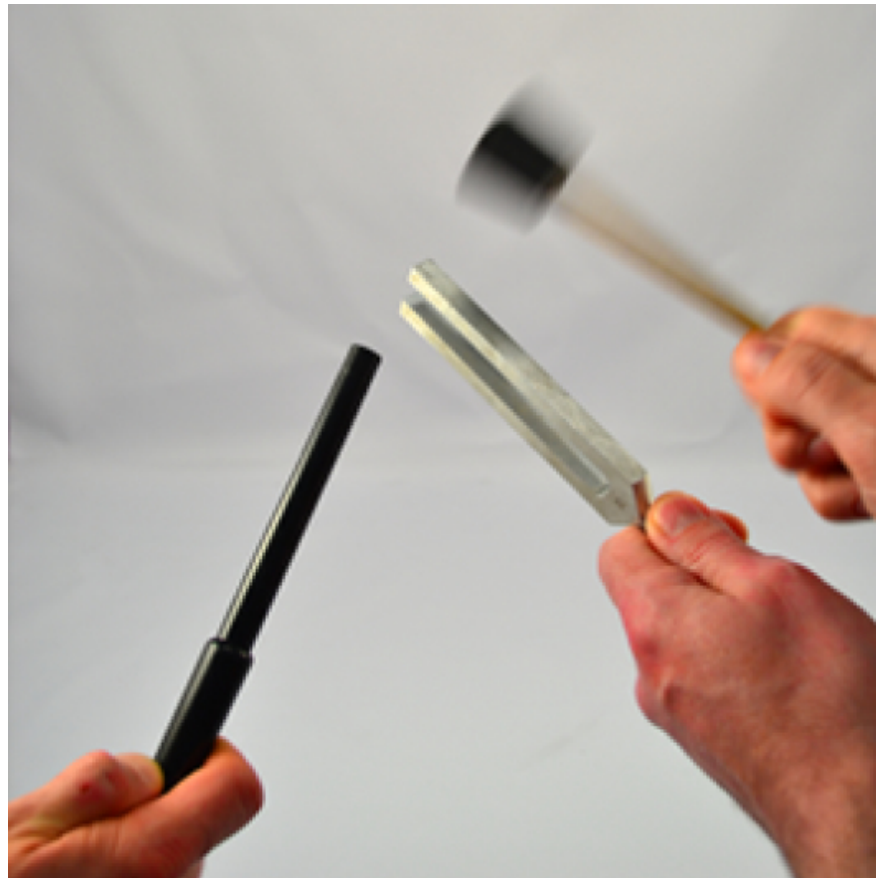
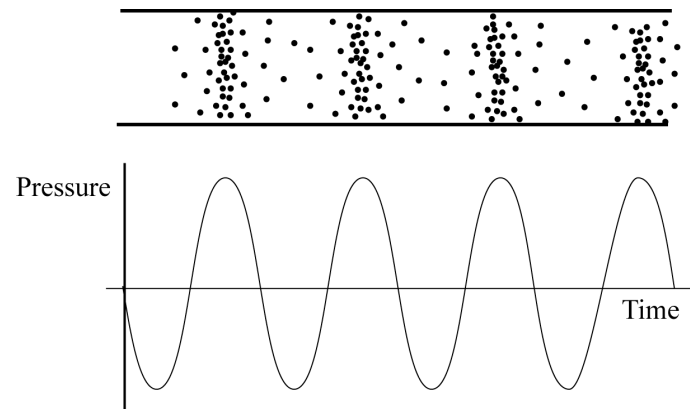


# Sound and Resonance



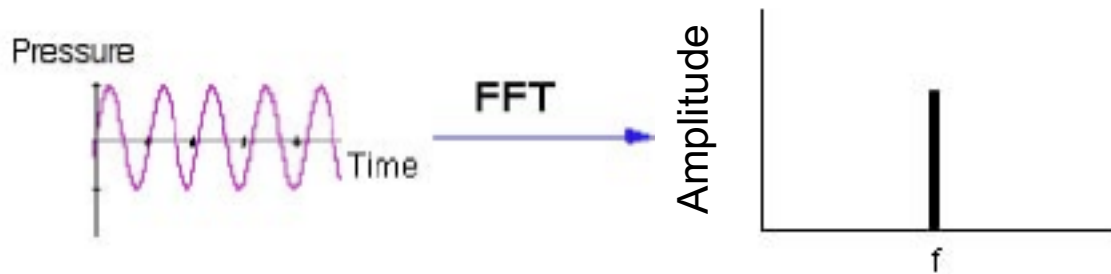
# Introduction

Sound waves are **longitudinal** waves. They can propagate in gases, liquids and solids. A sound wave in air creates regions of high pressure and regions of 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 that the pressure varies sinusoidally with respect to time.



# Introduction

The **Fast Fourier Transform** procedure, a.k.a. the **FFT**, decomposes a sound wave (pressure versus time data) into all of its frequencies. In the case of sounds consisting of only one note, the FFT of that sound wave would register a single frequency,  $f$ , which corresponds to the frequency of that note. An example is shown:



Here, we see that the single frequency shown in the pressure versus time plot – illustrated by the sinusoidal function here – is transformed by the FFT algorithm and becomes a single peak in the amplitude versus frequency plot. This indicates that only a single frequency is present in the signal. If a sound wave is composed of many frequencies, the FFT will show **all frequencies** present in that sound.

# Introduction

Frequency, velocity, and wavelength are related by the equation

$$v = f\lambda$$

A pipe **open at both ends** will allow standing waves at certain frequencies. In particular, if the pipe has length  $L$ , then it will allow frequencies of the following form

$$f = \frac{nv}{2L}, n = 1, 2, 3 \dots$$

where  $v$  is the speed of sound in air. The index  $n$  is called the harmonic number.

For a tube **open at one end**, the resonant frequencies are given by

$$f = \frac{nv}{4L}, n = 1, 3, 5 \dots$$

The speed of sound in air is temperature dependent and is given by

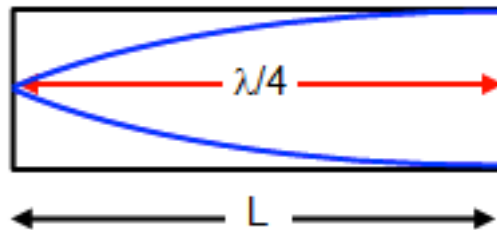
$$v = 331 \frac{m}{s} + (0.6 \frac{m}{s \text{ } ^\circ C}) T_c$$

where  $T_c$  is the air temperature in Celsius degrees.

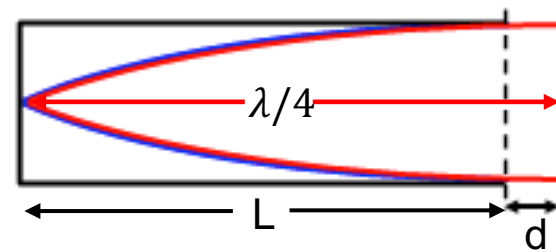
# Introduction

## Real Tubes vs Ideal Tubes

A primary difference between real tubes and ideal tubes is that when standing waves exist in real tubes, a portion of the wavelength actually protrudes a small distance outside an open end of the tube. This causes an error in calculating wavelengths in the tube.



## End corrections



# Objectives

---

In today's experiment, you will examine the sound of a tuning fork using a microphone and *LoggerPro*.

You will also produce resonance in a tube open at both ends and use your results to determine the speed of sound in air.

Finally, you will compare the resonances in a tube open at both ends to the resonances in a tube open at one end.

# Apparatus

- Microphone
- Mallet
- Tuning fork
- Tube
- Cap

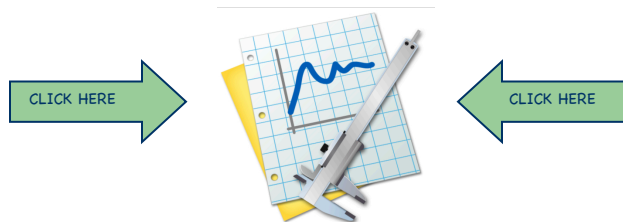
The active element of the microphone (transducer) is the 9 mm diameter disk located on the end of the plastic case. To detect sound, point the end of the microphone directly at the sound source.

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



# Experimental Method

Launch the *LoggerPro* program by clicking on the icon below.



It should open with two graphs: **pressure versus time** and **amplitude versus frequency (FFT)**.

The top graph is called the waveform. It is a sinusoidal graph. It has a distinct period and therefore a distinct frequency. The bottom graph is your FFT, showing the frequency content of the top, sinusoidal graph. Ring a tuning fork near the microphone and click **Collect**.


Only strike the tuning fork with the mallet!

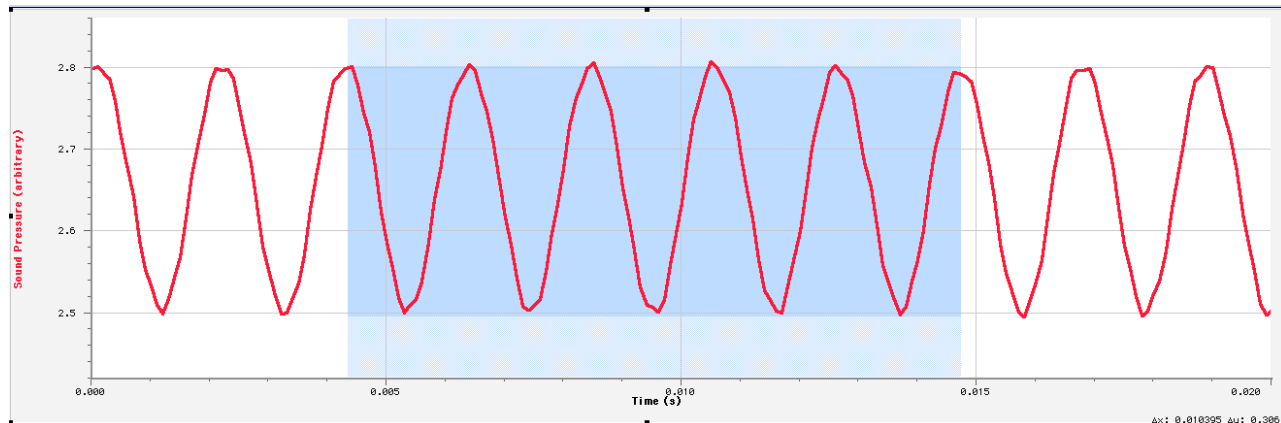




# Understanding the FFT

Highlight the peak to peak distance of five oscillations of your waveform as shown.

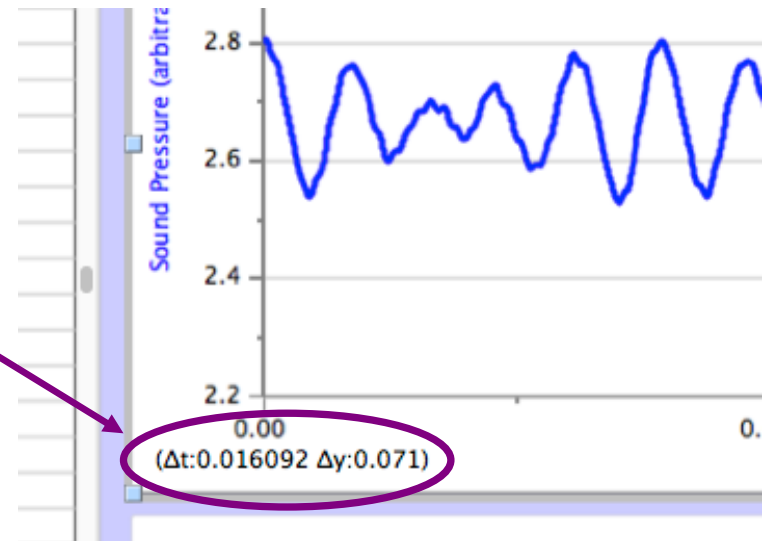
**NOTE:** You can autoscale your graph by clicking on the blue  in the bar above the FFT.



# Understanding the FFT

- Record the total time in **Table 1**.
- Using the total time, determine the period of the oscillation and record this in **Table 1**.
- Using the period, determine the frequency of the oscillation and record this in **Table 1**.

The total time for the five oscillations is given as  $\Delta t$  in the lower corner of the graph.



# Understanding the FFT

The lower graph is the FFT or spectrum. It shows the frequency present in the waveform.


Activate the FFT graph by clicking on it.

Click **Analyze** then **Examine**. Move the mouse over the peak on the spectrum. The value of the frequency is displayed in the pop-up box.

**QUESTION 1:** According to the spectrum:

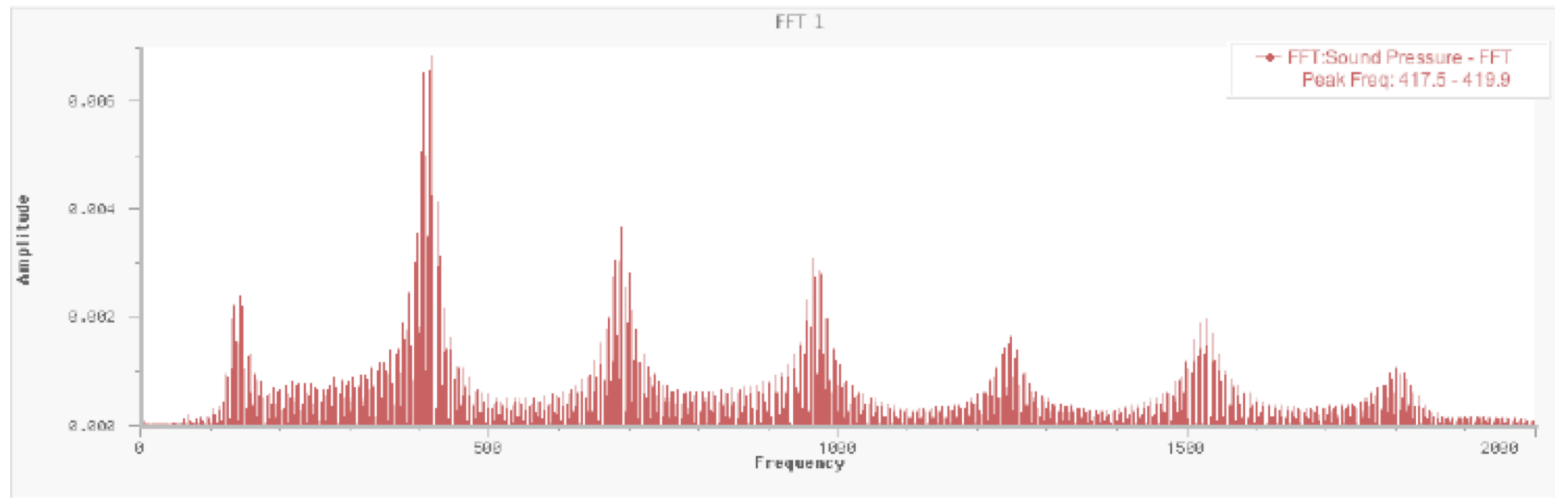
- a) What frequency is present in the waveform?
- b) Does this value agree with your frequency calculated in Table 1 within  $\pm 3 \text{ Hz}$ ?
- c) Do these values agree, within a few hertz, with the value stamped on the tuning fork?

# Resonance in a tube - Apparatus

Click  while holding the microphone at one end of the tube and blowing across the other end, as shown below.



# Resonance in a tube - Experiment



Graph produced should look similar to the one show above.

Each peak in amplitude indicates a resonant frequency in the sound.

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

**Experiment → Store Latest Run.**



# Resonance in a tube - Predictions

Q

QUESTION 2: Why are there multiple peaks in the FFT graph?

Q

QUESTION 3: a) Using the equation

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

Determine the equation for the slope of a  $f$  vs  $n$  graph.

Refer to plotting and interpreting graphs section in the preliminary pages of your workbook for reference.

b) What do you expect for the intercept? Explain.


c) Sketch the expected shape of the graph of  $f$  vs  $n$ .

!

LW

Using the metre stick, measure the length of your tube. Record your results in **Table 2**.

# Resonance in a tube - Data

Activate the **FFT** graph by clicking on it. Click the  button and use the cursor to determine the resonant frequencies of the observed harmonics.

**Note:** The first resonance is called the 1<sup>st</sup> harmonic. If the second resonance has twice the frequency of the first then it is labeled the 2<sup>nd</sup> harmonic ( $n = 2$ ).  $n$  is called the harmonic number.

**LW**

Record the frequencies and harmonic number of the observed harmonics in **Table 3** of your Laboratory workbook.

# Resonance in a tube - Analysis

- Launch **Graphical Analysis** by clicking on the icon below.



- Plot **frequency** versus **harmonic number** for your pipe.
- Create a linear fit to your graph by clicking **Analyze** then **Linear Fit**.
- Find the uncertainty in your slope and intercept by double clicking on the pop up box and checking the option to “Show uncertainty”.
- Record the slope, intercept, and uncertainties in **Table 4**.
- Print your graph by clicking **File**, then **Print**. Attach your printed graph to your Laboratory Workbook.



# Resonance in a tube - Analysis

Q

**QUESTION 4:** Use your slope and your result from Question 3 to determine the speed of sound in air. Include units and uncertainty.

Q

**QUESTION 5:** How does your intercept compare to your expected value? Comment.

LW

Record the room temperature  $T_C$ , as displayed in the lab, in **Table 5**.

Q

**QUESTION 6:** Using the equation

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

determine the theoretical value for the speed of sound in air and its uncertainty.

Q

**QUESTION 7:** Do the two speed of sound values agree within uncertainties?

## 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 until the amplitudes of both data sets are roughly equal.
- Record your new frequency results in **Table 6**.

**Careful! You will need to assign values of  $n$ .**

**Hint: The 5<sup>th</sup> harmonic ( $n = 5$ ) has a frequency which is 5 times the frequency of the 1<sup>st</sup> harmonic.**

**Have an instructor come check your plot and initial your lab report.**

LW

!

CP

# Resonance in a tube open at one end

Q

**QUESTION 8:** Summarize how the frequency peaks in the FFT differ for the tube open at both ends and tube closed at one end.

Q

**QUESTION 9:** List two sources of uncertainty in this experiment and classify them as either random or systematic.

- Check that you have completed all the **Tables** of your Laboratory workbook.
- Make sure that you have answered all the **Questions** completely.
- Attached to your Laboratory workbook should be the following graph:  
Frequency vs Harmonic Number (Graphical Analysis)



**Don't forget to sign out!**