Traveling Programs

Sound and Hearing

What is Sound?

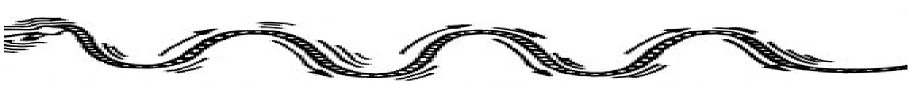
Sound is a form of energy. It can be generated, moved, can do work, can dissipate over time and distance, and can carry tremendous amounts of energy. Sound will continue only as long as there is energy in the system to keep it going.

Sound is defined as something that can be heard. It is a wave that is a series of vibrations traveling through a medium, especially those within the range of frequencies that can be perceived by the human ear. Sound can travel through many types of mediums, for example: gasses, liquids and solids. The compressions and rarefactions that move through the atmosphere are compressing and stretching the molecules of nitrogen and oxygen all around us. Sound cannot be heard in a vacuum, like outer space.

Types of Waves

A sound wave is an audible pressure wave caused by a disturbance in water or air and carried forward in a ripple effect. A sound wave is characterized as a mechanical wave. Mechanical waves require a medium in order to transport their energy from one location to another. Because mechanical waves rely on particle interaction in order to transport their energy, they cannot travel through regions of space, which are void of particles.

One type of wave is a transverse wave, which is a series of disturbances traveling through a medium in which particles of the medium vibrate in paths that are *perpendicular* to the direction of motion of the disturbances of the wave.



Examples of this would include waving a rope in an undulating motion and people doing the wave at a football game.

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The other type of wave is called a longitudinal wave, which is a series of disturbances traveling through a medium in which the particles vibrate in paths *parallel* to the directions the disturbances of the wave are traveling. Longitudinal waves are waves in which the motion of the medium is in the same direction as the motion of the wave.

Sound is not thought of as a transverse wave because of the behavior of the particles in the medium. Sound can be thought of as a longitudinal wave because of the vibrations of the particles of the medium.

Stationary or standing waves occur when two waves of equal wavelength and amplitude travel in opposite directions at the same velocity through a medium. Stationary waves are present in the vibrating strings of musical instruments.

Properties of Waves

Transverse waves are made up of crests and troughs. The crest is the portion of a transverse wave that lies above the horizontal time axis. The axis line is referred to as the rest or equilibrium point. The trough is the portion that lies below the axis line.

A wavelength in a transverse wave is the distance from the beginning of the crest to the end of an adjacent trough. It also described as the distance from the point of maximum displacement in one crest to the point of maximum displacement in the next closest crest. λ is the symbol for wavelength.

A longitudinal wave consists of compression and rarefaction. Compression is the part of the longitudinal wave where the particles of the medium are pushed closer together. Rarefaction is that part of the longitudinal wave where the particles of the wave are spread apart the most. Often a slinky is used to demonstrate this wave pattern. A longitudinal wave starts with a compression and ends with the next compression in a train of waves. Longitudinal waves are the best model for explaining the behavior of sound waves. If you picture a pebble being tossed into a pond you would see circular ripples forming and traveling outwards from the source. Sound is similar to that picture but in three dimensions, like a sphere.

Characteristics of Sound

Sound waves diffract (bend around corners) and refract (change direction when traveling from one medium to another) and reflect (bounce off surfaces). When a wave encounters a barrier the wave may be diverted in the opposite direction such as an echo, which is called reflection.

If two sound waves meet at a point that a rarefaction from one source meets compression from another wave and the source is at the same frequency (or the speed at which something vibrates), they will completely cancel each other out.

When the waves occupy the same physical space, the result is called interference. This depends on where each wave is in its cycle. The combined wave will be the sum of the amplitudes, or loudness of each of the interfering waves.

Pitch depends on the frequency – the higher the frequency, the faster the vibration and the higher the pitch while the lower the frequency, the slower the vibration and the lower the pitch. The material, the size, the shape and the tension of the object determine frequency. The shorter the object means the higher the pitch.

Resonance is the increased amplitude (or loudness) of vibrations of an object caused by a source of sound that has the same natural frequency as the object's frequency. Resonance occurs when two interconnected objects share the same vibrational frequency. When one of the objects is vibrating, it forces the second object into vibrational motion. The result is a large vibration and a loud noise. An example would be hitting one tuning fork near another tuning fork with the same natural frequency. The second tuning fork would vibrate even though it was not struck with a mallet but reacts to the vibrating air particles from the first tuning fork. The sounds we, ourselves, make produce resonance in the air filling the hollows in the throat, mouth and nasal cavities.

Speed of Sound

The speed of a sound wave in air depends upon the properties of the air, namely the temperature and the pressure. The pressure of air, like any gas, will affect the mass density of the air and the temperature will affect the strength of the particle interactions.

The sound waves are in a 3d circular pattern from the origin of the sound because the speed of the wave disturbances is constant. The speed of sound is about 331.5 m/s at 0º C or 1087 ft/s at 32º F, which translates to 740 mi/hr.

The faster a sound wave travels, the more distance it will cover in the same period. If a sound wave is observed to travel a distance of 700 meters in 2 seconds, then the speed of the wave would be 350 m/s. A slower wave would cover less distance – perhaps 660 meters – in the same time period of 2 seconds and thus have a speed of 330 m/s. Faster waves cover more distance in the same period of time.

Sound waves will travel faster in solids than they will in liquids and travel faster in liquids than they do in gases. A sound wave will travel faster in a less dense material than in a more dense material. An example is: a sound wave will travel nearly three times faster in Helium as it will in air, which is mostly due to the lower mass of Helium particles as compared to air particles.

The speed of sound is constant at a given temperature and is constant in each medium. The speed of sound changes with temperature changes. In air at 0º C the speed is about 331.5 m/s and increases about 0.60 m/s for every degree C increase in temperature. At 32º F the speed is about 1087 ft/s and increases 1.1 ft/s for every degree F increase in temperature.

Sound travels faster in warmer temperatures than colder temperatures. The wavelength in warmer temperatures is slightly longer than at freezing temperatures. The frequency, or rate at which the waves pass a given point, of the sound does not change due to a change in temperature – that is determined by the frequency at the source of the sound.

Sound travels slower in higher layers of the atmosphere than it does just above the surface of the ocean and land.

What is Hearing?

Unlike the senses of smell or taste, which rely on chemical interactions, hearing is a mechanical process in which the ear converts sound waves entering the ear into electrical signals the brain can understand.

The process of hearing begins with sound. An object produces sound when it vibrates in matter. This could be through something solid, liquid, or gaseous. Humans mostly hear sound that travels through the air.

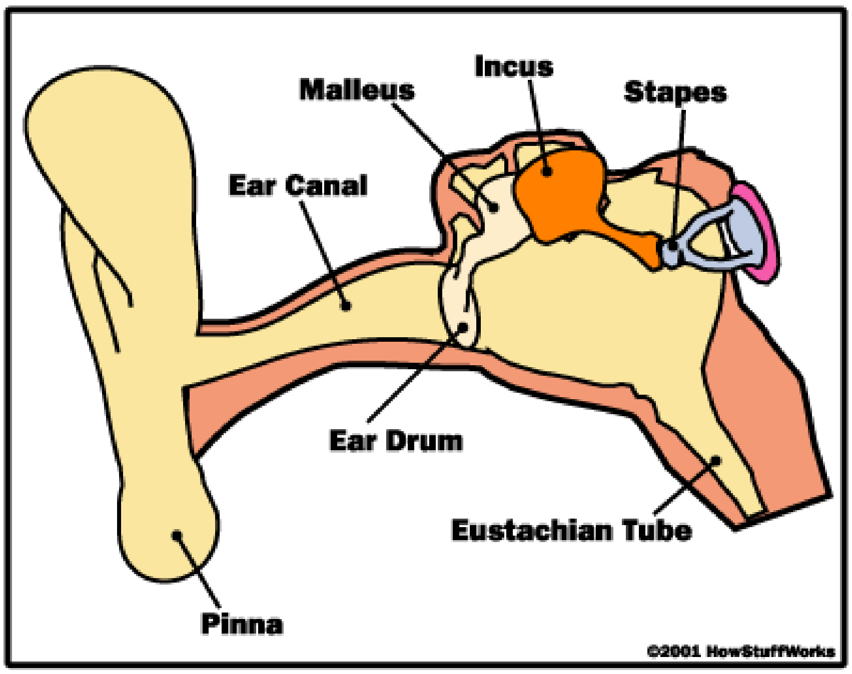
For example, when a bell is struck, it vibrates. This vibration is actually the metal flexing in and out. This physically moves the air particles next to the metal. Those particles, in turn, move the particles next to them and so on. In this way, the vibration moves through the air.

How You Hear

To hear the sound traveling through the air, three things have to happen. One, the sound has to be directed into the hearing part of the ear. Two, the ear has to sense the fluctuations in air pressure. Three, the fluctuations have to be translated into electrical signals that the brain can understand.

The pinna, or outer/visible part of the ear, catches the sound waves. In humans, the pinna is pointed forward. It helps to determine where the sound is coming from. The direction of the sound is determined by the way the sound wave bounces off the pinna. The brain can distinguish the subtleties in the sound reflection and tell where the sound came from. The horizontal position of the sound is determined by comparing the information from both ears. If a sound is coming from your right, it will enter your right ear slightly sooner than your left and will be slightly louder. Human cannot really focus in on a sound because the pinnae do not move. Some mammals, such as dogs, have large movable pinnae and so can focus in on a sound.

Once a sound wave has entered the ear, it travels along the ear canal. At the end of the ear canal is the tympanic membrane (or eardrum). The eardrum is a thin, cone-shaped piece of skin that is positioned between the ear canal and the middle ear. The middle ear is connected to the throat by the Eustachian tube and equalized pressure on both sides of the eardrum keeps us balanced. The change in air-pressure moves the eardrum. When a sound wave travels down the ear canal, it pushes the eardrum back and forth. The movements of the eardrum are very small and since the inner ear conducts sound though a fluid, not a gas, the total pressure of the sound has to be increased. This takes place in the ossicles, a group of bones in the middle ear.



The ossicles bones are the malleus (hammer), the incus (anvil), and the stapes (stirrup). The eardrum moves the bones which are, in turn, attached to the cochlea at the oval window. The cochlea is filled with fluid. When the eardrum is pushed by sound waves, the ossicles move and the faceplate of the stapes pushes on the liquid inside the cochlea. The stapes works basically like a piston and makes waves within the liquid of the cochlea. The pressure from the stapes applied to the cochlea fluid is about 22 times the pressure that the sound wave had at the eardrum. This is enough to pass the sound information to the inner ear. It is in the inner ear that the sound waves are translated into nerve impulses that the brain then interprets into what we understand as sound.

The Cochlea

The most complex part of the ear is the cochlea. It is here that the physical sound vibrations are translated into electrical impulses.

The cochlea consists of three adjacent tubes separated by thin, sensitive membranes. These tubes are coiled in the shape of a snail shell. When the stapes pushes against the oval window it creates pressure though out the cochlea. The round window is a membrane separating the cochlea from the middle ear and this membrane moves in and out, giving the

fluid somewhere to go. The middle membrane, or the basilar membrane, is rigid and extends the length of the cochlea. The vibrations from the stapes moves along the basilar membrane. This membrane is made up of 20,000 to 30,000 reed-like structures that extend along the width of the cochlea. At the end with the oval window the fibers are short and stiff. They become longer and more supple the further you go from the oval window. The fibers have different resonant frequencies. Each frequency corresponds with a specific sound wave length. The wave, vibration, moves along the membrane until it reaches the fibers with the same resonant frequency. At this point the waves energy is released. The energy is strong enough to move the hair cells of the organ of corti. The organ of corti lies on the surface of the basilar membrane and extend the length of the cochlea. When the hair cells are moved they send an electrical impulse through the cochlear nerve which sends the signals to the cerebral cortex. The brain then interprets the impulses into recognizable sounds.

There is still much research being conducted on the sense of hearing.

Fun Sound Facts!

1. Shorter strings vibrate more rapidly than longer strings.
2. More rapid vibrations seem to produce a shriller sound.
3. Sound does not move through a vacuum.
4. The frequency of motion is measured in Hertz (Hz) – the number of vibrations in a second.
5. Speed = distance/time

6. The loudest natural sounds ever made on Earth are probably gigantic volcanic eruptions, such as the explosions of the island of Krakatoa.
7. Some of the loudest sounds produced by our own invention are the noise of space rockets blasting from the launch pad. The biggest were the Saturn V rockets that launched the USA's Apollo moon missions of 1968-72.
8. In the deep ocean, the sperm whale uses sound to stun or kill its prey. Its sends out giant grunts, immensely powerful bursts of sound that can disable nearby fish, squid and other victims

9. The blue whale can produce sounds up to 188 decibels. This is the loudest sound produced by a living animal and has been detected as far away as 530 miles.

10. Sound is measured in decibels. Examples:
    a. Whisper - 10 decibels
    b. Classroom - 50 decibels
    c. Jackhammer - 100 decibels
    d. Jet airplane taking off or rock music - 120 decibels
    e. Exposure to 90 decibels or more for prolonged periods of time can cause pain or loss of hearing
11. Ultrasonic – higher frequencies that are not perceived by the human ear (15 Hz to 20,000 Hz per second)
12. Animals can hear at different frequencies. Examples:
    a. Dogs and cats – up to about 30,000 Hz
    b. Bats – up to 100,000 Hz
    c. Whales and elephants - less than 15 Hz
13. Mach 1 refers to the speed of sound through the air at or near sea level at 20º C (343 m/s or 1235 km/h)
14. Thunder – it take 3 seconds for the sound of thunder to travel 1 km. To determine the distance count the number of seconds between the flash and the sound and divide by three.
15. Notes on a musical scale are at different frequencies. Examples:
    a. Middle C 262 Hz (near the top of the singing range)
    b. D 294 Hz
    c. E 330 Hz
    d. F 349 Hz
    e. G 392 Hz
    f. A 440 Hz
    g. B 494 Hz
    h. High C 524 Hz

16. Sound travels through different mediums at different frequencies. Example at 68º F:
    a. Air - 1,132 speed (f/s)
    b. Alcohol - 3,835

c. Fresh water - 4,890
d. Glass - 18,610
e. Steel - 19,670

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