Sound Waves

Objective

In this lab, you will investigate the properties of sound wave using an online tone generator and Microsoft Excel. This lab explores the concept of **modelling**, where we will use Microsoft Excel to create things we cannot directly observe with math and draw conclusions based on what we create. Specifically, you will:

- Generate sound with the online tone generator, and use Excel to model the waves and observe the differences in the properties of the waves,
- Generate two different frequencies simultaneously to observe beats,
- Use a YouTube video to observe the Doppler Effect, and use provided data to determine the speed of the car based on the sound of the horn alone!

Materials

- Online Tone Generator: https://onlinetonegenerator.com
- Microsoft Excel
- Doppler Effect YouTube Video: https://www.youtube.com/watch?v=a3RfULw7aAY

Background Information

Sound Waves

Sound waves are disturbances that move air molecules forward and backward, along the direction that the sound is traveling. These simple disturbances combine to produce anything from a fugue to a symphony to a rhapsody to a guitar riff. In all music there are distinct and regular patterns formed by sound waves.

As with waves on a string, sound waves have a relationship between period T and frequency f; for a refresher on these terms, take a look back at the **Anatomy of a Wave** section in the Wave Patterns on Massive Strings lab. The relationship between period and frequency is

$$f = \frac{1}{T} \tag{1}$$

A wave can be defined with a sinusoidal equation,

$$y = A\sin(\omega t) \tag{2}$$

where A is the amplitude of the wave (how loud in the case of sound), t is the time, and ω is the angular frequency. ω is defined as

$$\omega = 2\pi f \tag{3}$$

Beats

Beats occur when two waves superimpose with very similar (but different) frequencies; the information on superposition was also covered in the Background Information of the Wave Patterns on Massive Strings lab. The beat is the interference pattern between the two sound waves as they overlap. The rate of the beat pattern or **beat frequency** is the difference between the two frequencies.

The Doppler Effect

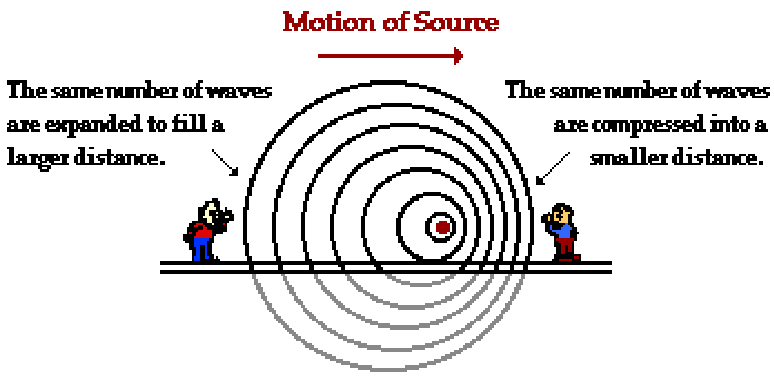

Figure 1: The Doppler Effect. Notice the difference between standing where the source of the sound is receding (Point A) and where the source of the sound is approaching (Point B).

Imagine you are sitting in your car at a railroad crossing, and the train blows the horn as it passes you. As the train gets nearer, the volume of the horn increases and then decreases as the train passes you. However, something else changes about the sound of the horn as it passes you.

Figure 1 illustrates why the sound changes when the source is approaching or receding. As the sound source approaches (for the observer on the right in Figure 1), the sound waves are "bunched up", causing the wavelength to decrease and the frequency to increase. The frequency heard as the source approaches is calculated by:

$$f_{approaching} = \frac{1}{1-\frac{v_{source}}{v_{sound}}} f_{source} \tag{4}$$

where v_{source} is the velocity of the source (the object making the sound), f_{source} is the frequency of the sound being made by the source, and v_{sound} is the speed of sound in air (typically, around 343m/s, however, this value can change depending on a variety of factors, including temperature!). As the sound source recedes (for the observer on the left in Figure 1), the sound waves are "spread out", causing the wavelength to increase and the frequency to decrease. The frequency heard as the source recedes is given by:

$$f_{receding} = \frac{1}{1+\frac{v_{source}}{v_{sound}}} \ f_{source} \tag{5}$$

Notice that these two equations are different! Think about how the change from a positive sign to a negative sign in the denominator of each equation would affect the frequencies heard.

This is very similar to how police officers determine the speed of a car. Radar uses radio waves rather than sound waves (you will learn about radio waves in the second semester physics class). Police officers bounce radio waves off of moving cars and measure the frequency shift in the returning waves compared to the signal that was sent out. The greater the shift, the faster the car is moving towards or away from the officer!

To calculate this, Equations 4 and 5 are combined and rearranged to give us

$$v_{source} = \frac{X}{2-X} v_{sound} \tag{6}$$

where the variable *X* is the frequency shift, given as

$$shift\ in\ frequency = X = \frac{f_{approaching} - f_{receding}}{f_{approaching}} \tag{7}$$

What this means is that we can determine the speed of an object simply by how the sound changes when it passes an observer!

Procedure

Part 1: Musical Notes

In this part of the lab, you will use an online tone generator (either search for your own, or use the one in the Materials List) to generate tones at the musical notes of low C, middle C, and high C. Using those frequencies, you will plot the corresponding sound waves in Excel to qualitatively look at the waves.

1. Open the tone generator in your browser (https://onlinetonegenerator.com). Change the frequency to 262Hz, and press Play (to avoid damaging your ears (especially if you're using headphones!) make sure the volume toggle on the site is set low, and that your volume settings are also low – increase them until you can hear the tone).

2. Change the frequency to 131Hz, and then to 524Hz. You may need to use headphones to hear the 131Hz tone. The 131Hz, 262Hz, and 524Hz are the frequencies for low C, middle C, and high C respectively. Answer Question 1 in the report.

3. Change the type of wave in the tone generator. At each frequency, listen to a sine, sawtooth, and triangle waveform. Answer Question 2.

4. You will now model these musical notes as waves in Excel. Open a new Excel file, and label your first column as time. We want to put several time increments in Column A, starting at 0.001s and increasing by increments of 0.0005s until we reach 0.015s. To do this, type 0.001 in cell A2 (directly underneath your column header), and type 0.0015 into cell A3. Highlight both A2 and A3, and hover over the square in the lower right corner (see Figure 2, next page). Drag your time values down until you reach a value of 0.015. You have now autofilled a column of data for time, and it was way faster than trying to do it manually!

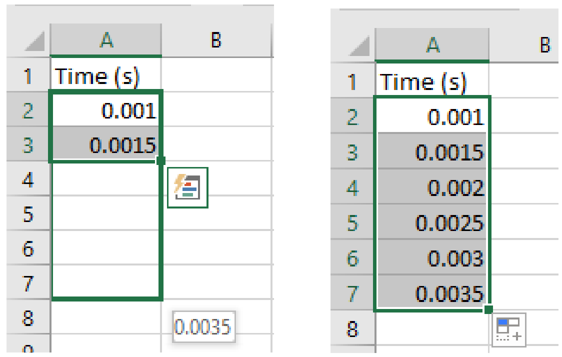

Figure 2: Autofilling cells in Excel. (left) When you click on the small box in the lower right corner of your two cells, your cursor will change to a thin black crosshair. Drag downward until you reached your desired value. (right) The result of the autofill gives you incrementally spaced values.

5. In column B, we can model the equation for our wave using Equation 2. We will assume an amplitude of 60dB, and we will start by using the low C frequency (131Hz). Calculate the angular frequency using Equation 3, and then input Equation 2 into cell B2 (you will need to call cell A2 for the time *t*). You can find a refresher on how to use Excel equations in the Introduction to Data lab module, under the Useful Videos and Tutorials Page – the Intro to Excel video would be a good refresher.

6. Once you define cell B2, click the same box in the lower right corner you did for Step 4 and drag the value to last row of your data table. Check that the values in your column are different from each other; if you have the same value repeating, you need to make sure that you call the cell for time, not just type in the number.

7. Repeat Steps 5 and 6 for columns C and D to create waves for middle C (262Hz) and high C (524Hz).

8. Plot the data for your three waves on a single graph; to do this, simply highlight all four columns of data and create a scatter plot <u>with a line</u>. Answer Questions 3 and 4.

Part 2: Beats

In this part of the lab, you will play two tones simultaneously to produce beats, and model the waves in Excel.

1. Open the online tone generator in two different tabs in your browser. Make sure that each tab is selected on sine waves. In one tab input a frequency of 262Hz, and in the second input a frequency of 280Hz. Play both of the tabs separately, and then at the same time. Answer Question 5.

2. Create a new sheet in Excel (you can do this in the same file from Part 1 by clicking on the 'plus' sign along the bottom of your screen, near where it says "Sheet 1"). Create a time column using the same technique as in Part 1; you need a start time of 0.001, a time increment of 0.0005, and an end time of 0.06.

3. Create two waves, one for each frequency (262Hz and 280Hz). You will use the same equation and technique you used in Part 1. Assume an amplitude of 60dB, and make sure your wave data columns extend down to the end of your time data.

4. In a new column, superimpose the waves by adding them together at each time. Use Figure 3 to check your work; these should be the values you have.

	A	B	C	D
1	Time (s)	262Hz Wave	280Hz Wave	Superimposed Wave
2	0.001	59.82953402	58.93723504	=B2+C2
3	0.0015	37.36726683	28.90522045	
4	0.002	-9.013535347	-22.08747316	
5	0.0025	-49.62483446	-57.06339098	
6	0.003	-58.47161237	-50.65967553	
7	0.0035	-29.89110632	-7.519994014	
8	0.004	17.82249489	41.07282636	
9	0.0045	54.12803756	59.88160371	
10	0.005	55.78658915	35.26711514	
11	0.0055	21.736522	-14.92139323	
12	0.006	-26.226946	-54.28962315	
13	0.0065	-57.40272309	-54.28962315	

	A	B	C	D
1	Time (s)	262Hz Wave	280Hz Wave	Superimposed Wave
2	0.001	59.82953402	58.93723504	118.7667691
3	0.0015	37.36726683	28.90522045	66.27248728
4	0.002	-9.013535347	-22.08747316	-31.10100851
5	0.0025	-49.62483446	-57.06339098	-106.6882254
6	0.003	-58.47161237	-50.65967553	-109.1312879
7	0.0035	-29.89110632	-7.519994014	-37.41110033
8	0.004	17.82249489	41.07282636	58.89532125
9	0.0045	54.12803756	59.88160371	114.0096413
10	0.005	55.78658915	35.26711514	91.05370429
11	0.0055	21.736522	-14.92139323	6.815128772
12	0.006	-26.226946	-54.28962315	-80.51656915

Figure 3: Creating two waves in Excel; check your values against the ones shown above. The photo on the left shows the function you should use to calculate the sum, and the photo on the right shows the values you should get for the sum.

5. Plot the summation (the "Superimposed Wave") vs. Time as a scatterplot <u>with a line</u>. Answer Question 6.

Part 3: The Doppler Effect

In this part of the lab, you will watch a YouTube video that displays the Doppler Effect. You will then use provided data to determine the speed that the car is moving based only on the sound the horn makes.

1. Open the following YouTube video (https://www.youtube.com/watch?v=a3RfULw7aAY) and listen to the sound of the car's horn as it passes. Answer Question 7 in the report.

2. Open the "Dopper Effect Data" file from the Canvas module. This file has three columns; the time, the sound wave as the horn approaches, and the sound wave as the horn recedes. Plot all of this data as a scatter plot <u>with a line</u>.

3. You will input all of the following values into Table 1 of the report. Determine the period of each of the two waves, and use this period to calculate the frequency of each wave. Calculate the frequency shift, as given in Equation 7. Use Equation 6 to determine the speed of the car (v_{source}), given that v_{sound} is the velocity of sound in air, 343m/s.

4. Save your report as a PDF, and upload both the report <u>and your Excel file</u> to the Canvas assignment. You're done!