Acoustics: How does sound travel?
Teacher Version

In this lab, you will learn about where sound comes from, how it travels, and what changes the loudness of a sound or the pitch of a sound. We will do this using a slinky and a rubber band guitar.

California Science Content Standards:

- **4. Waves: Waves have characteristic properties that do not depend on the type of wave.**
- 4a. Students know waves carry energy from one place to another.
- 4b. Students know how to identify transverse and longitudinal waves in mechanical media, such as springs and ropes, and on the earth (seismic waves).
- 4c. Students know how to solve problems involving wavelength, frequency, and wave speed.
- 4d. Students know sound is a longitudinal wave whose speed depends on the properties of the medium in which it propagates.
- 4f. Students know how to identify the characteristic properties of waves: interference (beats), diffraction, refraction, Doppler effect, and polarization.

Prerequisites:

- Good for most students
- Advanced version has an extra section on tuning instruments

Complete list of Materials:

- a large plastic tub, 6 inches or deeper
- water
- a cereal bowl
- a ping pong ball
- a pencil
- Slinkies, or one very large Slinky
- Length of rope (1/4 to ½ thickness, at least 6 feet long)
- Shoebox or tissue box
- 4 to 6 rubber bands, of varying lengths and thicknesses
- Craft sticks
- plastic drinking straws, thin
- 6 plastic drinking straws, thick
- hole punch
- scissors

Key Concepts:

- Sound comes from moving objects
- Sound is made of vibrating molecules that push against one another
- Molecules don't travel across the room to get the sound to us; they vibrate in a very small space and transfer sound energy by collisions
- The harder the molecules push each other, the louder the sound we hear
- The faster the molecules push each other, the higher the pitch we hear

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- Sound reflects off of dense objects as an echo. In a musical instrument, reflected sound is trapped to form standing waves, which we hear as tones

Sound is created by **vibrating objects**. For example, a plucked guitar string vibrates, sending sound waves in all directions. Sound travels through any space with molecules in it - whether solid, liquid, or gas. It cannot travel in a vacuum ('In space, no one can hear you scream") since there are very few to no molecules. **Sound waves contain energy**, and so it can change forms, becoming for instance electrical energy (telephones and speakers) or kinetic energy (vibrating eardrums). Sound energy can only be perceived by our bodies when it strikes a physical object, like a bone or our skin, causing it to vibrate. This lab will help connect **sound production** (sources of sound) with **sound perception** (using our sense of hearing, sight, or touch).

Sound travels through space in **longitudinal waves**. Objects that vibrate in air, like the guitar string, push against surrounding gas molecules at regular intervals. There are now areas where air molecules are very dense (**compressions**) and not as dense (**rarefactions**). These alternating areas of dense and far apart air molecules move outward from the source of vibration in all directions. Sound waves travel through air at a rate of 343 m/s (768 mph) at 68 degrees F. The speed of sound changes slightly at different temperatures, and dramatically in different materials (for example, in steel alloy, it travels 6000 m/s and in fresh water at 25 degrees F, it travels at 1497 m/s). As long as a sound wave is moving through the same medium, it maintains a constant speed.

Figure 1: Longitudinal Waves

Sound waves are described as having a "**wavelength**" and a "**frequency**", though you probably here the term frequency more often when talking about sound. "Wavelength" is the distance between one compression "ripple" (or **cycle**) and the one immediately before or after it. "Frequency" is the number of these cycles that move past a point in a given amount of time. Mathematically, wavelength (λ) and frequency (f) are just the inverse of each other:

$$f = \frac{1}{\lambda}$$

So we can talk about one and easily find the other. Note that the shorter the wavelength, the higher the frequency; and the longer the wavelength, the lower the frequency. The frequency (or pitch) of sound is measured in Hertz, which are cycles/sec. We perceive high frequency sound waves as "high pitched", like a squeal or a siren. We hear low frequencies as "low pitched", like a grunt or the rumble of a subwoofer.

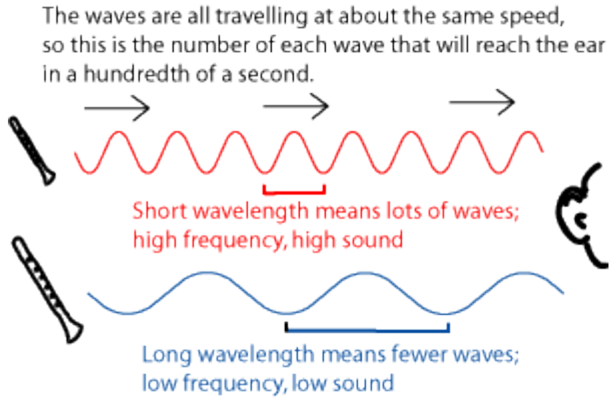


Figure 2: Frequency and Wavelength
Schmidt-Jones, Catherine. Frequency, Wavelength, and Pitch. Connexions. 12 Apr. 2010. <http://cnx.org/content/m11060/2.10/>.

Another aspect of sound is **volume**. Ranges of volume are probably easier to distinguish than ranges of pitch. Loud volumes can physically hurt because they impart so much energy to our ears! Volume is directly related to the amplitude of the sound wave - how strongly molecules are pushing against one another as the sound wave moves. This is seen in the height of the waves below.

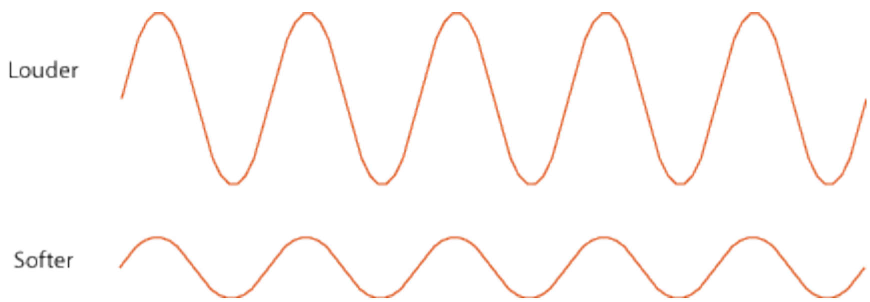


Figure 3: Amplitude determines volume
Source: Schmidt-Jones, Catherine. Sound Amplitude and Musical Dynamics. Connexions. 12 Apr. 2010 <http://cnx.org/content/m12372/1.5/>.

You hit a drum with a greater force, you impart a greater amount of energy. This is evinced in the louder sound you hear - you have caused the drum skin to push on the molecules in the air to push with greater force, and so the sound wave has more energy.

To summarize physics terms dealing with waves to everyday terms we use with sound:

Frequency <---> Pitch (how high or low)
Amplitude <----> Volume (how loud or soft)

The two waves in Figure 2 have the same wavelength but different amplitude.
Q1. Do they sound the same? Yes / No
If no, which one is louder? Wave on top / wave on the bottom

Misconception Mishaps:

- A vibrating string has a wave moving through it too, but it is not a longitudinal wave. It is a **transverse wave**, meaning that the molecules of the string move perpendicular to the length of the string, sliding past each other, not in the direction of the wave. In longitudinal waves, the molecules that carry the wave do move in the direction of the wave, bumping into each other. Often sound waves are represented in diagrams as transverse wave.

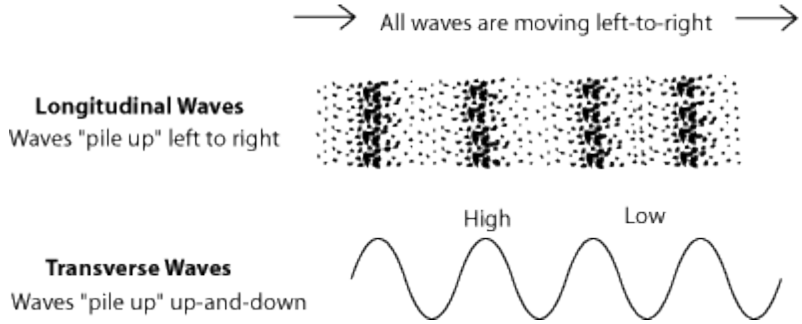


Figure 4: Two types of waves

Source: Schmidt-Jones, Catherine. Transverse and Longitudinal Waves. Connexions. 13 Apr. 2010. <http://cnx.org/content/m12378/1.6/>.

- It is important to understand that when sound travels through air, for example, the molecules themselves don't travel long distances at high speed, but they vibrate (**oscillate**) in a very small space.

- Higher frequency sounds do not reach you faster than lower frequency sounds. While the individual molecules that bump into each other vibrate quicker, the energy wave still moves at the same rate.

Some students (and even teachers) will have a hard time distinguishing pitches. If this is a problem for you or a student, try and focus more on volume differences, or relate change in pitch to a another sense (like touch or sight - see experimental section)

TEACHER NOTE

Kick-off activities:

1. Summarize the above information in your own words. Help any students who are having trouble understanding the information in the "Introduction" section of their packets.

2. Go to http://www.smm.org/sound/soundcard/top.html and play a few sound files. Ask students what they think they are hearing. Ask them to describe the sound or compare sounds. Are all sounds simple? In one sound "idea" are there really several sounds that combine? (e.g. jiggling keys all knock against each other at different speeds and times). Direct their attention to this image:

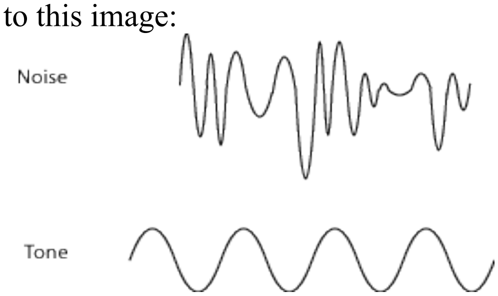


Figure 5: Noise vs. Tone

Source: Schmidt-Jones, Catherine. Standing Waves and Musical Instruments. Connexions. 12 Apr. 2010 http://cnx.org/content/m12413/1.10/

3. Explain that we are interested today in “simple” sounds or tones: one wave pattern at a time. For a **Sound Wave Motion** animation, visit http://paws.kettering.edu/~drussell/Demos/waves/wavemotion.html. We are going to make guesses and observe these waves using our sense of touch, sight, and hearing.

Part 1: Core Concepts Experiments
(to be completed with the whole group):

These experiments will get the kids thinking about where sound originates, how it travels, and how it changes. Despite their names, these activities are relatively sound-free. Thus we will rely on touch and sight for learn. Some students may move through these quickly and some may linger for a while. Just be sure they understand the science behind each one before moving to the "Design Your Experiments" section.

Pool of Sound

Materials:
- a large plastic tub, 6 inches or deeper
- water
- a cereal bowl
- a ping pong ball
- a pencil

1. Fill the tub with water until it is three inches from the top.

   TEACHER NOTE
   Explain that we are now going to explore sound as if it were waves on the surface of water.

2. Direct a student to pick an object to bob in the water. They may drop it in from a short height (less than one inches to about 2 inches above the surface), or manually force it in and out of the water, so long as only the object touches and not their fingers.
3. Let them explore variations in the size of object used, dropping vs. bobbing continuously, and the force used to create waves.

Q2. What shape are the waves that go out from the object?
Circles, or they take the shape of what is bobbing

Can you count them?

How big are they?

What changes can we make that affect the size and number of these waves?

QSA3. What causes the waves to build up so high that they almost (or totally) run over the sides? Can we affect our movement of the object in the water to prevent or promote this?
If we move the object up and down in a regular motion, the waves it creates will "stack" on each other, adding their energies together to cause water to reach higher up the sides of the container. This is called constructive interference. If we shake the object irregularly, the waves' energies will cancel each other out – destructive interference – and water stays low in the container

The bobbing object is a point source for sound. The waves leave in all directions evenly. The water waves are a little like sound waves and a little not. They move when compressed, but they take the shape of longitudinal waves. Moving the object in the water with greater force increases the size (amplitude) of the outgoing waves. Moving the objects quicker increases the number of waves (shortens wavelength, increases frequency).

Sound Round-up

Materials
- Slinkies, or one very large Slinky
- Length of rope (1/4 to ½ thickness, at least 6 feet long)

1. Tie or fix one end of the rope or Slinky to a stationary object.
2. Send a wave down it.
    - With the rope, jerk the rope quickly up and down or side to side.
    - For the Slinky, stretch and push back on it

Watch the wave move down the line.

QS3, QSA4. Does the wave only move in one direction along the length?

Does it come back?

What are the pieces of rope or Slinky doing at different times?

Sound waves are most like the Slinky, where molecules move back and forth parallel with the wave's motion. Vibrating strings, like on a guitar or a violin, move like the rope and tips of the wave machine bars, with pieces of the rope and bar tips moving perpendicular with the wave's motion. BOTH kinds of waves (longitudinal and transverse) can PRODUCE sound, but sound moves from one place to another only by longitudinal motion (like the Slinky).

Part 2: Design Your Experiment

Background
Musical instruments, when played correctly, produce tones. Tones are "ordered noise", a group of sound waves that are the same size and distance apart. Musical instruments create this order by trapping sound waves via reflection (echo) off the surfaces of its own structure. The sound

waves build up and reinforce one another until they reach a "standing" order, where they are continuously passing back and forth without disturbing or interrupting each other. The result is what appears to be just one wave fixed in space. This standing wave compresses air molecules at regular intervals, sending a unified sound outward as longitudinal sound waves. On a string, the standing wave is visible as a "fuzziness" after the string is plucked. This resolves to a still, motionless string after a short while because of internal friction and air resistance. In a wind instrument, the standing wave is not visible and is running up and down the length of the tube. Changing the length of the string or the openings in a wind instrument influences pitch. Shorter strings, tighter strings, and shorter tubes produce higher frequencies, and vice versa.

(Source: Schmidt-Jones, C. Standing Waves and Musical Instruments, Connexions Web site. http://cnx.org/content/m12413/1.10/, Apr 12, 2010.)

Rubber Band Guitar (Chordophone)

Materials:
- Shoebox or tissue box
- 4 to 6 rubber bands, of varying lengths and thicknesses
- Craft sticks

Stretch the rubber bands around the open end of the box so they are arranged like strings over the sound hole of a guitar. Pluck the strings and listen.

QS4, QSA5. Which ones sound lower or higher?

Thicker bands should sound lower, thinner ones sound higher.

List them in order from lowest sound to highest sound

Lowest Highest

QS5, QSA6. Does the sound change by how much we tug on the rubber band when plucking?

Try inserting the craft stick between the strings toward one end of the instrument. Pluck the strings from the other end.

QS6, QSA7. Does the craft stick change the sound?

The craft stick shortens the length of the band, shortening the wavelength of the sound emitted. This should raise the pitch (make it sound higher, possibly quieter)

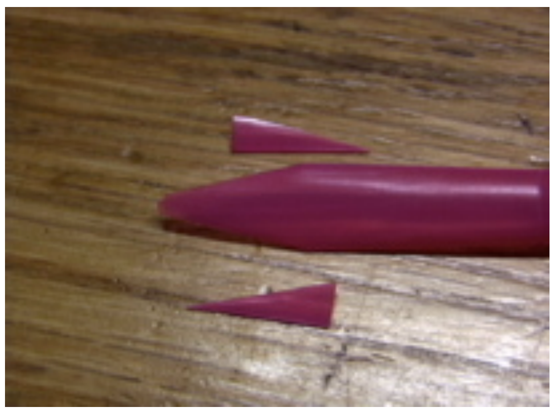
Record your observations:

Straw Reed Instrument (aerophone)

Design and construct your own wind instrument that uses a vibrating reed and makes sounds with four different pitches.

Materials:
- 6 plastic drinking straws, thin
- 6 plastic drinking straws, thick
- hole punch
- scissors

1. Flatten one end of drinking straw by rubbing it between your nail or a straight edge. Make a straw reed by cutting a wedge about 1 cm (1/2 inch) long at one end of a plastic drinking straw.



   Be sure the two cuts are even in length and their angle to the tip of the straw.

2. Punch 3 holes in the side of the straw using a hole punch. Space the holes out equally, starting 2 inches from the tip of the reed at least. It will help if you make the holes so they are at the top of the instrument when you play it. Note: don't punch through both sides of the straw! Rather, press the straw in half and insert the folded edge halfway into the hole punch.

3. To make a longer instrument, flare the end opposite the reed by inserting a pencil and stretching the plastic. Remove the pencil and fit another straw of the same size into the flared end.

4. Insert the reed in your mouth, slightly past the lips. Blow a steady, strong stream of air. Adjust the amount of straw in your mouth and the strength of your blowing the reed vibrates and a sound comes out.

Experiment with your instrument.

QS7, QSA8. What part is moving?

How did you get it to move?

Try to make the pitch higher or lower by covering the holes.

QS8, QSA9. What do you have to do to make a louder or softer sound?

Write down what you did to change the sound, and the result

What I changed	*The Result*

To make a slide instrument, take two straws-- one thick and one thin. At one end of the smaller straw, make a reed. Insert the other end of the thin reeded straw into the thicker straw.

Experiment with this instrument.

QS9, QSA10. What does sliding the straws in and out do to the sound?
Lengthening the tube lowers the pitch

QS10, QSA11. How is this like covering the holes?
Covering more holes keeps the pitch low, but uncover a hole nearer the reed, and the pitch sounds higher

Source: http://www.smm.org/sound/nocss/activity/ssl7.htm

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Extension Activity: Tuning

Background

Returning to the topic of standing waves and instruments from the Background to Part 2, standing waves take a slightly different shape on strings and in wind instruments:

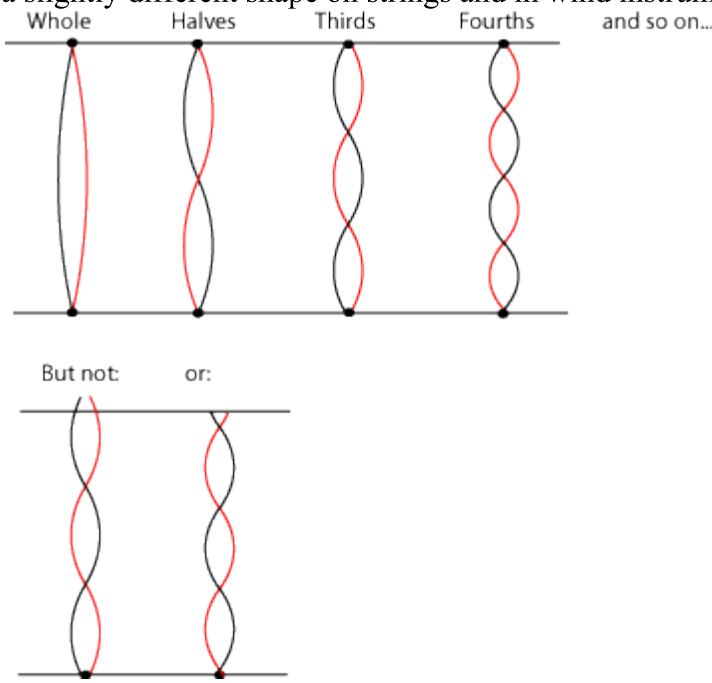

Figure 6: Harmonic Series on Strings

Schmidt-Jones, Catherine. Standing Waves and Musical Instruments. Connexions. 12 Apr. 2010 <http://cnx.org/content/m12413/1.10/>.

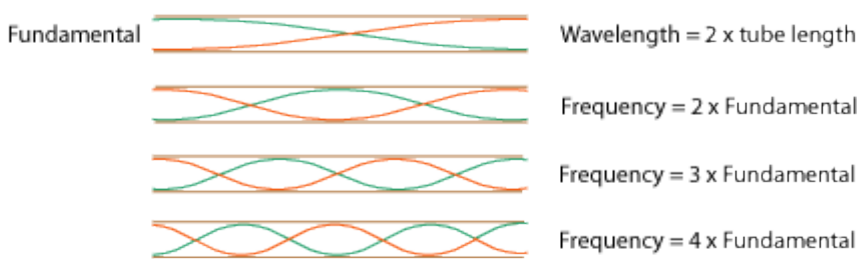

Figure 7: Harmonic Series in Tubes

Schmidt-Jones, Catherine. Standing Waves and Wind Instruments. Connexions. 12 Apr. 2010 <http://cnx.org/content/m12589/1.9/>.

Notice how the waves on a string must end on a **node** (crisscross point), and the waves in an open tube must end on an **antinode** (top of peak). The wavelength of the **fundamenta**l (whole) is always 2L, the length of the string or tube. The next level up is the second harmonic and is L (two waves in one there-and-back trip), the third harmonic 2/3L, the fourth 1/2Land so on. Since the wavelength goes down, the frequency goes up by the same factor. Mathematically:

$$f^1 = \frac{1}{2L}, \quad f^2 = \frac{2}{2L}, \quad f^3 = \frac{3}{2L}, \ldots$$

The fundamental and all the layers of harmonics that are derived from it are present in a finely tuned instrument's single tone. For the instruments made in this lab, which are rough at best, the pitch we hear is mixture of many tones; it is more like a "noise". Still, we can tune them relatively well to each other. Tuning is adjusting instruments to sound united (in an orchestra) or true to a specific standard pitch (like a piano tuner's tuning forks). In the "Extension Activity: Tuning", advanced students will attempt to tune their rubber band guitar or straw reed instrument to another student's creation using math and their own sense of pitch from hearing.

Procedure:

1. Find a partner with a different instrument than you (Guitars pair with Reeds)

Guitarists:

1. Pick a rubber band and measure its length in centimeters from end to end. Record in Table 1.
2. Insert the craft stick at the halfway point, so that only half the string will be able to vibrate when played. Measure this length.
3. Slide the craft stick around to 2 other positions, measuring the length of the rubber band piece and recording it. You should have 4 data points when finished.
4. *Copy your partner's data from their Table 2 to your Table 2.*

Reed Instrument Players:

1. Measure your instrument from reed tip to the other end in centimeters. Record in Table 2.
2. Measure it from the reed tip to the farthest hole. Record.
3. Measure it from the reed tip to the next farthest, and then the next farthest. Record these lengths. You should have 4 data points.
4. *Copy your partner's from their Table 1 to your Table 1*

Partners:

1. Compare the distances you recorded in Table 1 to those in Table 2.
   QSA12. Are any of them similar?

2. Play your instruments together at these positions.
   QSA13. Do the numbers correctly predict if they will sound the same? Yes/No

3. Try tuning your instruments using just your ears. Try to make them sound the same.
   QSA14. Do you think musicians tune the first way (by measuring their instruments) or the second way (by ear)?

Table 1

	1.	2.	3.	4.
Length (L)				
Frequency (1/L)				

Table 2

	All holes covered	One hole uncovered	Two holes uncovered	Three holes uncovered
Length (L)				
Frequency (1/L)				

Concept Questions

QS11, QSA15. How are sound waves like water waves? How are they different?

Water waves look like transverse waves on the surface (really, they are a combination of transverse and longitudinal). Sound waves are longitudinal.

QS12, QSA16. Name 2 ways you changed the sound coming out of your instruments you made.

QS13, QSA17. How can an instrument with only 4 strings make more than 4 sounds?

By stretching out the strings or placing your finger on them (like a guitar player positions his fingers on the fret board), you can alter the pitch on a single string.

QS14, QSA18. When a trumpet player pushes a value on the trumpet, it opens up an extra loop of tubing. What does this do to the trumpet? To the sound?

The trumpet gets longer on the inside. This lengthens the space for a wave to bounce around in. The wavelength increases, the frequency lowers, and the pitch goes down.

QSA19. How is measuring the instruments' lengths supposed to predict their sound?