

# PHYS 1P92 Experiment 03

## Oscillatory Motion and Waves: Speed of Sound

---

### Notes

- Words in **blue** are links to additional reading or videos.
- Text in **gray** boxes are hints and things to take note of.
- Text in **red** boxes are important instructions or prompts that guide you to DISCUSS some of the key RESULTS and CONCEPTS learned in the lab. These prompts may not be the only items that need to be included in your report.

### 1 Objectives

- Determine the speed of sound using a tube of paper, a speaker, and the iOLab's microphone.
- Understand the relationship between sound, frequency, and wavelength.
- Understand harmonic frequencies.

**For each equation that error propagation must be used please write both the equation and the propagation rules/derivation on a separate piece of paper. Scan and submit it as a second file with your lab on Sakai. There are lots of free document scanner apps which can be used to scan and create files with your phone. Follow the instructions found [here](#).**

### 2 Introduction

The **speed of sound**  $v$  has the same relation to wave frequency and wavelength as all waves do:  $v = f\lambda$ , where  $f$  is the frequency of the wave and  $\lambda$  is its wavelength.

When we play a sound through a tube with the far end closed, the waves travel through the tube at the speed of sound. When they hit the other side of the tube, they reflect back

to where they came from. The **resonant frequencies** of the tube are those for which the reflected wave will be aligned so that it interferes constructively with the incoming wave, creating resonance. This is shown in Figs. 17.22 through 17.25 in the [Openstax book](#).

The lowest resonant frequency is called the **fundamental**. All resonant frequencies are integral multiples of the fundamental, and they (including the fundamental itself) are collectively called **harmonics**. The next higher resonant frequency after the fundamental is called the **first overtone**, the one after that is called the **second overtone**, and so on.

### 3 Procedure

In this lab, you will need:

- A speaker (laptop speaker, phone speaker, headphones, *etc*).
- Two to four pieces of regular paper and tape (DO NOT use the conductive paper from the accessory kit).

#### 3.1 Theoretical derivation

Sound waves occur as highs and lows of pressure in the air. When you are passing a sound wave through a closed tube, the fundamental frequencies manifest themselves in a shape like the figures below. Note that the amplitude of the wave represents the pressure created by the sound at that point in the tube.

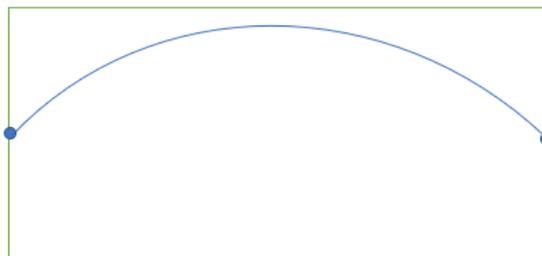


Figure 1: The first resonant frequency is called the fundamental frequency and manifests itself as a wave in which the length of the tube  $L = \frac{1}{2}\lambda$ .



Figure 2: The second resonant frequency fits a whole wavelength exactly in the tube, causing  $L = \lambda$ .

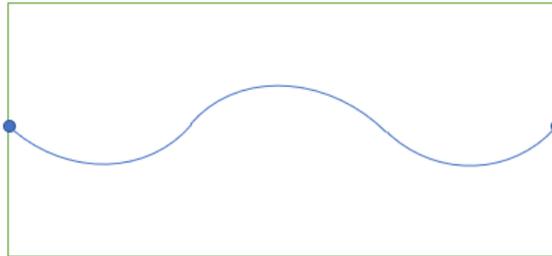


Figure 3: The third resonant frequency follows a similar trend to the above figures. In this case the wave manifests  $\frac{3}{2}\lambda$  in the length of the tube.

Following the pattern from Figures 1-3, as well as the formula  $v = f\lambda$  one can derive an expression for the fundamental frequencies of a tube of given length.

Derive the correct formula for this case, using the fact that the waveform must have a node at each of the closed ends. (Hint: What length of  $L$  is the next fundamental frequency wavelength?)

### 3.2 Preparing the frequency sweep generator

For this lab we will use the following online frequency sweep generator:

<https://onlinetonegenerator.com/frequency-sweep-generator.html>

Open the website on your device (computer, phone, tablet. . .). You can also Google “frequency sweep generator”, and it will be one of the first results.

To understand how the tone generator works, experiment with different settings for start and end frequency, duration, waveform (sine, square, sawtooth, or triangle), linear or exponential sweep, and volume. Make sure to **uncheck “Continue playing tone after sweep has finished”**, otherwise it will keep playing indefinitely!

The recommended settings for this experiment are:

- Start frequency: 100 Hz
- End frequency: 5000 Hz
- Duration: 10 seconds
- Waveform: Sine
- Sweep: Linear
- Continue playing tone after sweep has finished: No
- Start volume: 50
- End volume: 10

### 3.3 Creating the tube

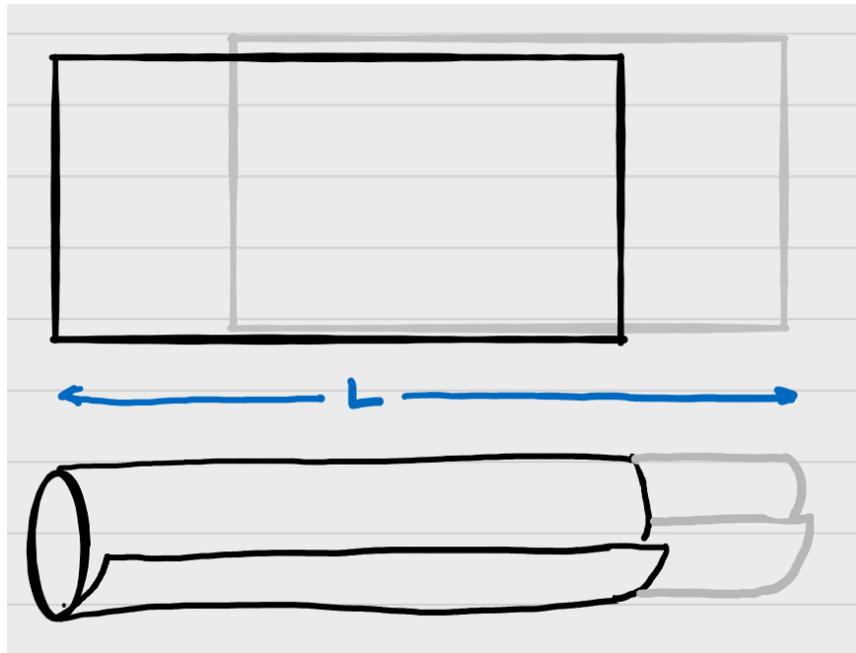


Figure 4: Rolling a sound tube from two pieces of paper.

Take two pieces of paper and overlay them lengthwise one atop the other, with an offset to the left or right, making the total length longer than the individual pieces of paper, as shown in Figure 4. Roll them into the shape of a tube of arbitrary fixed length  $L$ , and tape them together.

**IMPORTANT:** the diameter of the tube should be quite small so that when one end is placed on the iOLab device it covers the microphone sensor but doesn't go over the edge. This experiment looks at a tube closed at both ends, so you want the 'open' air allowed to enter the tube from either end to be at a minimum.

You may make the tube thicker (and thus more soundproof) by using more than one piece of paper.

Measure and record the length of the tube from one end to the other.

The length  $L$  at which you set the tube is arbitrary and chosen by you. Make sure to tape it so that the length does not change during the experiment.

### 3.4 Recording a calibration run

First, we will make a recording **without** the tube, so we can compare it to the recording with the tube later.

Put the iOLab microphone (located at the top left of the device) in front of the speaker, separated by the length of the tube, but without playing the sound through the tube itself.

You can place the tube between the speaker and the iOLab device to get the approximate distance, and then move the tube to the side **before** playing the sound. Similarly, you could use a tape measure/ruler to approximate the distance.

Open iOLab Online and set the collect time to 12 seconds. Record a full frequency sweep.

If the top and bottom of the recorded waveform are flattened out at maximum intensity, this means that the volume of your speaker is too high, resulting in a distorted waveform. Decrease the volume of the speaker and try again.

If the waveform is too small, this means that the volume of your speaker is too low. Increase the volume of the speaker and try again.

Try to make the waveform as uniform as possible. If the intensity is too high or low at higher frequencies compared to lower frequencies, adjust the end volume in the generator.

Once you reached the optimal volume, the waveform should look somewhat similar to (but definitely not exactly the same as) this:

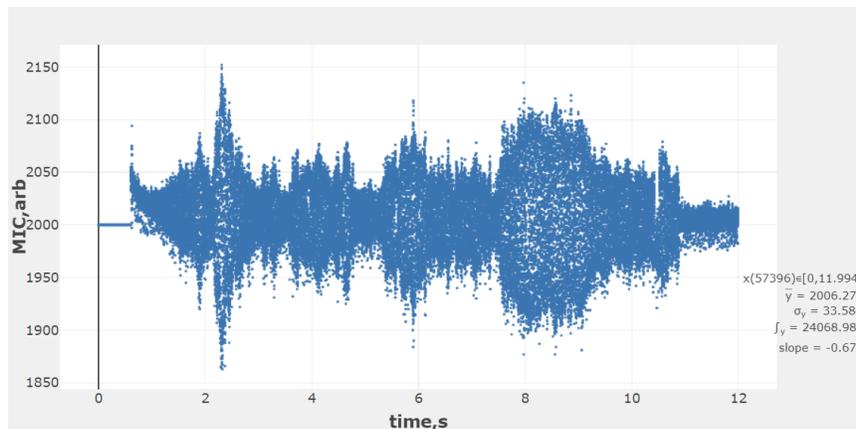


Figure 5: The calibration waveform.

Look at the waveform you recorded and notice how it is mostly homogenous. There may be some peaks here and there, but they do not occur at regular intervals.

### 3.5 Recording through the tube

Put the speaker or headphones at one end of the tube, and put the iOLab microphone at the other end of the tube. Make sure that both ends of the tube are **completely covered**, so that you can use the formula **you** derived above for a tube closed at both ends.

Record a full sweep using the iOLab Online software.

Optimize the volume of your speaker like before (section 3.4), so that the waveform is uniform in volume, and neither distorted nor too quiet. Note that since the tube

amplifies the volume, you will need to use a lower volume this time, compared to the calibration run.

The waveform should look somewhat similar to this:

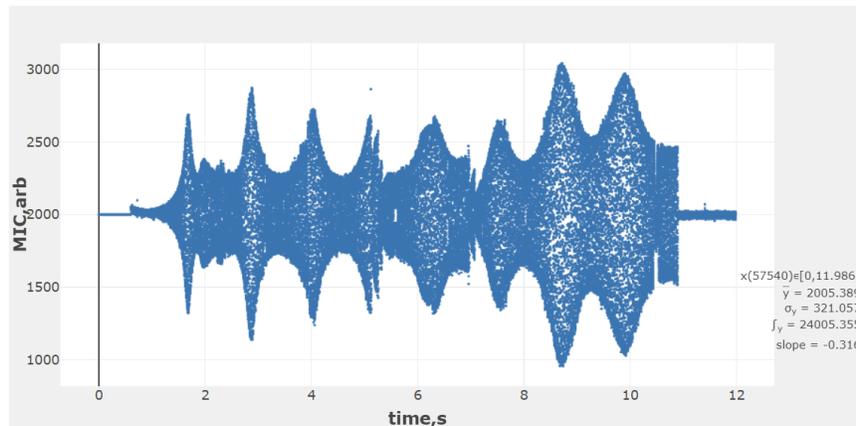


Figure 6: The waveform as recorded through the tube.

You will now notice very prominent **regular** peaks in intensity throughout. These peaks are a result of the resonance in the tube, which is why they were not present when we recorded without the tube.

### 3.6 Analyzing the results using a Fourier transform

The recorded waveform is displayed in the **time domain**, which simply means that the  $x$  (horizontal) axis represents time. However, for this experiment, we are interested in finding the resonant frequencies, so we need to convert the waveform to the **frequency domain**, where the  $x$  axis represents frequency.

A **Fourier transform** converts the signal from the time domain to the frequency domain. Since the computer records the signal in discrete steps, we will be applying a **discrete** Fourier transform. More specifically, we will be using an algorithm called **fast Fourier transform**, or **FFT** for short.

In iOLab Online, hover with the mouse over the waveform plot and click on the “Toggle FFT” button:

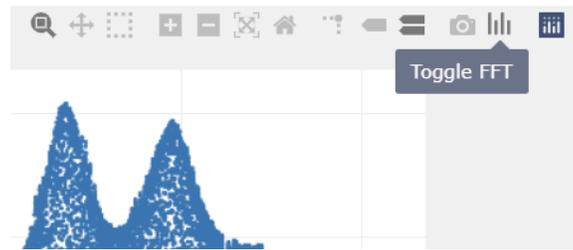


Figure 7: The “Toggle FFT” button.

Now, with the mouse, select the first peak on the top graph (the time domain). It will be highlighted in orange, and you will get a corresponding peak in frequency on the bottom graph (the frequency domain):

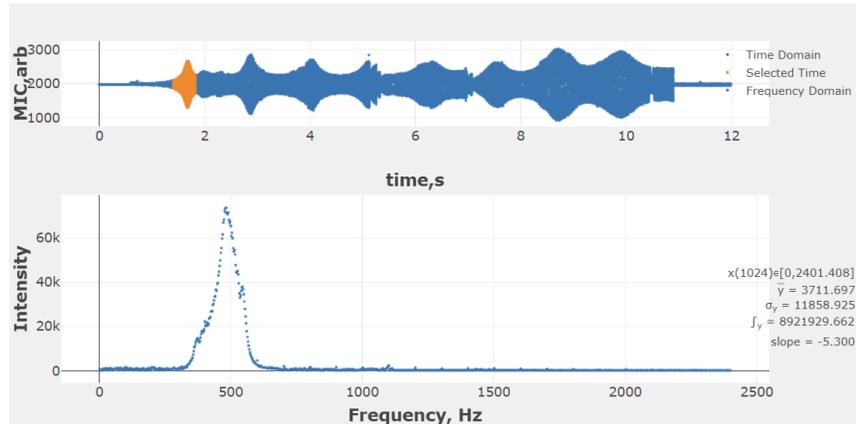


Figure 8: The Fourier transform of the first peak.

Make sure not to select the entire waveform! This may crash your browser, as it will give the algorithm too much data to process. Furthermore, it will not produce any usable information, since we need to process each peak separately, to get the frequency that caused the resonance at that particular point in time.

Record the frequency from the FFT of the first peak in your microphone waveform. See Figure 8 for a properly selected setup. Record the frequency of the tallest peak in the Fourier transform plot. If you see multiple peaks close together do your best to find the average value OR go back and select a slightly different region in your Mic graph (still centered around the same microphone waveform).

Do the same for the next three peaks. You should now have a total of four frequencies.

The precision of the frequency value in the FFT plot depends on the amount of significant figures iOLab Online has been told to report. The actual uncertainty in this measurement is dependent on the collection frequency and the sample window. It can be calculated as:

$$\sigma_f = \frac{4800 \text{ Hz}}{(\text{End Frequency} - \text{Start Frequency}) * \text{Duration}}$$

The uncertainty for all frequencies determined this way will be the same. See page 4 if you do not know what the Start and End Frequencies refer to.

Now repeat this above experiment two more times with different lengths of tubing. However, find the first resonant frequency only this time. Record the length of the tube as well as the frequency.

Calculate the theoretical resonant frequencies for all of your experimental frequencies. Use the known speed of sound in air at room temperature.

Do the theoretical values match the experimental values?

### 3.7 Calculating the speed of sound

You are now ready to calculate the main result of this experiment:

Based on the formula you derived above, calculate the speed of sound using the four resonant frequencies that you measured and the length of the tube from the first trial. Note that each frequency will have a different value of  $n$ .

Put this data into iOLab Online with  $n$  as your  $x$ -axis data, and the speed of sound as your  $y$ -axis data. Record the average and standard deviation of this plot. This will give you the average value for the speed of sound.

Don't forget to do a sanity check on your results! Compare your results with the known value of the speed of sound in air. If your measurement differs from this value by more than ~25%, then you

probably did not do the experiment or calculation correctly.

Use the two additional fundamental frequencies from your trials of varying lengths, and the first fundamental frequency you acquired in the constant length trial to plot the frequency (as  $y$ ) and lengths (as  $x$ ). In the fitting equation box below the data window type in  $A/(2*x)$  and click the FIT button. A fit line that closely matches your data should appear.

Record your value for fit parameter A and its uncertainty. Compare the fit  $y = \frac{A}{2L}$  to the equation  $f_n = \frac{nv_s}{2L}$ . What does the parameter A represent? Note: adding a constant (B) to your fit may help if the fit doesn't look too good.

Is the acquired value for A in agreement with your previous value acquired?

### 3.8 Creating a diagram of the results

Using the constant length trials experimental frequencies create a schematic of the waveforms to see if you identified the correct resonant frequencies. The trial you pick must have at least 3 resonant frequencies!

First you must convert the frequencies to wavelengths using the true value for speed of sound in air at room temperature.

You will plot the waveforms (using Desmos) for the first three resonant frequencies as a function of length using the formula below. (Note  $n$  stands for the resonant frequency number *i.e.*  $n = 1$  corresponds to the first frequency,  $n = 2$  corresponds to the second, *etc.*)

$$y = \sin(2 * \pi * x / \lambda_n)$$

In this function  $x$  represents **Length**. Make a line on the graph at  $x=L$ , where  $L$  is the value of the length of your tube in meters. Essentially, your tube runs from  $0 \rightarrow L$ .

Along with the vertical line, plot the waveform for the first resonant frequency using the equation above. Repeat this for the second and third waveforms.

Do your resonant frequencies line up with the theoretical predictions based on your schematic?

Thought Experiment: The speed of sound in air depends on temperature. Describe how you could estimate the speed of sound at a different location with a sufficiently different temperature (*e.g.* outside in the snow) by repeating the experiment there, assuming that the temperature at the location where you performed the original experiment is known.

## Finishing Up

Now that you have completed the lab, be sure you filled out all portions of the data tables (templates found in the Resources Tool on [Sakai](#)), include figures, and develop a robust discussion using prompts found throughout the manual.

Ensure to give yourself enough time to complete the report and to hand it in by the due date as late lab reports will not be accepted! If you have any questions please attend a live lab session to get help from one of the course lab demonstrators, or email [Phys1P92@brocku.ca](mailto:Phys1P92@brocku.ca).