

Student's name \_\_\_\_\_

### Experiment E3

## DETERMINATION OF RESISTANCE WITH WHEATSTONE BRIDGE

**Objective:** *to study direct current laws and master Wheatstone method of resistance determination.*

### 1 EQUIPMENT

- 1) Current source of known *emf*;
- 2) galvanometer of magneto-electric system;
- 3) variable resistor;
- 4) studied resistors;
- 5) rheochord, rheostat;
- 6) switch and connecting wires.

### 2 THEORY

Electric current is the flow of electric charges through a conductor. The amount of flow depends on the material through which the charges are passing and the potential difference across the material. The current value is the rate at which charge flows through this surface. If  $dq$  is the amount of charge that passes through this area in a time interval  $dt$ , the current  $I$  is equal to the charge that passes through cross section per unit time:

$$I = \frac{dq}{dt} \quad (2.1)$$

The SI unit of current is the ampere ( $1A= 1 C/ 1 s$ ).

It is conventional to assign to the current the same direction as the flow of positive charge. In electrical conductors, such as copper or aluminium, the current is due to the motion of negatively charged electrons. Number of free electrons, able to conduct a current, in metals is of order of  $10^{28}$  per  $1 m^3$ . In some cases, such as those involving gases and electrolytes, for instance, the current is the result of the flow of both positive and negative charges.

If the ends of the conducting wire are connected to a battery, the battery sets up a potential difference between the ends of the loop, creating an electric field within the wire. The electric field exerts forces on the conduction electrons in the wire, causing them to move, thus creating a current. A current that is constant in direction is called a direct current (DC). It is common to refer to a moving charge (positive or negative) as a mobile charge carrier. Electric resistance is due to scattering of charge carriers by vibrations of positively charged ions, which are by far heavier than electrons. That is why electric resistance is temperature-dependent: the higher is the temperature, the more intensive are ion vibrations and, as a consequence, the higher is electrical resistance of conductor.

There are several experimental methods for measuring a resistance. Usual methods apply ohmmeter, ammeter and voltmeter or Wheatstone bridge.

**Ohmmeter** is a galvanometer with scale graduated in resistance units. The higher is resistance of circuit, the less is scale deflection. This allows to measure resistance directly,

but the method has low accuracy. One may use combined **ammeter and voltmeter** to measure both current and voltage and then calculate the value of resistance by Ohm's law.

The most accurate method is **Wheatstone bridge**, shown in figure 2.1. It is composed of rheochord **AC**, sensitive galvanometer **G** and two resistors, one of known resistance  $R_0$  and the other, of unknown resistance  $R_x$ . A rheochord (also known as a slide-wire) is a homogeneous wire of constant cross-section, along which a slide-bar **D** can slide.

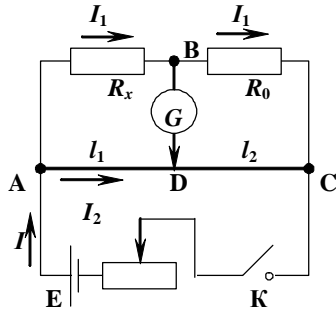


Figure 2.1

Consider the circuit shown in Figure 2.1 without the segment **BD**. If the key **K** is closed, current  $I_2$  start flowing through wire **AC**, along the wire some The highest potential  $j_A$  is set in point **A** and the lowest value  $j_C$  is in point **C**. In segment **ABC** current  $I_1$ , is flowing at these condition and electric potential is falling from  $j_A$  to  $j_B$  on the resistor  $R_x$  and from value  $j_B$  to  $j_C$  on the resistor  $R_0$ . Obviously, in point **B** the potential has an intermediate value  $j_B$  ( $j_A > j_B > j_C$ ). In consequence of this, there always is a point **D** on the segment **AC** the potential  $j_D$  which has the same value, as the potential  $j_B$  of point

**B**. If a galvanometer is connected across points **B** and **D**, no current flows through it because electric potentials of these points have the same value,  $j_D = j_B$ . Under this condition the bridge is said to be balanced. The balance condition can be derived using two principles called Kirchhoff's rules. The first of these states that the algebraic sum of the currents entering and leaving any junction in a circuit must equal zero:

$$\sum_{i=1}^n I_i = 0, \quad (2.2)$$

where  $n$  is number of currents entering and leaving the junction. This equation is also called the Kirchhoff's junction rule. A junction is any point in a circuit where a current can split. This split results in less current in each individual resistor than the current leaving the battery. Because electric charge is conserved, the current that enters junction must equal the total current leaving that junction.

The second rule (Kirchhoff's loop rule) states the following. The sum of the voltages across all elements around any closed circuit loop must be equal to the sum of emf's around the circuit:

$$\sum_{i=1}^n I_i R_i = \sum_{i=1}^k e_i, \quad (2.3)$$

where  $I_i$  is current in  $i$ th element of the circuit;  $R_i$  is  $i$ th element's resistance;  $e_i$  is emf acting on  $i$ th element;  $n$  is number of elements with active resistance;  $k$  is number of elements with emf.

We may use the loop rule for subcircuits **ABD** and **BCD** to obtain, that

$$\begin{aligned} I_1 R_x - I_2 r_{AD} &= 0; \\ I_1 R_0 - I_2 r_{DC} &= 0. \end{aligned} \quad (2.4)$$

Solution of system (2.2), expresses the balance condition for Wheatstone bridge:

$$\frac{R_x}{R_0} = \frac{r_{AD}}{r_{DC}}. \quad (2.5)$$

As resistances of segments **AD** and **DC** of rheochord are proportional to their lengths  $l_1$  and  $l_2$ , we have

$$R_x = R_0 \frac{l_1}{l_2} \quad (2.6)$$

If total length of the rheochord is  $l$ , then  $l_2 = l - l_1$ , and

$$R_x = R_0 \frac{l_1}{l - l_1} \quad (2.7)$$

The above equation is used as a computation formula in present experiment.

By Wheatstone method one may also determine equivalent resistance of resistors connected in parallel or in series. These experimental results are to be compared with ones calculated theoretically. For resistors, connected in series (as links in chain), the same current passes through all of the resistors in a given time interval. The voltage across the whole series is calculated as a sum of voltage across the first resistor plus the voltage across the second and so one. As a consequence, the equivalent resistance equals a sum of all individual resistances connected:

$$R = \sum_{i=1}^n R_i \quad (2.8)$$

The resistance  $R$  is equivalent to the series combination of all  $R_i$  in the sense that the circuit current is unchanged when  $R$  replaces the combination of  $R_i$ .

For resistors, connected in parallel, difference of potential across terminal junctions has the same value for all of the resistors. As voltages are equal and, by Kirchoff's junction rule, a current splits up in parts, inversely proportional to resistances of particular conductors, we obtain inverse of equivalent resistance for the parallel connection as

$$\frac{1}{R} = \sum_{i=1}^n \frac{1}{R_i} \quad (2.9)$$

These relationships indicate that the equivalent resistance of a series connection of resistors is always greater than any individual resistance, and resistance of a parallel connection is less than any of individual resistances.

### 3 PROCEDURE AND ANALYSIS

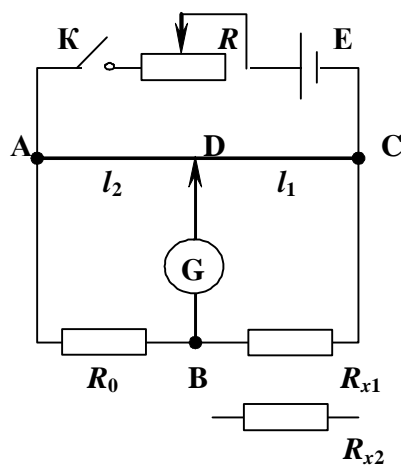


Figure 3.1

zero by moving slide-bar **D**.

- 3.1 Assemble electric circuit according to diagram shown in Fig. 3.1.
- 3.2 Set resistance  $R$  to maximum value.
- 3.3 Set slide-bar **D** in center of rheochord **AC** and vary the resistance  $R_0$  until galvanometer **G** reading is zero at closing the key **K**.
- 3.4 Set resistance of rheostat to minimum value and vary the resistance  $R_0$ , then move slide-bar **D** until the galvanometer's reading is zero again.
- 3.5 Fill the table 3.1 with obtained results for  $R_0$ ,  $l_1$  and  $l_2$ .
- 3.6 Repeat the measurements for two more values of resistance  $R_0$ , one 10% higher, the other 10% lower than the initial value. The galvanometer reading is set to

3.7 Analogously,  $R_{x2}$ , as well as parallel and series configurations of  $R_{x1}$  i  $R_{x2}$  are investigated.

Note that the circuit is to be completed for very short time only (just to take galvanometer's reading) because current flow leads to heating of conductors and change the resistances.

3.8 Values of unknown resistances are calculated by formula (2.7), absolute and relative errors are calculated for series of measurements.

3.9 Equivalent resistances for in series and in parallel connections are calculated by formulae

$$R_{ser} = R_{x1} + R_{x2} \quad \text{and} \quad \frac{1}{R_{par.}} = \frac{1}{R_{x1}} + \frac{1}{R_{x2}}, \quad \text{respectively, and compared with experimental results.}$$

**Table 3.1**

Resistance		$R_0,$ $\Omega$	$l_1,$ mm	$l_2,$ mm	$R_x,$ $\Omega$	$DR_x,$ $\Omega$	$R_{mean.},$ $\Omega$	$DR_{mean.},$ $\Omega$	$e_x,$ %
$R_{x1}$	1								
	2								
	3								
$R_{x2}$	1								
	2								
	3								
In series $R_{x1}$ and $R_{x2}$	1								
	2								
	3								
In parallel $R_{x1}$ and $R_{x2}$	1								
	2								
	3								