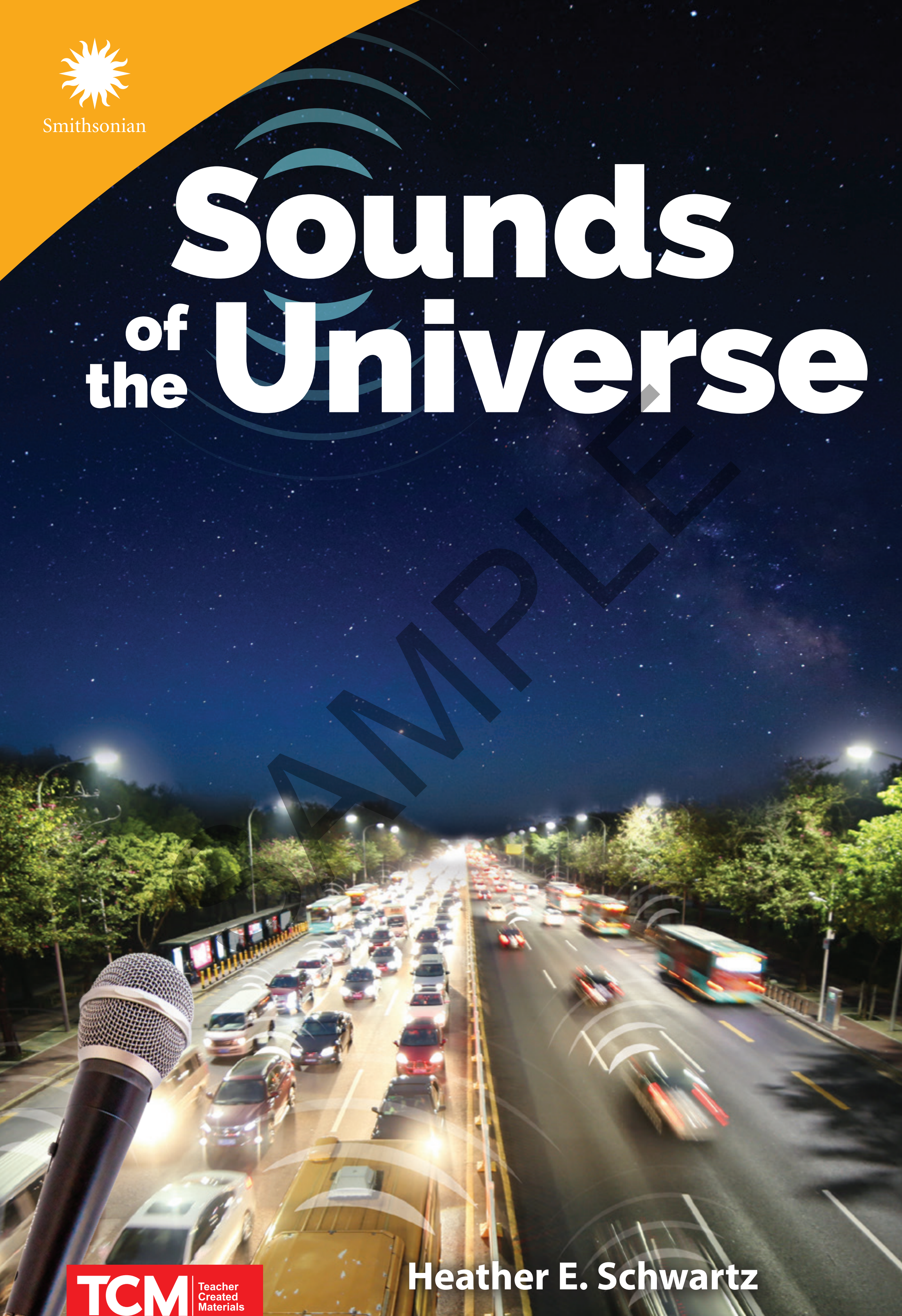

Smithsonian

Sounds of the Universe

Heather E. Schwartz

TCM Teacher Created Materials

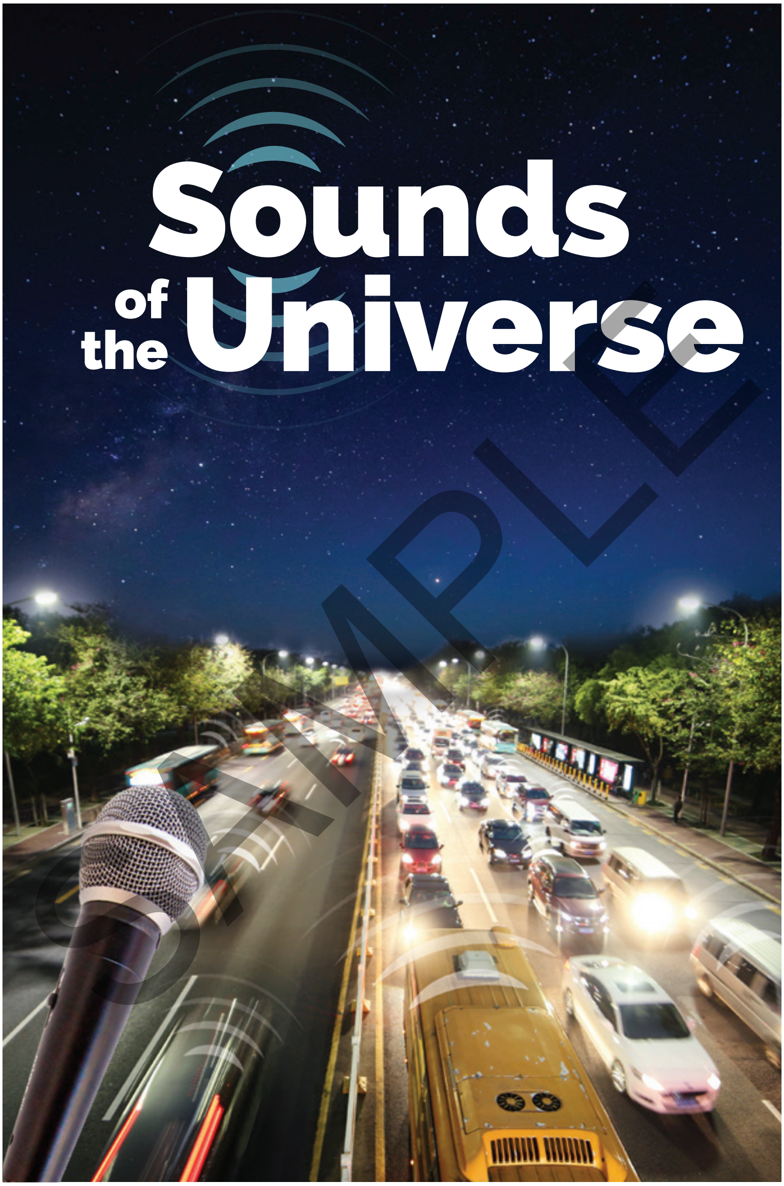

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Table of Contents

Sounds All Around

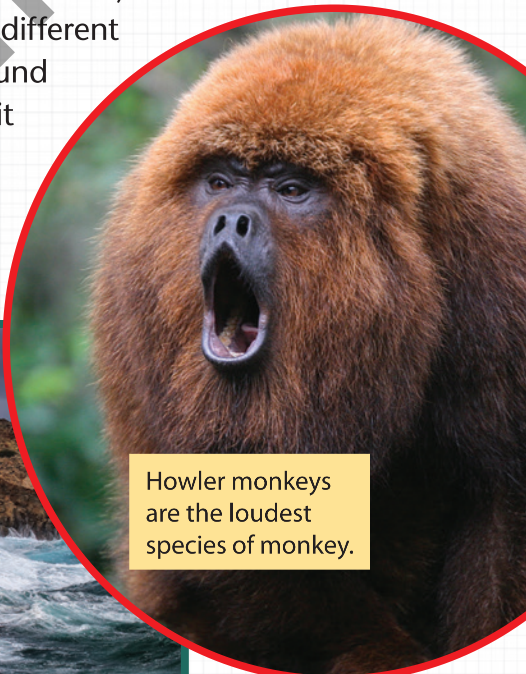
Pause for a moment, and listen to the sounds you hear around you. Perhaps you hear your classmates whispering to each other. Maybe a pencil drops from a desk with a *clink* and rolls noisily across the floor. Or maybe you hear the voices of other students and teachers as they walk down the hallway. Everyday life is filled with all kinds of different sounds.

Sounds have meanings that are important to you, and they send signals that you can **interpret**. For example, the hum of a refrigerator tells you the appliance is working. A cat's purr tells you it is happy and content. The roar of a truck's engine warns you to watch out before crossing a road.

Wolves howl to communicate with members of their packs and warn off rival packs.

Sounds are also used for communicating and helping people understand information. Humans can use their voices to communicate questions, ideas, wants, needs, and more. Animals can use sounds to communicate with others, find food, and navigate their environments. Humans and animals experience sound differently. Humans can only hear a specific range of sounds, and some animals have better hearing than humans do.

The whole universe is filled with sounds, and the way sounds work depends on different factors. These include where a sound comes from and what substances it moves through. Let's tune in to how sound works on Earth, in our oceans, and in outer space!



Howler monkeys are the loudest species of monkey.

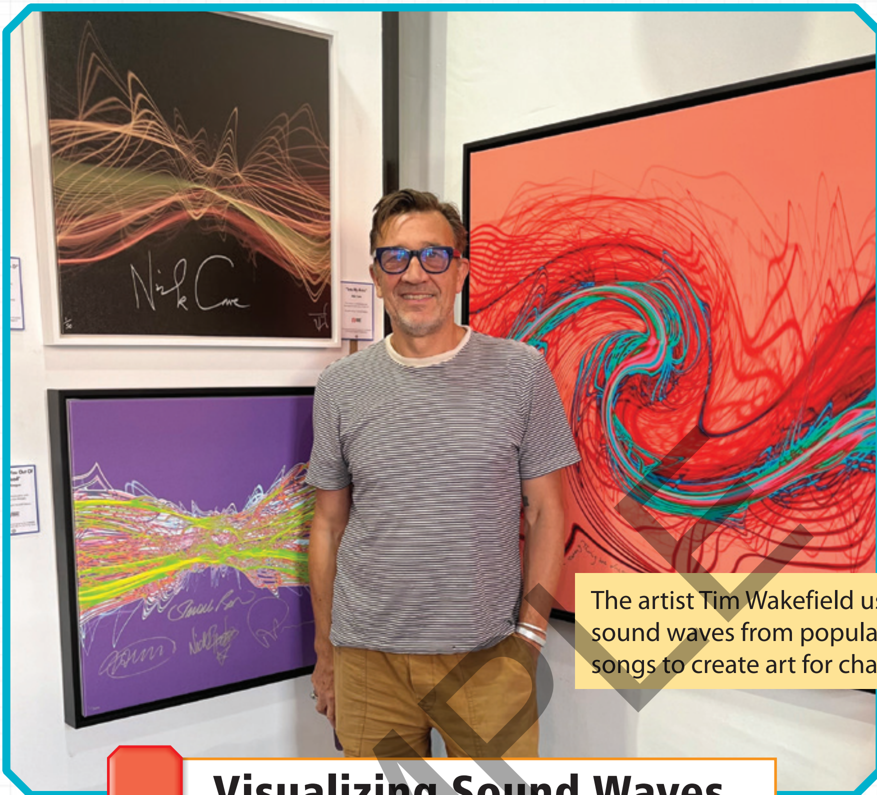
Ocean waves make loud crashing sounds.

What Are Sounds?

You can't see sounds, and you can't hold them, either. That's because sounds are actually a form of energy created by **vibrations**. Creating a sound takes a few steps, and this process happens in an instant.

An object first has to move. For example, a guitar string could be plucked, a drum could be hit, or a cell phone could buzz. Any object can create a sound if it is moved or disturbed in some way. Think of dropping a book on the floor—*smack*! Or imagine pulling open a drawer—*whoosh*. The movement of an object causes vibrations.

As an object is vibrating, it disturbs the **medium** around it. The medium could be air, water, or even solid objects. More specifically, the vibrating object disturbs the **molecules** of the medium. Each vibrating molecule bumps into other nearby molecules. This makes them vibrate, too.



The artist Tim Wakefield uses sound waves from popular songs to create art for charity.

ARTS

Visualizing Sound Waves

Sound waves are invisible to the naked eye. But they can be seen on a screen while using a microphone. This tool changes sound energy into electrical energy. Artists around the world use these visual sound waves as inspiration for paintings, sculptures, and jewelry. Artists have created art using the sounds of songs, heartbeats, and people's voices!

All these vibrations cause a pattern of energy movement called a *sound wave*. Sound waves are pressure waves that continue moving until their energy runs out. The direction, speed, and length of a sound wave will depend on the medium. For example, sound waves move faster in water than in air.

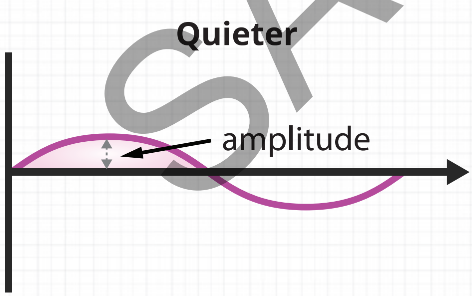
Finally, when a receiver is near the source of the sound, the sound can be heard. Common receivers include human or animal ears and microphones.

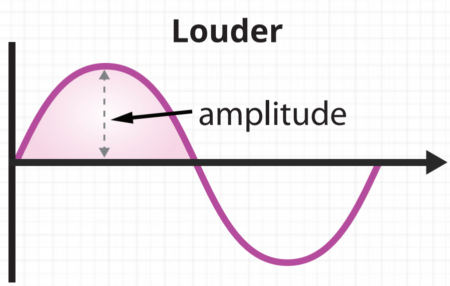
Properties of Sounds

All sounds are different because of their properties. Properties are characteristics of sound waves, and they determine whether sounds are quiet or loud. There are three key properties of sound waves: amplitude, frequency, and intensity.

Amplitude is the height of a sound wave. Sound waves with high amplitudes have more energy than sound waves with low amplitudes. This means sound waves with high amplitudes are loud. For example, sound waves from a train speeding along its tracks will have higher amplitudes than sound waves from rustling leaves.

Frequency is the number of times per second a sound wave repeats itself. It is measured in **hertz** (Hz). Sounds that are **audible** to humans fall in the range of 20 to 20,000 Hz. Sounds with high frequencies are high-pitched, meaning they may sound harsh or sharp. Sound waves created by a baby's cries have a high frequency. Meanwhile, sounds with low frequencies are low-pitched and deeper, such as the notes from a bass drum.

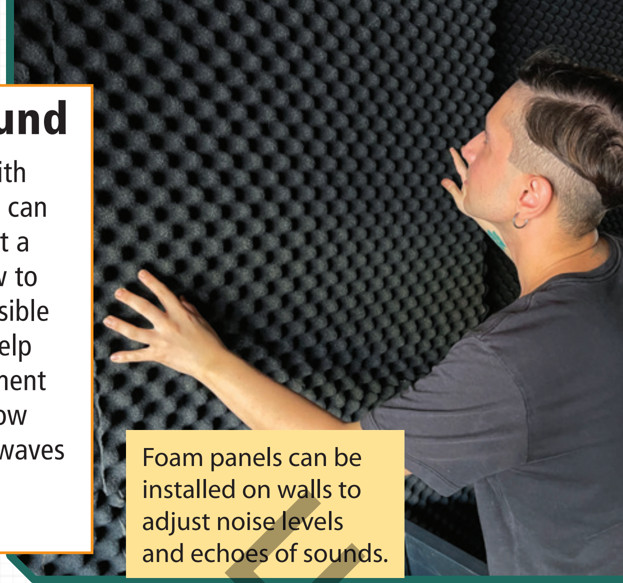




ENGINEERING

Working with Sound

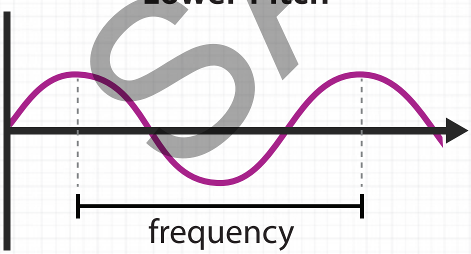
Acoustical engineers work with sounds in different ways. They can help set up the sound system at a concert venue. They know how to make the music as clear as possible for the crowd. They can also help with the construction of apartment buildings and homes. They know which materials absorb sound waves to decrease the noise levels of outside sounds.



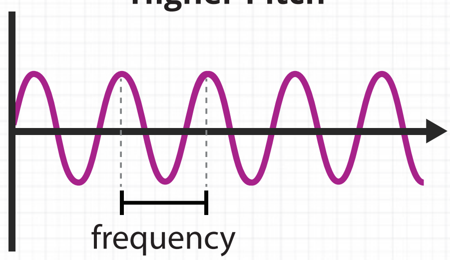
Foam panels can be installed on walls to adjust noise levels and echoes of sounds.

Intensity refers to the energy sound waves have as they travel through an area. Louder sounds have higher intensity, and quieter sounds have lower intensity. Sound intensity is proportional to amplitude and frequency, so as those two factors increase, so does intensity. Intensity is measured in decibels (dB). A whisper is roughly 30 dB, while the sound of a gas-powered lawn mower is 100 dB. Listening to high-decibel sounds for a long time can damage a person's hearing.

Lower Pitch



Higher Pitch

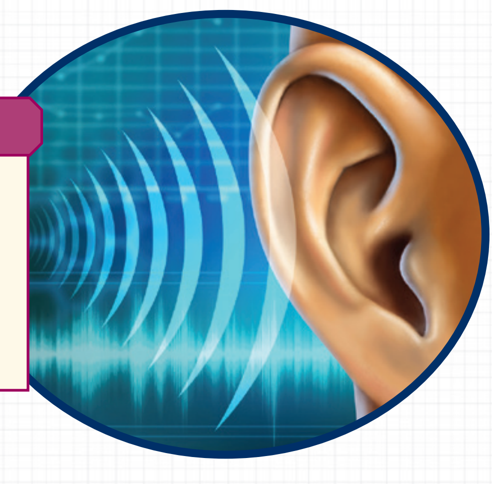


How Humans Hear

In a noisy environment, such as a crowded gym or carnival, you might feel as if you're surrounded by sound. The sounds you hear might include voices shouting, buzzers buzzing, balls bouncing, and feet pounding on the floor. Even in a quiet environment, such as in the middle of a forest, complete silence is rare. You might hear the wind blowing, birds chirping, or insects buzzing. In normal circumstances on Earth, sounds are everywhere. Have you ever wondered how humans can hear sound?

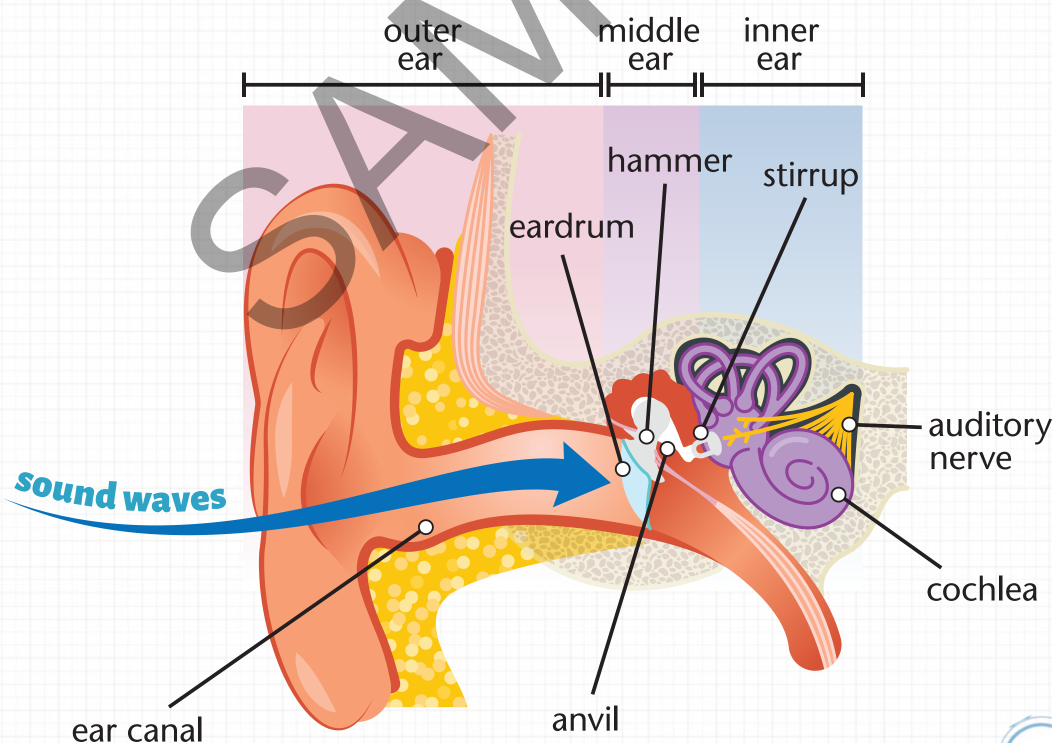
FUN FACT

Have you ever noticed that turning your head can change how loud or quiet a sound is? That's because you're changing the position of your ears, which receive sounds. It's more difficult to hear clearly when sound waves can't travel straight into your ears.



Hearing starts when vibrations that create sound waves reach a person's ear. These vibrations move into the outer ear. They continue through the ear canal to the middle ear. There, they reach the eardrum, causing it to vibrate. These vibrations move three tiny bones behind it: the malleus, incus, and stapes. These bones are commonly known as the hammer, anvil, and stirrup. They're the smallest bones in the human body. In fact, all three bones together are no bigger than an orange seed. But they have a critical job to do!

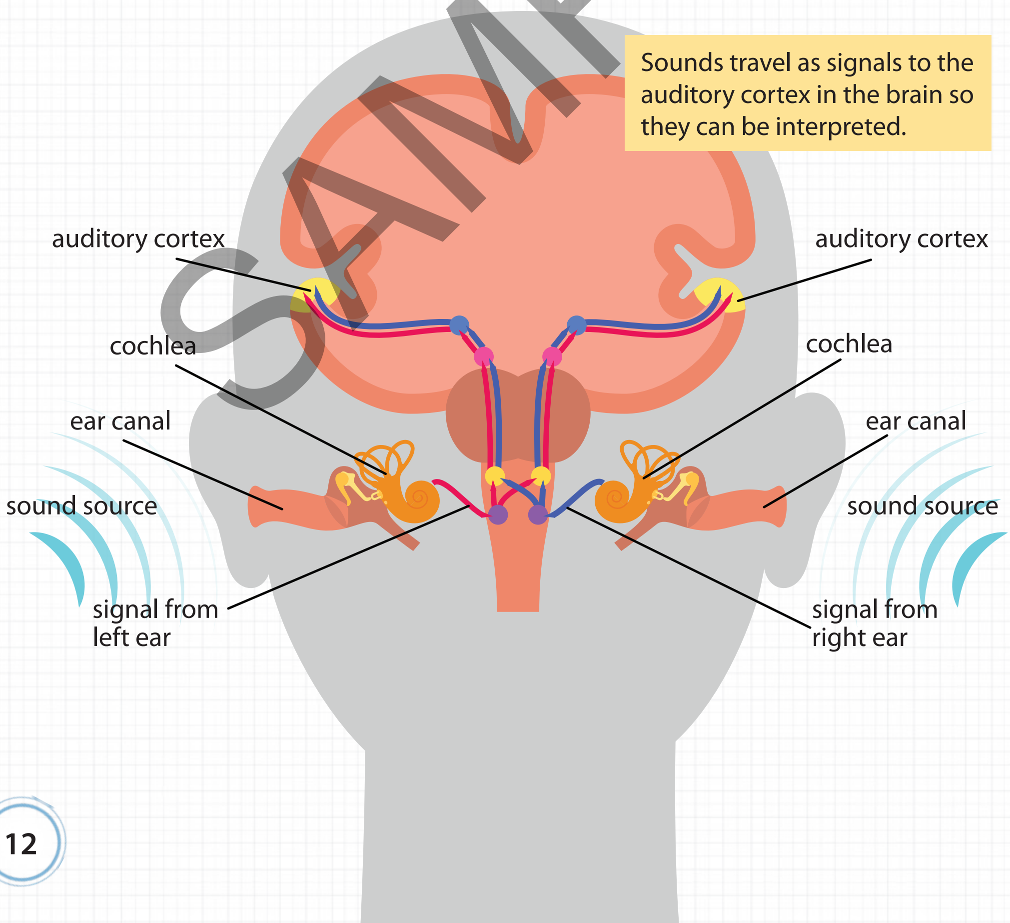
These three tiny bones **amplify** the sound wave vibrations, sending them to the cochlea. This is a snail-shaped organ in the inner ear. When the sound waves arrive, they vibrate fluid inside the cochlea. That causes 25,000 to 30,000 **nerve** endings to move as they detect sounds.



From the Ear to the Brain

Your ears take in sound waves that come from any kind of noise. Are you hearing rain tapping on the roof, a bee buzzing by, or an egg frying in a pan? To know what sound you're hearing, the information received in your ears has to travel to your brain.

This transfer of information happens quickly, and it all starts in the cochlea. There, nerve endings change sound wave vibrations into electrical signals. These electrical signals move out of the ear and to the central nervous system. They zoom along the auditory nerve to the brain. When the signals arrive, the brain interprets the information. This is how you know what you're hearing, such as the words to a song or the honking of cars in the street.

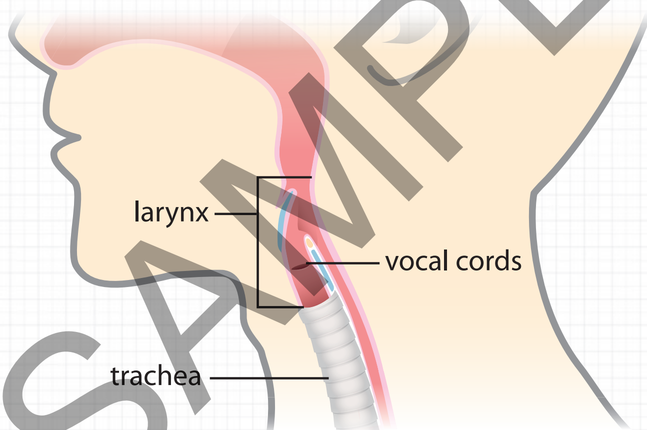


Sounds travel as signals to the auditory cortex in the brain so they can be interpreted.

How Humans Speak

Humans can speak to one another thanks to their vocal cords. These are folds of tissue in a person's larynx, or voice box. Air from the lungs passes between the vocal cords, making them vibrate. Then, a person uses their tongue, teeth, lips, and the roof of their mouth to shape the sounds that make words. For example, think about how you would say the letter *p*. You close your mouth, bringing your lips together, before you can say the letter.

Humans use speech in a variety of ways, including conversations, music lyrics, and speeches. These sound waves travel through the air to our ears and brains, helping us understand and navigate the world.



MATHEMATICS

Hearing and Age

As people get older, they typically experience hearing loss. People who are younger than 25 can hear high-pitched sounds that older adults cannot. Young people can hear sounds up to 20,000 Hz. As people age, they often lose the ability to hear higher frequencies.

Inaudible Sounds

If a tree falls in the forest and no one is around to hear it, does it make a sound? For centuries, philosophers have posed this question, and scientists today know the answer. Of course it does! When sound waves vibrate through the air, sound is created. It doesn't matter whether humans are around to receive them.

However, some sounds are **inaudible** to humans. These sounds are outside the range of human hearing, and human ears cannot recognize them. Humans can use special technology to pick up on these sounds and adjust their properties, bringing them into an audible range. One type is **infrasonic** sound. These are low-frequency sounds below 20 Hz. Earthquakes, volcanoes, wind, and thunder can make low-frequency sounds. Another type is **ultrasonic** sound. These are high-frequency sounds above 20,000 Hz. Certain electronic devices, such as alarms, can make these sounds.

Active volcanoes make sounds that can be detected thousands of kilometers away from an eruption.

TECHNOLOGY

Special Devices

Hearing aids can amplify sounds for people who have hearing loss. These small electronics are worn in or behind the ears. Cochlear implants require surgery for use. These implants mimic the functioning of a healthy inner ear. They avoid using the hammer, anvil, and stirrup. Instead, they detect sounds as signals directly in the cochlea.

Loss of Hearing

Humans experience a wide range of hearing loss. Hard of hearing and deaf individuals use a visual language instead of one reliant on sound. In the United States, American Sign Language (ASL) is used to communicate through hand movements rather than speech.

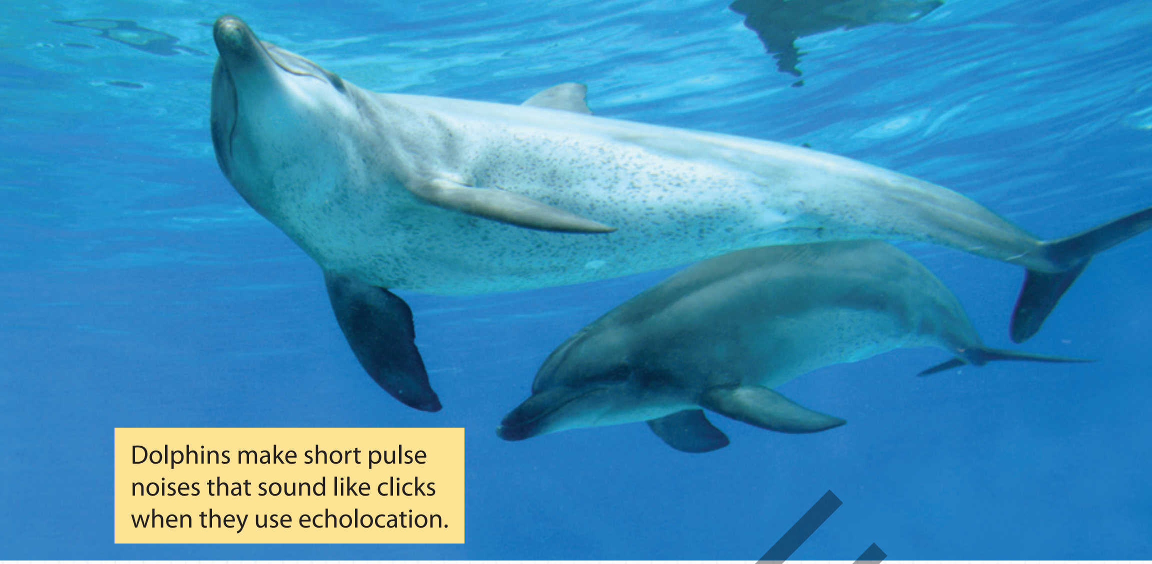
People who have experienced hearing loss can still experience sound through their sense of touch and sight. At a very loud rock concert, they can feel the vibrations in their bodies caused by sound waves. (Maybe you have experienced this, too.) To boost these feelings, they can hold balloons in their hands to focus and amplify the vibration.

Animals and Sounds

Animals make and use sounds in a variety of ways. Just like humans, one of the biggest reasons animals make sounds is for communication. Birds sing to attract mates. Kittens meow to tell their mothers when they're hungry or cold. Lions roar to scare away predators and protect their cubs. Different types of animals can make different sounds to express themselves.

FUN FACT

Vampire bats mostly feed on the blood of other animals. The parts of their brains that process sound have adapted over time to detect the breathing sounds of sleeping animals. Then, these bats swoop in and use their sharp front teeth to pierce the skin of their prey.

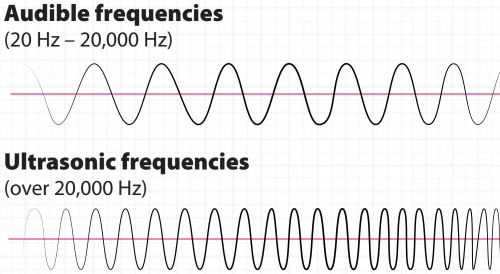


Dolphins make short pulse noises that sound like clicks when they use echolocation.

High-Frequency Sounds

Animals can hear sounds in frequencies that are inaudible to humans. Cats, whales, dolphins, and bats are among the critters that can hear high-frequency sound waves. Dogs are another example, and humans have taken advantage of this with the creation of dog whistles. Dog whistles make ultrasonic sounds that only dogs can hear. Humans can use these whistles to train dogs or get their attention without creating loud, irritating noises for humans to hear.

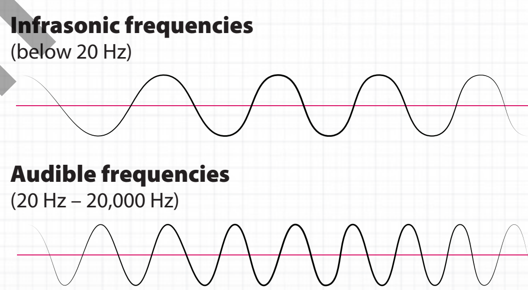
Some animals use sound to navigate their environments. Some dolphins, whales, and bats use a process called *echolocation* to move around and hunt prey. These animals make squeaking and clicking noises that produce high-frequency sound waves. The sound waves create echoes when they reflect off nearby objects. Then, the animals interpret the echoes, determining where the objects are. The animals also learn the sizes and shapes of objects. That's how dolphins and whales locate fish for their meals and how bats find insects to eat.



Low-Frequency Sounds

Certain types of animals can hear low-frequency sounds, including some whales and elephants. Larger animals are more sensitive to the vibrations caused by certain types of natural disasters, such as earthquakes. They can hear the low-frequency sounds that the vibrations create. That's why elephants can sense when a **tsunami** is coming before humans have any idea.

Elephants can also make low-frequency sounds of their own—sounds that humans can't detect. An elephant making low-frequency trumpeting sounds can communicate with herd members that are more than 10 kilometers (6.2 miles) away! Infrasonic sound waves can travel farther than sound waves that are audible to humans. These sound waves have longer wavelengths that help them move around objects, such as trees and boulders. They keep moving in the same direction, carrying their energy for longer distances. This is different from high-frequency sound waves, which bounce off objects, move in new directions, and lose energy.



Pets often find hiding places during periods of loud noise to make themselves feel safer.

Environmental Changes

Scientists have found that animals are sensitive to even the slightest changes in their environments and will act accordingly. Before a weather event, such as a storm or flash flood, air pressure drops. Animals can sense pressure changes in their environments, and as a result, they may hide and protect themselves from whatever's coming. For animals with sensitive hearing, loud noises from thunderstorms or fireworks can be distressing.

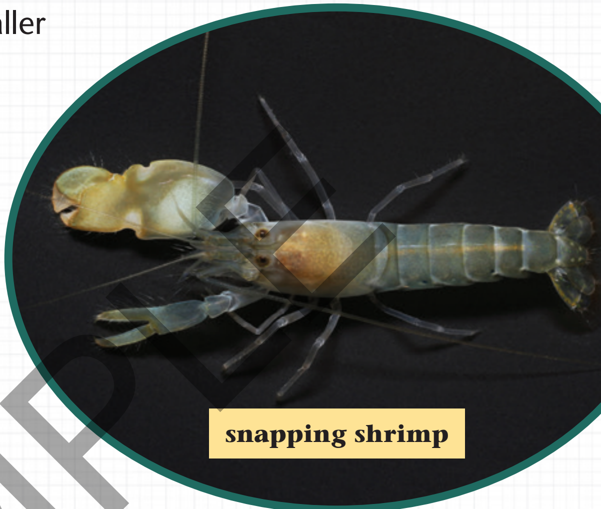
Underwater Sounds

Sound travels four times faster underwater than it does through air. That's because the molecules that make up water are closer together than the molecules in the air. This density allows sound waves to travel faster and farther. Many ocean animals rely on sounds for survival.

Communication is one way that underwater animals use sounds. Male humpback whales, for example, make songlike sounds underwater that help them communicate with one another. These low-frequency sounds can travel across vast distances. Using a **hydrophone**, a scientist in Virginia was able to hear whales singing off the coast of Ireland. Whales can also slap their tails and fins on the surface of the water to create loud sounds. These sound waves travel quickly through the water below, disrupting the fish. Startled, the fish stick together and form a school. This is good news for whales, who then have an easier time hunting in one place.

Humpback whales sing at their feeding grounds and when they migrate to breeding areas.

Echolocation is not the only way animals hunt underwater. Tiny snapping shrimp have a particularly unique approach. Each of these small animals has one normal-sized claw and one larger claw. When they snap their large claw shut, it creates a powerful wave of bubbles that can stun or even kill smaller fish. The snap they make is super loud, too. When large numbers of snapping shrimp form colonies, they can be very noisy. Some snapping shrimp colonies have interfered with **sonar** communication!



snapping shrimp

FUN FACT

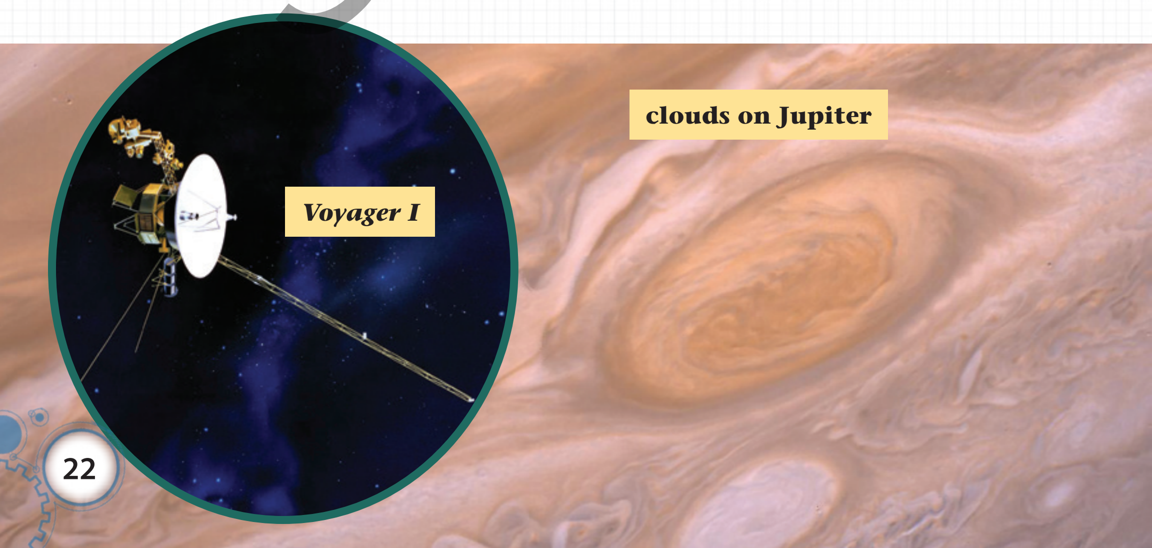
Have you ever tried speaking or singing underwater with a friend? Underwater, your voice sounds different because sound waves don't move through your eardrum and middle ear. Instead, sound waves vibrate through the mastoid bone behind your ear. **Bone conduction** brings the vibrations to your inner ear.

Sounds in Outer Space

The universe is so enormous that it is measured in light-years, which is the distance that light travels in one year. One light-year is about 9.46 trillion kilometers (5.88 trillion miles). The universe contains our solar system, plus trillions of other galaxies, planets, and stars. With that in mind, would you guess that Earth is the only place in the universe where there are sounds? If you said no, you guessed correctly!

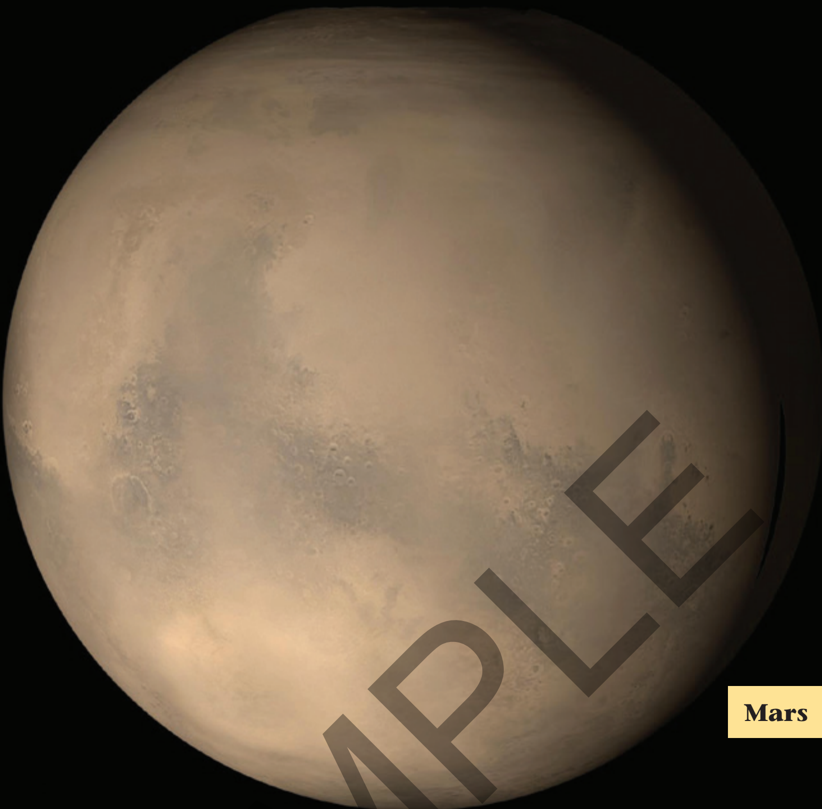
Scientists have listened to sounds from other planets. For instance, the spacecraft *Voyager 1* picked up low-frequency waves coming from clouds on Jupiter. Scientists listened to the audio and found that these waves were similar to lightning on Earth. Scientists confirmed that lightning exists on Jupiter thanks to these sounds. Scientists have also recorded vibrations from wind on Mars and sounds coming from the atmosphere of Venus.

But what about sound in outer space itself? For a long time, scientists believed that the conditions in outer space meant there was no sound in space. Most of outer space is a vacuum in which there is no matter at all. Sound waves can't be created when there is no medium, such as air or water, for energy to vibrate through.

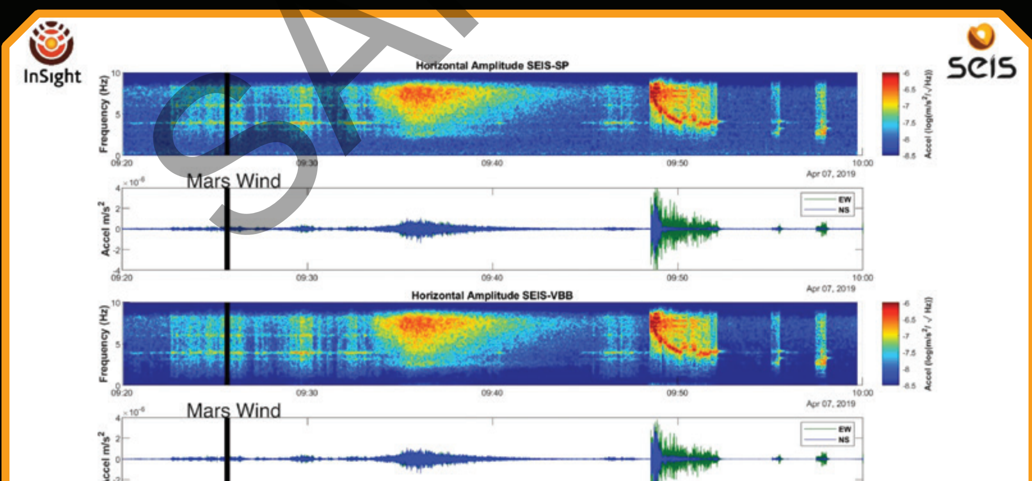


clouds on Jupiter

Voyager I



Mars



Scientists used special software to record this representation of the wind on Mars.

Today, scientists know that there *are* sounds in some areas of outer space. Scattered throughout outer space are different mediums, such as dust and gas from old stars. These mediums have very low densities. This means they are made up of molecules that are far apart from one another. But the molecules can still carry the energy that is needed for sound waves to travel.

Sound waves that are created in outer space are very low-frequency. So, even if humans were close to these sound waves, they couldn't hear what outer space sounds like. These sounds fall below the range of audible human hearing. However, with a little help from technology, scientists have changed that. They have made inaudible sound waves from space audible to humans.

In 2003, an **X-ray** telescope created by **NASA** picked up sound waves coming from a galaxy cluster called *Perseus*. There, thousands of galaxies surround a black hole. Scientists discovered that the black hole sent waves into the gases of the cluster. But since it was at such a low frequency, humans could not hear the sounds that were created. Decades later, in 2022, scientists used a special technique to make them audible. As a result, it's now possible for people to listen to the eerie roar of a black hole in outer space.

Black holes have gravitational fields so strong that light can't escape them.

SCIENCE

Telescope Observations to Sound

To make the black hole sounds audible, NASA scientists translated visual data into sound. To do this, they adjusted the frequencies of the sound waves. The version humans can hear is 57 to 58 **octaves** higher than the original frequency. For comparison, a standard piano has 7 full octaves. To play a note in the black hole's octave, you'd need to extend the keyboard about 10 meters (32 feet) to the right!

hot gas in the Perseus galaxy cluster

A Universe of Sounds

We know we're making sounds when we clap our hands and use our voices. And we know we're hearing sounds when we listen to people singing or talking to us. When a big truck in the street rumbles by, we can feel the vibrations from it. When music is at its highest volume, we can see how sound waves vibrate speakers. But we don't often think about how sound is made by invisible sound waves moving through a medium. After all, we're more focused on interpreting the information presented by sounds. But when we know the science behind sound, it's easier to understand how it works.

Even sounds humans can't hear affect other living beings. Animals in different environments use sounds to communicate, hunt, and navigate. From the tiniest snapping shrimp to the largest whales in the ocean, animals use sounds to help them survive. And we know sound waves are moving all over our universe, all the time—through air, water, and gases in outer space. Even the farthest planets and black holes are capable of producing sounds. With special technology, humans can make inaudible sounds audible.

What would life be like without sounds? It's impossible to know. Sounds are all around us, whether we hear them or not!






STEAM CHALLENGE

Define the Problem

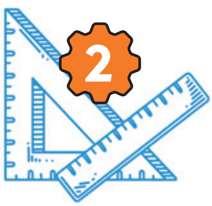
Today's teens are at a higher risk of hearing loss because of the latest technology, including noise-canceling earbuds and subwoofers that make low-frequency sounds. So, audiologists want your help to design a pair of protective ear covers. The ear covers should diffuse or deflect a wide range of frequencies while also having an appealing design.

Constraints: You may only use the materials provided to you.

Criteria: Your protective ear covers should fit snugly over your ears. They should minimize the amount of sound that reaches the ear canal. The design should be appealing as well.

Research and Brainstorm

What range of hertz are audible to humans, and how does this change with age? What types of materials are best suited for noise reduction to deflect or absorb sound waves? How can you create an ear cover that will remain in place?



Design and Build

Sketch at least two protective ear covers. Be sure to list the necessary materials and label the parts. Discuss your ideas with a partner. Then, draw and build a prototype together.

Test and Improve

Elect one partner to wear the protective ear covers. Using an electronic device, go to an online frequency generator and play various frequencies to test your protective ear covers. Can you hear all the frequencies? What frequencies are more difficult to hear or are not audible at all? After collecting your baseline data, make modifications to your design and test it again. Make sure it meets all the necessary criteria.

Reflect and Share

What part of this challenge was most interesting to you? What did you and your partner do well? What could you have done better? Would your protective ear covers be necessary in all parts of the universe? Why or why not?

Glossary

acoustical—of or relating to the sense or organs of hearing, to sound, or to the science of sounds

amplify—to increase in strength

audible—heard or capable of being heard

bone conduction—the movement of sound waves through the bones of the skull to the inner ear

hertz—a unit of frequency equal to one cycle per second

hydrophone—an instrument for listening to sound transmitted through water

inaudible—impossible to hear

infrasonic—having or relating to a frequency below the audible human hearing range

interpret—determine the meaning of something

medium—a substance, such as air, water, or gas, that allows for transmission of something

molecules—microscopic chemical compounds made up of two or more atoms bonded together

NASA—National Aeronautics and Space Administration; an agency of the U.S. government

nerve—one of many thin tissues that connect the nervous system with other organs and carry messages between parts of the body and the brain

octaves—multiple series of eight notes, or musical sounds

sonar—a method or device for detecting and locating underwater objects with sound waves

tsunami—a great sea wave produced by an earthquake or underwater volcanic eruption

ultrasonic—having or relating to a frequency above the audible human hearing range

vibrations—rapid back-and-forth motions of the particles of a substance

X-ray—a high-energy type of radiation with a shorter wavelength than ultraviolet light

Index

CAREER ADVICE
from Smithsonian

Do you want to work with sound or be a scientist?

Here are some tips to keep in mind for the future.

"Listen to the sounds the world makes. How do they change? What do they feel like?"

*—**Cari Corrigan**, Geologist, National Museum of Natural History*

"Science is how we know the world, and everything in it, works."

*—**Kadie Bennis**, Volcano Data Researcher, National Museum of Natural History*

Read and Respond

1. What are the loudest and quietest sounds you have heard, and where did you hear them?
2. What are the three key properties of sound, and what do they measure?
3. Why do sound waves travel faster through water than air?
4. What is the difference between ultrasonic and infrasonic sound?
5. How does echolocation work?
6. Do you think scientists will keep discovering new sounds in space? Why or why not?

PHYSICAL SCIENCE

Sounds of the Universe

Every sound you hear is a signal, telling you something about the world. But sounds aren't limited to what humans can hear—or even to planet Earth. Animals make and use sounds differently from humans, and faraway objects in outer space can produce sounds. There are sounds to discover throughout the universe!

The Natural World

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