GOALS
In this activity you will:
• Describe red shift.
• Sketch a graph.
• Observe changes in pitch.
• Calculate with a formula.

What Do You Think?
You have probably heard the sound of a fast-moving car passing by you.

• Why is there a change in tone as the car moves by?

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.

For You To Do
1. Listen to a small battery-powered oscillator. It makes a steady tone with just one frequency. The oscillator is fastened inside a Nerf™ ball for protection.
Activity 8 The Doppler Effect

2. Stand about 3 m away from your partner. Toss the oscillator back and forth between you. Listen to the pitch as the oscillator moves. As you listen, observe how the pitch changes as the oscillator moves.
   a) How is the oscillator moving when the pitch is the highest?
   b) How is the oscillator moving when the pitch is the lowest?

3. Stop the oscillator so you can listen to its “at rest” pitch.
   a) With the oscillator moving, record how the pitch has changed compared to the “at rest” pitch. How has the pitch changed when the oscillator is moving towards you?
   b) How has the pitch changed when the oscillator is moving away from you?

4. Look at the graph axes shown. The axes show pitch vs. velocity. When the velocity is positive, the oscillator is moving away from you. When the velocity is negative, the oscillator is moving towards you.
   a) On a similar set of axes in your log, sketch a graph of your pitch observations. Explain your graph to the other members of your group.

5. You can do an outdoor Doppler lab using the horn of a moving car as the wave source. Tape-record the horn when the car is at rest next to the tape recorder. Then, with the driver of the car maintaining an agreed-upon speed, tape the sound of the horn as the car passes. Have the driver blow the horn continuously, both as the car approaches and as it moves away. Be very careful to stay away from the path of the car.
Patterns and Predictions

6. You can determine the observed frequency by matching the recorded tone to the output of an oscillator and loudspeaker. Use this formula:

\[ f = f_0 \left( \frac{s}{s-v} \right) \]

- \( f_0 \) = frequency when car is at rest
- \( v \) = speed of the car
- \( s \) = speed of sound = 340 m/s

\( a \) When the car is moving toward you, \( v \) is positive. When the car is moving away from you, \( v \) is negative. Use the equation to calculate the speed of the car from the data you collected.

FOR YOU TO READ

Measuring Distances Using the Doppler Effect

Astronomers measure distances to stars in two different ways. One way is with parallax, but this method works only for the nearest stars. For all other stars astronomers apply the Doppler effect. They use the Doppler shift of spectral lines. The next-nearest galaxy is Andromeda, more than a million light-years away.

Astronomers have observed galaxies at far greater distances, up to about 12 billion light-years away. These incredible distances are measured by observation of the absorption lines of light. These lines are consistently Doppler-shifted towards the red end of the spectrum, and the result is called the “red shift.”

All the lines are shifted toward longer wavelengths. Since this is a shift towards lower frequencies, the galaxies are moving away from Earth. By measuring the size of the shift, astronomers find the speed of distant galaxies. Different galaxies move away at different speeds, but with a clear pattern. The farther away the galaxy, the faster it is moving away, as shown in the graph.

Astronomers explain this result with the Big Bang theory, which says that the universe began in an explosion about 15 billion years ago. After the explosion, the matter in the galaxy continued to move apart, even after the galaxies formed.
Reflecting on the Activity and the Challenge

You have learned that the pitch of a sound changes if the source of the sound is moving toward you or away from you. This is called the Doppler effect for sound. You also learned that there is a Doppler effect for light where the frequency or color of the light would change if the source of the light were moving. Measurements of sound frequency can be used to determine the speed of the source of sound. Measurements of light frequencies from distant galaxies can be used to determine the speed of the galaxies. The speed of galaxies moving away from Earth has been shown to relate to the distance of the galaxies from Earth. A measurement of light frequency and the Doppler effect can be used to measure distances. Measuring speeds through the use of changes in frequency of sound or light is good science. Some people may say that hearing a person’s voice indicates to them whether that person is kind or gentle. If this were to have a scientific basis, you would have to conduct experiments. You should be able to contrast the experimental evidence you have for the Doppler effect and the lack of evidence you have for finding out what a person is like by their voice as you decide the kinds of proposals you may fund.

Physics To Go

1. a) If a sound source is moving towards an observer, what happens to the pitch the observer hears?
   b) If a sound source is moving towards an observer, what happens to the sound frequency the observer measures?

2. a) If a sound source is moving away from an observer, what happens to the pitch the observer hears?
   b) If a sound source is moving away from an observer, what happens to the sound frequency the observer measures?

3. a) If you watch an auto race on television, what do you hear as the cars go by the camera and microphone?
   b) Sketch a graph of the pitch you hear vs. time. Make the horizontal axis of your graph the time, and the vertical axis the pitch. (Hint: Don’t put any numbers on your axes. Label the time when the car is going right by you.)
c) Sketch a graph of the frequency you observe vs. time. As in Part (b), label the time when the car is going right by you. (Hint: Don’t put any numbers on your axes.)

4. a) In Question 3 above, what would happen to your graphs if the speed of the racing car doubled? Make a sketch to show the change.

b) What would happen to your graphs if the speed of the racing car was cut in half? Make a sketch to show the change.

5. a) Red light has a longer wavelength than blue light. Which light has the lower frequency? You will need the equation:

\[
\text{wave speed} = \frac{\text{wavelength}}{\text{frequency}}
\]

Show how you found your answer.

b) When the oscillator moved away from you, was the pitch you heard lower or higher?

c) When the oscillator moved away from you, was the frequency you heard lower or higher?

d) If light from a distant galaxy is shifted towards the red, is it shifted to a lower or a higher frequency?

e) If the light is shifted towards the red, is the galaxy moving away from Earth or towards Earth?

**Stretching Exercise**

Watch a broadcast of an auto race. Listen closely to the cars as they zoom past the microphone. Use the Doppler effect to explain your observations.