Sound
Content Background Document

1. Introduction

Sound is everywhere. As teachers, we're bombarded with it continually! Every single day in our classrooms, we must corral a herd of lively, energetic soundmakers. First graders are noisy, and it isn't easy controlling the sound they generate. Teaching 1st graders about sound is no easy task either. Your students know about sound and use it every day, so they think they understand it. Like your students, you know about sound and use it every day, but how well do you actually understand it? What do you know about how sound is produced? Do vibrations produce sound? What do energy and sound waves have to do with vibrations? How do our ears process sound? These are just some of the ideas we'll explore in this reading.

This document was written with you, the teacher, in mind. It will challenge you to answer questions about sound that you may never have considered before. It will also broaden and deepen your understandings of sound so that you'll be better prepared to teach the science content to your students.

The subject matter is tied to the lessons you'll be teaching, but the concepts are presented at a higher level to equip you with the tools and background you'll need to guide student learning.

2. Vibrations

Consider the Stop and Think question below for a moment. Think about the objects in your classroom or home that make sounds. What do these soundmakers have in common?

STOP AND THINK

What do all soundmakers have in common?

If you lightly touched an object that's producing a sound, you'd feel vibrations. Try touching a sound-system speaker while music is playing, or your throat while you're talking, or your computer while it's running. All of these objects produce vibrations. Sometimes it's possible to *see* the vibrations, such as a string on a guitar vibrating after it's plucked, a cymbal vibrating after it's struck with a stick, or an uncovered speaker vibrating when the music is loud. Other soundmakers produce vibrations we can't see. If you blow into a flute or over the top of a soda bottle, what vibrates? Certainly, both the bottle and the flute vibrate, but they aren't the first thing to vibrate. The way you blow into a flute or over the top of a bottle causes the air inside these objects to vibrate. Though we can't see the air vibrating, it causes anything it touches to vibrate too. We hear sound because something is vibrating. If you pinch a vibrating guitar string, the vibrations stop—and so does the sound!

STOP AND THINK

Do all vibrations produce sound?

Wave your hand back and forth quickly. Did you hear a sound? The definition of *vibrate* is "to move back and forth quickly," but when your hand vibrated as it moved back and forth, you didn't hear any sound, did you? Why not? The human ear is only able to detect, or hear, sound from materials or objects that vibrate between 20 times per second and 20,000 times per second. Since you're unable to move your hand 20 times per second, you can't hear the sound of it vibrating. We also can't hear sound when materials or objects vibrate *more than* 20,000 times per second. Consequently, humans can only hear sound in a range of approximately 20 to 20,000 vibrations per second, or hertz (Hz), although this can vary by age. *Hertz* is a unit that represents the number of times an object vibrates per second. This is one way to express the rate of vibration, or *frequency*. Frequency not only determines whether you can hear a sound, but it also determines *pitch*, another characteristic of sound. We'll talk more about this later.

Just because you can't hear vibrations lower than 20 Hz or higher than 20,000 Hz doesn't mean there is no sound outside this range. You may not be able to detect the sounds, but your dog may be able to! Dogs can hear vibrations that range from 40 Hz to 60,000 Hz. That's why some people use a special whistle for dog training. These whistles emit a sound above 20,000 Hz so humans can't hear it, but dogs can. However, the range of sound frequencies that dogs can hear varies with age and breed.

STOP AND THINK

How do we hear sound from an object that's vibrating some distance away? Write down your ideas and include a sketch or diagram to help explain what you're thinking.

How did you answer the Stop and Think question above? We've been describing sound as vibration. But did you know that vibrations can cause other vibrations? When an object vibrates some distance away from you, it also causes the air around it to vibrate. These vibrations travel through the air to your ears and cause your eardrums to vibrate so you hear sound! We'll discuss this in more detail a little later, but first, let's find out what energy has to do with vibration.

3. Energy

A transfer of vibrations from one object to another is really a transfer of energy. A transfer of vibrations is a transfer of motion, which is a transfer of energy. What is energy? This is a difficult concept to understand because in everyday language, the word *energy* has many meanings. Scientists have a very specific way of defining this term:

Energy is the ability to do work.

To most of us, that definition isn't very helpful. It doesn't exactly match our experience of the energy we sense when we turn on the radio or see the flash of a lightning bolt.

The term *work* also has a particular meaning in science that's different from the way we use it in everyday language. Basically, work is moving something a distance. So work is simply something in motion. A moving bowling ball can do work on a set of bowling pins because it (hopefully!) causes the pins to move. So the bowling ball has energy. A moving grocery cart can bump into a display of macaroni-and-cheese boxes and topple it. So the grocery cart has energy. A vibrating tuning fork can cause air particles to move, so the tuning fork has energy. We call this energy of motion *kinetic energy*.

The scientific definition of *energy* also refers to the "ability" to do work. So an object doesn't have to be moving to have energy. Think of a stretched rubber band, a boulder on top of a cliff, or a young girl on a swing that Dad has pulled back just before releasing it. All of these objects have the *ability* to do work, but they aren't moving—yet. Scientists call this *potential energy* because these objects have the *potential* to move and do work. Potential energy may also be referred to as *stored energy*.

STOP AND THINK

What is the relationship between energy and sound?
Hint: Remember that vibrating objects produce sound.

Moving objects have kinetic energy, and vibration is described as a rapid back and forth movement. So a vibrating object and the surrounding air that's vibrating—and even your vibrating eardrums—have kinetic energy. As one vibrating object causes another object to vibrate, energy is transferred, or moves, from object to object.

You may have heard someone use the term *sound energy* or refer to sound as a "form of energy." Consider this clarification from *A Framework for K–12 Science Education* (2012), the precursor to the *Next Generation Science Standards*:

The idea that there are different forms of energy, such as thermal energy, mechanical energy, and chemical energy, is misleading, as it implies that the nature of the energy in each of these manifestations is distinct when in fact they all are ultimately, at the atomic scale, some mixture of kinetic energy, stored energy, and radiation. *It is likewise misleading to call sound or light a form of energy; they are phenomena that, among their other properties, transfer energy from place to place and between objects.* (p. 122, emphasis added)

4. Vibrations Move in Waves

Let's say you're several feet away from a tuning fork. Your colleague strikes the tuning fork, and you hear the sound it produces. How did you hear a sound produced several feet away? How did the sound get to your ears? We know that a vibrating tuning fork causes the air all around it to vibrate (see figure 1 and the tuning-fork animation at http://www.physicsclassroom.com/class/sound/Lesson-1/Sound-is-a-Pressure-Wave). But how do these vibrations move through the air?

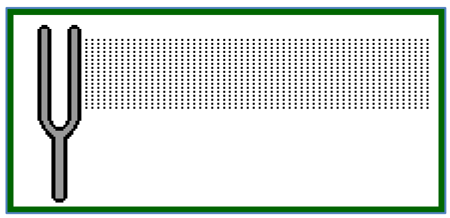

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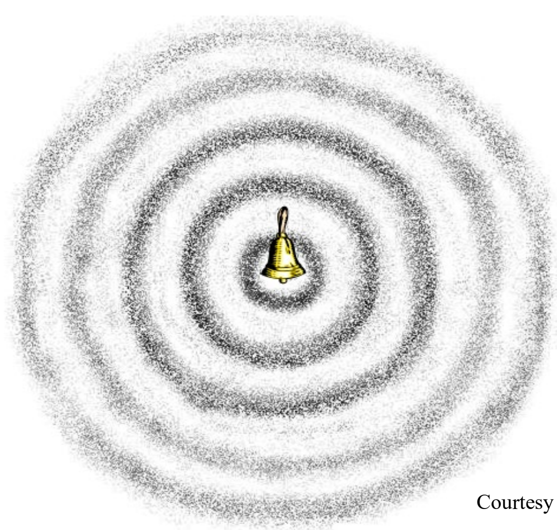
Figure 1. Vibrating tuning fork

The vibrating tuning fork is able to move particles of air. The animation and illustration only show the path of the sound moving in one direction—to the right of the tuning fork. In reality, the vibrations move out from the tuning fork in all directions—like a three-dimensional sphere.



Courtesy of BSCS

Figure 2. Actual direction of vibrations from tuning fork

The diagram in figure 2 isn't completely accurate either, because sound waves propagate in three dimensions, not two. However, it does show that areas of high and low pressure are more pronounced closer to the source of the sound. As the sound wave moves farther away from the source, the energy it carries spreads out as well. Some of the energy is also transformed to heat because of the friction between air molecules. As the vibrating tuning fork causes the air around it to vibrate, a *pressure wave* is created, with areas of high pressure called *compressions*, where air particles are packed closer together, and areas of low pressure called *rarefactions*, where air particles are spread apart (see figure 3).

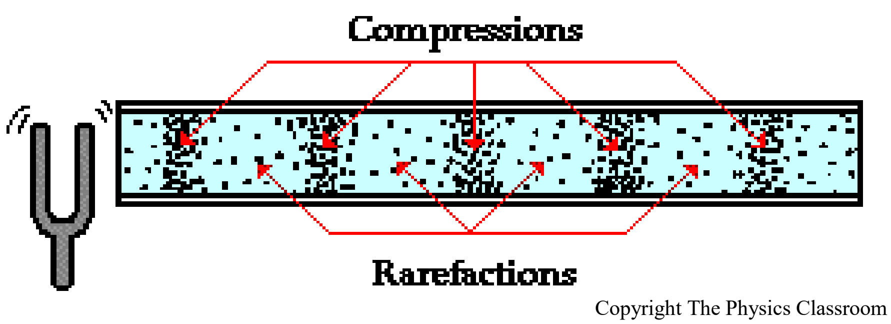
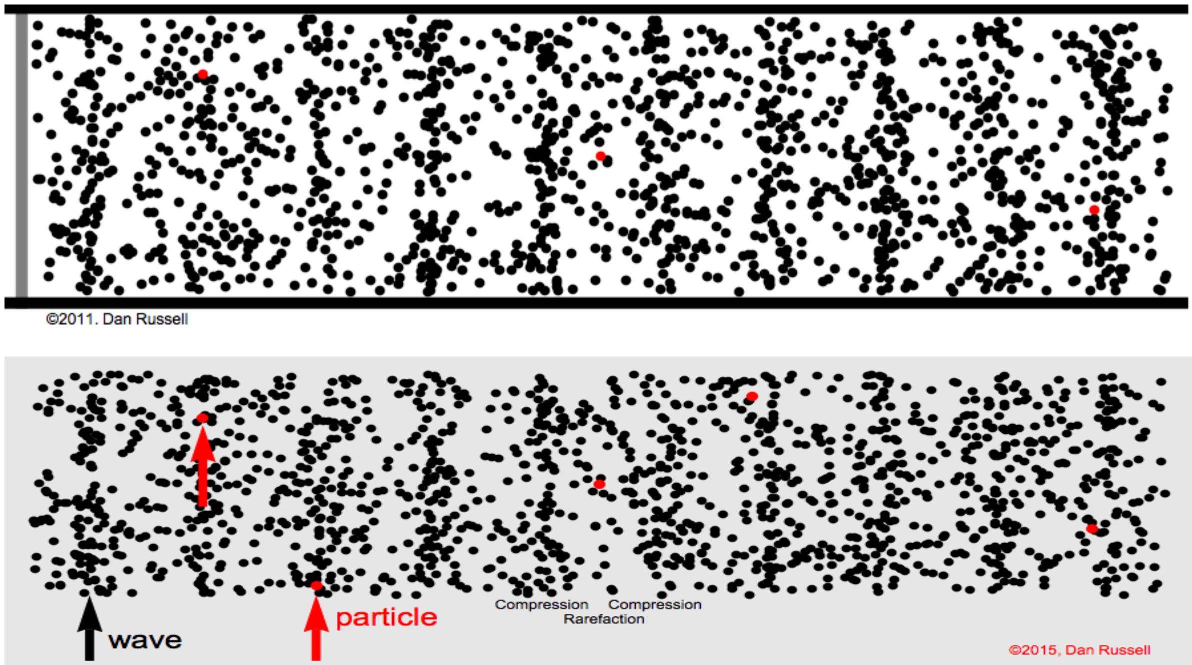


Figure 3. A pressure wave showing areas of high and low pressure

STOP AND THINK

Look at figure 4 and the animation of the same image at http://www.acs.psu.edu /drussell/Demos/waves/wavemotion.html.

1. Describe the motion of one particle. (**Hint:** In the animation, focus on the motion of only one particle. Some particles are shaded in red.)
2. Describe the motion of the wave. (**Hint:** Look at the moving, compressed areas in the animation.)



Courtesy of Dan Russell

Figure 4. One-dimensional longitudinal wave moving down a tube

Vibrations travel as a type of wave called a *longitudinal wave*. In a longitudinal wave, the particle movement is parallel to the direction of wave motion.

Figure 4 and the corresponding online animation show a one-dimensional longitudinal wave flowing down a tube. As the wave moves down the tube, the air particles in the rarefaction (low-pressure) areas move back and forth (oscillate) in a fixed space and aren't carried along with the wave. The tightly packed air particles in the compressed area form a wave that moves through the tube from left to right. Waves like these are also called *compressional waves* or *pressure waves*.

Since compressional or pressure waves are hard to draw, students will represent them as *sine waves* in the lessons on sound. The sine wave in figure 5 shows the relationship between pressure and time. Notice the sound wave has a repeating pattern of compressions (high pressure or high density) and rarefactions (low pressure or low density). If we plotted this relationship on a graph with *x* and *y* coordinates, it would be a sine wave. Study the relationship between the two graphs in figure 5.

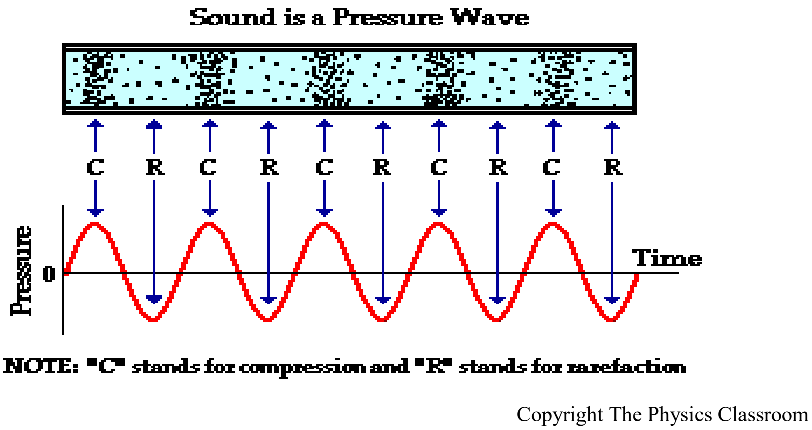


Figure 5. Graphs showing a pressure wave (top) and a sine wave (bottom)

In the lower graph, the highest points of the sine wave correspond to compressions, the low points correspond to rarefactions, and the zero points correspond to the pressure that the air would have if no disturbance were moving through it.

This diagram can be somewhat misleading, however. Using a sine wave to represent sound is merely a way of showing how air pressure changes over time. Sound waves traveling through air are indeed *longitudinal* waves, with compressions and rarefactions and *parallel* particle movement, not transverse waves with crests and troughs and *perpendicular* particle movement.

STOP AND THINK

How would the longitudinal wave for a loud sound look compared to the longitudinal wave for a quiet sound? How would the sine-wave representation look for a loud sound and a quiet sound? (**Hint:** Draw a sketch of each type of wave for a loud sound and a quiet sound.)

Let's talk for a moment about transverse waves. Waves moving through water, waves on a rope as you jiggle it back and forth, and the motion of guitar strings are all different from sound waves because they transfer energy as *transverse waves*. In transverse waves, the motion of the matter in the wave is *perpendicular* to the motion of the wave.

Imagine sitting next to the ocean and watching the surface of the water. It probably isn't flat and mirror-like but has a variety of ripples, waves, or swells. As the waves move through the water, they transport energy. You can see this energy as the waves flow toward the beach and crash on the shoreline.

Now imagine floating on the water in a kayak. As a wave passes and moves toward the shoreline, you bob up and down. The motion of water molecules is similar. In a transverse wave, the motion of the water molecules (or you and your kayak!) move *perpendicular* (up and down) to the motion of the wave flowing toward the shore, not parallel like air particles in a longitudinal wave. Transverse waves are shaped like sine waves and have crests and troughs.

5. Sound Waves and Their Properties

In this unit, students will consider only one property of sound: volume. They won’t be responsible for explicitly naming this property but will learn that sounds can be loud or quiet. They’ll consider the relative volume of sound by comparing one sound with another and determining which sound is louder or quieter.

Keep in mind that volume is a very subjective perception of sound, so a sound that seems loud to you may not seem loud at all to your 1st graders!

Have you ever told your students to turn down the volume on their MP3 players or tablets? If they adjusted the volume on these devices, they changed the loudness or *intensity* of the sound, as well as the vibrations producing the sound. Intensity is related to the energy of the sound. More energy means more intensity. Less energy means less intensity.

Intensity can be measured, so it isn’t as subjective as volume. If the sound is very intense, then the compressions in the sound wave would have very high pressure or density, and the rarefactions would have very low pressure or density. A high-intensity sound would be considered a loud sound.

STOP AND THINK

How would the vibrations that produce a loud sound differ from the vibrations that produce a quiet sound?

Bigger vibrations produce louder sounds with greater energy, and smaller vibrations produce quieter sounds with lower energy.

Think back to the vibrating tuning fork and the animation of the surrounding air (figure 1). If you were able to increase the vibrations of the tuning fork, this would create very compressed areas—even more compressed than before you increased the vibrations.

How could you cause the tuning fork to vibrate more? Strike it with more energy!

STOP AND THINK

1. What would a pressure-time wave or sine wave look like for a very loud sound compared to a very quiet sound? In the two boxes below, draw what you think the waves would look like. Draw the same number of waves ("humps" for sine waves and compressions for pressure waves) in each box. The boxes represent the same amount of time.
2. How do your drawings here compare to your earlier drawings?

Quiet Sound	Loud Sound

Louder sounds have higher intensity and larger amplitudes. Intensity of sound is measured in decibels (dB). Amplitude is easy to measure in a sine wave (see figure 6). You simply measure from the highest point in the wave (or the lowest point) to the rest or "zero" position. In a sound wave, you must measure a particle's maximum displacement from the rest position, which is hard to do when the particles are atoms and molecules! So it's much easier to measure the amplitude of a wave when the wave is drawn as a sine wave.

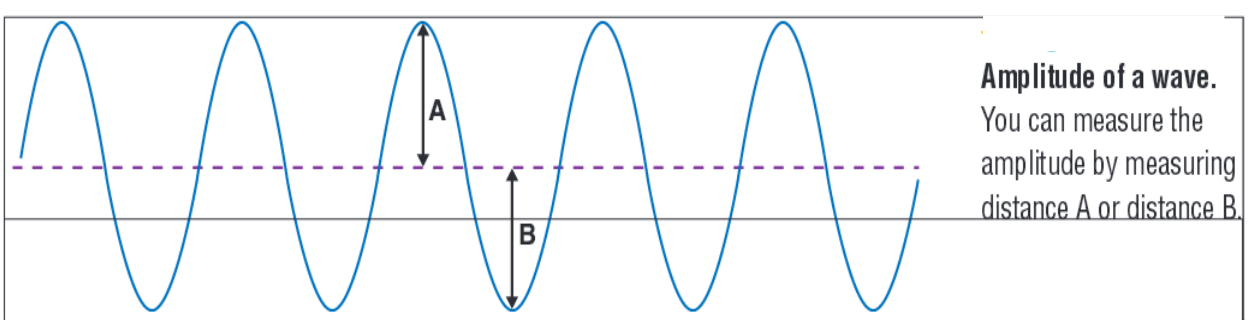
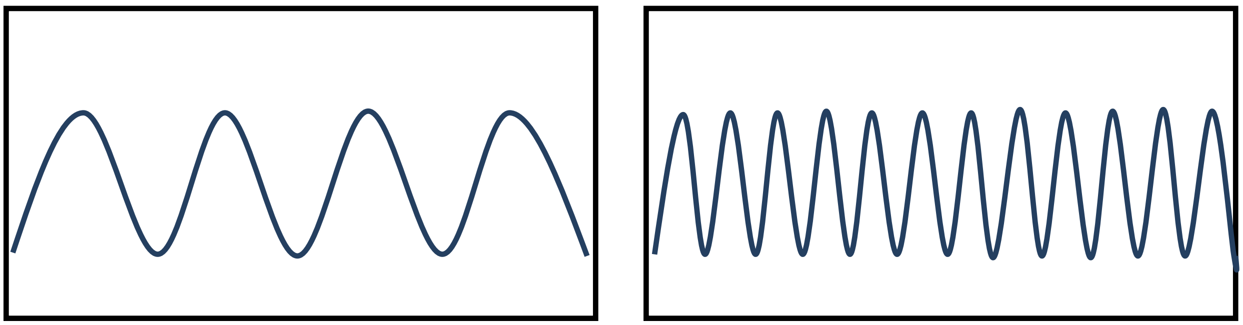


Image from *BSCS science: An inquiry approach*

Figure 6. Amplitude of a wave

Another property of sound is *pitch*. Pitch isn't included in the 1st-grade lessons, but the idea might come up in classroom discussions. Young children have difficulty distinguishing between pitch and loudness. This is one of the reasons we chose to limit the properties in this module to volume. *Pitch* is the highness or lowness of sound. It also relates to the frequency of sound. *Frequency* is the number of back-and-forth motions or vibrations in a set amount of time (e.g., per second). In other words, frequency is how many waves pass a given point in one second. When we talk about the number of waves per second, we use hertz (Hz) as the unit of frequency (e.g., 1 Hz = 1 wave/second).

Figure 7 shows two different waves, one with a low frequency and one with a high frequency. All of the boxes represent the same amount of time, and the *x*-axes represent time.



Low Frequency,
Low Pitch

High Frequency,
High Pitch

Figure 7. Examples of waves with low frequency and high frequency

STOP AND THINK

Compare the loudness of the two waves in figure 7. How can you tell which is louder?

How does frequency compare with energy? We learned earlier that waves with a higher amplitude transfer more energy than waves with a lower amplitude. Imagine making waves with a rope. You would have to use more energy to make bigger waves (waves with higher amplitude).

Now think about making waves with a rope like the two waves in figure 7. Which wave would require more energy to make? Waves with higher frequency transfer more energy than waves with lower frequency.

Wavelength—measured from one point on a wave to a wave to the corresponding point on the adjacent wave—is shorter for high-frequency waves and longer for low-frequency waves. This relationship between wavelength and frequency holds true if the waves are traveling at the same speed.

Speed is measured as the distance a wave travels divided by the time it took. The speed of sound in air varies with the properties of the air. Two properties of air that can affect the speed of sound are density and temperature. Sound travels faster in warmer air than in cooler air. In warmer air, the molecules are moving faster and bump into one another more often, so they can transmit the sound wave in less time. The speed of sound increases about 0.6 meters per second (m/s) with each degree Celsius rise in temperature.

If the sound is traveling through substances other than air, the speed depends on the properties of the material. The average speed of sound in air at room temperature is 340 m/s, but the average speed of sound through steel is about 5,200 m/s!

STOP AND THINK

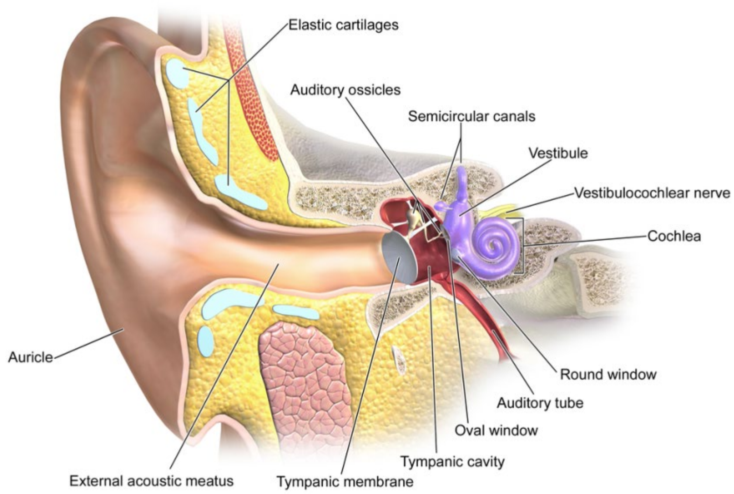
In each box below, draw a sine wave representing the sound described in the caption. All of the boxes represent the same amount of time, and all of the waves are traveling at the same speed.

High-pitched, Quiet Sound	Low-pitched, Quiet Sound
High-pitched, Loud Sound	Low-pitched, Loud Sound

6. Hearing Sound

A soundmaker vibrates and causes the air around it to vibrate. Once these vibrations in the air reach your ear, you hear sound. But how exactly does that work? Well, vibrating air can also make other objects vibrate—your eardrum, for example. Study the animation at http://www.physicsclassroom.com/mmedia/waves/edl/cfm to see what happens when a pressure wave reaches your eardrum.

A series of high- and low-pressure regions in the pressure wave interact with your eardrum, causing the eardrum to vibrate by pushing it inward and then pulling it outward. These vibrations, in turn, cause the bones of the middle ear—the hammer, anvil, and stirrup—to vibrate (see figure 8). And this causes the fluid in the inner ear to vibrate. The inner-ear vibrations change to electrical nerve impulses that travel to the brain, and your brain turns it all to sound. Amazing!



Courtesy of Wikipedia

Figure 8. The anatomy of the ear

STOP AND THINK

1. The unit central question for the Sound module is *Why do we hear sound?* Answer this question using what you've learned in this document.
2. Can sound travel (move) through a vacuum? Explain your answer. (**Note:** There's no matter in a vacuum—not even air.)

References

National Research Council (NRC). (2012). *A framework for K–12 science education: Practices, crosscutting concepts, and core ideas*. Washington, DC: National Academies Press.