Physics 11 IB   **Resonance of Air Columns**

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1 Aim

To verify the linear relationship between the length and the resonant frequency of an air column in a closed tube and to determine the speed of sound in air.

2 Hypothesis

Given the accepted value for the speed of sound in pure air at 20 ℃ to be $343\,m/s$, I hypothesize the calculated speed of our sound to be slightly higher than this, give the change in temperature.

3 Materials

1. Resonance tube apparatus
2. Set of tuning forks
3. Thermometer
4. 1 L beaker
5. Rubber mallet

4 Data Collection

Diameter of the tube $= 0.025m \pm 0.005m$

Trial	Frequency (Hz)	Length $L(m)$
1	480.0	0.167
2	512.0	0.152
3	320.0	0.257
4	341.3	0.241
5	426.7	0.188
6	256.0	0.326

Table 1: Data Collection

Uncertainty in Frequency $= \pm 1\%$
Uncertainty in Length $= \pm 0.002m$

5 Data Analysis

Trial	Frequency f (Hz)	$1/f$ (Hz)	Length L (m)
1	480.0	2.08×10^{-3}	0.167
2	512.0	1.95×10^{-3}	0.152
3	320.0	3.13×10^{-3}	0.257
4	341.3	2.93×10^{-3}	0.241
5	426.7	2.34×10^{-3}	0.188
6	256.0	3.91×10^{-3}	0.326

Table 2: Data Analysis

See attached graph L vs. $1/f$

From graph:

Slope $= 88.364$

Slope $= \frac{v}{4}$
$\therefore v = \text{Slope} \times 4$
$\therefore v = 88.364 \times 4$
$\therefore v = \underline{\underline{353.5 \ m/s}}$

6 Evaluation

From the above *Data Analysis*, the speed of sound in air is found to be approximately $353.5 m/s$. The theoretical value for the speed of sound in pure air at 20 ℃ is $343 m/s$.

Percentage difference $= \frac{353.5 - 343.0}{343.0} = 3.06\%$

There is this slight difference in results due to the following reasons:

1. The lab was not conducted at 20 ℃. There was a small change in temperature, and the speed of sound in air varies with a change in temperature.

2. The temperature did not remain constant throughout the course of the experiment. Since the speed of sound varies with temperature, it can be said that our results wouldn't be consistent over a period of time.

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3. The bottom end of the air column is closed by the water level. Since water is more dense than air, the water surface represents (and only represents) a rigid wall. It is thus *assumed* that the air molecules are so great confined at this end that they cannot vibrate. This is not the case however. Not all waves reflect off the water barrier.

4. The tuning fork was not always held at the very top of the resonance tube. Most of the time, the fork was held a few millimeters above the tip of the tube. This could have caused minor modifications to our results.

5. In deriving the equation $f_n = n(\frac{v}{4L})$, it was assumed that the displacement antinode occurs exactly at the open end of the tube—this is not strictly true. When a compression reaches an open end, it does not reach *full* rarefaction (expansion) until it passes somewhat beyond the end. However, this can be compensated by accounting for a short distance d_c in our above equation. This d_c turns out to be the y-intercept in our graph.

Our results are thus quite close to the accepted value for the speed of sound in air.

By taking advantage of our knowledge about resonance, and how resonance results in an increase in amplitude, we were able to determine the length L of a tube that a sound of frequency f should take in order to create a resonating vibration in the hollow tube.

Such a frequency at which resonance occurs is known as a *natural frequency.* It is also possible to determine several natural frequencies by increasing the multiplication factor n. In this experiment, however, we only studied the shortest air column length L required to create a resonating vibration in the air column (ie. $n = 1$).

We also took advantage of the linear relationship between the length L of the air column and the reciprocal of the frequency of the tuning fork $1/f$ to determine the slope of the graph thus obtained. It was then possible to determine the speed of sound, because the slope equalled nothing but $\frac{v}{4}$, where v is the velocity of sound. This linear relationship between the length and the resonant frequency of an air column in a closed tube has thus been verified.

7   Conclusion

In this lab, we were able to approximate the velocity of sound waves in air at a given temperature. This was done quite modestly with the use of simple apparatus and some water. At resonance, the amplitude of vibration at the open end of the tube increases to a maximum. This is heard as an increase in sound intensity of the tuning fork. There is thus a definite linear relationship between the length and the resonant frequency of an air column in a closed tube.