Name: ______________________________________ Date: ________________________

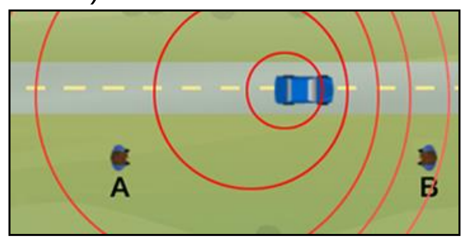
Student Exploration: Doppler Shift Advanced

[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)? _____

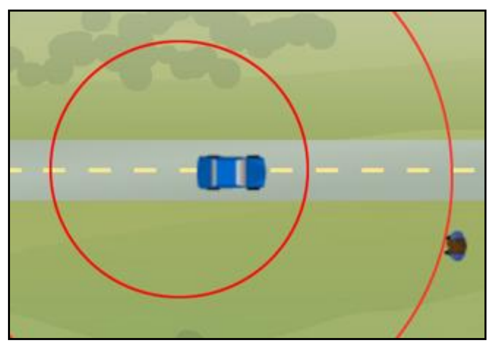
   Which observer hears the lowest pitch? _____

2. 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? ____

   ____

2. How will the sound of the car change as the car passes the observer? _________________

   ____

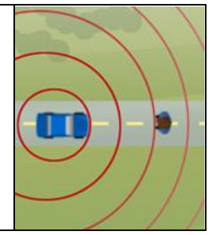
   ____

Activity A:

Source moving towards observer

Get the Gizmo ready:

- Click **Reset** ( ).
- Set the frequency ($\boldsymbol{f}_{source}$) to 1,000 Hz, the velocity of the source ($\boldsymbol{v}_{source}$) to 60 m/s and the speed of sound ($\boldsymbol{v}_{sound}$) to 240 m/s.
- Turn on the **Observed frequency (Hz)** checkbox.



Introduction: Waves are described by their **frequency**, or number of cycles per second. The source frequency (f_s) 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? _______________________

2. Gather data: Subtract the velocity of the source (v_s) 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 (f_s = 1,000 Hz) to complete the table. This value represents the magnitude of the Doppler shift.

Speed of sound (c)	***Velocity of source (v_s)***	***$c - v_s$***	***Observed frequency (f)***	***f / f_s***
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			

3. Analyze: Compare the first, third, and fifth columns of the table. What is the relationship between the speed of sound (c), $c - v_s$, and the ratio f / f_s?

   ____

4. Make a rule: Express this relationship in an equation that relates c, $c - v_s$, f, and f_s.

   =

(Activity A continued on next page)

Activity A (continued from previous page)

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

v_s =

Show your work:

6. 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? ___________________

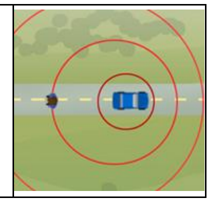
Show your work:

7. 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 $\boldsymbol{f}_{\textbf{source}}$ to 1,000 Hz, $\boldsymbol{v}_{\textbf{source}}$ to 60 m/s, and $\boldsymbol{v}_{\textbf{sound}}$ to 240 m/s.	

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? _______________________

2. Gather data: Add the speed of sound (c) to velocity of the source (v_s) 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 (v_s)***	$c + v_s$	***Observed frequency (f)***	f / f_s
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			

3. Analyze: Compare the first, third, and fifth columns of the table. What is the relationship between the speed of sound (c), $c + v_s$, and the ratio f / f_s?

   ____

4. Make a rule: Express this relationship in an equation that relates c, $c + v_s$, f, and f_s.

   =

5. Manipulate: Solve your equation for the velocity of the source: v_s =

   Show your work:

(Activity B continued on next page)

Activity B (continued from previous page)

6. 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? ___________________

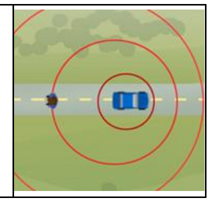
   Show your work:

7. 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 $\boldsymbol{v}_{\textbf{source}}$ to 0 m/s and $\boldsymbol{v}_{\textbf{sound}}$ to 240 m/s. • Set $\boldsymbol{v}_{\textbf{observer}}$ to -60 m/s.	

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? ______________________

2. Gather data: Subtract the observer velocity (v_r) 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 (v_r)***	***$c - v_r$***	***Observed frequency (f)***	***f / f_s***
240 m/s	-60 m/s			
240 m/s	-80 m/s			
240 m/s	-120 m/s			
240 m/s	-160 m/s			

3. Analyze: Compare the first, third, and fifth columns of the table. What is the relationship between the velocity of sound (c), $c - v_r$, and the ratio f / f_s?

   ____

4. Make a rule: Express this relationship in an equation that relates c, $c - v_r$, f, and f_s.

   =

5. Manipulate: Solve your equation for the velocity of the observer. v_r =

   Show your work:

(Activity C continued on next page)

Activity C (continued from previous page)

6. 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:

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

   ____

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

   ____

   ____

   ____

9. 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 v_r for the velocity of the observer and v_s for the velocity of the sound source.

   Use the following sign conventions:

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

   $f =$

   Test your equation using the Gizmo.