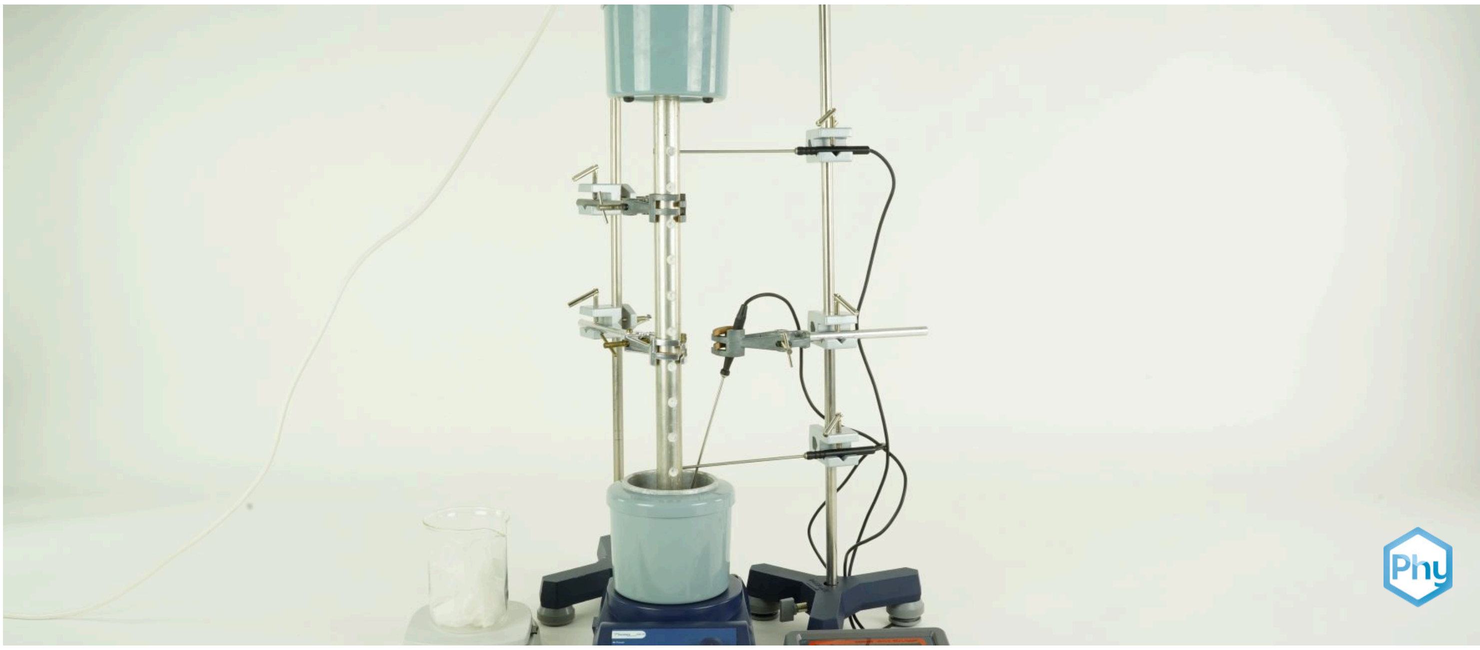
# Thermal conductivity of metals



| | | | |
|---|---|---|---|
| Physics | Thermodynamics | Temperature & Heat | |
| Physics | Thermodynamics | Heat energy, thermal capacity | |
| Applied Science | Engineering | Materials Science | Thermal & Electrical Properties |
| Applied Science | Engineering | Renewable Energy | Basic Principles |

| Difficulty level | Group size | Preparation time | Execution time |
|---|---|---|---|
| medium | 2 | 45+ minutes | 45+ minutes |

This content can also be found online at:

http://localhost:1337/c/6006e68293e22500031f5bae

# General information

## Application

Fig. 1: Experimental set-up

Thermal conductivity of metals has many applications in applienses such as heat sinks.



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## Other information (1/2)

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**Prior knowledge**

The prior knowledge for this experiment is found in the Theory section.

**Main principle**

The thermal conductivity of copper and aluminium is determined in a constant temperature gradient from the calorimetrically measured heat flow.

## Other information (2/2)

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**Learning objective**

The goal of this experiment is to investigate the thermal conductivity of copper and aluminium.

**Tasks**

1. Determine the heat capacity of the calorimeter in a mixture experiment as a preliminary test. Measure the calefaction of water at a temperature of 0 °C in a calorimeter due to the action of the ambient temperature as a function of time.
2. To begin with, establish a constant temperature gradient in a metal rod with the use of two heat reservoirs (boiling water and ice water) After removing the pieces of ice, measure the calefaction of the cold water as a function of time and determine the thermal conductivity of the metal rod.



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## Safety instructions

**Caution:**
**Keep the water level such, that the immersion heater is always sufficiently immersed, keep refilling evaporated water during the experiment – the heater will be destroyed by overheating, if the water level is too low.**

## Theory (1/2)

If a temperature difference exists between different locations of a body, heat conduction occurs. In this experiment there is a one-dimensional temperature gradient along a rod. The quantity of heat dQ transported with time dt is a function of the cross-sectional area A and the temperature gradient dT/dx perpendicular to the surface.

$$\frac{\mathrm{d}Q}{\mathrm{d}t} = -\lambda A \cdot \left(\frac{\partial T}{\partial x}\right) \quad (1)$$

The temperature distribution in a body is generally a function of location and time and is in accordance with the Boltzmann transport equation

$$\frac{\partial T}{\partial t} = \frac{\lambda}{\rho \cdot c} \cdot \left(\frac{\partial^2 T}{\partial x^2}\right) \quad (2)$$

Where $\rho$ is the density and c is the specific heat capacity of the substance.



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# Theory (2/2)

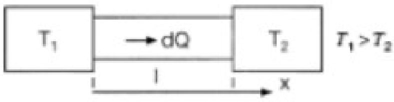
After a time, a steady state

$\frac{\partial T}{\partial t} = 0$ (3)

is achieved if the two ends of the metal rod having a length l are maintained at constant temperatures $T_1$ and $T_2$. respectively, by two heat reservoirs.

Substituting equation (3) in equation (2), the following equation is obtained:

$T(x) = \frac{T_2 - T_1}{l} \cdot x + T_1$ (4)



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# Equipment

| Position | Material | Item No. | Quantity |
|---|---|---|---|
| 1 | Calorimeter vessel, 500 ml | 04401-10 | 1 |
| 2 | Calor.vessel w.heat conduct.conn. | 04518-10 | 1 |
| 3 | Heat conductivity rod, Cu | 04518-11 | 1 |
| 4 | Heat conductivity rod, Al | 04518-12 | 1 |
| 5 | Temperature meter digital, 4-2 | 13618-00 | 1 |
| 6 | Universal power supply, 600mA 3/4.5/5/6/7.5/9/12V, incl. 9 adaptors | 11078-99 | 1 |
| 7 | Immersion probe NiCr-Ni, steel, -50...400 °C | 13615-03 | 1 |
| 8 | Surface probe NiCr-Ni -50...300°C | 13615-04 | 2 |
| 9 | Immers.heater,300W,220-250VDC/AC | 05947-93 | 1 |
| 10 | Magnetic stirrer without heating, 3 ltr., 230 V | 35761-99 | 1 |
| 11 | Magnetic stirring bar 30 mm, cylindrical | 46299-02 | 1 |
| 12 | Heat conductive paste, 60 g | 03747-00 | 1 |
| 13 | Gauze bag | 04408-00 | 1 |
| 14 | Digital stopwatch, 24 h, 1/100 s and 1 s | 24025-00 | 1 |
| 15 | Tripod base PHYWE | 02002-55 | 2 |
| 16 | Support rod, stainless steel, 750 mm | 02033-00 | 1 |
| 17 | Support rod, stainless steel, 1000 mm | 02034-00 | 1 |
| 18 | Universal clamp | 37715-01 | 4 |
| 19 | Right angle clamp expert | 02054-00 | 6 |
| 20 | Beaker, Borosilicate, low-form, 400 ml | 46055-00 | 1 |
| 21 | Portable Balance, OHAUS CX2200 | 48921-00 | 1 |



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# Setup and Procedure

## Procedure (1/5)

1. Measurement of the heat capacity of the lower calorimeter
   - Weigh the calorimeter at room temperature.
   - Measure and record the room temperature and the temperature of the preheated water provided.
   - After filling the calorimeter with hot water, determine the mixing temperature in the calorimeter.
   - Reweigh the calorimeter to determine the mass of the water that it contains.
   - Calculate the heat capacity of the calorimeter.
   - Determine the influence of the heat of the surroundings on the calefaction of the water (0 °C without pieces of ice) by measuring the temperature change in a 30-minute period.



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## Procedure (2/5)

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2. Determination of the thermal conductivity

- Perform the experimental set-up according to Fig. 1.
- Weigh the empty, lower calorimeter.
- Insert the insulated end of the metal rod into the upper calorimeter vessel. To improve the heat transfer, cover the end of the metal rod with heat-conduction paste.
- Attach the metal rod to the support stand in such a manner that the lower calorimeter can be withdrawn from beneath it.
- The height of the lower calorimeter can be changed with the aid of the supporting block. When doing so, care must be taken to ensure that the non-insulated end of the rod remains completely immersed in the cold water during the experiment.

## Procedure (3/5)

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- The surface temperature probe must be positioned as close to the rod as possible.
- The outermost indentations on the rod (separation: 31.5 cm) are used to measure the temperature difference in the rod. To improve the heat transfer between the rod and the surface probe, use heat-conduction paste.
- Using an immersion heater, bring the water in the upper calorimeter to a boil, and keep it at this temperature.

**Caution: Keep the water level such, that the immersion heater is always sufficiently immersed, keep refilling evaporated water during the experiment – the heater will be destroyed by overheating, if the water level is too low.**



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## Procedure (4/5)

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- Ensure that the upper calorimeter is well filled to avoid a drop in temperature due to contingent refilling with water.
- Keep the water in the lower calorimeter at 0°C with the help of ice (in a gauze pouch).
- The measurement can be begun when a constant temperature gradient has become established between the upper and lower surface probes, i.e. when no changes occur during the differential measurement.
- At the onset of measurement, remove the ice from the lower calorimeter.
- Measure and record the change in the differential temperature and the temperature of the water in the lower calorimeter for a period of 5 minutes.
- Weigh the water-filled calorimeter and determine the mass of the water. Settings of the temperature measuring device 4-2:

## Procedure (5/5)

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In the first display on the measuring device, the temperature of the lower calorimeter is displayed.

In the second display, the differential measurement between the upper and the lower surface probe is shown.

- The thermal conductivity of different metals can be determined from the measuring results.



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# Evaluation

## Task 1

The heat capacity of the calorimeter is obtained from results of the mixing experiment and the following formula:

$C = c_{\mathrm{W}} \cdot m_{\mathrm{W}} \cdot \left( \frac{\vartheta_{\mathrm{W}} - \vartheta_{\mathrm{M}}}{\vartheta_{\mathrm{M}} - \vartheta_{\mathrm{R}}} \right)$ (5)

$c_W$ = Specific heat capacity of water, $m_W$ = Mass of the water, $\vartheta_W$ = Mass of the water, $\vartheta_W$ = Mixing temperature, $\vartheta_R$ = Room temperature

The measurement supplies a value of approximately 78 J/K $\pm$25%. The large variations in the results are a result of the manner in which the experiment is performed and of the experimental set-up.

The addition of heat from the surroundings is calculated from the temperature increase ΔT of the cold water in the calorimeter.

$\Delta Q = (c_{\mathrm{W}} \cdot m_{\mathrm{W}} + C) \cdot \Delta T$ (6) $T_0$ = Temperature at time t = 0



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## Task 2 (1/4)

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The heat energy supplied to the lower calorimeter can be calculated using Equation (6). The values and the change in the temperature difference on the metal rod are plotted as a function of time.

In the diagram illustrating the temperature difference, one can see that the temperature essentially remains constant. Consequently, equation 3 can be considered as having been satisfied. In order to calculate the heat energy transported by the metal rod according to Equation 1, the ambient heat fraction must be subtracted.

$$\frac{\mathrm{d}Q_{\mathrm{rod}}}{\mathrm{d}t} = \frac{\mathrm{d}Q_{\mathrm{tot}}}{\mathrm{d}t} - \frac{\mathrm{d}Q_{\mathrm{surr}}}{\mathrm{d}t} \quad (7)$$

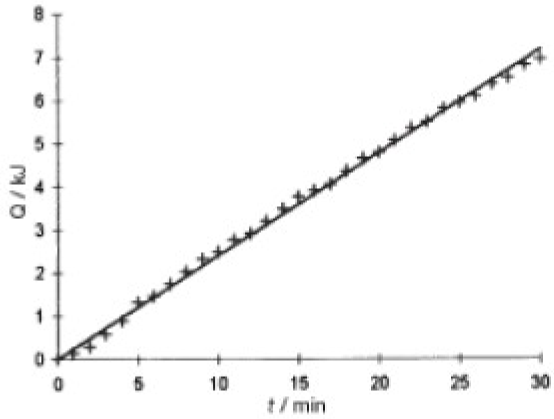


Fig. 2: Diagram: Heat of surroundings over time.

## Task 2 (2/4)

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dQ/dt for the ambient heat can be calculated from the slope of the graph in Fig. 2. dQ/dt for the entire set-up can be calculated from the slope of the graph of Q over t in Figs. 3 and 4. With the values for the length of the rod (Δx = 31.5 cm), the area (A = $4.91 \cdot 10^{-4}\ \mathrm{m}^2$ and the averaged temperature on the metal rod, the heat conduction number can be calculated using Equation (1). The following result as the average values:

$\lambda_{\mathrm{Al}}$ = 254 W/Km, $\lambda_{\mathrm{Cu}}$ = 447 W/Km

The literature values are: $\lambda_{\mathrm{Al}}$ = 220 W/Km, $\lambda_{\mathrm{Cu}}$ = 384 W/Km



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## Task 2 (3/4)

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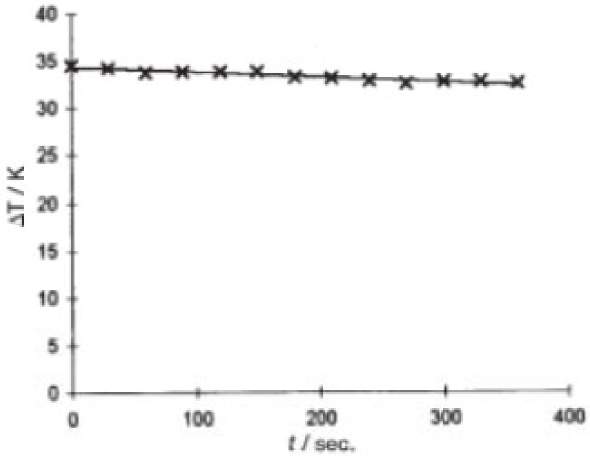


Fig. 3a: ΔT as function of time for aluminium.

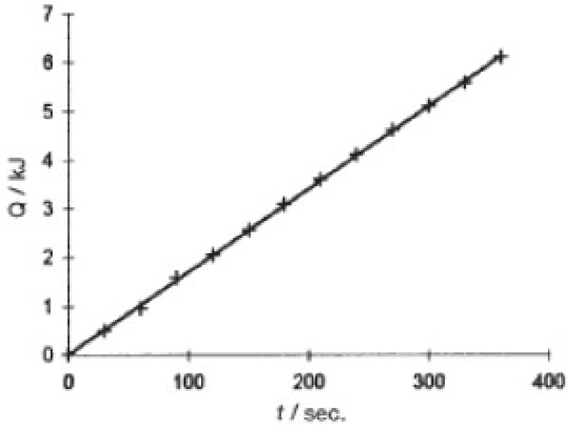


Fig. 3b: *Q* as a function of time for aluminium.

## Task 2 (4/4)

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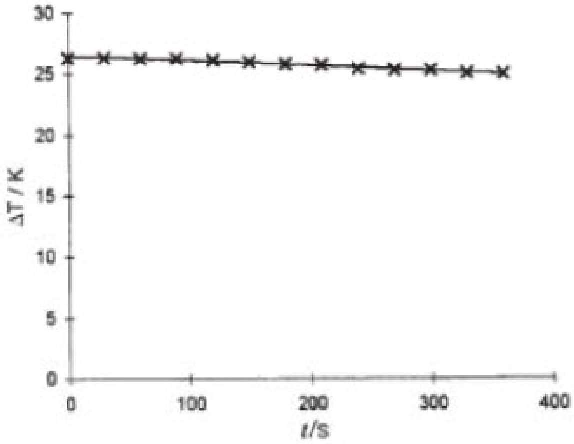


Fig. 4a: ΔT as function of time for copper.

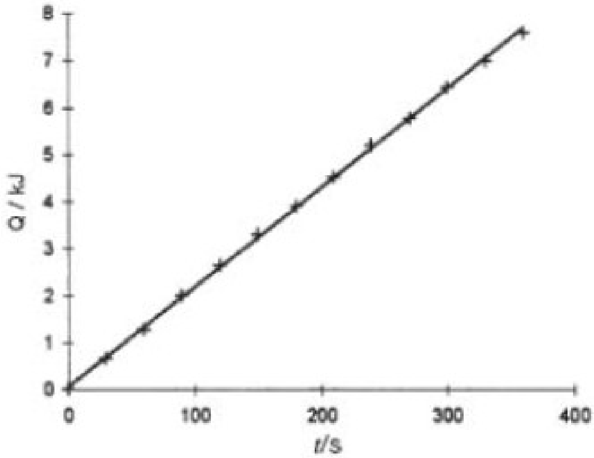


Fig. 4b: *Q* as a function of time for copper.



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