DIY small scale resonance tube for measuring the speed of sound in air

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Abstract. This research invented a small scale with no cost experimental set to determine the speed of sound in the air by resonance method. Equipment consisted of a bubble tea straw with label measuring scale, a full plastic water bottle and the n-Track Tuner (iOS) or Guitar Tuner (Android) application for generating sound waves. Sound waves were sent down a bubble tea straw filled with air. The waves reflected back up the straw from a water surface and interfered with the waves traveling downward. By properly adjusting the water level, a resonance condition could be established. By knowing the frequency of the sound wave and the position of the water level for two different resonant lengths, the speed at which sound waves travel through the air was found. In this experiment, the frequency was specified 1,500 Hz at 24.00 °C, 26.00 °C and 30.00 °C respectively. The sound speed which was calculated was 345.0, 347.0 and 349.0 m/s respectively. The standard value of sound speed at the same temperature was 345.4, 346.6 and 349.0 m/s respectively. The percent error value of the sound speed was calculated to compare with the standard value of sound speeds was 0.1%, 0.1% and 0.0% respectively. This an experiment was effective and could be efficiently used in educational physics. Moreover, it is easy to use, low cost, and portable. Students can also prepare the equipments themselves.

1. Introduction

Sound is a mechanical wave that is transmitted through solids liquids or gases. These waves are transmitted as a sequence of pressure changes which move through compressible media such as liquids and gases. The temperature and pressure of a substance can affect the speed of sound as these properties affect the density of the substance. Sound cannot travel through a vacuum. The speed of sound in air depends on temperature. For example, in air at 0 °C the speed of the sound is 331 m/s while in the air at 20 °C its speed increases up to 341 m/s [1].

The experiment in class, the speed of sound in air is to be found by using tuning forks of known frequency. The wavelength of the sound will be determined by making use of the resonance of an air column. The apparatus for the experiment consists of a long cylindrical plastic tube attached to a water reservoir. The length of the water column may be changed by raising or lowering the water level while the tuning fork is held over the open end of the tube. Resonance is indicated by the sudden increase in
the intensity of the sound when the column is adjusted to the proper length [2]. However, experimental studies usually involve expensive and sophisticated equipment that is out of reach of school laboratory facilities [3].

Hence, the researcher develops an experiment by using an application for generating sound waves instead of tuning forks and substitute a bubble tea straw for a long cylindrical plastic tube. This experiment suitable for class because it is precision. It is also easy to use and low cost.

2. Theory
A sound wave is a longitudinal wave in which the wave oscillates along the direction of propagation. For a traveling wave of speed $v$, frequency $f$, and wavelength $\lambda$, the following relationship holds:

$$v = f \lambda .$$ (1)

Consider a sound wave traveling through a resonance tube as illustrated in figure 1. These sound waves travel down the tube and are reflected upon reaching the surface of the water. The incoming and reflected waves interfere and form standing waves [4]. In a tube closed at one end, the closed end is a displacement node because the rigid barrier at this end does not allow longitudinal motion of the air. Because the pressure wave is 90° out of phase with the displacement wave, the closed end of an air column corresponds to a pressure antinode (that is, a point of maximum pressure variation).

![Figure 1. Resonance tube](image)

The open end of an air column is approximately a displacement antinode1 and a pressure node. We can understand why no pressure variation occurs at an open end by noting that the end of the air column is open to the atmosphere; therefore, the pressure at this end must remain constant at atmospheric pressure [5].

At constant temperature the speed of sound is fixed; in addition, for a given tuning fork the frequency is also fixed, then, according to equation 1, the wavelength of the sound wave should also be fixed. As a result, the resonance conditions can only be satisfied when the length of the tube $l$ is such [4]

$$\Delta l = \frac{1}{2} \lambda .$$ (2)

From equations (1) and (2), the speed of sound wave is determined by

$$v = 2f \left( l_{2} - l_{1} \right),$$ (3)

where this relationship between the two consecutive resonances will be used to find the wavelength of the standing sound wave as shown in figure 2 [4].

![Figure 2. Examples of resonance for $n = 1, 3, and 5$](image)
In actual practice, antinode is not formed at the opened, but it is formed a little above from the open end. Then the difference between actual position of the antinode and the position of the open end is called end correction (e). If to be the first resonating length and be the wavelength in the tube then in first resonance:

\[ l_1 + e = \frac{\lambda}{4}. \]  

(4)

Similarly, if \( l_2 \) be the second resonating length and be the wavelength in the tube [6]:

\[ l_2 + e = \frac{3\lambda}{4}. \]  

(5)

According to the theory, the speed of sound in air depends upon the temperature of the air through the following relationship:

\[ v = 331 + 0.6T. \]  

(6)

Here, \( T \) is the temperature in centigrade (degrees Celsius) [4].

3. Methods

First, fill up the bottle with water and set up the application on smart phone with frequency is specified 1,500 Hz at 24.00 °C. Next, place the smartphone on the end of bubble tea straw. Sound waves pass down to the straw and reflect back at the water surface. At the same time, raise the straw and the smartphone with a maximum sound was heard and measure the length of air column at position. This is taken as the first resonant length, \( l_1 \) as shown in figure 3(a) and raises the straw approximately ten times the first resonant length. Excite the smartphone again and place it at the end of the bubble tea straw. Then change the height of the straw until the maximum sound is heard and measure the length of air column at that position. This is taken as the second resonant length, \( l_2 \) as shown in figure 3(b) and raises the straw approximately ten times the second resonant length.

![Figure 3. (a) the first resonant length (b) the second resonant length](image)

Then, calculate the speed of sound in air by using the equation (3). After that, repeat the experiment by changing temperature and in each time, and calculate the value of \( v \). Finally, calculate the standard value of sound speed that by using the equation (6) and calculate percent error for each of the average \( v \)’s from

\[
\text{percent error} = \left| \frac{\text{standard} - \text{experimental}}{\text{standard}} \right| \times 100.
\]
4. Results

| Temperatures (°C) | Average resonant length (× 10^-2 m) | Speed of sound (m/s) | percent error (%) |
|-------------------|---------------------------------------|----------------------|-------------------|
|                   | l_avg                                 | l2avg                | ∆l_avg            | Experimental | Standard |         |
| 24.00             | 4.800                                 | 16.30                | 11.50             | 345.0        | 345.4    | 0.1     |
| 26.00             | 4.477                                 | 16.30                | 11.56             | 347.0        | 346.6    | 0.1     |
| 30.00             | 4.970                                 | 16.60                | 11.63             | 349.0        | 349.0    | 0.0     |

Table 1 shows the results of the average speed of sound by repeat experiment ten times compared with the standard value of sound speed at 24.00 °C, 26.00 °C and 30.00 °C. Each temperature has the frequency 1,500 Hz. The temperature 30.00 °C has no percent error while the temperature 24.00 and 26.00 °C have percent error are 0.1%.

5. Conclusion and discussion

For the results see the above table. The percent error on the measured speed of the sounds are hardly different which show that the method presented above to measure the speed of sound is quite accurate. It does not involve large errors and give a quite good value for the experimental speed of sound. In addition, the approximate frequencies that can be used are 1,200 to 1,600 Hz. The lower frequency is used, the longer straw and bottle students prepare. Hence, in this experiment, the frequency was used 1,500 Hz because the resonant length in this frequency is appropriate for bubble tea straw and bottle. These equipments can be prepared and carried or moved by student.

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