Electricity

Transport of Charge and Current

PHYSICS EXPERIMENT

Electrical Conductors

DETERMINE THE ELECTRICAL CONDUCTIVITY OF COPPER AND ALUMINIUM

- **Measure voltage drop *U* as a function of distance d between contact points at a constant current *I*.**
- **Measure voltage drop U as a function of current *I* for a fixed distance *d* between contact points.**
- **Determine the electrical conductivity of copper and aluminium and make a comparison with values quoted in literature.**

UE3020200

07/16 UD

Fig. 1: Experiment set-up

GENERAL PRINCIPLES

Electrical conductivity of a material is highly dependent on the nature of the material. It is defined as the constant of proportionality between the current density and the electric field in the respective material. In metals it is determined by the number density and mobility of electrons in the conduction band and is also dependent on temperature.

For a long metal conductor of cross-sectional area *A* and length *d*, a relationship between current *I* through the conductor and the voltage *U* which drops over a distance *d* along it can be deduced from the following formula:

(1) $j = \sigma \cdot E$

j: current density, *E*: electric field

That relationship is as follows:

(2) $I = j \cdot A = A \cdot \sigma \cdot \frac{U}{d}$

In the experiment, this relationship is used to determine the conductivity of metal bars using four-terminal sensing (Fig. 2). This involves feeding in a current *I* through two wires and measuring the drop in voltage *U* between two contact locations separated by a distance *d*. Since the area of the cross section *A* is known, it is possible to calculate the conductivity σ.

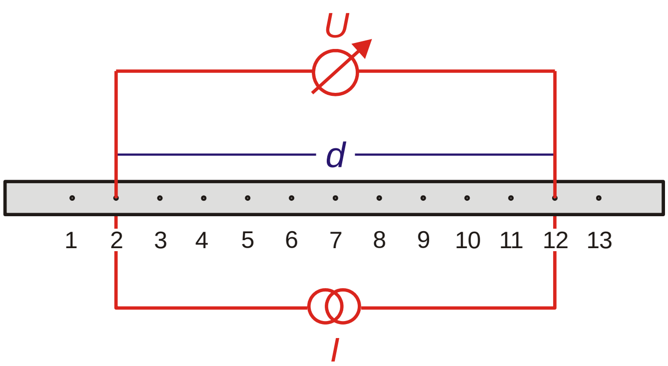

Fig. 2: Schematic of four-terminal sensing measurement

LIST OF EQUIPMENT

1	Heat Conducting Rod Al	1017331 (U8498292)
1	Heat Conducting Rod Cu	1017330 (U8498291)
1	DC Power Supply 1 - 32 V, 0 – 20 A @230V	1012857 (U11827-230)
or		
1	DC Power Supply 1 – 32 V, 0 – 20 A @115V	1012858 (U11827-115)
1	Microvoltmeter @230V	1001016 (U8530501-230)
or		
1	Microvoltmeter @115V	1001015 (U8530501-115)
1	Digital Multimeter E	1006809 (U8531050)
1	Set of 15 Experiment Leads 2.5 mm²	1002841 (U13801)

SET-UP

- Put the copper or aluminium heat conducting rod on an insulated surface.
- Connect the "–" output socket on the back of the power supply to the hole in the side of the conducting rod level with the second measuring point (Fig. 2). Connect the "+" output socket on the back of the power supply to the hole in the side of the conducting rod level with the twelfth measuring point. Connect the digital multimeter in series between them for the purpose of measuring voltage.
- Short the input to the microvoltmeter and calibrate the display to 0 with the help of the DC offset knob. Check the zero calibration regularly in the course of your measurements.
- Connect two measuring probes to the 4-mm safety sockets of the microvoltmeter.
- Set the upper limit of the frequency on the microvoltmeter to "OFF" by means of the "Filter Hz" knob and select a measuring of up to 200 μV DC.

EXPERIMENT PROCEDURE

Notes:
Take care not to exceed the maximum current capacity of the power supply, 20 A.

Thermo-electric voltages at the measurement points could restrict the accuracy of the measurements.

The relative distance between adjacent measurement points is $d_{N+1} - d_N = 4$ cm, i.e. $d_{N+k} - d_N = k \cdot 4$ cm.

Dependence on distance

- Set up the power supply such that a current I of about 10 A flows through the conduction rod. Read off the value from the multimeter and write it down.
- Make contact between the measuring probe connected to the ground socket of the microvoltmeter and the second measurement point (N = 2).
- Use the other probe to make contact with the third to twelfth measurement points in sequence, read off the voltage U for each one and enter the results into Table 1.

Dependence on current

- Use the power supply to increase the current from 1 A to 10 A in steps of 1 A. Read off the current values for each step from the multimeter and enter them into Table 2.
- At each step, measure the voltage between the 2nd and 12th measurement points (d = 40 cm) with the measuring probes (take care with the polarity). Read off the values from the microvoltmeter and enter them into Table 2.

SAMPLE MEASUREMENT

Table 1: Voltages measured as a function of the distance between measurement points, I = 9.92 A (copper) and 9.90 A (aluminium).

N	$d = d_N - d_2$	U / μV	
		Copper	Aluminium
3	4 cm	15,2	37,3
4	8 cm	29,1	75,6
5	12 cm	40,7	113,8
6	16 cm	58,6	151,2
7	20 cm	69,6	187,4
8	24 cm	82,5	231,0
9	28 cm	98,4	266,0
10	32 cm	113,9	303,0
11	36 cm	128,6	345,0
12	40 cm	140,7	382,0

Table 2: Voltage measured as a function of current, d = 40 cm.

Copper		Aluminium	
I / A	U / μV	I / A	U / μV
1,01	14,4	1,01	40,5
2,00	27,5	2,00	80,7
2,99	41,3	2,99	118,6
3,99	52,5	4,00	154,7
4,99	67,3	4,99	194,6
5,99	82,5	5,99	230,0
6,99	95,4	6,99	269,0
7,99	112,7	7,99	312,0
8,99	128,3	8,99	344,0
9,91	139,7	9,91	382,0

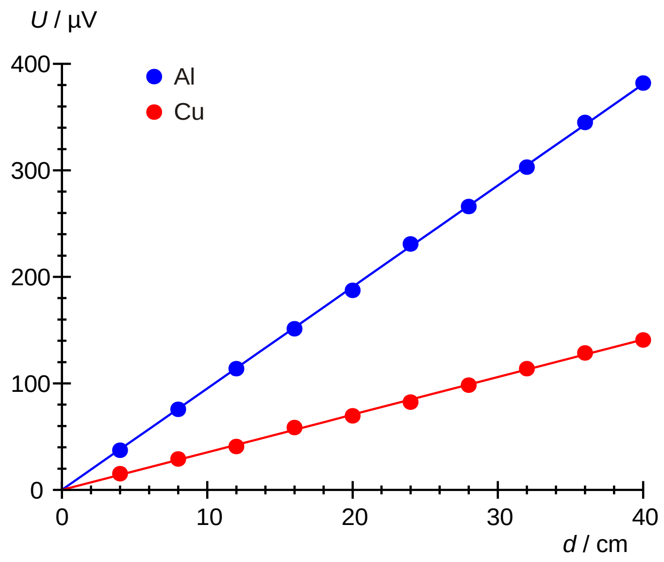

Fig. 3: Plot of *U* against *d* for copper and aluminium

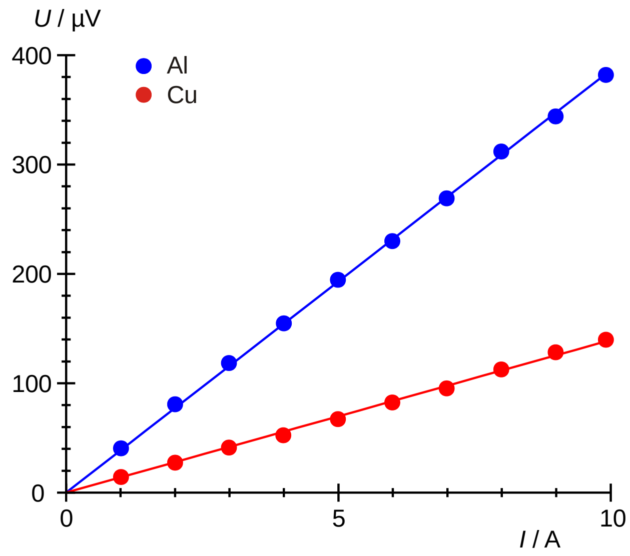

Fig. 4: Plot of *U* against *I* for copper and aluminium

EVALUATION

Dependence on distance

- Plot the voltages *U* measured as a function of distance *d* (Tab. 1) for the copper and aluminium rods on one graph (Fig. 3) and fit a straight line through the origin to each set of points.

NOTE:
Contact voltages between the measurement probes and the metal bar may become apparent by causing the straight lines to be shifted away from the origin.

According to equation (2), the following is true

$$(3)\quad \alpha = \frac{I}{A \cdot \sigma}\,.$$

Since *I* and *A* are known, it is possible to calculate the conductivity:

$$(4)\quad \sigma = \frac{I}{A \cdot \alpha} = \begin{cases} \dfrac{9{,}92\ \text{A}}{490\ \text{mm}^2 \cdot 3{,}53\ \dfrac{\mu\text{V}}{\text{cm}}} = 57 \cdot 10^6\ \dfrac{\text{S}}{\text{m}} & \text{(Cu)} \\ \dfrac{9{,}92\ \text{A}}{490\ \text{mm}^2 \cdot 9{,}53\ \dfrac{\mu\text{V}}{\text{cm}}} = 21 \cdot 10^6\ \dfrac{\text{S}}{\text{m}} & \text{(Al)} \end{cases}$$

Dependence on current

- Plot the voltages *U* (Tab. 2) measured as a function of current *I* for the copper and aluminium rods on one graph (Fig. 4) and fit a straight line through the origin to each set of points.

NOTE:
Contact voltages between the measurement probes and the metal bar may become apparent by causing the straight lines to be shifted away from the origin.

According to equation (2), the following is true

$$(5)\quad \beta = \frac{d}{A \cdot \sigma}$$

Since *d* and *A* are known, it is possible to calculate the conductivity:

$$(6)\quad \sigma = \frac{d}{A \cdot \beta} = \begin{cases} \dfrac{40\ \text{cm}}{490\ \text{mm}^2 \cdot 13{,}96\ \dfrac{\mu\text{V}}{\text{A}}} = 58 \cdot 10^6\ \dfrac{\text{S}}{\text{m}} & \text{(Cu)} \\ \dfrac{40\ \text{cm}}{490\ \text{mm}^2 \cdot 38{,}63\ \dfrac{\mu\text{V}}{\text{A}}} = 21 \cdot 10^6\ \dfrac{\text{S}}{\text{m}} & \text{(Al)} \end{cases}$$

The result for copper is in good agreement with the value stated in literature for pure copper $\sigma = 58 \cdot 10^6$ S/m. Comparison of the measured value for aluminium with that quoted in literature for pure aluminium $\sigma = 37 \cdot 10^6$ S/m indicates that the heat conduction rod used here is not made of pure aluminium but is an alloy of it.

NOTE:
The experiment uses the same metal bars investigated in the experiment on heat conduction, UE2020100. Two measurement probes are used to measure the voltage drop between the contact points, which can also be used to measure temperature along the bars.

By comparing the measurements with the heat conductivity values obtained in experiment UE2020100 it is possible to verify the Wiedemann-Franz law. This states that thermal conductivity λ is proportional to electrical conductivity σ in metals and the factor is a universal value temperature-dependent coefficient *L* (Lorenz coefficient):

$$(7)\quad \frac{\lambda}{\sigma} = L(T) \cdot T\,.$$

T: temperature

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