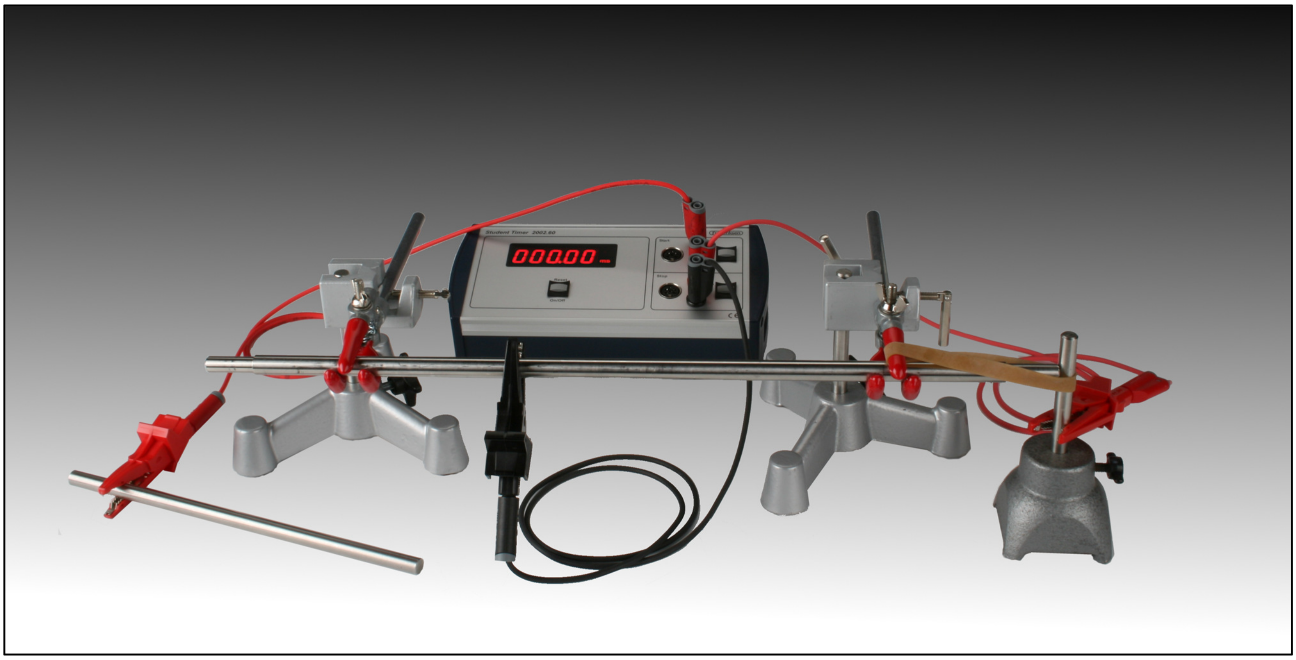
The Speed of Sound in Steel

Number 131420-EN	*Topic*	Sound, kinematics, Measurement techniques			
Version 2018-01-29 / HS	*Type*	Student exercise	*Suggested for* grade 10+	*p.*	1/4



Objective
To determine the speed of sound in steel.
Two types of waves or pulses are investigated: Longitudinal and transverse.

Principle
An electronic stopwatch is started and stopped by electric signals from the two ends of a steel rod carrying the waves.

The rod is connected to one of the black sockets on the stopwatch (0 V). The sound pulse is started by hitting the end of the rod with a smaller steel rod, connected to the red *Start* socket. This starts the timing. When the pulse reaches the opposite end of the rod, it will kick another short rod away. This breaks the connection to the red *Stop* socket and the timing stops.

When one of the two red sockets isn't shorted to 0 V, it is internally pulled "high" (a few volt). The stopwatch reacts on both rising and falling slopes.

Equipment
(See detailed equipment list on p.4)

A 200280 Student Timer is used. (Photo shows the older model 200260 – also applicable.)

The waves propagate in a steel rod resting in a couple of holders. In the receiving end, the rod must be prevented for slipping in the holder (in the photo, a rubber band is used for that).

For emission and detection of the sound pulses, a couple of short (10 cm) steel rods are used.

The receiver is built as shown by stabilising a short rod in a bosshead. The short rod is pressed lightly against the end of the long rod by means of a rubber band.

Connections to the rods are made by large crocodile clips that can easily open wide enough.

The length of the steel rod is measured with a tape measure.

As a minimum, the timing measurement should be performed with steel rods of 150 and 25 cm. If other lengths are available, they are included.

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Procedure

The *Reset, On/Off* button on the stopwatch is used for turning on and for zeroing. Keeping the button depressed for a few seconds will turn the instrument off.

1 – Longitudinal pulses

Prepare the receiver as shown on the "Stop" image. The vertical short steel rod is pressed lightly against the longer rod with a rubber band.

The short receiver rod is connected to the red *Stop* socket. The vertical rod is connected to one of the black sockets.
Now the *Stop* input is held at 0 V until a sound pulse kicks it away briefly.

The *Start* socket is similarly connected to the short steel rod that serves as a "hammer". The *Start* input will react when connection is established to the vertical rod, pulling the input down to 0 V.

Reset the stopwatch.

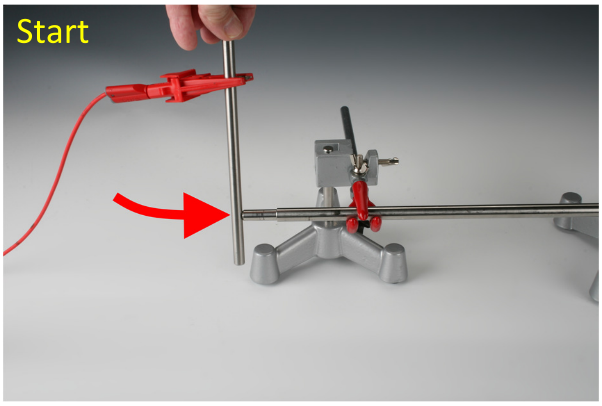
Let the starter rod hit lightly, but precisely, at the end of the vertical rod in a direction along its axis.
The stopwatch should display a time below 1 ms.

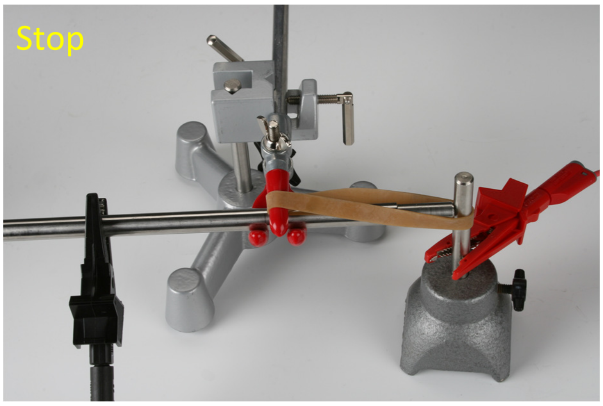
Repeat the measurement *at least* 10 times.

Measure the length of the rod.

Repeat this procedure with a rod of a different length.

Rods of 150 cm and 25 cm must be used, but should be supplemented with other lengths if available.





2 – Transverse pulses

Change the receiver as shown.
The rubber band are no longer needed; the receiver simply rests against the vertical rod.

Reset the stopwatch.

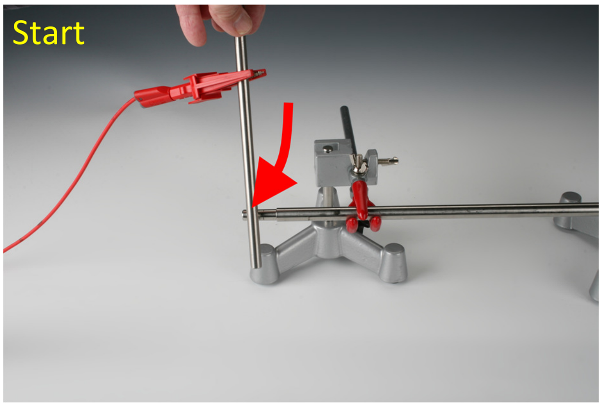
Let the starter rod hit lightly, but precisely, at the end of the vertical rod in a direction perpendicular to its axis. Hold the starter rod in the same angle as the receiver. Notice the spot you hit and the position of the receiver – it is the distance between these that you will measure later.

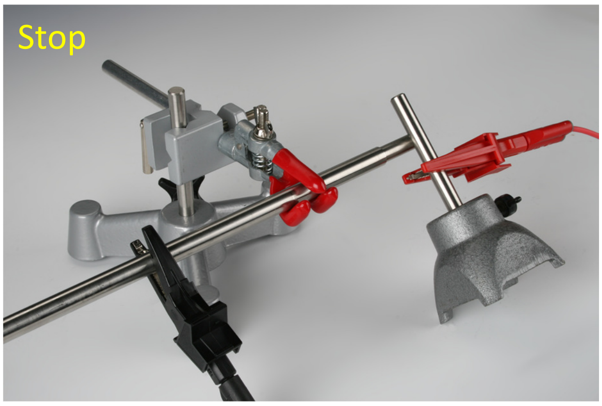
The stopwatch should display a time that is a few times larger than for experiment 1.

Repeat the measurement *at least* 10 times.

Measure the length that the sound pulse travels (not the whole length of the rod).

Repeat this procedure with the remaining rods used in experiment 1.





Theory

Calculation of speed

The speed is found as the distance the pulses travel divided by the time used

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

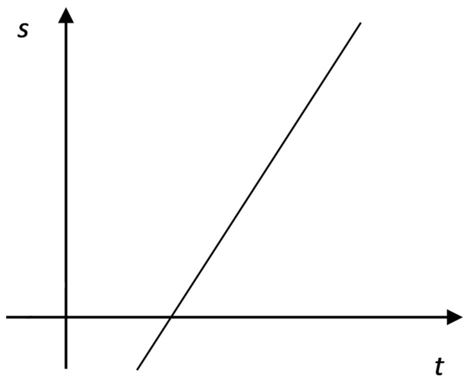
We measure a number of correlated values of the length s and the time t.

Plotting the length as a function of the time in a coordinate system enables us to fit a straight line to the points.

The *slope of the line* equals the speed of the sound pulses.

Typically, the line will not pass through the origin of the coordinate system. This is due to mechanical differences in the start and stop “switches” which leads to different reaction times.

Note: This means that the speed cannot simply be calculated as s divided by t.



Calculations

Enter the measurements in a spreadsheet – take care to keep the two propagation modes separated (longi-tudinal and transverse). Convert all values to SI units.

Discard obviously absurd values.

You may for instance encounter a “tail” of too long times in case the rods don’t make good electrical contact (see table – here, drop values above 0.6 ns).

Calculate the average of the time measurements for each length

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

Let the spreadsheet draw the best straight line through the points. Read the value of the slope

t / ms	N
0.55	11
0.56	9
0.57	2
0.58	2
0.59	1
0.60	1
0.63	1
0.64	1
0.69	1
0.74	1
0.75	1
0.77	1
0.78	1

Example of a measurement series with a “tail” (truncate before calculation of average)

Discussion and evaluation

The measured speed of *longitudinal* sound should be consistent with a table value for the speed of sound in stainless steel.

The speed of propagation of *transverse* sound waves is somewhat lower. It depends to some extent on the dimensions of the material and is therefore more difficult to compare with an expected value.

By repeating the same measurement several times you gain an impression of the experimental uncer-tainty.

How much are the measured times scattered (for a fixed length and propagation type)?

Use (a copy of) the spreadsheet to estimate how much the measured value of the speeds can change when you alter the time values within the limits of the observed spread.

Specify this uncertainty of the speed values as a percentage.

Teacher's notes

Concepts used

Speed

Mathematical skills

(A spreadsheet is strongly recommended – especially for estimating the uncertainties)

Graph plotting
Slope of a line

Possibly: Standard deviation, etc.

In the *Discussion and evaluation* paragraph, the uncertainty of the time measurements is introduced in only semi-quantitative terms. If the students are familiar with the concept of standard deviation this could be used instead. Students with a profound knowledge of statistics could even calculate the resulting standard deviation of the speeds directly.

About the equipment

For both start and stop, the Student Timer reacts on the *first* change in voltage.

As soon as the display reads "Low bat." it is recommended that the batteries are changed. The precision will suffer when the battery voltage drops.

Detailed equipment list

Specifically for the experiment

200280	Student Timer (or older model 200260)

Standard lab equipment

000860	Retort stand rod 10 cm (Qty 3)
000850	Retort stand rod 25 cm (Qty 2)
000830	Retort stand rod 50 cm
000810	Retort stand rod 100 cm
000800	Retort stand rod 150 cm
002310	Bosshead, square (Qty 2)
001800	Stand clamp (Qty 2)
000600	Stand base, tripod, 1.0 kg (Qty 2)
004100	Stand base, square, 0.57 kg
105740	Safety cable 100 cm, black
105741	Safety cable 100 cm, red
105751	Safety cable 200 cm, red
109020	Insulated crocodile clip, Black
109021	Insulated crocodile clip, Red (2 stk.)
140010	Tape measure 200 cm

Spare parts and consumables

Rubber band – We have the following:

591050	Rubber bands, approx. 200 pcs.
351005	Battery LR6 1.5V [AA] (200280 use 6 at a time - included)