Measuring Doppler Shift Using Sound

Written by George J. Bendo, UK ALMA Regional Centre Node

Version: October 2015

Overview

In this experiment, we will make measurements of the change in frequency of sound waves from a sound source that is moving relative to the microphone. One person will run with a sound source along a measured distance, a second person will time the runner, and the third person will measure the change in frequency of the sound source. We will then use this to estimate the velocity of the moving sound source, which we can then compare to what we measure using a tape measure and a stopwatch.

Introductory Science Concepts

When a source producing either sound waves or electromagnetic waves (including radio wave and visible light) is stationary, those waves will appear to be the same frequency no matter which direction they are viewed in. However, when the source moves, the waves will appear different depending on how the object is observed. When the emitting object is moving towards the observer, the waves will appear bunched together, and the frequency of the waves will get higher. When the emitting object is moving away from the observer, the waves will get stretched out, and the frequency will get lower. This phenomenon is called Doppler shifting.

In everyday life, Doppler shifting can be experienced in a variety of settings. The most common example is the tone of the siren from a police car or ambulance as it drives by on the street. When the vehicle is approaching, the siren sounds higher pitched than when it is travelling away. Radar devices use the Doppler shifting of radio waves to determine the speed at which objects (including airplanes, cars, and clouds) are moving.

In astronomy, Doppler shifting is commonly used to measure the velocities at which stars, nebulae, and galaxies are moving. The spectra of starlight contain dark absorption lines found at specific wavelengths created by atoms and molecules in the outer atmospheres of the stars. The spectra of interstellar gas contain bright emission lines from the atoms and molecules in the gas. When the stars or gas move, these absorption and emission lines shift, and astronomers can compare the measured frequencies of these lines to the expected frequencies when the objects are at rest to determine how quickly the objects are moving.

As a side note, when astronomers look at the spectra of galaxies, the Doppler shifting of the lines shows that the galaxies are moving away from us. Furthermore, more distant galaxies appear to be moving away faster than nearby galaxies; the distances can be related by the equation

$$v = H_0 d \qquad (1)$$

where H_0 is the Hubble constant. Since light appear redder when the galaxies move away, astronomers normally refer to the Doppler shift for galaxies as the redshift. They can use the redshift as a substitute for distance. This phenomena demonstrated that the universe is expanding and led astronomers to determine that the universe must have formed in an explosion now called the Big Bang.

Science Concepts in This Experiment

In this experiment, we will measure the velocity v_{source} of a running person holding a sound source using two different techniques.

First, we will measure the velocity of the runner by measuring the amount of time Δt it takes for the runner to cross between two points separated by a distance Δd. The velocity is given by

$$v_{source} = \Delta d/\Delta t. \qquad (2)$$

Second, we will measure the velocity of the runner by measuring the shift in the frequency of the sound waves from the sound source. When the sound source is at rest, it will produce sound at a constant frequency that we will refer to as the rest frequency f_{rest}. When the sound source is moving relative to the observer, the observed frequency f_{obs} will change depending on whether the source is moving towards or away from the observer. When the sound source is approaching the observer, the observed and rest frequencies are related by

$$v_{source} = v_{sound}(1-f_{rest}/f_{obs}), \qquad (3)$$

and when the sound source is moving away from the observer, the relation between the frequencies is given by

$$v_{source} = v_{sound}(f_{rest}/f_{obs}-1),. \qquad (4)$$

In these equations, v_{sound} is the speed of sound, which is 343 m/s at 20° C.

Equipment

- *Sound source* – You can use a smartphone with a tone generator app. Many such apps can be either purchased or downloaded for free for Android and Apple devices; we use Tone Generator Pro on an iPod Touch.
- *One high-sensitivity microphone* – This should be a highly amplified microphone, not standard microphones. We use a Sonic Sleuth microphone, but this microphone and similar microphones are also sold under other names (such as Bionic Ear and Sonic Explorer).
- *Audio cable*
- *Computer with frequency analysis software* – You need a program that can plot sound intensity versus frequency, We are using Spectrum Lab by Wolfgang Büscher (http://www.qsl.net/dl4yhf/spectra1.html) on a laptop running Windows 8. This software is free.
- *Tape measure or ruler*
- *Timer*

Procedure

1. Find a space where someone can run several meters. This experiment may need to be set up outdoors, in a gym, or in a long hallway. Measure a distance (such as 5 m) over which you will measure a person running with the sound source. Mark the end points of these locations.

2. Turn on the computer and start the sound analysis program. The program needs to be set up to show the intensity of the sound as a function of frequency.
3. Plug the microphone into the computer. The microphone should be set up about 1 m from the finish point.
4. Turn on the sound source and set the frequency. A frequency between 1500-2000 Hz works well for this experiment.
5. Measure the frequency of the sound when the sound source is stationary. The sound wave should appear as an intensity spike. Zoom in on the frequency where the intensity spike is seen; you want to display a range of 40-50 Hz with the intensity spike in the middle.
6. Simultaneously have three people do the following:
    a. One person should run with the sound source towards the microphone. It would be good if the person starts running about 1 or 2 m before reaching the start point so that he is at full speed when he passes between the start and finish points.
    b. One person should time the runner as he passes between the start and finish points.
    c. One person should measure the maximum frequency of the sound source when the runner passes between the points. This will be the maximum frequency of the location of the intensity spike displayed by the sound analysis software. *If possible, the frequency should be measured to 4 significant figures.*
7. Repeat step 6 several times.
8. Repeat step 6 several times, but this time, the runner should run away from the microphone. In this case, the person measuring the frequency should measure the minimum frequency of the sound source.
9. Use Equations 3 and 4 to calculate the velocity of the runner in each trial. Compare this to the velocity that you measure using Equation 2.

Additional Exercises

1. Try repeating the experiment with a different frequency (one that is 2 times higher or lower in frequency). Do you get the same answer?
2. Instead of comparing the velocities, solve Equations 2, 3, and 4 for the speed of sound.