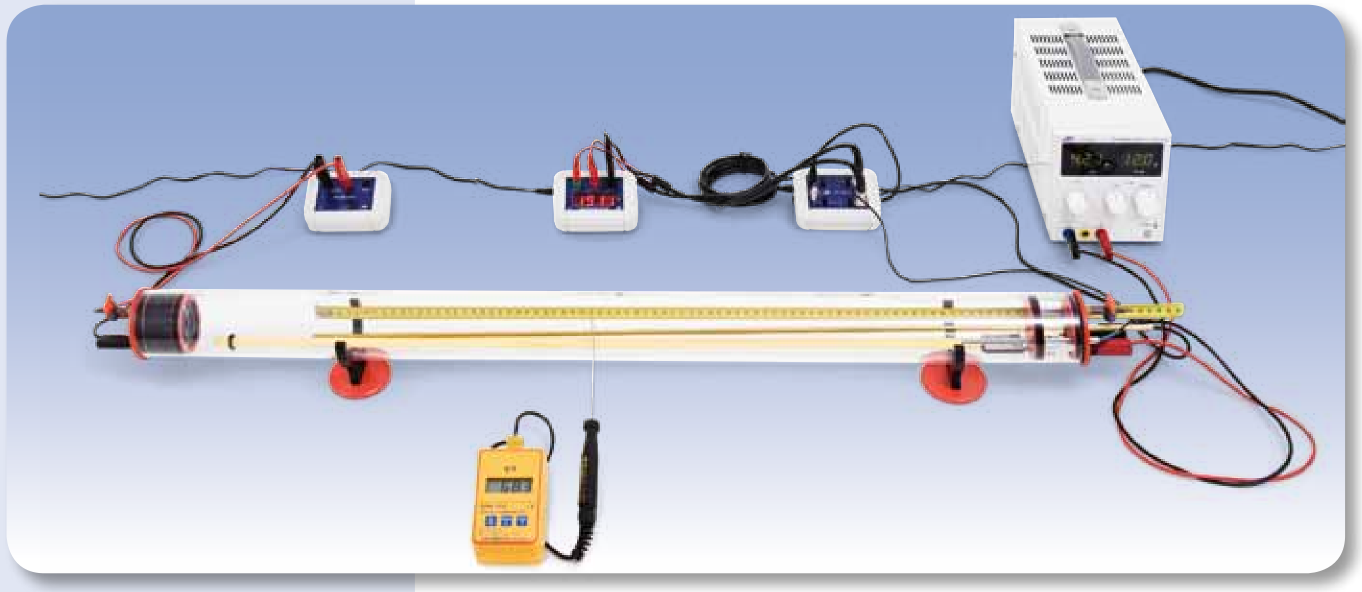
SPEED OF SOUND IN AIR



EXPERIMENT PROCEDURE

- **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.**

OBJECTIVE

Measuring the propagation time of sound pulses in Kundt's tube.

SUMMARY

Sound waves propagate longitudinally in gases. The group velocity here is equal to the phase velocity. In this experiment, we will measure the propagation time of a sound pulse between two microphone probes in Kundt's tube, and use the result to calculate the speed of sound. The temperature dependence of the speed of sound is examined between room temperature and 50°C. The measurement result matches the result of Laplace's derivation.

REQUIRED APPARATUS

Quantity	Description	Number
1	Kundt's Tube E	1017339
1	Pulse Box K	1017341
1	Probe Microphone, long	1017342
1	Microphone Probe, short	4008308
1	Microphone Box (230 V, 50/60 Hz)	1014520 or
	Microphone Box (115 V, 50/60 Hz)	1014521
1	Microsecond Counter (230 V, 50/60 Hz)	1017333 or
	Microsecond Counter (115 V, 50/60 Hz)	1017334
1	Heating Rod K	1017340
2	HF Patch Cord, BNC/4 mm Plug	1002748
1	DC Power Supply 0 – 20 V, 0 – 5 A (230 V, 50/60 Hz)	1003312 or
	DC Power Supply 0 – 20 V, 0 – 5 A (115 V, 50/60 Hz)	1003311
1	Digital Quick Response Pocket Thermometer	1002803
1	K-Type NiCr-Ni Immersion Sensor, -65°C – 550°C	1002804
1	Pair of Safety Experiment Leads, 75 cm	1002849
Additionally recommended:		
	a variety of technical gases	***

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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) $$c = \sqrt{\frac{C_p}{C_V} \cdot \frac{p}{\rho}}.$$

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

For an ideal gas at absolute temperature T:

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

$$R = 8{,}314 \frac{\text{J}}{\text{Mol} \cdot \text{K}}$$: Universal gas constant.

M: Molar mass

The speed of sound in this gas is therefore:

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

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

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

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

T_0 = 273.15 K = 0°C

In the experiment, we will measure the propagation time t of a sound pulse between two microphone probes spaced at a distance s. The sound pulse is produced by a sudden movement of a loudspeaker diaphragm controlled by a voltage pulse with steep edge. High-resolution measurement of the propagation time using a microsecond counter starts when the sound pulse reaches the first microphone probe, and stops when the second microphone probe at a distance s is reached.

A heating element is used to heat the air in Kundt's tube to up to 50°C for measurements of propagation time as a function of temperature. The temperature distribution during the cooling process is sufficiently homogeneous. It is therefore sufficient to measure the temperature at one point in Kundt's tube.

A tube connector can be used to supply Kundt's tube with technical gases other than air.

EVALUATION

The speed of sound is calculated as the quotient of the travelled distance s and the propagation time t:

$$c = \frac{s}{t}$$

Figure 2 represents it as the reciprocal of the slope.

The temperature dependence of the speed of sound is described by equation 3 with the following parameters:

$$M = 28.97 \frac{\text{g}}{\text{Mol}}, \quad \frac{C_p}{C_V} = \frac{7}{5}$$

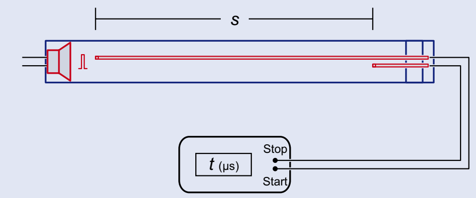

Fig. 1 Schematic of the experiment setup.

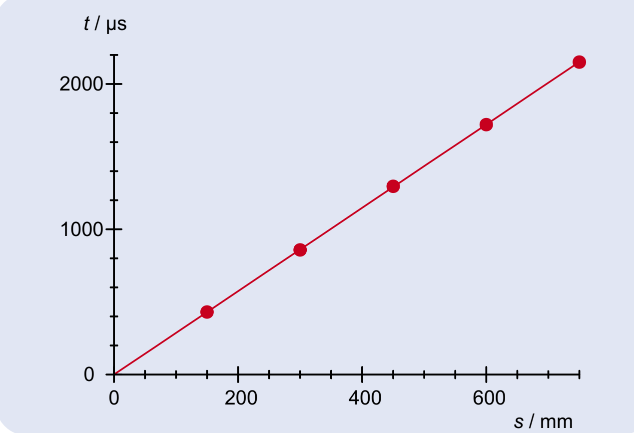

Fig. 2 Sound propagation time t in air as a function of the travelled distance s at room temperature.

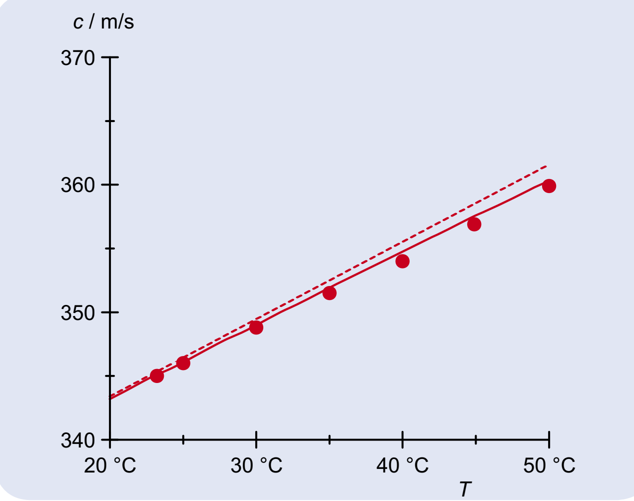

Fig. 3 Speed of sound c in air as a function of the temperature T.
Solid line: Calculation according to equation 3.
Dashed line: Calculation according to equation 5.