Exercise **44a**	**THE MEASUREMENT OF THE DEPENDENCE OF RESISTIVITY OF METALS AND SEMICONDUCTORS ON TEMPERATURE**

Measurement procedure

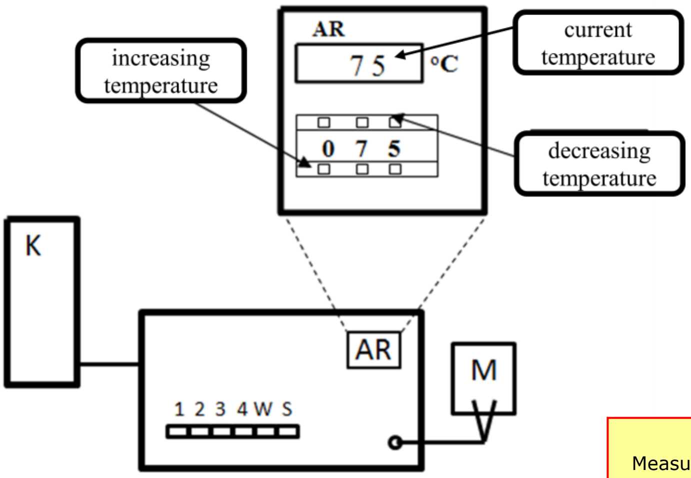
1. List of equipment

1. A chamber *K* with a heater and a ventilator cooler and with the investigated samples made of metal (conductor) with resistivity R_m and of semiconductor with resistivity R_s.
2. Control unit *CU* including: mains switch *S*, temperature controller *AR*, switches enabling choosing one of four samples, switch of the ventilator cooler *W*.
3. Ohmmeter *MR.*

2. Goal

The measurement of resistivity of metal and semiconductor as a function of temperature and calculation of the temperature coefficient of resistivity of metal and energy gap of semiconductor.

3. Measurement setup



CU - control unit
1, 2, 3, 4 - switches enabling connection of one of four samples to ohmmeter.
AR - temperature controller
S - mains switch
W - ventilator cooler switch
K - measurement chamber with samples, heater and ventilator cooler.
M - ohmmeter

Fig. 1. The scheme of the measurement setup.

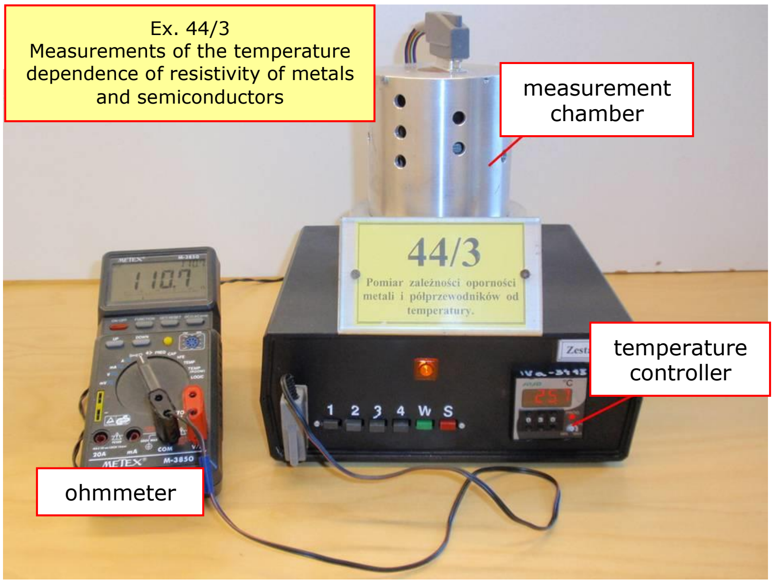


Fig.2. The photo of the measurement setup.

4. Experimental procedure

1. In order to measure resistivities of the samples connect the ohmmeter *M* to the control unit.
2. Ask the supervisor for checking the setup! On the temperature controller set up the initial temperature lower then room temperature, e.g. 15°C.
3. Switch on the mains *S* (the ventilator cooler *W* should be switched off). Read the temperature and the resistivities of all samples. Then set up the temperature 5°C higher and wait until it becomes stable and read the temperature and the resistivities of the samples. In the same way continue the measurements up to 100°C.
   There may be small difference between the temperature which was set up and the actual temperature (note only the last one). **Do not exceed 110°C !**
4. Cool the samples: on the temperature controller set up the temperature 15°C and switch on the ventilator cooler W.
   Do not forget to switch off the ventilator cooler before leaving the laboratory.
5. Switch off the mains.

5. Calculations and analysis of the results

1. On the basis of the data obtained from the measurements decide which samples are metals and which are semiconductors. For further analysis choose only one metal and one semiconductor sample.
2. Plot the function $\boldsymbol{R_m = f(t)}$ for metal and $\boldsymbol{lnR_S = f(1000/T)}$ for semiconductor, where T and t are the temperatures expressed in Kelvins and in degrees Celsius, respectively.
3. On each function for one chosen measured point plot the area of uncertainty caused by the inaccuracy of the devices applied for measuring.
4.

a) **Metal**

Applying the method of linear regression find out the coefficients a and b of the straight line which is the best fit to the measured points of the dependence $\boldsymbol{R_m = f(t)}$ for the metal. Write down the uncertainties of the coefficients *u(a)* and *u(b).* Plot the straight line on the graph. Comparing the equation of the straight line:

$$y = a \cdot x + b$$

to the equation for the resistivity of metal dependent on the temperature:

$$R_m(t) = R_o \cdot \alpha \cdot t + R_o$$

find out the temperature coefficient of resistivity α. Notice that x corresponds to the temperature t, so from the comparison it can be concluded that:

$$a = R_o \cdot \alpha \quad \text{and} \quad b = R_o.$$

Hence we obtain:

$$\alpha = \frac{\boldsymbol{a}}{\boldsymbol{R_o}}, \qquad \text{so:} \quad \alpha = \frac{\boldsymbol{a}}{\boldsymbol{b}}. \tag{1}$$

Having from linear regression coefficients a and b and their uncertainties *u(a)* and *u(b)* and using equation (1) derive the formula for the combined uncertainty of the temperature coefficient of resistivity $u_c(\alpha)$.

b) **Semiconductor**

It is known that in semiconductors in the range of higher temperatures the intrinsic conduction dominates, so the resistivity of the semiconductor can be expressed by the equation:

$$R_s = R_{s,o} \exp \frac{E_g}{2kT} \ .$$

After taking the natural logarithm of both sides we may obtain:

$$lnR_s = 10^{-3}\frac{E_g}{2k} \cdot \frac{1000}{T} + lnR_{s,o}. \qquad (2)$$

It can be noticed that lnR_s depends linearly on *1000/T*. Applying the method of linear regression find out the coefficients *A* and *B* of the straight line which is the best fit to the measured points of the dependence ***lnR$_S$ = f(1000/T)*** for the semiconductor. Write down the uncertainties of the coefficients $u(A)$ and *u(B).* Plot the line on the graph. Comparing the equation of the straight line

$$y = A \cdot x + B$$

to the equation (2) and noticing that *1000/T* corresponds to *x* find out the energy gap of the semiconductor E_g. From this comparison it can be noticed that:

$$10^{-3}\frac{E_g}{2k} = A.$$

So:

$$E_g \ = 2000 \cdot k \cdot A, \qquad (3)$$

where: k = 1,3806 10^{-23} J/K - Boltzmann constant.

Having from linear regression coefficient *A* and its uncertainty *u(A)* and using the equation (3) derive the formula for combined uncertainty of the energy gap $u_c(E_g)$ (neglect the uncertainty of Boltzmann constant).

5. The results of the measurements and calculations write down in the tables.

6. Additional information

Express the energy gap E_g of the semiconductor in both joules [J] and electronvolts [eV].

7. Suggested tables

Table 1. Results of the measurements of the temperature and the resistivity of metal and the coefficients of the straight line and the temperature coefficient of resistivity and their uncertainties.

No.	t	R_m	a	b	α
	°C	Ω	$\frac{\Omega}{^\circ C}$	Ω	°C^{-1}
1					
2					
3					
⋮					
n					
ΔX	(1)	(1)			
$u(X)$	(1)	(1)	(2)	(2)	
$u_c(X)$					

(1) Calculations of uncertainties Δt, *u(t)*, ΔR_m , $u(R_m)$ do for one chosen number.

(2) Uncertainties of *u(a)* and *u(b)* obtained from linear regression.

Table 2. Results of the measurements of the temperature and the resistivity of semiconductor and the coefficient *A* of the straight line (slope) and the energy gap of the semiconductor and their uncertainties.

No.	t	$1000/T$	R_S	$\ln R_S$	A	E_g	E_g
	°C	$\frac{1}{\mathrm{K}}$	Ω		K	J	eV
1							
2							
3							
⋮							
n							
ΔX	(3)		(3)				
$u(X)$	(3)		(3)		(5)		
$u_c(X)$		(3)		(3) (4)			

(3) The calculations of uncertainties Δt, $u(t)$, $u_c(1000/T)$, ΔR_S , $u(R_S)$, $u_c(\ln R_S)$ do for one chosen number.

(4) $u_c(\ln R_S)=u(R_S)/R_S$.

(5) Uncertainty $u(A)$ obtained from linear regression.