Name: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ Date: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**Student Exploration: Doppler Shift Advanced**

*[Note to teachers and students: This Gizmo was designed as a follow-up to the* Doppler Shift *Gizmo. We recommend doing that activity before trying this one.]*

**Vocabulary:** Doppler shift, frequency, pitch, radar gun

**Prior Knowledge Questions** (Do these BEFORE using the Gizmo.)

The image at right shows two observers watching a car pass by. The red circles represent sound waves.

1. Which observer hears the highest **pitch** (tone)? \_\_\_\_\_

Which observer hears the lowest pitch? \_\_\_\_\_

1. How can you tell? \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**Gizmo Warm-up**

The change in pitch an observer hears as an object passes by is an example of the **Doppler shift**. With the *Doppler Shift Advanced* Gizmo, you will investigate how the speed of the moving object is related to the magnitude of the Doppler shift.

On the Gizmo, check that ***v*observer** is 0 m/s, ***f*source**is
500 Hz, ***v*source** is 100 m/s, and ***v*sound** is 340 m/s, close to the velocity of sound in air. Click **Play** ().

1. Click **Pause** (). How does the distance between sound waves compare in front of and behind the car? \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

1. How will the sound of the car change as the car passes the observer? \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

|  |  |  |
| --- | --- | --- |
| **Activity A:** **Source moving towards observer** | Get the Gizmo ready: * Click **Reset** (Reset).
* Set the frequency (***f*source**) to 1,000 Hz, the velocity of the source (***v*source**) to 60 m/s and the speed of sound (***v*sound**) to 240 m/s.
* Turn on the **Observed frequency (Hz)** checkbox.
 | 584SE3 |

**Introduction:** Waves are described by their **frequency**, or number of cycles per second. The source frequency (*fs*) is equal to the frequency of waves emanating from a moving source of sound. The observed frequency (*f*) is equal to the number of waves passing the observer each second. In the *Doppler Shift Advanced* Gizmo, each red ring represents 1,000 sound waves.

**Question: How can you use the Doppler shift to measure the velocity of an object moving towards an observer?**

1. Measure: Place the observer in the middle of the road so he is directly in front of the car. Click **Play**, and then click **Pause** when sound waves are striking the observer.

What is the frequency of the sound waves hitting the observer? \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

1. Gather data: Subtract the velocity of the source (*vs*) from the speed of sound (*c*) to fill in the third column of the table. Next, use the Gizmo to measure the observed frequencies (*f*). Divide each observed frequency by the source frequency (*fs* = 1,000 Hz) to complete the table. This value represents the magnitude of the Doppler shift.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| ***Speed of sound (c)*** | ***Velocity of source (vs)*** | ***c* – *vs*** | ***Observed frequency (f)*** | ***f / fs*** |
| 240 m/s | 60 m/s |  |  |  |
| 240 m/s | 80 m/s |  |  |  |
| 240 m/s | 120 m/s |  |  |  |
| 240 m/s | 160 m/s |  |  |  |
| 240 m/s | 180 m/s |  |  |  |

1. Analyze: Compare the first, third, and fifth columns of the table. What is the relationship between the speed of sound (*c*), *c – vs*, and the ratio *f* / *fs*?

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

1. Make a rule: Express this relationship in an equation that relates *c*, *c – vs*, *f*, and *fs*.

=

**(Activity A continued on next page)Activity A (continued from previous page)**

1. Manipulate: Rearrange your equation to solve for the velocity of the source.

*vs* =

Show your work:

1. Practice: The speed of sound at sea level is normally about 340 m/s. A car honks its horn as it drives toward an observer. The frequency of the horn is 800 Hz, but the observer hears an 860-Hz pitch.

What is the velocity of the car? \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

Show your work:

1. Challenge: A **radar gun** is a device that uses the Doppler shift to measure the velocity of objects. Police officers use radar guns to catch speeders, while baseball scouts use them to measure fastballs. A radar gun works by sending out a radio signal that bounces off a moving object and returns to the gun with a different frequency.

Suppose a radar gun sends out radio waves with a frequency of 2,000,000.0 Hz. The waves bounce off a moving car and return with a frequency of 2,000,000.2 Hz. If the speed of light (*c*) is 300,000,000 m/s, what is the velocity of the car? Show your work.

Velocity of car: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

Show your work:

|  |  |  |
| --- | --- | --- |
| **Activity B:** **Source moving away from the observer** | Get the Gizmo ready: * Click **Reset**.
* Set ***f*source** to 1,000 Hz, ***v*source** to 60 m/s, and ***v*sound** to 240 m/s.
 | 584SE4 |

**Question: How can you use the Doppler shift to measure the velocity of an object moving away from an observer?**

1. Measure: Place the observer in the middle of the road so he is directly in front of the car. Click **Play**, and then click **Pause** after the car has passed the observer.

What is the frequency of the sound waves hitting the observer? \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

1. Gather data: Add the speed of sound (*c*) to velocity of the source (*vs*) to fill in the third column of the table. Next, use the Gizmo to measure the observed frequencies (*f*). Divide each observed frequency by the source frequency (1,000 Hz) to complete the table.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| ***Speed of sound (c)*** | ***Velocity of source (vs)*** | ***c* + *vs*** | ***Observed frequency (f)*** | ***f / fs*** |
| 240 m/s | 60 m/s |  |  |  |
| 240 m/s | 80 m/s |  |  |  |
| 240 m/s | 120 m/s |  |  |  |
| 240 m/s | 160 m/s |  |  |  |
| 240 m/s | 240 m/s |  |  |  |

1. Analyze: Compare the first, third, and fifth columns of the table. What is the relationship between the speed of sound (*c*), *c + vs*, and the ratio *f* / *fs*?

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

1. Make a rule: Express this relationship in an equation that relates *c*, *c + vs*, *f*, and *fs*.

=

1. Manipulate: Solve your equation for the velocity of the source: *vs* =

Show your work:

**(Activity B continued on next page)Activity B (continued from previous page)**

1. Practice: The speed of sound at sea level is normally about 340 m/s. An ambulance has a siren with a frequency of 10,000 Hz. After it passes an observer, the observer records a frequency of 9,500 Hz.

What is the velocity of the ambulance? \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

Show your work:

1. Challenge: In many cases, the observer does not know the original frequency of the waves emitted by a moving object. In this situation, it is still possible to calculate the velocity of the object based on the total observed frequency shift.

Calculate the total frequency shift for a car that is driving toward a stationary observer at a speed of 30 m/s. Assume the original frequency of sound is 2,000 Hz and the speed of sound is 340 m/s.

What is the total frequency shift? \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

Show all work below:

|  |  |  |
| --- | --- | --- |
| **Activity C:** **Moving observer** | Get the Gizmo ready: * Click **Reset**.
* Set ***v*source** to 0 m/s and ***v*sound** to 240 m/s.
* Set ***v*observer** to -60 m/s.
 | 584SE4 |

**Question: How can you use the Doppler shift to measure the velocity of an observer?**

1. Measure: Place the observer in the middle of the road so he is directly in front of the car. Click **Play**, and then click **Pause** when sound waves start hitting the observer.

What is the frequency of the sound waves hitting the observer? \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

1. Gather data: Subtract the observer velocity (*vr*) from the speed of sound to fill in the third column of the table. (Note: All observer velocities are negative in the table, so subtracting a negative velocity is the same as adding a positive velocity.) Next, use the Gizmo to measure the observed frequencies (*f*). Divide each observed frequency by the source frequency (1,000 Hz) to complete the table.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| ***Speed of sound (c)*** | ***Observer velocity (vr)*** | ***c* – *vr*** | ***Observed frequency (f)*** | ***f / fs*** |
| 240 m/s | -60 m/s |  |  |  |
| 240 m/s | -80 m/s |  |  |  |
| 240 m/s | -120 m/s |  |  |  |
| 240 m/s | -160 m/s |  |  |  |

1. Analyze: Compare the first, third, and fifth columns of the table. What is the relationship between the velocity of sound (*c*), *c* – *vr*, and the ratio *f* / *fs*?

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

1. Make a rule: Express this relationship in an equation that relates *c*, *c* – *vr*, *f*, and *fs*.

=

1. Manipulate: Solve your equation for the velocity of the observer. *vr* =

Show your work:

**(Activity C continued on next page)Activity C (continued from previous page)**

1. Practice: The speed of sound at sea level is normally about 340 m/s. A stationary fire alarm has a frequency of 15,000 Hz. An observer running towards the fire alarm hears a frequency of 15,300 Hz.

What is the velocity of the observer? \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

Show your work:

1. Predict: How do you think the formula for observed frequency (*f*) will change if the observer is moving *away* from the sound source?

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

1. Test: Test your prediction using the Gizmo. Describe the results of your experiment below.

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

1. Challenge: Based on everything you have learned, try to create a *single* equation for the observed frequency of a wave if both the observer and the source are in motion. Use *vr* for the velocity of the observer and *vs* for the velocity of the sound source.

Use the following sign conventions:

* If the observer is moving toward the sound source, *vr* is negative.
* If the observer is moving away from the sound source, *vr* is positive.
* If the sound source is moving toward the observer, *vs* is positive.
* If the sound source is moving away from the observer, *vs* is negative. (Note: This is opposite of the convention you used in activity B.)

*f* =

Test your equation using the Gizmo.