# Sound

**sound:** saund (noun) 13th century

1 a : a particular auditory impression :
b : the sensation perceived by the sense of hearing
c : mechanical radiant energy that is transmitted by longitudinal pressure waves in a material medium (as air) and is the objective cause of hearing

Merriam-Webster On-line Dictionary
http://www.m-w.com/

## What is sound?

The wind, music, talking, thunder, roaring engines, humming computers - sound is all around us all the time. Sound is everything that we hear, and a bit more.

*Are there sounds we can't hear?*

Some animals, like dogs, can hear - and make - sounds that humans can't hear. To understand more about why dogs can hear more sounds than we can, we have to learn a little more about the science of sound which is called acoustics.

To start, you should know that sound is a form of energy which travels in waves.

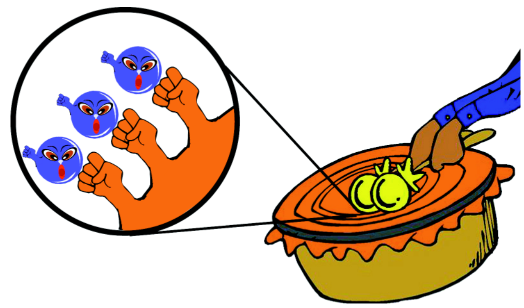
## Sound waves are mechanical waves

If you have a rope and snap one end, you can watch a wave travel through the rope to the other end.

*What causes the wave to move through the rope?*

Waves are actually movements of energy. In the rope, the mechanical energy you physically put in at one end of the rope travels all the way through to the other end. Scientists classify waves based on the kind of energy causing the movement - mechanical energy or electromagnetic energy. Sound waves are mechanical waves. Mechanical waves can only travel through solids, liquids and gasses, because the energy actually moves by transferring from one molecule to another.

If you are at a community event where drums are being played, the sound energy caused by the vibration of the drum skin literally hits the molecules of air right near it. Energy is transferred from the drum skin into the molecules, making them vibrate. Because they suddenly have all this extra energy, these particles bump into particles nearby, transferring energy to them. This process keeps on going from one set of particles to the next until the sound energy reaches your ear and you hear the beating of the drums.



Air molecules get hit by the vibrating drum head. They start to vibrate and hit other near by molecules.

*If sound waves needs molecules, how do astronauts in the vacuum of space talk to each other ?*


You can feel sounds waves easily. Put your hand against your mouth and hum. The vibrations you feel in your hand are sound waves.

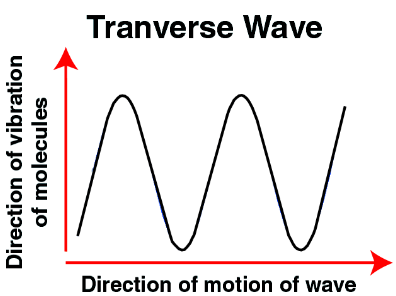
*Have you felt sound from other sources?*

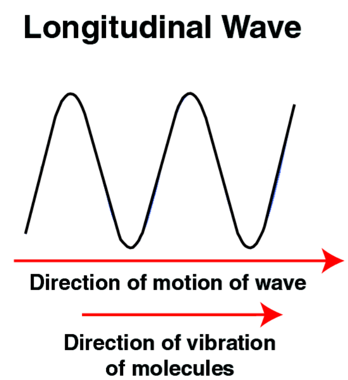
## Sound waves are longitudinal waves

Scientists also classify waves by the direction the molecules vibrate compared to the direction of motion of the wave.

The waves you see on a lake or the ocean are transverse waves. This means that while the waves move towards the shore, the molecules in them are actually vibrating up and down, or perpendicular to the direction of motion.

Sound waves are longitudinal waves. This means the molecules vibrate parallel to the direction of movement.

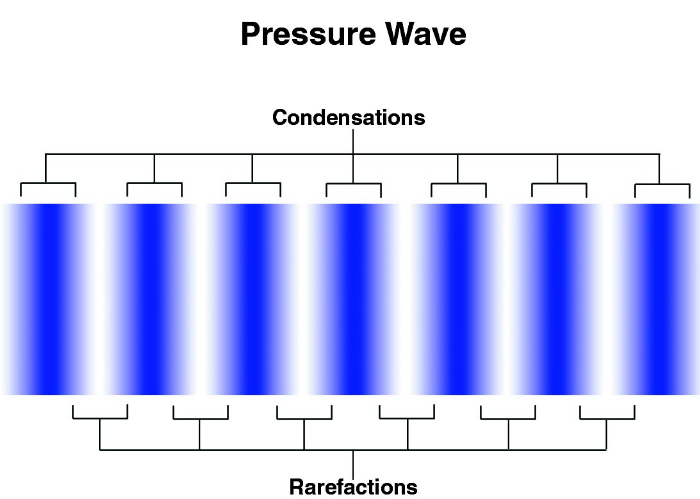



## Sound waves are pressure waves

Longitudinal sound waves move away from the source of the sound unless they hit something hard and get reflected back.

*Do you know another name for reflected sound?*

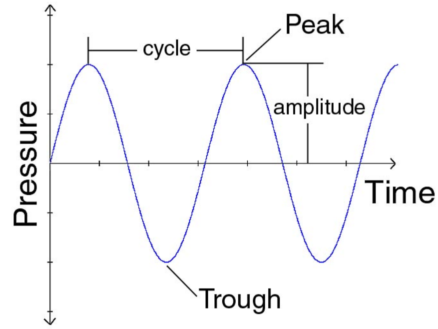


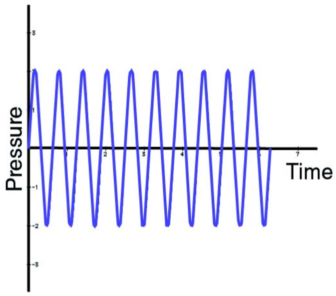

Sound waves may travel quite far, but the molecules which carry and transfer the sound energy don't actually move all that much. They vibrate back and forward pushing on neighbouring air molecules both in front and behind them. This back and forth pushing quickly creates areas where there are lots of molecules compressed together, called condensations,  and areas where there are fewer molecules, called rarefactions.

Condensations have a higher pressure than rarefations. Because sound waves create these areas of high and low pressure, they are pressure waves.

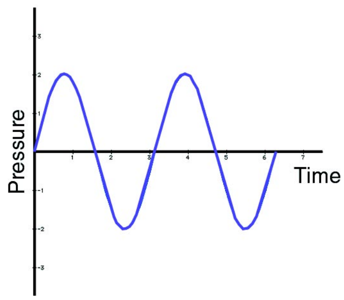
## Measuring waves

One of the ways scientists are able to study sound is by creating images of waves. They use a device which measures the changes in pressure created by the sound energy and plot the pressure against time. The resulting image allows them to measure frequency and amplitude. The amplitude is the height of the wave, it represents strength or loudness. So bigger amplitudes mean louder sounds.




High frequency sound.




Lower frequency sound.

The frequency is the number of cycles of the wave which are produced in one second. A cycle is one full wave, from the peak of one wave to the peak of the next, or from the trough of one wave to the trough of the next. Frequency is measured in cycles per second or Hertz, and is abbreviated Hz.

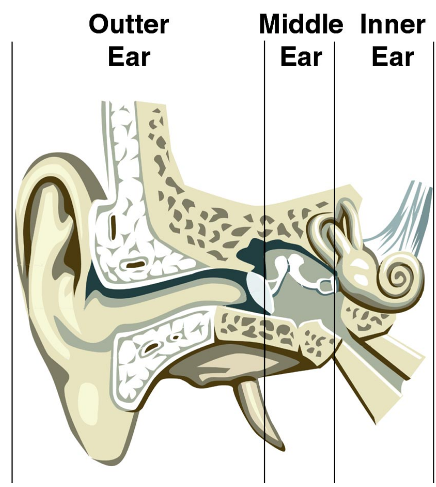
## Human ears

The average human can hear sounds in frequencies of 20-20,000Hz. Our ears are actually constructed for precisely those frequencies.

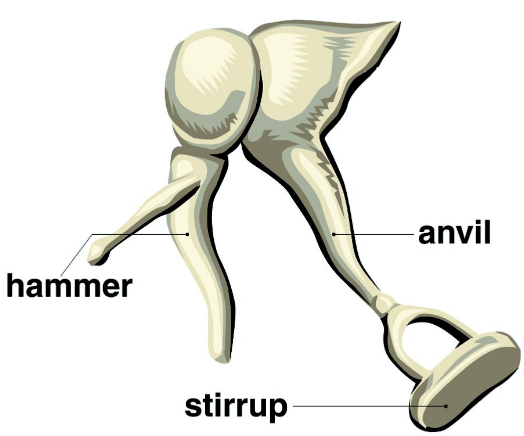
The human ear is divided into three parts: the outer ear, the middle ear and the inner ear.

The outer ear channels sound from the environment through the ear channel to the ear drum.

## The Ear



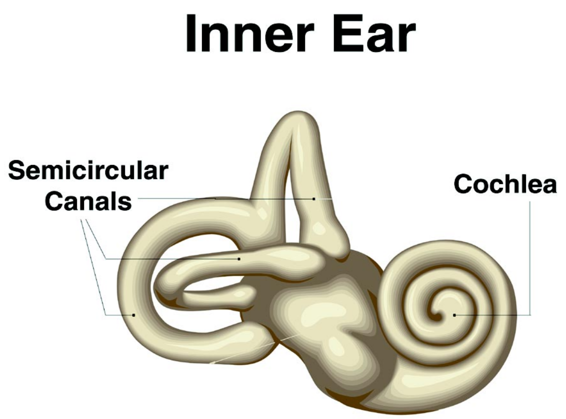

## Middle Ear




The eardrum is the beginning of the middle ear. It is a thin, membrane which completely seals the middle ear from the outer ear. It is connected to a series of three tiny bones called the hammer, the anvil and the stirrup.

When sound waves hit the ear drum it begins to vibrate, just like the drums you see or use at community gatherings. The eardrum vibrates at exactly the same frequency as the sound wave which hit it. The vibrations cause the hammer, anvil and stirrup to start moving at the same frequency. The stirrup, the last bone in the middle ear, is connected to the outside of the inner ear.

# Inner Ear




The inner ear is a fluid filled cavity, which consists of the cochlea, the semicircular canals and the auditory nerve. Only the cochlea and auditory nerve are involved in hearing.

*Do you know what other function the inner ear serves?*

The cochlea is shaped a bit like a snail. Its interior walls are covered with more than 20,000 hair-like nerve cells. Each individual nerve cell is a marginally different length than all the others; each is sensitive to a different frequency. When the stirrup in the middle ear moves against the opening of the inner ear, it causes the fluid inside to swish back and forward in waves at the frequency of the sound. When the fluid passes over the nerve cells which are sensitive to that frequency they sway more than all the other nerve cells in the ear. This action activates an electric impulse which travels along the auditory nerve to the brain where it is interpreted as sound.

Now we can answer the question about why some animals can hear more sounds than humans; their ears contain nerve cells which are sensitive to frequencies which are either higher or lower than the nerve cells in human ears.

## Constructive and destructive interference

The drumbeats of ceremonial songs are imitations of the human heartbeat. The rhytyms produced always carry a message. They may be slow, to soothe a baby to sleep, a bit faster, as in honour songs, or very fast, to indicate good news or danger. While you are listening, science is probably one of the last things on your mind, but there's lots of it going on.

*Have you ever been walking through a really noisy room and just for a brief second passed through an area where the sound seems to disappear? What do you think happened?*

Well, let's look at the drums for an explanation. We'll assume that we have two identical drums at opposite ends of the room. As each drum is struck, sound waves begin to move through the air.

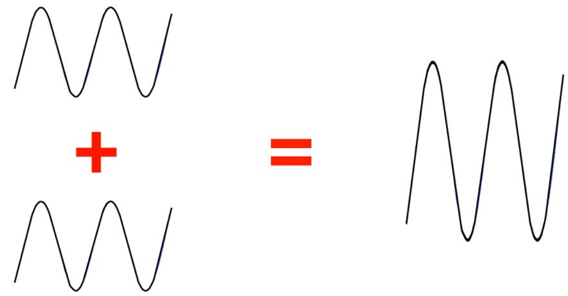
*What happens when the sound waves meet each other?*

When sound waves meet, they combine. Scientifically the meeting of waves is called interference.

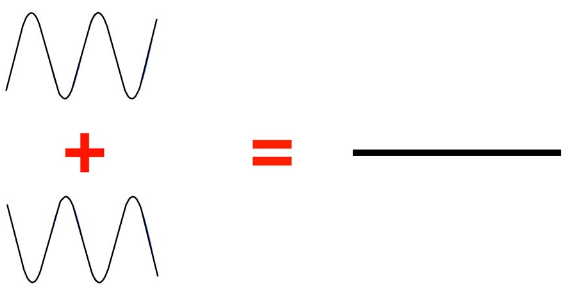
When two wave peaks (or condensations) meet, they combine to make a bigger peak - a wave with a bigger amplitude, and so, a louder sound. When two troughs (or rarefactions) meet they combine to form a bigger trough, and again you get a louder sound. When either peaks or troughs meet, it is called constructive interference because the waves combine together to produce a new wave with a larger amplitude.

If sound waves from our two drums have exactly the same amplitude, and the waves meet so that the peaks combine with peaks and troughs combine with troughs, they'll produce a sound wave which has twice the amplitude of the wave coming from either drum alone.

**Constructive Interference**




**Destructive Interference**




When a peak meets a trough, the result is a bit different - they cancel each other out. This combination of waves is called destructive interference because the waves combine together to form a new wave with a smaller amplitude.

Again, if sound waves from our two drums have exactly the same amplitude, and the waves meet so that the peaks from one drum combine with the troughs from the other, they will produce a perfectly flat sound wave, or no sound at all.

It's very difficult to find these points of destructive interference without special electronic listening devices. If you've ever dropped two pebbles in the water at the same time you'll know why. The drums aren't sending out one wave at a time, the sound they create is actually a series of waves, like ripples on the water. In a space, the waves from each drum will meet and combine in complex ways, and the points of destructive interference will be hard for human beings to detect.

## Sound Intensity

Along with frequency and amplitude, scientists also measure sound intensity. Remember that sound is actually a form of energy. Sound intensity is the amount of energy that moves over a given area per unit of time. Mathematically,

$$Intensity = \frac{Energy}{Time \times Area}$$

Energy divided by time is also known as power, so $Intensity = \frac{Power}{Area}$

and is measured in Watts per meter squared, or $W/m^2$.

*Where have you seen the term "watts" used at home?*

## Decibels

Because humans have sensitive ears, they can hear sounds of very low intensity. In fact, most humans can hear sounds with an intensity as low as $1 \times 10^{-12}$ W/m$^2$. This is called the threshold of hearing. The intensity at which sound causes damage to the ears is more than 1 billion times the threshold of hearing, so scientists came up with the decibel scale to more easily describe the intensity of sound.

The decibel scale is a logarithmic scale, or one based on powers of ten. The threshold of sound, $1 \times 10^{-12}$ W/m$^2$, is 0 decibels (abbreviated dB). 10 dB is ten times more intense than 0dB and is equal to $1 \times 10^{-11}$ W/m$^2$. 20dB is 10 times more intense than 10dB, and 100 times more intense than 0dB; it is equal to $1 \times 10^{-10}$ W/m$^2$.

*How much more intense is 60dB than 10dB?*

The table shows the decibel level of some common sounds.

| **Sound** | **Intensity Level (dB)** | **Intensity Level (W/m$^2$)** | **Times greater than the threshold of hearing** |
|---|---|---|---|
| Threshold of hearing | 0 | $1 \times 10^{-12}$ | 1 |
| Rustling leaves | 10 | $1 \times 10^{-11}$ | 10 |
| Soft whisper | 20 | $1 \times 10^{-10}$ | 100 |
| Library | 30 | $1 \times 10^{-9}$ | 1 000 |
| Quiet conversation | 40 | $1 \times 10^{-8}$ | 10 000 |
| Quiet office | 50 | $1 \times 10^{-7}$ | 100 000 |
| Normal conversation at 30 cm | 60 | $1 \times 10^{-6}$ | 1 000 000 |
| Busy street traffic | 70 | $1 \times 10^{-5}$ | 10 000 000 |
| Vacuum cleaner at close quarters | 80 | $1 \times 10^{-4}$ | 100 000 000 |
| Riding on a motorcycle | 90 | $1 \times 10^{-3}$ | 1 000 000 000 |
| Walkman at maximum volume | 100 | $1 \times 10^{-2}$ | 10 000 000 000 |
| Front rows of a rock concert | 110 | $1 \times 10^{-1}$ | 100 000 000 000 |
| Riding on a snowmobile | 120 | $1 \times 10^{0}$ | 1 000 000 000 000 |
| Threshold of pain | 130 | $1 \times 10^{1}$ | 10 000 000 000 000 |
| Military jet take-off | 140 | $1 \times 10^{2}$ | 100 000 000 000 000 |
| Rifle shot | 150 | $1 \times 10^{3}$ | 1 000 000 000 000 000 |
| Instant perforation of eardrum | 160 | $1 \times 10^{4}$ | 10 000 000 000 000 000 |

## Attenuation of sound

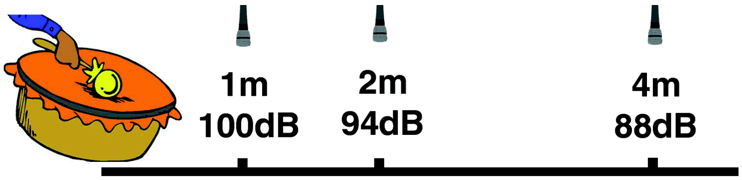
*What happens when you move away from a sound?*

Generally, when you move away from a sound it seems less loud. Loudness is hard to measure, because everybody's ears are slightly different. You know this already; your parents probably find the volume of the music you play much louder than you do. Scientists measure sound using sound intensity because is not a subjective measure.

Imagine you are a scientist measuring sound intensity at a community gathering. You would probably measure the intensity at several points in the gathering space, starting right near the source of the sound (drums or a speaker), and then at points increasingly farther away.

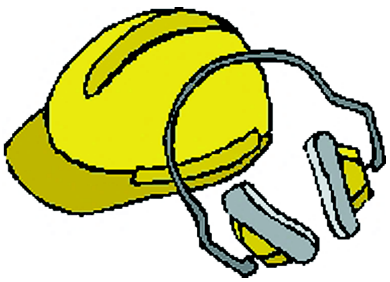
*What do you think you would discover about sound intensity as you moved away from the drums?*

If you are using an instrument which measures decibels you would find that every time you double your distance from the source, the sound intensity drops by 6 dB. So if you measure a sound intensity of 100dB at 1m from the source, 2 meters from the source you would measure 94dB, and 4 meters from the source you would measure 88dB.




The decrease in sound intensity with distance is known as sound attenuation. Sound can be attenuated in other ways too.

If it is not possible for people to move farther away from a loud or annoying sound, it may be possible to place a barrier between people and the source of the sound. In big cities, concrete sound barriers are built alongside highways to protect nearby homes from excessive traffic noise.



Another type of sound barrier is used by construction workers and people who work in heavy industry. They often wear ear plugs or ear muffs to protect their ears from being damaged by the loud noises in their workplace. Even though the noises they work with may not be loud enough to damage their ears right away, long-term exposure to even moderate noise levels can damage hearing. Ear plugs can attenuate noise by up to 30dB, while ear muffs can attenuate noise by up to 35dB.

*Can you think of other people who are exposed to noise on a regular basis who would benefit from the use of ear plugs or ear muffs?*

## Applying the science: Acoustical engineering

As applied scientists, engineers take the principles of basic science and apply them to problems which people come up against in their daily lives. Engineers who deal with sound are called acoustics engineers.

*What could an acoustics engineer do in your community?*

As an acoustics engineer you would have a wide range of skills which could contribute to your community. You could study the effects of low level flying on caribou herds and children's hearing levels. You could help local fisherman by equipping boats with sonar systems which detect schools of fish and fill their nets faster. You could redesign the town meeting hall so people in the back of the room can hear those at the front. You could develop sound safety standards for ATV and skidoo riders. You could even contribute to land claims negotiations by sonically mapping mineral and oil deposits on or near traditional lands. Acoustical engineering would be a sound choice for both you and your community.

## Sources

**On-line**

Current, waves and tides
http://mbgnet.mobot.org/salt/motion/waves.htm
Newton's Apple - Compact Disks
http://www.pbs.org/ktca/newtons/11/cdlp.html
Newton's Apple - Hearing
http://www.pbs.org/ktca/newtons/13/hear.html
Newton's Apple - Movie Sound Effects
http://www.pbs.org/ktca/newtons/12/movisnd.html
Percussion for Kids
http://www.stomponline.com/percuss1.html
The Physics Classroom
http://www.physicsclassroom.com/Class/sound/soundtoc.html
Sound Connexions - National Museum of Science and Technology
http://www.science-tech.nmstc.ca/english/schoolzone/sound.cfm

**Books**

The Usbourne Internet-Linked Science Encyclopaedia

## Math Problems

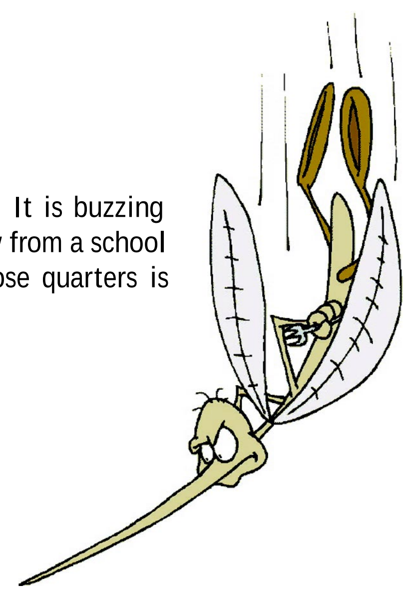
You will need to use the table on page 6 to answer some of the questions.

1. You have your Discman cranked up to its maximum volume. Your mom comes running into the room and tells you, your friends have arrived to go snowmobiling.

   a) Which activity is worse for your ears?
   b) How many Discman would you have to be playing at maximum volume, in order to equal the sound intensity of riding on a snowmobile?

2. You're out on the land hunting with your family. Every time someone shoots a rifle next to you (0.5m away) your ears hurt.

   a) To protect our ears, how far away should you stand from the person who is shooting? You can assume the sound intensity where you are standing is the same as the sound intensity experienced by teh person shooting the rifle.
   b) Your grandfather finds some ear plugs in his pocket. They are supposed to attenuate sound by 20dB. Will they stop your ears from hurting?
   c) When you go to bed at night a mosquito gets into your tent. It is buzzing around your head and you can't seem to wave it away. You know from a school research project that the sound intensity of mosquitos in close quarters is 40dB. Will your grandfather's ear plugs help you get to sleep?



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