The Doppler Effect with Sound

We are surrounded and constantly bombarded by waves. **Wave** is a common term for different ways in which energy can be transferred from one place to another. Light waves, radio waves, ultraviolet and infrared waves can all travel through the emptiness of space. Sound waves, on the other hand, can only be transmitted by the collisions of the particles of the material through which it travels.

You are familiar with the sound of an approaching siren, car horn, or train whistle. You hear a change in the pitch or tone of the sound changes when is passes. That change in pitch is the result of the **Doppler Effect**. The Doppler of is a phenomenon of waves, that occurs when either the source of the wave, or the observer, is in motion.

This experiment will help you understand the Doppler effect, by measuring the ***change in frequency*** of a steady audible sound, relative to the motion of the observer. These same principles affecting sound waves can also be applied to light, providing astronomers a valuable tool for understanding the cosmos.

Watch the YouTube video introducing and explaining the Doppler effect and then demonstrating the experiment; https://youtu.be/2UhX5dugKmg

What you will need:

- Smartphone with the PhyPhox app installed (https://phyphox.org/)
- A source of sound (tone generator app or website).(1)
- Calculator

(1)Here's a good on-line tone generator; https://www.szynalski.com/tone-generator/

Experiment 1 – Measuring Frequency in Linear Motion

In this experiment, you will use a stationary audio source, and a mobile phone running the Phyphox app. You will try moving your phone steadily back and forth, to record the frequency of the sound observed, relative to the frequency of sound emitted from the audio source.

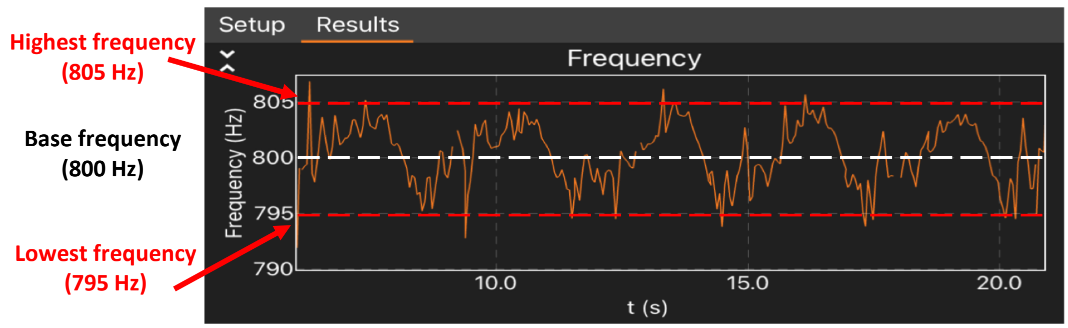
Two important notes.

(1) ***Be quiet***! Any talking, tv, shuffling around, fans, etc. will add unnecessary noise to your recorded signal and you will not be able to interpret your results.
(2) Moving your phone back and forth in front of the audio source over your head should be at a ***constant speed*** as much as possible.

Procedure

1. Select the frequency on your audio source you want to use for your experiment (something between 500 Hz and 1200 Hz works well).
2. Open PhyPhox and select the Doppler effect experiment under the sound options.

3. Enter the ***base frequency*** you chose to use from your audio source. You should not need to change any of the other settings.
4. Sit or stand in a fixed position, as close as you can to your audio source and still be able to move your phone in a steady linear motion, back and forth relative to the audio source. Try to reverse directions quickly and maintain a constant slow speed along both directions.
5. Start the sound, then start the Doppler Effect experiment, and begin a back and forth motion of your phone. Remember to maintain a ***constant speed*** as much as you can between switching directions.
6. Collect data for 7-8 repetitions, stop the Doppler app first, then stop the audio source.
7. Go to ***Results*** on the Phyphox app and examine the Frequency graph. Click on the graph and drag/expand the view to fill the screen to look something like this:



   The graph of your results should contain a series of peaks and valleys; the peaks indicate the highest frequencies detected by your phone, the valleys will correspond to the lowest frequencies detected. The mid line is your base frequency. If your graph is not clear, or has a lot of extra noise, try repeating the data collection.
8. Once you have collected the cleanest data set you can, record the highest and lowest frequencies from the pattern you see in your graph.

   Base frequency _________ Highest frequency ________ Lowest frequency _________

Making sense of your data

When either the audio source, or the observer (in this case your phone) moves away from the other, the sound waves appear to be longer, as if they are stretched out. If the source or observer move toward each other, the sound waves bunch together and appear shorter.

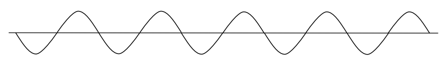
1. Compared to the base frequency you used in your experiment,
   a. What is the ***change in frequency*** of the sound waves detected by your phone moving toward the audio source?

   b. What was the ***change in frequency*** of the sound waves moving away from the sound source?

2. If you set your audio tone to, say a frequency of 800 Hz, what would you hear (higher or lower pitch) if:
    a. The wavelength increased?

    b. The frequency increased?

3. The shape of the wave for a base frequency in a Doppler experiment is shown below.



In the following table, draw what you think the shape of the wave will be (compared to the above wave) with the motion of the observer. Also indicate if you think the *frequency* will increase or decrease, compared to the original frequency.

Movement of observer	Shape of the wave	Observed frequency will (circle one)
Toward the audio source		increase / decrease
Away from the audio source		increase / decrease

4. Describe the frequency or pitch of the sound ***you heard*** from the audio source as you moved the phone back and forth during the experiment.

5. In your own words, describe the relationship between the frequency of waves and the wavelength of the wave.

Experiment 2 – Measuring Frequency in Circular Motion

Now that you know how to use the PhyPhox Doppler effect app, you can try something a little more exciting. This time you will measure the changes in frequency detected by your phone in a circular orbit, relative to a stationary sound source.

Note: When rotating your phone in circles over your head, maintain a ***constant speed*** and ***constant radius*** circle and, like before, **be quiet**.

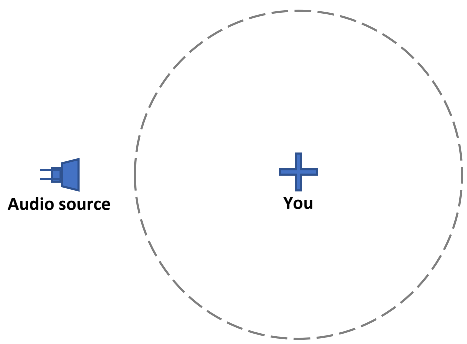
Procedure

1. Select a base frequency on your audio source. You can use the same frequency that you used before, or another frequency between 500 Hz and 1200 Hz.
2. Enter your ***base frequency*** in the PhyPhox app.
3. Sit or stand in a stationary position, as close as you can to your audio source and still be able to swing your phone around in circles over your head.
4. Start the audio source, then start Phyphox, and begin rotating the phone. Remember to maintain a ***constant speed*** and the ***same radius*** around the circle.
5. Collect data for 10-15 seconds, stop Phyphox and then stop the audio source.
6. Go to ***Results*** on the Phyphox app and examine the Frequency graph, as you did before:
7. Record the highest and lowest frequencies from the pattern you see in your graph.

Base frequency __________ Highest frequency _________ Lowest frequency __________

Making sense of your data

1. The diagram below shows a possible path of motion of your mobile phone relative to the audio source. First, draw an arrow to show the direction in which the phone is moving on the path.



   a. Mark the position on the circle (using the **capital letter L**) that would correspond to the longest wavelength recorded by your phone.
   b. Mark the position on the circle (with the **capital letter S**) that would correspond to the longest wavelength recorded by your phone.
   c. Are there any position(s) on the circle where the frequency recorded by your phone would be equal to the base frequency? Mark where you think this might be with the **capital letter E**.

2. Compared to the base frequency, explain what you think would be the effect on the frequencies observed by your phone running the Phyphox app if,
   a. You swing the phone in a *larger circle*, but at the *same speed*?

   b. You swing the phone in a circle of the *same radius* circle, but at a *faster speed*?

What IS the wavelength of a sound wave, actually? (Optional)

So, we have used the words wavelength and frequency, and you have heard and measured different frequencies. But, what about wavelength? How long is an audible sound wave? You can answer that question for yourself given just a little bit of information.

As you have already discovered, the **wavelength** of a wave, and the **frequency** of the wave are **inversely proportional**. As the wavelength increases, the frequency decreases. Multiplied together, the product of wavelength and frequency is equal to the speed of the wave. The speed of sound waves in air at normal temperatures is **340 m/s**.

If you know the speed of the wave, and the frequency (for example 800 Hz), then you can calculate the wavelength. In the form of an equation,

$$speed\ of\ the\ wave\ =\ frequency\ x\ wavelength$$

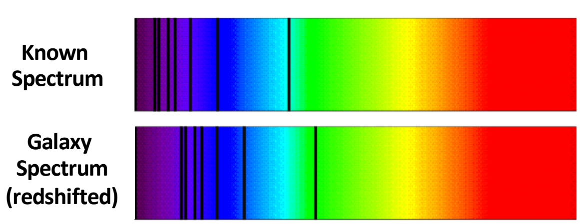
Include the correct unit in your answer. FYI, when we use the term Hz (Hertz), the unit for Hz is actually reciprocal seconds, or 1/s. So another way to write 800 Hz is 800/s, meaning 800 waves per second.

Show your work here, and don't forget to label the quantities with the correct units.

Using the Doppler effect in astronomy

Light reaching us from distant galaxies and other luminous objects in the Cosmos bears a common message – the universe is expanding. How do we know? The answer comes from what astronomers refer to as a consequence of the Doppler effect called ***redshift***.

Light, like sound, is also a wave and, in a similar way, light waves can also appear to be either compressed or expanded, relative to the motion of the source and/or observer. Light waves reaching Earth from distant galaxies almost always appeared to be longer than they really are, appearing more toward the red end of the visible spectrum, or ***redshifted***.



http://voyages.sdss.org/preflight/light/redshift/

The lines that appear in a spectrum of a luminous object like a galaxy come from the chemical elements present. The top spectrum is from a stationary source. The bottom spectrum is from a galaxy speeding away through the expansion of space. Notice the shift of the spectral lines toward the red end of the spectrum.

The idea of an expanding universe was proposed by Edwin Hubble in 1929. Hubble built his theory from a series of observations by V.M. Slipher, who had noted in 1914 the redshift of stars in distant galaxies indicating they were moving much faster than stars in our own galaxy (the Milky Way). How did Slipher calculate the velocities of stars? He used the Doppler shift.

Want to know more?

Neil deGrasse Tyson on the Big Bang;
https://www.youtube.com/watch?v=dxKgBkdOKr4&ab_channel=Bantaawanlagundong

The Doppler Effect: what does motion do to waves?
https://www.youtube.com/watch?v=h4OnBYrbCjY&ab_channel=AltShiftX

If you have questions about this, or any of the other instructional materials from Saturday Morning Astrophysics at Purdue, please contact Dr. David Sederberg at dsederbe@purdue.edu.