Acoustics

Wavelength and speed of sound

PHYSICS EXPERIMENT

Speed of Sound in Air

MEASURING THE PROPAGATION TIME OF SOUND PULSES IN KUNDT'S TUBE.

- **Measuring the propagation time *t* of a sound pulse in air at room temperature as a function of the distance *s* between two microphone probes.**
- **Confirming the linear relationship between *s* and *t*.**
- **Measuring the propagation time *t* of a sound pulse in air as a function of the temperature *T* over a fixed distance between two microphone probes.**
- **Determining the speed of sound (group velocity) as a function of temperature.**
- **Comparing the result with Laplace’s derivation.**

UE1070310

06/16 UD

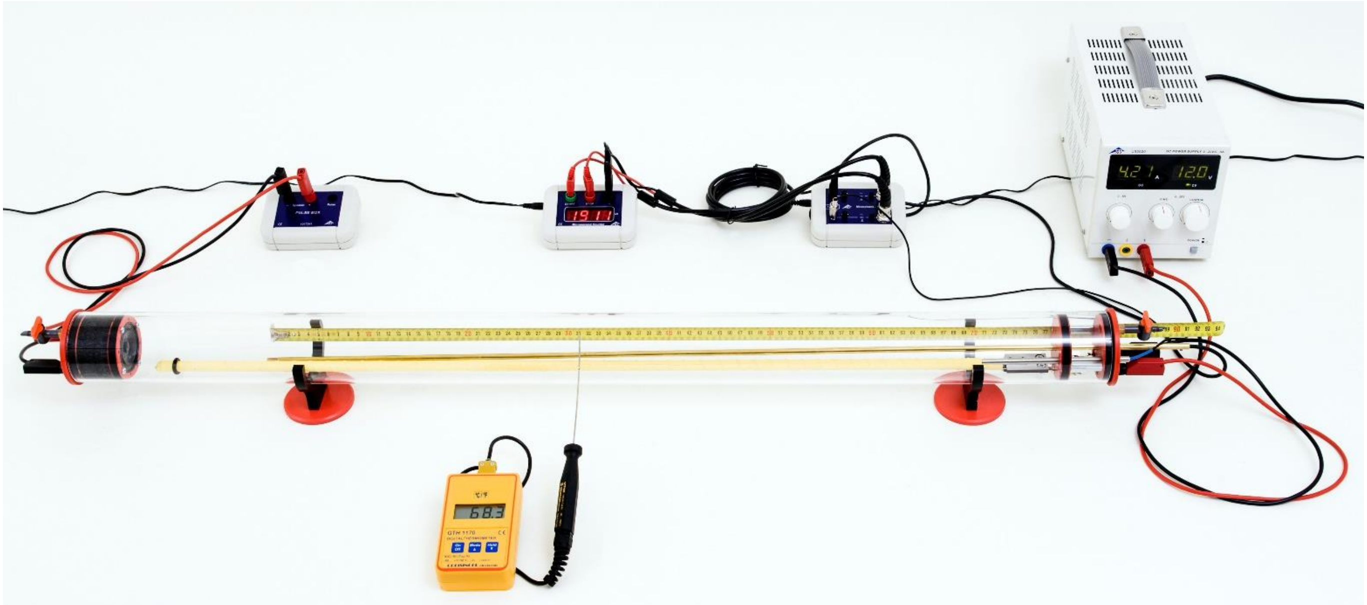

Fig. 1: Measurement set-up.

BASIC PRINCIPLES

Sound waves are elastic waves within a deformable medium. The wave velocity depends on the medium's elastic properties. In simple gases, sound propagates exclusively as longitudinal waves, the group velocity being equal to the phase velocity.

In a derivation according to Laplace, sound waves in gases are considered as changes in adiabatic pressure or density. The speed of sound is determined as being:

$$(1) \quad c = \sqrt{\frac{C_P}{C_V} \cdot \frac{p}{\rho}} \,.$$

p: Pressure, ρ: Density,
C_P, C_V: Heat capacities of the gas

For an ideal gas at absolute temperature T:

$$(2)\quad \frac{p}{\rho}=\frac{R\cdot T}{M}\,.$$

$R=8.314\frac{\text{J}}{\text{Mol}\cdot\text{K}}$: Universal gas constant,

M: Molar mass

The speed of sound in this gas is therefore:

$$(3)\quad c=\sqrt{\frac{C_P}{C_V}\cdot\frac{R\cdot T}{M}}\,.$$

For temperature differences ΔT which are not too large compared to a reference temperature T_0, the speed of sound is a linear function of the temperature change ΔT:

$$(4)\quad c=\sqrt{\frac{C_P}{C_V}\cdot\frac{R\cdot T_0}{M}}\cdot\left(1+\frac{\Delta T}{2\cdot T_0}\right)$$

For dry air as an ideal gas, the speed of sound is accordingly often expressed as follows:

$$(5)\quad c(T)=\left(331.3+0.6\cdot\frac{\Delta T}{\text{K}}\right)\frac{\text{m}}{\text{s}}$$

T_0 = 273.15 K = 0°C

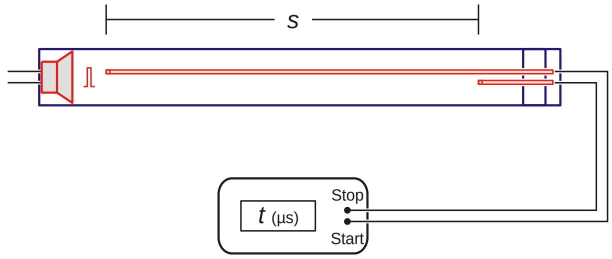

Fig. 2: Schematic of the experiment setup.

LIST OF EQUIPMENT

1	Kundt's Tube E	1017339 (U8498308)
1	Pulse box K	1017341 (U8498281)
1	Microphone probe, long	1017342 (U8498282)
1	Microphone probe, short	4008308 (U8498307)
1	Microphone box @230V	1014520 (U8498283-230)
or		
1	Microphone box @115V	1014521 (U8498283-115)
1	Microsecond counter @230V	1017333 (U8498285-230)
or		
1	Microsecond counter @115V	1017334 (U8498285-115)
1	Heating rod K	1017340 (U8498280)
2	HF patch cords, BNC/4-mm plugs	1002748 (U11257)
1	DC power supply 0-20 V, 0-5 A @230V	1003312 (U33020-230)
or		
1	DC power supply 0-20 V, 0-5 A @115V	1003311 (U33020-115)
1	Digital quick-response pocket thermometer	1002803 (U11853)
1	K-Type NiCr-Ni Immersion sensor -65 – 550°C	1002804 (U11854)
1	Pair of safety experiment leads, 75 cm	1002849 (U13812)

Additionally recommended:

A variety of technical gases

SET UP

- Set up the sound tube on the supplied feet (Fig. 1).
- Insert the end cap with the connector sockets for a loudspeaker into the end of the tube.
- Insert heating rod K into the end cap with the sockets for the heater and push the cap into the tube.

Note:
If necessary apply some glycerine or soap to the sealing gaskets to make insertion easier.

- Push the microphone probes through the holes in the end cap as far as they will go and thread them through the guide disc.
- Attach the movable scale to the mountings on the feet.
- Connect the pulse box to the pair of sockets for operation of the loudspeaker. Take note of the maximum power of the speaker (U_{rms} = 6 V max.). Set both outputs to Trigger and set the gain for both channels to a medium setting.
- Connect the DC power supply to the sockets for the heating rod.
- Connect the long microphone probe to the Channel A input of the microphone box and connect the short one to the input for Channel B.
- Use a BNC/4-mm adapter cable to connect the output of Channel A to the Start input of the microsecond counter (plug red 4-mm plug into green socket, black 4-mm plug into black ground socket).
- Connect the output of Channel B to the Stop input of the microsecond counter (plug red 4-mm plug into red socket, black 4-mm plug into black ground socket from the side).
- Connect the plug-in power supply to the microsecond counter and the microphone box and plug it into the mains.

Note:
When experimenting with so-called technical gases, fill the tube via the hose nozzles. The setting of the cocks needs to be in accordance with the density of gas.

PROCEDURE

Speed of sound in air at room temperature

- Set the distance between the long and short microphone probes to be 750 mm with the help of the sliding scale. This distance will correspond to the distance travelled by the sound. Enter its value into Table 1.
- Use the pulse box to generate a pulse of sound and read off the time it takes the sound to propagate between the long microphone probe and the short one from the micro-second counter. This is the time it has taken the sound to cover the distance. Enter the value into Table 1.

Note:
The sound pulse is generated by the rapid motion of a speaker membrane triggered by a steep-edged voltage pulse. The high-resolution measurement of the time the pulse takes to cover the distance is measured via the microsecond counter, which starts when the sound reaches the long microphone probe and stops when it reaches the short probe a distance *s* further away.

- By successively pulling the long microphone out, set up some longer distances. Repeat the measurement for each distance and enter the results for distance and time into Table 1.

Speed of sound in air as a function of temperature

- Set up a fixed distance *s* = 600 mm between the long and short microphone probes.
- Connect the immersion sensor to the pocket thermometer, push it through the hole in the sound tube and place it in the centre of the tube.
- Use the heating rod connected to the plug-in power supply to heat the air in the tube to 50°C.
- As the apparatus cools back down to room temperature, measure the time the sound takes to cover the distance as described above at steps of 5°C, for example. Enter the temperature and time values into Table 2.

Note:
The temperature must not exceed 50°C.

As the cooling occurs, the temperature distribution is sufficiently uniform that the temperature only needs to be measured at a single point inside Kundt's tube.

Kundt's tube can also be filled with technical gases other than air via a tube nozzle.

SAMPLE MEASUREMENT AND EVALUATION

Table 1: Travelled distance *s* and sound propagation time *t* in air at room temperature.

s / mm	*t* / µs
750	2150
600	1720
450	1295
300	858
150	431

Table 2: Sound propagation time *t* and speed of sound *c* in air as a function of the temperature *T*. Distance *s* = 600 mm.

T / °C	*t* / µs	*c* / m/s
50.0	1668	359.7
45.0	1681	356.9
40.0	1694	354.2
35.0	1707	351.5
30.0	1720	348.8
26.1	1731	346.6
22.4	1742	344.4

Time for sound to propagate in air at room temperature

- Plot the time *t* taken for the sound to cover the set distance *s* in a graph (Fig. 3).
- Fit a straight line $t = a \cdot s$ to the measurement points.

The speed of sound corresponds to the reciprocal of the straight line's gradient *a*:

$$(6)\quad c = \frac{1}{a} = \frac{1}{2.868}\,\frac{\text{mm}}{\mu\text{s}} = 348.7\,\frac{\text{m}}{\text{s}}\,.$$

The result is in good agreement with the value quoted in literature c = 346.4 m/s at T = 25°C.

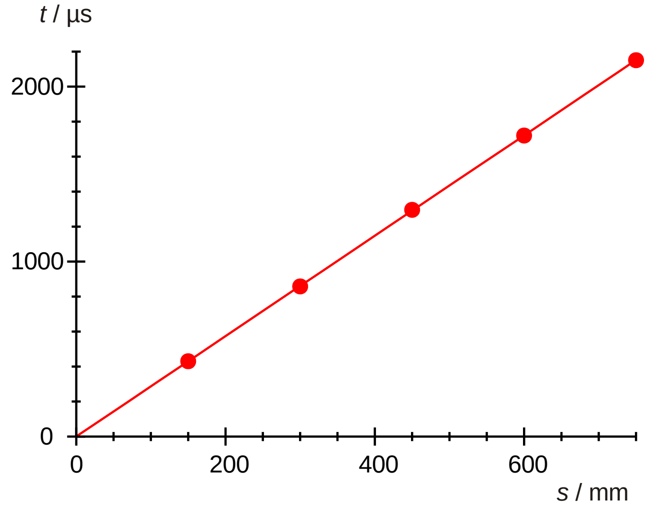

Fig. 3: Sound propagation time *t* in air as a function of the travelled distance *s* at room temperature.

Time for sound to propagate in air as a function of temperature

- For each temperature, calculate the speed of sound by taking the following quotients

  (7) $c = \frac{s}{t}$

  where t is the propagation time needed to cover the distance s (Table 2). Enter the results into Table 2.
- Plot the speed of sound c against temperature T in a graph (Fig. 4).
- Use equations (3) and (5) to calculate how the speed of sound depends on the temperature with the following parameters:

  (8) $M = 28.97\frac{\text{g}}{\text{Mol}}$ and $\frac{C_\text{p}}{C_\text{V}} = \frac{7}{5}$

  Enter the results in a graph of c against T (Fig. 4).

The values calculated using equation (3) describe the points as measured quite accurately with these parameters (8). The approximate description provided by equation (5), though, does not match as well.

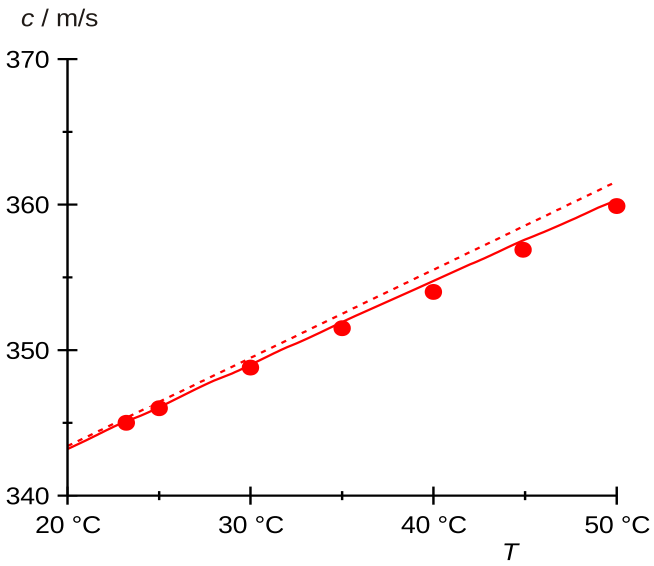

Fig. 4: Speed of sound c in air as a function of the temperature T.
Solid line: Calculation according to equation 3.
Dashed line: Calculation according to equation 5.