Heat conduction in solids

WT 2.2

The thermal conductivity of various metals and of glass are compared with each other. One side of rods bent into a U-shape are immersed in hot water. In the first part of the experiment, pieces of heat sensitive paper which turns red at approx. 40°C are stuck onto each rod, to demonstrate the conduction of heat. In the second part of the experiment, the warming up of a vessel on the other side of the rod shows that heat is transferred through a rod.

Materials

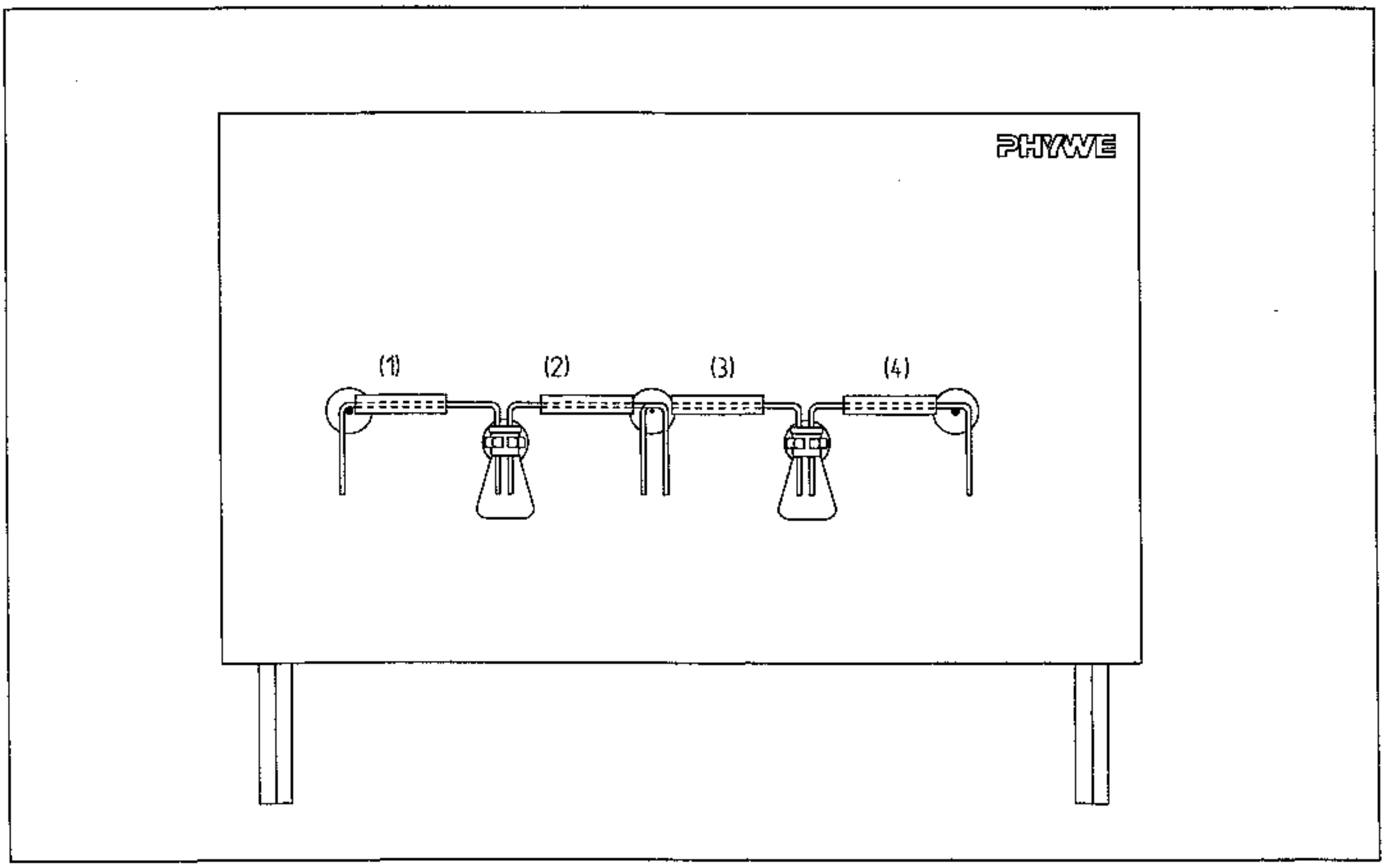
Demo-Board Physics	02150.00	1
Shaft with magnetic base	02151.02	1
Clip, d = 26 ... 36 mm, with magnetic base	02151.06	2
Clip, d = 0 ... 13 mm, with magnetic base	02151.07	2
Holder for hand-held measuring instruments, magnetic	02161.00	1
Holder for wire gauze, with magnetic base	02163.00	1
Wire gauze square, ceramic centre	33287.01	1
Beaker, polished	05903.00	2
Aluminium rod, U-shaped	05910.00	1
Copper rod, U-shaped	05910.01	1
Brass rod, U-shaped	05910.02	1
Glass rod, U-shaped	05911.00	1
Erlenmeyer flask, wide neck, 100 ml	36428.00	2
Silicone hose, i.d. 7 mm	39296.00	1
Funnel, plastic, dia. 50 mm	36890.00	1
Stop clock	03077.00	1
Heat sensitive paper, 5 sheets	04260.00	2
Immersion probe NiCr-Ni, 50/1000 C	13615.03	2
Hand-held measuring instrument 2xNiCr-Ni	07140.00	1
Digital large-scale display	07157.93	1
Data cable RS 232, SUB-D/USB	07157.01	1
Immersion heater, 300 W	05947.93	1
Aluminium pot, 500 ml	05933.00	1
Oven cloth		

1st Experiment: QUALITATIVE COMPARISON OF VARIOUS MATERIALS

Experimental set-up

— Two Erlenmeyer flasks serve as containers for hot water.
— Fix them to the board with 28...36 mm clips.
— Ease a piece of tubing over the shaft to insulate it.
— Position the two 0...13 mm clips and the shaft on the board as shown in Fig. 1, so that the cold ends of the U-shaped rods can lie on them.

Fig. 1: (1) copper, (2) aluminium, (3) brass, (4) glass



— Rest one side of the U-shaped rods on the rim of an Erlenmeyer flask and the other side on a clip or on the insulated shaft.
— Cut pieces from the heat sensitive paper and stick a piece on each of the rods (see Fig. 1), so that the students can observe the colour change.
— Remove the rods from the set-up and lay them on the bench, ready for use.

Procedure
— Fill the aluminium pot with water and heat it to boiling with the immersion heater.
— Carefully pour the boiling water through a funnel into the two Erlenmeyer flasks, filling them up to the brim.
— Simultaneously, or at least as quickly as possible, place the four rods next to each other on an Erlenmeyer flask and a second support in the succession: Glass, brass, aluminium, copper, i.e. starting with the material with the lowest thermal conductivity.
— Observe the colour change of the heat sensitive strips (these heat sensitive strips can be repeatedly used, as their colour change reverses on cooling).

Results
Table 1: Start of the red colouration

Material	Time taken
Copper	approx. 20 s
Aluminium	approx. 30 s
Brass	approx. 45 s
Glass	no red colouration

Table 2: Red colouration of the strips

Material	after approx 1.5 min	after approx. 3 min
Copper	three quarters	the whole length
Aluminium	more than half	three quarters, running thinly to the end
Brass	a quarter	a third
Glass	none at all	none at all

Evaluation
The colour of the heat sensitive paper changes from orange to red when the temperature increases above 40°C.
The heat spreads out at different speeds in the various rods. The heating up is made visible by the red colouration of the strips and is a measure of the thermal conductivity of the materials. When the materials are arranged from good to bad thermal conductivity, we obtain the following succession:
Copper – aluminium – brass – glass
The heat sensitive strips show also, in particular with aluminium and brass, that even after observing them for some time, there is a temperature gradient across the rods:
One side dips into hot water (temperature approx. 80°C) and in the region of the strips, the temperature changes from above 40°C to below 40°C.

2nd Experiment: TRANSFER OF HEAT

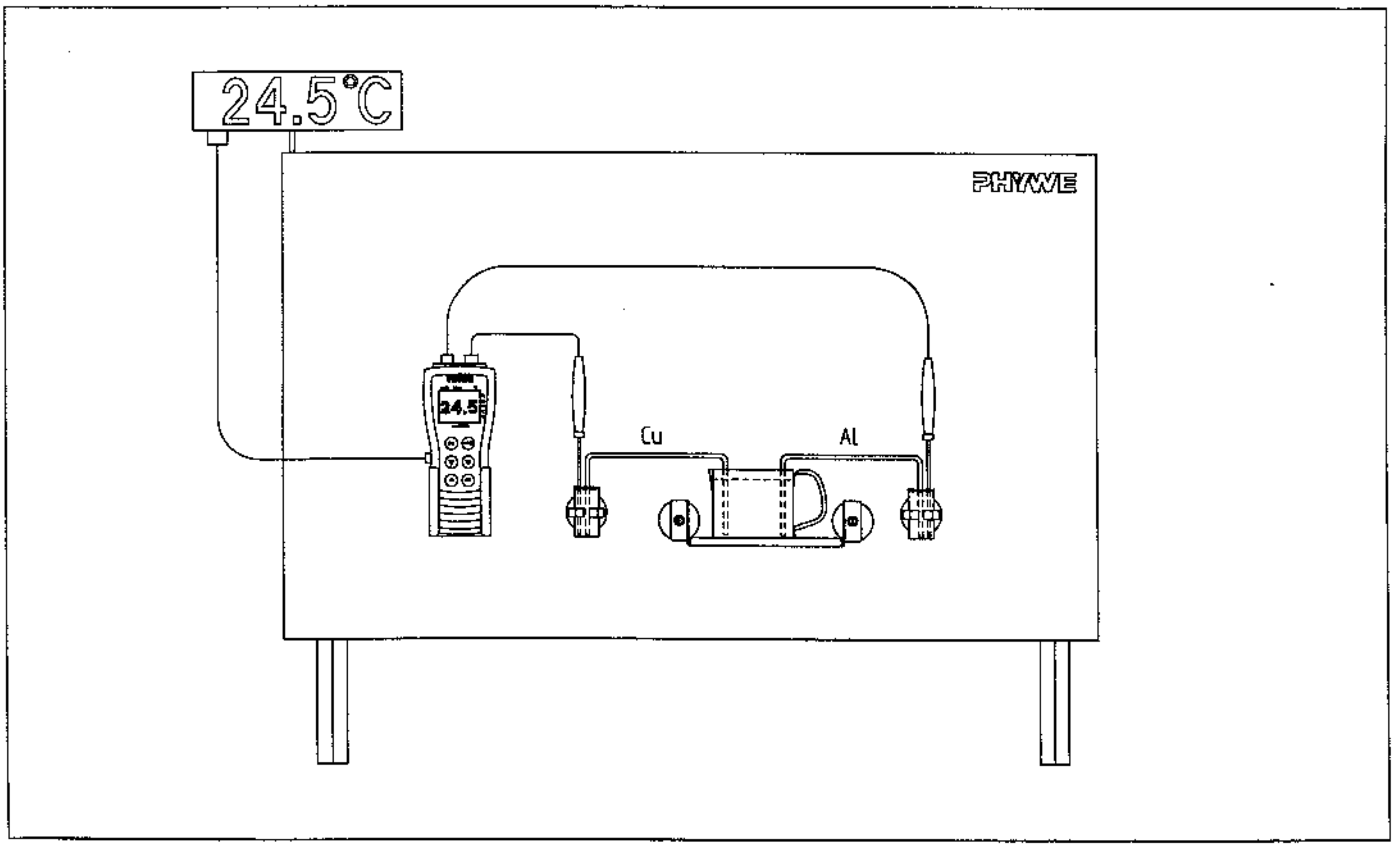
Experimental set-up

- Fix the holder for the wire gauze on the board, place the wire gauze on it and the empty aluminium pot on the gauze.
  Note:
  The holder for wire gauze is recommended as support for the aluminium pot with hot water rather than the shelf, as it has a stronger magnetic adhesion than the shelf.
- Use clips to fit the two polished beakers to the board, to the left and the right of the holder for wire gauze.
- Lay the U-shaped copper and aluminium rods each between the aluminium pot and a polished beaker (Fig. 2). The rods are used without heat sensitive paper in this experiment.
- Remove the rods from the set-up.
- Fill the two polished beakers up to approx. 2 mm from the rim with water.
- Use the magnetically attaching holder to fit the hand-held measuring instrument to the board. Connect the instrument to the large-scale display.
- Immerse the immersion probes in separate polished beakers and connect them to the measuring instrument.

Balancing the immersion probes:
NiCr-Ni thermoelements have an accuracy of approx. 3% when used to measure absolute temperatures, whereas they measure relative temperature changes with an accuracy of 0.1°C.
In order to start the measurements in the two beakers with the same display of temperature, the immersion probes must first be balanced against each other, or be set to a predetermined temperature, before starting the series of measurements (refer also to the operating instructions for the hand-held measuring instrument 07140.00).

- Press the <HOLD> key (until HOLD appears in the display)
- Press the <Δ> key (CAL appears in the display)
- Press the <HOLD> key (SET appears in the display)
- Use key <Δ> or <∇> to adjust the value in the large digital display (t_1) to the required value.
- Press the <CAL> key. A second temperature value (t_2) appears in the large digital display, again use key <Δ> or <∇> to adjust this value to the required value.
- Press the <CAL> key. Both temperature inputs are saved and the display returns to the normal measuring mode.

Fig. 2



Procedure

- First place the aluminium pot on the bench, fill it with water and bring the water to boiling with the immersion heater.
- Measure the initial temperatures in the polished beakers.
- Place the aluminium pot with hot water on the wire gauze.
- Lay the copper and aluminium rods as simultaneously as possible between the aluminium pot and a polished beaker, and start the stop clock.
- Measure the temperatures in the polished beakers after 5, 10 and 15 minutes.

Results

Table 3

Initial temperature 24.5°C

t/min	ϑCu/°C	ϑAl/°C	ΔϑCu/°C	ΔϑAl/°C
5	25.5	24.9	0	0
10	27.3	25.7	1.8	0.8
15	28.5	26.3	3.0	1.4

Evaluation

The temperatures in the polished beakers only increase slowly to start with, as the rods themselves must first heat up. The increase in temperature in the polished beakers is only a measure of the heat ΔQ which is transferred through the rod, when an (almost constant) temperature gradient has been formed. The change in temperature $\Delta\vartheta$ in the beakers is therefore calculated from the time $t = 5$ min on (see Table 3). The beakers contain the same amount of water m with the specific heat capacity c. We have:

$$\Delta Q = c \cdot m \cdot \Delta\vartheta \qquad (1)$$

The increase in temperature in the beaker with the copper rod is almost twice that in the beaker with the aluminium rod. The thermal conductivity of copper is therefore almost twice that of aluminium.

Note

The flow of energy $\Delta Q/\Delta t$ through a rod is dependent upon the thermal conductivity , the cross-sectional area A and the length of the rod λ, as well as on the difference in temperature (ϑ_w - ϑ_k) between the hot and cold sides of the rod.

$$\frac{\Delta Q}{\Delta t} = \lambda \cdot \frac{A}{l} (\vartheta_w - \vartheta_k) \qquad (2)$$

Table 4: The thermal conductivities of the materials used.

Material	λ/(W/mK)
Copper	384
Aluminium	220
Brass	111
Glass	1

The second part of the experiment shows, that heat is transferred through a metal rod, but only allows a rough comparison of the thermal conductivities of copper and aluminium.

For a quantitative determination of thermal conductivities, the rods must be thicker in comparison to their length and be insulated along their length to minimize heat losses. In addition, the temperature of the hot water must be kept constant. The Thermal Conductivity Measuring Apparatus (order no. 04518.01) is suitable for such determinations. It is supplied with thick, insulated copper and aluminium rods, and with two calorimeter vessels as heat storage tanks.