Number	131410-EN	Topic	Sound, kinematics, measurement techniques			
Version	2017-08-25 / HS	Type	Student exercise	Suggested for	grade 9-10	p. 1/4

Objective
Measuring the speed of sound in atmospheric air.

Principle
An electronic timer is started and stopped by the signal from two microphones placed with a certain distance between them. The sound source is placed so the sound passes the start microphone first and later reaches the stop microphone.

Equipment
(Detailed equipment list on the last page.)

Timing is performed with a 200280 student timer and two 248600 microphones placed in stand bases.
(Photo shows older model 200260)

Clapper board

Ruler or tape measure

Eventually an indoor thermometer

Procedure

The student timer's *Reset, On/Off* button is used to turn on the timer and to reset it. Pressing the button a few seconds will turn off the instrument

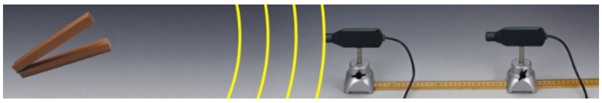
Plug in the microphones. Observe the correct orientation; the plugs *can* be forced into the sockets upside down.

Reset the timer and test the setup by tapping lightly with a fingertip at the two microphones.

Eventually place the two microphones along a table edge so they can be shifted along a straight line. If they are pointing in the same direction as shown, their distance can be found by measuring from front edge to front edge on the stand bases.

The clapper board clap must happen approx. on the extension of the line through the two microphones. Keep a distance of 1 to 2 metres to the start microphone.

Clap



Start

Stop

The microphones can react on other sounds, so the timer may start or stop unwanted.
It is therefore important to repeat the experiment a few times – and also in advance to have some idea of the size of the time interval:
Sound takes ***about*** 3 s to move 1 km so if the distance between the microphones is 1 m the timer should read ***about*** 3 ms.
And so on: ***about*** 1.5 ms for 0.5 m, ***about*** 6 ms for 2 m.

Vary the distance in steps of e.g. 25 cm – as far as the cables allow. Measure e.g. 5 times per distance – write down all measurements in order to find the average later.
Any completely atypical values should be discarded.

Measure (or estimate) the room temperature.

Theory

Speed calculation

Speed is calculated as the distance travelled divided by the elapsed time

$$v = \frac{\Delta s}{\Delta t}$$

We will measure a series of corresponding values for the distance s between the microphones and the time t measured on the timer. The data points are fitted by a straight line in a coordinate system and the speed is found as the slope of the line.

The speed of sound – basis for comparison

The table value is 344 m/s.
This is valid at 20°C and 50 % relative humidity.

From a measured or estimated room temperature, a more precise value for the speed of sound can be found.

Simple version

An approximated formula for the speed of sound at the temperature t (Celsius scale) looks like this:

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

This is valid for dry air around room temperature. Add 0,0126 m/s for every % of relative humidity.

Advanced version

Apart from the temperature, the speed of sound depends on the composition of the air:

$$v = \sqrt{\frac{\gamma \cdot R \cdot T}{M}}$$

where T is the absolute temperature of the air (Kelvin scale), R is the gas constant, M is the average molar mass of the air and γ is the ratio between the heat capacity at constant pressure and constant volume:

$$\gamma = \frac{c_P}{c_V}$$

(again as a weighted average over the constituents of the air).

Following nitrogen and oxygen, the main gasses in atmospheric air are carbon dioxide and water vapour.

In the atmosphere there is about 0.40 % CO_2 – indoors the level can be significantly higher.

The amount of water vapour in the air depends on the relative humidity and the saturated vapour pressure of water at the given temperature. The relative humidity can be measured with a hygrometer.

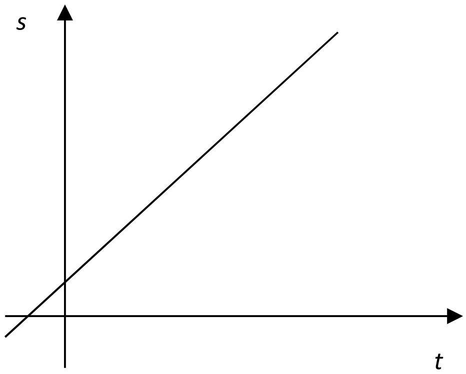
(Note that the influence on the speed of sound from these two gasses is *very* small under normal conditions.)

Calculations etc.

The measured data can with advantage be entered into a spreadsheet. Convert to SI units.

Draw a graph with time as the *x* axis and travelled distance as the *y* axis.

Draw the best straight line through the data points and use the slope of the line as a result of the measurement.



Discussion and evaluation

If the equipment behaved ideally, the straight line mentioned above would go through the origin of the coordinate system. Is this the case?
If not: Try to explain why.

Compare the measured and the expected value for the speed of sound.

Calculate the deviation as a percentage.

Teacher's notes

Concepts used

Speed

Advanced theory version uses:

Kelvin scale
Molar mass
Constants from gas laws
Composition of the atmosphere

Mathematical skills

Plotting graphs
Slope of a straight line

Advanced theory version uses:

Weighted average

About the equipment

The sensitivity of the microphones and the input of the timer has been selected for this experiment. Quiet conversation will not trigger the timer, but e.g. hitting the table will disturb the experiment.

Precise results require sound pulses which start abruptly. The slap from the clapper board works well but hand claps can be used at a pinch for fast demonstrations.

The student timer reacts on the *first* received start, resp. stop pulse. Therefore, reflected sound waves are ignored as they will arrive later than the direct sound from the clapper board.

When the battery reads "low bat.": Change the batteries immediately for the sake of accurate measurements.

Detailed list of equipment

Specifically for the experiment

200280	Student timer (or older model 200260)
248600	Microphone (Qty. 2)
248601	Cable DIN-6 to modular (Qty. 2)
248200	Clapper board

Standard lab equipment

140010	Tape measure 200 cm
000410	Stand base, square (Qty. 2)

Spare parts and consumables

351005	Battery LR6 1,5V [AA] (200260 use 6 at a time - included)