Resonance on Air Column

Objectives

a. To measure the speed of sound with the help of sound wave resonance in air column inside the tube with one end closed.
b. To do error analysis of speed of sound measurement.
c. To measure the speed of sound with the help of sound wave resonance in air column inside the tube with both end open.

Apparatus Required

Hollow Cylindrical Tube (blue) and One end closed tube with scale (white)

Speaker

Sine wave generator

Thermometer

Introduction

Sound waves are longitudinal waves. They need medium to travel. From the source to our ear sound will travel through air. It travels in air with constant speed at a specific temperature. For example, the speed of sound in air at 0ºC (273K) is 331m/s. The speed of sound (v) at any specific temperature (T) can be given by the following equation.

$$v = v_{273}\sqrt{\frac{T}{273}} \tag{1}$$

Where, v_{273} = 331 m/s is the speed of sound at 273K.

Resonance in air column in a tube with both ends open

When a sound wave passes through a resonance tube it undergoes multiple reflections from the boundaries. In some special condition, original and reflected waves travel in phase and the standing wave of maximum amplitude occur. Such special conditions are known as resonances or harmonics and are shown in Figure 1(a) For a given length of the air column in a tube open at both ends these resonances occur at specific wavelengths given by the following equation.

$$\lambda_n = \frac{2L}{n} \qquad (2)$$

Where, n = 1, 2, 3, 4 etc are number of harmonics and L = length of the tube. (Please look at the appendix for more detail)

The velocity of sound in air at the room temperature is fixed and can be calculated as:

$$v = \lambda_n f_n \qquad (3)$$

Where f_n is the resonance frequency of n^{th} harmonics.

Using equation (2) and (3) we can obtain the following equation

$$f_n = \frac{v}{2L} n \qquad (4)$$

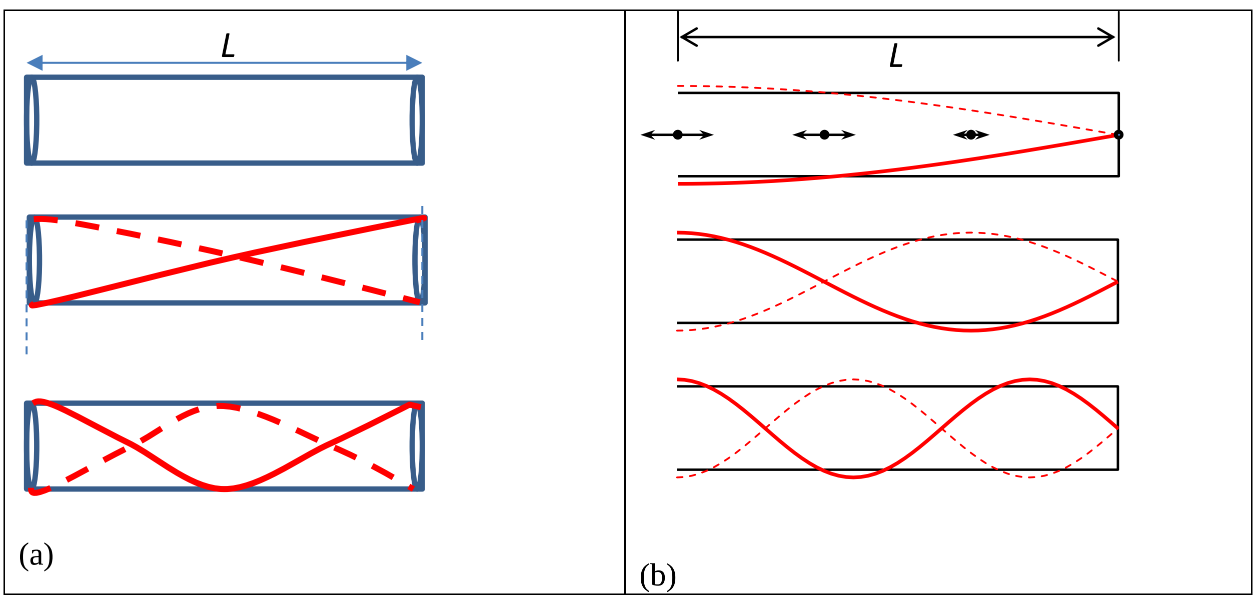

Figure 01: Schematic diagram of resonances in (a) a tube open at both ends and (b) a tube open at one end.

Resonance in air column in a tube with one end closed

When the tube has one end open there will be a node at the closed end and the antinode in the open end as shown in figure 1(b). Since the next harmonics will occur at each extra additional loop to their preceding harmonics, the relationship between λ_n and L_n will be as follows.

$$\lambda_n = \frac{4L_n}{n}$$

Where, n = 1, 3, 5, 7 ... and so on.
In the tube with one close end only odd harmonics are present.

At a fixed frequency f, we can obtain different harmonics (n) at different specific lengths (L_n) and the relationship between them can be written as:

$$L_n = \frac{v}{4f}n \qquad (5)$$

Part 1: Calculating speed of sound

From equation (1) we know that the speed of sound is temperature dependent. If we know the room temperature we can calculate the expected value of speed of sound at room temperature.

1.1 Find the thermometer in the lab and record the room temperature.
1.2 Convert the temperature to Kelvin and calculate the expected value of speed (v_{ex}) of sound in the lab.

The value of the speed of sound you just calculated came from a theory. You need to verify it experimentally.

The first possible experiment can be direct measurement of the speed. If we could measure the distance travelled by sound in certain time, we can easily find its speed. However, the sound moves very fast and the direct measurement of its speed is not trivial; although not impossible. In this experiment, you will be measuring the speed of sound indirectly as follows:

Part 2: Measuring the speed of sound with a tube close at one end.

In this part of the experiment, you will be finding the resonances in air column of a tube with one end close. You will be fixing the frequency of sound source and find resonances (n) for different length (L_n) of air column.

Procedure:

2.1 Fix the blue tube on two stands and place the sound source (speaker) close to one of the openings of the tube, making about 45° angle with the opening surface.

2.2 Insert the white tube with measuring scale inside the blue tube such a way that the close side of the inner tube would be facing towards the sound source.

2.3 Connect Sine Wave Generator to speaker and electric source. Fix the frequency (any value higher than 300 Hz) and adjust amplitude on a reasonable level.

2.4 Start Excel sheet as shown in table 1. With the help of equation (5) predict the resonance lengths (L_n) for different resonances (n). Use speed of sound from part I of the experiment.

n	***f(Hz)***	***L_n-predicted (m)***	***L_n-observed (m)***	*% error*
1				
3				
5				
7				
9				

Table 1

2.5 Extend the air column slowly, increasing the inner tube length. The loudness of the sound will noticeably increase as you approach to first resonance. Find the loudest sound through fine tuning of length. Make sure your first resonance is closer to the theoretically predicted value.

2.6 Repeat procedure #2. 5 for higher harmonics (n = 3, 5, 7 and 9).

2.7 Plot the $\boldsymbol{L_n}$ versus $\boldsymbol{n}$ graph. Obtain the speed of the sound from the slope of the graph and name it as v_1.

Part 3: Error Analysis:

The speed of sound thus measured may have some uncertainty due to various factors. The major contribution to the uncertainty may come from the uncertainties in the measurement of frequency and length.

From equation (3) the uncertainty in speed of sound for a specific harmonic can be derived as,

$$\Delta v = \left(\frac{\Delta\lambda}{\lambda} + \frac{\Delta f}{f}\right) v$$

Since the uncertainty in λ is linearly depends on the uncertainty in length.

$$\Delta v = \left(\frac{\Delta L}{L} + \frac{\Delta f}{f}\right) v \qquad (6)$$

The uncertainty in L and f can be found using the following procedure.

3.1 Find the first harmonic once again and measure its length. Slowly move the inner tube either way from the resonance position until you notice the slight decrease in sound level. The difference in position is the uncertainty on measuring length (ΔL). Take the tube back to the first resonance position.

3.2 Slowly increase or decrease the frequency until you observe the slight decrease in resonance sound. The frequency difference is your uncertainty on measuring the frequency (Δf).

3.3 Using equation (5) find the value of v for the first resonance.

3.4 Calculate Δv by using equation (6).

3.5 Find $v_{min} = v_{ex} - \Delta v,$ and $v_{max} = v_{ex} + \Delta v.$

Part 4 : Measuring the speed of sound from resonance tube open at both ends.

In this part of experiment, you will observe how the resonance occurs in the air column of tube with both end open. Keeping the length of the air column constant, you will observe resonances occurring at different frequencies.

Procedure:

4.1 Remove the inner white tube from the blue tube and measure the length (L) of the blue tube.
4.2 Open excel sheet (as in table 2) and predict resonance frequencies in the air column of the blue tube with the help of equation (4).

n	*L*(m)	***f_n-predicted (Hz)***	***f_n-observed (Hz)***	*% error in f*
1				
2				
3				
4				
5				

Table 2

4.3 Find the resonance frequencies (up to 5th harmonics) for both end open tube by performing experiment as in one end open tube but by changing frequency instead of length.

4.4 Plot the Excel graph between f_n and n and find the slope.

4.5 Obtain the speed of sound from the slope and name it as v_2.

4.6 Find the average value of v from v_1 and v_2.

4.7 Check if your value lies within the range of v_{min} and v_{max}.

Report Tail Questions: (Instructor can add more questions by themselves if needed)

1. From part 2 of the experiment, find the wavelength of the sound wave from any two resonances. Using this wavelength calculate the velocity of the sound.
2. From part 4 of the experiment, find the wavelength of the sound wave from any two harmonics. Using this wavelength calculate the velocity of sound.
3. Draw a conclusion for f, λ and v based on these two questions.

Appendix:

If a wave of angular frequency ω and wave vector k is travelling to the right through a stretched string fixed at both ends as shown in figure 1 (a) it can be represented by the following equation.

$$y = y_m sin(kx - wt) \qquad \text{(a-1)}$$

When the wave gets reflected from the boundaries and make a full round, it travels 2L distance more compare to the original wave. If the reflected wave returns to its original position in time period T, the equation can be written as:

$$y = y_m sin(k(x + 2L) - w(t + T)) \qquad \text{(a-2)}$$

Where, L is the length of the string between two fixed points. It should be noted that each time the wave reflects from the fixed boundary it undergoes phase change by π.

In such case the reflected wave and incident wave will be in phase, hence the first resonance will take place when:

$$k(x + 2L) - (\omega t + 2\omega T) - (kx - \omega t) = 0$$

$$k(2L) = 2\pi$$

But if the reflected wave returns to its original position in time period 2T, the equation can be written as:

$$y = y_m sin(k(x + 2L) - w(t + 2T))$$

In that case the condition of second harmonics will be:

$$k(2L) = 2(2\pi)$$

Similarly, the n^{th} harmonic will takes place when,

$$k(2L) = n(2\pi) \qquad \text{(a-3)}$$

Where, n = 1, 2, 3 ....n and is the number of harmonics.

Solving equation (a-3) for the wavelength ($\lambda_n = \frac{2\pi}{k}$) of the wave at n^{th} harmonics, we obtain,

$$\lambda_n = \frac{2L}{n} \qquad \text{(a-4)}$$