Institute of Physics
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Physics laboratory report

Performed on: 14.10.2024

Exercise 7: Determination of sound velocity in air File

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Introduction

This report details the experimental determination of the speed of sound and the adiabatic coefficient (κ) for air using a Kundt tube setup. The experiment involved measuring phase differences at various microphone positions and calculating derived values while accounting for uncertainties to validate results against theoretical values.

Measurement set-up

The source of the acoustic wave in the Kundt tube is a speaker, connected to a variable waveform generator. It generates a sound with a constant intensity and a preset frequency. The receiver of the signal is a microphone, mounted on a moving piston, whose position relative to the speaker is read from a ruler. It is a condenser microphone, one of whose covers is the microphone diaphragm, which moves under the influence of an acoustic wave. The movement of the diaphragm causes voltage changes between the capacitor plates, which are recorded by an oscilloscope. By changing the position of the piston, the propagation conditions of the wave are altered.

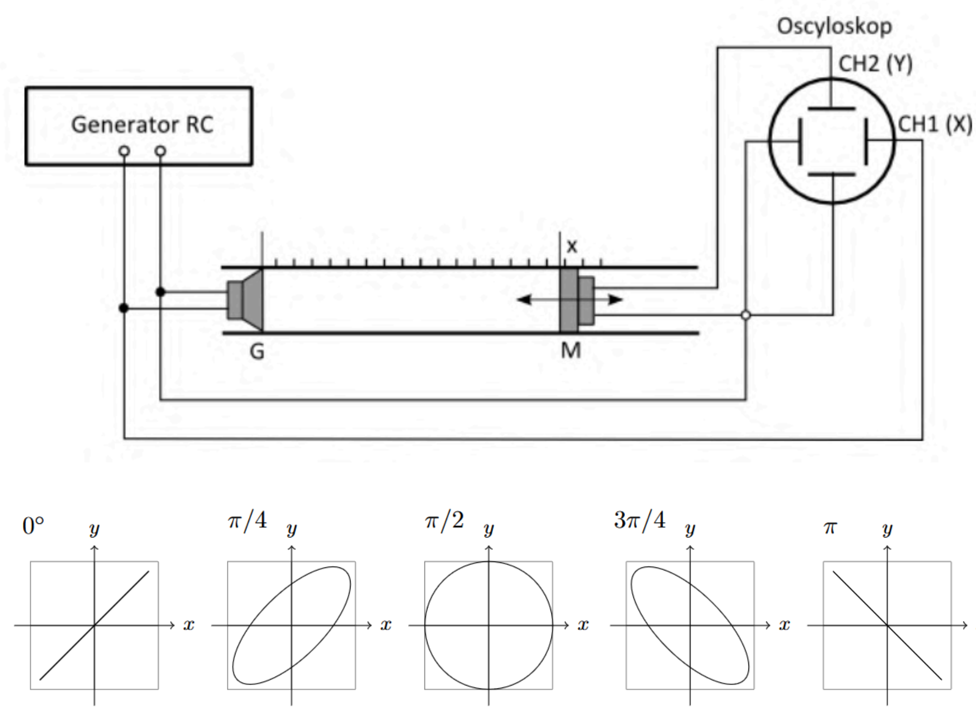


Figure 1 - measurement set-up diagram with diagram of read angles from oscilloscope.

Measurements

Distances (cm) for $1.5kHz$	**Distances (cm) for $1kHz$**	**Distances (cm) for $2kHz$**	**Angle $(^\circ)$**
212.8, 235.7	220, 254.5	209, 226.2	0°
211.7, 213.9, 234.4, 236.9	218.9, 222.5, 252.9	208.2, 209.4, 225.7, 226.7	45°
216.3, 227.8, 239.5, 250.6	215.9, 234, 250.8	209.6, 218.7, 227.3	90°
223.1, 225.3, 245.5, 248	205.1, 235.9, 239.7	216.8, 218.2, 234.1	135°
224.4, 247.1	237.2	217.6, 234.7	180°

Table 1 - values obtained during laboratories, table consists of all distances for each frequency in kHz and indication at which angle the distance was noted.

Data analysis

Task 1. Calculate the distances between the microphone positions at which the phase difference of the speaker and microphone signals differs by π:

$$\Delta x = x_{i+1} - x_i$$

For each frequency we calculated Δx, the results are visible in the table below:

Angles (°)	**Δx for $1.5kHz$ (m)**	**Δx for $2kHz$ (m)**	**Δx for $1kHz$ (m)**
0° $\rightarrow$ 180°	0.116	0.086	0.172
45° $\rightarrow$ 225°	0.114	0.086	0.170
90° $\rightarrow$ 270°	0.115	0.091	0.181
135° $\rightarrow$ 315°	0.113	0.075	0.170
180° $\rightarrow$ 360°	0.113	0.086	0.173

Table 2 - plotted results from task 1.

Task 2. Calculate the average value of Δx_{sr}, and its total uncertainty, taking into account the uncertainty of averaging $u_a(x_{sr})$ and the accuracy of the instrument used to measure the distance $u_b(x)$.

For average values Δx_{sr} we used:

$$\Delta x_{sr} = \frac{1}{n}\sum_{i=1}^{n} x_i \; [m]$$

The results were placed into the table:

Frequency (Hz)	Mean (m)
2000	0.085
1500	0.114
1000	0.173

Table 3 - plotted results for average values of $\Delta x's$.

To obtain $u_a(x_{sr})$ we used formula:

$$u_a(x_{sr}) = s \cdot u_b(x)$$

where:

- s is standard deviation calculated using:

$$s = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}\left(x_i - x_{sr}\right)^2}$$

- $u_b(x)$ is uncertainty in the ruler we used which was equal $0.5mm$.

To calculate total uncertainty $u_t(x)$ we used formula:

$$u_t(x) = \sqrt{u_a^2(x_{sr}) + u_b^2(x)}$$

The results were placed into the table:

Frequency (Hz)	**Total uncertainty (m)**
2000	0.002681
1500	0.000768
1000	0.002095

Table 4 - results for total uncertainties in x_{sr}.

Task 3. Calculate the speed of sound according to the formula:

$$c = 2f\Delta x_{sr}$$

where:

- f is frequency of the AC voltage applied to the speaker.

For each frequency we performed calculations according to formula provided in task description.

Frequency (Hz)	**Sound speed ($\frac{m}{s}$)**
2000	346.4
1500	342.6
1000	339.2

Table 5 - results from calculations for each frequency.

Task 4. Using the uncertainty transfer law, calculate the uncertainty of the determined velocity.

To obtain the uncertainty of the velocity we used formula:

$$\sqrt{\left(\frac{\partial c}{\partial x}\right)^2 u_t^2(x)} = 2fu_t(x)$$

where:

- f is frequency of the AC voltage applied to the speaker
- $u_t(x)$ is total uncertainty

Frequency (Hz)	Uncertainty of the velocity ($\frac{m}{s}$)
2000	10.726
1500	2.304
1000	4.19

Table 6 - results from calculations for each frequency.

Task 5. Analogically perform similar calculations for each acoustic wave frequency.

We performed each calculations for all frequencies using such pairs of distances:

For $1.5kHz$:

Pair 1	Pair 2	Pair 3	Pair 4	Pair 5
212.8	211.7	216.3	223.1	224.4
224.4	223.1	227.8	234.4	235.7

Table 7 - table of pairs constructed to obtain results in Task 1 for $1.5kHz$.

For $2kHz$:

Pair 1	Pair 2	Pair 3	Pair 4	Pair 5
209,	208.2	209.6	218.2	217.6
217.6	216.8	218.7	225.7	226.2

Table 8 - table of pairs constructed to obtain results in Task 1 for $2kHz$.

For $1kHz$:

Pair 1	Pair 2	Pair 3	Pair 4	Pair 5
220	218.9	215.9	235.9	237.2
237.2	235.9	234	252.9	254.5

Table 9 - table of pairs constructed to obtain results in Task 1 for $1kHz$.

Results are visible in tables Table 2, Table 3, Table 4 and Table 5.

Task 6. Calculate the weighted average of the received sound velocities in air and the uncertainty of the weighted average.

We calculated weighted mean using formula:

$$\bar{c} = \left(\sum_{i=1}^{n} c_i w_i\right)\left(\sum_{i=1}^{n} w_i\right)^{-1} \left[\frac{m}{s}\right]$$

where:

- c_i - is speed of sound
- w_i - is weight calculated using formula:

$$w_i = 1 - u_{ti}(x)$$

this approach takes into consideration the total uncertainty. As uncertainty rises the outcome weight decreases.

From calculations we obtained:

$$\bar{c} = 342.734 \frac{m}{s}$$

Task 7. Perform a consistency test of the obtained value of c with the theoretical value of the speed of sound for dry air, for the temperature prevailing in the laboratory. Comment on the result of the test.

To check the theoretical value of sound for dry air for the temperature prevailing in the laboratory we used this tool[1]. We calculated mean of temperatures during laboratories. We entered temperature $20.066667^{\circ}C$ into the input and got $c_{theoretical} = 343.2 \frac{m}{s}$. Next we subtracted our c from $c_{theoretical}$. The difference between the values is equal to $0.466 \frac{m}{s}$. The difference in theoretical and our value is small which indicates that experimental set-up is accurate and reliable.

Task 8. Calculate the exponent of the adiabatic equation.

$$\kappa = \frac{\mu c^2}{RT}$$

where:

- R = $8.31\ J/(mol - K)$ - universal gas constant
- μ = $28.87\ g/mol$ - molar mass of air
- T - temperature of the air, expressed in K

From calculations we obtained $\kappa = 1387.84$.

Task 9 - Using the uncertainty transfer law, calculate the uncertainty of the resulting adiabatic coefficient and record in the appropriate format.

To calculate uncertainty in adiabatic coefficient we used formula:

$$u(\kappa) = \sqrt{\left(\frac{\partial \kappa}{\partial s}\right)^2 + \left(\frac{\partial \kappa}{\partial T}\right)^2}$$

From calculations we obtained 1.38784.

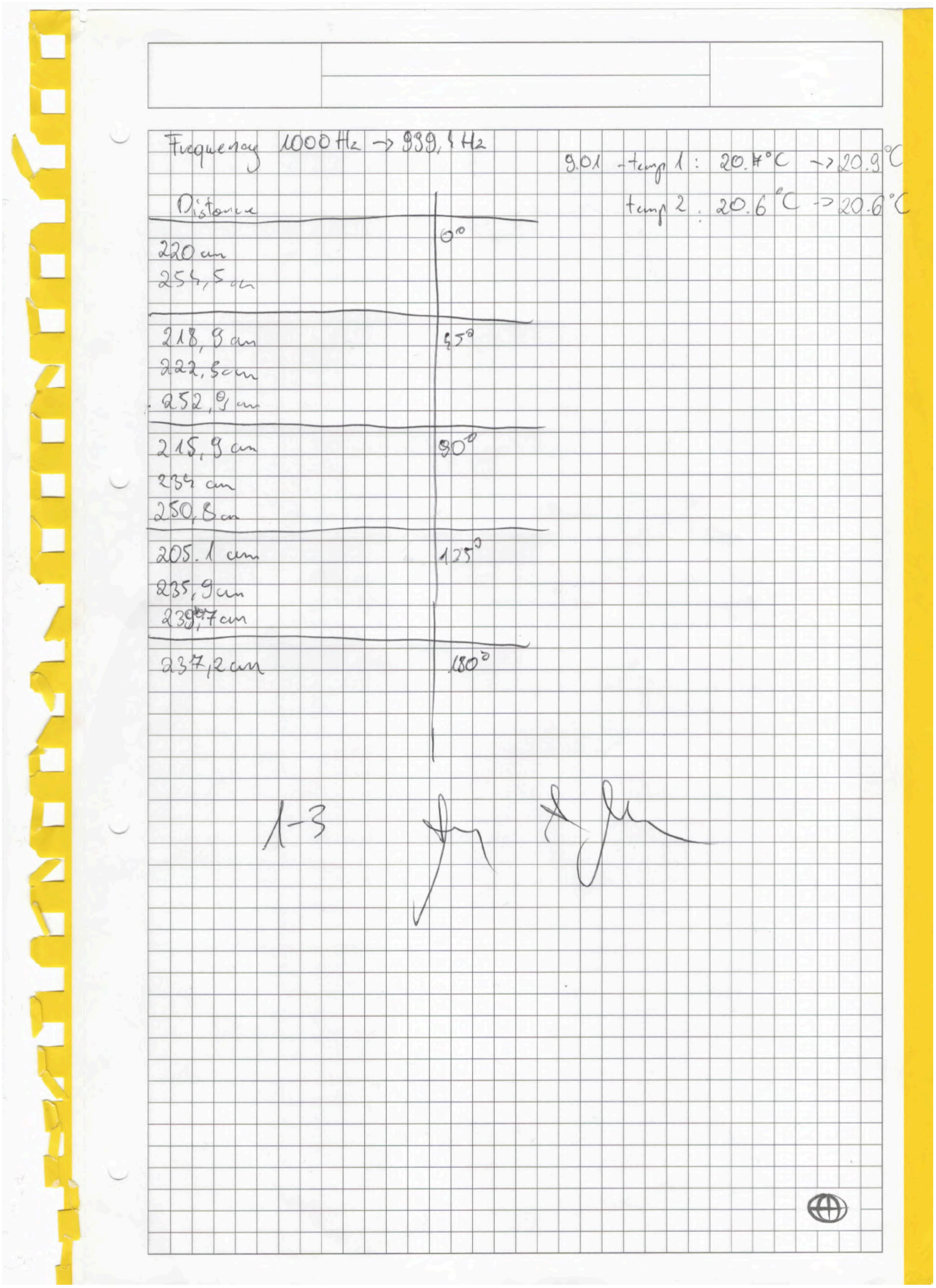
Task 10 - Perform a test of consistency of the obtained κ value with the array value. Comment on the result of the test.

From the table[2] we read that for $T \approx 20^{\circ}C$ the coefficient is approximately 1.4. The difference between our evaluation and theoretical value equals 0.1216. This minor deviation suggests that the experimental setup and calculations are reasonably accurate.

Summary

The experiment successfully measured the speed of sound and the adiabatic coefficient in air at laboratory conditions. The results showed minor deviations ($0.466\frac{m}{s}$ for c and 12.16 for κ) from theoretical values, demonstrating the accuracy of the setup. Uncertainty calculations further confirmed the reliability of the experimental approach.

Measurement cards



Frequency 1000 Hz -> 999,4 Hz

9.01 - temp 1 : 20.7°C -> 20.9°C

temp 2 : 20.6°C -> 20.6°C

Distance	
220 cm 254,5 cm	0°
218,9 cm 222,5 cm 252,9 cm	45°
215,9 cm 234 cm 250,8 cm	90°
205.1 cm 235,9 cm 239,7 cm	135°
237,2 cm	180°

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Physics lab 1

Section 7 - experiment 7

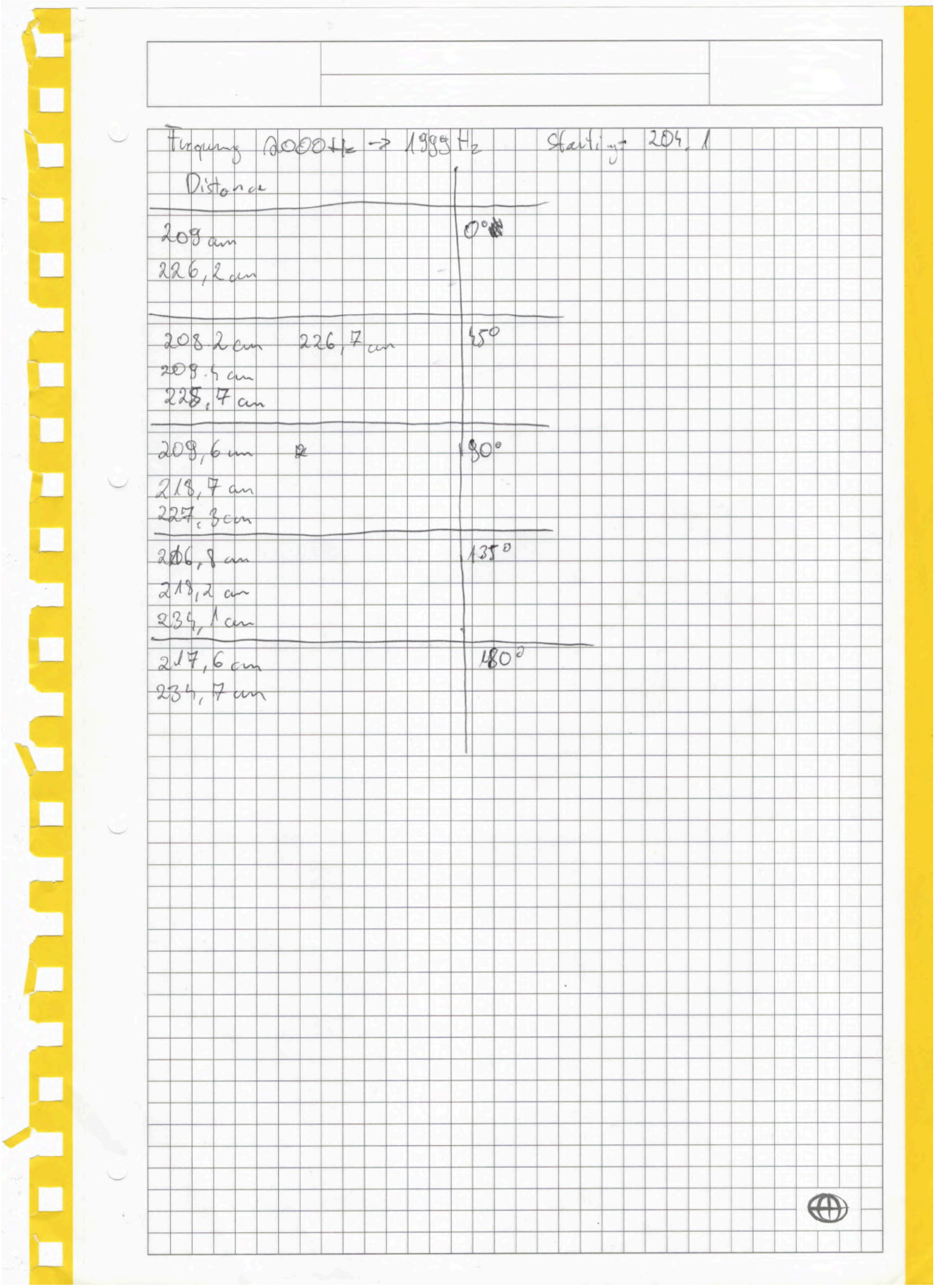
Temp:

8:18 - temp 1: 19.9°C -> temp 1: 20.6°C

temp 2: 19.3°C temp 2: 20.3°C

Frequency: 1500 Hz -> 1495Hz Starting: 204,1 cm

Distance		
212,8 cm		0°
235,7 cm		
211,7 cm	236,9 cm	45°
213,9 cm		
234,4 cm		
216,3 cm	250,6 cm	90°
227,8 cm		
239,5 cm		
223,1 cm	248 cm	135°
225,3 cm		
245,5 cm		
224,5 cm		180°
247,1 cm		



Frequency 2000Hz -> 1999 Hz   Starting: 204,1

Distance	
209 cm 226,2 cm	0°
208.2 cm 226,7 cm 209.4 cm 228,7 cm	45°
209,6 cm 218,7 cm 227,3 cm	90°
206,8 cm 218,2 cm 234,1 cm	135°
217,6 cm 234,7 cm	180°

Sources:

[1]Tool URL: https://www.omnicalculator.com/physics/speed-of-sound

[2]Table URL: https://www.wikiwand.com/en/articles/Heat_capacity_ratio