Velocity of sound using Kundt's tube

Related topics

Longitudinal waves, sound velocity in gases and solids, frequency, wavelength, stationary waves, natural vibrations.

Principle and task

A metal rod is made to vibrate longitudinally by rubbing it with a cloth. The gas column in a glass tube is caused to vibrate naturally as a result of resonance, through the radiation of sound from a disc attached to the end of the rod.
The ratio of the velocities of sound in the gas and in the vibration generator is determined by measuring the wavelength.

Equipment

Charging strip	03474.01	1
Piston	03474.02	1
Glass tube, e.d. 38 mm, l 640 mm	03918.00	1
Vibration generator, brass	03476.01	1
Vibration generator, steel	03476.02	1
Cork dust, 3 g	03477.00	1
Lycopodium powder, 10 g	02715.00	1
Thermometer -10...+30 C	05949.00	1
Bench clamp -PASS-	02010.00	4
Meter scale, demo, l = 1000 mm	03001.00	1
Universal clamp	37715.00	1
Reducing valve for CO_2 / He	33481.00	1
Steel cylinder, CO_2, 10 l, full	41761.00	1
Wrench for steel cylinders	40322.00	1
Glass tubes, straight, 80 mm, 10	36701.65	1
Rubber stopper, d 38/31 mm, 1 hole	39260.01	1
Rubber tubing, i.d. 7 mm	39282.00	1

Problems

1. To measure the wavelength of stationary waves using a steel or a brass rod as the vibration generator. The longitudinal velocity of sound in the material of the vibration generator is determined, given the velocity of sound in air.
2. To measure the wavelength for CO_2, and to determine the sound velocity in CO_2 from the ratios of the wavelengths in air determined in 1. above.

Set-up and proceudre

1. The experiment is set up as shown in Fig. 1. The vibration generator (160 cm long) is firmly secured to the two marker rings each 40 cm away from the ends.
   The diameter of the hard paper discs (diameters 30, 31, 32 and 33 mm) which transmit the sound, is chosen so that the distance between the edge of the disc and the wall of the glass tube does not exceed 1 mm and so that there is no possibility of touching even if the vibration generator bends during rubbing.
   The filler strip, which has cork flour (or lycopodium) evenly scattered over it, is emptied by rotating it in the tube. The ground cork flour and the glass tube should be as dry as possible.
   The Kundt's tube is rotated about its axis, taking care not to jerk it, just enough to lift the cork flour from its lowest position and make it stick to the sides.
   To generate the vibration, a felt cloth on to which some colophonium powder has been scattered, is drawn along the middle section of the generator rod. This should produce a pure, powerful note.

Fig. 1: Experimental set-up for determining the wavelength ratios in air and in steel or brass.

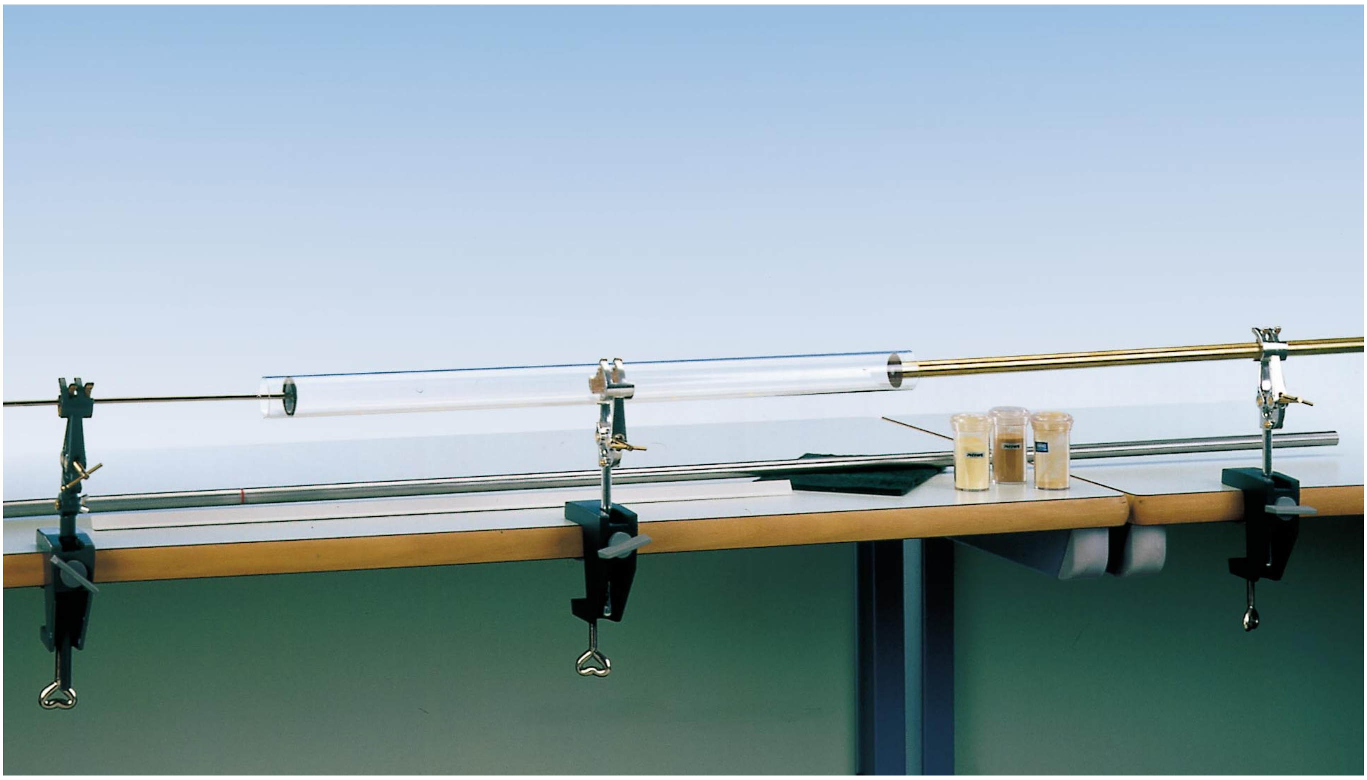
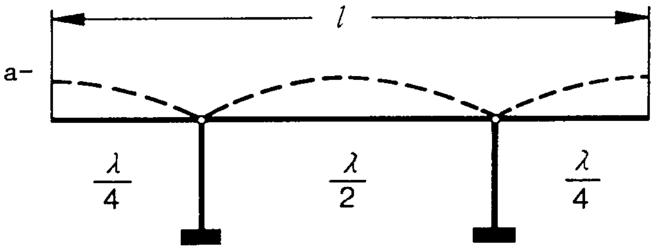


Fig. 2: Longitudinal vibration in the generator rod.



The vibration generator is cleaned with a cloth dipped in methylated spirit it necessary. Stationary waves form in the glass tube, and the cork flour sticking to the sides of the tubes falls away and forms 'festoons' at the antinodes, the places where there is considerable movement of air.
The tuning slide is moved 1 cm at a time until well-defined dust patterns are formed.
The distance between the well-defined nodes is determined with the scale.
The air temperature is measured in order to calculate the sound velocity.

2. The experiment is set up in the same way as in 1. in order to determine the length of sound waves in CO_2. The gas flows through the Kund tube continuously. Tuning is done by moving the tube against the vibration generator.
   The temperature fo the gas in the tube is taken immediately after each experiment.

Theoroy and evaluation

The sound velocity in the generator rod is expressed by

$$c_{\text{rod}} = f \cdot \lambda_{\text{rod}} \qquad (1)$$

The modes of a longitudinal vibration as shown in Fig. 2 are determined by the type of clamping. The length of the rod thus corresponds to the wavelength:

$$\lambda_{\text{rod}} = 160 \text{ cm.}$$

By analogy, the expression for the gas in the Kundt's tube is

$$c_{\text{gas}} = f \cdot \lambda_{\text{gas}} \qquad (2)$$

the wavelength being double the distance between the nodes of the stationary wave.

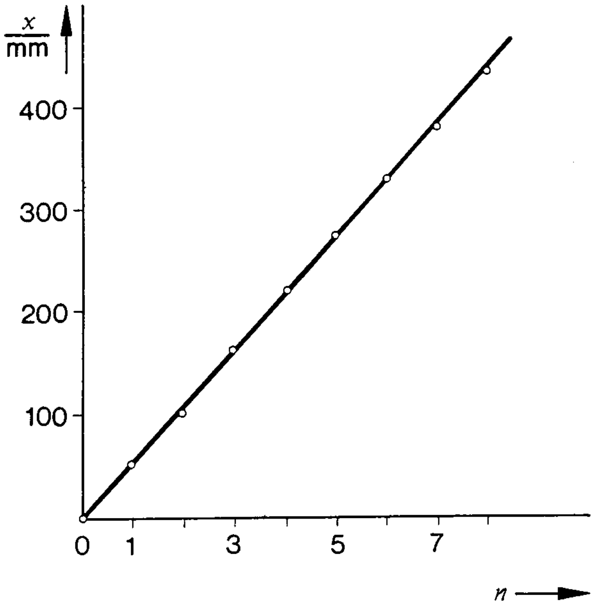
1. The sond velocity in the metal rods can be determined from equations (1) and (2) in accordance with:

$$c_{\text{rod}} = c_{\text{gas}} \frac{\lambda_{\text{rod}}}{\lambda_{\text{gas}}} \qquad (3)$$

   assuming that c_{gas} is known.

Fig. 3: Positions of the vibration nodes as a function of the number of nodes.

Vibration generator:	steel
Gas:	air



Figs. 3 and 4 represent examples of measurements taken at an air temperature ϑ of 25 °C.

Vibration generator:	brass
Gas:	air

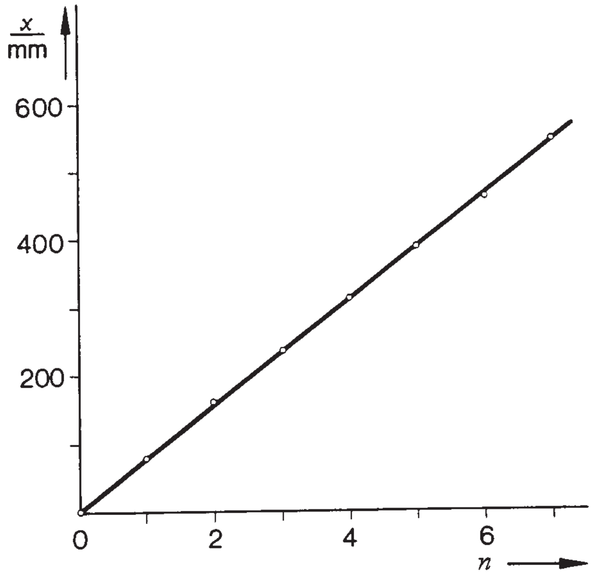


Fig. 4: Positions of the vibration nodes as a function of the number of nodes.

Vibration generator	$\frac{\vartheta}{°C}$	$\frac{a}{mm}$	$\frac{s_a}{\text{mm}}$	$\frac{c_{rod}}{\text{m/s}}$	$\frac{s_{c(rod)}}{\text{m/s}}$
Steel	25	54.9	0.4	5060	40
Brass	25	77.0	0.5	3600	30

Table 1: air

Table 1 gives the node spacings

$$a = \frac{\lambda_{gas}}{2}$$

as the slopes of the regression lines, for longitudinal waves in the vibration generator and with the standard error s_a, together with the sound velocities c_{rod} calculated in accordance with equation (3).

(c_{air} = 346 m/s at a temperature ϑ of 24 °C, see Appendix).

2. The ratio of the sound velocites in two gases (using the same vibration generator) are obtained as follows, using equations (2) and (2):

$$\frac{c_{gas\ 1}}{c_{gas\ 2}} = \frac{\lambda_{gas\ 1}}{\lambda_{gas\ 2}} \tag{4}$$

Vibration generator: steel
Gas: CO_2

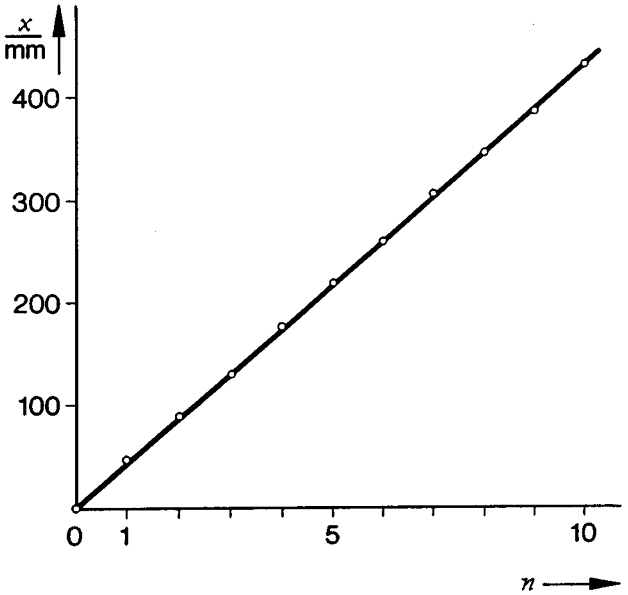


Fig. 5: Positions of the vibration nodes as a function of the number of nodes.

Vibration generator: brass
Gas: CO_2

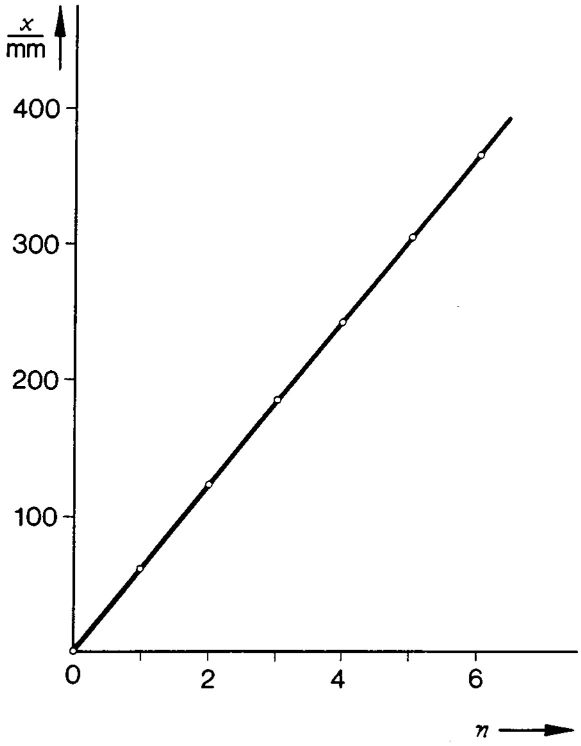


Fig. 6: Positions of the vibration nodes as a function of the number of nodes.

The temperature ϑ was 25 °C for these measurments with CO_2.

Table 2 gives the node spacings

$$\alpha = \frac{\lambda_{gas}}{2}$$

as the slopes of the regression lines, with the standard error s_a, together with the sound velocity in CO_2 calculated in accordance with equation (4) using the sound wave-lengths in air from section 1.

Table 2: CO_2

Vibration generator	$\frac{\vartheta}{^oC}$	$\frac{\alpha}{\text{mm}}$	$\frac{s_a}{\text{mm}}$	$\frac{c_{CO_2}}{\text{m/s}}$	$\frac{s_{c(CO_2)}}{\text{m/s}}$
Steel	25	42.7	0.2	269	2
Brass	25	59.8	0.3	269	2

Note

Dependence of sound velocity in gases on temperature:

$$c_{\text{gas}} = \sqrt{\frac{k \cdot R \cdot T_{abs}}{M_{molar}}} \sim \sqrt{T_{abs}} \qquad (5)$$

$$c_{\text{air}} = 331.5 \cdot \sqrt{1 + \frac{\vartheta/°C}{273}}\ \frac{m}{s}$$

$$c_{\text{CO}_2} = 258 \cdot \sqrt{1 + \frac{\vartheta/°C}{273}}\ \frac{m}{s}$$

The adiabatic coefficient k can be determined from the sound velocity in gases in accordance with equation (5).

When the density ρ is known, the modulus of elasticity E can be determined from the longitudinal velocity in rods in accordance with

$$c_{\text{rod}} = \sqrt{\frac{E}{\rho}}$$