Teacher Guide: Doppler Shift

Learning Objectives

Students will…

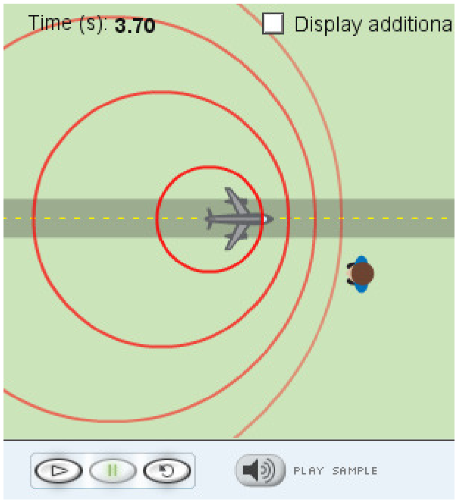
- Observe the wavelength and frequency of sound waves emitted by a stationary and a moving sound source.
- Explain why the Doppler shift occurs.
- Discover how a sonic boom is created by objects moving faster than the speed of sound.
- Determine how the sound frequency, source speed, and speed of sound affect the magnitude of the Doppler shift.

Vocabulary

Doppler shift, frequency, pitch, sonic boom, sound waves, wavelength

Lesson Overview

If you've ever heard an ambulance siren or a train whistle, you may have noticed how the pitch of the sound changes as the vehicle passes by. When a sound source is moving toward an observer, the sound waves are compressed, causing the apparent pitch of the sound to be higher. When the sound source is moving away, sound waves are stretched out, lowering the apparent pitch. This is called the Doppler shift.



The *Doppler Shift* Gizmo™ illustrates why the Doppler shift occurs. Students can observe sound waves emitted from a moving car or airplane. The sound frequency, vehicle velocity, and sound velocity are all adjustable.

The Student Exploration sheet contains three activities:

- Activity A – Students explain why the Doppler shift occurs.
- Activity B – Students investigate what happens when the sound source is moving faster than the speed of sound.
- Activity C – Students measure how changing the sound frequency, source velocity, and speed of sound affects the magnitude of the Doppler shift.

Suggested Lesson Sequence

1. **Pre-Gizmo activity** (5 – 15 minutes)
   Play several video clips showing examples of the Doppler shift. (See the **Selected Web Resources** on page 3 of this document.) After playing the clip, ask students to describe what they heard and why they think the sound changed.

   To introduce the connection between frequency and pitch, try the *Hearing: Frequency and Volume* Gizmo.

2. **Prior to using the Gizmo** (10 – 15 minutes)
   Before students are at the computers, pass out the Student Exploration sheets and ask students to complete the Prior Knowledge Questions. Discuss student answers as a class, but do not provide correct answers at this point. Afterwards, if possible, use a projector to introduce the Gizmo and demonstrate its basic operations. Demonstrate how to take a screenshot and paste the image into a blank document.

3. **Gizmo activities** (15 – 20 minutes per activity)
   Assign students to computers. Students can work individually or in small groups. Ask students to work through the activities in the Student Exploration using the Gizmo. Alternatively, you can use a projector and do the Exploration as a teacher-led activity.

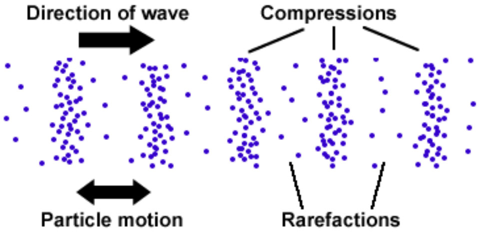
4. **Discussion questions** (15 – 30 minutes)
   As students are working or just after they are done, discuss the following questions:
   - Why are the sound waves compressed in front of the moving sound source, and stretched out behind the sound source?
   - What causes a sonic boom? [As the sound source moves ahead, the waves that are left behind “pile up” to form a conical *shockwave*. The observer hears the sonic boom when the shockwave reaches them.]
   - Why does the magnitude of the Doppler shift increase when the speed of sound is reduced? [As the velocity of the sound source approaches the speed of sound, the Doppler shift increases. This can be achieved by increasing the speed of the sound source or decreasing the speed of sound.]
   - Would you observe a Doppler shift if you were moving toward a stationary sound source? Explain why or why not. [Yes—the frequency of sound waves would be higher as you approach the source, and lower and you move away.]

5. **Follow-up activities** (variable)
   There are many possible ways to follow up the *Doppler Shift* Gizmo. For a quantitative treatment of the Doppler shift, see the *Doppler Shift Advanced* Gizmo. A fun way to illustrate the Doppler shift is to make a “Doppler ball,” which is a spongy ball with a buzzer embedded inside. Students can listen to how the pitch changes as they throw the ball back and forth. See the **Selected Web Resources** for instructions.

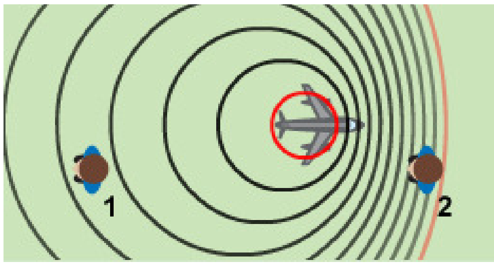
   The Doppler shift often is taught in connection to *redshift*, an important astronomical phenomenon. When a light source is moving away from an observer at a high velocity, the light waves are stretched out. As a result, light from a retreating star or galaxy is shifted toward the red end of the visible light spectrum. Evidence from redshifted galaxies showed that the universe is expanding and led to the famous Big Bang theory. Students can observe redshifted spectra in the *Star Spectra* Gizmo.

Scientific Background

A sound wave is an example of a *longitudinal wave*, a type of wave in which the particles in the medium move back and forth in the same direction as the motion of the wave. The result is a series of high- and low-pressure regions called *compressions* and *rarefactions*.



We perceive a sound when the compressions and rarefactions strike our eardrums. The greater the frequency of waves, the higher-pitched the sound will be. Shortening the distance between compressions (wavelength) will increase the frequency of the waves and raise the pitch.

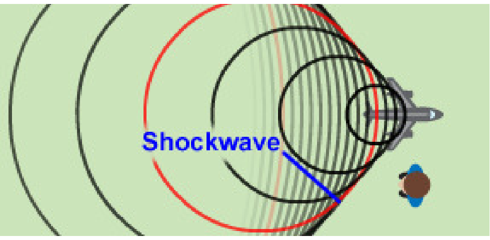


Now imagine that the source of sound waves is in motion from left to right. One sound wave is emitted, and then the source moves to the right a bit before the next wave is emitted. As a result, the wavelength of sound waves is shorter in front of the moving source and longer behind the source. In the diagram at right, observer **1** will hear a lower-pitched sound while observer **2** will hear a higher-pitched sound.

The Doppler shift applies to other types of waves, including light waves. Changing the wavelength shifts the color of a light wave. In the visible spectrum, light from an object moving toward the observer is *blueshifted*, while light moving away is *redshifted*. Scientists use this information to tell if a galaxy is moving towards or away from our own galaxy, or to detect small movements that may indicate the presence of planets around a distant star.

Historical Connection: Breaking the sound barrier

When a sound source is moving faster than the speed of sound, sound waves are left behind, forming a *shockwave* that is similar to the wake produced by a speeding boat. An observer will experience a loud noise, or *sonic boom*, when the shockwave reaches her. This occurs after the sound source has passed by.




Courtesy USAF

As an aircraft approaches the speed of sound, compressed sound waves start to buffet the craft, making it extremely difficult to control. After a series of dangerous test flights, Chuck Yeager became the first man to officially break the sound barrier on October 14, 1947. The Bell X-1 plane he flew (left) was essentially an aerodynamic rocket with wings.

Selected Web Resources

Doppler shift videos and clips: http://www.wfu.edu/physics/demolabs/demos/3/3b/3B40xx.html, http://videos.howstuffworks.com/discovery/27963-assignment-discovery-doppler-effect-video.htm, http://science.discovery.com/videos/time-doppler-effect.html
Doppler shift demonstrations: http://molebash.com/doppler/home.htm
    Doppler movies: http://molebash.com/doppler/horn/horn1.htm
    How to make a Doppler ball: http://molebash.com/doppler/pitch/dopplerball.htm
Doppler shift explanation: http://imagine.gsfc.nasa.gov/YBA/M31-velocity/Doppler-shift-2.html
Redshift: http://www.exploratorium.edu/hubble/tools/doppler.html

Related Gizmos:
Doppler Shift Advanced: http://www.explorelearning.com/gizmo/id?584
Hearing: Frequency and Volume: http://www.explorelearning.com/gizmo/id?518
Star Spectra: http://www.explorelearning.com/gizmo/id?558