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Kundt's tube Experiment

Determine the speed of sound in air

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***Abstract*—In this experiment, we have calculated the speed of sound using a Kundt's tube. Here we changed the frequencies of sound using a frequency generator and measured the distance between the consecutive nodes/antinodes in the tube which helped us to calculate the speed of sound.**
This experiment provides information regarding the properties of sound waves. It also allowed us to apply concepts of physics, such as wave propagation frequency-wavelength relationship and standing wave formation.

***Index Terms*—Reflector, loudspeaker, microphone, wavelength, headphone, resonance, nodes and antinodes.**

I. Objective

The aim of the experiment is to find the speed of sound using Kundt's tube.

II. Materials and Methods

A. Materials

1) Transparent tube of 59mm diameter and 1000mm length with a reading scale.
2) A loudspeaker attached at one end of the tube
3) A movable piston with a reflector and a microphone on the other end of the tube.
4) Amplifier along with a DSO
5) Speaker and headphones
6) Support block to avoid contact of the tube with the surface.

B. Methods

This experiment studies sound waves, which are longitudinal waves. Since longitudinal waves are caused by the displacement of gas molecules, which in turn is caused by a change in pressure, they are also called compression waves.

This experiment involves the generation of standing waves within the air column of Kundt's tube. This is done by propagating a sound wave from the speaker at one end. This sound wave is then reflected by the reflector attached at the other end of the tube along with the piston. Standing waves are generated when waves of equal wavelength and amplitude propagate in opposite directions.

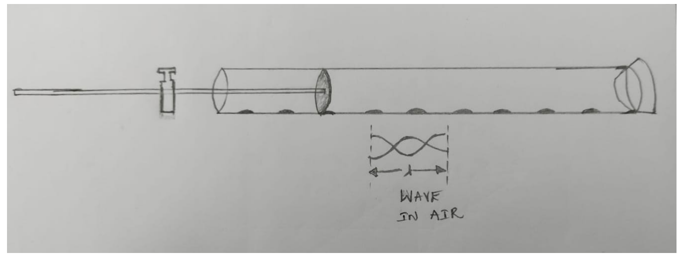


Fig. 1. Generation of Standing waves

if we assume the original wave is $y_t = Asin(kx - \omega t)$ and the reflected ray is $y_r = Asin(kx + \omega t)$ where ω is angular frequency and k is angular wave number i.e.$\frac{2\pi}{\lambda}$.
Both equations are identical except for the sign showing that both of them are propagating in opposite directions. The resultant wave is given by:

$$y = y_t + y_r$$
$$y = Asin(kx - \omega t) + Asin(kx + \omega t)$$

Using trigonometric identities, we get:

$$y = 2Asin(kx)cos(\omega t)$$

This is the equation for the standing wave so obtained. Here the amplitude of the wave is $2Asin(kx)$. Now if we consider nodes then the amplitude at nodes is zero

$$A = 0$$
$$2Asin(kx) = 0$$
$$\therefore sin(kx) = sin(n\pi)$$
$$\therefore kx = n\pi$$
$$\therefore \frac{2\pi}{\lambda}x = n\pi$$
$$\therefore x = \frac{\lambda}{2}n \text{ where } n = 0, 1, 2, 3.....$$

Similarly, if we consider antinodes the amplitude is maximum, Now this can be in either positive or negative direction.

$$\therefore 2Asin(kx) = \pm 2A$$
$$\therefore sin(kx) = \pm 1$$
$$\therefore kx = (2n+1)\frac{\pi}{2}$$
$$\therefore \frac{2\pi}{\lambda}x = (2n+1)\frac{\pi}{2}$$
$$\therefore x = (2n+1)\frac{\lambda}{4} \text{ where } n = 0, 1, 2, 3.....$$

Thus, the distance between two consecutive antinodes i.e $(n+1)^{th}$ and n^{th} is:

$$x_{n+1} - x_n = (\frac{2(n+1)+1}{4} - \frac{2n+1}{4})\lambda$$
$$x_{n+1} - x_n = \frac{\lambda}{2}$$

Hence we can clearly see that the distance between any two nodes or antinodes is given by $\frac{\lambda}{2}$
Now, by measuring the distance between two nodes or antinodes, we can easily determine the Wavelength (λ) of the

wave, and if the frequency (ν) is known, then we can find the velocity of sound (V) using the relation:

$$\boxed{V = \nu \times \lambda}$$

III. Procedure

1) Ensure that Kundt's tube apparatus is set up on a level surface.
2) Connect the speaker within the tube to the audio oscillator.
3) Connect the microphone to the amplifier and then to the oscilloscope.
4) Change settings in the oscilloscope to take the oscilloscope readings.
5) Set up the frequency generator to generate a wave in the range (between 0.200 kHz to 5 kHz).
6) Apply this AC voltage to the speaker.
7) Start Adjusting the oscillator's frequency and observe the amplitude of the sound wave at different locations in the tube using the oscilloscope.
8) Now, measure the distance between a contiguous maximum and minimum in the standing wave pattern, giving us the half wavelength

   $\frac{\lambda}{2}$ = distance between consecutive min/max

9) Calculate the wavelength of the sound wave using the formula $\lambda = 2\frac{(X_1 - X_2)}{n}$
10) Note the value of frequency (ν)
11) Calculate the velocity (V) of the sound wave using the formula $V = \nu \times \lambda$
12) Record the frequency and velocity of the wave for different positions of the movable piston.
13) Repeat the same procedure with different air columns of different lengths to verify the accuracy of the results.
14) Now calculate the average velocity of the wave from the measurements taken at different piston positions.
15) Calculate the standard deviation of the velocity measurements to estimate the uncertainty in the experimental results.

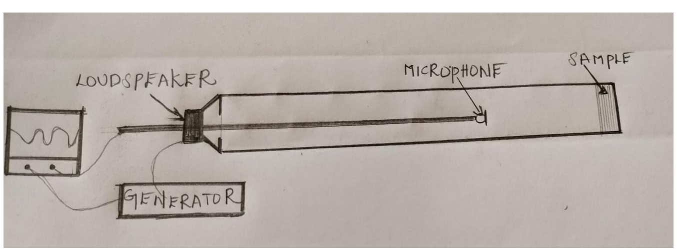


Fig. 2. Kundt's Tube apparatus

IV. Observation and Calculations

Freq (ν) (in Hz)	Length of tube (in mm)	X_1 (in mm)	X_2 (in mm)	n	$\lambda = 2\frac{(X_2-X_1)}{n}$ (in mm)	$V = \nu \times \lambda$ (in m/s)	$\lvert Vi - Vo \rvert$ (in m/s)	$\lvert Vi - Vo \rvert^2$ in $(m/s)^2$
595	775	120	695	2	575	342.125	16.286	265.224
700	656	70	590	2	520	364.000	5.589	31.240
1500	780	120	720	5	240	360.000	1.589	2.526
2000	585	100	540	5	176	352.000	6.411	41.097
2500	485	90	460	5	148	370.000	11.589	134.312
3000	580	70	555	8	121	363.750	5.339	28.508
3500	330	55	310	5	102	357.000	1.411	1.990
Mean V (Vo) = 358.411 m/s								
Mean Deviation = 6.888 m/s								
Standard Deviation = 8.493 m/s								

TABLE I
Observation and calculation of V

V. Results, Discussions and Analysis

Calculating the error propagated due to the least count:

$$V = \nu \times \lambda \tag{1}$$

Taking logs on both sides:

$$log(V) = log(\nu) + log(\lambda) \tag{2}$$

Differentiating both sides:

$$\frac{\Delta V}{V} = \frac{\Delta \nu}{\nu} + \frac{\Delta \lambda}{\lambda} \tag{3}$$

Now, $\Delta f = 1Hz$ Since it is the least count of frequency $\Delta \lambda = 1mm = 0.001m$ Since it is the least count for the scale in the tube. Thus,

$$\Delta V = V(\frac{\Delta \nu}{\nu} + \frac{\Delta \lambda}{\lambda}) \tag{4}$$

Calculating ΔV for all the readings, we get the following values for each V:

V (m/s)	ΔV (m/s)
342.125	1.170
364.000	1.220
360.000	1.740
352.000	2.176
370.000	2.648
363.750	3.121
357.000	3.602

TABLE II
Values of ΔV for each V

Thus, the average error in V is the average of all the values of ΔV

$$\boxed{\therefore \Delta V = 2.240 m/s}$$

Thus the value of speed of sound comes out to be:

$$\boxed{V = 351.411 \pm 2.240 m/s} \tag{5}$$

VI. Possible sources of errors

1) The speed of sound in a medium depends on its elasticity which in turn depends on temperature. Now it is quite possible that while performing the experiment, there were some fluctuations in the value of the surrounding temperature, which could have introduced inaccuracies in the value.
2) Throughout the experiment, we have to listen to the sound and determine the node and antinode based on the loudness. This loudness is subjective, and thus we (humans) may not have correctly detected the loudest sound, which introduced Human Errors
3) In an ideal setup, the node should be obtained where the amplitude is zero, that is, no sound is audible, i.e. SWR (Standing wave ratio)=infinity. However, during the experiment, there was some sound audible at a node, which means SWR was constant, which could have led to inaccuracies in the answer.
4) The Frequency of the amplifier also kept fluctuating continuously, which may have caused the wrong frequency reading, which in turn affected the final answer.

VII. Conclusion and Future Prospects

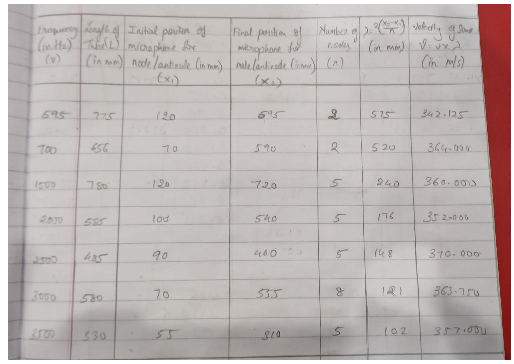
A. Conclusion

After performing Kundt's tube experiment, the speed of sound comes out to be $V = 351.411 \pm 2.240 m/s$. The standard deviation in the value so obtained is $8.493 m/s$.Different errors caused this deviation in the final result. After listening to the sound waves through the given headphones, we carefully measured properties like frequency and positions of nodes and antinodes. Using these measurements along with the tube's length, we calculated the speed of sound.
In conclusion, it's a simple way to calculate the speed of light and study the system of stationary waves and the interference between them.

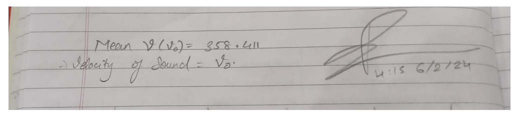
B. Future Prospects

Future experiments could use better equipment, like speakers and microphones, to improve the accuracy of the measurements and achieve even more precise results. Also, since the speed of sound is dependent on the elasticity of the medium, which in turn is dependent on temperature, we can try and keep a track of temperature along with other values in order to obtain better results.

VIII. Reading images



Frequency (in Hz) (ν)	Length of Tube (L) (in mm)	Initial position of microphone for node/antinode (in mm) (x_1)	Final position of microphone for node/antinode (in mm) (x_2)	Number of nodes (n)	$\lambda = 2\left(\frac{x_2 - x_1}{n}\right)$ (in mm)	Velocity of Sound $\vartheta = \nu \times \lambda$ (in m/s)
595	775	120	695	2	575	342.125
700	656	70	590	2	520	364.000
1500	780	120	720	5	240	360.000
2000	585	100	540	5	176	352.000
2500	485	90	460	5	148	370.000
3000	580	70	535	8	121	363.750
3500	330	55	310	5	102	357.000



Mean $\vartheta (\vartheta_0) = 358.411$
→ Velocity of Sound = ϑ_0.
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IX. Author Contributions

Name	Roll number	Contribution	Signature
Faayza Vora	23110109	Material and Methods, Observations and Calculations, Results, Discussion and analysis, Possible sources of error and Lab readings/equipment handling	
Goraksh Bendale	23110118	Absent	
Dishant Tanmay	23110100	Abstract, Objective , Procedure, Results,Lab readings/equipment handling	
Haravath Saroja	23110127	Conclusion and future prospects, Diagrams, Lab redaings	

TABLE III
Author's Contribution