SECTION 1

Sounds in Vibrating Strings

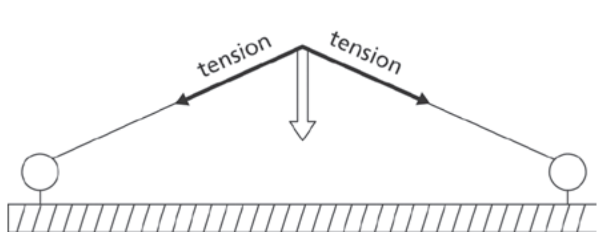
Section Overview

Students begin the study of sound and musical instruments by investigating two variables—tension and length—that determine the sounds made by a vibrating string. They hang a weight on the end of the string to set the tension. With the tension fixed, they vary the length of the string and observe the pitch produced. Then with the length fixed, students vary the tension and again observe the pitch. They make general statements about the effect of changes in string length and tension. Finally, in *Inquiring Further*, they design an experiment to test how varying the thickness of a string affects its pitch.

Background Information

Sound is a wave phenomenon produced by vibrating materials. The vibrations cause your eardrums to vibrate. Most often the vibrations travel from a vibrating object like a guitar string through the air to your ears. In *Section 1*, students explore how the vibrations of a string are related to their perception of the pitch of a sound.

A tensioned string can produce vibrations. When a string is pulled back and released, the tension in the string accelerates the string back toward its equilibrium position, as shown in the drawing below.



The speed with which a wave pulse travels along a string is determined by the tension in the string and the string's mass per unit length. The tension is the force that the rest of the string exerts on any segment of the string. When a part of the string is pulled to the side away from its equilibrium position, the restoring force on that part is equal to the sum of the two components of the tension that are perpendicular to the undisturbed string. The larger the tension, the larger the restoring force, hence, the more rapidly the string will accelerate back toward the equilibrium position.

The mass per unit length is also important due to the string's inertia. The higher the mass per unit length the larger the inertia, and the more slowly the disturbed part of the string will accelerate back toward equilibrium, thereby lowering the wave speed.

When the string is tied at both ends, standing wave patterns on the string can be set up if the length of the string has the appropriate relationship to the wavelength of the wave. Since the speed of a wave is determined by the tension in the string and the mass per unit length, the right frequency for "shaking" the string must be chosen to set up a standing wave pattern of a given wavelength.

The mass per unit length of the string (although students do not investigate it in this section) also affects the possible standing wave frequencies through the wave speed. Take a look at piano strings or guitar strings. The bass strings of a piano are much more heavily wound than the mid-range or treble strings. In a nylon-string guitar, the base strings are wound with metal wire, and the lower the pitch produced by the string, the heavier the wire. The larger the mass per unit length of the string, the less it responds to the tension that pulls it back toward the equilibrium position. The larger the mass per unit length, the lower the frequency for a given tension and wavelength.

Crucial Physics

- The pitch of a sound corresponds to the frequency of vibration of the object producing the sound. The higher the pitch, the higher is the frequency.
- Decreasing the length of a vibrating string increases its vibration frequency (if the tension in the string stays the same).
- Increasing the tension in a string increases its frequency of vibration (if its length stays the same).

Learning Outcomes	Location in the Section	Evidence of Understanding
Observe the effect of string length on the pitch of the sound produced.	***Investigate*** Step 4	Students vary the length of a vibrating string to observe a difference in the pitch of the sound produced.
Observe the effect of tension on the pitch of the sound produced.	***Investigate*** Steps 5 and 6	Students increase tension by adding another 500-g weight attached to a string. Students will move a pulley over and observe the effect on the pitch of the sound produced.
Control the variables of tension and length.	***Investigate*** Steps 3–6	Students can predict the pitch increases when the tension is increased or length decreased.
Summarize experimental results.	***Investigate*** Steps 4.b) and 6.b)	Students write a general statement indicating that the pitch increases with decreasing length and increasing tension.

NOTES

Section 1 Materials, Preparation, and Safety

Materials and Equipment

PLAN A		
Materials and Equipment	**Group (4 students)**	**Class**
Meter sticks	1 per group	
3" C-clamp	1 per group	
500-g weight with hook	4 per group	
Pulley with mount	1 per group	
Safety glasses, impact	4 per group	
Styrene-foam cup, 12 ounces	2 per group	
Scissors	1 per group	
Fishing line - 30 lb test (55 yards)	1 per group	
Large area clear of obstructions*	1 per group	

*Additional items needed not supplied

Time Requirement

- Allow one class period or 45 minutes for the *Investigate* and other parts of the section as indicated in the *Pacing Guide*.

Teacher Preparation

- Assemble the required material and set up the *Investigate* in advance to find out how long the string must be.
- Use nylon monofilament rated at least 15-lb test. Cut the string in advance, and be sure the string is long enough to drape over the pulley and tied to the mass hanger.

Safety Requirements

- Students must wear safety goggles for this section's *Investigate*.
- The masses attached to the string that hang over the pulley may fall to the floor if dislodged or if the string breaks. Make certain students do not have their feet underneath the masses. Placing a soft pad on the floor beneath the masses will also prevent damage to the floor if the masses fall.
- If monofilament line is used, be aware that this line may be difficult to tie to a mass or mass hanger. Students should knot the line several times for safety.
- Test the string prior to students completing the *Investigate* to ensure that the string is capable of handling the required tension with a safety margin of a factor of two.

Materials and Equipment

PLAN B		
Materials and Equipment	**Group (4 students)**	**Class**
Meter sticks	1 per group	
3″ C-clamp	1 per group	
500-g weight with hook	4 per group	
Pulley with mount	1 per group	
Safety glasses, impact	4 per group	
Styrene-foam cup, 12 ounces	2 per group	
Scissors	1 per group	
Fishing line - 30 lb test (55 yards)	1 per group	
Large area clear of obstructions*	1 per group	

*Additional items needed not supplied

Time Requirement

- Allow one class period or 45 minutes for the *Investigate* and other parts of the section as indicated in the *Pacing Guide*.

Teacher Preparation

- Assemble the required material and set up the *Investigate* in advance to find out how long the string must be.
- Use nylon monofilament rated at least 15-lb test. Cut the string in advance, and be sure the string is long enough to drape over the pulley and tied to the mass hanger.

Safety Requirements

- Students must wear safety goggles for this section's *Investigate*.
- The masses attached to the string that hang over the pulley may fall to the floor if dislodged or if the string breaks. Make certain students do not have their feet underneath the masses. Placing a soft pad on the floor beneath the masses will also prevent damage to the floor if the masses fall.
- If monofilament line is used, be aware that this line may be difficult to tie to a mass or mass hanger. Students should knot the line several times for safety.
- Test the string prior to students completing the *Investigate* to ensure that the string is capable of handling the required tension with a safety margin of a factor of two.

Meeting the Needs of All Students

Differentiated Instruction: Augmentation and Accommodations

Learning Issue	Reference	Augmentation and Accommodations
Understanding the purpose of an *Investigate*	***Learning Outcomes***	**Augmentation** • Students often complete an *Investigate* as a discrete item that is not connected to a common goal. This makes it much more difficult to analyze results, draw conclusions, and make meaning from new learning. Explicitly review the *Learning Outcomes* at the beginning of each section to set a purpose and make students aware of the big picture.
Differentiating high, medium, and low pitch	***Investigate*** Steps 3, 4, 5, and 6	**Augmentation** • Students with auditory discrimination issues may not be able to qualitatively discriminate differences in pitch. Provide examples for students to use as a reference for comparison. For example, students might have three different tuning forks that they could use for comparison. Students could also practice making high, medium, and low pitch sounds with their own voices to use for comparison. **Accommodation** • Students with more severe hearing issues should be paired with a student who can easily discriminate the sounds and can describe the differences with words.
Creating an expanded table from a model	***Investigate*** Steps 3.a) and 6.a)	**Augmentation** • Instruct students to use an entire page in their logs and orient the notebook to portrait format to create these tables. Instruct students to divide the page in half horizontally and use the top half for one table and the bottom half for the other table. Students should then draw two vertical lines to divide the page into three columns. Depending on the number of trials that are required, students should then mark off their rows using the lines on the page to assist with this task. • Provide a visual model of the tables as the instructions are given. **Accommodation** • Provide a blank table for students to tape into their logs and complete.
Comparing instruments	***Checking Up*** ***Physics Essential Questions*** ***Physics to Go***	**Augmentation** • Students may not have the background experience to visualize a variety of musical instruments. Provide real-life instruments or pictures of instruments for students to compare.

Strategies for Students with Limited English-Language Proficiency

Learning Issue	Reference	Augmentation
Vocabulary comprehension	***Investigate***	Students may not be familiar with the term "plucking." Demonstrate the plucking action on a rubber band pulled taut between two fingers. Point out that the back-and-forth motion of the rubber band is a "vibration." Help students comprehend "pitch" by saying "high" in a high-pitched voice and "low" in a low-pitched voice.
Using parts of speech	***Investigate*** Step 4.a)	Concerning "relative pitches," it is not enough for students to know that a pitch is "high" or "low." Sometimes they will need to compare how high or how low the pitches are. Explain to students that to make the comparisons, they start first with the basic adjective (high, for example), then add the comparative form (higher), and finally, if needed, the superlative form (highest).
Connecting concepts connections	***Investigate*** Step 6.b)	To help students connect the information in this section to what they learned in *Chapter 2*, ask them to use the word "force" to explain what adding mass to the mass hanger does to the string. (It increases the pulling force.)
Vocabulary comprehension Understanding concepts	***Physics Talk***	Review the word "variable." Tell students the root of the word "variable" is "vary," which means "to change." A variable in an experiment is anything that can be changed, such as the mass on the string or the length of the string. To study the effect of a variable, scientists change only one variable at a time in their experiments.
Vocabulary comprehension Understanding concepts	***Active Physics Plus***	The word "density" appears a couple of times in this section. Students have not yet encountered the term in this physics program. For purposes here, it is sufficient that they understand that density is the ratio of the mass of the string to the length of the string (mass/length). Be sure students do not confuse mass "of" the string with mass "on" the string (the mass weights).

Midway through the *Investigate*, students are asked to "make a general statement about what happens to the pitch you hear as you change the length of the vibrating string." They are being asked to construct a cause-and-effect relationship between pitch and length of string. One way for students to identify and remember relationships among variables is to make a cause-and-effect chart.

Have students copy the following table and fill it in with the relationships they discover as they work through the *Investigate*. To help them fully understand the relationships, have them record each relationship and its opposite. For example, increasing string length lowers pitch, while decreasing string length raises pitch.

Cause	Effect
Increasing string length	
Decreasing string length	
Increasing tension	
Decreasing tension	

Once students have filled in the cause-and-effect table using the language in the book, have them create another table to give the same information, only this time using their own words. Students may say, for example, "a longer string makes a lower pitch" rather than "increasing string length decreases pitch," the terminology used in the book.

SECTION 1

Teacher Suggestions and Sample Answers

What Do You See?

The *What Do You See?* illustration provides a range of possible interpretations that will further students' curiosity. Pick an image from this visual and ask students to respond to what the illustrator is trying to show. Prompt them to discuss this illustration in relation to *Sounds in Vibrating Strings*. It is important for students to begin with an engaging discussion as this will set this section up prior to the *Investigate*.

Chapter 5 Let Us Entertain You

Section 1 Sounds in Vibrating Strings

What Do You See?

Learning Outcomes

In this section, you will

- **Observe** the effect of string length on the pitch of the sound produced.
- **Observe** the effect of tension on the pitch of the sound produced.
- **Control** the variables of tension and length.
- **Summarize** experimental results.

What Do You Think?

When the ancient Greeks made string musical instruments, they discovered that cutting the length of the string by half or two-thirds produced other pleasing sounds.

- **How do guitarists or violinists today make different sounds?**
- **If someone were pretending to play a guitar (for example, the air guitar), how would the player position his or her fingers to make the highest pitch notes?**

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

Investigate

In this section, you will make sounds by plucking a string. You will first investigate how the length of the string affects the pitch (how high or low the note is) of the sound produced, and then how the tension in the string affects the pitch. The following steps will guide you in setting up the equipment and changing the length and tension of the string.

484

Students' Prior Conceptions

Students should "care about" the concepts explored in this section as they generally care deeply about music and the sources of musical sounds. This section should grab their attention because they discover the relationships between vibrations in materials and the transfer of the sounds created by these vibrations through space. As you lead students through this and other sections within the chapter, it is beneficial to keep a model of the *Engineering Design Cycle* handy and to encourage students to add *Inputs* continuously and process these *Inputs* with explanations.

1. **Sound is something that is carried by individual molecules through a medium; sound moves between particles of matter rather than through matter.** Carefully examine the language students use to describe what they observe to ensure they understand that sound vibrations establish wavelike disturbances that travel through air, away from the source like a cone of ever-increasing circular waves. Make certain that they understand that molecules of air carrying the sound are not traveling from the source of the sound to the ear.
2. **Loudness and pitch are confused with each other.** Students liken higher pitch to louder sounds. Examination of the pitch and frequency of vibrations that are both loud and soft enables students to "hear" and perhaps to "see" (if they can see the frequency of sounds with a computer or other device) that pitch and amplitude of a sound are two

What Do You Think?

You might want to start the *What Do You Think?* section by beginning with a general discussion on music. You will receive varied answers. These answers should lead to a stimulating discussion that actively engages students. Encourage them to continue answering even if they are uncertain about the validity of their answer. Emphasize that during this phase of learning, they should write down their answers in their *Active Physics* logs. Also make sure that all of them have a clear understanding of the questions.

What Do You Think?

A Physicist's Response

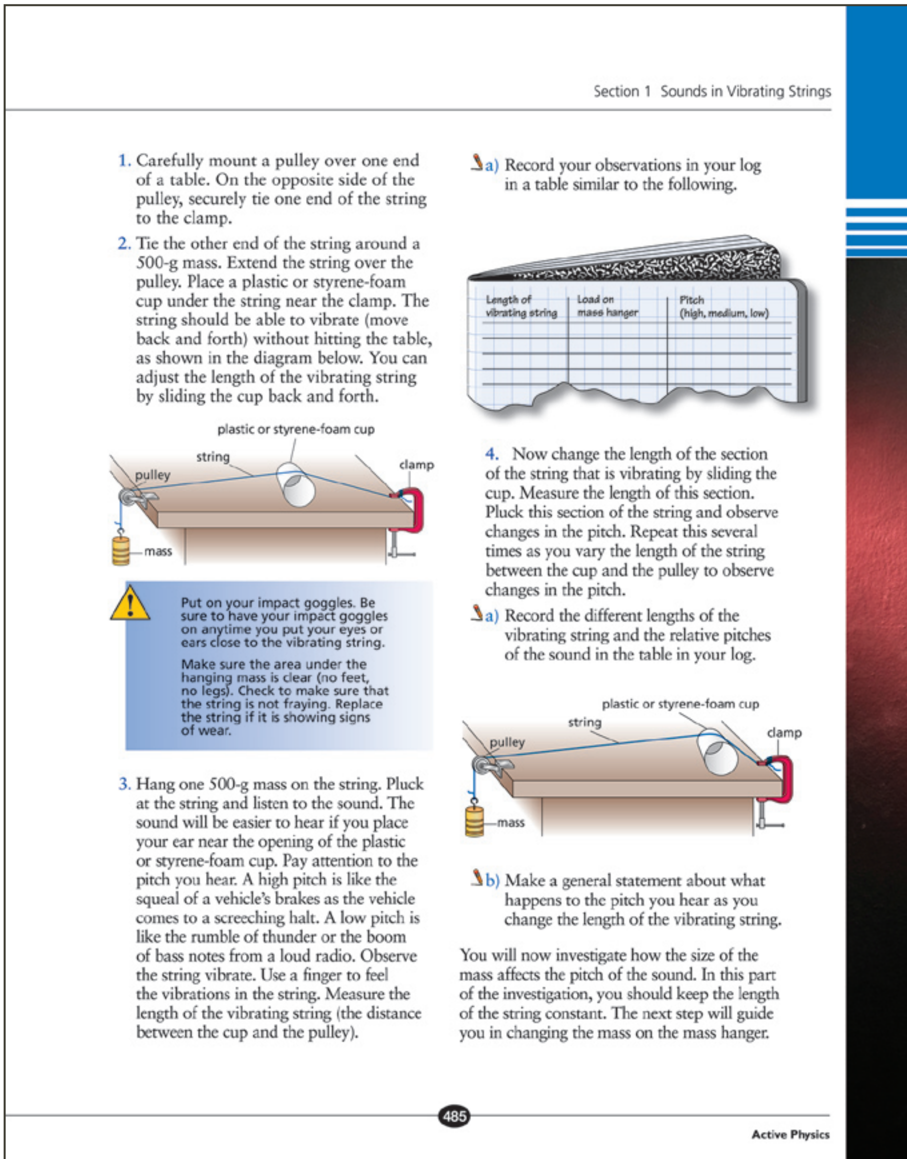
Both guitarists and violinists make different sounds but in similar ways. The player pushes the string against the neck of the instrument at different positions to play different notes. One significant difference is that the guitar has frets, thin metal strips that run across the neck, right under the strings. The guitarist pushes the string down against the fret, whereas the violinist must find the correct position to push the string down to make a particular note. In addition, each string is tuned to a different note, so each string has a different range. Guitarists and violinists tune their instruments by adjusting the tension in the strings. Guitarists turn knobs on the tuning machine, a set of gears that increase torque through mechanical advantage. The violinist turns pegs, which have larger knobs than those on the guitar but which are connected directly to the strings. The guitarist or violinist pushes on the string to make the vibrating length shorter to produce higher pitch notes. A video (with sound) of a guitar player might be helpful to observe this technique. When students play their "air guitars," they will probably move their hands toward the body of the guitar for high-pitch notes and away from the body of the guitar for low-pitch notes. When they move toward the body of the guitar, they would, with a real guitar, be shortening the length of vibrating string, leading to higher pitch notes.

CHAPTER 5

different concepts. Point out that you perceive sounds of some pitches to be better than others, making them appear louder, although they may have the same amplitude (loudness).

3. **The pitch of a tuning fork changes as the vibrations slow down; the tines of the fork run out of energy and stop vibrating.** Hands-on experience with vibrating tuning forks and listening to the sounds of these vibrations should help to root out this prior student conception. However, students may hear frequencies differently or not be able to discern changes in pitch with personal auditory functions. Provide simulations of sounds and their frequency identifications or their wavelike characteristics with tools that enable students to "see" the sameness of the pitch as the tines of a tuning fork slow down or students can "see" the diminishing of the amplitude of a wave form that has the same wavelength with the decreasing vibrations of the tuning fork. Students need to experience the loudness and softness of the same sound in some manner. If you do not have access to classroom tools for students to visualize these differences (for example, an oscilloscope with microphone input, or a computer program that emulates an oscilloscope), explore the many options available as "applets" or interactive tutorials with computer simulation.

NOTES



1. Carefully mount a pulley over one end of a table. On the opposite side of the pulley, securely tie one end of the string to the clamp.
2. Tie the other end of the string around a 500-g mass. Extend the string over the pulley. Place a plastic or styrene-foam cup under the string near the clamp. The string should be able to vibrate (move back and forth) without hitting the table, as shown in the diagram below. You can adjust the length of the vibrating string by sliding the cup back and forth.

Put on your impact goggles. Be sure to have your impact goggles on anytime you put your eyes or ears close to the vibrating string.

Make sure the area under the hanging mass is clear (no feet, no legs). Check to make sure that the string is not fraying. Replace the string if it is showing signs of wear.

3. Hang one 500-g mass on the string. Pluck at the string and listen to the sound. The sound will be easier to hear if you place your ear near the opening of the plastic or styrene-foam cup. Pay attention to the pitch you hear. A high pitch is like the squeal of a vehicle's brakes as the vehicle comes to a screeching halt. A low pitch is like the rumble of thunder or the boom of bass notes from a loud radio. Observe the string vibrate. Use a finger to feel the vibrations in the string. Measure the length of the vibrating string (the distance between the cup and the pulley).

a) Record your observations in your log in a table similar to the following.

Length of vibrating string	Load on mass hanger	Pitch (high, medium, low)

4. Now change the length of the section of the string that is vibrating by sliding the cup. Measure the length of this section. Pluck this section of the string and observe changes in the pitch. Repeat this several times as you vary the length of the string between the cup and the pulley to observe changes in the pitch.

a) Record the different lengths of the vibrating string and the relative pitches of the sound in the table in your log.

b) Make a general statement about what happens to the pitch you hear as you change the length of the vibrating string.

You will now investigate how the size of the mass affects the pitch of the sound. In this part of the investigation, you should keep the length of the string constant. The next step will guide you in changing the mass on the mass hanger.

Investigate

1.

Students set up equipment. Be sure the masses hang beyond the pulley but are not touching the floor.

Teaching Tip

A plastic coffee cup is preferable to a styrene-foam cup, due to the downward force on the string in subsequent portions of the investigation.

2.

Students should continue to set up the equipment. The edge of the box or cup upon which the string rests marks the end of the segment of string that can vibrate.

3.

If the strings of the various groups are the same material and length, the sounds will have the same pitch. Be sure that the students are measuring the length of the vibrating part of the string, not the length of the entire string.

3.a)

Students record their observations in their log.

4.a)

Students vary the length of the string and record their observations in their logs.

4.b)

The pitch becomes higher as the length of the vibrating part of the string gets shorter.

CHAPTER 5

5.

Students adjust the length of the string to the maximum value they used in *Step 4.a)*. The students should record the length of that part of the string that is vibrating, not the total length of the string.

5.a)

Students make a new table to record their data.

5.b)

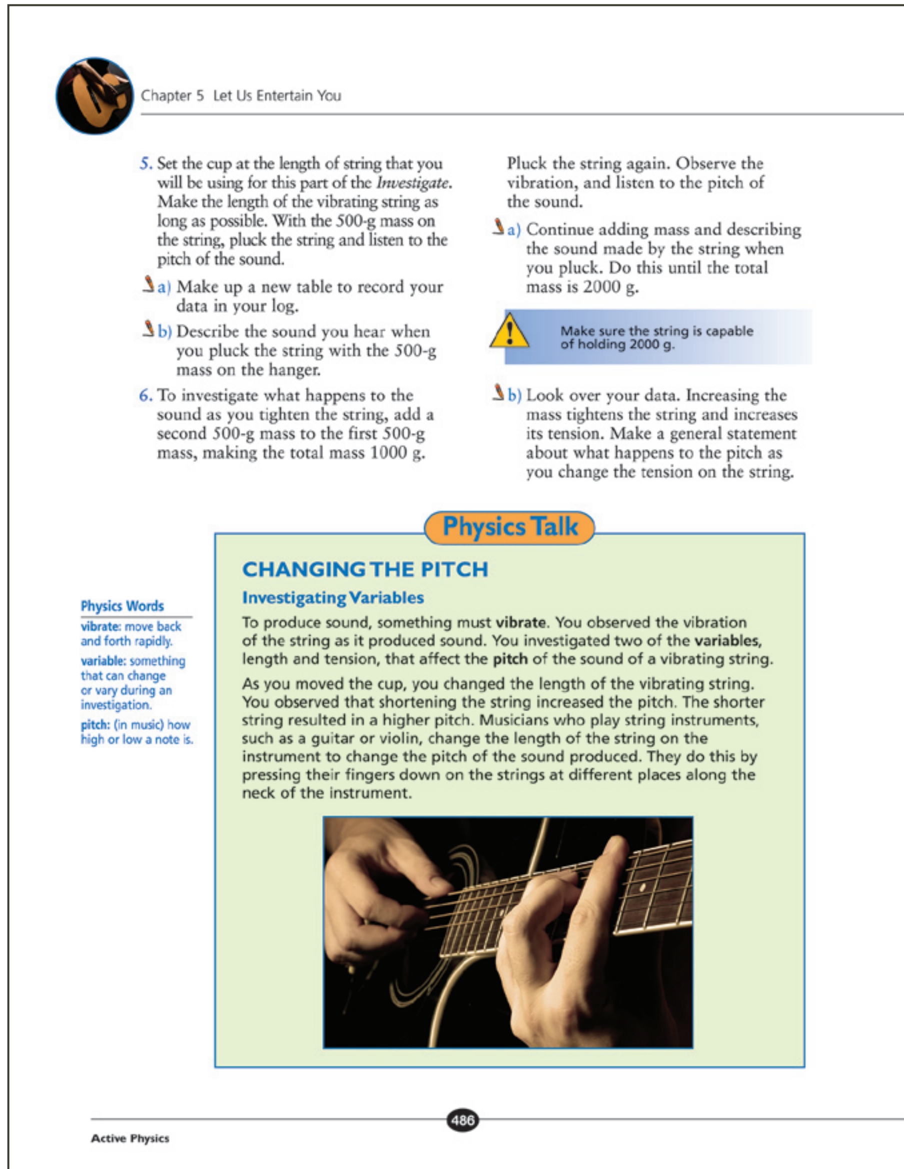
Students record their impression of the pitch at the longest length of the string. They should record this as the lowest pitch in their succeeding measurements.

6.a)

Students record the pitch. They should make sure that the length of the string remains constant.

6.b)

As the tension in the string is increased, the pitch of the vibrating string increases.



Chapter 5 Let Us Entertain You

5. Set the cup at the length of string that you will be using for this part of the *Investigate*. Make the length of the vibrating string as long as possible. With the 500-g mass on the string, pluck the string and listen to the pitch of the sound.

a) Make up a new table to record your data in your log.

b) Describe the sound you hear when you pluck the string with the 500-g mass on the hanger.

6. To investigate what happens to the sound as you tighten the string, add a second 500-g mass to the first 500-g mass, making the total mass 1000 g. Pluck the string again. Observe the vibration, and listen to the pitch of the sound.

a) Continue adding mass and describing the sound made by the string when you pluck. Do this until the total mass is 2000 g.

Make sure the string is capable of holding 2000 g.

b) Look over your data. Increasing the mass tightens the string and increases its tension. Make a general statement about what happens to the pitch as you change the tension on the string.

Physics Talk

CHANGING THE PITCH

Investigating Variables

To produce sound, something must **vibrate**. You observed the vibration of the string as it produced sound. You investigated two of the **variables**, length and tension, that affect the **pitch** of the sound of a vibrating string.

As you moved the cup, you changed the length of the vibrating string. You observed that shortening the string increased the pitch. The shorter string resulted in a higher pitch. Musicians who play string instruments, such as a guitar or violin, change the length of the string on the instrument to change the pitch of the sound produced. They do this by pressing their fingers down on the strings at different places along the neck of the instrument.

Physics Words

vibrate: move back and forth rapidly.

variable: something that can change or vary during an investigation.

pitch: (in music) how high or low a note is.

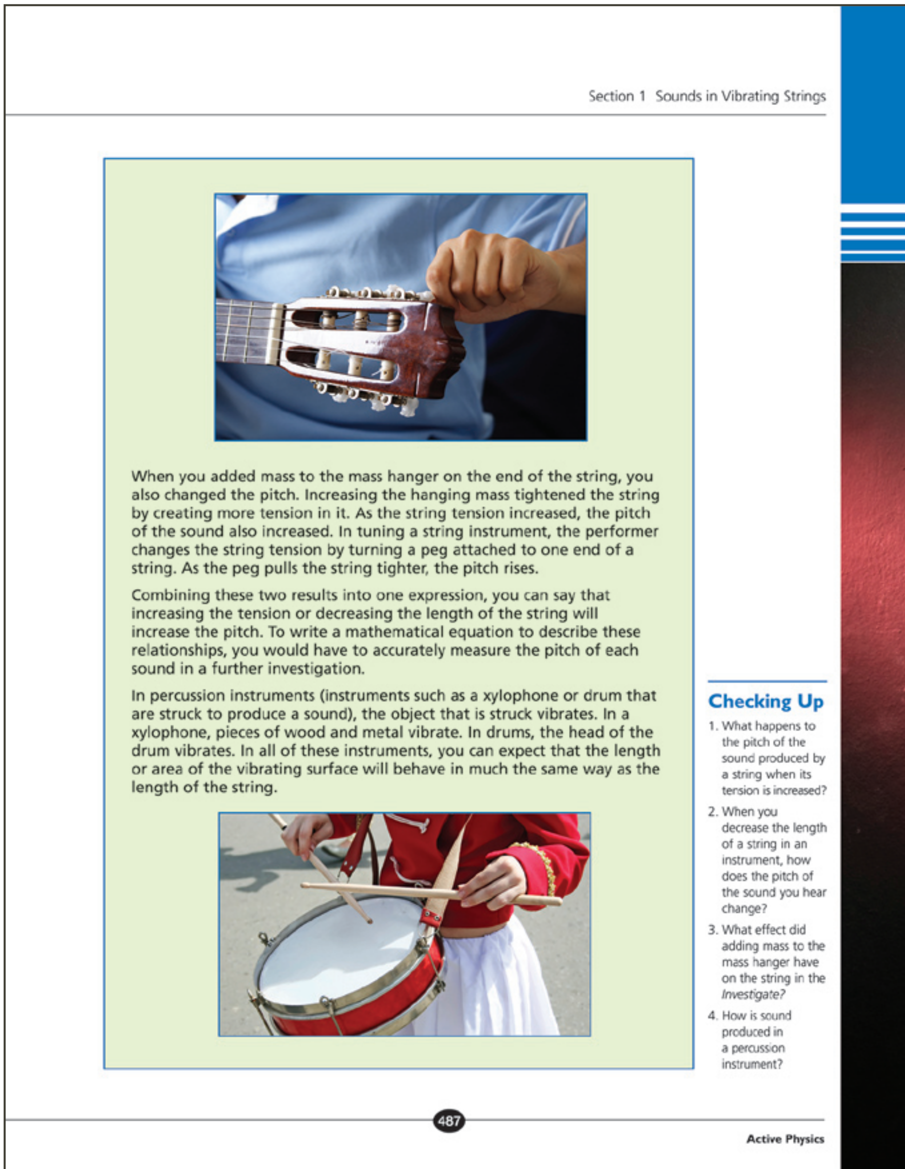
486

Active Physics

Physics Talk

The *Physics Talk* investigates variables that affect the pitch of a sound. It highlights the significance of observations made by students when they changed the length of the vibrating string or added mass to the mass hanger. It also compares a musicians' technique of playing string instruments to students' investigations to provide a concrete example that explains the concept of pitch.

As students read this section, continue to emphasize that the pitch produced by a string instrument depends on the variables of the string's length and mass. Similarly, with percussion instruments, the pitch depends on the area of the vibrating surface and its thickness. Consider asking students how the pitch of a sound is increased or decreased, and how a performer changes the string tension. You might want to ask your students if any of them play musical instruments. A student's knowledge of musical instruments can be used to liven up your class discussion. You will find many opportunities from a common experience of music and musical instruments to highlight the significance of variables that affect sound.



Section 1 Sounds in Vibrating Strings

When you added mass to the mass hanger on the end of the string, you also changed the pitch. Increasing the hanging mass tightened the string by creating more tension in it. As the string tension increased, the pitch of the sound also increased. In tuning a string instrument, the performer changes the string tension by turning a peg attached to one end of a string. As the peg pulls the string tighter, the pitch rises.

Combining these two results into one expression, you can say that increasing the tension or decreasing the length of the string will increase the pitch. To write a mathematical equation to describe these relationships, you would have to accurately measure the pitch of each sound in a further investigation.

In percussion instruments (instruments such as a xylophone or drum that are struck to produce a sound), the object that is struck vibrates. In a xylophone, pieces of wood and metal vibrate. In drums, the head of the drum vibrates. In all of these instruments, you can expect that the length or area of the vibrating surface will behave in much the same way as the length of the string.

Checking Up

1. What happens to the pitch of the sound produced by a string when its tension is increased?
2. When you decrease the length of a string in an instrument, how does the pitch of the sound you hear change?
3. What effect did adding mass to the mass hanger have on the string in the *Investigate*?
4. How is sound produced in a percussion instrument?

487

Active Physics

Checking Up

1.

The pitch of the sound increases in a string as its tension is increased.

2.

Decreasing the length of a string increases the pitch of the sound produced in an instrument.

3.

Adding the mass in the *Investigate* increased the tension on the string.

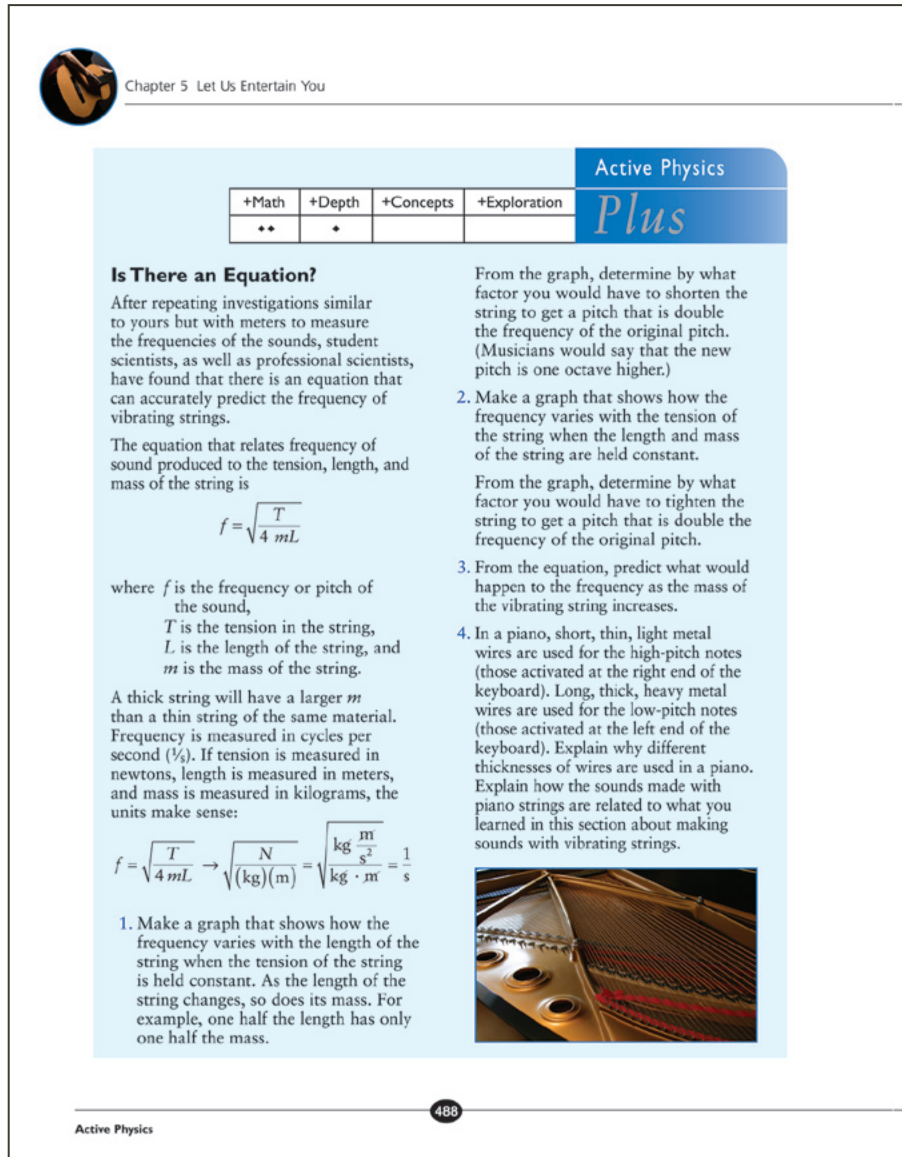
4.

In percussion instruments, the area of the vibrating surface responds to tension similar to a string.

CHAPTER 5

Active Physics Plus

For a given amount of tension and the same length, a light string (less mass per unit length) will vibrate at a higher frequency than a heavy string (more mass per unit length). A simple explanation: The tension is the restoring force that tends to pull the string back to its equilibrium (resting) position. If the string has more mass per unit length (a thicker or heavier string), the acceleration of a displaced piece of the string will be smaller and the time to move back toward the equilibrium position will be longer; hence, its vibration frequency (oscillations per second) will be lower.



Chapter 5 Let Us Entertain You

Active Physics Plus

+Math	+Depth	+Concepts	+Exploration
◆◆	◆		

Is There an Equation?

After repeating investigations similar to yours but with meters to measure the frequencies of the sounds, student scientists, as well as professional scientists, have found that there is an equation that can accurately predict the frequency of vibrating strings.

The equation that relates frequency of sound produced to the tension, length, and mass of the string is

$$f = \sqrt{\frac{T}{4\,mL}}$$

where f is the frequency or pitch of the sound,
T is the tension in the string,
L is the length of the string, and
m is the mass of the string.

A thick string will have a larger m than a thin string of the same material. Frequency is measured in cycles per second ($^1/_s$). If tension is measured in newtons, length is measured in meters, and mass is measured in kilograms, the units make sense:

$$f = \sqrt{\frac{T}{4\,mL}} \rightarrow \sqrt{\frac{\text{N}}{(\text{kg})(\text{m})}} = \sqrt{\frac{\text{kg}\,\frac{\text{m}}{\text{s}^2}}{\text{kg}\cdot\text{m}}} = \frac{1}{\text{s}}$$

1. Make a graph that shows how the frequency varies with the length of the string when the tension of the string is held constant. As the length of the string changes, so does its mass. For example, one half the length has only one half the mass.

   From the graph, determine by what factor you would have to shorten the string to get a pitch that is double the frequency of the original pitch. (Musicians would say that the new pitch is one octave higher.)

2. Make a graph that shows how the frequency varies with the tension of the string when the length and mass of the string are held constant.

   From the graph, determine by what factor you would have to tighten the string to get a pitch that is double the frequency of the original pitch.

3. From the equation, predict what would happen to the frequency as the mass of the vibrating string increases.

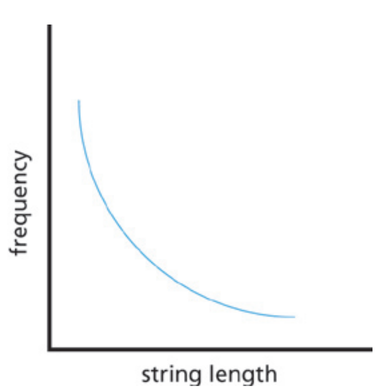
4. In a piano, short, thin, light metal wires are used for the high-pitch notes (those activated at the right end of the keyboard). Long, thick, heavy metal wires are used for the low-pitch notes (those activated at the left end of the keyboard). Explain why different thicknesses of wires are used in a piano. Explain how the sounds made with piano strings are related to what you learned in this section about making sounds with vibrating strings.

488

Active Physics

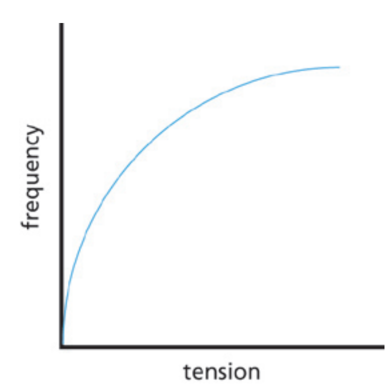
1.

The graph should appear similar to the one below. The graph should show that as the length of the string increases, the pitch decreases. Although the frequency should decline as one over the square root of the length, a simple inverse graph will indicate student understanding. Students will have to graph the data using values from the equation to answer this question, or employ the equation to answer it.



2.

The graph students sketch should appear similar to the one at the right. It should demonstrate that frequency increases with the square root of tension. Students will have to graph data using values from the equation to answer this question, or employ the equation to answer it.



3.

From the equation, as the string density (essentially (ρ)) increases, the frequency will decrease. As in the answer to *Question 1*, the frequency will decrease as the inverse square root of the density increases.

4.

Changing the thickness of the wire changes the string density (ρ), so that thick wires will have a lower frequency when they have the same tension and length as thin wires. To accommodate the large range of frequencies that a piano produces, the wires not only get longer as lower frequencies are needed, but they also get thicker. This allows the piano to be smaller than would be required if only changing string length was responsible for providing lower frequencies.

NOTES

CHAPTER 5

NOTES

What Do You Think Now?

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

- **How do guitarists or violinists today make different sounds?**
- **If someone were pretending to play a guitar (for example, the air guitar), how would the player position his or her fingers to make the highest pitch notes?**

You investigated the effects that changing the length of the string and the tension of the string have on the pitch of the sound produced. How do you now think that these musicians make sounds with different pitches? Use evidence from your investigation to support your answer.

Physics Essential Questions

What does it mean?

A violin is less than 0.5 m long. A bass fiddle is more than 1.5 m long. Which instrument do you expect to be able to play notes with a lower pitch and why?

How do you know?

What experiment can be conducted to demonstrate that higher-pitched sounds can be produced by either shortening the length of a vibrating string or by increasing the tension of a vibrating string?

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

* A goal of physics would be to identify principles that can accurately predict all sounds from all instruments. Although you worked with strings in this investigation, as student scientists you can probably predict correctly how different pieces of wood or metal could be used to make a xylophone or a marimba (often played in Zimbabwe, Zambia, and other African nations). How might the length of the string and the tension of the string relate to properties of the wooden bars in these instruments?

Why should you care?

Vibrations occur in many situations. In this section, you investigated vibrations that give rise to sound. List some examples where vibrating strings show up in musical instruments. Describe how a drum produces a sound. How will what you learned in this section help you with your challenge of creating sound?

What Do You Think Now?

Have students revisit the *What Do You Think?* questions. Ask them to review their answers and give reasons for modifying or replacing their previous responses. Students should be able to refer to their observations from the *Investigate* to show how changing the length and the tension of a string will affect the frequency of vibration (the pitch).

Physics Essential Questions

What does it mean?

The bass fiddle will be able to play the lower frequency note. The frequency of a note from a stringed instrument is dependent on the length of the string—the longer the string, the lower the note.

How do you know?

You can listen to the note generated when a short string and a long string are plucked. If a frequency meter is available, you can measure the frequencies.

Why do you believe?

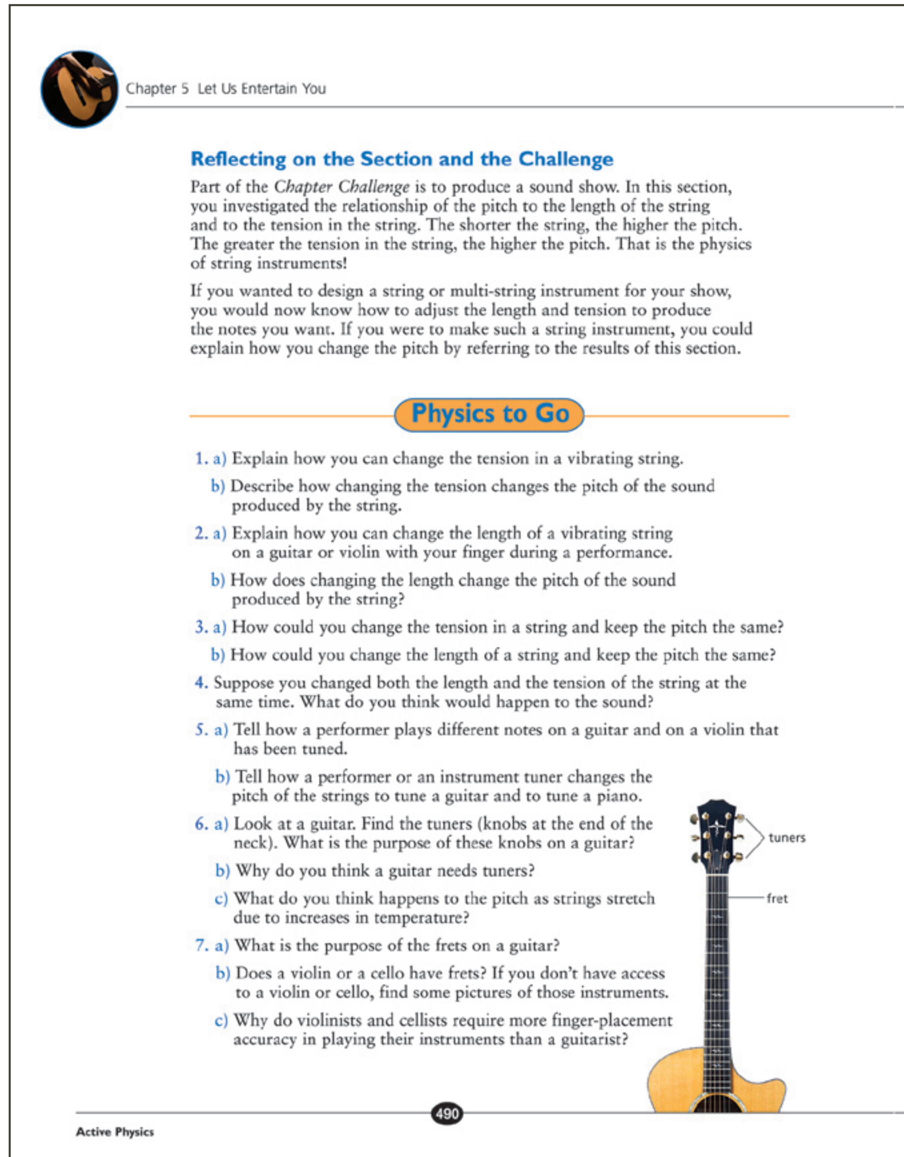
Wooden bars also vibrate. The tension of a string is probably similar to the stiffness of the wood, which may depend on its density. The length of the string is similar to the length of the piece of wood.

Why should you care?

Vibrating strings produce the sounds in guitars, violins, violas, cellos, string basses, and harps. In pianos, a sound is produced when the string is hit rather than plucked, while in drums, the drum head vibrates to produce a sound. For the challenge, a musical instrument can be built with different length strings.

Reflecting on the Section and the Challenge

Instruct students to read the *Chapter Challenge*. Emphasize how their knowledge of pitch in relation to the length and tension of a string will help them build their instruments for the sound and light show. Ask them to reflect on what they have learned in this section and prompt them with questions related to the *Investigate* to make them aware of connections they are building as they get further along in the chapter.



Reflecting on the Section and the Challenge

Part of the *Chapter Challenge* is to produce a sound show. In this section, you investigated the relationship of the pitch to the length of the string and to the tension in the string. The shorter the string, the higher the pitch. The greater the tension in the string, the higher the pitch. That is the physics of string instruments!

If you wanted to design a string or multi-string instrument for your show, you would now know how to adjust the length and tension to produce the notes you want. If you were to make such a string instrument, you could explain how you change the pitch by referring to the results of this section.

Physics to Go

1. a) Explain how you can change the tension in a vibrating string.
   b) Describe how changing the tension changes the pitch of the sound produced by the string.
2. a) Explain how you can change the length of a vibrating string on a guitar or violin with your finger during a performance.
   b) How does changing the length change the pitch of the sound produced by the string?
3. a) How could you change the tension in a string and keep the pitch the same?
   b) How could you change the length of a string and keep the pitch the same?
4. Suppose you changed both the length and the tension of the string at the same time. What do you think would happen to the sound?
5. a) Tell how a performer plays different notes on a guitar and on a violin that has been tuned.
   b) Tell how a performer or an instrument tuner changes the pitch of the strings to tune a guitar and to tune a piano.
6. a) Look at a guitar. Find the tuners (knobs at the end of the neck). What is the purpose of these knobs on a guitar?
   b) Why do you think a guitar needs tuners?
   c) What do you think happens to the pitch as strings stretch due to increases in temperature?
7. a) What is the purpose of the frets on a guitar?
   b) Does a violin or a cello have frets? If you don't have access to a violin or cello, find some pictures of those instruments.
   c) Why do violinists and cellists require more finger-placement accuracy in playing their instruments than a guitarist?

Physics to Go

1.a)

You can change the tension in a vibrating string by changing the weight hung on the end of the string (or, in an instrument, by turning the knobs on the tuning machine).

1.b)

Increasing the tension increases the pitch of the sound produced by the string.

2.a)

For a guitar or violin, the string is shortened by pressing down on the frets along the neck (for a guitar) or just on the neck for a violin.

2.b)

Decreasing the length of the string increases the pitch of the sound.

3.a)

If the tension is increased, the string length should also increase to keep the pitch the same.

3.b)

If the string length is decreased, the tension in the string should also decrease to keep the pitch the same.

4.

If the tension increased (or decreased) while the length was changed in the opposite direction or not changed by an equal amount in the same direction, the pitch would change.

5.a)

A performer plays different notes on a guitar or a violin by pressing the string down on the neck of the guitar or by using different strings.

5.b)

For both instruments, the instrument tuner adjusts the pitch by changing the string tension.

6.a)

These knobs are used to change the tension on the strings.

6.b)

Tuners are used to change the tension in the guitar strings. Increasing the tension raises the pitch, while decreasing the tension lowers the pitch of the string when plucked.

6.c)

Increases in temperature would cause the string to increase in length, and thus, decrease the string tension. Lowering the tension causes the pitch to decrease.

7.a)

Frets make it easier to press the string against the neck at the right place, so the note has the right pitch.

7.b)

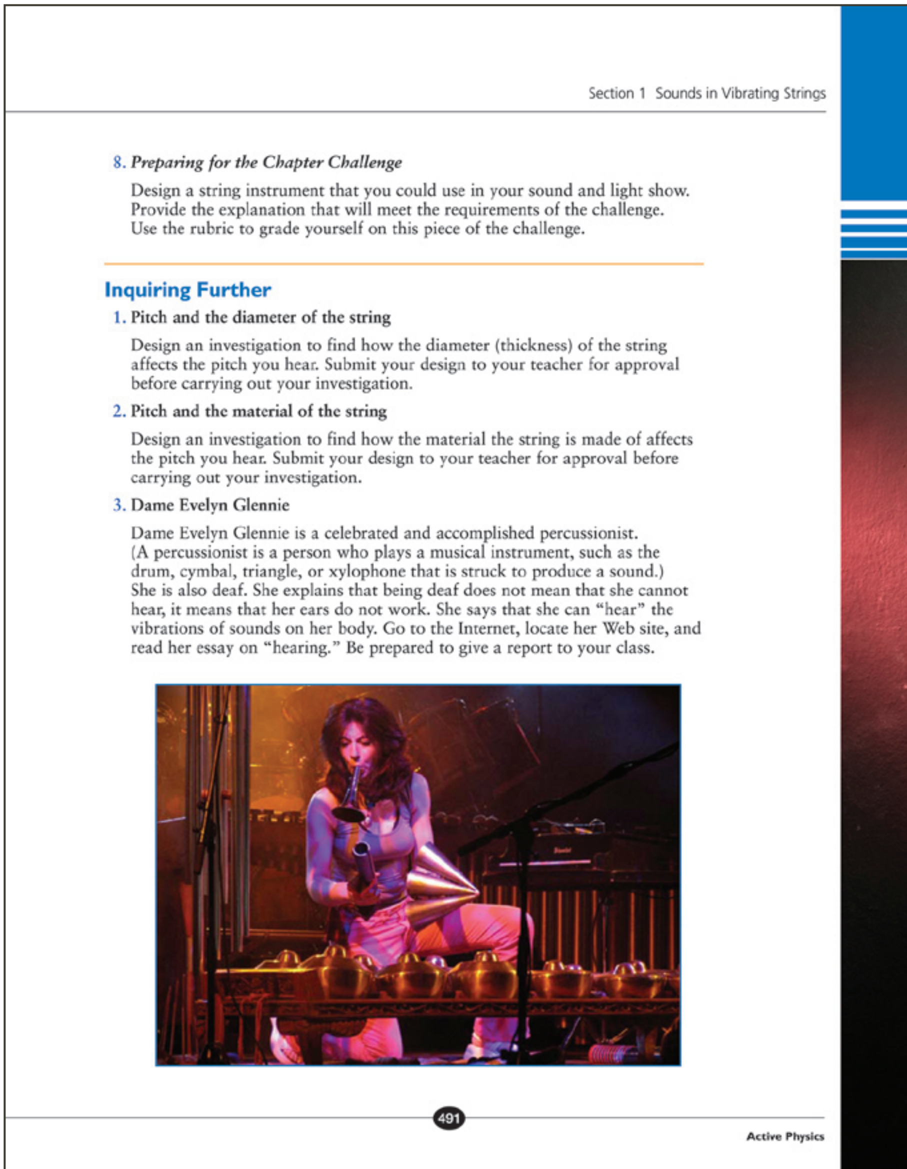
No.

7.c)

Violinists and cellists must judge where to press the string down, so each note has the correct pitch.

NOTES

NOTES



Section 1 Sounds in Vibrating Strings

8. *Preparing for the Chapter Challenge*

Design a string instrument that you could use in your sound and light show. Provide the explanation that will meet the requirements of the challenge. Use the rubric to grade yourself on this piece of the challenge.

Inquiring Further

1. Pitch and the diameter of the string

Design an investigation to find how the diameter (thickness) of the string affects the pitch you hear. Submit your design to your teacher for approval before carrying out your investigation.

2. Pitch and the material of the string

Design an investigation to find how the material the string is made of affects the pitch you hear. Submit your design to your teacher for approval before carrying out your investigation.

3. Dame Evelyn Glennie

Dame Evelyn Glennie is a celebrated and accomplished percussionist. (A percussionist is a person who plays a musical instrument, such as the drum, cymbal, triangle, or xylophone that is struck to produce a sound.) She is also deaf. She explains that being deaf does not mean that she cannot hear, it means that her ears do not work. She says that she can "hear" the vibrations of sounds on her body. Go to the Internet, locate her Web site, and read her essay on "hearing." Be prepared to give a report to your class.

491

Active Physics

8. *Preparing for the Chapter Challenge*

Student responses will vary. Most will probably make a variation of a guitar with strings that are stretched at different lengths. The rubric students may come up with might include whether or not the strings were of different lengths and had different tensions. The rubric may also include the quality of the sounds made by the instrument.

Inquiring Further

1. Pitch and the diameter of the string

Students might find strings of different diameters made from the same material to test the effect that diameter has on pitch. Alternatively, they might wrap one string around another to increase string mass.

2. Pitch and the material of the string

Students can choose strings of different material (cotton, nylon, plastic, and so on) to test the pitch produced. Students should pay particular attention to keeping the string length and string tension the same in all trials. Keeping the string diameter constant might prove particularly difficult but will also be an important factor to constrain.

3. Dame Evelyn Glennie

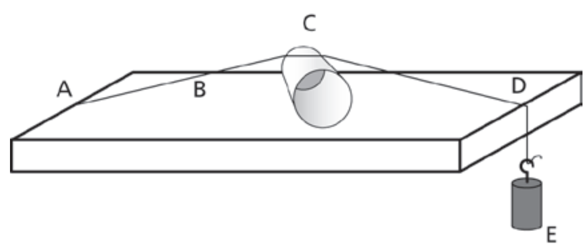
Students should look up the information needed from the Internet and prepare a report to give to the class.

CHAPTER 5

SECTION 1 QUIZ

5-1a Blackline Master

1. The diagram below shows a string under tension on a table, with a cup located between the string and the table. When the string is plucked at point B, a sound is heard. If the string is plucked harder, the sound produced will be



a) a higher pitch and louder.

b) a lower pitch and louder.

c) a higher pitch but no louder.

d) louder but the same pitch.

2. The cup shown in *Question 1* is moved toward point D, and the string is plucked at point B. Compared to the pitch heard when the cup was at point C, the pitch heard now will be

a) lower.

b) higher.

c) the same.

3. If the cup is in the same position as in *Question 2*, and you have to produce a pitch similar to when the cup was at position C, you should pluck the string at position B and

a) pluck the string harder than you did for *Question 2*.

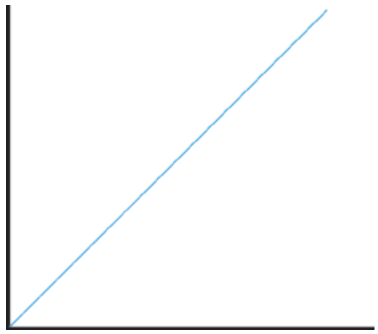
b) increase the height of the cup.

c) increase the tension in the string.

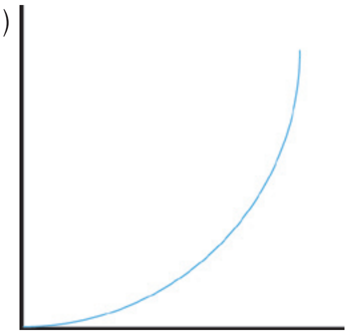
d) hold the section of the string between the cup and D so it does not vibrate.

4. Which graph below represents the relationship between the length of a vibrating string and the frequency of the sound it produces?

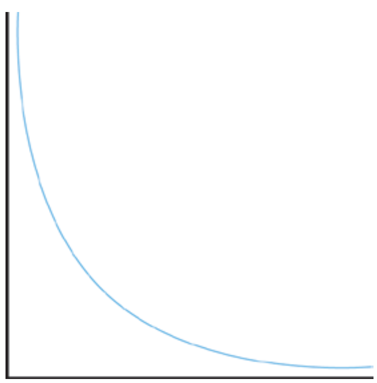
a)



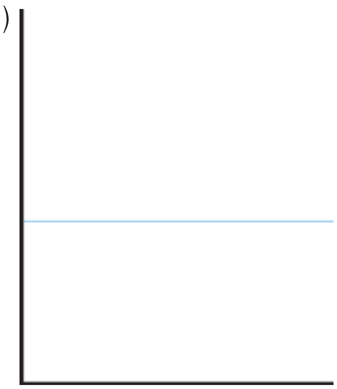
b)



c)



d)



5. Which of the following statements describes the relationship between the pitch heard and the vibration rate of a string under tension?

a) As the vibration rate increases, the pitch increases.

b) As the vibration rate decreases, the pitch increases.

c) As the vibration rate increases, the pitch decreases.

d) The vibration rate and the pitch heard are not related to each other.

SECTION 1 QUIZ ANSWERS

1. d) Because plucking the string harder does not change the length of the string vibrating, the pitch remains the same. All the other answers have a changing pitch, which must be incorrect.

2. a) Increasing the string length increases the wavelength of the wave produced, thus, lowering the pitch.

3. c) Because moving the cup to position D lowers the pitch, tension must be increased to raise the pitch. Plucking the string harder does not change the pitch, except the loudness. Raising the height of the cup would only increase the string length, making the pitch even lower. Holding the string so it does not vibrate would have no effect, since that section is not the one producing the sound.

4. c) As the string length increases, the pitch decreases. The other graphs either show the pitch remaining the same, as in choice *d)*, or increasing with increasing length, as in choices *a)* and *b)*.

5. a) The pitch is the rate of vibration, so as one increases the other must also increase.

NOTES

NOTES

CHAPTER 5