3 The Nature Of Sound

READING

THE VARIATION OF sounds in the world is vast. Some sound waves carry small amounts of energy, such as a whisper or the sound of breathing. Other waves, such as the sound from an explosion, can be loud enough to damage tissue in the ear. Some sounds, such as voice or music, carry complex information. Despite the wide variety of sounds, all types of waves share some of the same characteristics, such as frequency and speed. In this activity, you will read about these common characteristics that identify sound. Then you will explore ways that sound is used in everyday devices.

Tuning forks of various frequencies

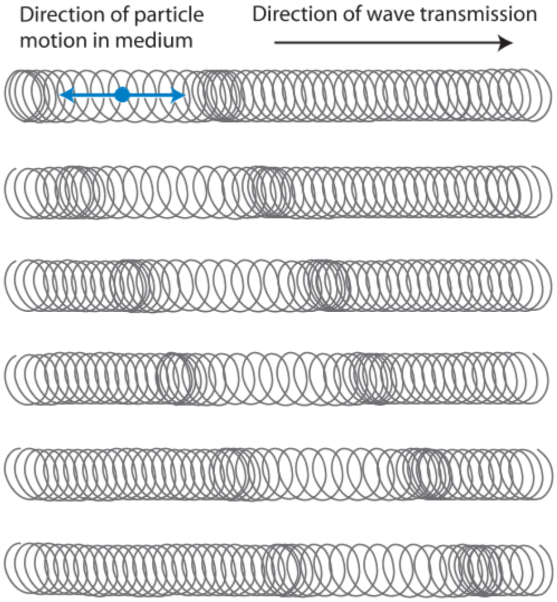
GUIDING QUESTION

What are the properties of sound waves?

READING

Longitudinal Waves

Sound waves, like some other mechanical waves, are longitudinal waves. A **longitudinal wave** is one that transfers energy through compressions and rarefactions in the material through which the energy travels. A compression is the region of the wave in which the material through which the wave is transmitted is pressed together. A rarefaction is the region in which the material is spread apart. When you hear a sound wave through the air, you are detecting a disturbance in the pressure of the air. In a longitudinal wave, like sound, the material in which the energy travels vibrates parallel to the direction the energy travels.



Wave Media

When a wave transmits energy, it is important to note that the individual molecules or particles in the medium are not transmitted. In other words, the medium does not move along with the wave. A **medium** (plural is media) is the material in which wave energy travels. Mechanical waves, such as sound or seismic waves, move through the ground, water, air, and other materials. For example, when making varied noises with a rubber band, the rubber band vibrating is the source of the wave, but the air is the medium through which the energy travels. The disturbance moves away from the source through a medium to our ears. When this happens, the air does not permanently change its position relative to the source. Namely, the air touching the rubber band does not move across the room and land in someone's ear. The medium itself—the air—is not transferred from the source of the sound to the receiver of the energy.

STOP TO THINK 1

If air is often the medium for sound, what is the medium for a seismic wave?

Speed of Sound

The **speed of sound** can be directly measured, like moving objects, using the relationship

$$speed = \frac{distance}{time}$$

For example, the sound from a thunderclap that happens 1,000 m away and takes 2.9 s to get to you, traveled at an average speed of

$$speed = \frac{1{,}000\ m}{2.9\ s}$$
$$= 345\ m/s$$

Waves travel at various speeds depending on the medium. The same wave travels at different speeds through different substances. The speed is affected by physical properties, such as the density of the material. For example, sound travels about 10 times faster through wood than through air, as shown in the table on the next page. The tight spacing of the vibrating molecules in the denser material enables sound to travel faster. In general, but not always, sound travels faster through solids than liquids and faster through liquids than gases.

Sound also travels at various speeds through the same substance depending on its temperature and humidity (if it is a gas). For example, sound travels faster in hot air compared with cooler air

A supersonic jet traveling faster than the speed of sound. The vapor cone behind the jet is a cloud of condensed water that forms due to humid air entering a low-pressure region.

because the air molecules are moving quicker, which increases the speed at which they transfer energy. The speed of sound in air changes from 331 m/s at 0° C to 355 m/s at 40° C.

Because sound waves depend on the physical disturbance of atoms or molecules, they must have a medium in order to travel. Sound cannot transmit energy through a vacuum because there are no atoms or molecules in a vacuum. Although outer space is not a perfect vacuum, the molecules are so far apart that they do not allow for compressions and rarefactions. Therefore, sound cannot travel in outer space.

Speed of Sound

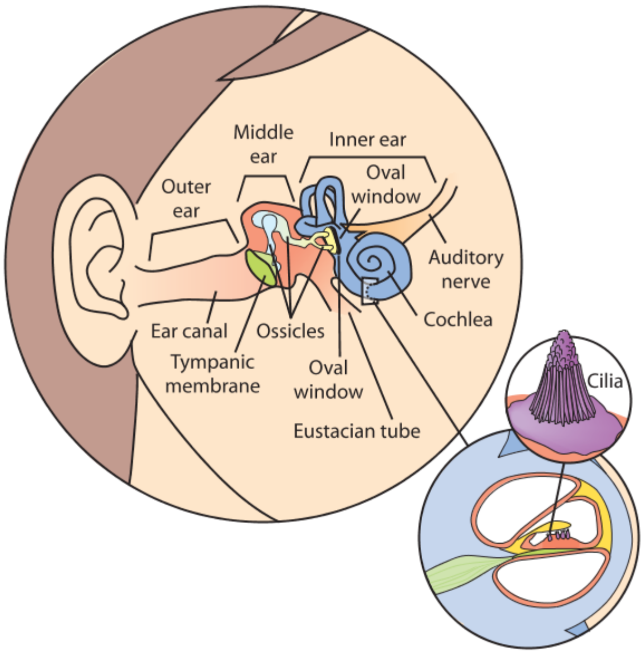
Medium	***Speed (m/s)***
Vacuum	*0*
Carbon dioxide (0˚C)	*258*
Air (20˚C)	*344*
Helium (20˚C)	*927*
Water, fresh (20˚C)	*1,481*
Wood	*3,500*
Aluminum	*6,400*

STOP TO THINK 2

What is the speed of sound for a noise that travels 2 km in 5.8 s?

Sound and Hearing

Hearing is a result of a sound wave transmitting from the air though the various parts of the ear, from the outer to the inner ear where the signal is sent to the brain for interpretation. When a sound wave reaches the ear, the compressions and rarefactions are first channeled through the outer ear onto the eardrum, or the tympanic membrane. The vibration on this flexible membrane is transmitted into the middle ear. Once in the middle ear, the vibration is transmitted quickly through an opening (known as the oval window) in three small solid bones to another membrane on the inner side of the middle ear. This vibration sends energy into the inner ear. The inner ear contains the cochlea, a snail-shaped organ filled with fluid. When the vibration from the oval window moves the fluid in the cochlea, the fluid activates up to 25,000 tiny specialized cells. The specialized cells, called cilia, then send an electrical signal to the brain through the auditory nerve.



Cochlea cross section

A person's hearing loss depends on which parts of the ear do not respond to these waves. Problems with the outer or middle ear lead to inefficient transfer of sound. This type of hearing loss is called *conductive hearing loss* because the outer and middle ear do not conduct the sound into the inner ear. Conductive hearing loss can be caused by things such as a hole in the eardrum, inflammation of the middle ear, excessive wax, trauma to the head, or dysfunctional bones in the middle ear. *Sensorineural hearing loss* means that sound arrives to the inner ear, but the information is not fully passed on to the auditory nerve. For example, repetitive exposure to a sound at the same frequency will damage the cilia cells that receive that particular frequency such that they can no longer respond to that frequency.

Sensorineural hearing loss can be inherited or caused by things such as old age, a sudden loud noise, repeated exposure, medication, inner ear infection, or head trauma. It is possible for a person to have both conductive and sensorineural hearing loss, which is known as *mixed hearing loss*.

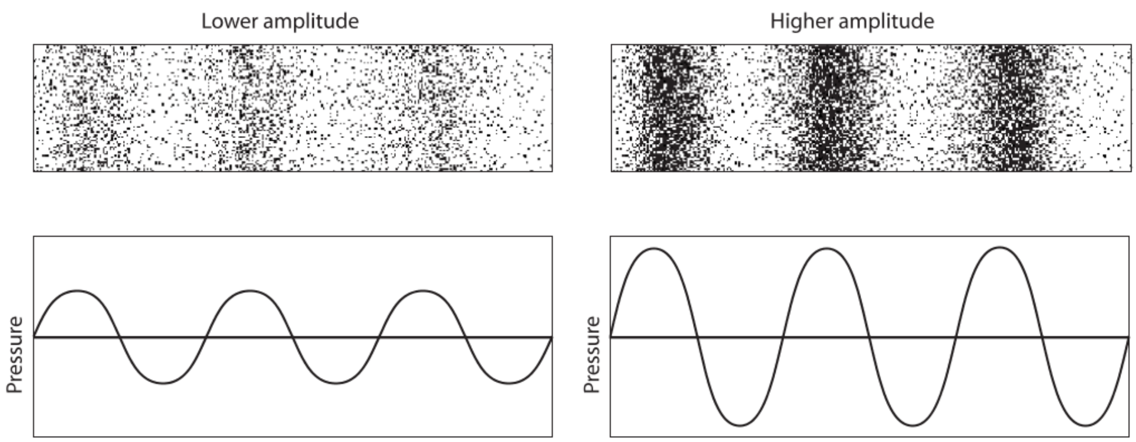
STOP TO THINK 3

If you have an ear infection that temporarily adds fluid to the middle ear, what kind of hearing loss do you have?

Wave Energy and Amplitude

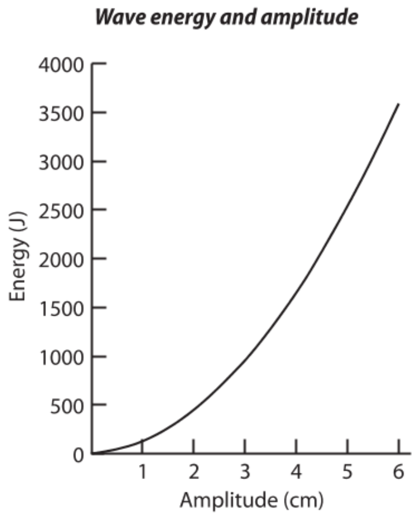
For sound and other mechanical waves, the amount of wave energy is related to its amplitude. The **amplitude** of a wave is the maximum displacement from its state of rest. For sound, amplitude is closely related to the sound's intensity, which was explored in previous activities. It can be measured as a distance or a pressure. The units for amplitude vary depending on the kind of wave.

Amplitude Comparison

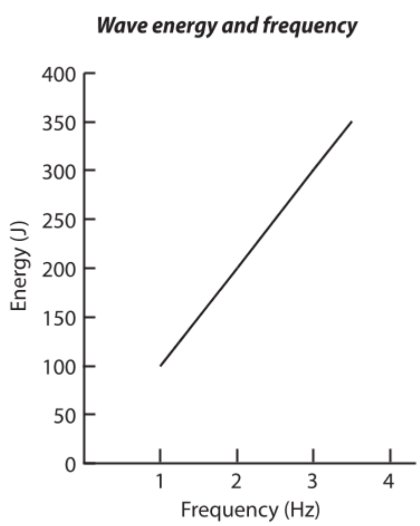


These diagrams model sound. The top row uses dots to represent air molecules and the bottom row shows variation of air pressure. The waves on the right have higher amplitude than those on the left.

If two waves are traveling at the same speed and frequency, the one with the larger amplitude will deliver more energy. For example, if water waves are hitting the shore, a taller wave will hit the shore with more energy. Likewise, a sound wave with a bigger amplitude will sound louder. The relationship between the amplitude and the energy of a wave is shown in the graph on the next page.



Another way to increase the amount of energy transferred over time by a wave is to increase the frequency. Increasing the frequency of a wave will deliver more cycles of energy in a given amount of time. For example, if water waves are hitting the shore and the frequency is doubled, then twice as many waves will hit the shore. If the energy of each wave is the same, then twice as much energy is delivered. In sound, a higher frequency at the same amplitude delivers more energy into the ear.



STOP TO THINK 4

What are two ways to increase the energy of a wave?

Extending the Senses

Since our world is full of the sights and sounds of waves, scientists and engineers have created many devices to help us better understand the waves around us. One critical invention is the hearing aid, which contains a small microprocessor that clarifies and amplifies sound for an individual.

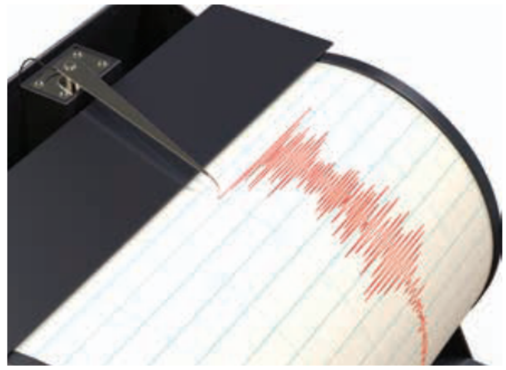
Another everyday device that allows us to extend our senses is sonar. Sonar uses sound produced at frequencies that are not detectable by human ears. Sonar allows personnel on ships and submarines to detect the depth of water and the presence of fish and other boats on or under the surface. It does so by bouncing sound waves off the surfaces and calculating distances based on the time taken for the echo to return to the device.

Some animals, such as the bat and dolphin shown here, navigate their environments using sound waves.

Another important device related to sound waves is the seismograph. This device detects longitudinal waves in the earth in the form of seismic waves. Seismic waves are low-frequency waves caused by such events as explosions and earthquakes. By measuring seismic waves with a seismograph—even those waves that are not felt by humans on Earth's surface—scientists locate earthquake epicenters and create maps showing regions at risk of earthquakes. All of these examples illustrate ways in which people have invented devices that use wave energy to measure things we would not ordinarily see or hear.

STOP TO THINK 5

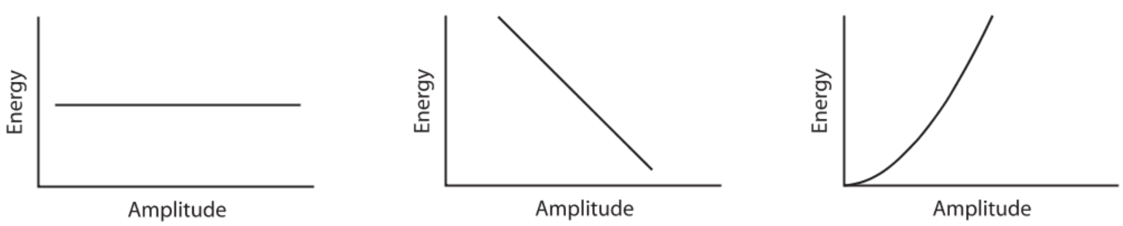
What is another example of a device that uses sound waves?



Seismograph

ANALYSIS

1. If you started the motor of a boat in the middle of a lake, who would detect the sound of the motor first: a friend sitting on the shore of the lake or a friend snorkeling just below the surface of the water at the same distance from the boat? Explain your answer.
2. Lightning and thunder occur at the same time, yet we see the flash of lightning before we hear the clap of thunder. What does this indicate about the speed of light compared with the speed of sound?
3. Whales communicate with other whales by making low-frequency sounds. They navigate by making high-frequency sounds that echo back to them. Military sonar systems on ships produce sounds as loud as 200 dB, and these sounds travel great distances across oceans. Describe how such systems might affect whales.
4. Look at the following graphs that show the relationship between the amplitude and energy for a wave. Which one was supported by the patterns you observed in the reading?



Graph A *Graph B* *Graph C*

5. If you want to increase the amount of energy a wave transfers over time, will it be most effective to double the frequency or double the amplitude? Explain using the graphs in the Reading and provide an example.
6. A student stands 100 m in front of a large smooth wall and claps loudly. Another student figures out the time for the sound to travel to the wall and back. If the sound takes 0.58 s for the sound to leave and return, what is the speed of the sound?

EXTENSION

Find through research an example of a technology not found in the Reading that uses sound to extend the way we measure, explore, model, and compute during scientific investigation. Explain how the technology uses sound.