ACTIVITY 4: Sound Waves

Purpose

Sound is all around us every day, from the background noises of everyday life, to the conversations we have with other people, and the music we listen to. But what is sound? How is it produced and detected, and how does it travel from the source to the receiver? You are probably aware that sound can be regarded as a wave of some sort, but in this activity we will take a closer look at these waves.

What are sound waves and what are some of their characteristics?

Initial Ideas

Your instructor will connect a bell to an electrical source and let it ring (or show you a video of this).

Write several sentences to describe what you think is happening that allows people to hear the sound of the bell. Also draw and label a diagram to illustrate your thinking

If the ringing bell were placed in a sealed container, do you think you it could still be heard? Why or why not?

Now suppose most of the air was removed from inside the sealed container, with the ringing bell still inside, do you think it could still be heard as easily? Why or why not?

Participate in a class discussion about your ideas and predictions.

You instructor will now place the ringing bell in a sealed container and use a pump to remove the air (or show you a video of the experiment being done.)

Before the air was removed from the container, could the bell still be heard? What about after most of the air was removed?

If the results do not agree with your prediction, make a note of any different ideas the class suggests that might be useful?

Collecting and Interpreting Evidence

Exploration #1: What are sound waves?

You will need:

- Ruler
- Tuning fork and ‘mallet’ (optional, may be shared with other groups)
- Computer with internet connection

STEP 1: Hold the ruler flat on the table so that part of it is hanging over the edge. Now give the ‘free’ end of the ruler a quick ‘flick’ so that it begins oscillating up and down. (If you do not hear a sound, adjust how much of the ruler is hanging over the edge of the table.)

What do you think is happening to make the sound that you hear?

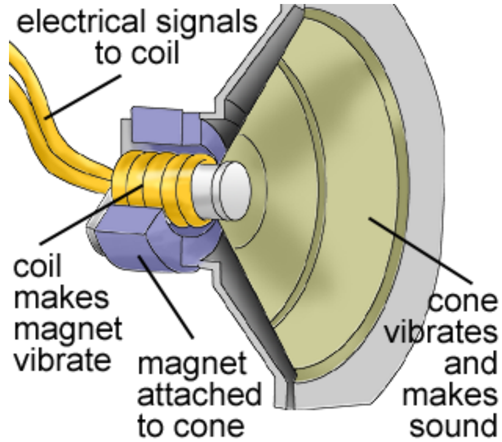
Why do you think the ruler creates a sound when it is moving up and down but not when it is stationary (or moving in only a single direction)?

If a tuning fork is available to you, hold the handle end in your hand and strike one of the ‘prongs’ firmly with the ‘mallet’. Otherwise watch ***UWS-A4 - Movie 1.***

What is it about the tuning fork that produces the sound you hear?

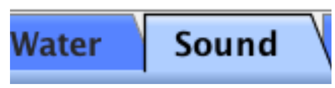
To check your thinking, gently touch one of the prongs while you can still hear the sound.

What do you feel with your finger when you do this? Is this what you expected?

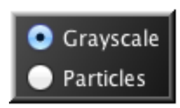


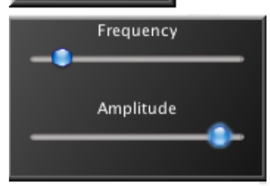
As you are probably aware, sound is produced when objects vibrate. The movement of the vibrating source affects the air around the object to produce sound waves. One common way to do this is using a device we call a loudspeaker in which an oscillating electrical current (which is another example of a wave) is passed through a coil. Because of the *electromagnetic interaction* between them, a magnet located in the center of this coil then vibrates back and forth, and so the cone attached to this magnet also vibrates, producing sound waves. You will now use a simulation to examine the nature of these sound waves.

STEP 2. Open ***UWS-A4 - Sim***. (This is the same PhET simulator you used in the previous activity.) Before starting to use it, you need to make some adjustments to the default setup.



First, select the 'Sound' tab at the top of the window. The window should now show a single loudspeaker.



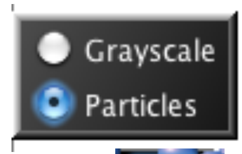


- Make sure the 'Grayscale' option is selected.
- Adjust the *frequency* slider it is only a short way along from the left.
- Adjust the *amplitude* slider so it is at its maximum (all the way to the right).

The loudspeaker should now be moving forward and backward, creating sound waves that you can see moving through the air away from the loudspeaker. (This representation is similar to that you saw for water waves in the previous activity.)

Does the motion of the loudspeaker suggest that the sound waves it is creating are transverse or longitudinal? Briefly explain your thinking.

STEP 3: Let us now examine the mechanism by which the sound waves created by the loudspeaker move through the air. As you are probably aware air consists of tiny particles (too small to see) that move around in all directions. To see what effect the loudspeaker has on these air particles, select the 'Particles' option in the simulator. The simulator should now show tiny blue spheres that represent 'air particles.' To get a clearer view, also click the green '+' button to expand the window.



Some particles are marked with a red 'X' to help you focus on one at a time. Watch some of the marked air particles that are on the right side of the window, farthest away from the loudspeaker.

As the sound waves move, do these air particles move mostly forward and backward (in the same the direction that the waves are moving), or do they mostly upward and downward (perpendicular to the direction that the waves are moving)?

Does the motion of the air particles suggest the sound waves are transverse or longitudinal? Does this agree with your conclusion from watching the motion of the loudspeaker in STEP 2?

When the loudspeaker moves forward, it pushes the air particles directly in front of it forward also. As these air particles move forward, they collide with other particles that are in front of them.

Describe what happens to both air particles during such a collision.

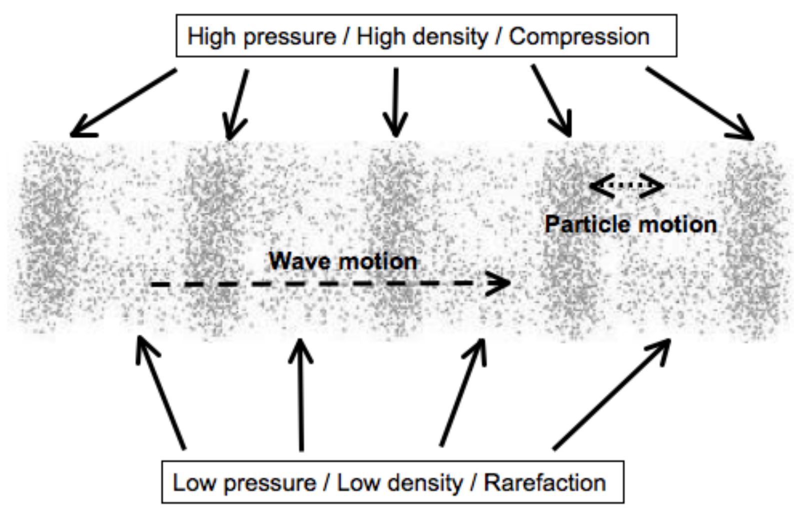
Explain how a series of such collisions leads to a longitudinal 'pulse' moving through the air.

STEP 4: We can describe the different regions of the longitudinal sound waves as they move through the air in terms of *air pressure*.

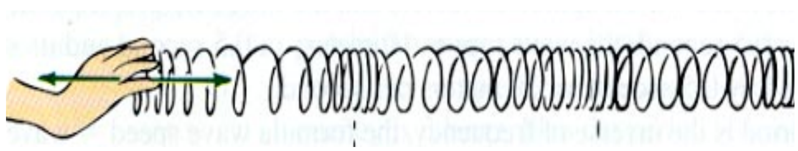
As the loudspeaker cone moves forward, the air particles in front of it have a smaller space to move around in. This increases the air pressure in that area slightly above its normal value. However, when the loudspeaker moves backward, there is now a larger space for the air particles in front of it to move around in. Because of this, they now spread out more, decreasing the air pressure in that area slightly below its normal level. In the simulator these regions of low and high pressure can be seen as regions in which the particles are further apart and closer together than normal.

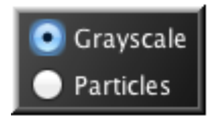
Thus, as the loudspeaker (or other source of sound) vibrates back and forth, the air pressure in front of it alternates between being slightly higher and slightly lower than normal. The collisions between the air particles are then the mechanism by which these high–pressure and low-pressure regions move through the air, creating a *sound wave*. Note that it is disturbances in pressure that move out from the loudspeaker, not the air particles themselves. Looking at individual particles in the simulator shows that they simply oscillate backward and forward, becoming part of the successive regions of high pressure and low pressure that pass.

Looking at the entire collection of air particles in the simulator, the regions of compressed particles can be seen as (partially) circular wavefronts that move outward from the loudspeaker. This means we can also regard a sound wave as a compression wave (the particles move such that successive regions of compression and rarefaction are created) or as a density wave (the particles move such that successive regions of high and low density are created).



When regarding sound waves in this way, you can see that the behavior of the air particles is very like the behavior of the coils on a long spring that become stretched and compressed as a longitudinal wave moves along it.





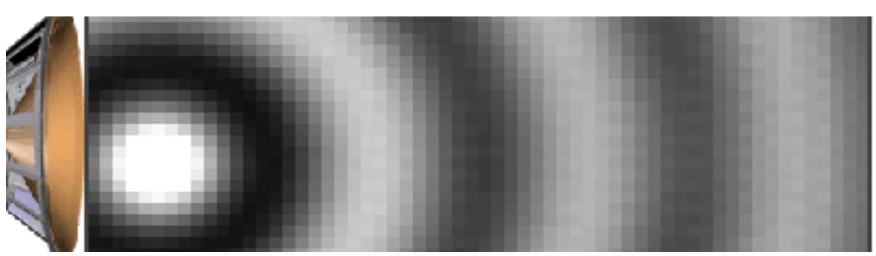
STEP 5: In reality, it is impossible to see individual air particles, so return the simulator to the 'Grayscale' representation and shrink the window by clicking on the red '–' button.

To find out how the shading represents high and low pressure, click the 'Show Graph' button at the bottom of the window. A 'Pressure vs. position' graph will appear that shows the air pressure along the dashed line in the middle of the window. (***Note: While the pressure graph looks like a transverse wave, it is important to note that the pressure wave itself is longitudinal. The graph is simply showing how the pressure caused by the wave is varying at different locations.***)

Is it the darker or lighter shading that represents a region of higher pressure? If you are not sure, pause the simulator and compare the graph and the grayscale display.

Recall that the wavelength of a transverse wave is defined as the distance between successive peaks or successive troughs on the wave. Since sound waves are longitudinal in nature, their wavelength is the distance between successive regions of high pressure **<u>or</u>** successive regions of low pressure.

Below is a small section of a sound wave taken from the simulator. Mark a single wavelength (λ) in two different places on this picture.



Keep the simulator window open, as it will be needed in Exploration #2.

Exploration #2: What are some properties of sound waves and how are they detected?

You will need:

- Large board
- Computer with internet connection

STEP 1: Now that you have seen how sound waves are created and how they move through the air, we will move on to investigate how they are detected and what some of their properties are.

One of your group should hold a single sheet of paper at one end so it hangs straight down. Another group member should hold the large board up vertically about 2 feet from the paper and facing toward it. Now move the board forward and backward quickly (toward and away from the paper) many times while the other group members watch the paper.

How does the paper behave while the board is being moved forward and backward?

Why do you think the paper is behaving in this way? Explain your thinking in terms of what effect the moving board is having on the air in front of it, and what effect that air is having on the paper.

The person with the board should now gradually move further away from the paper, still moving the board forward and backward as before.

How does the movement of the paper change as the moving board gets further away? Why do you think this is?

Just like the paper, the varying air pressure of sound waves can make any object move, even if only a little.

Describe an example from your everyday experience in which a sound wave has made a physical object move.

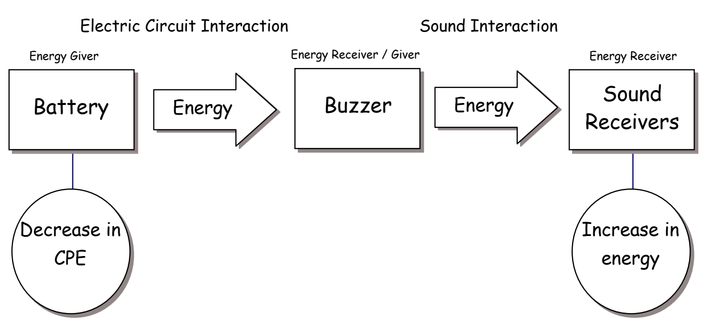
The moving board and paper can also serve as an aid to understand the process of a person hearing a sound.

How do you think the board and paper are like the process of human hearing? What do you think the board represents? What about the paper?

As you are probably aware, the human ear contains a thin film, called the eardrum. When a sound wave enters the ear, the alternating regions of higher and lower air pressure make the eardrum move in and out, just like the paper was moved by the pulses in the air created by the movement of the board. A complex mechanism in the inner ear then converts these movements of the eardrum into electrical signals that travel to the brain, resulting in hearing[1].

STEP 2: In an earlier unit, when examining the function of an electric buzzer in terms of ideas about energy, we simply said there was a *sound interaction* between the *buzzer* and some *sound receivers* during which energy was transferred between them.

Here is a G/R energy diagram for a battery-powered buzzer (in an equilibrium state) as we might have drawn it earlier in the course.



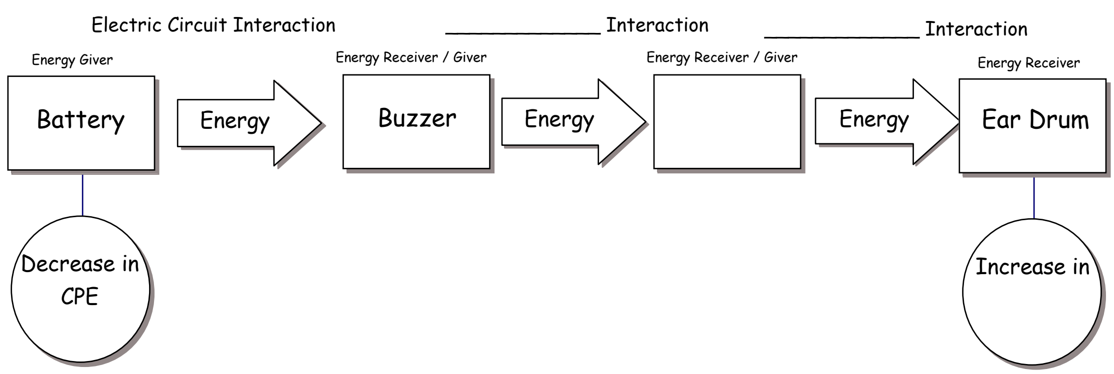
[1] This is also how microphones work; the varying air pressure of a sound wave makes a small object move and this motion is turned into electrical signals

However, now that we have investigated how sound waves are created, transmitted, and detected, we can expand this diagram to include this information.

What type of interaction is occurring between the buzzer and the air when this is happening? (What do we call an interaction in which one object pushes on another with which it is in contact?)

What type of interaction is occurring between the air and the eardrum of a listener?

Complete the expanded G/R energy diagram for someone listening to an electrical buzzer? Check your diagram with another group.



STEP 3: From your real world experience, you know that if a sound is very loud, one way to decrease how loud you perceive it to be is to move further away from its source.

Bearing in mind how human hearing works, explain why you think this is in terms of the pressure variations in a sound wave as they move further away from a source of sound.

Return to the simulator and look at the 'Pressure vs. position' graph.

What happens to the amplitude of the pressure variations in the sound wave as it moves further from the source? Do they get bigger or smaller?

How does this behavior help to explain why, as a listener moves away from a source of sound, the volume (loudness) she perceives gets less and less?

STEP 4: Recall from previous activities that it is the motion of the source that determines the amplitude and frequency of a wave, but it is the properties of the medium it is moving through that determines its speed. You also saw that the wavelength of a wave is related to its frequency and the speed with which it moves by a simple relationship.

$$Wavelength\ of\ wave = \frac{Speed\ of\ wave}{Frequency\ of\ wave}$$

We will now investigate how these ideas apply to sound waves.

Suppose you changed the amplitude of the loudspeaker's back and forth motion, what do you think would be different (if anything) about the pressure variations in the sound wave it produces? Why do you think so?

To check your thinking, return to the simulator and vary the amplitude control.

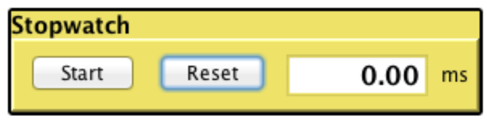
As the amplitude of the loudspeaker movement increases, does the amplitude of the pressure variations in the sound wave increase, decrease, or stay the same?

Now suppose you were to increase the frequency of the loudspeaker's back and forth motion.

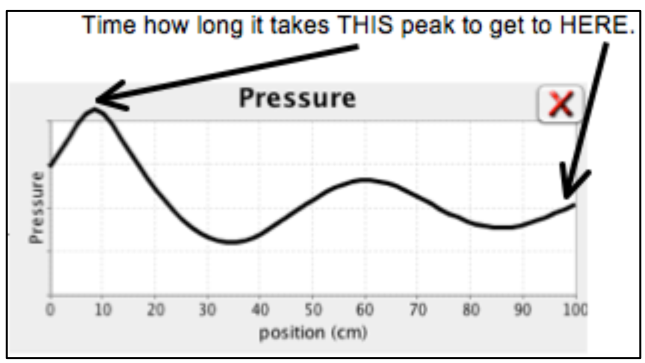
Do you think this would make the sound wave move through the air faster, slower, or would it not affect the speed? Why do you think so?

Do you think increasing the frequency would give the sound wave a longer or shorter wavelength, or would it not affect the wavelength? Why do you think so?

STEP 5: To check your thinking about the speed of the sound wave when the frequency is changed, return to the simulator and display the 'Stopwatch' tool.



Now watch the pressure graph as peaks and valleys in the pressure are generated at around the 10 cm position. These peaks and valleys then move to the right as the pressure wave moves trough the air. To get a measure of the speed of these waves, start the stopwatch when the pressure at the 10 cm mark reaches its maximum value and stop it when the peak that this creates reaches the end of the graph window.



Repeat this measure for different settings of the 'Frequency' slider control, but do not set it very high or it will be difficult to follow a particular peak. ***(Remember, you are looking at how fast a peak in the pressure wave moves from left to right, not how fast the graph goes up and down at one particular location.)***

As you increase the frequency of the loudspeaker movement, does the speed of the sound wave increase, decrease, or does it remain about the same? What evidence supports your answer?

Since you know that it is **<u>only</u>** the properties of the medium that determine the speed of a wave, why does it make sense that sound waves of different frequencies all move through the air at the **<u>same speed</u>**?

Now look at the distance between successive peaks in the wave as you vary the frequency. (You can either look at the grayscale display or the pressure graph.)

As you increase the frequency of the loudspeaker movement, does the wavelength of the sound wave get longer, shorter, or does it remain about the same? How do you know?

Why does this relationship between the frequency of the loudspeaker movement and the wavelength of the sound wave make sense? (Hint: think about how far one region of high pressure will have moved through the air by the time the next region of high pressure is created by the loudspeaker.)

STEP 6: Finally, let us investigate what effect changing some properties of a sound wave has on how the sound is perceived by a listener.

When the amplitude of a sound wave is increased, how do you think a listener perceives the sound differently, if at all? What about if the frequency is increased?

To check your ideas, your instructor will lead a demonstration using a tone generator.

As the amplitude of the loudspeaker movement is increased, what happens to how listeners perceive the sound? What about when the frequency is increased?

Recall that the frequency of a wave is measured in units of Hertz (Hz). For sound waves this is a measure of how many cycles of pressure variation occur in one second. The human ear can only detect sound waves with a certain range of frequencies. Typically the range runs from a low of around 15 Hz (15 cycles per second) to an upper limit somewhere between 10 and 20 kHz (a kHz is one thousand Hz, so 20 kHz is 20,000 cycles per second).

Your instructor will use a tone generator to demonstrate how the actual hearing range can vary among individuals[2].

According to this demonstration what is your own individual range of hearing?

[2] Since this demonstration is not done under controlled conditions, it should not be taken as definitive or diagnostic.

Note that the range of human hearing tends to diminish with age, particularly at the upper end. Other animals have very different ranges, with dogs and cats generally able to hear sounds at higher frequencies than any humans. Some bats can even hear sounds up to frequencies of 200 kHz!

Sound waves in other media

Because the mechanism involves neighboring particles pushing on each other, sound waves can actually move through any medium. The speed with which they do so depends on how quickly neighboring particles can affect each other. (Because particles are moving more quickly at a higher temperature, this means the speed of sound also depends on the temperature of the medium.) Also, because the particles in a liquid and a solid are closer together than in a gas, sound waves actually move more quickly through liquids and solids than they do though air.

This table gives the typical value of the speed of sound waves through some different materials.

Material	Speed (m/s)
Air at 0°C	331
Air at 100°C	386
Water at 25°C	1,490
Aluminum	5,100
Iron	5,130
Granite	6,000

Summarizing Questions

S1: In most science fiction movies set in space, weapons, explosions, and spacecraft engines can be heard. Is this realistic? Why or why not?

S2: If a tree falls in the forest and no one is there to hear it, does it still make a sound? Explain your reasoning.

S3: You are at the back of a crowd enjoying a concert in the park. At some point a violin plays a high E (frequency = 2637 Hz) at the same moment that a bass plays a low E (41 Hz). Which note will you hear first, if either, and why?

S4: A loudspeaker is placed so that it is in contact with side-by-side regions of air, water, and iron, as shown in the diagram below. The loudspeaker is connected to a tone generator that is turned on and plays a note with a frequency of 200 Hz.

a) In which material would the 200 Hz sound wave created reach the other end first. Which would be last? Briefly explain how you know.

b) In which material would the 200 Hz sound wave have the longest wavelength? In which would it be shortest? Using the simulator 'Grayscale' representation, shade in the boxes in the diagram above to show how the wavelength of the 200 Hz sound wave would be different in each of these materials. Explain your reasoning.