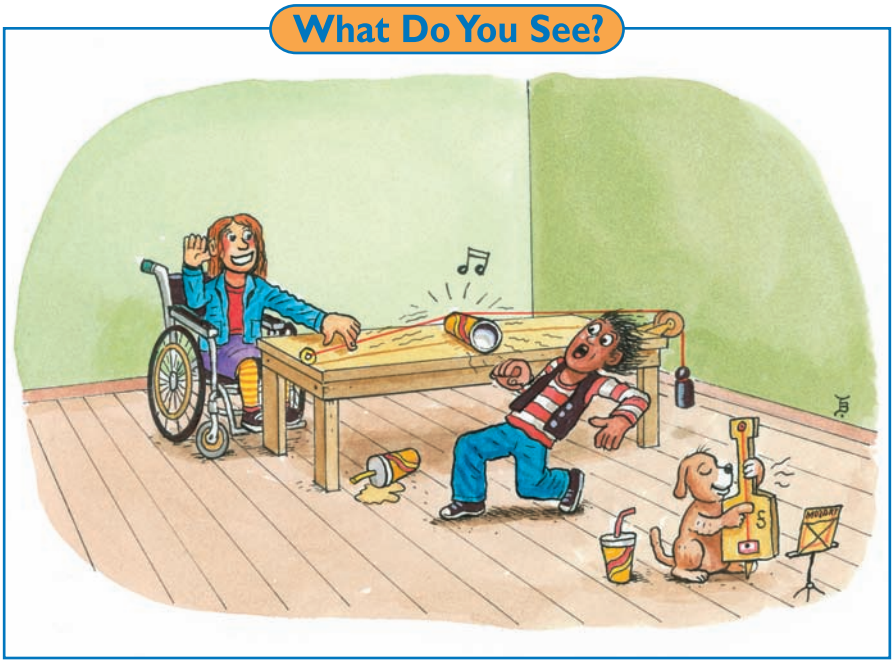
Section 1 Sounds in Vibrating Strings

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 See?



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.

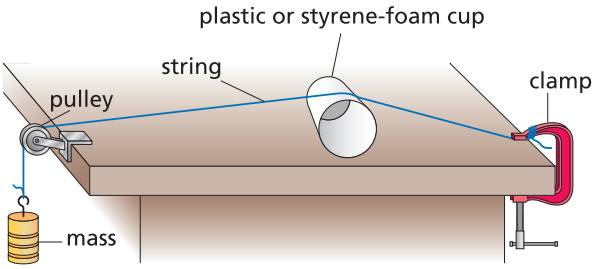
- **How do guitarists or violinists today make different sounds?**
- **If someone were pretending to play a guitar (for example, the air guitar), how would the player position his or her fingers to make the highest pitch notes?**

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.

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.

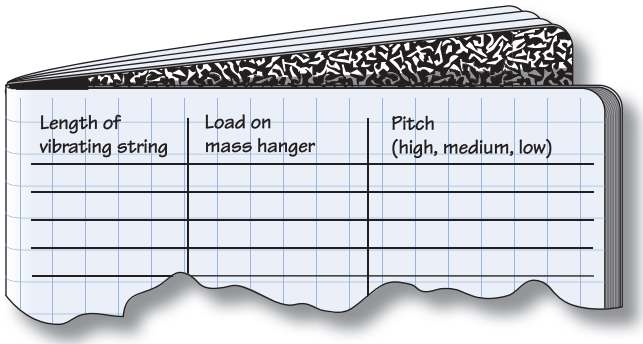


Put on your impact goggles. Be sure to have your impact goggles on anytime you put your eyes or ears close to the vibrating string.

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.

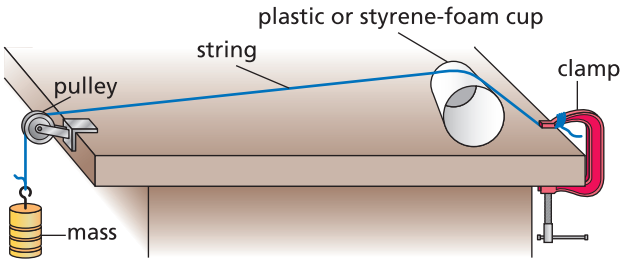
3. Hang one 500-g mass on the string. Pluck at the string and listen to the sound. The sound will be easier to hear if you place your ear near the opening of the plastic or styrene-foam cup. Pay attention to the pitch you hear. A high pitch is like the squeal of a vehicle's brakes as the vehicle comes 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.



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.

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

Physics Words

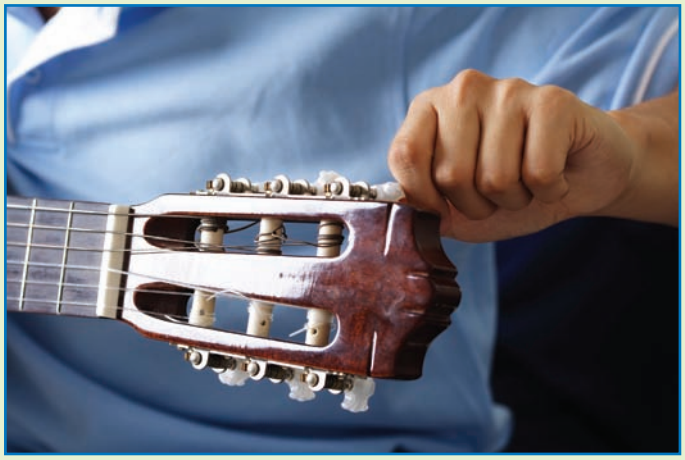
vibrate: move back and forth rapidly.

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

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

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.



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?

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:

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

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.

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?

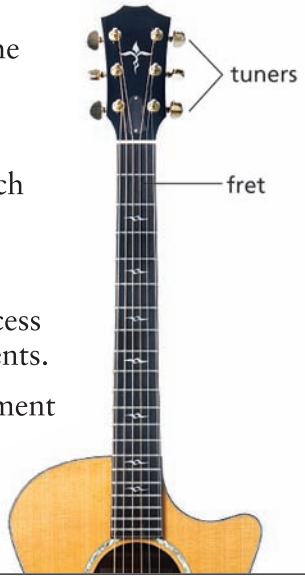
Reflecting on the Section and the Challenge

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?



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.