Section 4 Sounds from Vibrating Air

What Do You See?

Learning Outcomes

In this section, you will

- **Identify** standing waves in different kinds of air-filled tubes.
- **Observe** how pitch changes with the length of the tube.
- **Observe** the effect of closing one end of the tube on the pitch of the sound.
- **Observe** sound bending around corners and spreading.
- **Relate** observations of pitch to drawings of standing waves.
- **Summarize** experimental results.
- **Organize** observations to find a pattern.

What Do You Think?

The longest organ pipes are about 11.0 m long and flutes are about 0.5 m long.

- **How do flutes and organ pipes produce sound?**

Record your ideas about this question in your *Active Physics* log. Be prepared to discuss your responses with your small group and with your class.

Investigate

In this *Investigate*, you will blow air across different-length straws and test tubes filled with different amounts of water to observe the differences in the sounds produced. You will investigate how sound can travel around a corner. You will also explore how to make your own reed instrument.

Part A: Vibrations in Tube-Shaped Instruments

1. Carefully cut a drinking straw in half. Cut one of the halves into two quarters. Cut one of the quarters into two eighths. Give a cut-up piece of the straw to each member of your group.

   (Your teacher may decide to distribute lengths of PVC tube as a substitute for the straws.)

2. Gently blow into the top of the piece of straw (or tap the PVC tube on the palm of your hand).

   a) Describe what you hear.

   b) Listen as the members of your group blow into their straw pieces one at a time. Describe what you hear.

   c) Write a general statement about how changing the length of the straw changes the pitch you hear.

3. Now cover the bottom of your straw piece with your finger and blow into it again. Uncover the bottom and blow again.

   a) Compare the sound the straw makes when the bottom is covered to when it is uncovered.

   b) Listen as the members of your group blow into their straw pieces, with the bottom covered and then uncovered. Write a general statement about how covering the end of the straw changes the pitch.

   c) Write a general statement about how changing the length of the straw changes the pitch you hear when one end is covered and then uncovered.

Make sure the outsides of the test tubes are dry.

4. Obtain a set of four test tubes. Leave the first one empty. Add water to the second until it is about 1/5 full. Fill the third to 1/3 full and the fourth to 1/2 full. Give a test tube to each member of your group. Blow across your test tube.

   a) Describe what you hear.

   b) Listen as the members of your group blow, one at a time, across their test tubes. Record what you hear.

   c) Describe the pattern you find in the observations you recorded.

   d) Compare the results of blowing into the straws with blowing across the test tubes. How are the results consistent?

5. Review your observations and then answer the following questions.

   a) What is vibrating in the straw and in the test tube to make the sound that you hear?

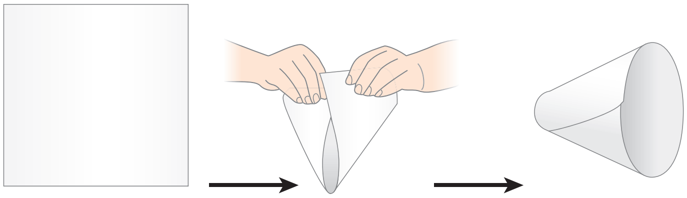
   b) Is the test tube similar to the straw with the bottom covered or uncovered? Why?

Part B: The Spreading and Bending of Sound Waves

1. Have one lab partner stand around the corner of the door and out of sight. Have your partner make a sound.

   a) Make a drawing that shows how the sound waves travel from beyond the corner of the doorway to your ear.

2. Roll a sheet of paper into the shape of a megaphone.



   Emit a sound without the use of the megaphone and then emit the same sound with the megaphone in front of your mouth. Have your lab partners report on the difference between the two sounds.

   a) Record this observation in your log.

Part C: Making a Reed Instrument

1. To make a musical instrument, obtain a straw and cut the ends to form a V-shape as shown in the diagram above.

2. Flatten the V-shaped end of the straw by gently biting on it with your teeth. Blow into the straw.

3. Make a sound by blowing into the straw, and as you emit the sound, use scissors to cut off the end of the straw. Cut the straw into shorter pieces in quick succession to enable you to continue making the sound with the straw without running out of breath.

> Be careful that the scissors do not get too close to your eyes or face.

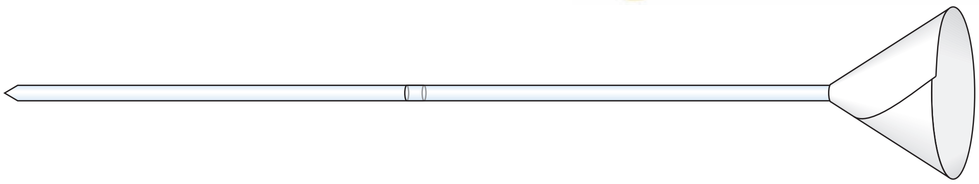
   a) Listen to the different frequencies of the sound as you shorten the straw. Record your findings.

4. Begin with a new straw. Add a horn to one end of the straw to construct a trombone. Make the horn out of a sheet of paper, as shown below.

   a) Record the effect that the horn has on the sound that your lab partners hear.

5. Try to make a trombone by inserting a second straw with a smaller diameter inside the first straw.

   a) Record any engineering design strategies you used to make the trombone.

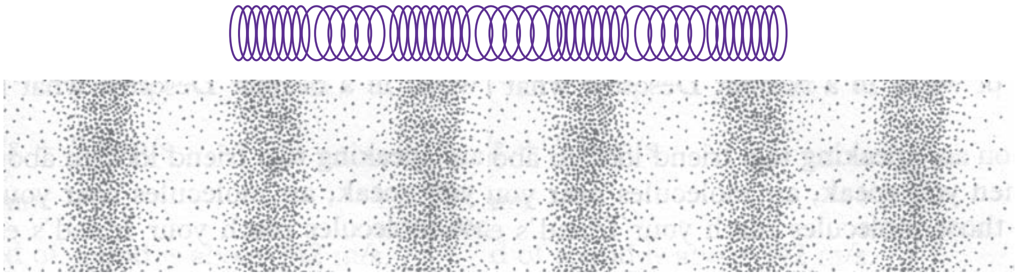


Physics Talk

SOME PROPERTIES OF SOUND WAVES

Compressing Air to Make Sound

Sound is a compressional (longitudinal) wave. The molecules of air squeeze together or spread out as the sound wave travels through the air, just like the coils of the spring that you observed in a previous section.



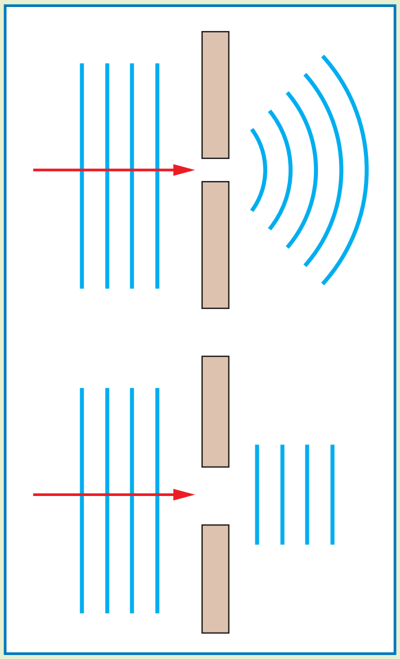
The molecules in the air bunch up in a similar fashion as coils of the spring bunch up in a compressional wave on a coiled spring.

In the *Investigate*, the air in the straw or the test tube was the medium through which the sound waves traveled. Standing waves were set up in the air. These waves traveled to your ears where you heard the sounds. These waves are similar to the standing waves made by the playing of the string instruments. At the bottom of the test tube, the air molecules cannot vibrate, because their motion is stopped by the glass at the end of the test tube. The wave's amplitude is zero at the bottom of the test tube. This point is a node of the standing wave. At the open end of the test tube, the amplitude of the wave is as large as it can possibly be. This vibration of air at the open end makes a sound wave that moves from the test tube to your ear. This point is an antinode of the standing wave.

Imagine 10 or 20 students lined up in a straight line, about one arm's length apart. The last person in the line moves closer to the person in the front. That person then moves closer to the next person in the line and this movement continues through the line. The closer spacing eventually forms a compressional wave that travels along the line of people.

If the person farthest in the line is standing against a wall, that person will not be able to move. That situation is similar to the closed end of a tube where the air molecules cannot move, and hence, have no displacement.

Wave Diffraction



Sound waves travel by spreading out or bending around barriers. When you speak to a friend, the sound waves leave your mouth and spread out in front of you and off to the sides. In *Part B* of the *Investigate,* you observed the spreading out and bending of the sound waves when your lab partner made a sound from around the corner of the door.

This ability of sound waves to spread out or change direction as they emerge from an opening is called **diffraction.** The smaller the opening, the more the sound waves diffract. The diffraction of the sound waves as they emerge from two openings can be shown with a diagram.

The wave in the top diagram goes through a small opening (in comparison to its wavelength) and diffracts a great deal. The wave on the bottom goes through a large opening (in comparison to its wavelength) and shows little diffraction.

In the *Investigate*, you noticed how much louder a sound you made was when you used a megaphone. You have probably seen cheerleaders use megaphones at sports events to change the amount of the diffraction. Therefore, cheerleaders are able to project a louder sound in front of the cheering crowds.

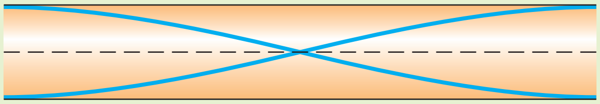
A smaller opening produces more diffraction than a large opening. How do you determine the size of an opening? The size of the opening may be determined by the wavelength of the sound wave. Whether an opening is large or small depends on the size of the opening compared to the wavelength of the wave.

Physics Words

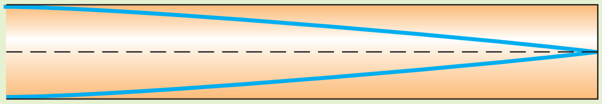
diffraction: the ability of sound waves to spread out or change direction as they emerge from an opening.

Vibrating Columns of Air

The sound you heard when you blew into the straw and across the test tube was produced by a standing wave in air. If both ends of the straw are open, the air molecules at both ends move back and forth forming a vibrating column of air. The drawing below shows the movement of the air as a standing wave. Where the blue lines are far from the axis of the straw, the displacement of the air molecules is large. Where the blue lines cross the axis, the displacement of the air molecules is zero.



Tube is open at both ends.
½ wavelength fits in straw.



Tube is closed at one end.
¼ wavelength fits in straw.

When you covered the bottom end of the straw, you prevented the air molecules from moving at the covered end and the pitch and frequency of the sound decreased. This drawing shows the pattern of displacement of the air molecules as a standing wave. Notice that the blue lines hit the axis at the closed end of the straw indicating that the displacement of the air molecules there is zero.

Recall that the speed of a wave is equal to the frequency multiplied by the wavelength. This formula can be expressed mathematically as $v = \lambda f$. Using your previous knowledge of an inverse relationship, you can infer the following from $v = \lambda f$: If the wave speed stays the same, the frequency decreases as the wavelength increases.

In the straw open at both ends, $\frac{1}{2}\lambda$ (one-half wavelength) fits in the length of the straw L. Therefore, the wavelength of the sound is $2L$.

In the straw closed at one end, $\frac{1}{4}\lambda$ fits in the length of the straw L. Therefore, the wavelength of this sound is $4L$. The wavelength in the open straw is half the wavelength in the straw closed at one end. This equation predicts that the frequency of the standing wave in the open straw is twice the frequency of the standing wave in the straw closed at one end.

Checking Up

1. How does sound travel through air?
2. How do sound waves diffract?
3. How do you express the speed of a wave in terms of its wavelength and its frequency? What is the relationship between wave frequency and wavelength if wave speed remains constant?

Active Physics Plus

+Math	+Depth	+Concepts	+Exploration
◆	◆		

Wave Diffraction

Wave diffraction (bending of waves through an opening, for example) becomes important when the size of the opening is about the same size as or smaller than the wavelength of the waves

1. a) Using the equation $v = f\lambda$, calculate the wavelength associated with a pitch of "middle A" (440 Hz) for sound waves traveling through air. Use the value of 340 m/s as the average wave speed in air.

   b) Would you expect to have significant diffraction of sound waves when they go through an open door? An open window? A garage door opening?

2. Calculate the wavelength of the note with each of the following frequencies.

   a) 22 Hz

   b) 220 Hz

   c) 880 Hz

   d) 8800 Hz

What Do You Think Now?

At the beginning of the section, you were asked the following:

- **How do flutes and organ pipes produce sound?**

Use what you learned in this section to explain how flute and organ pipes produce sound. How does the wave speed affect the frequency and wavelength of sound?

Physics
Essential Questions

What does it mean?

When a vibrating string produces sound, a standing wave is set up along the string. Air in a tube can also set up a standing wave to produce a sound. Describe the standing wave in the air in the tube and compare it to the standing wave on a string.

How do you know?

Physicists want to know how wave characteristics like wavelength and wave frequency depend on the properties of the medium in which a wave is traveling. How does the pitch of the sound produced in a tube depend on the tube's length? Does it matter if one end of the tube is open or closed? What evidence do you have for this from your experiments?

Why do you believe?

Connects with Other Physics Content	Fits with Big Ideas in Science	Meets Physics Requirements
Waves and interactions	Models	* Experimental evidence is consistent with models and theories

* Physicists like to develop general principles and models that apply to many different situations. By listing two similarities and two differences, compare and contrast the sound produced by vibrating strings and the sound produced by air in tubes.

Why should you care?

Scientists always like to find new situations that can be explained in terms of what they have learned in other situations. Give some examples of where sounds are produced by vibrating air in tubes. Include examples outside of the classroom where air or wind causes strings or pipes to vibrate to produce sounds.

Reflecting on the Section and the Challenge

In this section, you observed the sounds produced by different kinds of tubes and pipes. If the pipe is cut to a shorter length, the pitch of the sound increases. Also, when the pipe is open at both ends, the pitch is much higher than if the pipe were open at only one end. You have seen how simple drawings of standing waves in these tubes help you find the wavelength of the sound. If the tube is closed at one end, the air has zero displacement at that end. If the tube is open at one end, the air has maximum displacement there.

For your sound show, you may decide to construct some "wind" instruments using test tubes or straws, or other materials approved by your teacher. When it comes time to explain how these work, you can refer to this section to explain the physics.

Physics to Go

1. You can produce a sound by plucking a string or by blowing into a pipe.
   a) How are these two ways of producing similar sound?
   b) How are these two ways different?
2. a) For each piece of straw your group used, make a full-sized drawing to show the standing wave inside. Show both the straw closed at one end and open at both ends.
   b) Next to each drawing of the standing waves, make a drawing, at the same scale, of one full wavelength. For the long pieces of straw, you may need to tape together several pieces of paper for this drawing.
   c) For a periodic wave, wave frequency times the wavelength is the wave speed. The speed in air is the same for all frequencies. Based on your drawing in *Part 2.b*), what can you predict about the frequencies of the standing waves in the straw pieces?
   d) How well do your predictions from *Part 2.c*) agree with your observations in this experiment?
3. Find some information on the length of organ pipes.
   a) What is the length, in meters, of the longest organ pipe?
   b) Assume this pipe is closed at one end. Draw the standing wave pattern.
   c) For this pipe, what is the wavelength of this standing wave?
   d) Why does a large wavelength indicate that the frequency will be low? Give a reason for your answer.
4. Suppose you are listening to the sound of an organ pipe that is closed at one end. The pipe is 3 m long.
   a) What is the wavelength of the sound in the pipe?
   b) The speed of sound in air is about 340 m/s. What is the frequency of the sound wave?
   c) Now suppose you are listening to the sound of an organ pipe that is open at both ends. As before, the pipe is 3 m long. What is the wavelength of the sound in the pipe?
   d) What is the frequency of the sound wave?
5. Suppose you listen to the sound of an organ pipe that is closed at one end. This pipe is 1 m long. How does its frequency compare with the frequency you found in *Question 4.b*)?
6. Waves can spread into a region behind an obstruction.
   a) What is this wave phenomenon called?
   b) Draw a diagram to illustrate this phenomenon.

7. A drum corps can be heard practicing at a distance of 1.6 km (about 1 mile) from the field. What is the time delay between the drumstick hitting the drum and the sound heard by an individual 1.6 km away? (Assume the speed of sound in air to be 340 m/s.)

8. ***Preparing for the Chapter Challenge***

   List some ideas for producing sounds from air in tubes that can be used in a sound and light show. Describe how the instrument produces sounds with different frequencies.

Inquiring Further

1. **Musical test tubes**

   If you have a good musical ear, add water to eight test tubes, adjusting the amount of water to the pitch that you desire. Your goal is to create a musical scale when you successively blow over the top of each of the test tubes. Play a simple piece for the class.

2. **Measuring the frequency of vibrating columns of air**

   Carefully cut new straw pieces, as you did in *Investigate, Step 1*. This time, you will measure the frequency of the sound. Set up a frequency meter on your computer. Place the microphone near an open end of the straw. (A free frequency-counter program for your computer can be found on the Internet.)

   As before, each person blows into only one piece of straw. Make the sound and record the frequency. Now cover the end of the straw and predict what frequency you will measure. Make the measurement and compare it with your prediction. Repeat the measurements for all of the lengths of straw. Record your results, and describe what patterns you find.

3. **Investigating the effect of the diameter of a vibrating column of air on frequency**

   In this section, you found the relationship between the length of a tube and the pitch the sound produced. You also considered the differences between sounds made by air vibrating in open tubes and closed tubes.

   Design an experiment that will test to see if the pitch of a sound from a tube changes due to a change in the diameter of the tube. Use the frequency meter to measure the frequency of the sound made by your tubes. You could extend this investigation by measuring frequencies of sounds made in tubes of the same diameter but of different materials.

4. **History of wind instruments**

   Research for information about the Aeolian harp, an ancient musical instrument played by the wind. Present your findings to the class.