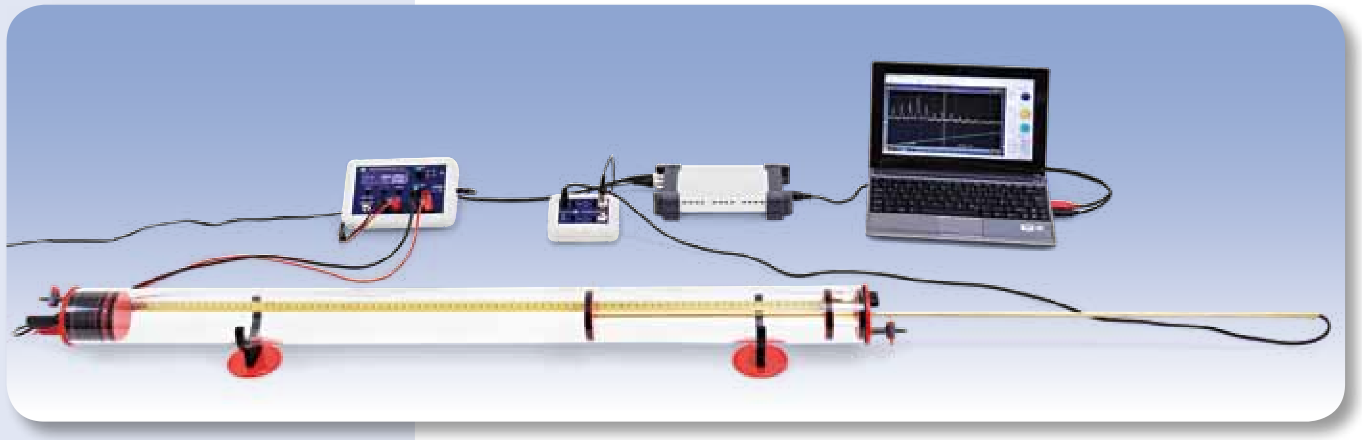
UE1070320

SPEED OF SOUND IN AIR



EXPERIMENT PROCEDURE

- **Generate standing waves in Kundt's tube with both ends closed off.**
- **Measure the fundamental frequency as a function of the length of the Kundt's tube.**
- **Measure the frequencies of the fundamental and overtones for a fixed length of tube.**
- **Determine the speed of propagation of the wave from the resonant frequencies.**

OBJECTIVE

Generate and measure standing sound waves in Kundt's tube.

SUMMARY

Sound waves propagate in gases in the form of longitudinal waves. The overall velocity is equivalent to the phase velocity. In this experiment a standing wave is generated inside Kundt's tube with both ends closed off. The fundamental frequency is measured as a function of the length of the tube, and the frequencies of the fundamental and overtones are also measured for a fixed length of tube.

REQUIRED APPARATUS

Quantity	Description	Number	
1	Kundt's Tube E	1017339	
1	Probe Microphone, long	1017342	
1	Microphone Box (115 V, 50/60 Hz)	1014521	or
	Microphone Box (230 V, 50/60 Hz)	1014520	
1	Function Generator FG 100 (230 V, 50/60 Hz)	1009957	or
	Function Generator FG 100 (115 V, 50/60 Hz)	1009956	
1	USB Oscilloscope 2x50 MHz	1017264	
1	Analogue Multimeter AM50	1003073	
1	HF Patch Cord, BNC/4 mm Plug	1002748	
1	Pair of Safety Experiment Leads, 75 cm	1002849	
1	HF Patch Cord	1002746	

GENERAL PRINCIPLES

It is possible to generate standing waves in Kundt's tube by producing waves of a suitable resonant frequency from a loudspeaker at one end of the tube, which are then reflected by the cap at the other end. If the length of the tube is known, it is possible to determine the speed of propagation of the waves from the resonant frequency and the number of the harmonics.

Sound waves propagate in air and other gases by means of rapid changes in pressure and density. It is easiest to describe them on the basis of the sound pressure, which is superimposed on top of atmospheric pressure. As an alternative to the sound pressure *p*, the sound velocity *v* can also be used to describe a sound wave. That is the average velocity of gas molecules at a given point *x* in the oscillating medium at a point in time *t*. Pressure and velocity of sound are linked, for example by an Euler equation of motion:

(1) $$-\frac{\partial p}{\partial x}=\rho_0\cdot\frac{\partial v}{\partial t}$$

ρ_0: Density of gas

In Kundt's tube, sound waves propagate along the length of the tube, i.e. they can be described with the help of a one-dimensional wave equation, which applies to both sound pressure and velocity:

(2) $$\frac{\partial^2 p(x,t)}{\partial t^2}=c^2\cdot\frac{\partial^2 p(x,t)}{\partial x^2}\quad\text{or}\quad\frac{\partial^2 v(x,t)}{\partial t^2}=c^2\cdot\frac{\partial^2 v(x,t)}{\partial x^2}$$

c: speed of sound

This experiment studies harmonic waves, which are reflected at the end of the Kundt's tube. To find the solutions to the wave equation, the superposition of the outgoing and reflected waves needs to be taken into account:

(3) $$p=p_{0>}\cdot e^{2\pi i\left(f\cdot t-\frac{x}{\lambda}\right)}+p_{0<}\cdot e^{2\pi i\left(f\cdot t+\frac{x}{\lambda}\right)}$$

$p_0>$, $v_0>$: Amplitudes of outgoing wave,
$p_0<$, $v_0<$: Amplitudes of returning wave
f: Frequency, λ: Wavelength

In this case

(4) $$f\cdot\lambda=c$$

By substituting these solutions into equation (1) and considering the outgoing and returning waves separately, the following can be derived:

(5) $$p_{0>}=v_{0>}\cdot Z\quad\text{and}\quad p_{0<}=v_{0<}\cdot Z.$$

The quantity

(6) $$Z=c\cdot\rho_0$$

Is known as the sound impedance and corresponds to the resistance to the waves from the medium itself. It plays a key role in considerations of the reflection of a sound wave by walls with an impedance of *W*:

The following then applies:

(7) $$r_v=\frac{v_{0<}}{v_{0>}}=\frac{Z-W}{Z+W}\quad\text{and}\quad r_p=\frac{p_{0<}}{p_{0>}}=\frac{\frac{1}{Z}-\frac{1}{W}}{\frac{1}{Z}+\frac{1}{W}}$$

In this experiment *W* is much higher than *Z* so that we may assume $r_v = 1$ and $r_p = -1$.

If the reflecting wall is selected, for simplicity's sake, to be at $x = 0$, the spatial component of the sound wave can be derived from equation (3) as follows:

(8) $$p=p_{0>}\cdot\left(e^{-2\pi\cdot i\cdot\frac{x}{\lambda}}+e^{+2\pi\cdot i\cdot\frac{x}{\lambda}}\right)\cdot e^{-2\pi\cdot i\cdot f\cdot t}=2\cdot p_{0>}\cdot\cos\left(\frac{2\pi}{\lambda}\cdot x\right)\cdot e^{-2\pi\cdot i\cdot f\cdot t}$$

and

$$v=v_{0>}\cdot\left(e^{-2\pi\cdot i\cdot\frac{x}{\lambda}}-e^{+2\pi\cdot i\cdot\frac{x}{\lambda}}\right)\cdot e^{-2\pi\cdot i\cdot f\cdot t}=-2\cdot i\cdot v_{0>}\cdot\sin\left(\frac{2\pi}{\lambda}\cdot x\right)\cdot e^{-2\pi\cdot i\cdot f\cdot t}$$

Only the real components of these terms have any actual physical relevance. They correspond to standing sound waves which have a pressure anti-node at the end wall (i.e. at $x = 0$), while the sound velocity at that point has a node in its oscillation. The velocity is phase shifted ahead of the pressure by 90°.

Sound waves are generated by a loudspeaker at a distance *L* from the wall. These waves oscillate with frequency *f*. At this point, too the pressure has an anti-node and the velocity has a node. Such boundary conditions are only fulfilled when *L* is an integer multiple of half the wavelength:

(9) $$L=n\cdot\frac{\lambda_n}{2}$$

From equation (3) then, the frequencies must fulfil the following condition for resonance:

(10) $$f_n=n\cdot\frac{c}{2\cdot L}.$$

During the experiment, the frequency *f* of the speaker is continuously varied while a microphone sensor measures the sound pressure at the reflecting wall. Resonance then occurs when the microphone signal is at its maximum amplitude.

EVALUATION

According to equation (9) the resonant frequencies determined f_n should have wavelengths

$$\lambda_n=\frac{2\cdot L}{n}.$$

In order to verify equation (3) and determine the wavelength, the wavelength values should be plotted on a graph of *f* against λ.

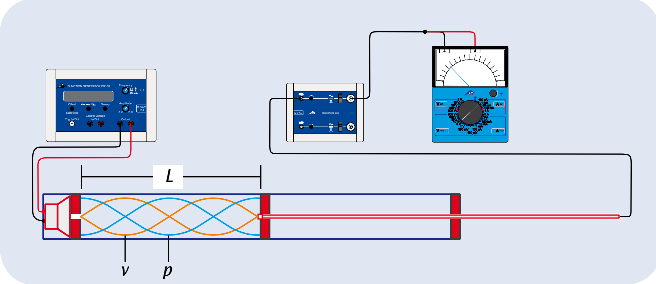


Fig. 1: Schematic of experiment set-up

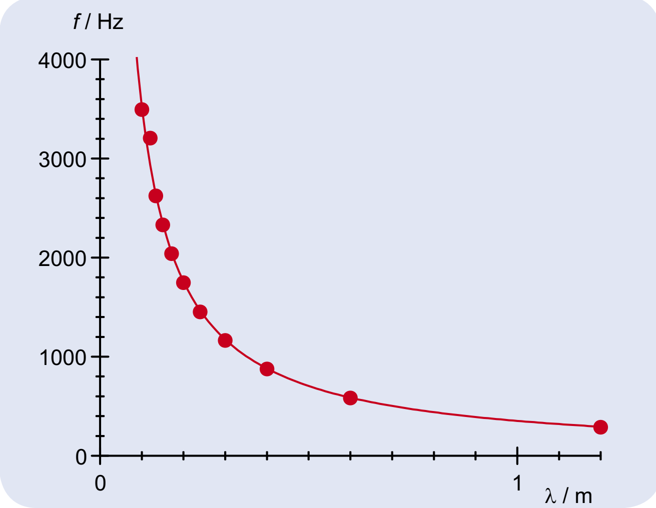


Fig. 2: Graph of frequency against wavelength

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