PHYS 130 - Section EF22

Lab 4: Speed of Sound

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Introduction

Objective

This lab report aims to measure the speed of sound in an air medium using the standing sound wave phenomena in a pipe and understand the effect of resonance in forming wave nodes and antinodes.

Theory

Sound is formed from longitudinal waves generated by a vibrating body which proceed to propagate by transferring energy through a medium. As a result the phenomena of sound allows living beings to hear their surroundings as well as develop methods of communication and entertainment. One such form of entertainment is music with the most notable developments being instrumental music such as woodwind and brass. These instruments utilize the standing wave phenomena of sound in a tube to generate varied frequencies at an amplified range. This ability is caused by resonance which occurs at specific tube depths in relation to the frequency through the formula $L_n = (2n-1)\lambda/4$, where L is the tube length, n is the harmonic number (number of antinodes), and λ is the wavelength. By incorporating the equation $v=f\lambda$ into the previous formula and adjusting for realistic factors one can obtain the equation $D_n = c_s (2n-1)/(4f) - x_0$, where D_n is the distance within the pipe (m), c_s is the speed of sound (m/s), f is the frequency (Hz) and x_0 is the slight distance (m) from the outside of the pipe where the first antinode actually takes place. There are two other equations that will be used in this experiment to determine the accuracy of the observations: $c_s = c_{s0}\sqrt{T/273.15K}$ where c_{s0} is the speed of sound (m/s) at 273.15K and T is the temperature in kelvin; $x_0 \sim= 0.6R$ where R is the radius (m) of the tube.

Methods

Equipment

Before beginning the experiment it is necessary to have the following equipment:

- A hollow pipe at least 1m long with a plunger inside that can adjust the pipe depth
- A meter stick and thermometer
- Tuning forks of varying frequencies and a rubber rod
- Two phones with the Phyphox app installed

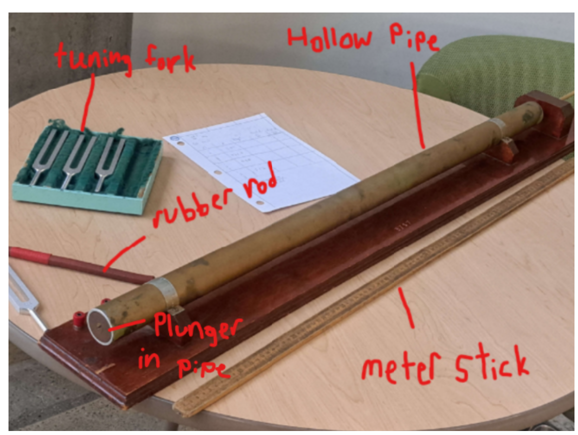


Figure 1.1: An example setup of equipment for the tuning fork experiment. Note that the plunger inside the tube can be pulled back to adjust pipe depth.
Also note that the rubber rod is an integral part of the experiment as its softness allows the tuning fork to resonate at only its fundamental frequency.

Procedure

1. Beginning with the setup in Figure 1.1 with the plunger at the opening of the tube, strike the tuning fork chosen with the rubber rod and hold it to the open end.
2. Slowly pull the plunger back while carefully listening for a loud amplification of tone, strike the tuning fork again if necessary to maintain vibration, an increase in tone indicates the first resonance point. Once the first resonance point is achieved one should stop pulling the plunger immediately and record the distance pulled (corresponding to the depth of the pipe exposed).
3. Without resetting the plunger one can continue pulling the plunger after re-striking the tuning fork with the rubber rod to attempt to find the next resonance point within the tube and record its distance. Make sure to record which distance correlates with its harmonic.
4. Once the plunger has reached the end of the pipe, reset it and begin again with the next tuning fork until all tuning forks are used.
5. In order to illustrate the uncertainty of this method of experiment, repeat the entire experiment once and compare the results. Afterwards record the length and diameter of the pipe as well as the ambient temperature.

The next experiment also measures the speed of sound but uses the Phypox app.

1. Place two phones with the Phypox app several meters apart and record the distance.
2. Inside the Phypox app, select Acoustic Stopwatch near the bottom and click the play button. Note that if the app is hearing background noise, increase the threshold slightly.
3. With one person standing next to each phone, one should clap to start the experiment and a couple of seconds later the other person claps to stop the experiment. Record the difference in time between the phones

Results

Data

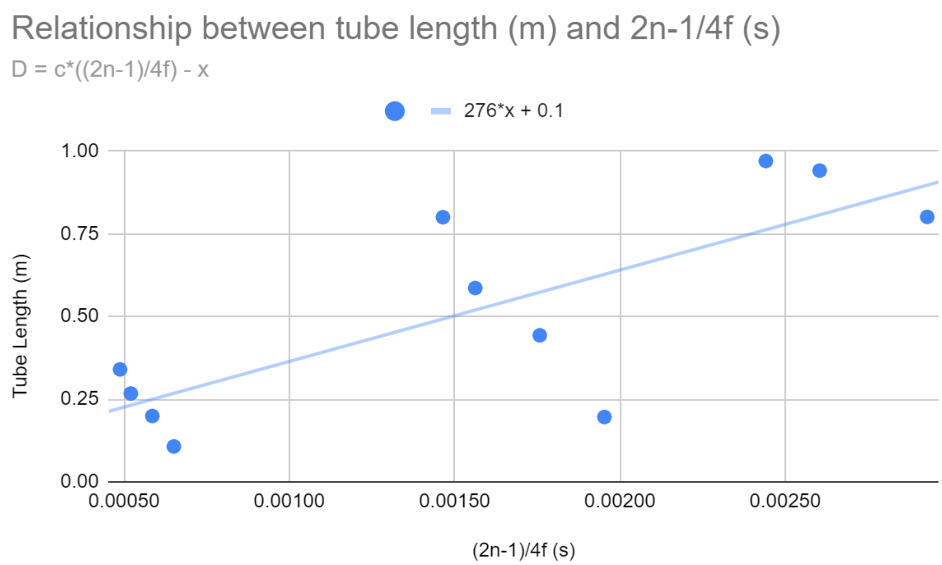
It is important to note that all distances were measured with a meter stick that was correct to the nearest mm and as such has an uncertainty of roughly ± 0.001 m.

Sample Table 1.1: Relationship between frequency (f), harmonic number (n) and the depth of the pipe with accordance to the formula $D_n = c_s\,(2n-1)/(4f) - x_0$. See Appendix 1 for the entire table.

			Distance (m) ± 0.01 m	
n	Frequency (Hz)	(2n-1)/4f (s)	Trial 1	Trial 2
1	384	0.00065	0.095	0.107
2	384	0.00195	0.242	0.196
3	426.7	0.00293	0.484	0.801
2	480	0.00156	0.493	0.586
1	512	0.00049	0.255	0.34

Sample Calculation for (2n-1)/4f with n = 2, f = 384:
(2n-1)/4f = (2*2 -1)/(4*384 Hz) = 3/(1536 Hz) = 0.00195 s

Graph 1.1: Scatter plot of the relationship between (2n-1)/(4f) and the pipe depth. Note that the linear equation is of the form $D_n = c_s$ (2n-1)/(4f) - x_0 and that Trial 2 was chosen for the graph.



Analysis

By observing the linear relationship presented in graph 1.1 and letting x denote the x-axis (2n-1)/4f with y denoting the y-axis D_n the equation y = 276x + 0.1 is formed. Comparing this equation to the original relationship $D_n = c_s$ (2n-1)/(4f) - x_0 we can determine that the slope is representative of c_s and the y-intercept is x_0. Incorporating these assumptions into a LINEST function of the data it is determined that the speed of sound (c_s) is (276 ± 76) m/s and the distance outside the tube (x_0) is (0.1±0.1)m.

Next it is necessary to compare these findings with their theoretical values using the equations $c_s = c_{s0}\sqrt{T/273.15K}$ and x_0 ~= 0.6R mentioned earlier in the introduction. These theoretical values can be determined by plugging in the observed values T = (20.90 ± 0.05) Celsius or (294.05 ± 0.05) Kelvin and R = (0.045 ± 0.001) m along with the already known c_{s0} = 331.3 m/s. Finally, we measured the experimental speed of sound again with the Phypox experiment where $c_s = 2d/\Delta t$, d was measured to be (3.04 ± 0.001) m and Δt was 0.017s.

Sample Calculations:
$c_s = c_{s0}\sqrt{T/273.15K} = 331.3 \text{ m/s} \sqrt{(294.05 \pm 0.05)K/273.15K} = (344 \pm 4)$ m/s
x_0 ~= 0.6R = 0.6 * (0.045 ± 0.001) m = (0.02700 ± 0.0006) m
$c_s = 2d/\Delta t$ = 2*(3.04 ± 0.001) m / 0.017s = (357.6 ± 0.1) m/s

Discussion

In summary, the observed speed of sound values determined through the resonance experiment and Phyphox experiment are (276 ± 76) m/s and (357.6 ± 0.1) m/s respectively while the theoretical value is (344 ± 4) m/s. The observed value for x_0 is (0.1±0.1)m while the theoretical value is (0.02700 ± 0.0006) m. By comparing the differences between theoretical and experimental it is determined that the differences are: (68±76)m/s ,(0.1±0.1)m, (14±4)m/s for the resonance experiment c_s and x_0 and the Phyphox c_s respectively. As the c_s and x_0 for the resonance experiment is within 1 error interval of theoretical 0 it is safe to assume that the values are in good agreement. On the other hand the Phyphox c_s is within 4 error intervals which indicates a poor agreement between the values.

Comparison calculations:

Resonance c_s

$\Delta c = |c_{se} - c_{s0}| = |344 - 276| = 68$ m/s

$\delta\Delta c = \sqrt{(\delta c_1)^2 + (\delta c_2)^2} = \sqrt{(76)^2 + (4)^2} = 76$ m/s

Phypox c_s

$\Delta c = |c_{se} - c_{s0}| = |344 - 357.6| = 13.6$ m/s

$\delta\Delta c = \sqrt{(\delta c_1)^2 + (\delta c_2)^2} = \sqrt{(0.1)^2 + (4)^2} = 4$ m/s

$\Delta x = |x_{0e} - x_{0o}| = |0.1 - 0.027| = 0.073$ m $\quad \delta\Delta x_0 = \sqrt{(\delta x_0)^2 + (\delta x_0)^2} = \sqrt{(0.1)^2 + (0.0006)^2} = 0.1$m

There are a number of possible sources of error in this experiment that must be noted. In the pipe/resonance experiment it is extremely difficult to detect the increase in pitch which can be seen by the drastically varying depths between Trial 1 and 2 in Table 1.1. The reason Trial 2 was chosen to be used for the data over Trial 1 is that it took time to get used to hearing the pitch change and Trial 1 and as a result many data points in Trial 1 did not match the trendline well. As a result the potential for error in the experiment increased drastically and some data points do not match well with the rest of the graph (for both Trial 1 and 2). For the Phyphox experiment, there is a large possibility that the distance was incorrectly measured as we used a single meter stick to measure multiple meters worth of distance. It would have been far more accurate to use a tape measure or even multiple meter sticks to increase the accuracy of the distance measurement. As it is the only real source of error in that experiment it is most likely the reason for the disagreement in values.

Conclusion

This experiment utilized various methods to measure the speed of sound in an air medium ranging from measuring temperature to utilizing PhyPhox and the harmonic nature of standing waves in a pipe. As a result, this experiment helps illustrate the nature of sound and its ability to propagate through a medium as well as reinforces students' understanding of harmonic resonance in a half-open pipe.

To summarize, the speed of sounds measured in the resonance and Phyphox experiments respectively were (276 ± 76) m/s and (357.6 ± 0.1) m/s while the theoretical value at the room's temperature was (344 ± 4) m/s. Comparing these results illustrates that the resonance experiment is in good agreement with the theoretical while the Phyphox experiment had poor agreement most likely due to an error in distance measurement. In addition, it was also observed that the small distance outside of the open tube where an antinode forms is approximately (0.1±0.1)m while the theoretical value is (0.02700 ± 0.0006) m and both are in good agreement with each other.

References and Acknowledgements

This lab report referenced the following for all equations used in this report:
Isaac, et al. 2022. Lab Manual PHYS 130. Edmonton: University of Alberta, Department of Physics.

This report acknowledges that the data used in this report was gathered with the assistance of fellow lab partner Bhuvish. This report also acknowledges TA Rishap Lamichhane for providing assistance in gathering data for the pipe resonance experiment.

Appendix 1

			Distance (m) ± 0.01 m	
n	Frequency (Hz)	(2n-1)/4f (s)	Trial 1	Trial 2
1	384	0.00065	0.095	0.107
2	384	0.00195	0.242	0.196
1	426.7	0.00059	0.165	0.199
2	426.7	0.00176	0.372	0.443
3	426.7	0.00293	0.484	0.801
1	480	0.00052	0.196	0.267
2	480	0.00156	0.493	0.586
3	480	0.00260	0.731	0.941
1	512	0.00049	0.255	0.34
2	512	0.00146	0.698	0.8
3	512	0.00244	0.99	0.97