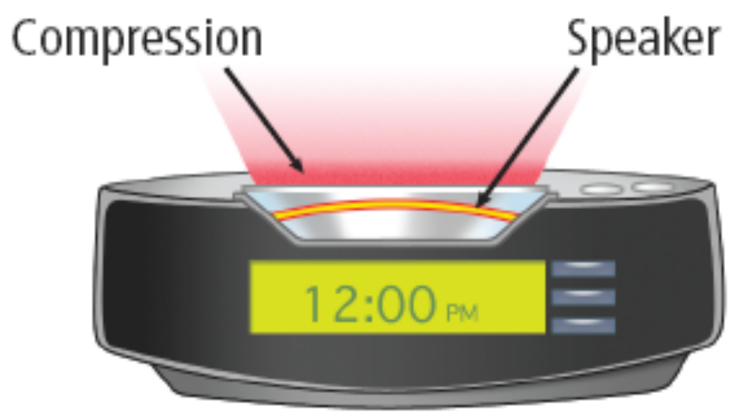
## What produces sound?

- Every sound is produced by an object that vibrates.
- For example, your friends' voices are produced by the vibrations of their vocal cords, and music from a carousel and voices from a loudspeaker are produced by vibrating speakers.

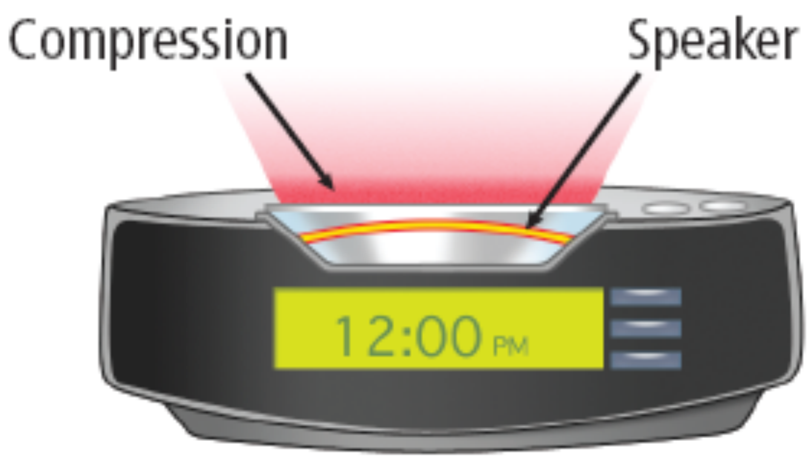
## Sound Waves

- Sound waves are longitudinal waves.
- A longitudinal wave is made up of two types of regions called compressions and rarefactions.



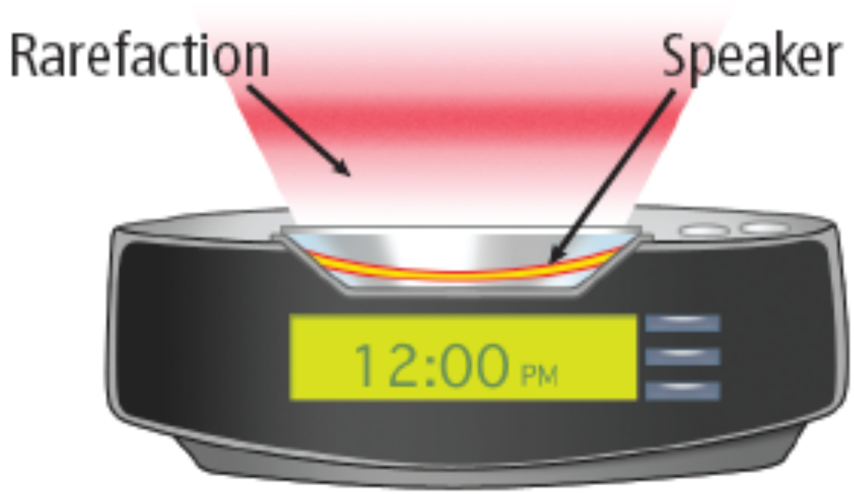
## Sound Waves

- You'll see that when a radio speaker vibrates outward, the nearby particles of air are pushed together to form compressions.



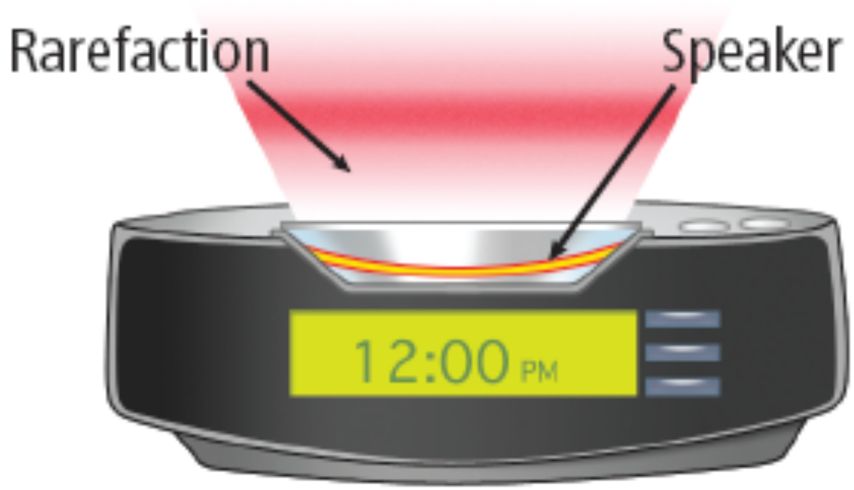
## Sound Waves

- As the figure shows, when the speaker moves inward, the nearby particles of air have room to spread out, and a rarefaction forms.



## Sound Waves

- As long as the speaker continues to vibrate back and forth, compressions and rarefactions form.



## Traveling as a Wave

- Compressions and rarefactions move away from the speaker as particles of air collide with their neighbors.
- A series of compressions and rarefactions forms that travels from the speaker to your ear.
- This sound wave is what you hear.

## Traveling Through Materials

- Most sounds you hear travel through air to reach your ears.
- If you've ever been swimming underwater and heard garbled voices, you know that sound also travels through water.
- Sound waves can travel through any type of matter—solid, liquid, or gas.

## Traveling Through Materials

- Sound waves can travel through any type of matter—solid, liquid, or gas.
- The matter that a wave travels through is called a medium.
- Sound waves cannot travel through a vacuum.

## The Speed of Sound through Different Materials

- The speed of a sound wave through a medium depends on the substance the medium is made of, its temperature and whether the medium is solid, liquid, or gas.

| Medium | Speed of Sound (m/s) |
|---|---|
| Air (0°C) | 330 |
| Air (20°C) | 340 |
| Cork | 500 |
| Water (0°C) | 1,400 |
| Water (20°C) | 1,500 |
| Copper | 3,600 |
| Bone | 4,000 |
| Steel | 5,800 |

## The Speed of Sound through Different Materials

- In general, sound travels the slowest through gases, faster through liquids, and even faster through solids.

| Medium | Speed of Sound (m/s) |
|---|---|
| Air (0°C) | 330 |
| Air (20°C) | 340 |
| Cork | 500 |
| Water (0°C) | 1,400 |
| Water (20°C) | 1,500 |
| Copper | 3,600 |
| Bone | 4,000 |
| Steel | 5,800 |

## The Speed of Sound through Different Materials

- Sound travels faster in liquids and solids than in gases because the individual molecules in a liquid or solid are closer together than the molecules in a gas.

| Medium | Speed of Sound (m/s) |
|---|---|
| Air (0°C) | 330 |
| Air (20°C) | 340 |
| Cork | 500 |
| Water (0°C) | 1,400 |
| Water (20°C) | 1,500 |
| Copper | 3,600 |
| Bone | 4,000 |
| Steel | 5,800 |

## The Speed of Sound through Different Materials

- However, the speed of sound doesn't depend on the loudness of the sound.
- Loud sounds travel through a medium at the same speed as soft sounds.

| Medium | Speed of Sound (m/s) |
|---|---|
| Air (0°C) | 330 |
| Air (20°C) | 340 |
| Cork | 500 |
| Water (0°C) | 1,400 |
| Water (20°C) | 1,500 |
| Copper | 3,600 |
| Bone | 4,000 |
| Steel | 5,800 |

## A Model for Transmitting Sound

- A line of people passing a bucket is a model for molecules transferring the energy of a sound wave.

Tim Courlas/Horizons Companies

## A Model for Transmitting Sound

- When the people are far away from each other, like the molecules in gas, it takes longer to transfer the bucket of water from person to person.

Tim Courlas/Horizons Companies

## A Model for Transmitting Sound

- The bucket travels quickly down the line when the people stand close together.
- The closer the particles, the faster they can transfer energy from particle to particle.

Tim Courlas/Horizons Companies

## Temperature and the Speed of Sound

- As the temperature of a substance increases, its molecules move faster.
- This makes them more likely to collide with each other.

Click image to view movie

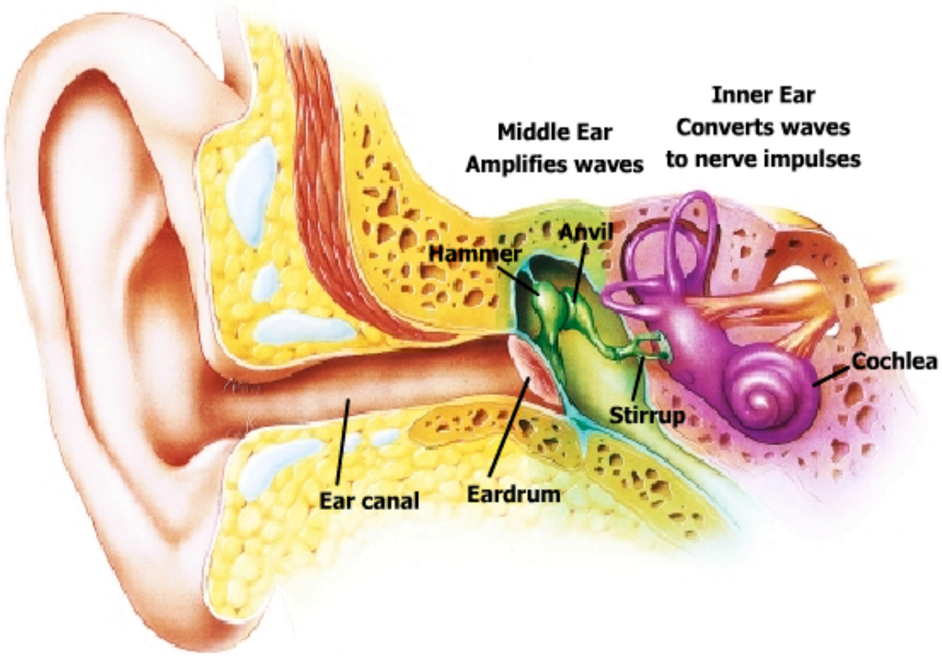
## Human Hearing

- Vocal cords and mouths move in many different ways to produce various kinds of sound waves.
- Your ears and brain work together to turn the sound waves caused by speech, music, and other sources into something that has meaning.

## Human Hearing

- First, the ear gathers the sound waves.
- Next, the ear amplifies the waves.
- In the ear, the amplified waves are converted to nerve impulses that travel to the brain.
- Finally, the brain decodes and interprets the nerve impulses.

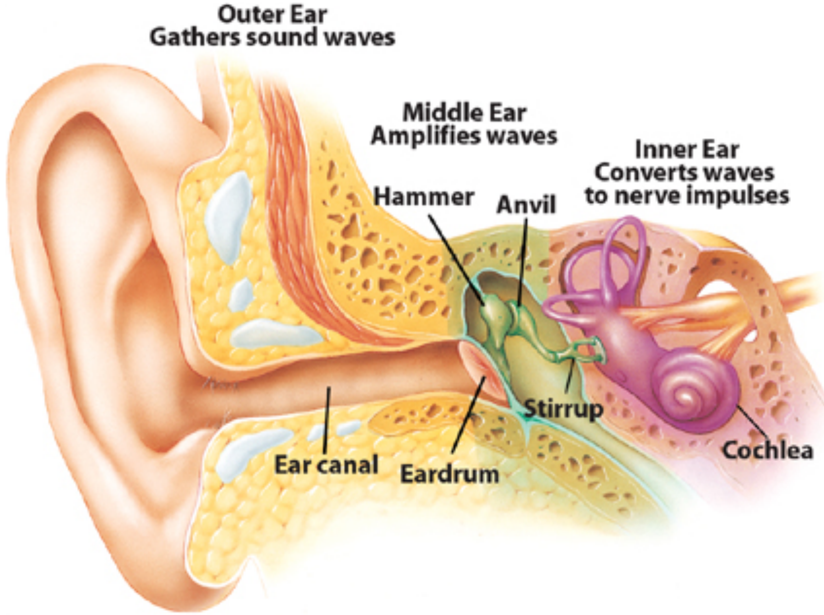
## Gathering Sound Waves —The Outer Ear



# The Nature of Sound

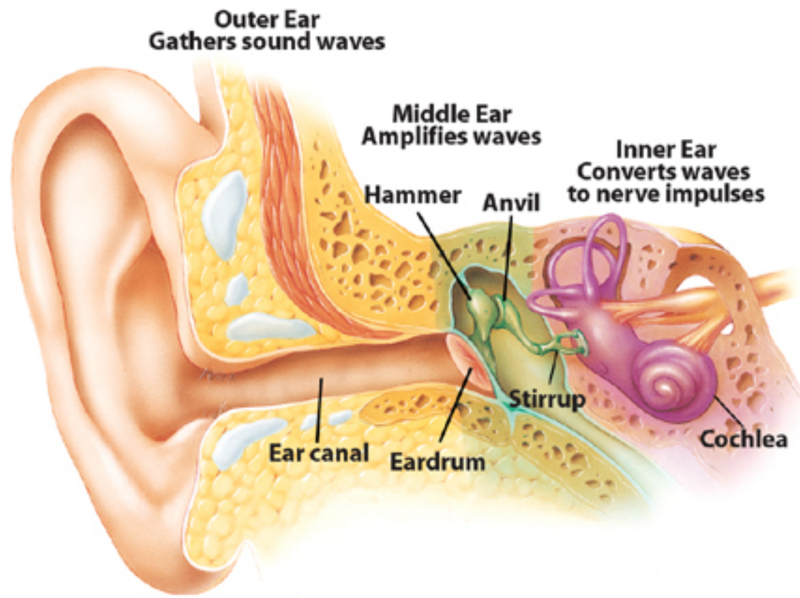
## Gathering Sound Waves —The Outer Ear

- The human ear has three sections called the outer ear, the middle ear, and the inner ear.
- The outer ear is where sound waves are gathered.



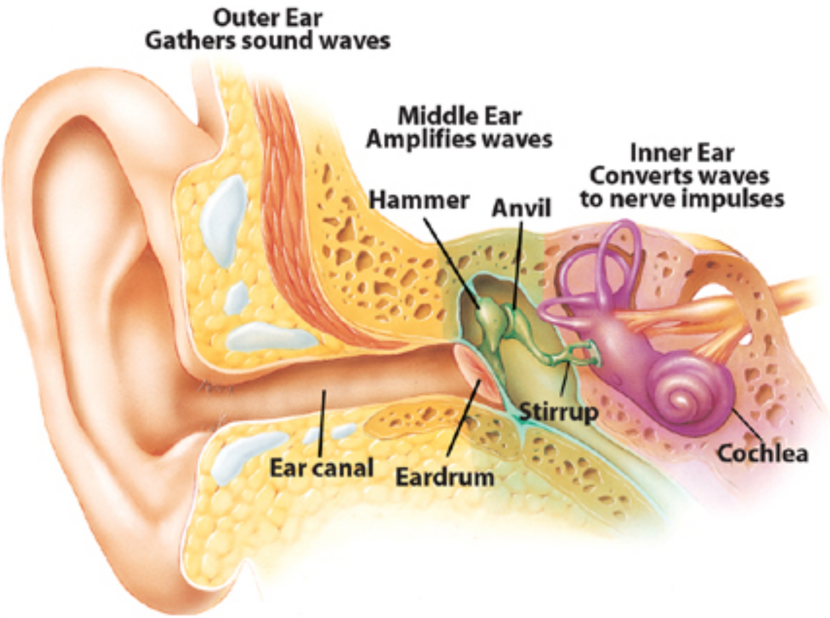
## Gathering Sound Waves —The Outer Ear

- The **eardrum** is a tough membrane about 0.1 mm thick.
- When incoming sound waves reach the eardrum, they transfer their energy to it and it vibrates.



## Converting Sound Waves—The Inner Ear

- The inner ear contains the **cochlea** (KOH klee uh), which is a spiral-shaped structure that is filled with liquid and contains tiny hair cells.



## Intensity and Loudness

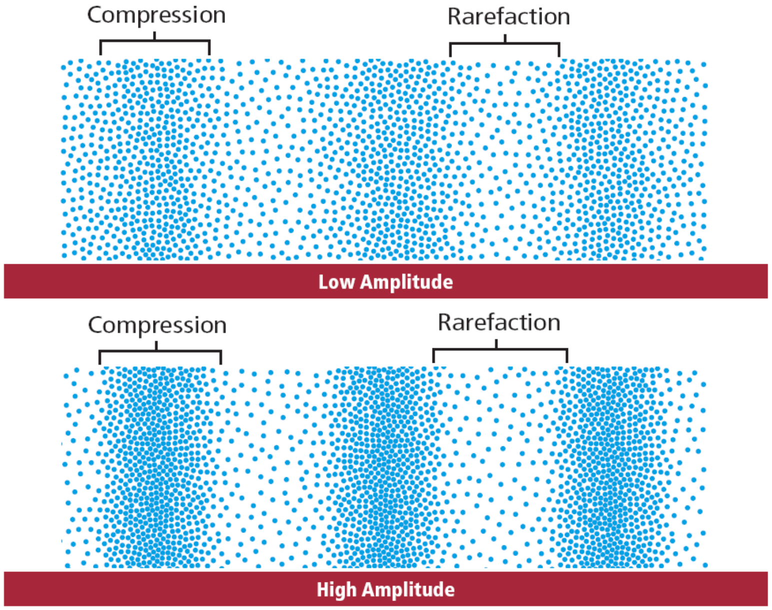
- What happens to the sound waves from your radio when you adjust the volume? The notes sound the same as when the volume was higher, but something about the sound changes.

## Intensity and Loudness

- The difference is that quieter sound waves do not carry as much energy as louder sound waves do.
- The amount of energy a wave carries corresponds to its amplitude.
- For a longitudinal wave, amplitude is related to how close together the particles are that make up the compressions and rarefactions.

## Intensity and Loudness

- When an object vibrates strongly with a lot of energy, it makes sound waves with tight, dense compressions.
- When an object vibrates with low energy, it makes sound waves with loose, less dense compressions.



## Intensity and Loudness

- The density of particles that make up the rarefactions behaves in the opposite way.
- It is important to remember that matter is not transported during the compression and rarefaction of a longitudinal wave—only energy is transported.
- The matter compresses and expands as the wave passes through that medium.

## Intensity

- **Intensity** is the amount of energy that is transferred across a certain area in a specific amount of time.
- When you turn down the volume of your radio, you reduce the energy carried by the sound waves, so you also reduce their intensity.

# Properties of Sound

## Intensity

- Intensity influences how far away a sound can be heard.
- If you and a friend whisper a conversation, the sound waves you create have low intensity and do not travel far.
- You have to sit close together to hear each other.

# Properties of Sound

## Intensity Decreases with Distance

- Sound intensity decreases with distance for two reasons.
- First, the energy that a sound wave carries spreads out as the sound wave spreads out.
- Second, some of a sound wave's energy converts to other forms of energy, usually thermal energy, as the sound travels through matter.

## Loudness

- **Loudness** is the human perception of sound volume and depends primarily on sound intensity.
- When sound waves of high intensity reach your ear, they cause your eardrum to move back and forth a greater distance than sound waves of low intensity do.

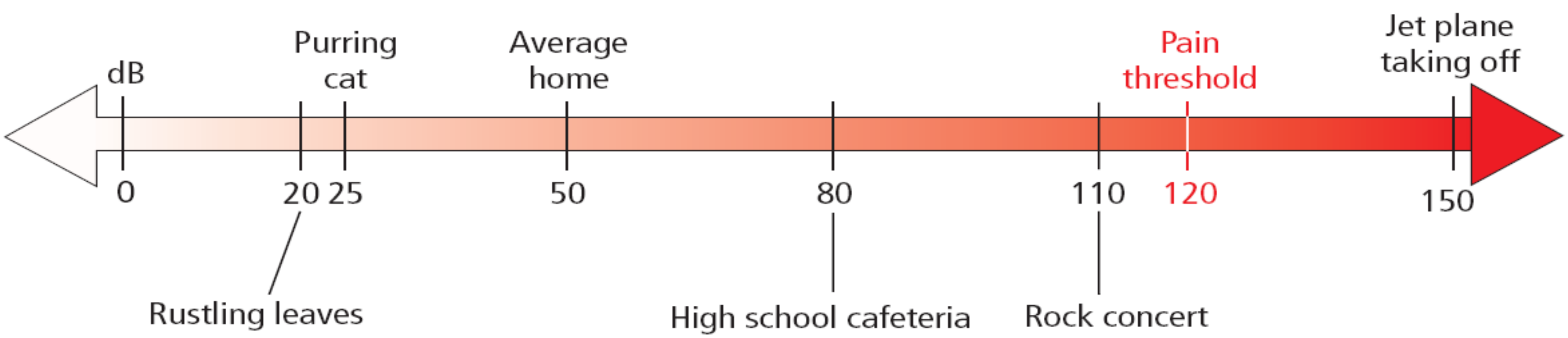
## Loudness

- The bones of the middle ear convert the increased movement of the eardrum into increased movement of the hair cells in the inner ear.
- As a result, you hear a loud sound.

## A Scale for Loudness

- The intensity of sound can be described using a measurement scale.
- Each unit on the scale for sound intensity is called a **decibel** (DE suh bel), abbreviated dB.

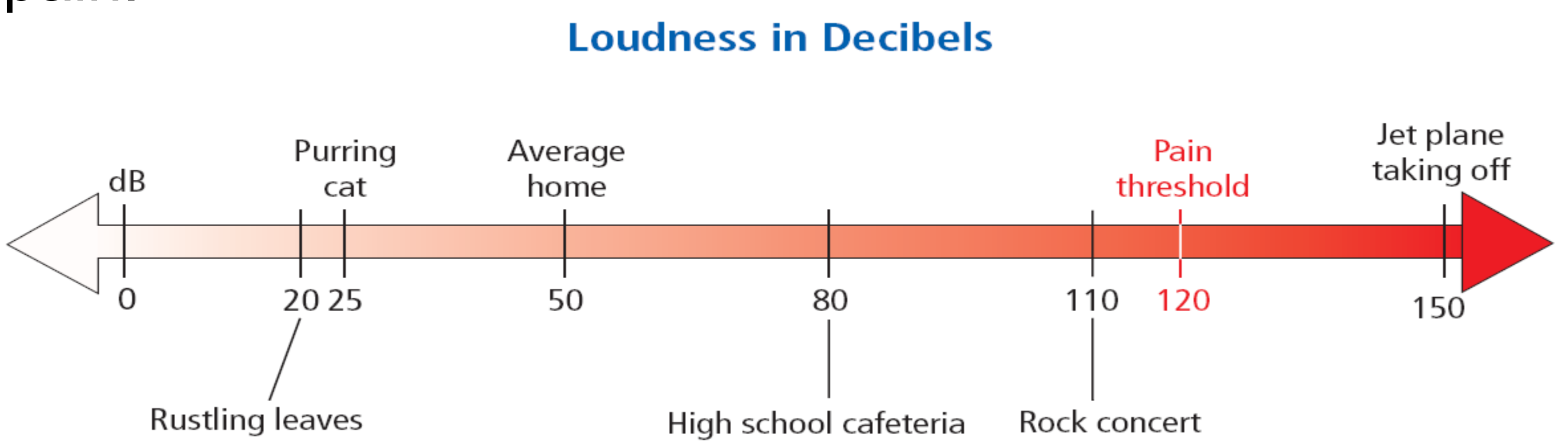
Loudness in Decibels



# Properties of Sound

## A Scale for Loudness

- On this scale, the faintest sound that most people can hear is 0 dB.
- Sounds with intensity levels above 120 dB often cause pain.



## Pitch

- If you were to sing a scale, your voice would start low and become higher with each note.
- **Pitch** is how high or low a sound seems to be.
- The pitch of a sound is related to the frequency of the sound waves.

## Frequency and Pitch

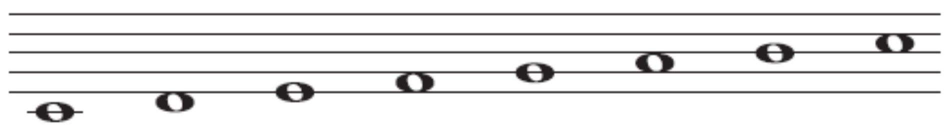
- Frequency is a measure of how many wavelengths pass a particular point each second.
- For a longitudinal wave, such as sound, the frequency is the number of compressions or the number of rarefactions that pass by each second.

## Frequency and Pitch

- Frequency is measured in hertz (Hz).
- When a sound wave with high frequency hits your ear, many compressions hit your eardrum each second.
- Your brain interprets these fast vibrations caused by high-frequency waves as a sound with a high pitch.
- As the frequency of a sound wave decreases, the pitch becomes lower.

## Frequency and Pitch

- This figure shows different notes and their frequencies.
- A healthy human ear can hear sound waves with frequencies from about 20 Hz to 20,000 Hz.



| | | | | | | | |
|---|---|---|---|---|---|---|---|
| C | D | E | F | G | A | B | C |
| do | re | mi | fa | sol | la | ti | do |
| 262 Hz | 294 Hz | 330 Hz | 349 Hz | 392 Hz | 440 Hz | 494 Hz | 523 Hz |

## Frequency and Pitch

- The human ear is most sensitive to sounds in the range of 440 Hz to about 7,000 Hz.

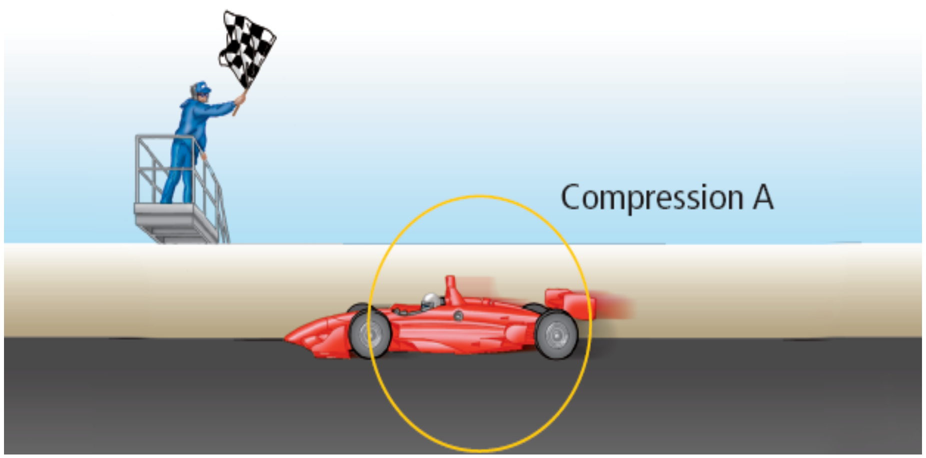
| | | | | | | | |
|---|---|---|---|---|---|---|---|
| C | D | E | F | G | A | B | C |
| do | re | mi | fa | sol | la | ti | do |
| 262 Hz | 294 Hz | 330 Hz | 349 Hz | 392 Hz | 440 Hz | 494 Hz | 523 Hz |

## The Doppler Effect

- The change in pitch or wave frequency due to a moving wave source is called the **Doppler effect**.
- The Doppler effect occurs when the source of a sound wave is moving relative to a listener.

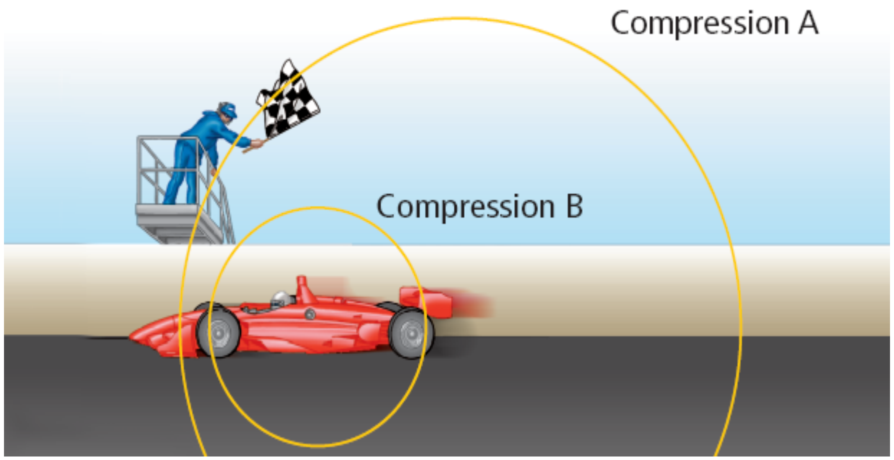
## Moving Sound

- As a race car moves, it sends out sound waves in the form of compressions and rarefactions.
- The race car creates a compression, labeled A.
- Compression A moves through the air toward the flagger standing at the finish line.



## Moving Sound

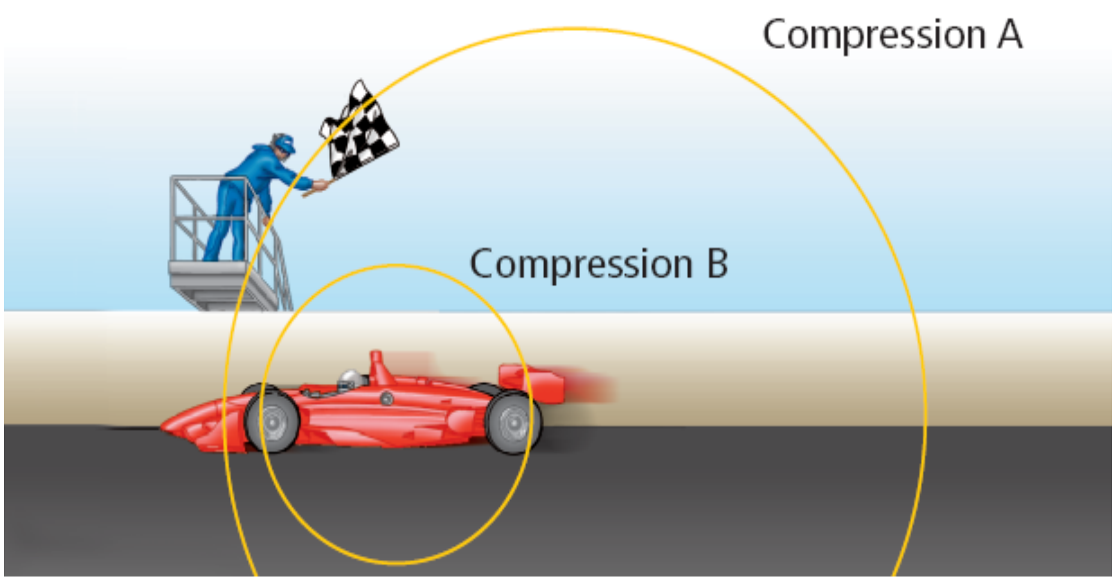
- By the time compression B leaves the race car, the car has moved forward.
- Because the car has moved since the time it created compression A, compressions A and B are closer together than they would be if the car had stayed still.



# Properties of Sound

## Moving Sound

- As a result, the flagger hears a higher pitch.



## A Moving Observer

- The Doppler effect happens any time the source of a sound is changing position compared with the observer.
- It occurs no matter whether it is the sound source or the observer that is moving.
- The faster the change in distance, the greater the change in frequency and pitch.

## Using the Doppler Effect

- The Doppler effect also occurs for other waves besides sound waves.
- For example, the frequency of electromagnetic waves, such as radar waves, changes if an observer and wave source are moving relative to each other.

## Using the Doppler Effect

- Radar guns use the Doppler effect to measure the speed of cars.
- Weather radar also uses the Doppler shift to show the movement of winds in storms, such as a tornado.

CORBIS

# Music

## What is music?

- Music and noise are caused by vibrations—with some important differences.
- Noise has random patterns and pitches.
- **Music** is made of sounds that are deliberately used in a regular pattern.

## Natural Frequencies

- Every material has a particular frequency at which it will vibrate, called its natural frequency.
- No matter how you pluck a guitar string, you hear the same pitch, because the string vibrates at its natural frequency.

Blend Images/Getty Images

# Music

## Resonance

- In wind instruments, the column of air inside vibrates.
- The air vibrates because of resonance—the ability of a medium to vibrate by absorbing energy at its own natural frequency.

IT Stock Free

## Sound Quality

- Suppose your classmate played a note on a flute and then a note of the same pitch and loudness on a piano.
- Each of these instruments has a unique sound quality.
- **Sound quality** describes the differences among sounds of the same pitch and loudness.

## Sound Quality

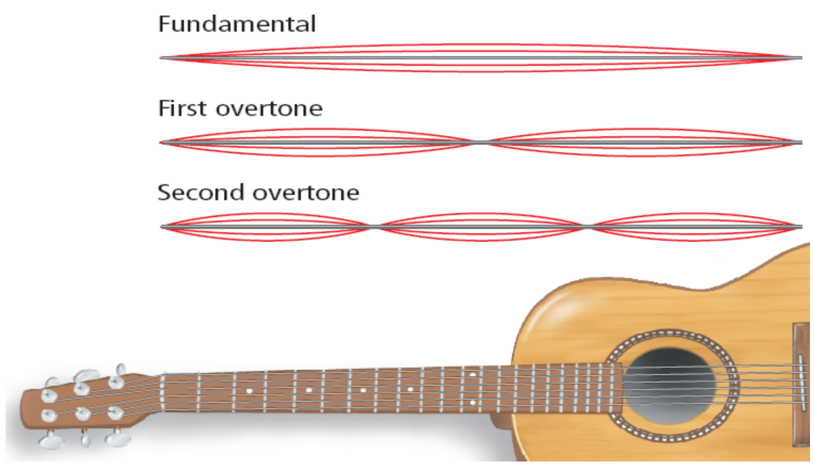
- Objects can be made to vibrate at other frequencies besides their natural frequency.
- The specific combination of frequencies produced by a musical instrument is what gives it a distinctive quality of sound.

## Overtones

- The main tone that is played and heard is called the fundamental frequency.
- On a guitar, for example, the fundamental frequency is produced by the entire string vibrating back and forth.

## Overtones

- In addition to vibrating at the fundamental frequency, the string also vibrates to produce overtones.
- An **overtone** is a vibration whose frequency is a multiple of the fundamental frequency.



# Music

## Musical Instruments

- A musical instrument is any device used to produce a musical sound.
- Violins, oboes, bassoons, horns, and kettledrums are musical instruments that you might have seen and heard in your school orchestra.

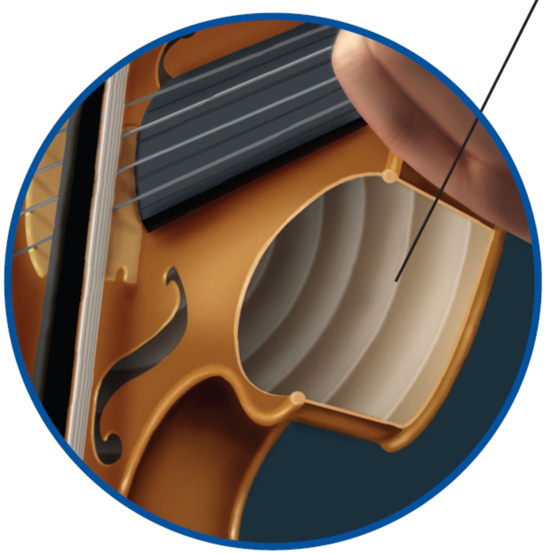
## Strings

- In string instruments, sound is produced by plucking, striking, or drawing a bow across tightly stretched strings.
- Because the sound of a vibrating string is soft, string instruments either have a resonator or rely on electric amplification.

# Music

## Strings

- A **resonator** (RE zuh nay tur) is a hollow chamber filled with air that amplifies sound when the air inside of it vibrates.



## Brass and Woodwinds

- Brass and woodwind instruments rely on the vibration of air to make music.
- Brass instruments have cone-shaped mouthpieces.
- This mouthpiece is inserted into metal tubing, which is the resonator in a brass instrument.

## Brass and Woodwinds

- As the player blows into the instrument, his or her lips vibrate against the mouthpiece.
- The air in the resonator also starts to vibrate, producing a pitch.

## Percussion

- Percussion instruments are struck, shaken, rubbed, or brushed to produce sound.
- Some, such as kettledrums, have a membrane stretched over a resonator.

The McGraw-Hill Companies, Inc./John Flournoy, photographer

# Music

## Percussion

- When the drummer strikes the membrane with sticks or hands, the membrane vibrates and causes the air inside the resonator to vibrate.


The McGraw-Hill Companies, Inc./John Flournoy, photographer

## Percussion

- The resonator amplifies the sound made when the membrane is struck.
- Some drums have a fixed pitch, but others have a pitch that can be changed by tightening or loosening the membrane.

# Music

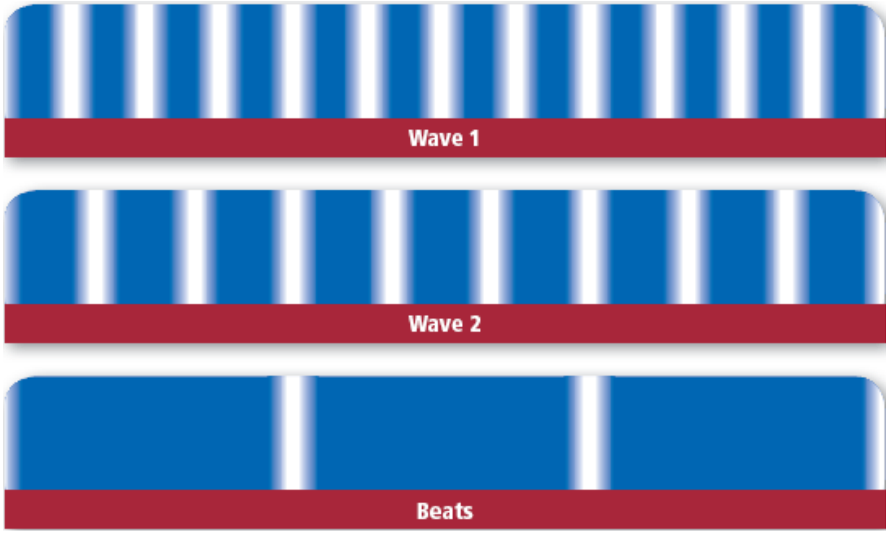
## Beats

- When two instruments play at the same time, the sound waves produced by each instrument interfere.
- The amplitudes of the waves add together when compressions overlap and rarefactions overlap, causing an increase in loudness.
- When compressions and rarefactions overlap each other, the loudness decreases.

# Music

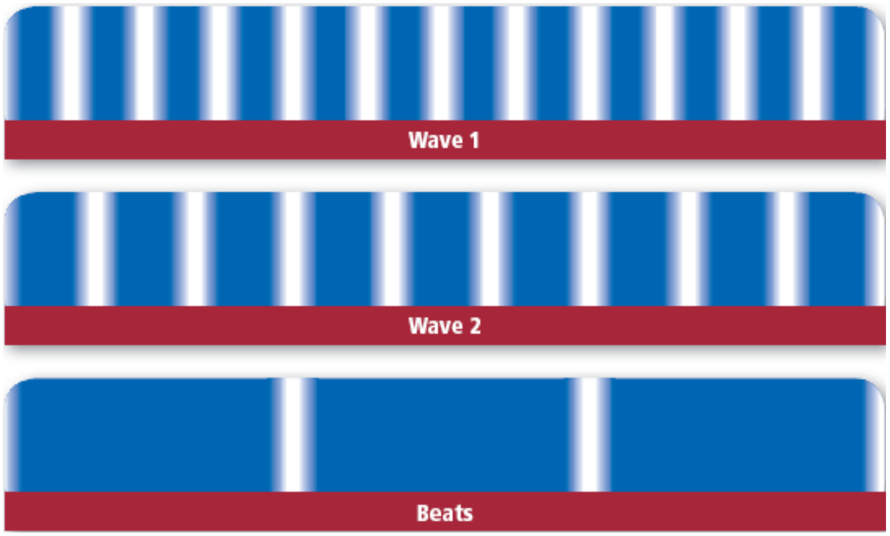
## Beats

- Beats can occur when sound waves of different frequencies, shown in the top two panels, combine.



## Beats

- These sound waves interfere with each other, forming a wave with a lower frequency, shown in the bottom panel.
- This wave causes a listener to hear a pulsing sound known as beats.



# Using Sound

## Acoustics

- When an orchestra stops playing, does it seem as if the sound of its music lingers for a couple of seconds?
- This echoing effect produced by many reflections of sound is called reverberation (rih vur buh RAY shun).
- During an orchestra performance, reverberation can improve or ruin the sound of the music.

# Using Sound

## Acoustics

- Some scientists and engineers specialize in **acoustics** (uh KEW stihks), which is the study of sound.

## Acoustics

- They know that soft, porous materials can reduce excess reverberation, so they might recommend that the walls of concert halls be lined with carpets and draperies.

# Using Sound

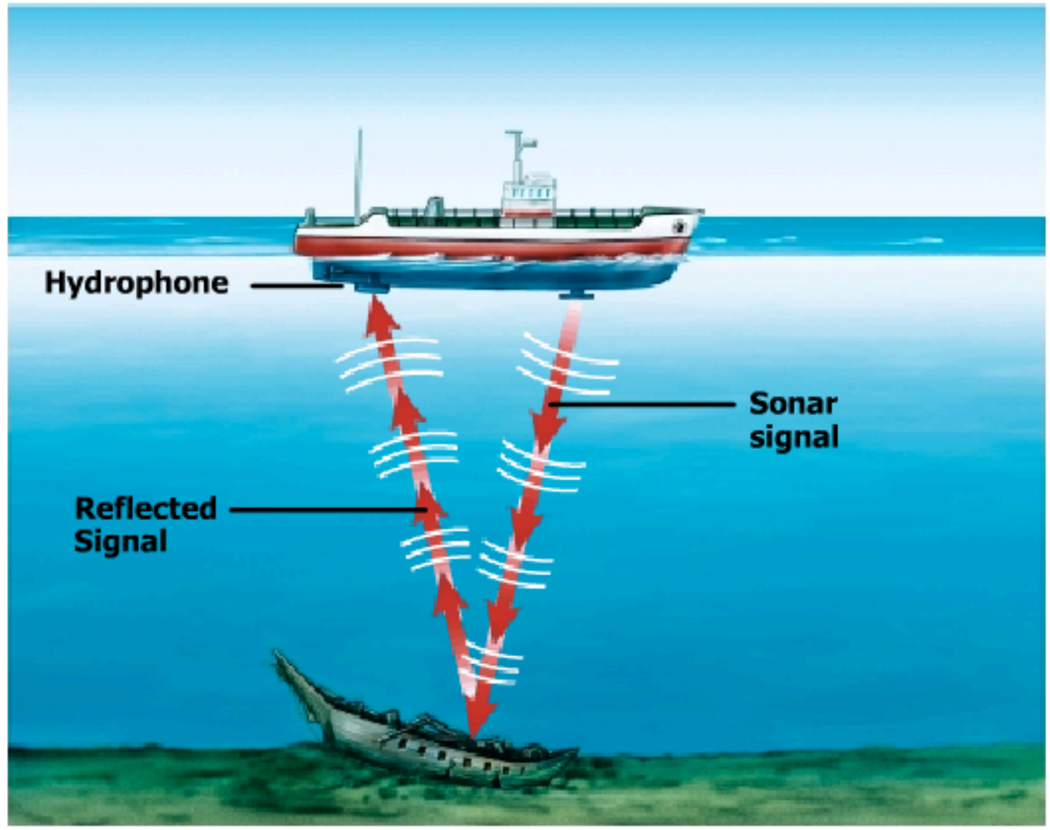
## Echolocation

- At night, bats swoop around in darkness without bumping into anything.
- Their senses of sight and smell help them navigate.
- Many species of bats also depend on echolocation. **Echolocation** is the process of locating objects by emitting sounds and interpreting the sound waves that are reflected back.

# Using Sound

## Sonar

- **Sonar** is a system that uses the reflection of underwater sound waves to detect objects.




MAC OSX users click here to view.

# Using Sound

## Ultrasound in Medicine

- One of the important uses of ultrasonic waves is in medicine.
- Using special instruments, medical professionals can send ultrasonic waves into a specific part of a patient's body.
- Reflected ultrasonic waves are used to detect and monitor conditions such as pregnancy, certain types of heart disease, and cancer.

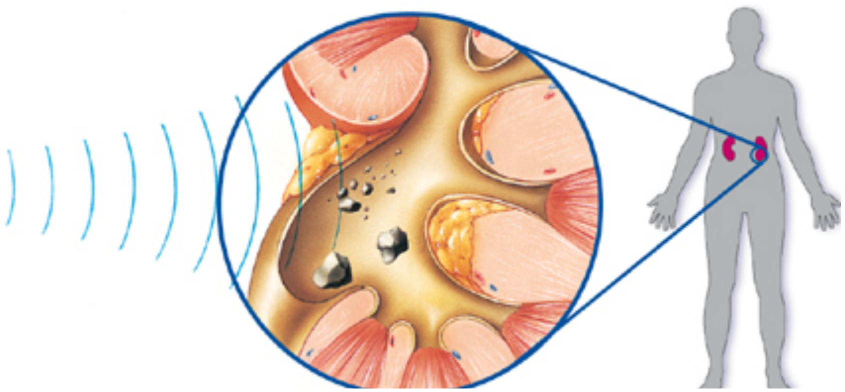
# Using Sound

## Ultrasound Imaging

- Like X-rays, **ultrasound** can be used to produce images of internal structures.
- The sound waves reflect off the targeted organs or tissues, and the reflected waves are used to produce electric signals.
- A computer program converts these electric signals into video images, called sonograms.

## Treating with Ultrasound

- Sometimes small, hard deposits of calcium compounds or other minerals form in the kidneys, making kidney stones.
- Ultrasonic treatments are commonly used to break them up.



# Using Sound

## Treating with Ultrasound

- Bursts of ultrasound create vibrations that cause the stones to break into small pieces.
- These fragments then pass out of the body with the urine.