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| <i>Number</i> | 131415-EN | <i>Topic</i> | Sound, kinematics, measurement techniques | | |
| <i>Version</i> | 2016-06-06 / HS | <i>Type</i> | Student exercise | <i>Suggested for</i> | grades 9-10 |
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Objective

Determining the speed of sound in atmospheric air.

Principle

An electronic stopwatch is started and stopped by the signals from two microphones which are placed with some distance between them. The source of the sound is positioned so that the sound first passes the start microphone and after that the stop microphone.

Equipment

(See Detailed List of Equipment on the last page)

One 197570 SpeedGate is used for timing with two microphones 248600, each placed in a small stand base. Two cables 197571 are used, one of these is included with the SpeedGate.

Clapper board

Ruler or tape measure

(Optionally an indoor thermometer)

About SpeedGate

The SpeedGate has primarily been developed for timing with the built-in photocells – but can just as well be used with external signals.

In this experiment we use the stopwatch in a SpeedGate with two microphones.

You just need to keep your fingers (and everything else) away from the light rays to avoid starting and stopping the timer inadvertently.

Procedure

SpeedGate has a combined *Reset* and *On/Off* button, marked *X*, which is used to turn on and zero the unit. Keeping the button depressed will turn the instrument off.

The display of the SpeedGate is divided in two:

The upper part shows results from the primary mode which is selected with the button *I*. When turned on, the mode *Front Time* is selected – this is OK; in fact we'll not use the primary mode.

With the button *II* the secondary mode is selected. Select *Interval Before*.

The microphones are plugged in:

The cable from the "Start" microphone goes into the socket marked *Chain IN*.

The cable from the "Stop" microphone goes into the socket marked *Aux IN*.

Reset the stopwatch and test the function by tapping the front of the microphones gently with a fingertip. The time difference is displayed in the lower display.

The two microphones are placed e.g. along a table edge, allowing them to be displaced along a straight line. If they point in the same direction as shown on the images, the distance between them can easily be found by measuring from front edge to front edge of the stand bases.

The clapper board must slap together approximately on the (extension of the) straight line through the microphones. Keep a distance of at least a meter (preferably two) to the nearest microphone.

The microphones may react on other things than the sound from the clapper board, starting and stopping the timer at unwanted times.

Therefore, it is important to repeat the experiment several times with the same distance and also have an idea about the expected interval:

It takes **about** 3 s for sound to travel 1 km, so the distance 1 m should correspond to **about** 3 ms (milliseconds).

And so on: **About** 1.5 ms for 0.5 m, **about** 6 ms for 2 m.

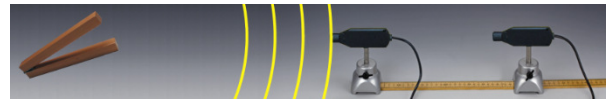
Vary the distance in steps of e.g. 25 cm as far as the cables allow. Measure for example 5 times per distance – write down all results in order to be able calculate average values later for each distance.

Any totally atypical values should be discarded.

The room temperature is measured or estimated.



Clap



Start



Stop

Theory

Calculation of speed

Speed is calculated by dividing the distance covered by the elapsed time.

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

We measure a number of correlated values for the distance between the microphones s and the time measured by the stopwatch t . The experimental data points are fitted with a straight line in a coordinate system and the speed is found as the slope of the line.

Speed of sound – comparison

The table value is 344 m/s.

This is valid for 20°C and 50 % relative humidity.

Based on a measured or estimated room temperature, a more precise value can be found.

Simple version

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

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

This relation applies to dry air near room temperature. Add 0.0126 m/s for every % of relative humidity.

Advanced version

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

The following applies:

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

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

$$\gamma = \frac{c_p}{c_v}$$

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

Apart from nitrogen and oxygen, the most abundant gasses in atmospheric air are carbon dioxide and water vapour.

In the atmosphere, there is about 0.40 % CO₂ – indoor levels can be significantly larger.

The amount of water vapour in the air depends on the relative humidity and the saturated vapour pressure at the actual temperature. The relative humidity is found with a hygrometer.

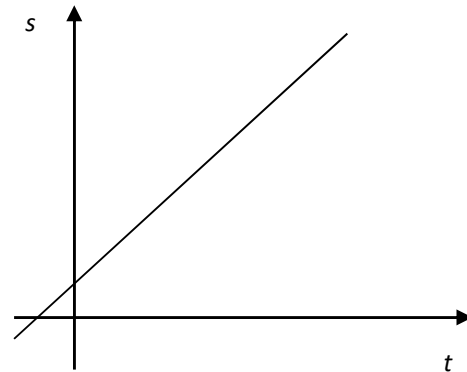
(Please note, that the influence on the speed of sound from these two gasses is very small under normal conditions.)

Calculations

The results can with advantage be processed in a spreadsheet. Convert to SI units.

Plot the results with time along the x axis and distance along the y axis.

Draw the best straight line through the data points and use the slope of the line as the experimental result of the measurements.



Discussion and evaluation

If the equipment was ideal, the straight line mentioned above would go through the origin of the coordinate system (0,0). Is this the case?

If no: Try to explain why not.

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

Determine the deviation as a percentage..

Teacher's notes

Concepts

Speed

Advanced theory version use:

Kelvin scale

Molar mass

Diverse constants from the ideal gas laws

The composition of the atmosphere

Mathematical skills

Graphs

Slope of straight line

Advanced theory version use:

Weighted average

The equipment

The sensitivity of the microphones has been chosen to fit this experiment. they will not react on quiet conversation while for instance knocking on the table easily can disturb the experiment.

Precise results require sound impulses that are loud and that starts abruptly. The snap from the clapper board works well, hand claps less so – but can be used for a quick demonstration.

The timing starts and stops on the first pulse of sound that is received on the two inputs. This means that reflections (from wall, ceiling etc.) are ignored as these sounds are arriving later.

Detailed equipment list

Specifically for the experiment

197570 SpeedGate (incl. one cable 197571)

248600 Microphone (2 are used)

197571 Cable modular plugs crossed 2m (one)

248200 Clapper board

Standard lab equipment

140010 Tape measure 200 cm

000410 Retort stand foot, square (2 are used)

Spare parts and consumables

351005 Battery LR6 1,5V [AA] (197570 uses 6 at a time – included)