Student's name ____

Experiment E5

THERMOCOUPLE CALIBRATION

Objective: to learn elementary theory of Seebeck effect and to calibrate a thermocouple.

1 EQUIPMENT

1) Thermocouple;
2) Galvanometer;
3) Thermometer;
4) Dewar;
5) Voltmeter;
6) Resistors, connecting wires and switch;
7) Battery of known emf;
8) Electric heater.

2 THEORY

Back in eighteen century Alessandro Volta found that two chemically different metals produce the contact potential, which is dependent only on their chemistry and temperature (Volta's first law). If a few conductors made of different metals are connected in series, there occurs a potential difference between outermost conductors. This potential difference is not dependent on what materials are between the outermost conductors and is determined only by (Volta's second law)

Occurrence of the contact potential difference can be a manifestation of thermoelectric emission and its different character for different contacting materials. Electrons of metal can leave their host metal if their kinetic energy is higher than photoelectric work ***A*** **(**this work is needed to overcome attraction of negative electrons and positive ions). At some temperature there always is some number of electrons able to temporarily leave the metal and then come back due to attraction of ions. Thus, over the surface of metals a negatively charged "electronic cloud" is formed and the surface itself has net positive charge. These charges create potential difference known as contact potential. Every metal has some characteristic value of photoelectric work and contact potential. The value of contact potential depends substantially on temperature and surface purity. The other possible cause of contact potential difference is the difference of electron concentration between different metals. Electrons are redistributed through the junction to equalize concentrations across the junction, until their electric field prevent the further redistribution.

If two heterogeneous metals **A** and **B** are joined together as shown in fig. 2.1, in equilibrium state there occur charged bilayers around junctions 1 and 2. If temperatures of both junctions are the same, sum of contact potentials along the **A**-**B** circuit equals zero. If temperatures of junctions are maintained at different temperarures t_1° i t_2°, contact potential differences becomes different due to their temperature dependence and there occur a thermo-emf

$$e = h \cdot \left(t_1^{\circ} - t_2^{\circ}\right), \qquad (2.2)$$

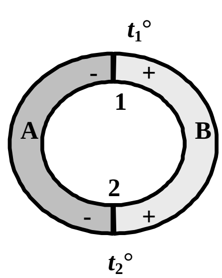


Figure 2.1

where h is Seebeck (or thermo-emf) coefficient for a given pair of metals (this effect is also known as Seebeck effect). The magnitude of h is of order of ~10^{-5} V/°C for metals and ~10^{-3} V/°C for semiconductors. Thermo-electric thermometers use Seebeck effect to measure high temperatures, for which usual thermometers are inapplicable.

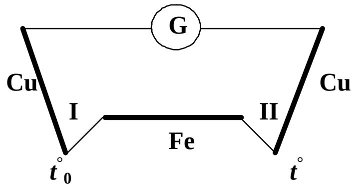


Figure 2.2

Consider a cirquit, in which thermo-couple is connected to a sensitive galvanometer and one of soldered junctions is maintained at constant temperature t_0^{o} (see fig. 2.2). If the metals of thermocouple are properly chosen, the magnitude of h is constant in a wide temperature range. Then the current flowing through the galvanometer is directly proportional to the temperature difference between the junctions. If a scale deflection of the galvanometer is $\boldsymbol{N}$ points for thermo-emf $\boldsymbol{\varepsilon}$, then

$$e = C \cdot N, \tag{2.3}$$

where $\boldsymbol{C}$ is galvanometer's graduation mark. By substitution of $\boldsymbol{\varepsilon}$ in formula (2.3) with $h\left(t^{\mathrm{o}} - t_0^{\mathrm{o}}\right)$, one obtains

$$h\left(t^{\mathrm{o}} - t_0^{\mathrm{o}}\right) = C \cdot N,$$

and, finally, Seebeck coefficient for the used thermo-couple is

$$h = \frac{C \cdot N}{t^{\mathrm{o}} - t_0^{\mathrm{o}}}. \tag{2.4}$$

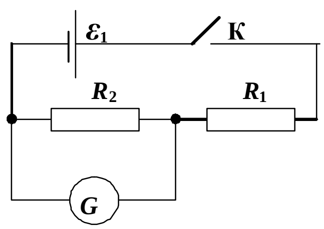


Figure 2.3

If the value of $\boldsymbol{C}$ is not given, it can be found with use of a circuit shown in fig. 2.3.

If a scale deflection is $\boldsymbol{N}$ points after switch **K** is closed, the galvanometer's graduation constant is

$$C = \frac{V}{N},$$

here $\boldsymbol{V}$ is the voltage across the resistor $\boldsymbol{R_2}$. Equivalent resistance of the parallel connection of $\boldsymbol{R_2}$ and galvanometer equals

$$R_{||} = \frac{R_G \cdot R_2}{R_G + R_2};$$

and total resistance of the circuit is

$$R_{||} + R_1 + r = \frac{R_G \cdot R_2}{R_G + R_2} + R_1 + r,$$

where $\boldsymbol{r}$ is internal resistance of the battery.

Current in the circuit can be found from Ohm's law to be

$$I = \frac{e_1}{\frac{R_G \cdot R_2}{R_G + R_2} + R_1 + r}.$$

Тут $\boldsymbol{\varepsilon_1}$ is emf of the battery.

Thus, the voltage $\boldsymbol{V}$ across terminals of resistor $\boldsymbol{R_2}$ equals

$$U = IR_{||} = \frac{E_1 R_{||}}{\frac{R_G \cdot R_2}{R_G + R_2} + R_1 + r}.$$

This expression may be simplified taking into account that $\boldsymbol{r} \ll \boldsymbol{R_1}$, $\boldsymbol{R_2} \ll \boldsymbol{R_G}$, to yield

$$U = \frac{E_1 R_2}{R_2 + R_1}.$$

Finally, for galvanometer's graduation mark we have

$$C = \frac{E_1 R_2}{(R_2 + R_1)N}. \tag{2.5}$$

Let us denote

$$\frac{h}{C} = n, \qquad (2.6)$$

then

$$n = \frac{N}{t^{\circ} - t_0^{\circ}}. \qquad (2.7)$$

The quantity $\boldsymbol{n}$ is a deviation of galvanometer's pointer at 1°C difference of temperatures of soldered junctions of thermo-couple, and is known as the sensitivity of thermo-couple.

If sensitivity $\boldsymbol{n}$ is known, the thermo-couple can be used as thermometer. From equation (2.7) we have

$$t^{\circ} = \frac{N}{n} + t_0^{\circ}. \qquad (2.8)$$

Then, if one soldered junction of thermo-couple is placed in the medium with unknown temperature $\boldsymbol{t}°$ and temperature t_0° of second junction is known, on basis of galvanometer's reading and formula (2.8) ne can calculate the unknown temperature.

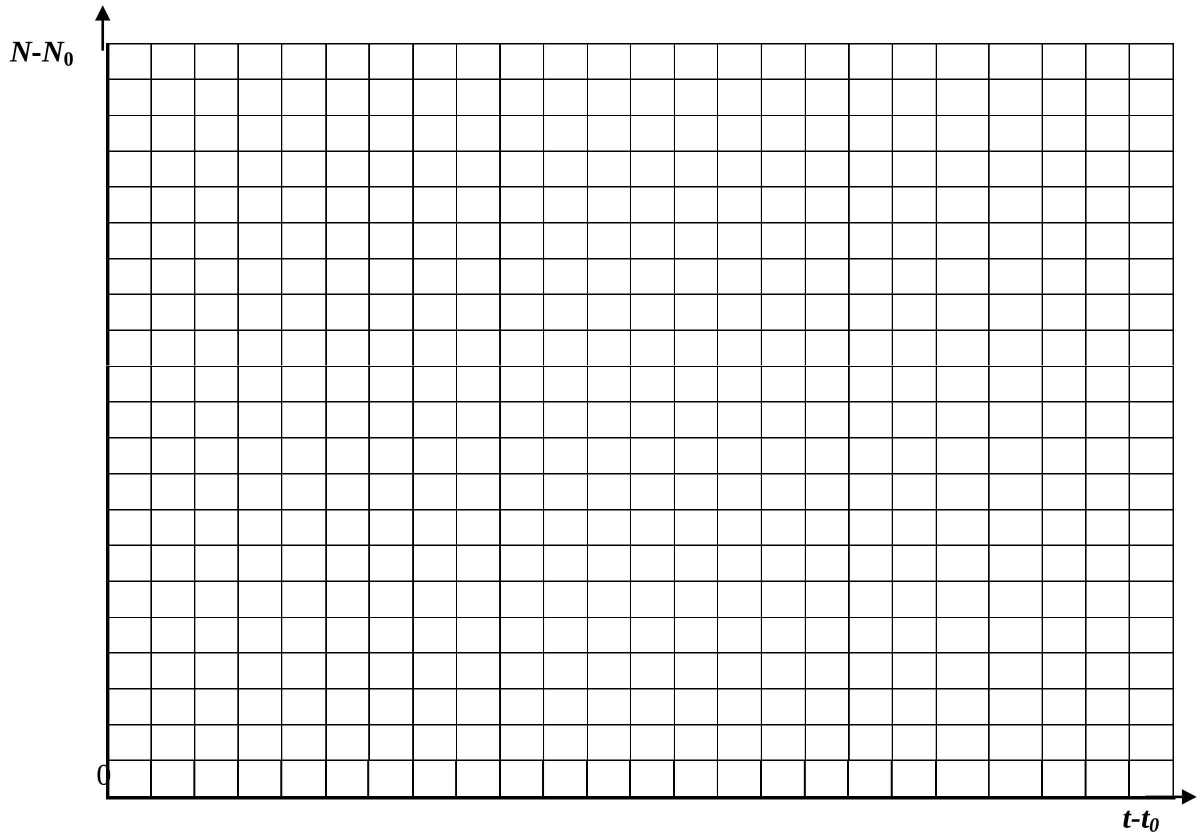
3 PROCEDURE AND ANALYSIS

3.1 Determine emf of battery $\boldsymbol{\varepsilon}_1$.
3.2 Assemble electric cirquit as shown in figure 2.3.
3.3 Measure the galvanometer's deflection $\boldsymbol{N}$ at closed circuit and determine constant $\boldsymbol{C}$ by formula (2.5).
3.4 Disassemble the circuit.
3.5 Connect the galvanometer into thermo-couple's circuit as shown in fig. 2.2.
3.6 Note initial reading $\boldsymbol{N_0}$ of the galvanometer (in initial state, both of soldered junctions have the same temperature).
3.7 Place one of the junctions to a thermostat filled with water of room temperature and the other junction to the container with water to be heated up.
3.8 Measure the room temperature $\boldsymbol{t_0}$ by thermometer with accuracy 0,5°C.
3.9 By heating, increase the temperature $\boldsymbol{t_1}$° in container with water and note readings $\boldsymbol{N_1}$ of galvanometer every 5°C until the water is boiling.
3.10 Fill the table 3.1 with results of experiment

Table 3.1

t_1, °C							
N_1							

3.11 Plot the galvanometer deflection $\boldsymbol{N_1}$-$\boldsymbol{N_0}$ versus difference of temperatures $\boldsymbol{t_1}$°-$\boldsymbol{t_0}$° between junctions graphically.
3.12 Calculate the galvanometer sensitivity by formula (2.7). For this end take the maximum temperature difference from graph and corresponding value of $\boldsymbol{N} = \boldsymbol{N_1} - \boldsymbol{N_0}$.
3.13 By formula $h = Cn$ calculate the value of h.


N-N_0
0
t-t_0