Thermal conduction coefficient of metals (Item No.: P1043200)

Curricular Relevance

Area of Expertise:	Education Level:	Topic:	Subtopic:	Experiment:
Physik	Klasse 7-10	Wärmelehre	Wärmetransport und Wärmedämmung	Wärmeleitungskoeffizie von Metallen

Difficulty	Preparation Time	Execution Time	Recommended Group Size
Intermediate	10 Minutes	10 Minutes	2 Students

Additional Requirements:

- Matches

Experiment Variations:

- with lab thermometer with stem

Keywords:

Task and equipment

Information for teachers

Additional Information

One end of a U-shaped metal rod is immersed in boiling water and the other in cold water. From the warming of the cold water qualitative and quantitative statements can be made about the influence of the rod's composition, length and diameter on the heat flow through it. Since the performance of the experiment is time consuming, the individual measurements should be carried out by different groups of students: a least 4 teams should be formed. Each team performs the experiment with only one rod; for the evaluation the results of all the groups are pooled.

Remarks

1. The glass and metal beaker should be placed so that the metal rod can be easily laid across them when the water boils. Before the water boils the rod is, however, not in this position!
2. When reading the temperature, values which do not fall exactly on one of the marks should be estimated to the nearest 0.5 °C.
3. The water in the metal beaker must be stirred regularly.
4. For this experiment a thermometer with 1/10-degree-divisions is recommended as very small temperature differences must be determined. A suitable thermometer is on the Material page.

Suggestions for evaluation

With these questions a quantitative confirmation of the formula for the heat flow can be attained.
We have dispensed with the calculation of the specific thermal conductivity because the results are subject to large errors for the reasons given below.

The heat flow through a metal rod depends on its length, its cross sectional area and the difference in temperatures on the two ends of the rod. The proportionality factor is the specific thermal conductivity λ of the material.

$$\Delta Q/\Delta t = \lambda \cdot (\vartheta_w - \vartheta_k) \cdot (A/l) = \lambda \cdot (\vartheta_w - \vartheta_k) \cdot (\pi/4) \cdot (d^2/l)$$

where
$\Delta Q/\Delta t$ = heat flow through the rod
ϑ_w = temperature of the boiling water
ϑ_k = temperature of the cold water
l = length of the rod

Robert-Bosch-Breite 10
D - 37079 Göttingen

Tel: +49 551 604 - 0
Fax: +49 551 604 - 107

info@phywe.de
www.phywe.com

A = cross sectional area of the rod
d = diameter of the rod

The dependence of the heat flow on d^2 and on $1/l$ can be strikingly shown using the measuring results of the students. A copper rod with d_0 = 5 mm and b_0 = 175 mm is used as the control rod.

Calculation of the specific thermal conductivity

Example:
To determine *λ* for the copper rod (*d* = 5 mm, *b* = 175 mm), the heat flow Δ*Q*/Δ*t* was determined for the steepest part of the curve (between t_1 = 2 min and t_2 = 7 min) in the chart.

$\Delta Q/\Delta t = c \cdot m \cdot \Delta\vartheta$

where
$\vartheta/\Delta t$ = 2 °C/120 s
c = 4,19 J/g°C
m = 20 g
yields
Δ*Q*/Δ*t* = 1,40 J/s.
When ϑ_W = 100 °C and ϑ_K = 24 °C, we obtain *λ* = 244 J/m°C.

Literature values for specific thermal conductivity are:
Copper: 384 J/m°C
Aluminium: 220 J/m°C

The deviation of the value determined with our measurement from the literature value is relatively large since the rod is very thin in relation to its length and, consequently, radiates a great deal of heat to its surroundings. The comparison of the rods under the same experimental conditions is however relatively successful: the specific heat conductivity of aluminium is slightly more than half as large as that of copper. This is also the result supplied by the measurement.

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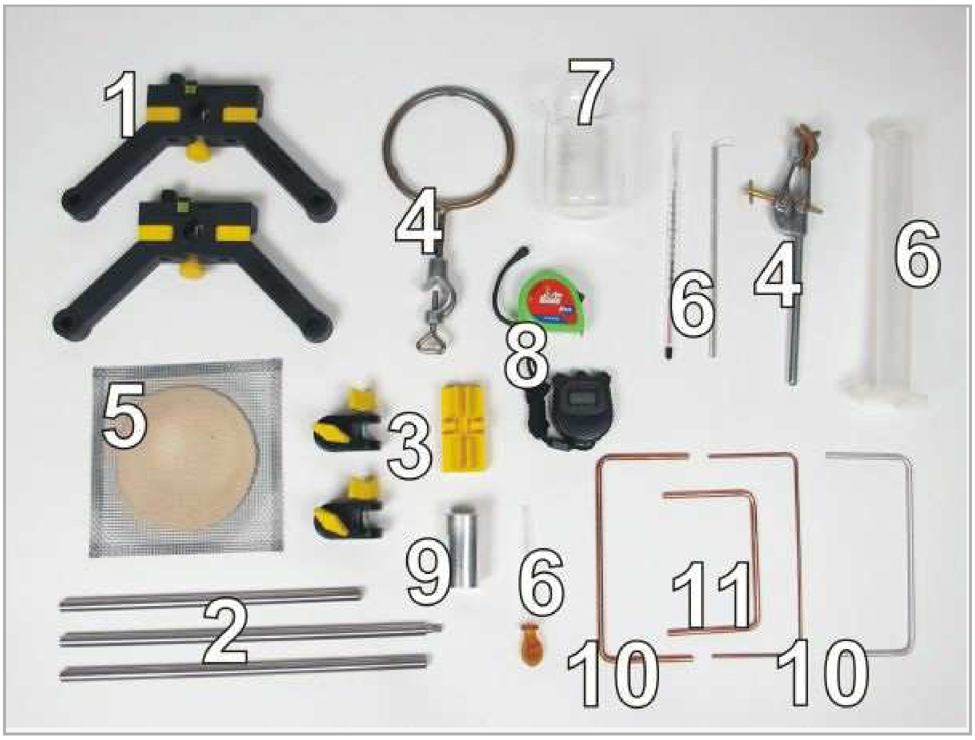
Task and equipment

Task

How is heat transported in metals?

Investigate the conduction of heat in metals as a function of the material and the dimensions of the rod.
To do so lay a metal rod between two beakers – one with hot and the other with cold water, then measure the temperature changes in the hot water.

Equipment



Position No.	Material	Order No.	Quantity
1	Support base, variable	02001-00	1
2	Support rod, stainless steel, l = 250 mm, d = 10 mm	02031-00	1
2	Support rod, stainless steel, l = 600 mm, d = 10 mm	02037-00	1
3	Boss head	02043-00	2
3	Glass tube holder with tape measure clamp	05961-00	1
4	Ring with boss head, i. d. = 10 cm	37701-01	1
4	Universal clamp	37715-00	1
5	Wire gauze with ceramic, 160 x 160 mm	33287-01	1
6	Agitator rod	04404-10	1
6	Pipette with rubber bulb	64701-00	1
6	Graduated cylinder 100 ml, PP transparent	36629-01	1
6	Students thermometer,-10...+110°C, l = 180 mm	38005-02	1
7	Glass beaker DURAN®, short, 250 ml	36013-00	1
8	Measuring tape, l = 2 m	09936-00	1
8	Stop watch 4	03078-00	1
9	Beaker, aluminum, polished	05903-00	1
10	Aluminium rod,U-shaped	05910-00	1
10	Copper rod, U-shape,d 3mm,w.175mm	05910-03	1
10	Copper rod, U-shaped	05910-01	1
11	Copper rod, U-shape,d.5mm,w.120mm	05910-04	1
	Butane burner, Labogaz 206 type	32178-00	1
	Butane cartridge C206, without valve	47535-01	1
	Boiling beads, 200 g	36937-20	1
Additional material			
	Matches		
As an alternative	(Additional Information on the Task page)		
	Lab thermometer with stem 50 mm, +15...+40 °C		1

Set-up and procedure

Set-up

Attention!

1. The U-shaped rods are hot at the end of the experiment!
2. When reading the thermometer, the temperatures should be estimated to the nearest 0.5 °C.

Setup

- Set up the support stand according to the following pictures.

Fig. 1

Fig. 2

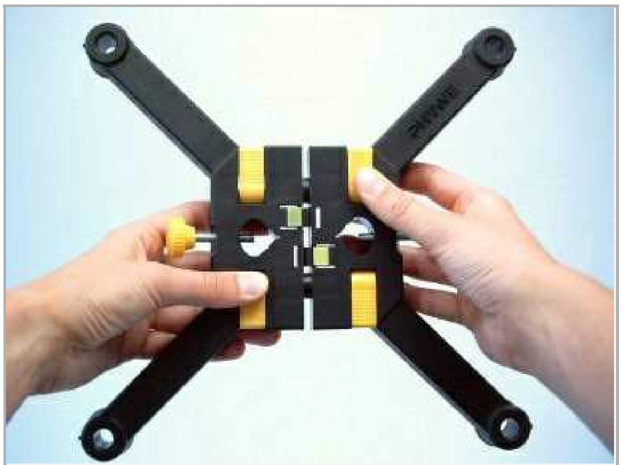


Fig. 3


Fig. 4a


Fig. 4b


Fig. 5


Fig. 6

- Pour 200 ml of water into the 250 ml beaker and drop two beads into it.


Fig. 7


Fig. 8

- Adjust the position of the support ring and the polished beaker so that you can lay the U-shaped rod which is to be tested between the two beakers.


Fig. 9


Fig. 10


Fig. 11


Fig. 12

- Clamp the thermometer so that its bulb is about 1 cm above the bottom of the polished beaker.


Fig. 13

Procedure

- The metal rod should not yet be laid between the glass and the polished beaker.
- Heat the water in the glass beaker to a boil and then reduce the size of the flame somewhat.
- Note the material, thickness d and length b of the metal rod which is to be measured above Table 1 in the report.
- Pour 20 ml cold water in the metal beaker (exact measurement with the graduated cylinder and the pipette!).


Fig. 14

- Measure the water temperature in the metal beaker and note it in Table 1 under t = 0 min.
- Hang the metal rod with one of its ends in the boiling water and the other in the metal beaker which contains cold water. Start the stop watch.
- Stir the water in the metal beaker frequently.
- Measure and record the water temperature in the metal beaker at one minute intervals.
- End the measurement series after 12 min.

Report: Thermal conduction coefficient of metals

Result – Table 1

Note down the water temperature ϑ at the indicated times.

Material	Cu	Al	Cu	Cu
Diameter d	5 mm	5 mm	3 mm	5 mm
Length b	175 mm	175 mm	175 mm	120 mm
t in min	ϑ in °C	ϑ in °C	ϑ in °C	ϑ in °C
0	1 ±0	1 ±0	1 ±0	1 ±0
1	1 ±0	1 ±0	1 ±0	1 ±0
2	1 ±0	1 ±0	1 ±0	1 ±0
3	1 ±0	1 ±0	1 ±0	1 ±0
4	1 ±0	1 ±0	1 ±0	1 ±0
5	1 ±0	1 ±0	1 ±0	1 ±0
6	1 ±0	1 ±0	1 ±0	1 ±0
7	1 ±0	1 ±0	1 ±0	1 ±0
8	1 ±0	1 ±0	1 ±0	1 ±0
9	1 ±0	1 ±0	1 ±0	1 ±0
10	1 ±0	1 ±0	1 ±0	1 ±0
11	1 ±0	1 ±0	1 ±0	1 ±0
12	1 ±0	1 ±0	1 ±0	1 ±0

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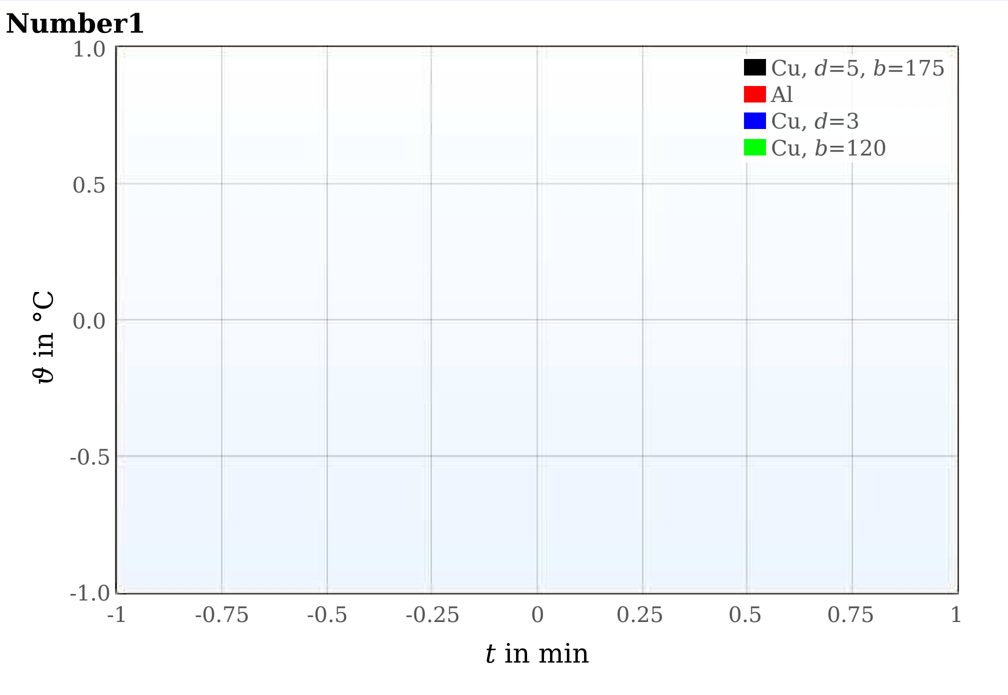

Evaluation – Question 1

Why does the temperature only rise slightly in the first few minutes?

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Evaluation – Question 2

How large is the temperature increase $\Delta\vartheta$ in the period of time between t_1 = 2 min and t_2 = 12 min? Complete the table.

Material	*d* in mm	*b* in mm	$\Delta\vartheta$ in °C
Cu	5	175	1 ±0
Al	5	175	1 ±0
Cu	3	175	1 ±0
Cu	5	120	1 ±0

Evaluation – Question 3

Which metal conducts heat better?

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Evaluation – Question 4

Which dimensions of a metal rod influence the quantity of heat which the rod conducts?

Evaluation – Question 5

Formulate the relationship between the dimensions of the rod and the quantity of heat in a "the.....the" statement.

Evaluation – Additional Task 1

$l = b + s_1 + s_2$

Using this value complete the table (all values with the Index 0 apply to the control rod! The value for Δϑ should be taken from Question 2).

Material	d in mm	b in mm	l in mm	$(d/d_0)^2$	l_0/l	Δϑ in °C	Δϑ / (Δϑ)$_0$
Cu			1 ±0			1 ±0	
Al			1 ±0			1 ±0	1 ±0
Cu			1 ±0			1 ±0	1 ±0
Cu			1 ±0		1 ±0	1 ±0	1 ±0

Evaluation – Additional Task 2

Express the correlation between heat flow (heat unit per time unit) through the rod and its dimensions as a proportionality.

Evaluation – Additional Task 3

What is the influence of the temperature difference between the two ends of the rod on the heat flow through it? (If necessary, conduct a suitable experiment by placing one end of the rod directly in a flame instead of placing it in boiling water and then measure the temperature increase of the cold water. Be careful! The rod becomes very hot!)

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