**Ohm's Law**

1. **Aim of experiment**

   The main purpose of this laboratory experiment is:
   - to learn the proper use of electrical meters
   - to measure the resistance of resistor by different methods
   - to examine the current-voltage relation for the simplest circuit element i.e. single resistor
   - to verify Ohm's Law using resistors in dc circuits

2. **Principles**

   2.1. **Ohm's Law**

   The most applied relation for a wide range of components used in electrical circuits is that known as Ohm's Law. It states that the potential difference (voltage drop or voltage) \( V \) across a circuit component is linearly proportional to the electric current \( I \) which passes through the component:

   \[
   V = R I, \tag{1}
   \]

   where the constant of proportionality, \( R \), is the resistance of the circuit component and the SI unit of resistance, ohm, is defined as one volt per ampere (1\( \Omega \)=1V/A).

   It is important to understand that the real content of Ohm's Law is the direct linear proportionality of \( V \) to \( I \). One has to note that equation [1] defines resistance \( R \) for any conductor, whether it obeys Ohm's Law or not. Only in the case when \( R \) is constant that does not depend on the value of voltage (at given temperature) one can call relationship [1] Ohm's Law. The materials obeying this law are known as ohmic or linear materials because the potential difference across it varies linearly with the current.

   For a circuit element that obeys Ohm's Law, a graph of the current as a function of potential difference (current-voltage relationship) is a straight line which slope is equivalent to the reciprocal of the element resistance (see Figure 1).
For given value of the voltage \( V_0 \), the current passing through the conductor (1) is higher than one passing through the conductor (2) (i.e. \( I_1 > I_2 \)). It means that the resistance of conductor (1) is higher than the resistance of second conductor.

**Figure 1:** Current-voltage relationships for two different ohmic devices.

All materials provide an electrical resistance. However, the resistance is dependent on the crystalline structure, the physical geometry, and the temperature of the material.

The resistance of a cylindrical conductor is related to its resistivity \( \rho \), length \( L \) and cross-section area \( A \) by the following relation:

\[
R = \rho L A^{-1}. \quad [2]
\]

**Figure 2:** The scheme of the cylindrical conductor.

Because the resistivity of materials varies with temperature, the resistance of specific conductor also depends on temperature. For temperature ranges that are not too great this dependence is approximately linear:

\[
R(T) = R_0 \left[ 1 + \alpha (T - T_0) \right],
\]

where \( R_0 \) is the resistance at room temperature, \( T_0 \) is the room temperature and \( \alpha \) is the temperature coefficient of resistance.
Symbols for Circuit Diagrams

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>_</td>
<td>conductor (with negligible resistance)</td>
</tr>
<tr>
<td>R</td>
<td>resistor (made to have a specific value of resistance between its ends)</td>
</tr>
<tr>
<td>V</td>
<td>voltmeter (measures a potential difference between its terminals)</td>
</tr>
<tr>
<td>A</td>
<td>ammeter (measures a current through it)</td>
</tr>
</tbody>
</table>

In electric circuit with two or more resistances, Ohm's Law may be applied to the whole circuit, to a portion of the circuit or to each individual resistance of the circuit.

For any combination of resistors it is always possible to find a single resistor that could replace the combination and result in the same current and potential difference. The resistance of this resistor is called the equivalent resistance of the combination.

Resistors can be connected in **series**; that is, the current flows through them one after another. The circuit in Figure 3 shows two resistors connected in series.

![Figure 3: Two resistors connected in series.](image)

The same current flows through all resistors in a series connection.

When several resistors are connected in series, the equivalent resistance is the sum of the individual resistances (what means that the equivalent resistance is greater than any individual resistance).

Resistors can be connected such that they branch out from a single point (known as a node), and join up again somewhere else in the circuit. This is known as a **parallel** connection.

![Parallel connection](image)

All resistors in a parallel connection have the same potential difference between their terminals.

When several resistors are connected in parallel, the reciprocal of equivalent resistance is the sum of the reciprocals of individual resistances (what means that the equivalent resistance is always...
2.2. Voltage and Current Measurements

Idealized meters that are used to measure the properties of electric circuits should not disturb the circuit in which they are connected.

A voltmeter is a device used for measuring the potential difference (voltage drop) between two points in an electric circuit. An idealized voltmeter has infinitely large resistance and measures potential difference without having any current diverted through it.

Figure 5: Voltmeter connected in parallel to the resistor.

An ammeter is a measuring instrument used to measure the flow of electric current in an electric circuit. An idealized ammeter has zero resistance and has no potential difference between its terminals.

Figure 6: Ammeter connected in series to the resistor.

A voltmeter and an ammeter can be used together to measure resistance which equals to the potential difference between its terminals divided by the current. In principle, the most straightforward way to measure R is to measure V and I simultaneously. In practice it is not quite simple.

In the circuit shown in Figure 7(a) ammeter reads the current in the resistor R. Voltmeter reads the sum of the potential difference across the resistor and the potential difference across the ammeter.

In the case presented in Figure 7(b) the voltmeter reads the potential difference across the resistor correctly but the ammeter reads the sum of the current in the resistor and the current in the voltmeter.

Either way, we have to correct the reading of one of the meters unless the corrections are small enough to be negligible (what is true for measuring the high resistance in first circuit or the low resistance in second one).
3. Experiment

3.1. Equipment

- the power supply unit
  (It supplies the applied voltage. A variable resistance inside the power supply units allows the output voltage to vary continuously using the control knobs labeled VOLTAGE (FINE/COARSE).
- the breadboard with 4 resistors to be measured (Figure 8)
  (Please note that the red and blue terminals should be used to bring the voltage from the power supply and the binding posts can be used for the interconnection of the resistors.)
- digital and analog multimeters (ammeter and voltmeter)
- 3 pairs of long connecting wires (red and black)
- 2 short banana wires

![Figure 8](image)

Figure 8: The breadboard with four resistors.

3.2. Hints and Cautions

1. To protect the voltage and current meters use the large scale first and then gradually move to a more sensitive scale. Starting with the sensitive scale first could seriously damage the unit. Choose your scale carefully so as not to blow-out the meter.
2. The ammeter should always be connected in series with the circuit elements.
3. The voltmeter should always be connected parallel to the circuit elements.
4. Do not use the voltmeter and ammeter displays on the power supply to record the circuit voltages and currents. Use the analog or digital multimeter (acting as ammeter or voltmeter).

5. Please note that the analog multimeter used in this experiment can operate only in horizontal position.

3.3. Reading the multimeters scales

**analog voltmeter**

![Analog Voltmeter Image]

ranges used for voltage measurements in dc circuit

actual range

scales used for reading of measured voltage values

upper for ranges of 0.1, 1, 10, 100

lower for ranges of 0.3, 3, 30

The systematic error of DC voltage readings is equal to 1% of full scale (i.e. for actual range of 30V: \( \Delta V = 1\% \cdot 30V = 0.3V \)).

**digital ammeter**

![Digital Ammeter Image]

In analyzed case the measuring range is equal to 2A and the measured value is equal to 0.800A. The systematic error of the measurement is equal to:

\[
1.2\% \cdot 0.800A + 1 \cdot 0.001A = 0.0096A + 0.001A = 0.0106A.
\]

And finally \( \Delta I = 0.011A \).

3.4. Procedure
• Make sure that all knobs of power supply unit are turned to the minimum and that the maximum ranges of multimeters are set (i.e. 2A for the ammeter and 30V for the voltmeter).
• The analog multimeter should be used as the voltmeter and the digital multimeter as the ammeter.
• Choose the resistor to be measured and wire the circuit paying attention to the proper polarity. Use the red wires to connect the terminals with the higher potential and the black wires for lower potential. If it is necessary get rid of other resistors by using short banana wires to connect opposite terminals of eliminated resistor(s).
• Ask assistant to check if your circuit is connected properly and switch on the power supply after his acceptance.
• Before starting taking data, make sure that the meter reads zero when no voltage source is present.
• Measure the current passing through the resistor \( R_4 \) as a function of the voltage applied to its terminals. Use the VOLTAGE COARSE/FINE control to vary the power supply voltage and make at least ten different measurements.
• Measure the current passing through each of resistor \( (R_1, R_2, R_3 \text{ and } R_4) \) for the specified value of the voltage.
• Note the multimeters ranges that were used for electric values measurements.
• Make sure that the minimum ranges for the power supply and the maximum ones for the multimeters are set after your measurements are finished.

3.5 Analysis

• Calculate the values of the resistances of all measured resistors.
• Use the error propagation method to calculate the errors of the resistances.
• Make a graph representing the voltage as a function of the current to determinate resistance of resistor \( R_4 \). The plot should be a straight line, and the slope of this line should be equal to the resistance. Use the least squares method to find the value of resistance of resistor \( R_4 \) and its error. Compare this result with a value obtained using simple calculations.

Measurements
1. **Aim of experiment**

The aim of this laboratory experiment is to measure a diameter of the metal rod using the micrometer screw gauge.

2. **Principles**

A micrometer screw gauge (commonly called a micrometer) is one of the most accurate mechanical devices commonly used for precise measuring of the size (thickness, width, diameter, depth, etc.) of the objects. The high precision of a micrometer is achieved by using a fine pitch screw mechanism. Because of this mechanical advantage it is easy to use enough force in closing the rods on the object being measured to deform either the measuring rods of the micrometer or the object. In this way the micrometer could be forced to squeeze the material giving an inaccurate measurement. To foresee this situation an additional feature of micrometers is included in the form of a friction screw which allows applying a certain torque to rotate the thimble in a gentle manner. The friction screw should be always used to close the measuring rods on an object to prevent incorrect measurements results. A locking lever fixes the position of the thimble and right-hand measuring rod.

![The scheme of micrometer screw gauge.](image)

**Reading a micrometer**

The spindle of the micrometer has 2 threads per millimeter, and thus one complete revolution moves the spindle through a distance of a half of millimeter. The longitudinal line on the frame is graduated with 1 millimeter divisions and a half of millimeter subdivisions. The left-hand side of the thimble has markings all around it. There are 50 graduations, each being one-hundredth of a millimeter.

To read a micrometer one should note the number of millimeter divisions visible on the scale of the sleeve and add the total to the particular division on the thimble which coincides with the axial line on the sleeve. Suppose that the thimble were screwed out so that graduation 8 and one additional 0.5 subdivision is visible (as shown in the Figure 10). In addition the
graduation 8 on the thimble coincides with the axial line on the sleeve. The reading then would be 8.00+0.50+0.08=8.58 mm.

Figure 10: A close-up of the micrometer showing its thimble.

3. Experiment
   3.1. Equipment
   - micrometer screw gauge
   - metal rod

   3.2. Procedure
   - Unlock the micrometer.
   - Check zero reading when the measuring rods are closed.
   - Measure 10-20 times the diameter of the metal rod.

   3.3. Analyses
   - Calculate the mean value of the rod diameter.
   - Find the standard deviation of the mean value.
   - Use histogram to represent your data.