibrates then stimulate nerve fibers that send an impulse to the brain.

13

## The Ear




14

## Loudness / Intensity

Loudness is determined by intensity.

***loudness***: depends partly on the energy contained in the sound wave

– This is based on our perception

***intensity***: describes the rate at which a sound wave transmits energy through a given area of a medium

– Intensity is measured in units called *decibels*, dB.

This is often called SPL (sound pressure level)

15

## Loudness / Intensity

The greater the intensity of a sound, the louder the sound will seem.

Decibels are logarithmic.

A sound that has 10 times the intensity is 10 dB higher.

Sound at 120 dB is 100 times more intense than 100 dB.

Rule of Thumb: Every 10dB sounds twice as loud.

Ex: Ten violins will sound twice as loud as one violin.

16

## Loudness / Intensity , *continued*

Intensity depends on

- The amplitude of the sound wave

  An amplifier is used to increase the amplitude

  A doubling of power will gain 3 dB

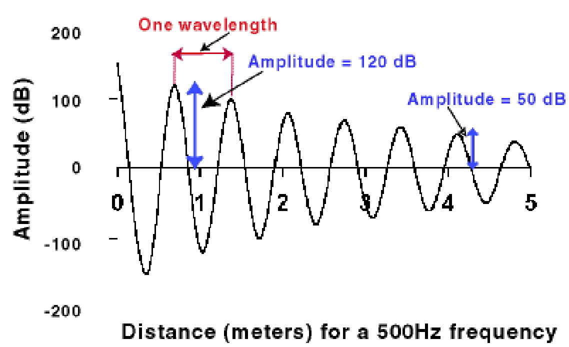
- Your distance from the source

  This is an inverse square relationship

  A set of Ipod headphone can reach 110dB to 120 dB in your ear. At a few meters away they are barely heard.

17

## Sound Intensity and Decibel Level




18

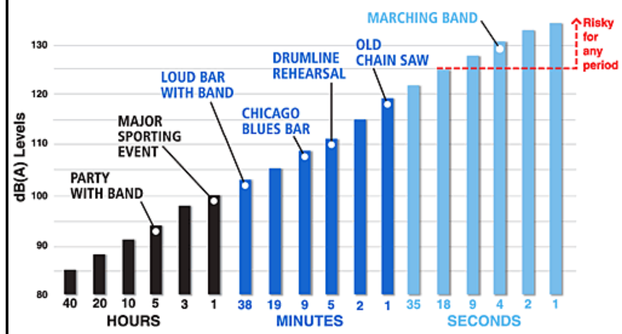
## Sound Intensity and Decibel Level

**Some Common Decibel Levels**

| Sound | Decibel level |
|---|---|
| The softest sounds you can hear | 0 |
| Whisper | 20 |
| Purring cat | 25 |
| Normal conversation | 60 |
| Lawn mower, vaccum cleaner, truck traffic | 80 |
| Chain saw, snowmobile | 100 |
| Sandblaster, loud rock concert, automobile horn | 115 |
| Threshold of pain | 120 |
| Jet engine 30 m away | 140 |
| Rocket engine 50 m away | 200 |

19

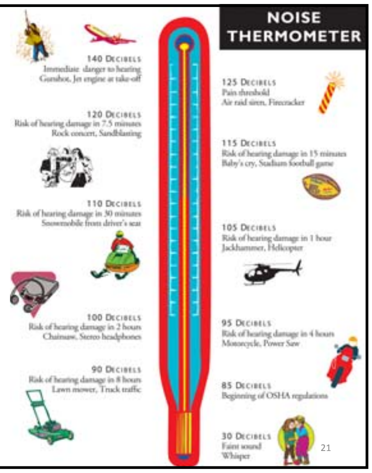
## Music and Hearing Damage




20

OSHA Noise Exposure Limits

| Noise Level | Exposure Limit |
|---|---|
| 90 dBA | 8.0 hours |
| 92 dBA | 6.0 hours |
| 95 dBA | 4.0 hours |
| 97 dBA | 3.0 hours |
| 100 dbA | 2.0 hours |
| 102 dBA | 1.5 hours |
| 105 dBA | 1.0 hours |
| 110 dBA | 30 minutes |
| 115 dBA | 15 minutes |




21

## Frequency

Pitch is determined by frequency.

**pitch:** a measure of how high or low a sound is perceived to be depending on the frequency of the sound wave

A high-pitched sound corresponds to a high-frequency. (Treble)

A low-pitched sound corresponds to a low frequency. (Bass)

22

## Frequency, continued

Humans can hear sound waves typically between 20 Hz to 20,000 Hz. Hearing damage will lower the range you can hear.

**Infrasound -** Any sound with a frequency below the range of human hearing. (Below 20 Hz)

**Ultrasound -** Any sound with a frequency above human hearing range (Above 20,000 Hz)

23

## Musical Instruments

Most instruments produce sound through the vibration of strings, air columns, or membranes.

Musical instruments rely on standing waves.

Standing waves can exist only at certain wavelengths on a string.

The primary standing wave on a vibrating string has a wavelength that is twice the length of the string.

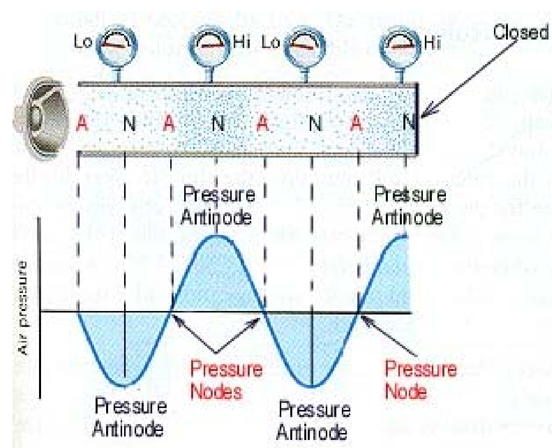
The frequency of this wave is called the *fundamental frequency.*

## Musical Instruments, *continued*

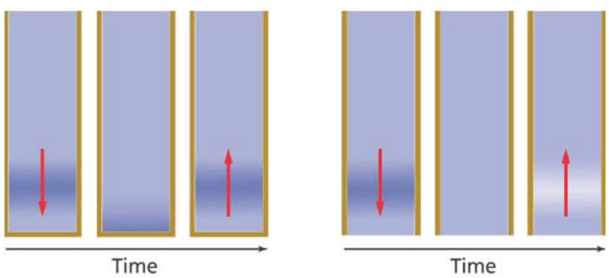
Instruments use resonance to amplify sound.

**Resonance:** a phenomenon that occurs when two objects naturally vibrate at the same frequency

- *natural frequencies:* the specific frequencies at which an object is most likely to vibrate
  - The natural frequency of an object depends on the object's shape, size, mass, and the material from which the object is made.



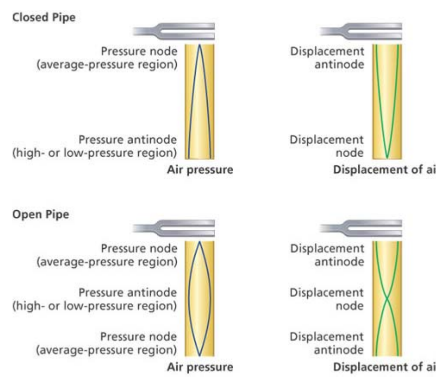

## Standing Pressure Waves



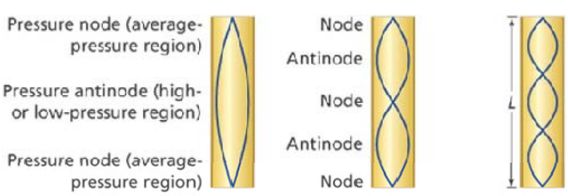

Closed pipes: high pressure reflects as high pressure

Open pipes: high pressure reflects as low pressure

## Sine Waves Represent Standing Waves in Pipes




## Resonant Frequencies in Open Pipes

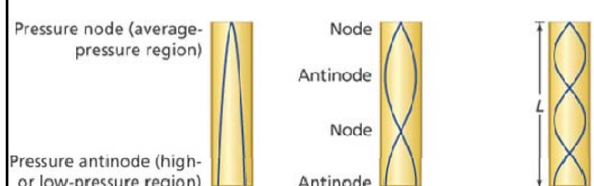



$\lambda_1 = 2L$ $\quad$ $\lambda_2 = L$ $\quad$ $\lambda_3 = \frac{2L}{3}$

$f_1 = \frac{v}{\lambda_1} = \frac{v}{2L}$ $\quad$ $f_2 = \frac{v}{L} = 2f_1$ $\quad$ $f_3 = \frac{3v}{2L} = 3f_1$

This occurs at when the pipe length is an even number of quarter wavelengths

## Resonant Frequencies in Closed Pipes

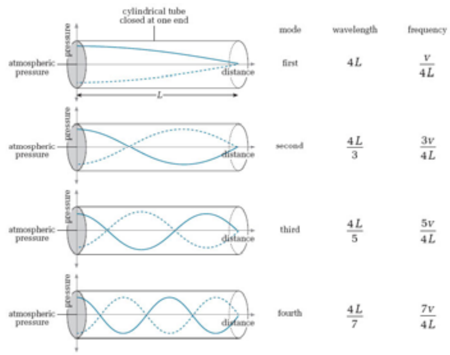



$\lambda_1 = 4L$ $\quad$ $\lambda_3 = \frac{4}{3}L$ $\quad$ $\lambda_5 \ \frac{4}{5}L$

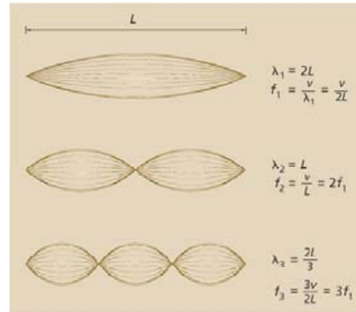
$f_1 = \frac{v}{\lambda_1} = \frac{v}{4L}$ $\quad$ $f_3 = \frac{3v}{4L} = 3f_1$ $\quad$ $f_5 \ \frac{5v}{4L} \ 5f_1$

This occurs at when the pipe length is an odd number of quarter wavelengths

## Resonant Frequencies in Closed Pipes




## Resonant Frequencies in Strings




This occurs at when the pipe length is whole numbers of half wavelengths