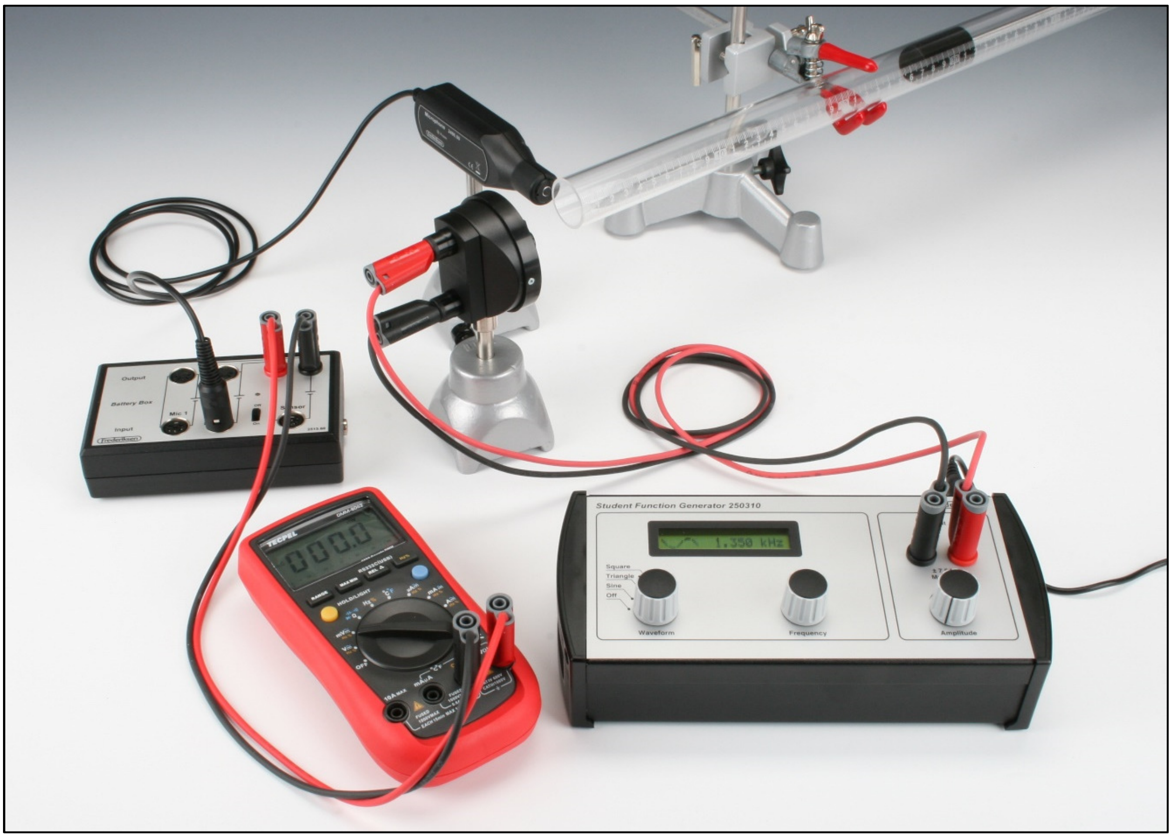
Resonance in an air column

Experiment number	132810-EN	*Topic*	Waves, sound				
Version	2017-09-01 / HS	*Type*	Student exercise	*Suggested for*	grade 10-12	*p.*	1/4



Objective

Investigating standing waves in the air column in a closed-end (i.e. half-open) pipe.

Determining the speed of sound in air.

Principle

Resonances in the pipe happens at certain combinations of the frequency of the sound and the length of the air column. In this experiment we will vary one of these parameters at a time.

The results from the measurements will be matching pairs of frequencies and wavelengths – from these, the speed of sound can be found.

Equipment

(Complete equipment list on p. 4.)

Kundt's tube (half-open resonance pipe)
Function generator
Loudspeaker
Microphone and battery box
Multimeter

Leads and stand material

Multimeters. Measuring AC voltage

The recommended multimeter (No. 386231) allows you to measure at reasonable sound levels. Set up like this:

- Select *mV* with the rotary switch
- Press the blue button to select AC
- Press *Range* twice to lock the display at mV with one decimal.

When using other types of multimeters, you should assure that the frequency range at least reaches above 1500 Hz.

Quite small AC voltages are used (mV).
With an insensitive multimeter, sound levels need to be higher.

Theory

Resonance in a half-open air column

A "half-open" pipe has a barrier at one end while air can pass freely in and out of the other end.

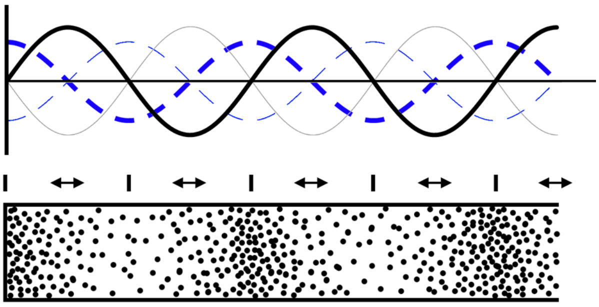
When sound hits the fixed barrier it is reflected. The reflected and the original waves will form a standing wave. Standing waves are characterized by specific points (*nodes*) having minimum sound pressure while other points (*antinodes*) have maximum pressure variations.

Perhaps surprisingly, part of the sound is also reflected by the open end causing multiple reflections back and forth. If the two (or four, six , etc.) times reflected sound is in step (*in phase*) with the original one, the standing waves are enhanced – this phenomenon is called *resonance*.

Resonance only happens when the wavelength and the tube length "fit together" – we will establish the precise condition below.

The figure represents a snapshot of the air molecules in the tube (black dots) at resonance. Vi ignore the thermal motion of the molecules.

The air cannot pass through the closed end to the left, leading to maximum pressure variations and zero velocity here. In the opposite end of the tube, nothing restricts the motion of the molecules, giving rise to maximum motion and minimum pressure variations.



The thick blue dashed line shows the pressure distribution along the tube at this instant while the thick black curve shows the speed.

Half an oscillation period later, the thin curves are valid. Similarly, the molecule density is high now where it was low before (and vice versa).

Note how the velocity graph is shifted by a quarter of a wavelength relative to the pressure graph

Below the graphs, short vertical lines mark the *nodes* (maximum sound pressure / minimum velocities) while the double arrows mark the *antinodes* (minimum sound pressure / maximum velocity variation).

You will notice that the distance between adjacent nodes is one half wavelength.

Imagine now that the barrier at the left end is moved one half wavelength to the right – then it will still constitute a node. This will not change the resonance in the remaining part of the tube.

In fact, the barrier can be moved all the way to the last node where only a quarter of a wavelength remains of the tube – and there will still be resonance.

The concepts of "node" and "antinode"

In this manual, "node" and "antinode" are used **focusing on pressure variations**. To clarify this, you can use the terms *pressure node* and *pressure antinode*.

Note that *pressure node* = *motion antinode* and *pressure antinode* = *motion node*.

The resonance condition

We can now set up a formula to describe when a half-open air column will resonate:

As remarked in the paragraph above, the length of the pipe must be *an integer number of half* wave lengths *plus one quarter* of a wavelength.

Call the length of the pipe L and the wavelength λ and let N be a non-negative integer. Then we have:

$$L = N \cdot \frac{\lambda}{2} + \frac{\lambda}{4} \qquad N = 0, 1, 2 \ \dots$$

Waves in general

For any wave, the wavelength λ, the frequency f and the speed of propagation v meet the condition

$$v = f \cdot \lambda$$

Hence, when you know the frequency and the wavelength, the speed of sound can be calculated.

Procedure

The setup is shown on p. 1.

Note how the microphone is placed immediately outside the mouth of the tube. The microphone is *pressure* sensitive – not velocity sensitive. Therefore when placed here, the microphone will give off a minimum signal at resonance.

The microphone is powered by the battery box. Connect the multimeter and set it for small AC voltages.

Place the loudspeaker 2-3 cm from the mouth of the tube. It is connected to the power output of the function generator. Select a *sine wave* signal.

During the experiment, adjust the volume to a suitable compromise between signal level and unpleasantly loud sound.

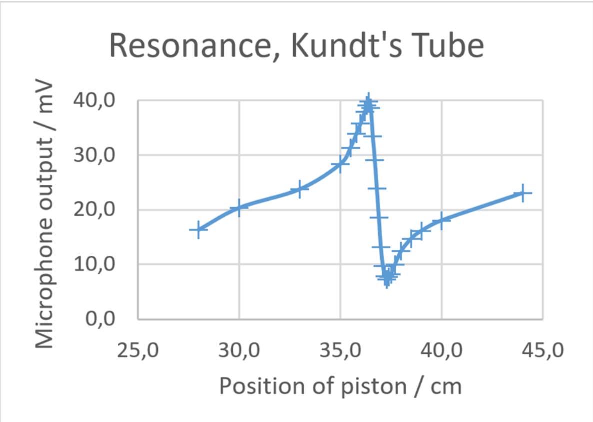
Note! The microphone output must not exceed 1.5 V measured with the multimeter. Otherwise, the signal will be distorted and the voltage reading invalid.

1 – Fixed frequency, varying length

Adjust the function generator frequency to 500 Hz.

The effective length of the tube is varied by moving the piston. We are searching the tube lengths that lead to a node at the mouth i.e. *minimum* signal.

You will quickly discover that close to the nodes you want you find tube lengths that gives a maximum sound pressure (see graph).



The sudden change in sound pressure can be heard as well as measured and can be used to quickly find the vicinity of the nodes. For the final fine tuning of the piston, use only the microphone voltage – not your ear.

All resonance positions must be found. (For this frequency there will be two.)

The length of the tube (from the mouth to the piston) is each time read with 1 mm precision.

2 – Fixed length, varying frequency

Pull the piston out to maximum tube length and read this length precisely.

Start at 1350 Hz and reduce the frequency slowly, hunting for frequencies leading to resonance and hence a node at the tube mouth.

As before you will find maximum sound pressure at frequencies very close to the minima sought.

Be careful to catch all the nodes! To ensure this, draw a number axis from 0 to 1350 Hz and mark the resonance frequencies found with crosses – it will be easy to spot if one is missing.

At low frequencies (below a few hundred Hz) the loudspeaker efficiency drops off. If necessary, turn the volume up *a little* and watch the voltmeter carefully.

3 – Fixed frequency, varying length (again)

Repeat the measurements in part 1, only at a different frequency: Use 1350 Hz this time.

There will be more nodes than in part 1 – be careful to find them all. Measure as before tube lengths with a precision of 1 mm.

Speed of sound, expected value

As a "table value" for the speed of sound, an approximated formula is used. At temperature *t* (Celsius), the speed of sound is:

$$v_t = \left(331{,}3 + 0{,}606 \cdot \left(\frac{t}{°C}\right)\right) \frac{m}{s}$$

This is valid for dry air around room temperature. Add 0.0126 m/s for every % relative humidity.

Calculations

As a standard of reference, calculate the expected speed of sound from the relevant values of temperature and humidity – preferably measured; if this is not feasible, guess at e.g. 22 °C and 60 %.

In the following, a spreadsheet program will be useful.

1 – Varying length

The distance between the nodes is λ/2. Use this for calculating an experimental value for the speed of sound. Compare with the table value.

2 – Varying frequency

If you found all resonance frequencies, the lowest of these corresponds to *N* = 0 in the resonance condition, the next one to *N* = 1 etc. Use these results to find a value for the speed of sound for each frequency – these should be approx. equal. Find the average.

In case the values found for the velocity varies strongly you might have missed a resonance. Try if a different set of N values gives a better fit.

3 – Varying length again

Assume that the shortest length corresponds to *N* = 0, the next to *N* = 1 etc.

Plot the measured tube lengths *L* as a function of the number *N* of nodes.

Explain why you should expect a straight line with a slope equal to λ/2.

(As above: In case the graph doesn't resemble a straight line at all, try re-numbering the nodes by dropping one of the N values.)

Calculate the slope of the line and from this the speed of sound. Compare with the table value.

Discussion and evaluation

How well do the measured values for the speed of sound fit the one expected?

Do the measurements in general correspond to the theoretical description (on p. 2)?

Extra exercise (for the toughest): Prove, based on the formula for the resonance condition, the assertion that the resonance frequencies are evenly spaced when measuring with a fixed tube length.

Teacher's notes

Concepts used

Sound pressure
Standing waves
Resonance
nodes
Antinodes

Mathematical skills

Expression evaluation
Graphs
Using a spreadsheet (advantage)

About the equipment

A microphone is used in order to determine the resonance points precisely.

If you have another type of multimeter than those mentioned, you can check the frequency range yourself by connecting It directly to the function generator. The signal amplitude from the generator is completely independent of the frequency in the relevant interval. A soft drop in sensitivity towards the higher frequencies is acceptable.

Instead of a multimeter you could choose to monitor the signal with an oscilloscope.

Detailed equipment list

Specifically for the experiment

247500	Kundt's tube (Plexiglas)
250310	Student function generator – or similar, e.g. 250350
250500	Loudspeaker on post
248600	Microphone
248601	Cable, modular plug to 6-pin DIN
251560	Battery box

Standard lab equipment

000600	Stand base (2 used)
000850	Steel rod, 25 cm (2 used)
002310	Bosshead, square (2 used)
001800	Stand clamp, overlapping jaws (2 used)
000410	Stand base, square (2 used)
105720	Safety cable, silicone 50 cm, black
105721	Safety cable, silicone 50 cm, red
105740	Safety cable, silicone 100 cm, black
105741	Safety cable, silicone 100 cm, red

Recommended multimeters

386231 Multimeter DMM-8062
0.01 mV AC resolution up to 60.00 mV and 0.1 mV resolution up to 600.0 mV. Range lock button. Provided with "analog bar graph".

This is the preferred instrument, but the (less expensive) alternatives below can be used if need be. As they are less sensitive, you will need to turn up the sound volume which can be annoying to listen to.

386135 Multimeter DMM-135A
Resolution 0.001 V AC up to 3.999 V. (Above 4 V: 0.01 V resolution.)

386215 Multimeter DMM-125
Resolution 0.001 V AC up to 3.200 V. (Above 3.2 V: 0.01 V resolution.) Provided with "analog bar graph" which, however, is not especially useful at the voltages used here.