General Physics II Lab (PHYS-2021)

Experiment WAVE-2:

RESONANCE OF SOUND IN A TUBE

Name: ______________________ Lab Section: __________

Equipment

Equipment Required	
QTY	**ITEM**
1	Resonance Tube Apparatus
1	Frequency Generator
1	Miniature Speaker
1	Digital Multimeter
1	Sound Level Meter

Objective:

In this experiment we will determine the conditions for resonance for both open and closed tubes and compare with theoretical predictions. In addition, we will make two measurements of the speed of sound, v_s, on this occasion for this temperature and atmospheric pressure, and compare these values to each other and to the expected value for these experimental conditions.

Introduction:

When a source of sound (such as a tuning fork) vibrates, it alternately compresses and rarifies the air in the immediate vicinity of the vibrating surfaces. These compressions (C) and rarefactions (R) constitute a longitudinal wave we call *sound.* The sound waves move away from the source at a speed V_s that is characteristic of the medium in which the source is located, as shown in Figure 1. (**NOTE: For Simplicity, only the wave from the right side of the tuning fork is shown.**)

Because it is easier to draw, the longitudinal sound wave is frequently represented by a sinusoidal (transverse) wave showing the tiny variations in atmospheric pressure along the wave. The frequency f of the sound wave is the same as that of the source (tuning fork), and the distance between corresponding points along the wave is the wavelength λ. The *simple wave equation* expresses the relationship between the frequency, wavelength and the speed of the wave:

Speed of sound = frequency × wavelength or

$$\Longrightarrow \; v_s = f\lambda \tag{1}$$

where the frequency f is usually expressed in hertz (Hz), the wavelength λ, in meters (m) and hence the speed of sound in m/s. It is important to note that the speed of the wave depends only on the characteristics of the medium and not at all on f or λ. For sound waves in air, $v_s \cong 345$ m/s at ordinary room temperature. The speed of sound in air is temperature dependent and can be described by the following equation:

$$v_s = (331.0 + 0.6T) \; m/s \tag{2}$$

where T is the temperature in Celsius degrees.

When a sound source of frequency f is brought near the end of a cylindrical tube, the sound waves travel down the tube and reflect back from the opposite end. At certain frequencies, the sound waves can reflect back and forth in the tube and establish resonance, a condition where the intensity (loudness) of the sound increases markedly. Resonance will occur when the frequency f, length of the tube L and the speed of sound v_s are related in a specific way. There are two general modes of resonance in a tube.

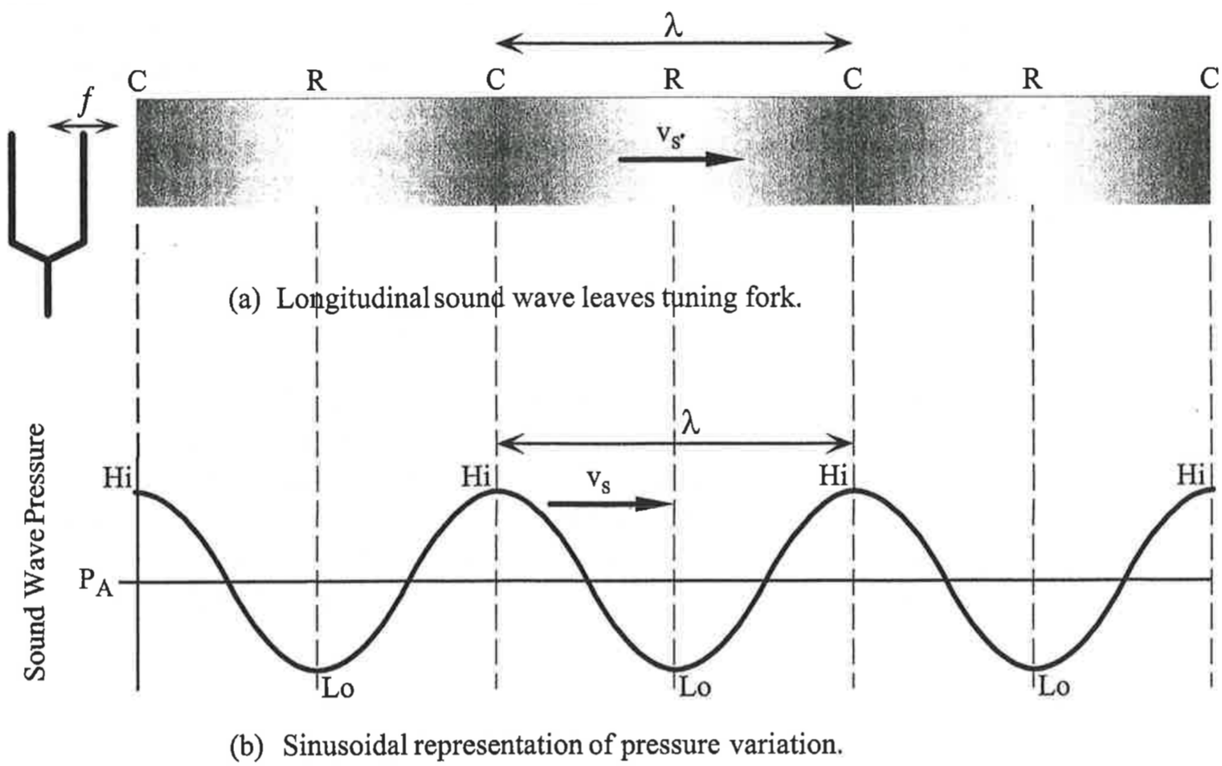

Figure 1: Longitudinal sound waves from a tuning fork.

Resonance in an open tube – i.e., a tube that is open at both ends

Sound from the sound source (tuning fork) travels down the tube and reflects back from the opposite end which is *open*. At resonance, both ends must be points of maximum disturbance called *antinodes* (A). There must be at least one point of minimum disturbance between antinodes, called a *node* (N), and hence the distance between the ends of the tube bust be at least $\lambda/2$. But there might be two, three, or more nodes between the ends of the tube. The first four resonant conditions for an open tube of length L are shown in Figure 2 (below). The resonance conditions are also summarized.

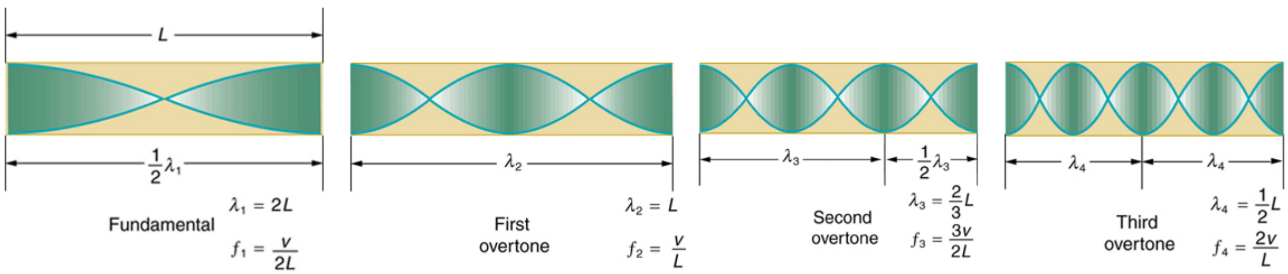

Figure 2: Lowest four resonant frequencies for an open pipe.

The pattern is clear. The possible resonant frequencies of an open tube of length L are:

$$f_n = n\frac{v_s}{2L}, \tag{3}$$

where n = 1, 2, 3, 4 . . . (all integers) and

$$f_n = nf_1,\ where f_1 \ = \ \frac{v_s}{2L}. \tag{4}$$

In theory, there are an infinite number of possible resonant frequencies, but in practice it is difficult to observe more than the first few.

Resonance in a closed tube – i.e., a tube open at one end and closed at the other

Sound from the source travels down the tube and reflects back from the opposite end, but in this case the opposite end is *closed*. At resonance, the closed end of the tube must be a point of minimum disturbance (i.e., a node (N) whereas the other end, near the sound source, must be an antinode (A). The minimum part of a wavelength between an antinode A and a node N is a quarter wavelength, and hence the length of the tube must correspond to $\lambda/4$ for the lowest resonant frequency. The four lowest resonant frequencies for a tube of length L are shown in Figure 3 (below), along with the conditions for resonance.

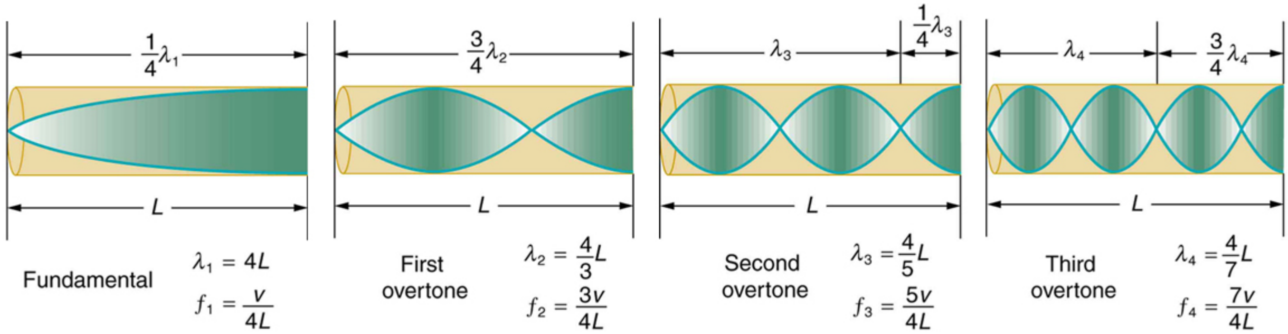

Figure 3: Lowest four resonant frequencies for a closed pipe of fixed length.

Once again, the pattern is clear. The possible resonant frequencies of a closed tube of length L are: given by:

$$f_n = n\frac{v_s}{4L}, \tag{5}$$

where n = 1, 3, 5, 7 . . . (all odd integers) and

$$f_n = nf_1, \tag{6}$$

where n = odd integers only.

Again, there are an infinite number of possible resonant frequencies, but only the first few are easy to observe.

Procedure

Resonance in an open tube.

1. Set up the apparatus as shown in Figure 4 (next page). Examine the frequency generator/amplifier carefully. Before you turn the power switch on, select the "sin" shape and the "100×" multiplier, adjust the "amplitude" to minimum and the frequency to 10.0. Thus the frequency of the signal delivered to the miniature speaker will be approximately 1,000 Hz. You will actually measure the frequency with a DMM set on its 0-10 volt scale; multiply the voltage reading by 100 to get frequency.

   Now increase the amplitude upward until the sound from the speaker can be clearly heard but is not loud. ***It is very important that you not overdrive the speaker***. You will not only damage the speaker but you will spoil your results.

2. Turn on the Sound Level Meter (SLM) and adjust the scale until the meter needle begins to respond when placed near the speaker – approximately the 80-db scale.

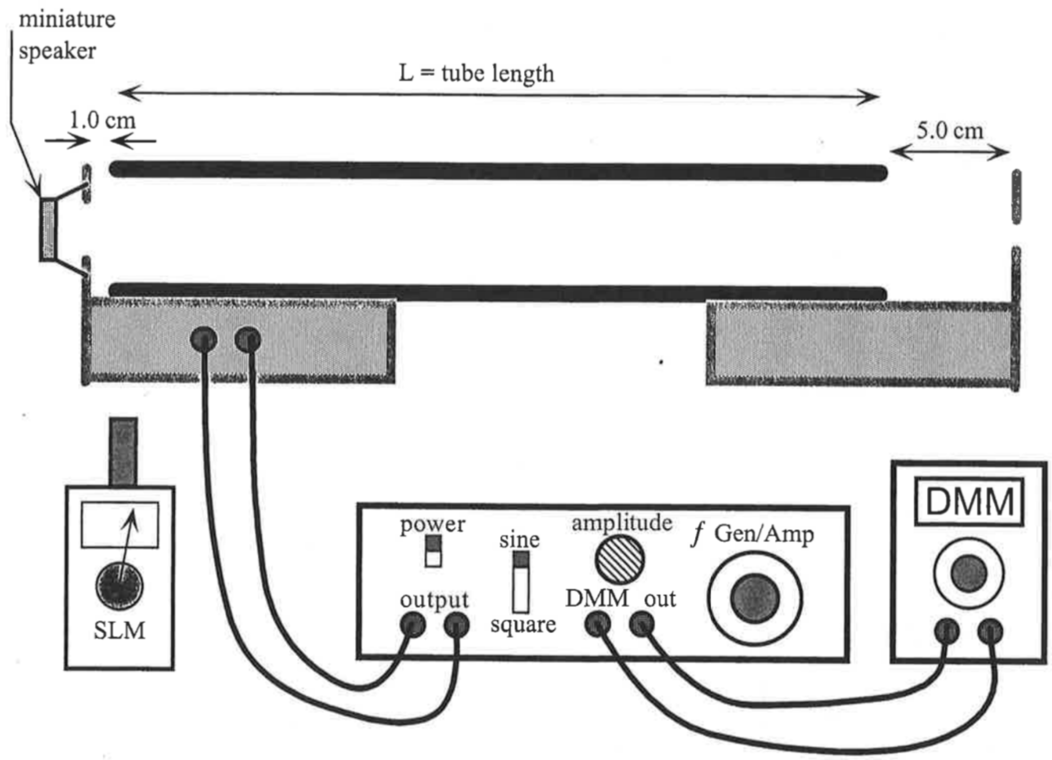

Figure 4: Setup for open tube resonance.

3. Very slowly adjust the frequency knob on the generator downward, and listen carefully for a noticeable increase in the loudness of the sound you hear. Try to accurately locate the frequency where the sound level is a maximum, using both your ears and the Sound Level Meter as a guide. If necessary, change the SLM scale setting in order to monitor the level more easily. Read the DMM and record this frequency as "Frequency A."

4. Repeat step 3 to identify and record successively lower resonant Frequencies B, C, D, etc. You should be able to identify a total of four or five resonances.

5. From Equation C, the resonance frequencies should be multiples of the fundamental f_1. *Hence the interval between the resonant frequencies you observe should equal* f_1. Compare frequencies A, B, C, etc., and determine whether or not the expected pattern was observed. Determine the fundamental frequency f_1. Were you able to observe it directly?

6. From Figure 2, the overall length, L, of the resonance tube should equal $\lambda_1/2$ for the fundamental resonant frequency – i.e., $\lambda_1 = 2L$ for f_1. Also, the speed of sound in air should be $v_s = f_1\lambda_1$. Use the data you have recorded to find the speed of sound in air in the lab on this occasion and compare to the value expected for this ambient temperature.

Resonance in a closed tube.

1. Re-configure the resonance tube apparatus by inserting the plunger, and adjust the plunger position until it is about 5.0 cm or so from the open (speaker) end of the tube. (See Figure 5.)

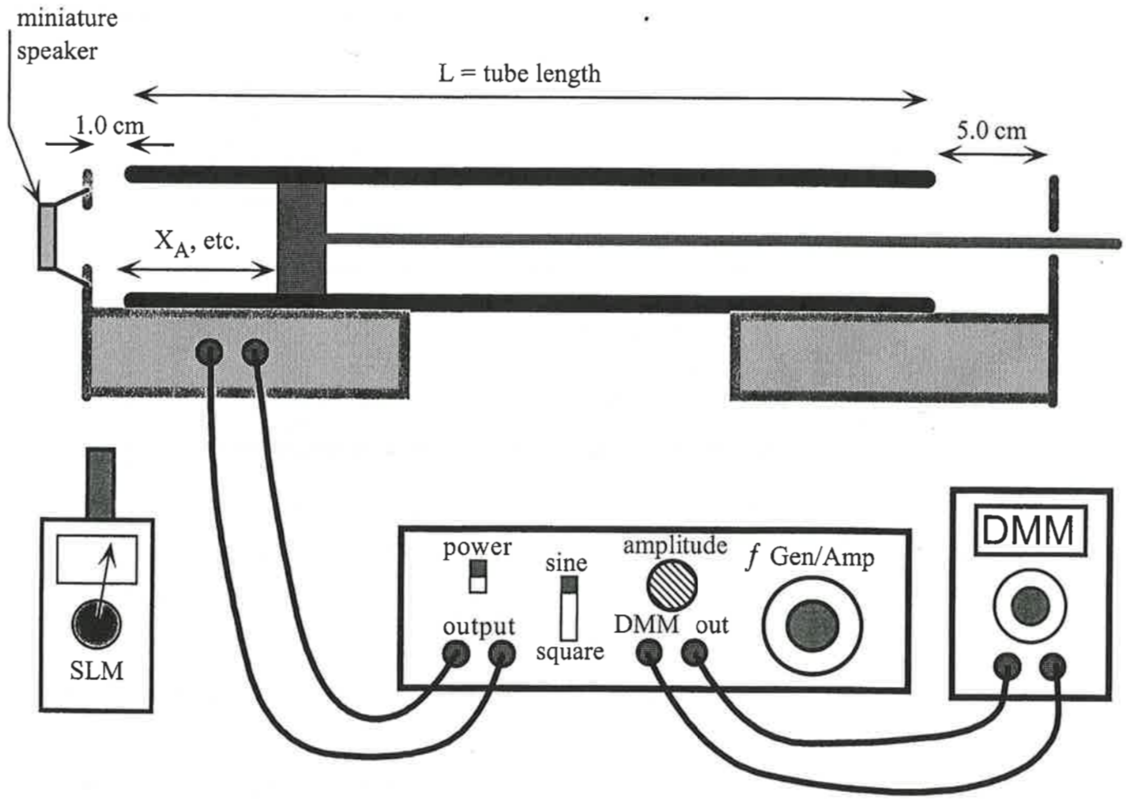

Figure 5: Setup for closed tube resonance.

2. With the amplitude set at minimum, set the frequency as closely as you can to 1,000 Hz using the DMM and "l00×"" multiplier. This will serve as a fixed resonant frequency, f_0 ,for this part of the experiment. *Once set, leave this frequency fixed.* Increase the amplitude of the signal until the sound is clearly audible (but not loud). Adjust the Sound Level Meter as in part 2.

3. Slowly withdraw the plunger while listening carefully for a noticeable increase in loudness-– i.e., a resonance. Use both the Sound Level Meter and your ears to locate the resonance as precisely as possible. Note the position of the plunger as accurately as you can on the built in scale. You will note that the position of the plunger measures the length of the tube section that is resonating. Call your distance measurement from the end of the tube to the plunger position X_A.

4. Continue to slowly withdraw the plunger and determine successive resonance positions for your fixed resonant frequency f_0 Record them as X_B, X_C, X_D , etc. You should be able to locate about five resonance positions.

5. Note that f_0 is <u>not</u> the fundamental resonant frequency, f_1, for this section of the tube, but rather an odd multiple of the fundamental. From the analysis leading to Equation D, we note that resonances for f_0 should occur at intervals of $\lambda_0/2$. (See Figure 6, below). Compare your position readings and determine the average distance between resonance positions, and thus determine λ_0 , the wavelength of the fixed frequency f_0 that you set in Part 8.

6. Use your values of f_0 and λ_0 to calculate $v_s = f_0\lambda_0$. Compare this value to the value of v_s you found earlier in Part 6?

7. If time permits, repeat parts 7-12 with the sound generator set to a different fixed frequency $f_0 = 2{,}000$ Hz.

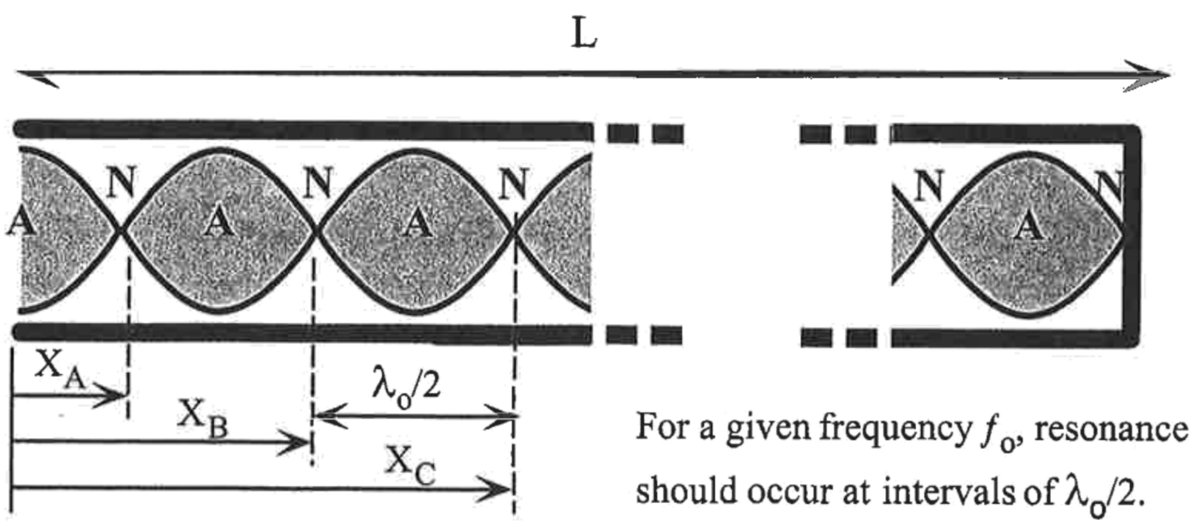

Figure 6: Resonance lengths of a closed tube at fixed frequency f_0.