SECTION 4

Sounds from Vibrating Air

Section Overview

Students continue the study of sound production and musical instruments by investigating the vibration of air in tubes and pipes. They blow into different-length drinking straws and describe the sound produced, as well as how the pitch changes with the varying lengths. In a similar investigation of closed-end tubes, they blow across a set of four test tubes, one empty and the rest filled with different levels of water. In *Part B* of the *Investigate*, students also see how sound is able to bend around corners. They then compare the volume of their voice without using a megaphone to one emitted through a megaphone.

In *Part C* of the *Investigate*, students make a reed instrument with a straw and continue to blow into it as they cut the straw into shorter pieces. They record different frequencies of the sound by shortening the straw and without running out of breath. They then add a horn (a megaphone analog) to record the effect the horn has on the sound. Finally, they record the design strategy of a trombone by inserting a second straw inside the first one.

Later, students read about the phenomenon of diffraction and how sound is produced by standing waves in a straw or a test tube by vibrating columns of air. They learn how the frequency and wavelength of sound is affected when a tube is closed at one end.

Background Information

The phenomenon of generating sound by blowing into a tube is an example of resonance. The term "resonance" is not used in the student text. However, understanding resonance will give you a good background for understanding sound waves in air-filled tubes. In resonance, a system that has a natural frequency is excited by an oscillation of the same frequency. A familiar example is pushing a child on a swing. The swing is a pendulum, with a natural frequency of oscillation. When the child is pushed so that the push is in the same direction as the child's velocity, energy feeds into the system and the child swings higher. If the pushes are synchronized with the swinging oscillations, there is a resonance effect and the child swings higher and higher. If the push is opposed to the child's velocity, energy drains out of the system rapidly. Sound, too, can be pictured as a regular series of pushes and pulls. The sound wave in air is compressional (longitudinal), so the wave is a pattern of regular pressure changes in which air molecules move back and forth.

One important difference between blowing into a tube and pushing a child on a swing is that the push is made at just the right time to get the child swinging with a large amplitude. The push, if done properly, has a single frequency. By contrast, blowing into a tube produces a random spectrum of frequencies. But when that spectrum contains a frequency that matches one of the natural oscillation frequencies for the air in the tube, the blowing will make the air in the tube resonate; then the sound level for that frequency in the tube builds up and up. Listening to a sea shell is the same effect: random frequencies of sound in the ambient air resonate with the natural vibration frequencies of the air in the sea shell. Now imagine a tube, with length "L," that is closed at one end. A sound wave reaches the open end of the tube. The wave moves to the end of the tube, reflects, and returns to the open end, which requires a time of $2L/v$.

When the wave returns to the open end, the wave will be pushing the air at this end out of the tube. For resonance to occur, the sound wave exciting the air molecules in the tube must have gone through half a cycle since it entered the tube, which requires a travel time of half the period T. Recall that the period is the reciprocal of the frequency:

For an open tube
$T_o = 1/f = 2L/v$

For a closed tube, in order for the wave to resonate, the wave must go the length of $2L$ in one-half cycle or,

$\frac{1}{2}T_c = 2L/v$ or $T_c = 4L/v$
Since $T = 1/f$, $f = 1/T = v/4L$
Substituting into $v = f\lambda$ gives
$v = (v/4L)(\lambda)$ or $L = \lambda/4$
This equation expresses the same result as the drawings toward the end of the *Physics Talk*.

Crucial Physics

- Vibrations in a column of air produce sounds as standing waves in the column.
- The shorter the column of air, the higher the pitch produced.
- If the column of air is open at both ends, the pitch produced by the column is higher than if the column of air is closed at one end.
- Sound waves spread out from small openings and bend around corners. This process is called diffraction.

Learning Outcomes	Location in the Section	Evidence of Understanding
Identify standing waves in different kinds of air-filled tubes.	***Investigate*** Part A: Steps 2–5 ***Physics Talk***	Students relate the constant pitch produced by blowing into a straw or test tube with the constant pitch produced by a standing wave on a vibrating string.
Observe how pitch changes with the length of the tube.	***Investigate*** Part A: Step 2	Students blow into straws of different lengths and describe the difference in sound they hear. They write a general statement about how changing the length of the straw changes the pitch of the sound they hear.
Observe the effect of closing one end of the tube on the pitch of the sound.	***Investigate*** Part A: Steps 3-5	Students blow into straw pieces of different lengths that are covered at one end, describe what they hear, and compare the results with what they hear. Students blow into a straw that is open at both ends.
Observe sound bending around corners and spreading.	***Investigate*** Part B: Steps 1 and 2 ***Physics Talk***	Students hear sounds made by their lab partners, who are hidden from sight, from beyond the corner of a doorway. They also emit sounds into a megaphone made of paper and report the difference in sound made without the megaphone.
Relate observations of pitch to drawings of standing waves.	***Physics Talk***	Students read about the properties of waves and correctly identify the standing waves associated with open and closed tubes.
Summarize experimental results.	***Investigate*** Part A: Step 5	Students correctly answer questions in *Step 5*.
Organize observations to find a pattern.	***Investigate*** Part A: Step 5 Part C: Step 4 ***Physics Talk***	Students add a horn to a "trombone," increasing sound dispersal like a megaphone. Students point out that an air column of the same length in the test tube and the closed-end straw produce the same pitch.

Section 4 Materials, Preparation, and Safety

Materials and Equipment

PLAN A		
Materials and Equipment	**Group (4 students)**	**Class**
Safety glasses, impact	4 per group	
Scissors	1 per group	
Large test tubes 20 x 150	4 per group	
Straw, drinking, transparent, pkg 100		2 per class
Access to water, 300 mL*	1 per group	

*Additional items needed not supplied

Time Requirement

- Allow one class period or 45 minutes for students to complete the *Investigate*.

Teacher Preparation

- Assemble the required materials beforehand. Larger diameter straws work better than smaller ones, and each class will require a new, uncut set of straws.
- A source of water and a place to dispose the water from the test tubes will be required.
- A disinfectant solution should be made up to clean the test tubes if they are to be reused by successive classes.
- Have rolls of tape available to help students keep the shape of the megaphones.

Safety Requirements

- Students should wear safety goggles for this *Investigate*.
- Caution students to be careful when cutting the straws with scissors. If you are uncertain about student's ability to perform the cutting safely, prepare the cut straws beforehand.
- Test tubes should be disinfected between classes if the same set is to be used for different classes.

Materials and Equipment

PLAN B		
Materials and Equipment	**Group (4 students)**	**Class**
Safety glasses, impact	4 per group	
Scissors	1 per group	
Large test tubes 20 x 150	4 per group	
Straw, drinking, transparent, pkg 100		2 per class
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NOTES

Meeting the Needs of All Students

Differentiated Instruction: Augmentation and Accommodations

Learning Issue	Reference	Augmentation and Accommodations
Making general statements	***Investigate*** Part A: Steps 2 and 3	**Augmentation** • Encourage students to discuss their observations as a group before recording their general statements. • Some students with auditory discrimination issues may struggle to hear the difference between similar frequencies. Instruct these students to listen to two extremes (a whole straw and an eighth of a straw) before they make a general statement. **Accommodation** • Provide sentence starters for general statements such as "Making the straw shorter causes the pitch to…"
Visualizing analogies	***Physics Talk***	**Augmentation** • Students often struggle to visualize comparisons made by analogies. The analogy in these paragraphs could be simulated as a quick whole-group investigation. Make sure students know that they are representing the molecules that move to form a wave, and the classroom or hallway is the test tube.
Comparing and contrasting	***Physics Essential Questions*** *Why do you believe?* ***Physics to Go*** Question 1	**Augmentation** • Comparing and contrasting sounds is a high-level comprehension skill that many students struggle to accomplish. Students would benefit from making two lists, one to summarize what they have learned about sounds produced in vibrating strings and one to summarize what they have learned about sound produced by air in tubes. Students can then compare their lists to look for similarities and differences. **Accommodation** • Some students may not be able to create two lists to use for comparison. Brainstorm the list as a whole group or provide students with two complete lists and ask them to list similarities and differences.
Comparing and calculating values for wave characteristics	***Physics to Go*** Questions 2, 5, 7	**Augmentation** • These questions about wave characteristics require that students synthesize skills from previous sections with the new knowledge acquired in this section. Refer students back to previous work they have completed that will assist them in answering these questions. • Provide direct instruction and review opportunities for students to synthesize this information. • Require students to show their work when doing calculations to assess what misconceptions they still have.

Strategies for Students with Limited English-Language Proficiency

Learning Issue	Reference	Augmentation
Vocabulary comprehension	***What Do You Think?***	Before students attempt to answer the question "How do flutes and organ pipes produce sound?" show them pictures of a flute and a pipe organ.
Vocabulary comprehension	***Investigate*** Part B: Step 2	Students may not be familiar with the term "megaphone," or they may not be familiar with the megaphone itself. Show students a picture or photograph of a megaphone and explain what it does. Or, if possible, have a member of your school's cheerleading squad lend one to the class. If you let students try using the megaphone, be sure to disinfect the mouthpiece with an alcohol wipe after each student has finished with it.
Vocabulary comprehension	***Investigate*** Part C	Some students may know very little about musical instruments. If possible, arrange for a music teacher to come to class with examples of reed instruments, a trumpet, and a trombone, so students can see the type of instruments they are going to make from other materials. Or, ask students in your class who are also in the school band or orchestra to bring their instruments to class. If neither option is possible, show students pictures of the instruments. Explain that a reed is a flexible strip obtained from a woody plant that vibrates when air is blown into it. Demonstrate the sliding action of a trombone, and tell students that a trumpet is shaped at the end to magnify sound in the same way as a megaphone.
Vocabulary comprehension	***Physics Talk***	Explain that "molecules" of air are tiny particles of air. Remind students that a "medium" is the material through which a wave can travel. It includes guitar strings, reeds, and the brass of trumpets and trombones that mechanical waves travel through, and the air through which sound waves travel.
Vocabulary comprehension	***Physics Talk*** Wave Diffraction	Students have learned that waves reflect, or bounce back, when they encounter an obstacle. Help students learn that waves "diffract," or spread out and change direction, as they pass through an opening and come out on the other side. The smaller the opening, the greater the "diffraction." A discussion of the illustration of diffraction in the *Student Edition* should suffice to serve this purpose.
Vocabulary comprehension	***Active Physics Plus***	A vibrating medium "resonates," or vibrates at certain frequencies natural to that medium, called "resonant frequencies." Standing wave patterns relate to these resonant frequencies called "harmonics."

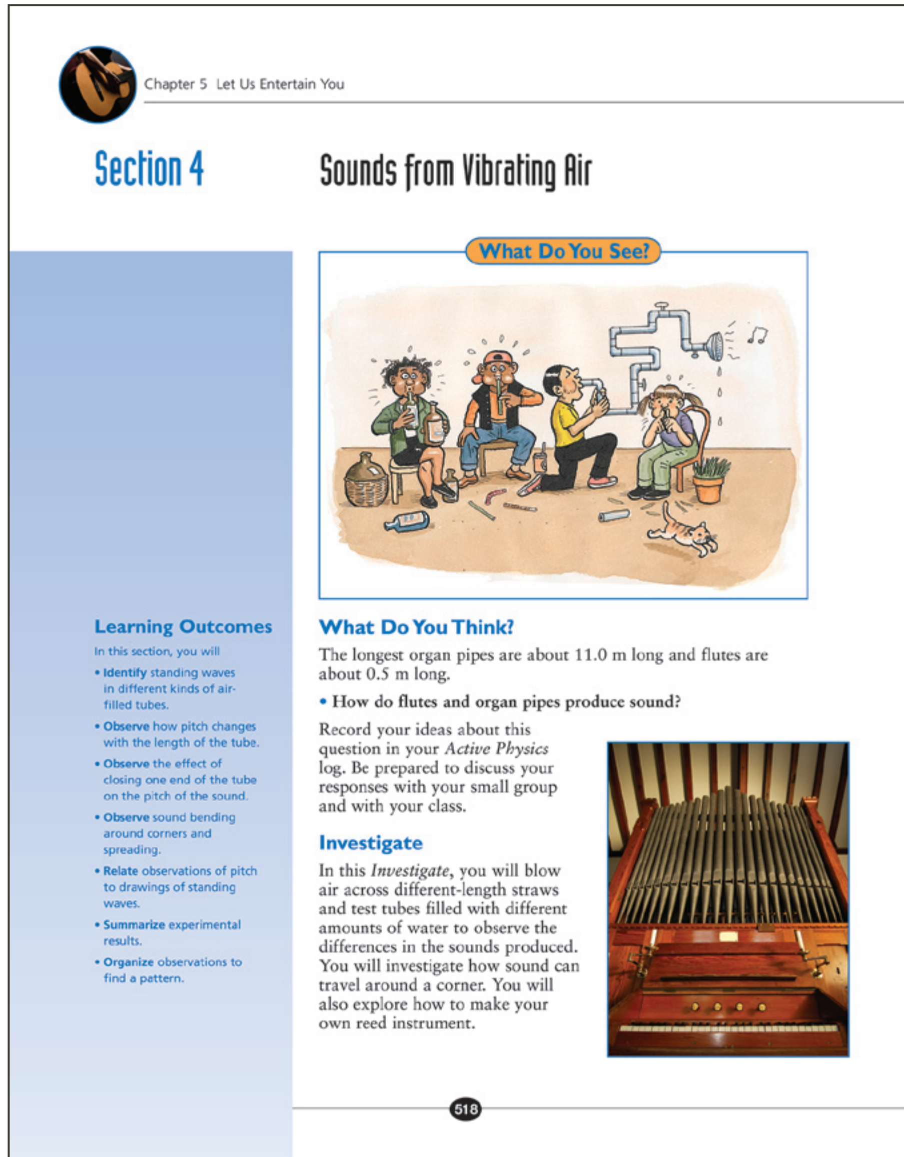
SECTION 4

Teaching Suggestions and Sample Answers

What Do You See?

The effective visuals in this illustration reveal many aspects of *Sounds from Vibrating Air*. Ask students to ponder the images carefully and record what they see. A quick discussion will bring together different impressions of the illustration that students should be asked to review after they have carried out the investigation and read the section in more detail.

Draw students' attention to each image of the *What Do You See?* illustration by showing a colored transparency of the image on an overhead projector. You might want to ask an open-ended question that prompts students to



Chapter 5 Let Us Entertain You

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.

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Students' Prior Conceptions

The manner in which students explore standing waves in open and closed-end tubes and the models they create to summarize experimental results will help them to root out preconceptions and to align them with scientific beliefs that relate frequency, pitch, and resonance to wave models. Again, it is imperative for you to evaluate student language and student explanations to ensure that they organize patterns aligned with science concepts and not with their inexperienced beliefs. As students relate pitch to drawings of waves, they are adding *Inputs* to their engineering design and getting *Feedback* that will contribute to the design of the *Mini-Challenge* that follows this section.

1. **Students believe that because air is less dense (thinner) than solids, it offers less of a barrier to the transmission of sound; hence, sound travels faster in air than in solids.** An interesting way to encourage students to write or to discuss what they think about the speed of sound in air or another medium is to refer to movies, comics, or other sources of transmission where a person bends and puts an ear to a track to hear a traveling train coming from far away by the sound made from the vibrations in the track. However, the person standing away from the tracks cannot hear the sound of the train traveling along the tracks. In addition to having tubes containing different types of air or gasses, it is useful to have a long, solid rod available for students to use in their inquiry.

think about prior investigations and encourage them to refer to those while interpreting this illustration.

What Do You Think?

Student responses will vary. They may make some relevant observations based on what they have studied in previous sections. They might also know how to play the flute or an organ pipe. Ask students to apply their prior understanding of sound produced by musical instruments to answer the *What Do You Think?* question. Let them discuss their ideas and record their answers in their *Active Physics* logs. Encourage them to keep referring to their recorded response while they are performing the *Investigate* or reading the *Physics Talk*. This inquiry-based mode of learning will enhance students' skills in analyzing information gathered in subsequent sections.

What Do You Think?

A Physicist's Response

A flute and an organ produce sound from a vibrating air column. The flutist's lips direct a stream of air into the mouthpiece to set up the vibration of the air inside the instrument. The strength, direction of the air stream, and length of the air column determine the harmonic content of the vibration and thereby the octave of the musical note. In the organ, compressed air is blown into each tube to create the resonance. Each pipe in the organ has a different length and produces a different note, with longer pipes producing lower notes. The flutist produces different notes by pressing keys to expose openings in the instrument that, in effect, change its length.

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2. **In a wind instrument, the wood or material of the instrument vibrates itself.** As students blow into or across different straws, bottles, or test tubes and make reed instruments, they learn how internal columns of air vibrate as air molecules are displaced, and that it is not the wood or material of the instrument that is vibrating.
3. **Diffraction—the bending of waves around corners.** This concept is introduced in this section but is not difficult for students to address when they are studying sound or when they are talking about the transmission of sound waves because they "hear" sounds in other rooms and know that sound must travel around corners, under openings, and through materials in order to reach their ears. Diffraction of light is more difficult and conflicts students' prior conceptions of light traveling in straight lines rather than bending around corners.
4. **Air, which is always circulating and traveling, brings the sound from the origin to the ears.** Only through inquiry and building models for the generation and transmission of compression waves will students alter their naïve conceptions that individual molecules of sound travel from the instrument or object making sound to the listening ear.

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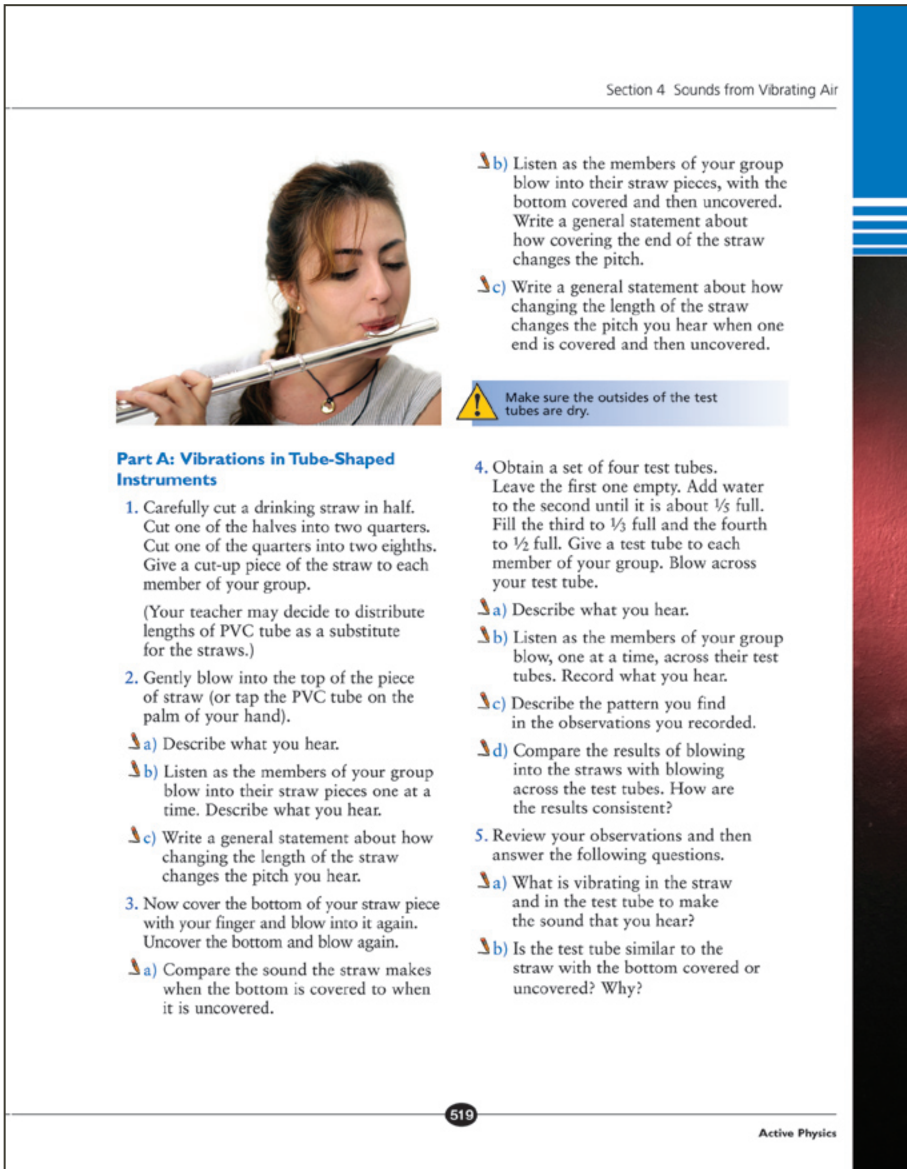


Part A: Vibrations in Tube-Shaped Instruments

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?

Investigate

Part A: Vibrations in Tube-Shaped Instruments

1.

Students cut straws into different lengths.

2.

Students blow into the top of the piece of straw.

2.a)

A faint tone is produced.

2.b)

A faint tone is produced.

2.c)

The shorter the straw, the higher the pitch.

3.a)

When the bottom of the straw is covered, the pitch is much lower than when both ends are open. It is also usually louder.

Teaching Tip

If blowing into the PVC tubes with the ends uncovered does not produce a satisfactory sound, the tubes can also be tapped on the palm and then pulled away immediately to hear the difference between an open and a closed tube's resonance. A closed tube's resonance can be produced by tapping the tube on the palm and keeping it in place.

3.b)

Covering the end of the straw lowers the pitch of the sound produced.

3.c)

In general, the shorter the straw, the higher the pitch. The pitch is lower when the end of the straw is covered, compared to the pitch when the end of the straw is uncovered. In fact, the frequency should double when the straw is uncovered.

4.a)

A faint tone is heard similar to when the students blow into the straws.

4.b)

The student listening should record that as the other students blow across the test tubes, the one blowing across the shortest air column has the highest pitch, and the pitch decreases as the length of the air column increases.

4.c)

The shorter the air space in the tube, the higher the pitch.

4.d)

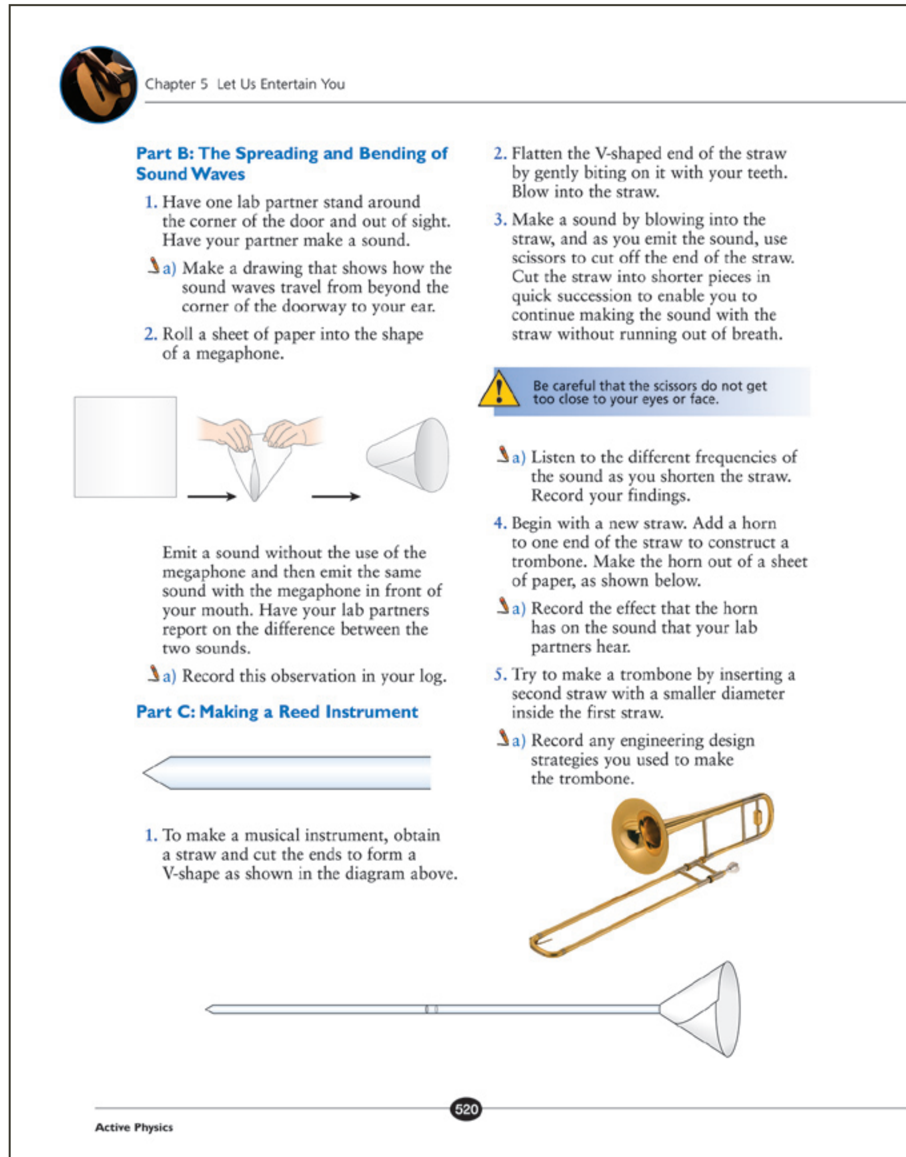
The tone produced by students blowing into the closed-end straws is similar to the one produced when they blow across the test tubes. If the straw and the test tube have an air column of the same length, the frequencies should be just about the same. The different widths of the tubes will cause a slight difference in the frequency.

5.a)

The air molecules in the straws are vibrating.

5.b)

The test tube is similar to the straw with the bottom covered because the test tube only has one opening.



Chapter 5 Let Us Entertain You

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.

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Part B: The Spreading and Bending of Sound Waves

1.a)

Students' drawings will vary. Some may show sound waves reflecting off surfaces, while others may show the sound waves bending around the corner.

2.a)

Students should notice that the sound is louder when a megaphone is used in contrast to when it is not used. Students record this observation in their logs.

Part C: Making a Reed Instrument

1.–2.

Students make a musical instrument from the straw and blow into it.

3.a)

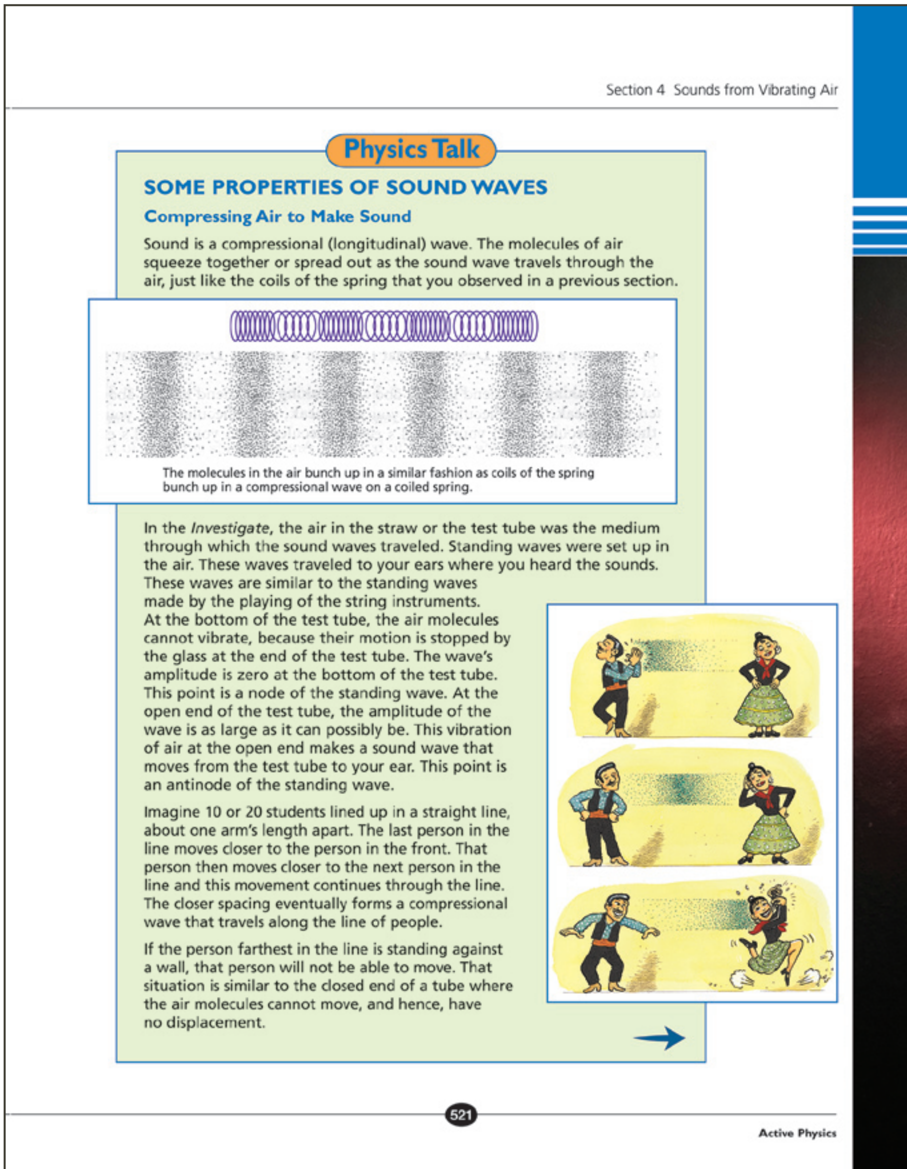
As the straw is shortened, the pitch produced by the straw increases.

4.a)

Adding the horn to the straw makes the sound louder similar to using a megaphone.

5.a)

Students should try various combinations of straws to make the trombone. Some may want to slit the straw lengthwise to fit one straw over the other. Others may try to find straws of different diameters.


Section 4 Sounds from Vibrating Air

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.

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Physics Talk

Students read that sound is produced by air molecules that are compressed to make a longitudinal wave, much like the compressed coils of a spring. To illustrate the concept of wave motion, tell students that the standing waves were set up in the air inside a straw or test tube, similar to the standing waves made by plucking a string or those formed on a vibrating spring. Students should note that sound waves are a series of compressions and rarefactions of vibrating air molecules that travel through a medium. The compressions and rarefactions of the air are similar to the crests and troughs of a transverse wave.

Ask students how sound travels to their ears when they blow into a straw or across a test tube. Ask them why a standing sound wave is produced when they blow into a test tube, where the displacement is the largest in a tube, and where it is the least. Have them support their explanations with drawings in their *Active Physics* logs. Initiate a class discussion on the properties of sound waves, encouraging students to share their responses.

Reading about the formation of sound waves in air provides an easy transition for students into the concept of wave diffraction. Refer to the investigation where a megaphone is used to see how sound gets louder, and discuss how sound is projected; why smaller openings produce greater diffraction than a large opening. You might want to ask students how using a megaphone increases the volume of the sound produced. Point out that the diffraction of a sound wave leaving a person's mouth is much greater than when a megaphone is used, concentrating the sound in the forward direction. Ask students to carefully study the diagrams in their textbook.

The *Physics Talk* is pivotal in explaining the experiments in the *Investigate*. Students discuss the connections of what they read in this section to the *Investigate*, as they progress in their understanding of sound waves. Point out that drawings of the sound waves are shown as transverse waves to give a visual description of how waves behave when they are in an open-ended or closed-end instrument, and how they behave when their movement is blocked from one end. While studying the movement of air in vibrating

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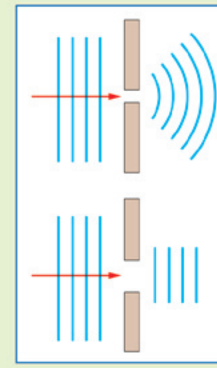
columns, students should distinguish the pattern of sound waves formed when both ends of a tube are open from the pattern of sound waves formed when only one end of the tube is open. Consider asking students what effect the decrease in wavelength for an open-ended tube has on the pitch when the wave speed stays the same. Have students explain their answers using their knowledge of the wave equation.

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.

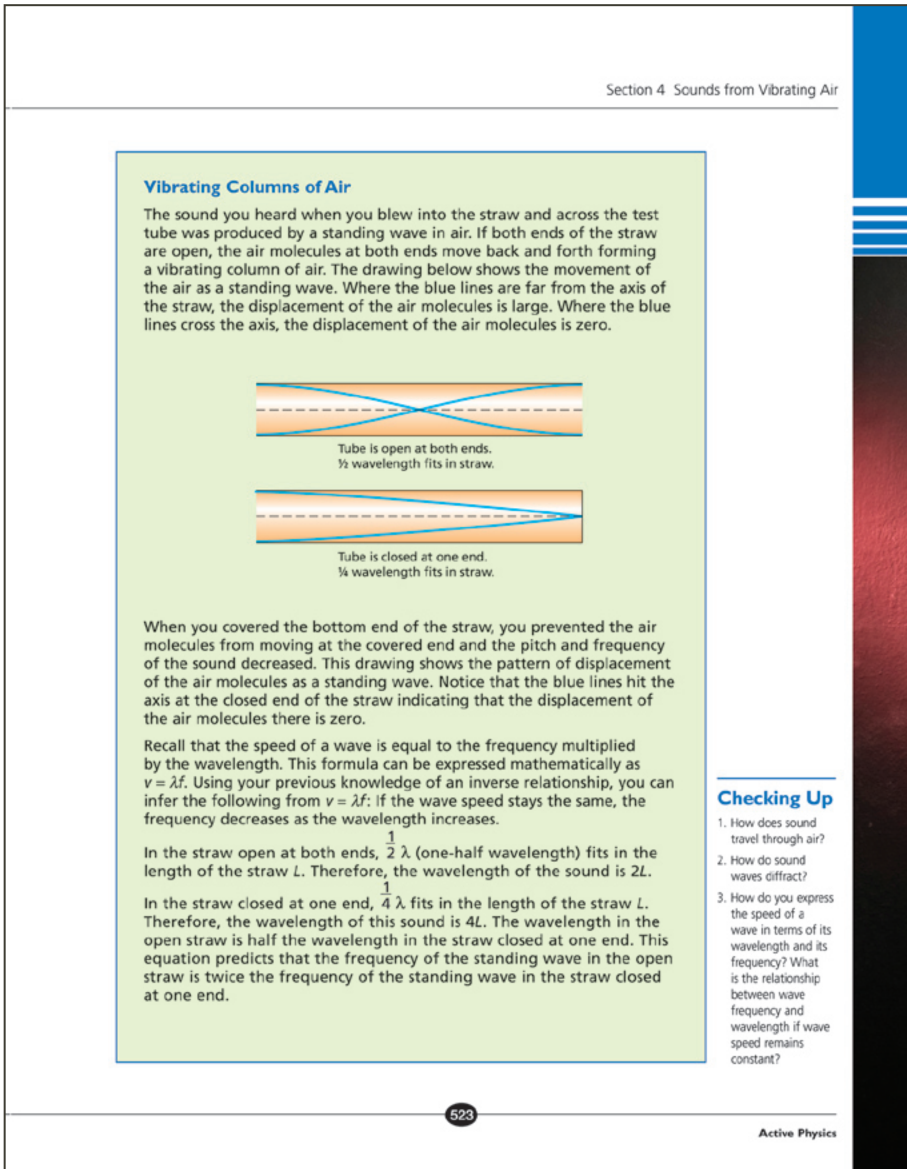
This ability of sound waves to spread out or change direction as they emerge from an opening is called **diffraction.** The smaller the opening, the more the sound waves diffract. The diffraction of the sound waves as they emerge from two openings can be shown with a diagram.

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

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 that 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.



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?

5-4a **Blackline Master**

Checking Up

1.

Sound travels through air in compressional waves. The molecules squeeze together and then spread out to produce a vibration that is heard as sound.

2.

When sound waves spread out from smaller openings or change direction they undergo diffraction.

3.

The speed of a wave is equal to the frequency multiplied by its wavelength. If wave speed remains constant and wavelength increases, the frequency will decrease.

Active Physics Plus

This *Active Physics Plus* explores how wave diffraction becomes important when the size of an opening is about the same size or smaller than the wavelength of waves. Students calculate the wavelength of sound at different frequencies. Discuss the results of students' calculations and how they interpret their answers in relation to the physics of diffraction.

1.a)

The wavelength of the sound wave can be calculated from the relationship among wave speed, wave frequency, and wavelength $\lambda = v/f$ with v = 340 m/s (sound in air) and f = 440 Hz (middle A). The result is $\lambda = 0.77$ m.

1.b)

You would expect significant diffraction when the opening size is about the same or smaller than the wavelength. Thus, a significant diffraction is expected for an open door or an open window, but not for a garage door opening.

2.

Given the velocity of sound in air as 340 m/s, using the equation $v = f\lambda$ and solving for λ gives

a) $\lambda = v/f$ or
$\lambda = (340\ \text{m/s})/(22\ \text{Hz}) = 15$ m.

b) $\lambda = v/f$ or
$\lambda = (340\ \text{m/s})/(220\ \text{Hz}) = 1.6$ m.

c) $\lambda = v/f$ or
$\lambda = (340\ \text{m/s})/(880\ \text{Hz}) = 0.39$ m.

d) $\lambda = v/f$ or
$\lambda = (340\ \text{m/s})/(8800\ \text{Hz}) = 0.04$ m.

Chapter 5 Let Us Entertain You

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?

clarinet oboe bassoon trumpet

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Active Physics

What Do You Think Now?

Share *A Physicist's Response* with your class and ask them to refer to their previous responses to the *What Do You Think*? question so that they can modify or change their answers in their *Active Physics* log. Students should be able to describe how the pitch of the sound produced depends on the length of the vibrating column of air in a flute and in a organ pipe. Emphasize that in a flute, the length of the vibrating column of air is controlled by the holes that are closed by the fingers.

Section 4 Sounds from Vibrating Air

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.

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Reflecting on the Section and the Challenge

Students should be able to reflect on how they can use their findings in the *Investigate* to build instruments that improve the quality of sound. Emphasize the connection between wavelength and pitch and discuss how they affect the sound produced by an instrument.

Ask students to read this section aloud and have them pause at intervals where you may want to elaborate on the meaning of a key idea. This strategy should help them focus on what they have learned so far. Now students have the opportunity to plan how they would want their instruments to work for their sound and light show.

CHAPTER 5

Physics Essential Questions

What does it mean?

In a tube, the standing wave is set up in air. At some of the positions of the air called nodes, the air does not move back and forth. These nodes occur at a closed end of a tube. In a tube open at both ends, the ends are both antinodes. This is in contrast to a string, where the ends of the string are nodes.

How do you know?

The pitch of the sound is dependent on the length of the tube. As observed, the longer the tube, the lower the frequency. A tube open at both ends has a higher frequency than a tube which is closed at one end, as students observed in the *Investigate.*

Why do you believe?

In both strings and tubes, a standing wave is set up which has nodes and antinodes. The longer the string/tube, the lower the frequency. The ends of a string are nodes while the ends of open tubes are antinodes. Strings vibrate as transverse waves while tubes have air vibrating as a compressional (longitudinal) wave.

Why should you care?

Musical instruments like bugles and trumpets as well as those from reed instruments such as oboes and saxophones all create sounds from vibrating air. When you blow across a soda bottle, you also hear sounds from the vibrating air column.

Physics to Go

1.a)

The string is vibrating, and the air in the pipe is also vibrating.

1.b)

The string vibration is transverse, and the air vibration is compressional.

2.a)-b)

Students' drawing should be similar to the drawings toward the end of the *Physics Talk* in the *Student Edition*.

2.c)

If you double the length of the tube, you cut the frequency it produces in half. When both ends are open, the frequency will be twice as high as when one end is closed.

2.d)

There should be reasonably good agreement.

3.a)

11 m (This depends on the organ.)

3.b)

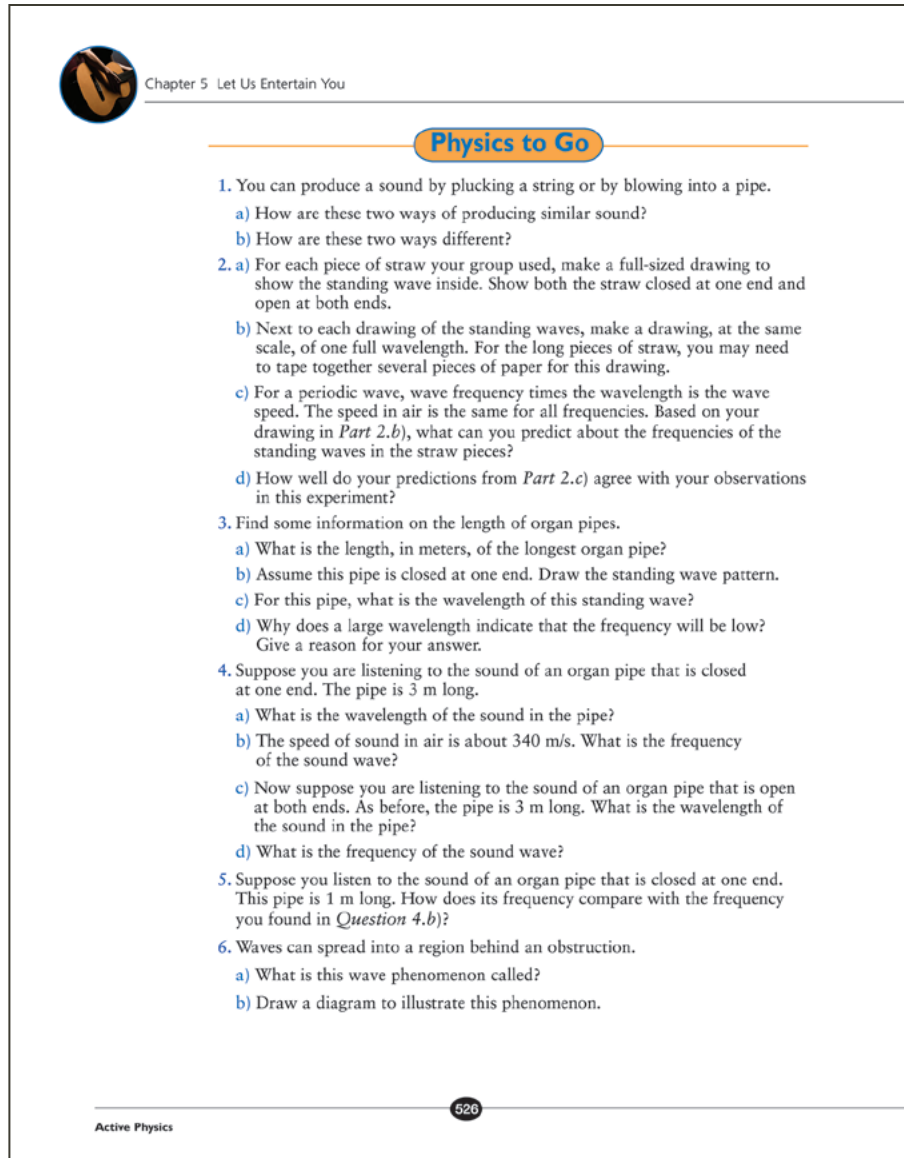
Students' drawing should be similar to the second drawing from the top featured toward the end of the *Physics Talk* in the *Student Edition*.

3.c)

The wavelength of the standing wave is $4 \times 11 \text{ m} = 44 \text{ m}$.

3.d)

The speed of sound is nearly independent of the wavelength. But the product of wavelength and frequency equals speed, so this product is a constant. Thus, a longer wavelength means a lower frequency.



Chapter 5 Let Us Entertain You

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.

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4.a)

$\lambda = 4 \times 3 \text{ m} = 12 \text{ m}$.

4.b)

$f = v/\lambda =$
$(340 \text{ m/s})/(12 \text{ m}) = 28 \text{ Hz}$.

4.c)

$2 \times 3 \text{ m} = 6 \text{ m}$.

4.d)

$f = (340 \text{ m/s})/(6 \text{ m}) = 57 \text{ Hz}$.

5.

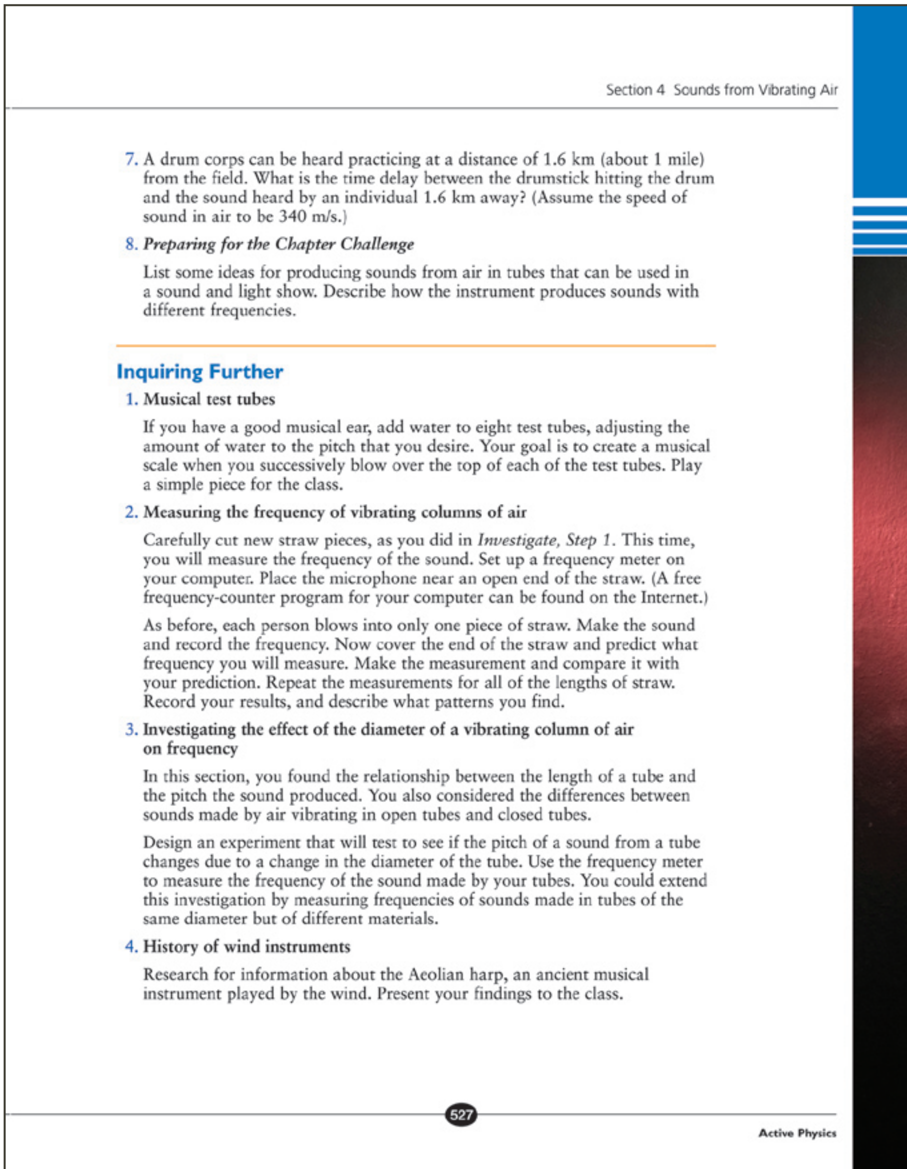
The frequency is three times higher.

6.a)

The spreading of waves into a region behind an obstruction is called diffraction.

6.b)

Students draw a diagram similar to the one in the *Investigate*.



Section 4 Sounds from Vibrating Air

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.

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Active Physics

7.

Because speed is distance traveled divided by the time elapsed, time elapsed equals the distance traveled divided by the speed.

For the numbers given, the time elapsed = 1600 m/340 m/s = 4.7 s. (Note that 1.6 km is about one mile. You might recall the way of estimating the distance of a lightning strike: when you see the lightning, count the number of seconds until you hear the thunder. Then divide the number of seconds by 5 to get the distance in miles.)

8.

Preparing for the Chapter Challenge

Wind instruments produce different frequencies by changing the length of the air column that is vibrating in the tube. This is done by opening and closing holes along the length of the tube for some instruments, or increasing the tube length in some brass instruments.

Inquiring Further

1. Musical test tubes

Students could try the following lengths for a major scale.

11 cm
9.8 cm
8.8 cm
8.3 cm
7.4 cm
6.6 cm
5.9 cm
5.5 cm

2. Measuring the frequency of vibrating columns of air

Use the same microphone and computer setup used in *Section 3, Inquiring Further*. Students should see that the frequency is halved when the end of the straw is covered.

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

Use the same microphone and computer setup used above. The students should try different diameter tubes all of the same length. PVC tube comes in ½, ¾, and 1-inch diameters as well as larger ones that may be used by students.

4. History of wind instruments

Students research information on the Aeolian harp and present their findings to the class.

CHAPTER 5

SECTION 4 QUIZ

5-4b **Blackline Master**

1. A student makes an instrument by placing a smaller drinking straw inside a larger one so the length of the tube can be changed. As the length of the combined straws is increased, what happens to the frequency and wavelength of the sound produced when the student blows into the straw?

   a) The frequency and wavelength both increase.

   b) The frequency and wavelength both decrease.

   c) The frequency increases and the wavelength decreases.

   d) The frequency decreases and the wavelength increases.

2. A students blows over a straw that is open at both ends. If the wavelength of the note produced was 30 cm, how long was the straw?

   a) 30 cm. b) 15 cm.

   c) 60 cm. d) 7.5 cm.

3. A student blows over a straw that is open at both ends and notes the pitch of the sound produced. She then covers the bottom of the straw with her hand and blows over the straw again. Compared to the pitch produced with the straw open at both ends, the pitch produced this time will be

   a) higher. b) lower. c) the same.

4. The diagram to the right shows waves passing through a small opening. As the size of the waves striking the opening decrease, the waves passing through the opening will

   

   a) become flatter and spread out less.

   b) become flatter and spread out more.

   c) become more curved and spread out less.

   d) become more curved and spread out more.

5. A student is blowing over a straw 25-cm long, which is closed at one end. If the sound produced has a wavelength of 350 Hz, what is the speed of sound in the straw?

   a) 87.5 m/s. b) 175 m/s.

   c) 1400 m/s. d) 350 m/s.

SECTION 4 QUIZ ANSWERS

1. d) Increasing the length of the tube increases the length of the vibrating air column, increasing the wavelength and decreasing the frequency (since the wave speed remains the same).

2. b) An open-ended tube produces a standing wave that equals $\frac{1}{2}$ the wavelength of the sound produced. If the wavelength is 30 cm, then $\frac{1}{2}$(30 cm) = 15 cm. Choice *a)* is just the wavelength of the sound, choice *c)* is double the wavelength rather than $\frac{1}{2}$, and choice *d)* is $\frac{1}{4}$ the wavelength, which would be correct for a closed-end tube.

3. b) Closing the bottom of the tube changes the standing wave from $\frac{1}{2}$ wavelength to $\frac{1}{4}$ wavelength. For the closed tube this means the wavelength is now 4 times the tube length, rather than double. Because the wavelength has increased, the frequency will decrease since the wave speed is constant.

4. a) The degree of diffraction depends upon the ratio of opening size to wavelength of the waves passing through. The larger the ratio, the less diffraction occurs and the less curved the wave front becomes, ruling out choices *c)* and *d)*. Since decreasing the wavelength means less diffraction, less spreading occurs, ruling out choice *b)*. Therefore, the waves spread less and will appear flatter as they move through the opening.

5. d) A closed tube vibrates at $\frac{1}{4}$ wavelength, so that the wave produced is 4 times the tube length or 4(0.25 m) = 1 m. The wave speed then is found by using the equation $v = f\lambda$ or v = (350 Hz)(1 m) = 350 m/s.

CHAPTER 5