Warsaw University of Technology
Faculty of Physics
Physics Laboratory I „P”

1

ANALYSIS OF THE RELATIONSHIP BETWEEN CURRENT AND VOLTAGE IN AN ELECTRICAL CIRCUIT

During this laboratory exercise the relationship between current flowing through the item of an unknown resistance and voltage is analyzed. This relationship is also called as the current-voltage characteristic. The circuit shown below is going to be used in the experiment.

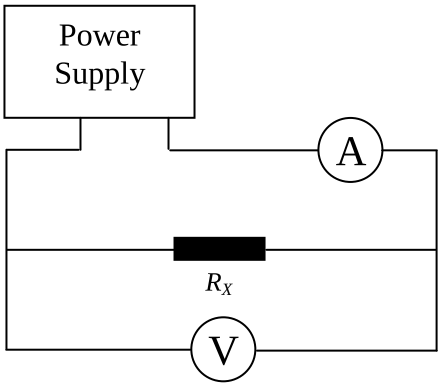


Fig. 1. The setup used for measurement of relationship between current flowing through the item R_x and voltage

The ammeter labeled as (A) is used for measurement of current flow.

The voltmeter labeled as (V) is used for measurement of voltage.

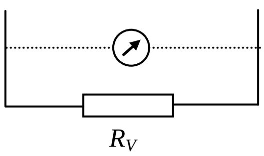
In the first part of measurement one is going to create current-voltage characteristics of the resistor made of a conductor (metal or alloy of metals). This kind of materials fulfills the Ohm's law:

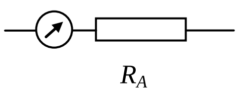
$$R = \frac{U}{I} \qquad (1),$$

thus the relationship between current and voltage is linear.

The application of the voltmeter and the ammeter does not affect the shape of the current-voltage characteristics, but it can be a source of erroneous measurement of resistance R_x. Both the ammeter and voltmeter feature their own internal resistances that are marked on diagrams as follows:

Representation of a voltmeter and an ammeter with extracted internal resistance

voltmeter: 

; ammeter: 

If one takes into consideration internal resistances of the meters used in the diagram shown in fig. 1., one will obtain a diagram shown in fig. 2. Once the power supply is switched on, the current flowing through the ammeter will be split into two branches. One contains the analyzed resistor and the second one – the voltmeter.

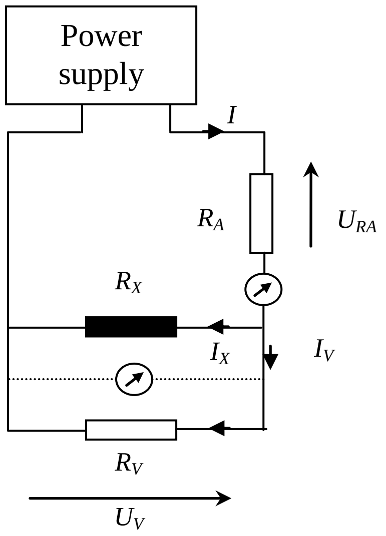


Fig.2. Diagram 1 with extracted resistances of the voltmeter and the ammeter.

According to the Kirchhoff's first law, the current flowing through the ammeter will be the sum of currents flowing through the branches:

$$I = I_X + I_V \tag{2}$$

Based on the Ohm's law, the currents flowing through the branches are respectively:

$$I_x = \frac{U_V}{R_X}, I_V = \frac{U_V}{R_V}, \tag{3}$$

then one can calculate the current measured with the ammeter:

$$I = \frac{U_V}{R_X} + \frac{U_V}{R_V} = U_V\left(\frac{1}{R_X} + \frac{1}{R_V}\right) = \frac{U_V}{R_X}\left(1 + \frac{R_X}{R_V}\right), \tag{4}$$

and the R_x can be calculated based on the formula:

$$I = \frac{U_V}{R_X}. \tag{5}$$

The $\frac{R_X}{R_V}$ part can only be ignored, if $R_X << R_V$.

If this condition is not fulfilled, cone can use another circuit (fig. 3). In this case, the voltmeter is going to show the sum of voltages on the resistor and ammeter:

$$U_V = I_X R_X + I_X R_A = I_X R_X\left(1 + \frac{R_A}{R_X}\right), \tag{6}$$

thus:

$$R_X = \frac{U_V - U_{RA}}{I_X} = \frac{U_V}{I_X} - R_A, \tag{7}$$

as the ammeter measures the I_X current, on can use the formula: $R_X = \frac{U_V}{I_X}$ for calculations.

The part containing R_A in formulas (6) and (7) can be ignored, if $R_X >> R_A$.

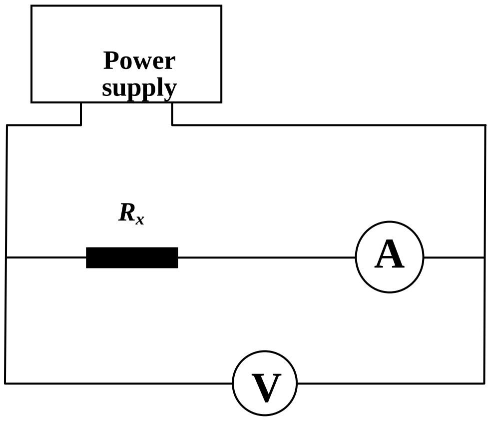


Fig.3 Measurement setup - the ammeter connected in series with the voltmeter

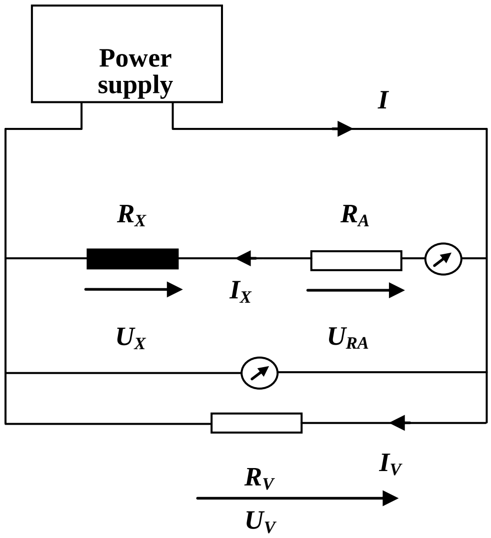


Fig.4. Diagram 3 with extracted resistances of the voltmeter and the ammeter.

Voltmeters usually feature a high internal resistance and ammeters a low one.
For a measured R_X resistance of the order of magnitude of 1 kΩ the condition $R_X << R_V$ is fulfilled "better" than the condition $R_X >> R_A$ and in this case we apply the circuit shown in fig. 1.

In the second part of the experiment, one has to measure a current-voltage characteristic of a non-linear item.

2. Measurement procedure

2.1 Connect the circuit according to the diagram shown in fig. 1. Make sure that terminals of the measurement devices marked with "+" sign are connected to the power supply terminal of a higher potential.

2.2 Perform measurement of the current-volt characteristics of a linear item:

a. Set the power supply control knob to the minimum voltage position (turn it to the left till the end of the scale), and the current efficiency knob (if it is available) - to the maximum position.

b. Set the voltmeter's measurement range to the 15 V or higher, and the ammeter's measure range to minimum 500 mA.

c. Before the power supply is set to on, the setup **HAS TO BE** checked by the supervisor. **Do not turn on any devices on your own!** The supervisor will turn the devices on and will define the measurement ranges.

d. Prepare a measurement table and perform about 10-12 measurements of U and I values for various voltage settings **without changing the measurement ranges**. The measurement points should be possibly homogenously spread on the whole range of changes of voltage and current.

e. Write down the accuracy class of the ammeter and the voltmeter, measurement ranges and number of ticks on both scales.

2.3 Perform measurement of the current-volt characteristics of a non-linear item (optional part):

a. Connect the circuit according to the diagram shown in fig. 1, connection the diode in this way so that it is polarized in forward direction. ***(Connect the red terminal of the diode with positive terminal of the power supply).***

b. Set the power supply control knob to the minimum voltage position (turn it to the left till the end of the scale), and the current efficiency knob (if it is available) - to the maximum position.

c. Set the voltmeter's measurement range to the range not higher than ***1 V****, and the ammeter's measure range to minimum* ***200 mA****.*

d. *Turn the power supply on and set the voltage on it at which the analyzed voltage (measured with the voltmeter) will be equal to approx. 0.1 V. Analyze the current flowing through the diode.*

e. *Perform about 10 measurements of U and I values within the range of the* ***measureable*** *changes of voltage are observed. Do not exceed the 750 mA current value flowing through the diode – any higher current can cause the diode burn out. Change the meter ranges in this way – if it is possible - so that the pointer surpasses half of the scale.*

3. Results preparation

3.1 Results preparation for the resistor measurement data (part 2.2)

a. Re-write the measured data (using the base SI units) and their uncertainties (in separate columns) into the spreadsheet of the ORIGIN software and perform a linear fit of the U(I) relationship for a line y = a + bx, where y=U, x= I, b=R_x.

b. Print the graph with the table of fitted parameters (add authoring students' names, their team's and group's numbers and to the chart).

c. In the fitting results in the ORIGIN software, find the standard uncertainty $u_c(R_x)$ calculated with the method type A.

d. Perform a linear fit of the I(U) relationship, where y=I, x=U, b=1/R_x. Calculate R_x and the standard uncertainty of R_x. Compare the obtained results.

e. Using the Ohm's law for one chosen measurement, calculate the R_X resistance and its combined standard uncertainty, taking into consideration the calibration uncertainty and the investigator uncertainty. Write down and report the obtained result correctly.

f. Add the uncertainty type A and B using the uncertainty propagation law.

g. Calculate the extended uncertainty and write down and report the final result correctly.

h. Use the χ^2 test to check if the analyzed relationship is linear.

3.2 Results preparation for the diode measurement data (part 2.3)

a. *Re-write the measured data (using the base SI units) into the spreadsheet of the ORIGIN software and plot a graph containing the measurement points only.*

b. *Is it reasonable to perform a linear fit for the diode measurements? Discuss a potential fitting method with your supervisor.*

<u>TASKS TO BE COVERED IN THE REPORT:</u>

1. A short description of methods (different to those applied during the experiment) of finding of the unknown resistance – a few sentences on each of them, their advantages and disadvantages and the application range, connection diagram. Do not copy the reference books or Wikipedia entries.
2. Calculations of R_x, $u_c(R_x)$ for one measurement (each team member chooses a DIFFERENT data pair from the current voltage characteristics of the resistor).
3. Calculations of R_x, $u_c(R_x)$ and U_c(Rx) using the least squares method based for **I(U)** and **U(I)** characteristics (both of them necessarily) with application of calculations preformed in Origin (**calculation description - see step 3.1 above**).
4. Graph of the diode characteristics. *(If the diode measurements have been performed)*
5. Answer the questions:
   a. What is the purpose of the least squares method?
   b. For what current values the relationship between U and I can be treated as linear? (Consider the Joule heating value that is emitted from the analyzed item and check in the literature temperature dependencies of the material resistance (usually this is a metal alloy) of which the resistor is made.)
   c. *Why is the I vs. U relationship for the diode not linear? (If the diode measurements have been performed).*

The rank of the report depends on how the specific tasks are covered - particularly the TASK 3. (Attachment of the printed origin graphs DOES NOT COVER this point at all!!!)