BS 192: Undergraduate Science Laboratory (Physics)

A
Laboratory Report
on

Kundt's Tube Experiment

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Experiment No. 5

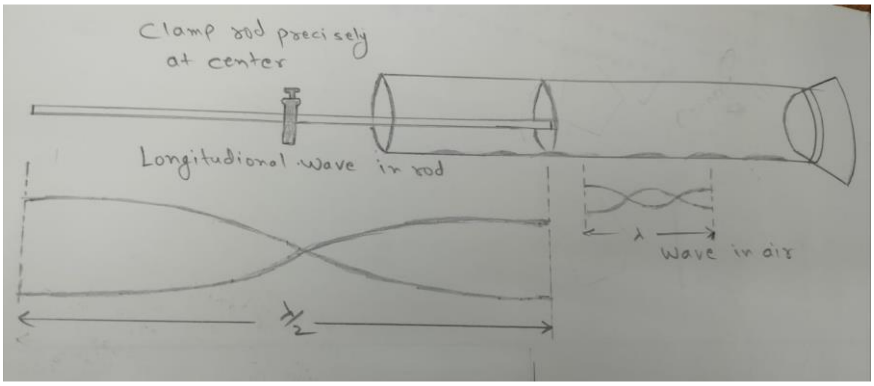
Kundt’s Tube Experiment

I. Aim:

To determine the speed of sound in air using the Kundt’s tube apparatus.

II. Apparatus:

Transparent tube of length $1000\,mm$ and diameter $59\,mm$ with graduations marked, and a loudspeaker attached at one end, with other end having an adjustable piston (reflector) with microphone attached, amplifier and an oscilloscope.



III. Theory:

Sound travels as longitudinal waves in the air and can propagate as longitudinal and transverse waves in solids like metal rods. In a longitudinal wave, the motion of the particles is parallel to the direction of propagation of the wave, whereas, in a transverse wave, the motion of the particles is perpendicular to the direction of propagation of the wave. The Kundt's tube experiment involves generating longitudinal sound waves in an air column using a glass tube apparatus. Standing waves exhibit nodes and antinodes. Nodes are the points where the amplitude is minimum, and antinodes are the points where the amplitude is maximum. The speed of sound (v) in the rod is determined by the formula,

$$v = f \times \lambda$$

where λ is the wavelength and f is the frequency. In the context of sound as a longitudinal and compression wave, gas molecules' displacement is influenced by changing pressure. Transverse waves aren't feasible in gaseous and fluidic substances due to the absence of perpendicular interlinking. The wave's propagation speed is related to the medium's elasticity, which is a factor that depends on temperature.

$$v = \sqrt{\frac{\gamma RT}{M}}$$

Kundt's tube experiment explores sound waves, with a loudspeaker emitting sound that along with the reflected wave from the reflector on the piston results in the formation of standing waves with patterns of nodes and antinodes. Distances between the nodes or antinodes are used to determine sound wavelength, which allows us to find the speed of sound.

Considering the equation for the transmitted wave to be $y_t = Asin(kx - \omega t)$, and the equation for reflected wave to be, $y_r = Asin(kx - \omega t)$, (where, A is the amplitude, k is the angular wave number, ω is the angular frequency, x is position, and t is time.)

Clearly, at certain positions, the value of y is always zero (nodes), and at certain positions it is maximum or minimum (antinodes).

Nodes:

$$sin(kx) = 0$$

$$\Rightarrow sin(kx) = sin(n\pi)$$

Or,

$$\frac{2\pi}{\lambda}x = n\pi$$

$$\Rightarrow x = \frac{n\lambda}{2}$$

Antinodes:

$$sin(kx) = 0$$

$$\Rightarrow sin(kx) = sin\left(\left(n + \frac{1}{2}\right)\pi\right)$$

Or,

$$\frac{2\pi}{\lambda}x = \left(n + \frac{1}{2}\right)\pi$$

$$\Rightarrow x = \frac{(2n + 1)\lambda}{4}$$

From here we can conclude that distance between two nodes or two antinodes is half the wavelength $\frac{\lambda}{2}$.

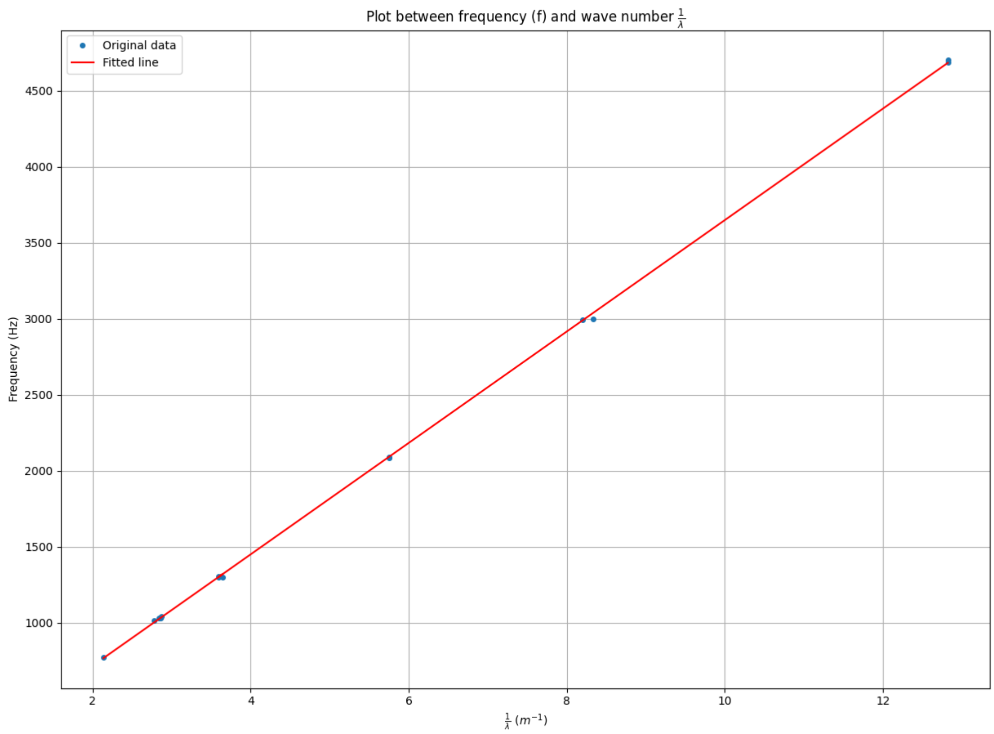
IV. Procedure:

1. First, connect the speaker, the headphones, and the microphone to the Amplifier-Oscillator unit and set the oscillator to a frequency between 0.2 kHz to 5 kHz.
2. Note down the value as f.
3. Start moving the piston slowly outward while listening carefully to the headphones.
4. Measure the length from speaker to reflector and note it down as L (length of the tube).
5. Now, move back the microphone close to the speaker and start pulling it back to the reflector.

6. When the loudness is minimum, note down the distance as X_1.
7. Pull back the microphone and count the number of the point where the loudness is maximum and note it down as n. Also, note down the position of minima after the nth point as X_2.
8. Now, repeat the same step for different frequencies and different tube lengths.
9. Also measure the speed of sound by calculating the slope of the graph of f vs $\frac{1}{\lambda}$.

V. Observations, Graphs and Calculations:

Length of tube (mm)	X1 (mm)	X2 (mm)	n	Frequency (KHz)	λ/2 = (X2-X1)/n (mm)	v = frequency*λ (m/s)	|vi-vo|^2 (m/s)^2
300	53	287	1	0.774	234	362.232	0.371
400	143	323	1	1.012	180	364.320	2.459
500	63	415	2	1.027	176	361.504	0.357
600	175	525	2	1.031	175	360.850	1.011
700	94	618	3	1.036	175	361.909	0.049
780	174	695	3	1.042	174	361.921	0.061
400	74	348	2	1.297	137	355.378	6.483
500	157	434	2	1.300	139	360.100	1.761
700	80	635	4	1.303	139	361.583	0.278
400	98	360	3	2.083	87	363.831	1.970
700	53	662	7	2.091	87	363.834	1.973
400	70	374	5	2.992	61	363.827	1.966
700	72	674	10	2.999	60	361.080	0.781
300	52	283	6	4.685	39	360.745	1.116
500	62	450	10	4.701	39	364.798	2.937
					Mean v (vo) (m/s)	361.861	
					Standard deviation (σ) (m/s)	1.254	



(Images of these readings are in Section VIII)

By taking average of our readings, we get the value for velocity of sound,

$$v = 361.861 \, m/s$$

We can also find out the value of velocity of sound by plotting a graph between frequency and wave number $(\frac{1}{\lambda})$ using least square fitting method.

By taking the slope, the velocity of sound comes out to be,

$$v = 366.583 \, m/s$$

Which is fairly close to the average value of readings.

VI. Results, Discussion and Error Analysis:

To calculate the error,

$$v = f \times \lambda$$

$$ln(v) = ln(f) + ln(\lambda)$$

Differentiating both sides,

$$\frac{\Delta v}{v} = \frac{\Delta f}{f} + \frac{\Delta \lambda}{\lambda}$$

$\Delta\lambda = 0.001 \, m$ which is the least count of the scale on the apparatus.

$\Delta f = 1 \, Hz$ which is the least count of the display on the amplifier.

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

Calculating Δv for all readings and taking r.m.s. $(\sqrt{\frac{\sum v_i^2}{n}})$

$$\Delta v = 2.499 \, m/s$$

The velocity of sound comes out to be,

$$v = 361.861 \pm 2.499 \text{ m/s}$$

Standard deviation $(\sigma = \sqrt{\left(\frac{\sum(v_i-\mu)^2}{N}\right)})$ across all readings for velocity comes out to be,

$$\sigma = 1.254 \text{ m/s}$$

The speed of sound in air at $25\,°C$ is 346.054 m/s,

Error percentage $= \frac{361.861-346.054}{346.054} \times 100 = 4.568\ \%$

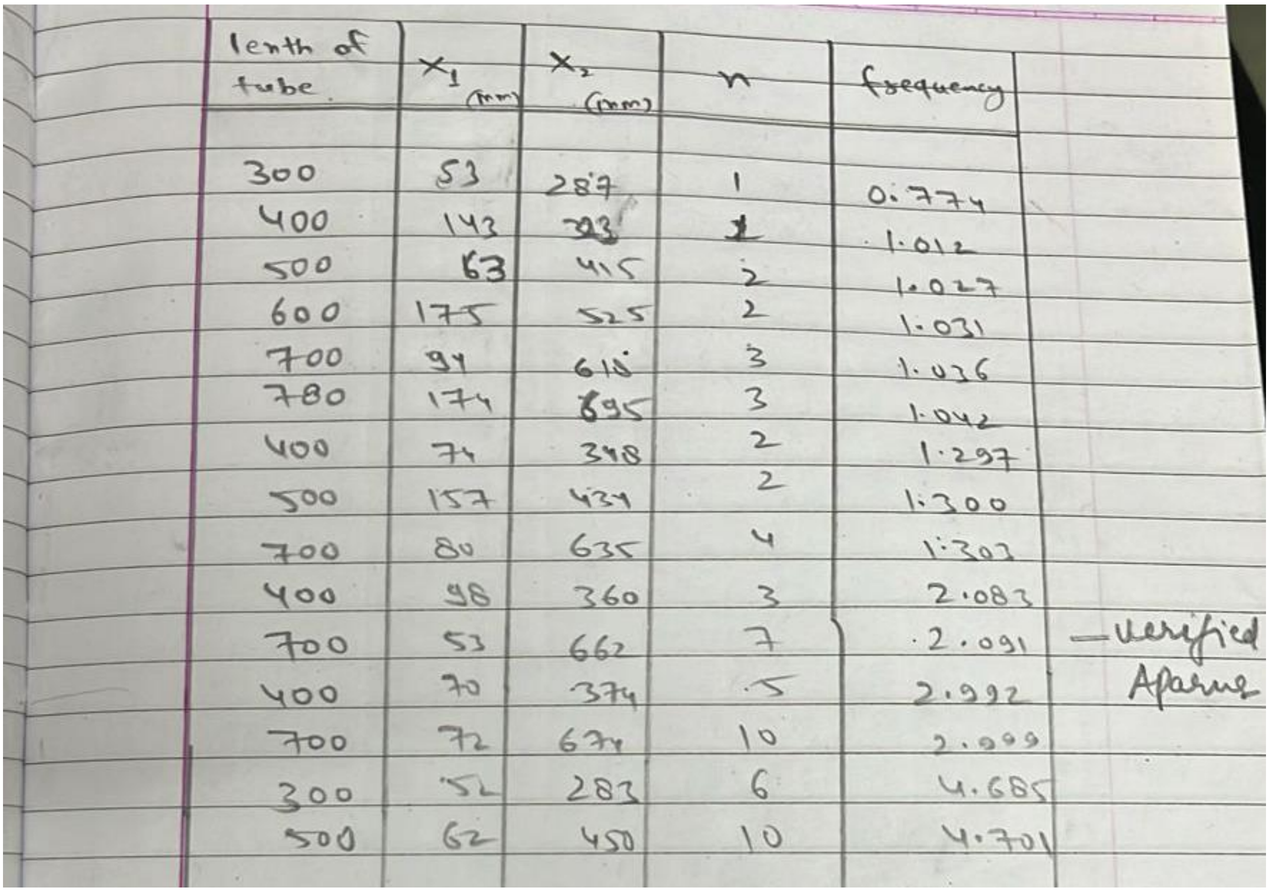
- Possible sources of errors:
  1. Since the velocity of sound depends on the temperature, we might have got the higher reading due to higher temperature in the Kundt's tube as compared to the room temperature.

2. Also, the pressure inside the tube could be higher than the pressure outside, that could have resulted in higher speed of sound.
3. The frequency of the amplifier kept fluctuating with time around a fixed value that could have slightly affected the value of the speed of sound.

VII. Conclusion:

We conducted this experiment to determine the value of the speed of sound in air, which comes out to be $v = 361.861 \pm 2.499$ m/s, with a standard deviation of 1.254 m/s. We observed that the loudness of sound changed as we moved the microphone across the length of the tube, which led us to confirm the existence of nodes and antinodes. We then got the wavelength for the given initial conditions and found out the velocity of sound. We also had an oscillator to visualise the sound wave captured by the microphone. We could see the wave pattern change when the microphone was around the nodes. To get a more accurate reading we should conduct the experiment in a much longer tube and take more readings. We can also have a thermometer inside the tube to measure the temperature and maybe even calculate the adiabatic constant for air. We can plot velocity of sound squared vs temperature if we have the option to vary the temperature and get the value of adiabatic constant (γ).

VIII. Readings Images:



lenth of tube	x_1 (mm)	x_2 (mm)	n	frequency	
300	53	287	1	0.774	
400	143	323	1	1.012	
500	63	415	2	1.027	
600	175	525	2	1.031	
700	94	618	3	1.036	
780	174	695	3	1.042	
400	74	348	2	1.297	
500	157	434	2	1.300	
700	80	635	4	1.303	
400	98	360	3	2.083	
700	53	662	7	2.091	— verified
400	70	374	5	2.992	Aparna
700	72	674	10	2.999	
300	52	283	6	4.685	
500	62	450	10	4.701	

IX. Author Contribution:

Name	Roll Number	Contribution	Signature
Jaskirat Singh Maskeen	23110146	Plotting graph using Matplotlib, Error analysis, Finding possible sources of error and conclusion.	Jaskirat Singh Maskeen
Nishchay Bhutoria	23110222	Index, Aim, Taking readings in lab, Cover page, Document structure, Theory.	
Kavya Lavti	23110164	Document structure, Taking readings in lab, Procedure.	
Kanhaiyalal	23110155	Noting readings, Apparatus Diagrams.	Kanhaiyalal