GDYNIA MARITIME UNIVERSITY
FACULTY OF MECHANICAL

PHYSICS LABORATORY
DEPARTMENT OF PHYSICS

Theoretical Introduction

Experiment "S O U N D"

Acoustic Resonance

The phenomenon of resonance and wave interference is often used to measure the speed of acoustic waves. A special form of interference of two waves is a standing wave. Standing waves are formed when two waves with the same amplitudes and frequencies, but propagating in opposite directions, overlap. Their phases must be shifted by π.

In the entire area where a standing wave propagates, there are alternately places where the amplitude of vibration is maximum, called antinodes, and places where vibrations cancel each other out, called nodes. The nodes and antinodes of the wave remain continuously in the same places.

Quincke's Tube

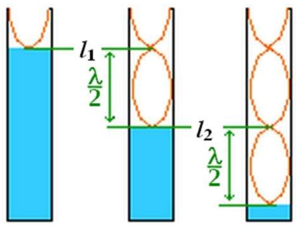
Quincke's tube is a vertical tube filled with water and connected to a water reservoir used to change the level of the water column. A loudspeaker producing a sound wave is placed at the top of the tube and is powered by a low-frequency generator.

The sounds emitted by the loudspeaker cause acoustic vibrations of the air column above the water surface in the tube. After the appropriate height of the air column is selected, a standing wave is formed as a result of the superposition of the original wave and the wave reflected from the closed end of the tube, that is, from the water surface.

A node of the standing wave is formed at the closed end of the tube, while an antinode is formed at the open end. The resonance condition is satisfied by the following lengths of the air column:

$$l_1 = \frac{\lambda}{4},\ l_2 = \frac{3}{4}\lambda,\ \dots,\ l_n = \frac{2n+1}{4}\lambda.$$

From the first two lengths at which resonance occurs, we obtain the equation used to determine the wavelength of sound in air: $|l_2 - l_1| = \frac{\lambda}{2} \Rightarrow \lambda = 2 \cdot |l_2 - l_1|$



The relationship between wavelength, speed and frequency is: $\lambda = \frac{c}{f}$,
therefore, the speed of sound c in air can be determined as the slope coefficient of the straight line: *Y* = *a X*:

$$\underbrace{2 \cdot |l_2 - l_1|}_{Y} = \underbrace{c}_{a} \cdot \underbrace{\frac{1}{f}}_{X}$$

The speed of sound in air changes mainly with temperature T, and only slightly with air density and humidity. Assuming an ideal gas, the variation occurs only because of temperature. At a temperature of $0°C$, it is: 331,5 m/s. For other temperatures, it can be approximated by the empirical formula:

$$c = 331{,}5\left[\frac{m}{s}\right] \cdot \sqrt{1 + \frac{T\ ^{\circ}C}{273{,}15\ ^{\circ}C}}.$$

For example, at a temperature of $20°C$, the speed of sound is: c = 343 m/s, whereas at a temperature of $25°C$, it is: c = 346 m/s.

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Preparation Questions:

1. What do we call a wave?
2. Discuss the types of waves.
3. Give the equation of a plane wave.
4. Define the basic quantities occurring in wave motion: wavelength λ, wave period T, wave frequency f, and wave speed v.
5. Give the relationship between wavelength and frequency of vibrations.
6. Discuss the conditions for the formation of a standing wave.
7. Define the following concepts: amplitude, node, antinode, reflection.
8. What is wave interference? When does wave reinforcement occur and when does wave cancellation occur?
9. Characterize longitudinal and transverse waves. What type of wave is sound?
10. Discuss the speed of sound in different media. What does it depend on?
11. In which medium, solids, liquids or gases, is the speed of sound the greatest?
12. Discuss the dependence of the speed of sound in air on the density and temperature of the medium.
13. What is acoustic resonance?
14. Discuss the operating principle of Quincke’s tube.
15. What is the speed of sound propagation in air and what is it in a vacuum?

Instructions for Performing the Measurements

1. Turn on the generator using the left knob, setting the signal shape to “Sine”.
2. On the generator, using the “Frequency” knob, set the initial frequency value in the range of 320–400 Hz, given by the instructor or technical assistant.
3. Set the appropriate volume using the “Amplitude” knob so that the sound is audible for collecting measurements.
4. By lowering or raising the equalizing reservoir, find such a position of the water level for which the greatest amplification is heard. In this position, the wave coming from the source exactly overlaps with the reflected wave, forming a so-called standing wave. The position of the water level indicates the node of this wave.
5. Record the position of the upper node l_1 and find the position of the next node l_2 below it.
6. Record the results: frequency f and distances l_1 and l_2, in the measurement table.
7. Increase the frequency on the generator by a step between 20 and 40 Hz, given by the instructor or technical assistant.
8. Repeat the measurements of the positions of the wave nodes l_1 and l_2 for 10 different frequencies.
9. Estimate the measurement uncertainties:
   Δf – estimate on the basis of the generator wave distortion, which is up to 0,3%
   Δl – determine by hearing.
10. After completing the measurements, place the regulating reservoir in the stand, turn off the generator and tidy up the workstation.
11. Perform the calculations according to the formulas in the report. In the calculations, remember to use the basic SI units.

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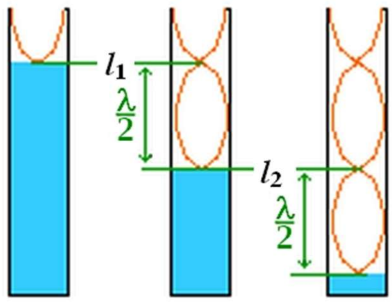
Methodological Template

Student 1: Determination of the speed of sound propagation in air.
Student 2: Verification of the dependence of the standing wave wavelength on its frequency.

Theoretical Basis:

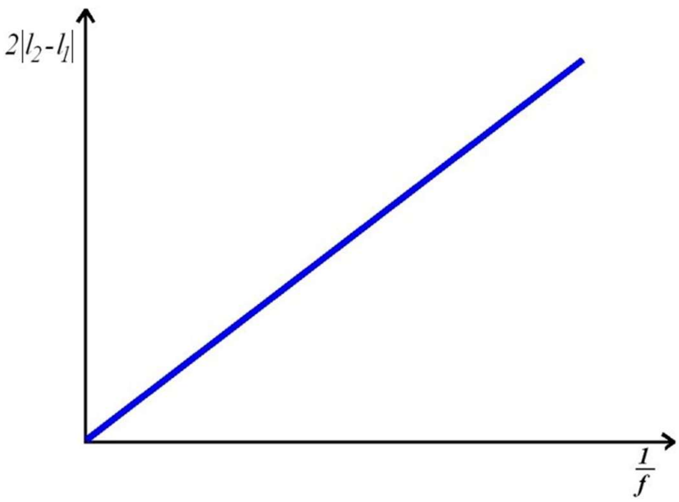
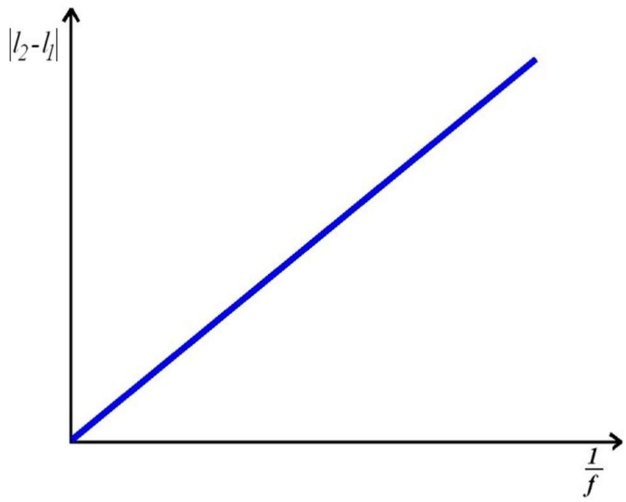
The wavelength can be expressed as the ratio of the speed of sound to its frequency: $\lambda = \frac{c}{f}$



For a standing wave, the distance between adjacent nodes is equal to half of the wavelength.

In Quincke’s tube, the wavelength can be determined as:

$$\lambda = 2 \cdot |l_2 - l_1|$$

 $\lambda = c \cdot \frac{1}{f}$	
Therefore, in order to determine the speed of sound propagation in air, one should: • for a given sound frequency, determine the height of the air column corresponding to the first and second resonance, l_1 and l_2, by slowly lowering the water reservoir, • prepare a graph of the dependence of wavelength λ on the reciprocal of frequency: • read from the graph the speed of sound propagation, which is the slope coefficient.	Therefore, in order to verify the dependence of the standing wave wavelength on its frequency, one should: • for a given sound frequency, determine the height of the air column corresponding to the first and second resonance, l_1 and l_2, by slowly lowering the water reservoir, • prepare a graph of the dependence: $\|l_2 - l_1\|$ of $\frac{1}{f}$ • analyse its linearity.

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Report Guidelines - Determination

Student 1: Determination of the speed of sound propagation in air.

I. Methodology (conceptual plan of the exercise)
II. Course of the exercise
II.1. Course of activities
II.2. Sketch of the measurement setup
III. Results
III.1. Measurement results

		1	2	3	4	5	6	7	8	9	10
f	[Hz]										
l_1	[cm]										
l_2	[cm]										

Δf = ... Δl = ... T = ...

III.2. Calculations (example calculations - referring, for example, to measurement no. 3)

$$\lambda = 2 \cdot |l_2 - l_1| = \ldots$$

$$\Delta\lambda = 4 \cdot \Delta l = \ldots$$

$$\frac{1}{f} = \ldots$$

$$\Delta\frac{1}{f} = \left|\frac{1}{f} - \frac{1}{f + \Delta f}\right| = \ldots$$

III.3. Calculation results

		1	2	3	4	5	6	7	8	9	10
λ	[...]										
$\Delta\lambda$	[...]										
$\frac{1}{f}$	[...]										
$\Delta\frac{1}{f}$	[...]										

III.4. Graph

- calculation of c, the slope of the “best-fit” straight line
- calculation of c', the slope of the deviated straight line
- calculation of the accuracy of the method: $\Delta c = |c - c'|$

VI. Summary
The determined value of the speed of sound c is ...
The accuracy of the method Δc wynosi ...
The measurements were carried out at the temperature: T = ... °C, for which the theoretical speed of sound should be: $c = 331{,}5 \cdot \sqrt{1 + \frac{T\,^\circ C}{273{,}15\,^\circ C}} = \ldots$
Within the limits of the result $\pm$accuracy of the method, the theoretical value of the speed of sound is / is not included*.
*Choose the correct option.
Additional conclusions, observations, causes of measurement uncertainties.

“S O U N D”

Report Guidelines - Verification

Student 2: Verification of the dependence of the standing wave wavelength on its frequency.

I. Methodology (conceptual plan of the exercise)
II. Course of the exercise
II.1. Course of activities
II.2. Sketch of the measurement setup
III. Results
III.1. Measurement results

		1	2	3	4	5	6	7	8	9	10
f	[Hz]										
l_1	[cm]										
l_2	[cm]										

$\Delta f = \ldots$
$\Delta l = \ldots$

III.2. Calculations (example calculations - referring, for example, to measurement no. 3)

$$|l_2 - l_1| = \ldots$$

$$\Delta|l_2 - l_1| = 2 \cdot \Delta l = \ldots$$

$$\frac{1}{f} = \ldots$$

$$\Delta\frac{1}{f} = \left|\frac{1}{f} - \frac{1}{f + \Delta f}\right| = \ldots$$

III.3. Calculation results

		1	2	3	4	5	6	7	8	9	10
$\|l_2 - l_1\|$	[...]										
$\Delta\|l_2 - l_1\|$	[...]										
$\frac{1}{f}$	[...]										
$\Delta\frac{1}{f}$	[...]										

III.4. Graph

IV. Summary

Since on the graph … it is possible to draw a straight line passing through all measurement uncertainty rectangles, there are no grounds to conclude a deviation from …
Alternatively:
The deviation from linearity in the range … may result from …
Additional conclusions, observations, causes of measurement uncertainties.