Report of laboratory experiment

Sound Waves

Laboratory of Experimental Physics for AI

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Abstract

This experiment will investigate sound wave propagation in an air-filled tube.

The goal is to verify theoretical formulas and examine relationships between wave frequency, the number of antinodes, and tube length. The experiment will also give an estimation of the sound velocity under varying conditions. A better understanding of the underlying principles of sound wave propagation will be achieved through graphical representations.

The analysis will involve studying open and closed tube configurations and observing the behaviour of stationary waves and square waves.

Variations in experimental conditions will be observed to determine their impact on the results. Measurement errors and instrument limitations will be considered throughout the experiment to enhance the accuracy and reliability of the findings.

The results will be compared with theoretical predictions to evaluate consistency and validity. A critical discussion of the results will follow to highlight key observations and their implications.

1 Goal of the experiment

- The physical phenomenon under study is the propagation of sound waves, which involves the movement of a disturbance through a medium. This disturbance transfers energy from one point to another without the actual movement of matter over the same distance. In the case of sound waves, this disturbance consists of alternating regions of high and low pressure that travel through the air.

  Sound waves are elastic, spherical, longitudinal waves that can travel through various media, with their speed dependent on the properties of the medium. In air, sound waves cause the air particles to vibrate, leading to changes in density and pressure along the direction of wave propagation.

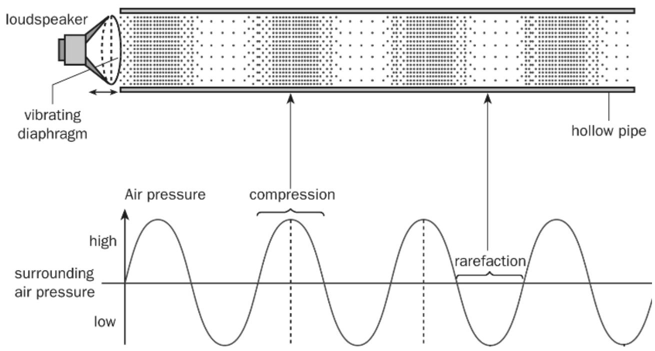
  The equation describing the pressure variation of a standing wave in a medium is the following:

$$\Delta p(x,t) = A\, sin\left(\frac{2\pi x}{\lambda}\right) cos(2\pi f t)$$

  where $\frac{2\pi}{\lambda}$ is the wave number k (which tells how quickly the wave oscillates in space) and $2\pi f$ is the wave frequency ω (which tells how quickly the wave oscillates in time).

  Figure 1.1 provides a clear visualization of the concept described above :

  (Figure 1.1)



  The condition for a stationary way to appear depends on whether the tube is closed or not at one side.

  - Wave propagation in a tube of length L open at both sides is analogous to that of a pulse travelling on a single wire fixed at its extremities. The variation of air pressure at the tube's extremities is minimal: the two open ends thus correspond to two nodes.

    In this configuration, a standing wave will appear if $L = \frac{n \cdot \lambda_n}{2}$ (for n = 1, 2, 3…). Since the velocity of a wave is given by $v = f_n \cdot \lambda_n$, the corresponding frequency is $f_n = n\frac{v}{2L}$.

- If a tube of length L is closed at one side, the variation of pressure in this point is maximal and thus corresponds to a wave antinode.

  In this configuration, a standing wave will appear if $L = \frac{(2n-1)\lambda_n}{4}$ (for n = 1, 2, 3…); the corresponding frequency is $f_n = \frac{(2n-1)}{4}\frac{v}{L}$.

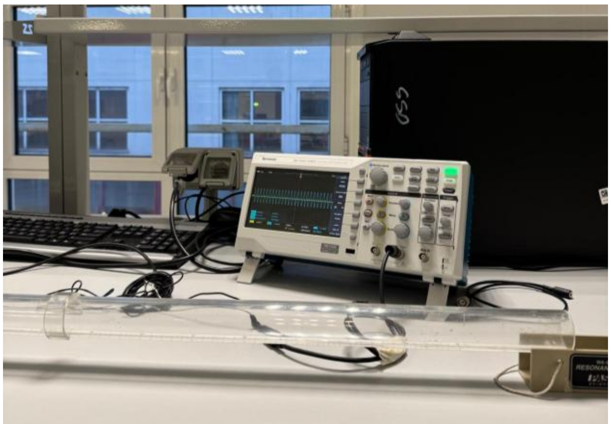
- In this experiment, we aim to practically prove the given formulae and explore the properties of sound waves in a tube. In particular, we will:
  - Investigate the error associated with our measurements.
  - Examine the relationship between the frequency of a stationary way and the number of antinodes, by increasing the frequency up to the 5th harmonic.
  - Verify the formula $f(n) = \frac{v}{2L}n$ by identifying the position of nodes and antinodes for n > 1.
  - Estimate the propagation velocity of acoustic waves using the measured value of L.
  - Verify the formula $f(n) = \frac{2n-1}{4} \cdot \frac{v}{L}$.
  - Investigate the relationship between the frequency of a stationary wave and the length of the tube, by closing one end and repeating measurements varying the tube length.
  - Use the reflection of a square wave to measure acoustic wave velocity.

2 Experimental setup and methods

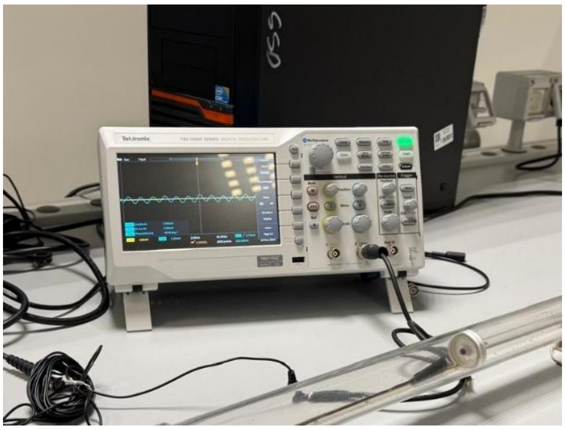
- The instrumentation used for the measurements consists of:
  - An HP Agilent Keysight 33220A generator capable of generating periodic sinusoidal functions with variable frequency and amplitude. The frequency is manually determined using a control knob.
  - A speaker with transducer functions, i.e. a speaker that converts electrical signals into sound waves.
  - A 90 cm long and 3 cm wide rigid tube for sound wave propagation (the sound wave travels through the tube, creating alternating high-pressure and low-pressure regions).
  - A microphone attached to a movable rod, allowing it to be positioned at different points along the tube. The microphone is equipped with an amplifier to detect and amplify sound waves.
  - A Tektronix TBS 1000C series digital oscilloscope (2-channels). The oscilloscope receives the electrical signal from the microphone and displays it as a waveform. The waveform represents the amplitude of the sound wave as a function of time.

  - A plastic piston, used to seal one end of the tube when necessary.

- Here are some images documenting our experiment:
  - The oscilloscope in the background and the tube in the foreground



  - The oscilloscope displaying a standing wave



  - The wave generator displaying a frequence of 567 Hz

- Possible sources of error could be:

  - Background noise: Conducting the experiment in a non-quiet environment introduces errors and imprecisions due to background noise detected by the microphone, which interferes with the measurement of the intended signal.

  - Frequency determination error: The experimental determination of the frequency relies on manually rotating the control knob, introducing human error. To estimate this error, we took 12 manual measurements of the first harmonic (data shown in Table 2.1 below). The mean frequency was calculated using Formula 2.2 resulting in 184.8 Hz. The standard deviation was computed as Formula 2.3, resulting in 0.83 Hz. The error on the mean (Formula 2.4) was determined to be 0.24 Hz.

    The result of such an error-determination measurement can thus be expressed as 184.8 $\pm$ 0.2 Hz.

(Formula 2.2)

$$\bar{x} = \frac{\sum_{i=0}^{N} x_i}{N}$$

(Formula 2.3)

$$\sigma_x = \sqrt{\frac{1}{N-1}\Sigma(x_i - \bar{x})^2}$$

(Formula 2.4)

$$\sigma_{\bar{x}} = \frac{\sigma_x}{\sqrt{N}}$$

(Table 2.1)

Attempt	Value
1	186
2	185
3	186
4	185
5	185
6	184
7	184
8	184
9	185
10	186
11	184
12	184

  - Measurement uncertainty: The uncertainty in determining the frequency is primarily influenced by the oscilloscope's resolution. The smallest frequency variation that produces a measurable amplitude change on the oscilloscope is 2 Hz, which defines the uncertainty in these measurements.

  - Position determination error: The spatial position of the antinode was experimentally determined by moving a microphone inside the tube. This measurement, of course, involves some degree of error. To quantify this, each of us manually measured the position of the antinode twice, focusing on the first maximum of the third harmonic. Using Formulas 2.2 and 2.3, we calculated the mean value as 14.2 cm and the standard deviation as 0.2 cm.

    The final result, accounting for the error, is expressed as: 14.2 ± 0.2 cm, i.e. 0.142 ± 0.002 m.

- The experimental approach used to collect the data will be discussed in detail when the measurements are presented. However, as a general approach, the following method was employed.

- For each value to be measured, multiple measurements were taken by alternating among the five of us, in order to minimize systematic errors arising from visual impairments or other human biases.
- All data were recorded in tables.
- To reduce computational errors, all analyses were carried out utilising Microsoft Excel's statistical functions AVERAGE, STDEV and a customed formula for the error on the mean.
- To improve clarity and make the data easier to read and interpret, Residual Plot Graphs and other visual representations were introduced.
- When required, the GeoGebra "Linear Regression" tool was used to fit the data to the most suitable function.
- Finally, the results were compared to assess their compatibility.

3 Results

3.1 Measurements with the open tube

- **Frequency of a stationary wave as a function of the number of antinodes**

  - To determine the relationship between the frequency of a stationary wave and the number of antinodes, we measured the frequencies of various harmonics.

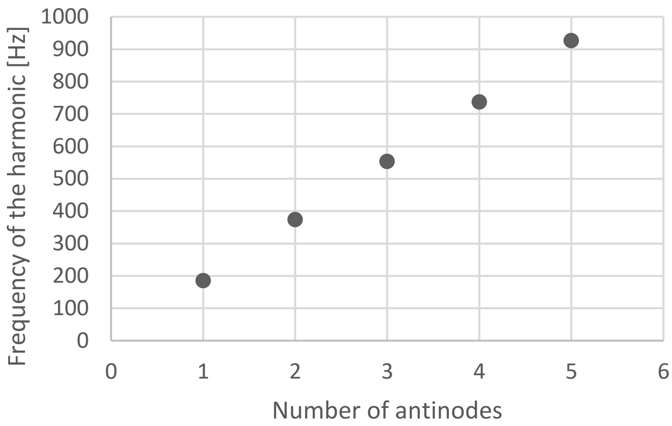
    Starting from the fundamental harmonic at 185 Hz, we gradually increased the frequency up to the fifth harmonic at 926 Hz.

    We then recorded the mean frequency values for each harmonic in Table 3.1 and created a graph (Figure 3.2) to display the data and illustrate the relationship between n (the number of antinodes) and f (the frequency of the n^{th} harmonic).

(Table 3.1)

Number of antinodes	Frequency
1	185 ± 2 Hz
2	374 ± 2 Hz
3	553 ± 2 Hz
4	737 ± 2 Hz
5	926 ± 2 Hz

(Figure 3.2)



- For each harmonic from the second to the fifth, we also recorded in Table 3.3 the number of antinodes and their respective distance from the speaker.

  The antinode for the first harmonic was not recorded because the interference was too large, making it difficult to locate its position with sufficient precision.

  Note: the error in the determination of the position of an antinode was computed above and resulted in 0.2 cm.

(Table 3.3)

	n = 2	n = 3	n = 4	n = 5
1st antinode	24.3 ± 0.2 cm	13.0 ± 0.2 cm	8.80 ± 0.2 cm	6.40 ± 0.2 cm
2nd antinode	66.6 ± 0.2 cm	45.4 ± 0.2 cm	34.0 ± 0.2 cm	25.0 ± 0.2 cm
3rd antinode		71.6 ± 0.2 cm	57.3 ± 0.2 cm	43.7 ± 0.2 cm
4th antinode			88.5 ± 0.2 cm	63.7 ± 0.2 cm
5th antinode				80.2 ± 0.2 cm

- **Linear behaviour of the relation between the frequency and the number of the harmonic**

  - From our measurements, we derived that the relationship between the frequency f and the number of antinodes n is linear, as the frequency increases proportionally with n.

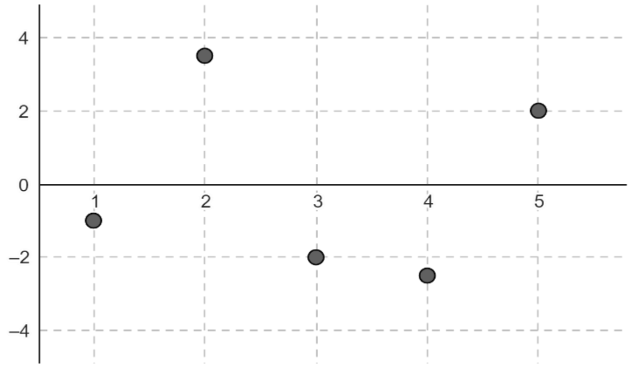
  - Using GeoGebra's "Best Fit Line" tool, we interpolated the dataset (using a Linear Regression Model) and obtained Equation 3.4, which describes the data.

(Equation 3.4)

$$f(n) = 184.5\ [Hz] \cdot n + 2.1\ [Hz]$$

  - We also created a Residual Plot Graph to check how accurately the linear model represents the data (Figure 3.5). The horizontal axis displays the number of the harmonic; on the vertical axis, the residuals are shown in Hz.

(Figure 3.5)



- Now that the Best Fit Function is known, we can compute the error on the data as $\sigma_f = \sqrt{\frac{1}{5-2}\sum_{i=1}^{5}(f_i - 2.1 - 184.5 \cdot n_i)^2} \cong 3.13\ Hz.$

- **Interpretation of the slope parameter**

  - We deduced that f is directly proportional to n and that the angular coefficient of the line that describes the relationship between the two quantities is 184.5.

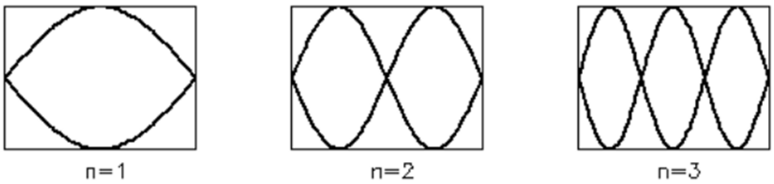
  - We then asked ourselves what information is contained in the slope parameter of the curve.

Given that: (i) the frequency f is directly proportional to the propagation velocity v of sound waves in air, specifically $v = f \cdot \lambda$ and (ii) the wavelength λ for a stationary wave in an open tube of length L is given by $\lambda = \frac{2L}{n}$ (see Note 3.6), we deduced that $f(n) = \frac{v}{\lambda} = \frac{v}{\frac{2L}{n}} = \frac{v}{2L}n.$

Thus, the angular coefficient we found earlier in Equation 3.4 corresponds to the ratio $\frac{v}{2L}$. The formula can now be rewritten as follows:

$$f(n) = \frac{v}{2L}n$$

(Note 3.6)



As can be deduced from the image above: (i) for the 1st harmonic, L corresponds to half a wavelength, so $\lambda = 2 \cdot L$; (ii) for the 2nd harmonic, L corresponds to a full wavelength, so $\lambda = L$; (iii) for the 3rd harmonic, L corresponds to $\lambda + \frac{1}{2}\lambda = \frac{3}{2}\lambda$, so $\lambda = \frac{2}{3}L$. We clearly observe a pattern: in all cases, $\lambda = \frac{2L}{n}$, where n is the number of antinodes.

- **Estimation of the propagation velocity using the measured length**

  – To estimate the propagation velocity of sound waves, we first measured the length of the tube, which was L = 90 cm. Using the empirical correction provided in the experiment's guide ($L' = L + 0.8 \cdot D$), we computed the corrected value of the length of the tube, resulting in 0.924 m.

  Therefore, knowing that $f(n) = \frac{v}{2L'}n$, the propagation velocity of sound waves is given by the formula:

$$v = \frac{f}{n} \cdot 2L'$$

  Table 3.7 below shows the relationship between n, f and the computed speed.

(Table 3.7)

n	Frequency	Speed
1	185 ± 2 Hz	342 m/s
2	374 ± 2 Hz	346 m/s
3	553 ± 2 Hz	341 m/s
4	737 ± 2 Hz	340 m/s
5	926 ± 2 Hz	342 m/s

  To express the speed with the highest precision, we calculated the mean value of the computed values, which is 342.16 m/s, and the standard deviation, which is 1.83 m/s. Therefore, the speed of sound waves can be expressed as: $v = 342.2 \pm 1.8$ m/s.

3.2 Measurements with tube closed at one side

- **Determination of the harmonic number given the frequency**

  – To determine the relationship between the frequency of a stationary wave and the harmonic number, we first found a resonant frequency (524 Hz) and then determined the number of the harmonic by counting the nodes. With 3 nodes present, we concluded that we were observing the 3rd harmonic.

  To confirm our assumption and assert the validity of the given formula $f = \frac{2n-1}{4} \cdot \frac{v}{L}$, we computed n as shown.
  Given: (i) the resonant frequency of 524 Hz; (ii) the value of v of $342 \pm 2\ m/s$; (iii) the length of the tube $L' = L + 0.4 \cdot D = 0.832\ m$; we found that: $n = 2f\frac{L}{v} + \frac{1}{2} \cong 3$, QED.

- **Linearity and behaviour at the origin of the relationship between the frequency and the number of the harmonic**

- As written above, the relationship between the frequency and the number of nodes of the stationary wave is:

$$f = \frac{2n-1}{4} \cdot \frac{v}{L}$$

This equation can be easily rewritten as a line:
$f(n) = \left(\frac{2n}{4} - \frac{1}{4}\right) \cdot \frac{v}{L} \rightarrow f(n) = \frac{2nv}{4L} - \frac{1}{4}\frac{v}{L} \rightarrow f(n) = \frac{v}{2L}n - \frac{v}{4L}$,
where $\frac{v}{2L}$ is the angular coefficient and $-\frac{v}{4L}$ is the y-intercept.

- Since $-\frac{v}{4L} \neq 0$, i.e. the y-intercept is not 0, the line does not pass through the origin of the axes.

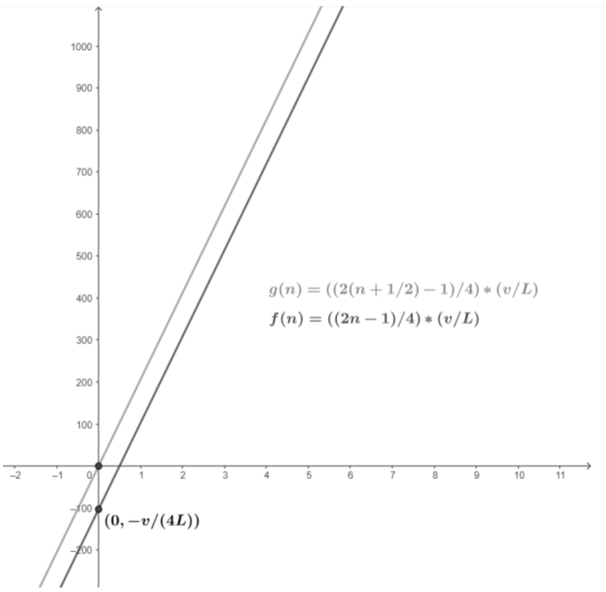
We are now interested in determining the correct way to modify the function so that it passes through the origin. Clearly, setting the y-intercept to 0 is not possible, as this would imply setting $v = 0$, which lacks physical meaning in the context of our experiment.

The best approach is to vertically shift the line so that the function equals 0 at the origin. To do so, we need to change the measurement of n by adding a certain value n' obtained as follows: $f = 0 \rightarrow \frac{v}{2L}n' = \frac{v}{4L} \rightarrow \frac{n'}{2} = \frac{1}{4} \rightarrow n' = \frac{1}{2}$.

The so obtained equation is $f = \frac{2(n+n')-1}{4} \cdot \frac{v}{L} = \frac{2\left(n+\frac{1}{2}\right)-1}{4} \cdot \frac{v}{L}$, which passes through the origin of the axes.

- The two lines in Figure 3.8 show the function before and after the translation (here $v = 342$ m/s and $L = 0.832$ m).

(Figure 3.8)



- **Hyperbolic behaviour of the relation between the tube length and the frequency**

  - In order to find the relationship between the frequency and the length of the tube, we chose to focus on the third harmonic and repeated the measurements of the resonant frequency for different tube lengths. Starting from 82 cm, we moved the piston by steps of 10 cm four times, up to 42 cm.

Note: as before, we corrected the measured value of L with $L' = L + 0.4 \cdot D$.

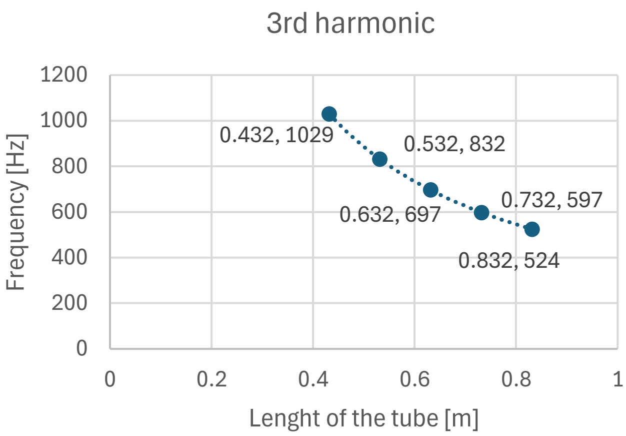
- The collected data are displayed in Table 3.9.

(Table 3.9)

Length of the tube	Frequency of the 3rd harmonic
0.832 m	524 ± 2 Hz
0.732 m	597 ± 2 Hz
0.632 m	697 ± 2 Hz
0.532 m	832 ± 2 Hz
0.432 m	1029 ± 2 Hz

- We then created a graph (Figure 3.10) to visualise the relationship between the two quantities. As can be trivially deduced from the equation $f(L) = \frac{2n-1}{4} \cdot \frac{v}{L}$, the trendline follows a hyperbolical trajectory (since $f \propto \frac{1}{L}$).

(Figure 3.10)



- **Linearization of the relationship between frequency and length**

  - To better visualise this relationship, we may want to make it linear, i.e. we may want to express $f(L)$ as $f^{\alpha} = S \cdot L^{\beta}$, where S is the ideal slope of the line. Since $f \propto \frac{1}{L}$, choosing α = 1 and β = −1 satisfies this condition. The optimal slope S is given by $\frac{2n-1}{4} \cdot v$.

  - The so-obtained linear relation between the frequency of the 3rd harmonic and the length of the tube is
$f^{\alpha} = S \cdot L^{\beta} \rightarrow f^{1} = S \cdot L^{-1} = \frac{2n-1}{4} \cdot \frac{v}{L^{-1}}$.
Since n = 3 (because we are dealing with the 3rd harmonic), $f = \frac{2 \cdot 3-1}{4} \cdot \frac{v}{L^{-1}} = \frac{5v}{4} L$.

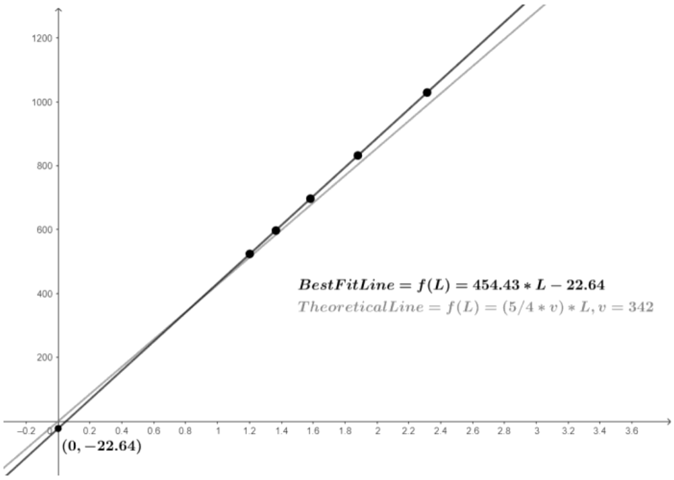
– This allowed us to employ a Linear Regression Tool for analysis. The line that best fits our dataset is given by Equation 3.11.

(Equation 3.11)

$$f(L) = 454.43\ [m/s] \cdot L\ [m] - 22.64\ [Hz]$$

– Figure 3.12 displays Equations 3.11 and $f(L) = \frac{5v}{4}L$.

(Figure 3.12)



- **Comparison of values of sound speed**

– We are now interested in comparing the sound speed derived from measurements using a closed tube with the values obtained for an open tube.

To compute the velocity, we can use the formula $f(L) = \frac{2n-1}{4} \cdot \frac{v}{L}$, where, once again, $L' = L + 0.4$. Rearranging for v, we obtain:

$$v = \frac{4f}{2n-1} \cdot \mathrm{L}$$

– Table 3.13 below illustrates the relationship between the length of the tube, the frequency, and the computed speed v. Note that n is fixed at 3 because we chose to work on the 3rd harmonic.

(Table 3.13)

L	Frequency	Speed
0.832 m	524 ± 2 Hz	349 m/s
0.732 m	597 ± 2 Hz	350 m/s
0.632 m	697 ± 2 Hz	352 m/s
0.532 m	832 ± 2 Hz	354 m/s
0.432 m	1029 ± 2 Hz	355 m/s

– To express the speed with the highest precision, we calculated the mean value of the computed values, which is 351.93 m/s, and the standard deviation, which is 3.10 m/s. Therefore, the speed of sound waves can be expressed as v = 351.9 ± 3.1 m/s.

3.3 Measurements with square waves

- **Measurement of acoustic wave velocity from the reflection of a square wave**

  – The speed of sound could also be measured by recording the time it takes for a sound pulse to travel along a tube. To do so, we used a wave generator to generate a square wave with a frequency of approximately 10 Hz; in this way, we produced a series of sound pulses spaced sufficiently apart to be treated as individual pulses, given the tube length. The microphone was placed at the beginning of the tube, at a selected distance Δx from the speaker; the pulse generator's amplitude was set to around 500 mV.

    The oscilloscope displayed the signal from the waveform generator on input channel 1 and the signal from the microphone on input channel 2, capturing the moment the microphone first detected the sound wave emitted by the speaker. Note: it was important to disregard secondary signals caused by reflections of the sound wave within the tube.

    Using the oscilloscope's cursors, we measured the time interval Δt between the two pulses. The measurement was repeated several times, with the piston being moved further from the microphone in regular 10-centimetre intervals. The collected data are displayed in Table 3.14.

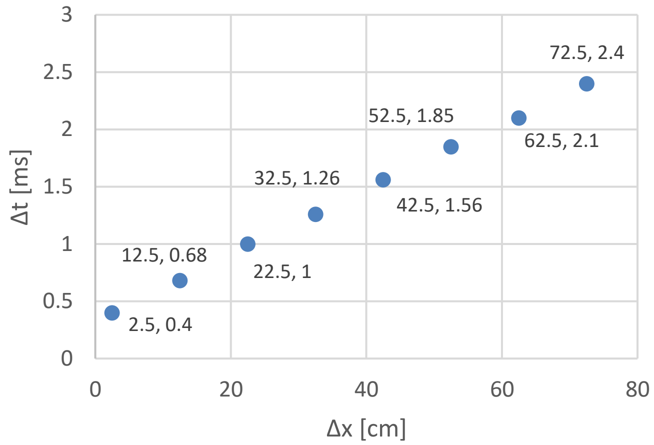
(Table 3.14)

Microphone distance Δx	Time interval Δt
2.5 cm	0.40 ms
12.5 cm	0.68 ms
22.5 cm	1.00 ms
32.5 cm	1.26 ms
42.5 cm	1.56 ms
52.5 cm	1.85 ms
62.5 cm	2.10 ms
72.5 cm	2.40 ms

- **Graphical representation of the relationship between Δx and Δt**

  – We now want to illustrate the relationship between the time taken by the square wave to reach the microphone and the distance between the latter and the speaker. Figure 3.15 below graphically shows our dataset.

(Figure 3.15)



- It is also interesting to present the inverse relationship, i.e. Δx as a function of Δt. After plotting the values (Δt on the horizontal axis and Δx on the vertical one), we used GeoGebra to determine the interpolated line.

  The primary reason for presenting the values in this configuration is that the slope of the interpolated line is now given by $\frac{\boldsymbol{\Delta x}}{\boldsymbol{\Delta t}}$ which, dimensionally, corresponds to a velocity -the speed of sound, in our case.

- The above-mentioned interpolated line, i.e. the line that best fits our dataset is given by Equation 3.16. Note that, in reporting the equation, we use [m] for the position and [s] for time.

(Equation 3.16)

$$x(t) = 350.6\ [m/s] \cdot t\ [s] - 0.118\ [m]$$

- Now that the Best Fit Function is known, we can compute the error on the data as $\sigma_x = \sqrt{\frac{1}{8-2}\sum_{i=1}^{8}(x_i - 0.118 - 350.6 \cdot t_i)^2} \cong$ 2.295 m.

- **Behaviour of the interpolated line at the origin**

- If we examine the interpolated line, we notice that it does not pass through the origin of the axes (as the vertical intercept is different from 0); however, from a theoretical point of view, it should.

  The reason the line does not pass through the origin lies in the method used to collect the data. Let’s break it down:

  1. The generator was connected to both the speaker and the wave analyser, sending the same signal to each simultaneously.
  2. The signal sent to the speaker was converted into sound waves.

3. The signal contained in the waves was then received by the microphone and transformed into an electrical signal.
4. The electrical signal was finally transmitted to the wave analyser.

Each of these steps introduced a delay, adding time to the time taken by the sound wave to travel from the speaker to the microphone. On the graph, this delay is represented as a vertical shift downwards of all the data points.

- **Comparison of values of sound speed**

– As said, the slope of the line represents the speed at which the sound wave travelled during the time Δt.

– Based on the analysis, the velocity of the sound wave, as determined from the slope of the interpolated line, was found to be approximately 350.6 m/s.

4 Discussion

- We are now interested in comparing the experimental results with theoretical predictions. In particular, we aim to focus on the values of sound speed obtained in sections 3.1, 3.2 and 3.3.
  - During the experiment, we calculated the speed of sound in three different ways:
    1. In section 3.1 we computed it by working with an open tube and by changing the frequency of the speaker, obtaining a value of v = 342.2 ± 1.8 m/s.
    2. In section 3.2 we used a tube closed at one side. By changing the length of the tube, we found different values and computed a mean of v = 351.9 ± 3.1 m/s.
    3. In section 3.3 we computed it by generating a square wave in a closed tube and by measuring the time that it took to reach a microphone, obtaining v = 350.6 m/s.
  - From a theoretical perspective, the exact value of sound speed is influenced by the temperature of the medium through which the sound waves propagate. In particular, the relation is the following:

$$v_{s\_air} = 331 \cdot \sqrt{1 + \frac{T[°C]}{273}}\ \frac{m}{s}$$

    Considering that the temperature of Lab U9b was approximately 21.5°C, the theoretical value of the sound speed is v = 343.8 m/s.

  - The first measurement, yielding a value of 342.2 ± 1.8 m/s, is in excellent agreement with the theoretical value of 344 m/s. This suggests that despite the challenges in locating the harmonic frequency, the result was still precise and reliable.

On the other hand, the second and third measurements, while compatible with each other, yielded values which are slightly off from the theoretical value. These discrepancies are likely due to minor inaccuracies in adjusting the tube length, potential limitations of the microphone's precision in capturing the sound and possible errors in the visual determination of highest amplitude of the standing wave. Despite these slight deviations, the first measurement resulted in a reliable baseline for the speed of sound, thus proving the robustness of our experimental approach and methodology.

5 Conclusions

- With the discussion and analysis complete, it's time to reflect on the key insights gained about sound wave behaviour and draw relevant conclusions from this experiment.
  - This experiment successfully explored the propagation of sound waves in air-filled tubes, examining the influence of tube configuration (open and closed at one end), wave frequency, number of antinodes, and tube length on the speed of sound. Through the analysis of stationary and square waves, we verified several theoretical principles while also identifying the discrepancies between experimental and predicted results.
  - As a team, we encountered several challenges, such as having to repeat measurements when noise interfered with our data, leading to inconsistencies. These challenges helped us realise the complexities of real-world experiments, in which uncertainties, physical and instrument limitations and measurement errors play an important role.
  - Along the way, we also gained practical experience with tools like Linear Regression and instruments such as the digital oscilloscope. While the theoretical explanations might be hard to fully grasp, applying them in practice made things much clearer.
  - Additionally, discussing our doubts and exploring the results with the professor in the Laboratory helped deepen our understanding, enabling us to reflect on our data and evaluate whether our results were meaningful or not.

Reference Book: *Serway, R.A., & Jewett, J. W. (2004). Physics for scientists and engineers (6th ed.). Thomson-Brooks/Cole*.

Source of Figure 1.1: *https://scienceready.com.au/pages/properties-of-longitudinal-waves*.

Software Tools used: *GeoGebra Team. GeoGebra. Version 6.0.871., Microsoft Corporation. Microsoft Excel. Version 16.*