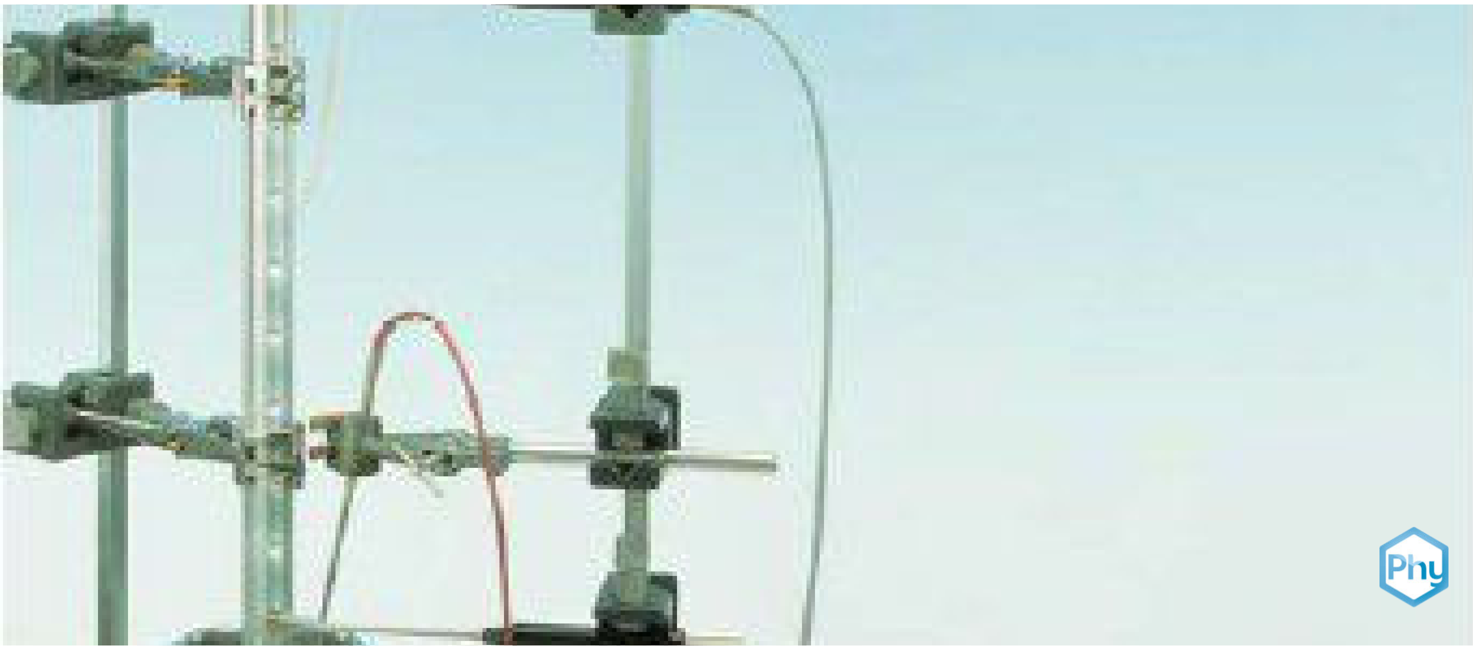
Electrical conductivity of metals



Physics | Electricity & Magnetism | Electric current & its effects

Applied Science | Engineering | Materials Science | Thermal & Electrical Properties

Applied Science | Engineering | Renewable Energy | Basic Principles

Applied Science | Engineering | Photonics | Basic Principles

Difficulty level	Group size	Preparation time	Execution time
easy	2	45+ minutes	45+ minutes

This content can also be found online at:

http://localhost:1337/c/6006ebcb93e22500031f5bbf

General information

Application

Fig. 1: Experimental set-up

Electrical conductivity of metals has many applications in electro technics.

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Other information (1/2)

Prior knowledge

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

Main principle

The electrical conductivity of copper and aluminium is determined, and the Wiedmann-Franz law is tested.

Other information (2/2)

Learning objective

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

Tasks

1. Determine the electrical conductivity of copper and aluminium by recording a current-voltage characteristic line.
2. Test of the Wiedemann-Franz law.

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Safety instructions

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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)

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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 ρ is the density and c is the specific heat capacity of the substance.

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Theory (2/2)

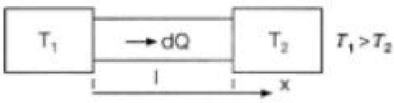
After a time, a steady state

$\frac{\partial T}{\partial t} = 0$ (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	Heat conductivity rod, Cu	04518-11	1
2	Heat conductivity rod, Al	04518-12	1
3	Rheostat, 10 Ohm , 5.7A	06110-02	1
4	PHYWE Multitap transformer DC: 2/4/6/8/10/12 V, 5 A / AC: 2/4/6/8/10/12/14 V, 5 A	13533-93	1
5	Digital multimeter, 600V AC/DC, 10A AC/DC, 20 MΩ, 200 µF, 20 kHz, −20°C… 760°C	07122-00	2
6	PHYWE Universal measuring amplifier	13626-93	1
7	Connecting cord, 32 A, 500 mm, red	07361-01	3
8	Connecting cord, 32 A, 500 mm, blue	07361-04	4
9	Connecting cord, 32 A, 1000 mm, red	07363-01	1

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Setup and Procedure

Procedure (1/2)

- Perform the experimental set-up according to the circuit diagram in Fig. 2 (set-up in accordance with a 4-conductor measuring method).
- Set the voltage on the variable transformer to 6 V.
- The amplifier must calibrated to 0 in a voltage-free state to avoid a collapse of the output voltage.
- Select the amplifier settings as follows:
  Input: Low Drift
  Amplification: 10^4
  Time Constant: 0

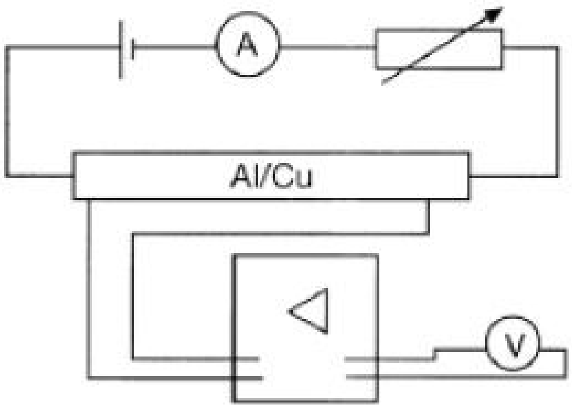

Fig. 2: Circuit diagram.

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Procedure (2/2)

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- Set the rheostat to its maximum value and slowly decrease the value during the experiment.
- Read and note the values for current and voltage
- The resistance, and thus the electrical conductivity, can be determined from the measured values.

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Evaluation

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Task 1 (1/2)

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At room temperature the conduction electrons in metal have a much greater mean free path than the phonons. For this reason heat conduction in metal is primarily due to the electrons. The resulting correlation between the thermal conductivity λ and the electrical conductivity σ is established by the Wiedemann-Franz law:

$\frac{\lambda}{\sigma} = LT$ (5)

The Lorenz number L, which can be experimentally determined using Equation (5), is established by the theory of electron vapour (for temperatures above the Debye temperature) to be:

$L = \frac{\pi^2}{3} \cdot \left(\frac{k^2}{e^2}\right) = 2.4 \cdot 10^{-8} \frac{\mathrm{W\Omega}}{\mathrm{K}^2}$ (6)

k = Universal gas constant = $1.38 \cdot 10^{-23}$ J/K, e = Elementary unit charge = $1.602 \cdot 10^{-19}$ AS

Task 1 (2/2)

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The electrical conductivity is determined by the resistance R of the rod and its geometric dimensions (l = 0.315 m,A = $4.91 \cdot 10^{-4}$ m^2).

$\sigma = \frac{l}{A \cdot R}$ (6)

From Equation (5) the following values result for T = 300 K and the λ from the second part of the experiment.

	R [10^{-6} Ω]	σ [10^7 $(\Omega\mathrm{m})^{-1}$]	L [10^{-8} $\mathrm{W\Omega K}^{-2}$]
Al	19.6	3.27	2.5
Cu	12.04	5.33	2.35

The Debye temperatures of copper and aluminium are 335 K and 419 K, respectively. Below the Debye temperature the ratio of the conductivity is smaller than given by Equation (5).

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