Experiment 12

Resonance in a Closed End Pipe

12.1 Objectives

- Determine the relationship between frequency and wavelength for sound waves.
- Verify the relationship between the frequency of the sound, the speed of sound in air and the length of the pipe.
- Measure the speed of sound in air.

12.2 Introduction

An interesting topic in physics is acoustics. How does sound travel? What *is* sound? It turns out that sound comes from vibrations traveling through the air as waves. We can hear the sounds because our hearing is sensitive to these waves. Today we will investigate the different characteristics of sound waves and how they relate to each other.

12.3 Key Concepts

As always, you can find a summary on-line at Hyperphysics.[1] Look for keywords: wave relationship, speed of sound

[1] http://hyperphysics.phy-astr.gsu.edu/hbase/hph.html

12.4 Theory

When a speaker produces a sound wave, it generates a pressure difference in the air (or whatever medium in which the sound wave travels). This pressure variation propagates through air with a specific speed c. A sound wave is a **longitudinal** wave, where the oscillation is parallel to the direction of the wave and its speed. If the sound generated by the speaker corresponds to a frequency f, then this results in a travelling wave with wavelength $\lambda = (c/f)$. For a given frequency, the wavelength depends on the speed of propagation c. This speed depends on the medium through which the wave travels. For example, the speed of sound in air is $c = 345 \pm 2$ m/s at lab room temperature and conditions. But in helium the speed of sound is much larger and is $c = 965$ m/s. *So a sound wave of a given frequency will have different wavelengths in air and in helium.* We can define conditions for a standing wave in a closed pipe. At the closed end of a pipe we have a **node** in the standing wave and at the open end we have a **maximum** (or anti-node). Only certain combinations of wavelength and length of the pipe will result in a standing wave or resonance. The conditions are given by:

$$\lambda_n = (4L/n) \text{ for } n = 1, 3, 5, 7, ...$$

$$f_n = (c/\lambda_n) = (nc/4L) \text{ for } n = 1, 3, 5, 7, ...$$

The frequencies f_n are called the **resonant frequencies** of the pipe. This implies that a pipe with a fixed length has only certain resonant (or audible) frequencies! This is the principle behind organ pipes, where many different lengths are needed to produce all frequencies. Woodwind instruments also operate according to these conditions. The conditions for resonance are displayed graphically in Figure 12.1.

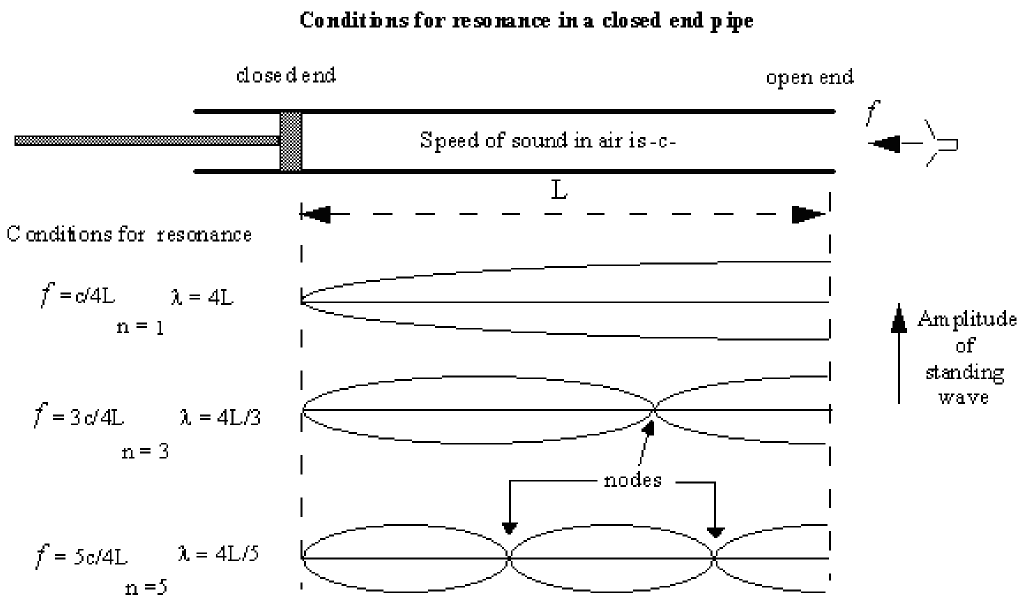

Figure 12.1:

12.5 In today's lab

Today we will drive different frequencies into an open ended pipe and measure the wavelength of the sound wave being produced. We will change the length of the pipe by moving a piston away from the speaker and listen for maxima in the wave. After doing this for multiple frequencies, we will use our data to measure the speed of sound.

12.6 Equipment

- Oscilloscope
- Speaker
- Sound Tube
- Ruler
- Plunger

12.7 Procedure

1. Turn on the oscilloscope, frequency generator, and microphone. Be sure to turn off the microphone at the end of the experiment to conserve battery life.

2. Set the frequency generator to 1000 Hz and turn the amplitude up to maximum.

3. With the plunger pushed all the way in towards the speaker end of the tube, slowly pull it outwards until you hear the tone at its loudest. Press the autoset button on the oscilloscope. Slightly adjust the plunger in or out until the sine wave displayed on the oscilloscope has a maximum amplitude. Record the length L_1 in your data sheet. Also record a reasonable value for δL.

4. Now pull the plunger out again until you reach the next maximum. Use the oscilloscope to help you find this and subsequent maxima. Record this length as L_2. $\Delta L = \lambda/2$ is the distance between successive maxima, so in this case, cell "D2" is $L_2 - L_1$.

5. Continue finding maxima, recording the correct lengths, and calculating ΔL until you reach the end of the pipe. Note that the number of lengths you fill in for each frequency will be different depending on the driving frequency.

6. After answering question 1, repeat steps 3–5 for $f = 1250, 1500, 1750,$ and 2000 Hz. Note that

$$\delta\lambda = \lambda\left(\frac{\delta\Delta L}{\Delta L}\right) = 2\Delta L\left(\frac{2\delta L}{\Delta L}\right) = 4\delta L$$

7. Calculate your measured wavelengths using the equation $\lambda/2 = \Delta L$ and fill in the remaining cells on your data sheet. Since you have multiple values for your wavelengths at the given frequencies, use the average values in the bottom cells of your Excel sheet.

8. Create a plot of f vs. $1/\lambda$ in KaleidaGraph and include a best fit line.

12.8 Checklist

1. Excel Sheets
2. Plot of f vs. $1/\lambda$
3. Questions

12.9 Questions

1. Are all of the wavelengths at 1000 Hz consistent?

2. From your graph, what is the speed of sound in air and its uncertainty?

3. Discuss the consistency of your measured value of the speed of sound in air with the expected value of 345 ± 2 m/s.

4. For a closed end pipe of fixed length L, will the resonant frequencies be the same in helium as they are in air? Why or why not?

5. If the time between seeing a flash of lightning and hearing the sound of the accompanying thunder is about five seconds, how far is the thunderstorm away from you (**Hint:** the speed of light is much larger than the speed of sound)?

6. For an organ pipe to have a fundamental ($f = 1$) frequency of 100 Hz, how long does it have to be?