4. COMPENSATION METHOD

1. Objective
The determination of the electromotive force of a galvanic cell.

2. Equipment needed
Potentiometer with measuring scale; galvanometer; power supply (rectifier); studied galvanic cell; voltage reference cell; switches.

3. Theory
Compensation method is used to determine the potential difference and electromotive force (emf, $\varepsilon$). First let observe the relationships of the voltage, potential difference and emf.

The voltage $U_{AB}$ at the circuit chain AB is equal to its potential difference ($\phi_A - \phi_B$) and the sum of the emf.

$$U_{AB} = \phi_A - \phi_B + \varepsilon.$$  \hspace{1cm} (1)

If circuit chain does not include a source of emf then

$$U_{AB} = \phi_A - \phi_B.$$ \hspace{1cm} (2)

According to Ohm’s Law

$$U_{AB} = I \cdot R_{AB},$$ \hspace{1cm} (3)

where $I$ is current and $R_{AB}$ resistance of the chain.

If the current is absent in circuit chain then $U_{AB} = 0$ and from the formula (1)

$$\varepsilon = \phi_B - \phi_A,$$ \hspace{1cm} (4)

which appears, that to determine the emf one has to measure the potential difference of the power supply terminals on condition that no current flows through power supply.

The potential difference of the clips of a galvanic element can be determined by connecting them to certain points of circuit chain, potential difference of what is the same as the potential difference of the clips of the element. In this case there is no current in the element. The principle scheme is submitted in figure 4.1.

Figure 4.1
According to the measuring circuit (figure 4.1.) the wire resistor (potentiometer) AB is connected to the clips of the power supply, through which the current $I$ is flowing:

$$I = \frac{U_{AB}}{R_{AB}},$$

(5)

where $R_{AB}$ is the resistance of potentiometer and $U_{AB}$ is voltage on potentiometer. By moving the slide C along the wire, voltage $U_{AC}$ can be changed from zero to $U_{AB}$.

Relying on the formulas (5) and (2) we get

$$U_{AC} = I \cdot R_{AC} = \phi_a - \phi_b.$$

Connecting the studied galvanic element $\varepsilon$ to the points A and C the potentials of point A and one terminal will be equal. By moving the slide C one will find its position when current is zero in the circuit consisting of galvanometer. The potential $\phi_c$ of the point C is then equal to the potential of other clip of the galvanic element.

Thus electromotive force emf $\varepsilon$ is now compensated with the voltage $U_{AC}$ on the shoulder AC of the potentiometer. Therefore the method is called compensation method. Compensation method allows the accurate measurement of emf.

Question is that we know the length of the segment AC but we do not know the respective voltage $U_{AC}$. To find the voltage $U_{AC}$ we must know the voltage on the unit of length of the potentiometer, that’s why the potentiometer must be calibrated to units of voltage. In this purpose with the help of it the certain high accurate emf $\varepsilon$ of the voltage reference cell is compensated (respective compensating voltage $U'_{AC}$) and the respective length $l'_{AC}$ of the segment is measured. Supposing the same area of cross section of wire resistor (in the potentiometer) we get the voltage pertain to unit of scale $\frac{U'_{AC}}{l'_{AC}} = \frac{\varepsilon'}{l'_{AC}}$.

By this in the case of the same current it is easy to find the respective voltage on the arbitrary length of the potentiometers scale segment. We had to know the respective voltage on the length of scale segment $l_{AC}$, by which the emf $\varepsilon$ of the studied galvanic element was balanced. Via the value of the scale unit it can expressed as

$$\varepsilon = \varepsilon' \frac{l_{AC}}{l'_{AC}}.$$

(6)

Consequently to find the emf $\varepsilon$ of the studied galvanic element, there has to be found out the emf $\varepsilon'$ of the voltage reference cell and respective lengths $l_{AC}$ and $l'_{AC}$ of the scale segment AC.

Last quantities are given in relation in the formula (6) so those can be measured in free selected units of potentiometers scale length.

The scheme used in this work is given in figure 4.2. Here the $\varepsilon$ is studied element, $\varepsilon'$ voltage reference cell and ACB potentiometer.
4. **Experimental procedure**

1. Set up a circuit as shown at the work place and compare the circuit to figure 4.2. Explain, where is the shoulder AC of the potentiometer.

2. Ask the instructor to control the scheme. The value of the emf of voltage reference cell can be found at the workplace.

3. Switch on power supply (rectifier). By the switch $K_2$ connect the studied element to the circuit. Closing pressure switch $K_2$ only for a moment, try to find such a balanced position of sliding contact C, when the galvanometer deflection is zero. Record the reading of the potentiometer into the table 4.1.

4. Place the voltage reference cell in the circuit and repeat procedure 3.

5. Connecting in turns studied and voltage reference cell in circuit measure $I_{AC}$ and $I'_AC$ for 7–10 times.

6. Find the average values of $\bar{I}_{AC}$, $\bar{I}'_{AC}$ and their A-type uncertainties.

7. Compute from the formula (6) emf of the studied element and its uncertainty $U_c(\varepsilon)$.

8. Estimate the reality of the result in consideration of nominal value of galvanic cell.

<table>
<thead>
<tr>
<th>Nr</th>
<th>Studied galvanic cell $\varepsilon$</th>
<th>Voltage reference cell $\varepsilon'$</th>
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<tr>
<td></td>
<td>$I_{AC}$</td>
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<tr>
<td>1.</td>
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<td>10.</td>
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$\bar{I}_{AC} = ...$  \hspace{1cm} $\bar{I}'_{AC} = ...$  \hspace{1cm} $\varepsilon' = ...$
5. Questions and tasks
1. What are potential, voltage and electromotive force?
2. Formulate the Ohm’s law about the circuit segment and about closed circuit.
3. Formulate Kirchhoff’s rules.
4. What is the compensation method?
5. How basically does the compensation method differ from measured by voltmeter?
6. Define the unit of electromotive force in SI system.
7. How to calculate a) electromotive force of a battery; b) a current through the load resistor R; c) an internal resistance of the sources of electromotive force connected in parallel and in series?
8. About what does the clip voltage of the power supply depend on?
9. What is internal resistance of an ideal power supply?
10. What is the short current?
11. What does the wire resistance depend on?

6. Literature