VELOCITY OF SOUND

Aim :

To determine the velocity of sound in air, with the help of a resonance column and find the velocity of sound in air at 0 °C, as well.

Apparatus Required:

1. Resonance tube apparatus

It is an air column formed by a tube with an arrangement to adjust the level of water filled in it. The surface of water in the tube and open end serve the purpose of rigid and yielding reflecting surfaces respectively. The surface of water will act as the closed end.

Generally, resonance apparatus (Figure 1) consists of a metal pipe of length and diameter 1 meter and 2.4 cm respectively, is clamped on a vertical wooden plank. The wooden plank is fixed on heavy metallic base with levelling screws. The lower end of the resonance column pipe is connected to water reservoir with a rubber tube. A transparent tube and scale is also connected parallel to the resonance pipe. The reservoir can be raised or lowered for adjusting the length of the air column.

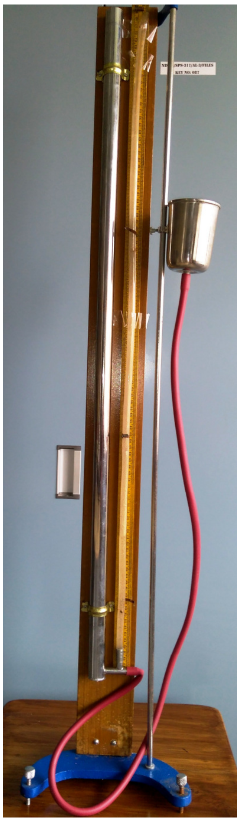

Figure 1. The resonance tube apparatus

2. Tunning forks of different frequencies

3. Rubber pad

4. Thermometer

General information related to the experiment

01. Sound is caused by the vibration motion of the particles of a medium. Sound can travel in solids, liquids and gases but not in vacuum.

02. Sound travels in the form of waves. There are two types of waves, longitudinal and transverse.

03. Longitudinal waves consist of compressions and rarefactions and particles of the medium vibrate in the same direction as that of the motion. One compression and one rarefaction form one complete wave. In gases, sound travels in the form of longitudinal wave.

04. Transverse wave consist of crests and troughs and the particles vibrate at right angles to the direction of propagation of the wave motion..

05. Time period is the time taken by the vibrating body to complete one vibration.

06. Frequency is the number of vibrations executed by a vibrating body in one second. If 'T' be the time period of vibration, then the frequency 'f ' is given by the relation

$$f = \frac{1}{T}$$

07. Wavelength is the distance travelled by a wave during that time in which a particle completes one vibration, it is denoted by the letter λ.

08. Tuning fork is a U shaped bar made of steel with a handle attached at the bend. When it is struck with a hard substance, the prongs begin to vibrate.

09. Velocity of sound. The distance travelled by the sound waves in one second is called the velocity of sound. If 'λ' is the wavelength of sound waves and 'f ' is their frequency, then the velocity ' v ' of the wave is given by the relation,

$$v = f\lambda$$

Further, the velocity of sound is proportional to

$$\sqrt{\frac{Pressure}{density}}$$

Pressure and density refer to the medium in which the sound is travelling. Since at a constant temperature the ratio (pressure/density) is constant for gas, hence the velocity of sound in gas is independent of pressure. The effects of other atmospheric conditions on the velocity of sound are under.

a. <u>Temperature effect</u>. The velocity of sound increases with the rise in temperature as $v \propto \sqrt{T}$, T being the absolute temperature.

b. <u>Humidity Effect</u>. Velocity of sound in humid air is relatively more compared to dry air as $v \propto \sqrt{(1/\rho)}$, ρ of humid air is less than ρ (density) of dry air.

c. Effect of the medium. The velocity of sound in water is about four times that in air at the same temperature. Also sound travels much faster in solids than in gases. Sound, however, does not really pass from one medium to another when the media differ.

Theory :

When the tuning fork is vibrated and held above the open end, longitudinal waves are sent down the air column. These waves are reflected at the water surface and thus produce standing waves. Nodes are produced at the water surface and antinodes are produced at the open end.

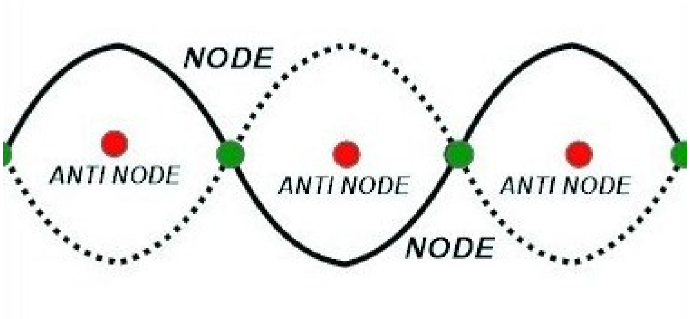

Figure 2. Representation of nodes and antinodes

A loud sound is produced in the air column, when the frequency of waves in the air column becomes equal to the natural frequency of tuning fork,. It is the condition for resonance. It occurs only when the length of air column is proportional to one-fourth of the wavelength of sound waves having frequency equal to frequency of tuning fork.

Let l_1 and l_2 be the first and second resonating lengths respectively for a tuning fork of frequency f, and 'λ' is the wavelength of the sound produced by the tuning fork .

Then, for first resonance,

$$l_1 = \frac{\lambda}{4}$$

and for the second resonance,

$$l_2 = \frac{3\lambda}{4}$$

Thus, from the above two equations, $\lambda = 2\,(l_2 - l_1)$

We know that for all forms of wave motion $v = f\lambda$, where 'v' is velocity, 'f' is frequency and λ is wavelength.

Therefore, the velocity of sound 'v_t' at the room temperature t ºC is given by the following formula

$V_t = 2f\,(l_2 - l_1)$ ....(1)

Making use of the Laplace's formula the velocity of sound (v_o) at 0ºC can be given as under

$V_0 = (V_t - 0.6t)$ m/sec ....(2)

Where, v_0 - velocity of sound in air at 0^0C.
v - velocity of sound in air at temperature t.
t - Room temperature.

According to equation 1, when V_t is constant, the graph between 'f' and ($l_2 - l_1$) should be a rectangular hyperbola.

The air inside the tube will resonate in much the same fashion as air inside an organ pipe that is when standing waves can be set up so that a pressure antinode occurs at the closed end of the tube while a pressure node occurs at the open end of the tube.

Procedure :

1. Partly fill the tube and water supply container with water and stand the tube upright in it.

2. Strike a tuning fork of known frequency with the supplied rubber pad. The tuning fork now produces longitudinal waves with a frequency equal to the natural frequency of the tuning fork.

3. Hold the vibrating tuning fork horizontally above the mouth of the tube. Caution: do not touch the tube with the tuning fork. Sound waves are passes down to the tube and reflect back at the water surface.

4. Move the water surface, up and down several times by using the movable water reservoir until a maximum sound is heard. Tighten the clamp at this position.

5. Measure the length of air column at that position. This is taken as the first resonant length, l_1.
6. Then raise the tube approximately about three times the first resonant length.
7. Excite the tuning fork again and place it on the mouth of the tube.
8. Change the height of the tube until the maximum sound intensity is heard.
9. Measure the length of air column at that position. This is taken as the second resonant length, l_2.
10. Find the difference in the two resonating lengths for each tuning fork.

11. We can now calculate the velocity of sound in air at room temperature by using the relation,

    $V_t = 2f\,(l_2 - l_1)$

12. Repeat the above procedures for the other tuning forks supplied and in each time, calculate the value of V_t.
13. The mean of the calculated values will give the velocity of sound in air at room temperature.

14. Measure the temperature of air inside the pipe with the help of a thermometer.

15. By using the value of V_t, we can calculate the velocity of sound in air at $0\ ^0C$ as,

$V_0 = (V_t - 0.6t)$ m/sec

Observation :

Temperature of air column inside the pipe = ...ºC
Table for the first and second resonating length for air column

S.N	**Frequency f (Hz)**	**First resonating length , l_1 (cm)**			**Second resonating length, l_2 (cm)**			**Diff. Meter (l_2-l_1)**	**Velocity** $V_t = 2f (l_2 - l_1)$ **(m/s)**
		I	**II**	**Mean l_1**	**I**	**II**	**Mean I_2**		
1									
2									
3									
4									
5									

Calculation :

01. Substitute the values of ‘f’ and $(l_2 - l_1)$ for each set of observation in the formula

$V_t = 2f (l_2 - l_1)$ and calculate for V_t i.e. the velocity of sound at tºC.

02. Substitute the value of V_t in Equation 2 and determine V_0, i.e. the velocity of sound in air at 0 ºC.

03. Draw a graph between 'f' and $(l_2 - l_1)$ entered in observation table with 'f' and $(l_2 - l_1)$ along X and Y axes respectively.

Result :

01. The graph between 'f 'and $(l_2 - l_1)$ comes out to be a rectangular hyperbola.

02. Velocity of sound in air is obtained as ....m/sec.

02. Value of the velocity of sound in air at 0ºC ....m/sec.

Precautions :

01. Align the resonance column perfectly vertical at the starting of the experiment.

02. Strike the tuning fork against the rubber pad carefully.

03. Near resonance, the length of air column should be changed in smaller steps.

04. The vibrating tuning fork should be held near the open end of the pipe in such a manner that its vibrations are in a vertical plane.

05. The tuning fork should not touch the pipe.

06. The surrounding should be free from any noise.

QUESTIONS

(a) Explain what is meant by the term "resonance". Explain in qualitative terms why a pressure antinode occurs at the closed end of the tube and a pressure node occurs close to the open end of the tube.

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(b) What approximate relationship holds between the length of the tube and the wavelength of the standing wave for this fundamental mode of vibration?

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(c) Write down the relationship that exists between *V, f*, and *l*.

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(d) What shape of graph should be obtained if wavelength, λ, is plotted versus frequency, *f*?

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