

Sound and Resonance



Prelab

LR

Write experiment title, your name and student number at top of the page.

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Prelab 1: Write the objective of this experiment.

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Prelab 2: Write the relevant theory of this experiment.

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Prelab 3: List the apparatus and sketch the setup.



Have these ready to be checked by lab staff
at the door on the day of your lab.

Introduction

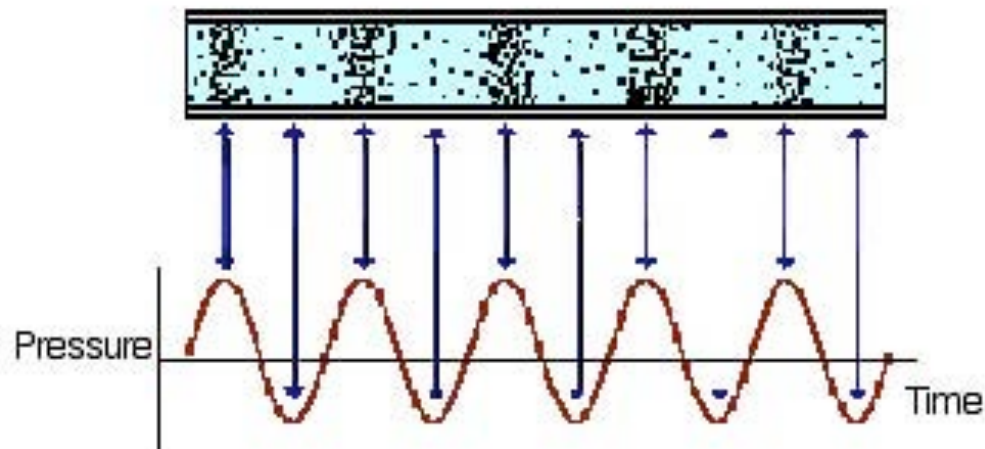
In this experiment, we'll look at sound and resonance in tubes; in the first case a tube open at both ends, and secondly open at only one end.

Resonance happens when there is an external force or boundary on an oscillation such that, at specific frequencies, there is a notable increase in amplitude of the wave as they constructively interfere.

Using FFT analysis, we'll study the resonances in tubes, the harmonics, and look at the frequencies that resonate and compare that to what we predict based on the geometry of the tube.

Introduction

Sound waves are **longitudinal** pressure waves. They can propagate in gases, liquids and solids. Sound waves in air travel by the motions of the air molecules as variations in the air pressure with respect to time. A sound wave in air creates regions of high pressure and regions low pressure, as shown below. These regions correspond to the wave crests and troughs, respectively. A sound wave of a single frequency is depicted here. Notice, in the diagram below, that **the pressure varies sinusoidally with respect to time**.



Speed of Sound in Air

The speed of sound in air depends on the ambient air temperature according to

$$v = 331 \text{ m/s} + \left(0.6 \frac{\text{m}}{\text{s}^\circ\text{C}}\right) T_C$$

where T_C is the **air temperature** in degrees Celsius.

Recall the general wave speed equation

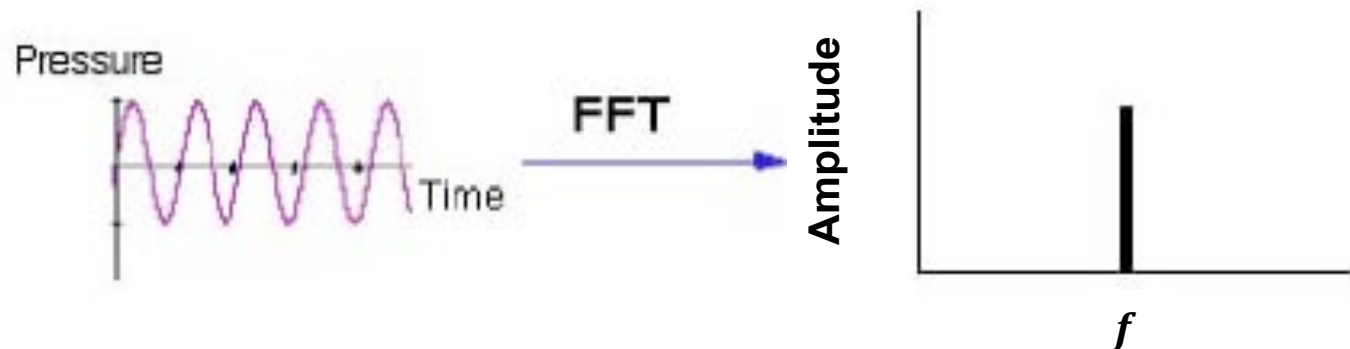
$$v = f\lambda ,$$

where f is the **frequency** and λ is the **wavelength**. Using this, we can relate the wave speed, in this case the speed of sound in air, to the frequency and wavelength of the resonating sound wave.

Fast Fourier Transform

The Fast Fourier Transform (FFT) procedure decomposes a sound wave (pressure versus time data) into its constituent frequencies.

Some sounds consist of only one note, such as the sound produced by a tuning fork in the last experiment. In this case, the FFT of that sound wave would register a single frequency, f , which corresponds to the frequency of that note as shown below.

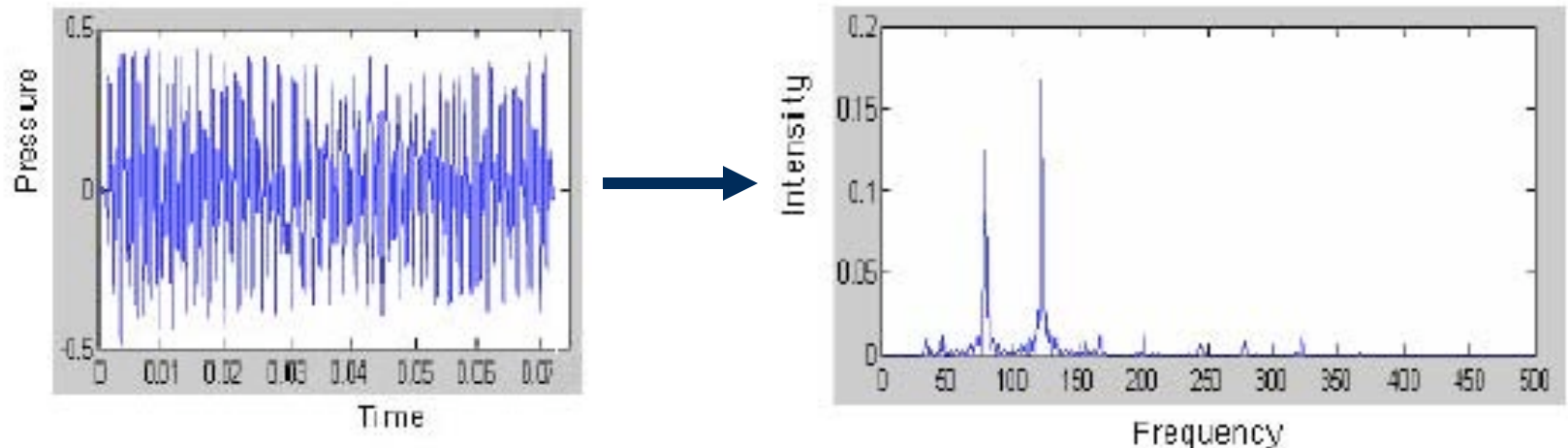


Fast Fourier Transform

Some sounds consist of multiple frequencies some of which may be more intense than others. In this case, the FFT procedure tells you which frequencies the sound contains and the relative amplitudes of each.

Depicted below (left) is a seemingly complex sound wave, consisting of two frequencies of different amplitudes, as well as some low intensity noise.

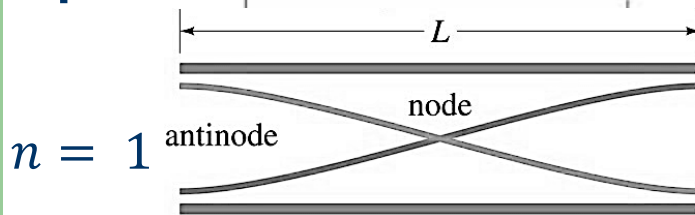
The plot below (right) is the FFT of the same sound wave showing the two dominant frequencies.



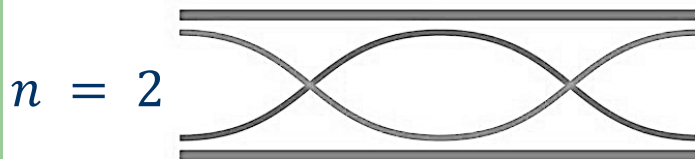
Resonance in Tubes

It's important to recognize that when a tube is resonating, many standing wave patterns coexist within the tube at the same time, not just a single frequency. These frequencies are referred to as the **harmonics**.

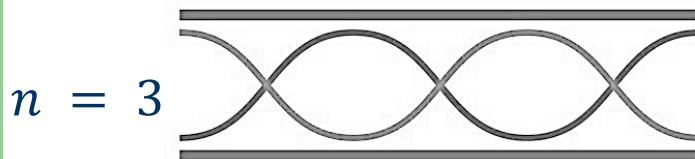
The **harmonic number**, n , indicates the mode of the resonance and determines the number of wavelengths present in that mode. For a tube **open at both ends**, the first three resonances are as follows:



$$f_1 = (1) \frac{v}{2L}$$



$$f_2 = (2) \frac{v}{2L}$$



$$f_3 = (3) \frac{v}{2L}$$

The general relationships are:

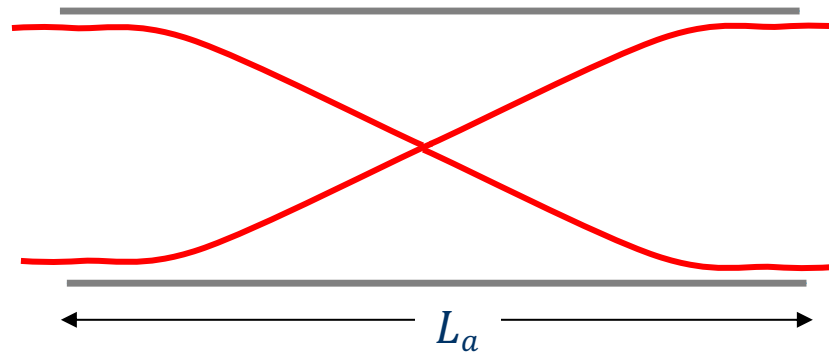
$$\lambda_n = \frac{2L}{n} \text{ and}$$

$$f_n = \frac{nv}{2L} ,$$

where $n = 1, 2, 3, \text{etc.}$

End Correction for Real Tubes

A primary difference between standing waves in real tubes and ideal is that a portion of the wavelength actually protrudes a small distance outside the tube.



An **end correction** accounts for this extensions beyond its actual length L_a . The end correction for a tube of **radius** r , is given by $L_{ec} = 0.61r$.

A tube of length L_a open at both ends will have an end correction for both of the open ends so that the **corrected length** of the tube is

$$L = L_a + 2L_{ec} .$$

Use this corrected length in all calculations.

Apparatus and Setup

The following equipment is provided:

- Microphone
- Tube
- End cap
- Metre stick
- Optional: digital caliper or steel ruler



Microphone

The microphone is shown at right.

The active element (transducer) is the 9 mm diameter disk located on one end of the plastic case.

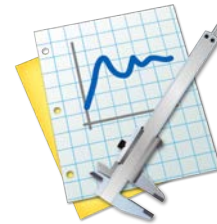
This transducer is very susceptible to wind noise. As such, air should not be blown directly into the transducer.

The cord should be plugged into the **CH1** socket on the *LabPro*.



Logger Pro

Click the icon to launch Logger Pro.



It should open with two graphs:

- Pressure versus time (waveform).
- Relative amplitude versus frequency (FFT).

Data will begin collecting once you click **Collect**.

To end the collection, click **Stop**.

To erase existing data and begin a new collection, click **Collect** again.

Resonance in a Tube

We will now investigate the resonance in a tube and look at the FFT results in this case. It will be useful to make some predictions for your data of sound in an open tube.

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Lab Report 1: a) Record the room temperature with uncertainty and calculate and record the speed of sound in air, with its uncertainty.

LR

b) Record your measurements for tube length and tube diameter. Calculate and record the values of end correction and corrected length with uncertainty.

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Use the **corrected length** for all following calculations.


LR

Lab Report 2: For your pipe, open at both ends, calculate the theoretical frequencies for the first 5 harmonics with uncertainties. Show your workings and record your results in a table.

LR

Lab Report 3: Sketch the predicted form for the FFT.

Resonance in a Tube

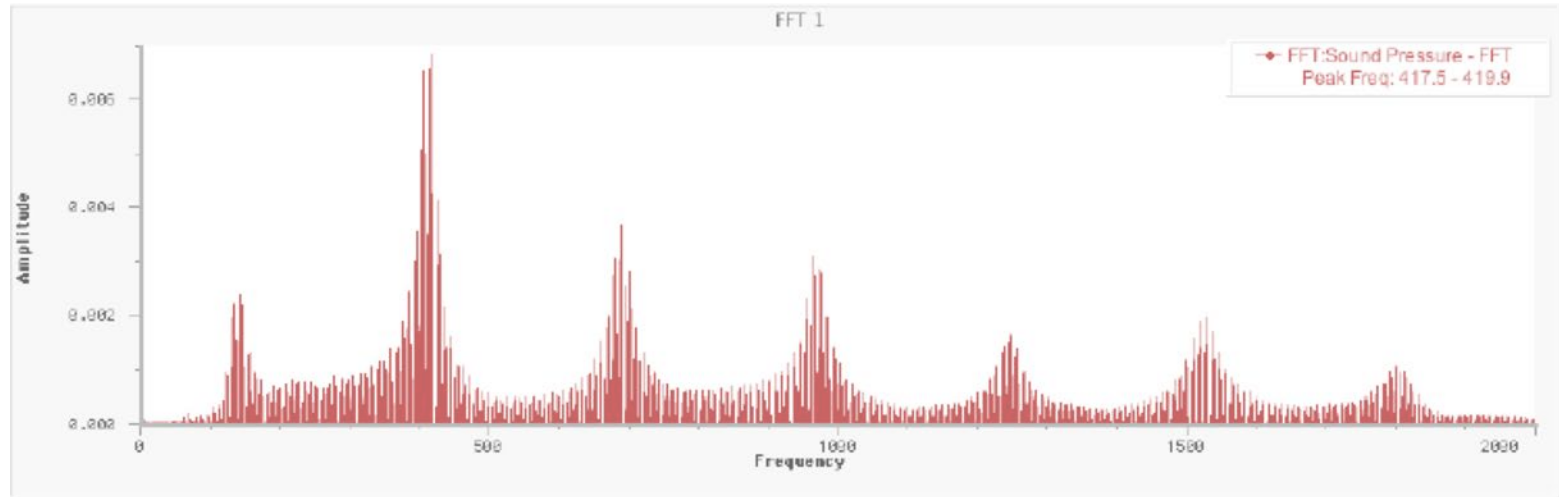
To see the resonances, we need to produce noise at one end of the tube and use FFT analysis to look at the frequency content of that noise and determine which frequencies tend to resonate. Click  or spacebar to activate Logger Pro. While holding the microphone at one end of the tube and blowing across the other end, as shown below.



Produce noise by blowing across the end of the tube, not down into it. Quick, short bursts of air tend to work best.



FFT Analysis



The FFT produced should look similar to the one shown above.


Each peak in amplitude indicates a resonant frequency, or harmonic, in the sound.

Once you have a satisfactory graph, from the top menu bar, choose:

Experiment → Store Latest Run.



Resonance in a tube

Activate the **FFT** graph by clicking on it. Use the **Analyze** and **Examine** function, or click the  button and use the cursor to determine the resonant frequencies of the observed harmonic peaks.

The first resonance is called the 1st harmonic ($n = 1$). The next successive peak is labeled the 2nd harmonic ($n = 2$), and so on.

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Record the frequencies and harmonic number of the observed resonance peaks and record their values in a table.

LR

Lab Report 4: How do the resonate frequencies from your graph compare to your predicted frequencies? Comment on any differences.

LR

Lab Report 5: Explain why there are multiple peaks and why there is still data between the peaks.

Resonance in a tube open at one end

Ensure that you have clicked **Experiment** → **Store latest run** to keep your current data as you collect new data.

Cap one end of the tube and hold the microphone just outside the open end of the tube. Collect new data by gently tapping the endcap to obtain a new FFT (It should superimpose on your previous FFT data).

Repeat data collection until the amplitudes of both data sets are roughly equal.

Use the **Examine** function to record your new resonant peak frequencies and assign their harmonic numbers. Assemble your results in a table.

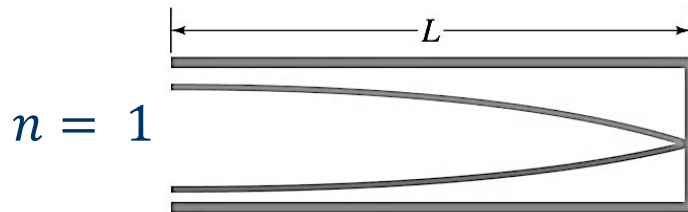
Have an instructor check your data and initial your lab report.

Lab Report 6: How does the new data differ from that of the data for a tube open at both ends? In particular, comment on the frequency values of the first resonant peaks.

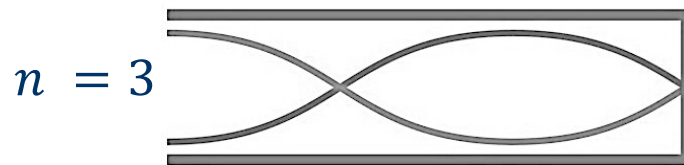
Resonance in a tube open at one end

You should notice a few differences between the two sets of data. The resonance pattern in a tube open at one end and closed at the other must have a node at one end and antinode at the other, as shown below.

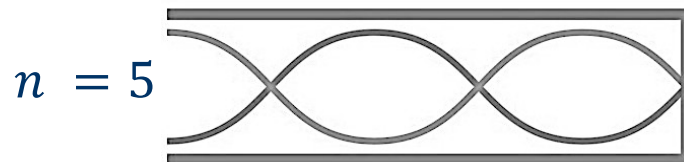
The **harmonic number**, n , in tubes open at one end are only odd integers. For a tube **open at one end**, the first three resonances are as follows:



$$f_1 = (1) \frac{v}{4L}$$



$$f_3 = (3) \frac{v}{4L}$$



$$f_5 = (5) \frac{v}{4L}$$

The general relationships are:

$$\lambda_n = \frac{4L}{n} \quad \text{and}$$

$$f_n = \frac{nv}{4L} \quad ,$$

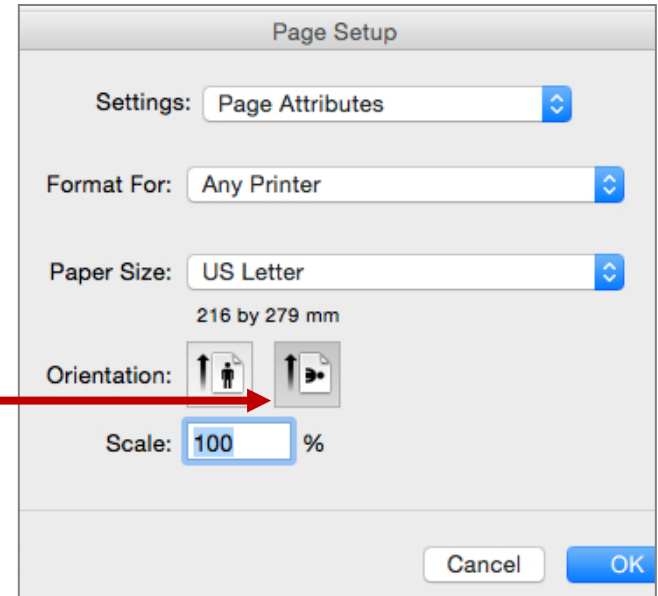
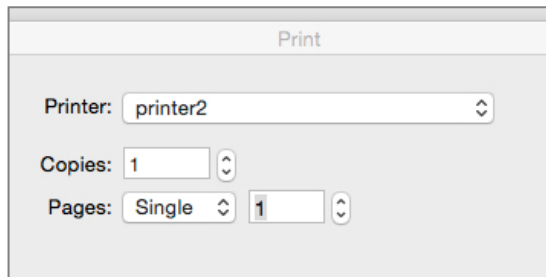
where $n = 1, 3, 5, \text{etc}$

Print FFT data

Click **File** then **Page Setup** and choose the landscape orientation.

Click **File** then **Print**.

To select the only necessary page:
Click Pages and choose Single.



Include your printed waveform and FFT with your report

Summary & Conclusion

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Lab Report 7: Briefly summarize your experiment, in a paragraph or two, and include any experimental results.

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Lab Report 8: List any sources of experimental uncertainty and classify them as random or systematic.

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Include your prelab, printed data, and all analysis with your report.