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Organization of Practical-Research Works with "Black Box" Method

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Abstract: The ability to use basic formulas to improve students' knowledge of the physical Olympiad, knowledge of units of measure and their ability to influence logical and abstract thinking. Algorithms and necessary instructions are used to calculate the tasks. The period of application of knowledge in practice has a leading place in the learning process because comprehensive activities of pupils in the execution of tasks are carried out through a great mental work. The Olympiad tasks allow to use creativity and thus expand the scope of their application. It is necessary to take into account that students cannot do without realistic mental activities on the basis of the analysis of the theoretical and practical skills required for the release of the Olympiad tasks. The solution of experimental tasks selects the theoretical proof of its execution, the method of its solution, evaluates the process of measurements, estimates of errors and analysis of received results.

Keywords: Physics, Black box, Logical thinking, Experimental research work, Olympiad tasks

Introduction

Organization of experimental research in physics at school is one of the essential elements of developing student's creative abilities. Tasks require the use of physical laws in any particular situation. That's why experimental work is important in helping to clarify the students' knowledge, to see the different aspects of general laws. There is no practical value for knowledge without experiments [1-2].

The experimental-research work is based on the development of the deeper study of physical laws, intensification of motivation, persistence in achieving the goals, the desire for physics, the ability of self-education and self-comprehension.

During the physical experimental research work of students, the following features are formed:

- Searching - finding out skills, increasing enthusiasm for knowledge.
- Uses textbooks, teaching aids, various definitions, and works with many scientific books, self-study and self-improvement.
- Logical thinking skills are developed, and further identification and proof of attitudes are revealed.
- Self-study, self-education, self-evaluation, self-determination of the results of their work.
- They are convinced that success in experimental research work, success in creative activities, overcome difficulties in life, and the ability to take responsibility for their own work.

The importance of organizing experimental research work comprehends by modern physical phenomena for the formation of modern physics teachers. In turn, we have put forward a study of the technique of physical experiment using the "black box" method. This method is compact, ergonomic and environmentally friendly and easy to use. Let's talk about the black box method in organization of experimental research works:

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Method

1) In the circuit diagram shown in the figure 1, all voltmeters are identical and have a resistance of R = 1.00 kΩ. Find the readings of all voltmeters if an ideal source with voltage Ɛ = 9.00 V is connected to them.

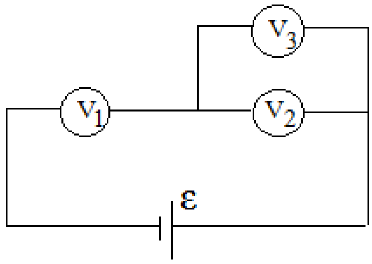

Figure 1. The circuit diagram

A black box is connected instead of one of the voltmeters (in the figure 2), the current-voltage characteristic of which have the form shown in the figure 3 below, where U_0 = 1.00 V and I_0 = 1.00 mA. Further, assume that the voltage given by the source can be adjusted.

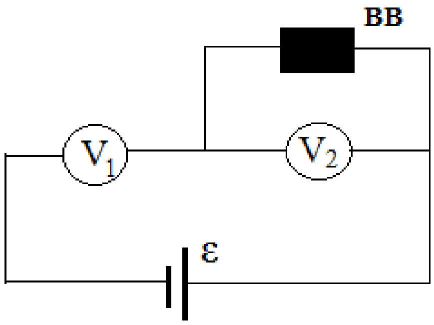

Figure 2. A black box is connected of the circuit

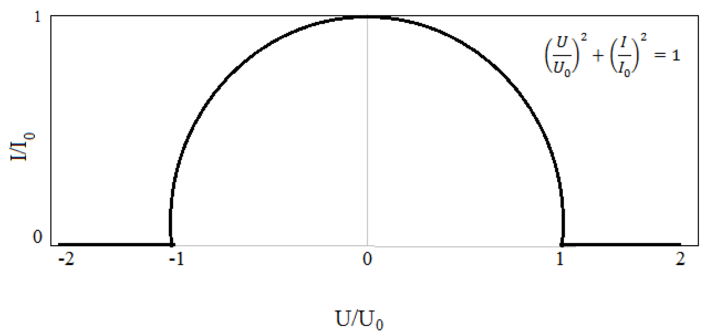

Figure 3. The current-voltage characteristic

2) Which element is necessary inside the black box.
3) Find the maximum power generated by the black box.
4) Find the voltage of the source Ɛ, at which the black box generates maximum power. What are the voltmeter readings in this case?
5) Find the voltmeter readings when the source voltage is equal to zero.
6) Find the readings of the voltmeters when the source voltage is Ɛ = 3.00 V.
7) Find the source voltage at which the current in the black box is maximum.
8) Find the readings of the voltmeters at the source voltage equal to Ɛ = 2,10 V.
9) Maximum source voltage at which current is not equal to zero.

Results and Discussion

1) It is known that voltmeters show the voltage on themselves. The resistance of the voltmeters connected in parallel is

$$R_{11} = \frac{RR}{R+R} = \frac{R}{2}, \tag{1}$$

and the equivalent resistance of the circuit

$$R_{tot} = R + R_{11} = \frac{3}{2}R \tag{2}$$

The current which flows through the voltmeter V_1 is

$$I = \frac{\varepsilon}{R_{tot}}, \tag{3}$$

and hence the voltage across it is equal to

$$V_1 = I_{tot}R = \frac{2}{3}\varepsilon = 6V \tag{4}$$

Voltage across voltmeters V_2 and V_3 are equal to each other and constitute

$$V_2 = V_3 = \varepsilon - V_1 = \frac{1}{3}\varepsilon = 3V. \tag{5}$$

2) It follows from the current-voltage characteristic that at a voltage equal to zero, the current through the black box is not zero. This means that there is a power supply (battery) in the black box.

3) The power generated by the black box is equal to

$$P = IU \tag{6}$$

where

$$\left(\frac{U}{U_0}\right)^2 + \left(\frac{I}{I_0}\right)^2 = 1 \tag{7}$$

From the symmetry of expressions (5) and (6) it follows that the maximum power is reached when

$$U = \frac{U_0}{\sqrt{2}}, \quad I = \frac{I_0}{\sqrt{2}} \tag{8}$$

and is

$$P_{\max} = \frac{I_0}{2}U_0 = 0.5mW \tag{9}$$

4) Let the black box generate the maximum power, then the current in it and the voltage are given by the expression (8). The current flowing through the voltmeter V_2 is

$$I_2 = \frac{U_0}{\sqrt{2}R}, \tag{10}$$

and hence the current flowing through the voltmeter V_1 is

$$I_1 = I_2 + \frac{I_0}{\sqrt{2}} \tag{11}$$

Hence we find the voltage of the power supply

$$\varepsilon = \frac{U}{\sqrt{2}} + I_1R = U_0\sqrt{2} + \frac{I_0}{\sqrt{2}}R. \tag{12}$$

In this case, the voltmeter readings are equal

$$V_1 = I_1 R = \frac{U_0 + I_0 R}{\sqrt{2}} = 1.41V, \tag{13}$$

$$V_2 = \frac{U_0}{\sqrt{2}} = 0.71V. \tag{14}$$

5) Suppose that the voltage drop across the black box is U, and the current flowing through it is I. The current flowing through the voltmeter V_2 is

$$I_2 = \frac{U}{R} \tag{15}$$

and hence the current flowing through the voltmeter V_1 is

$$I_1 = I_2 + I \tag{16}$$

Hence the voltage of the power supply

$$\varepsilon = U + I_2 R = 2U + IR. \tag{17}$$

Thus, the current flowing through the black box depends on the voltage of the power supply according to the law

$$I = \frac{\varepsilon - 2U}{R} \tag{18}$$

For convenience, we rewrite relation (18) in dimensionless form

$$\frac{I}{I_0} = \frac{\varepsilon}{U_0}\frac{U_0}{I_0 R} - \frac{U}{U_0}\frac{2U_0}{I_0 R} \tag{19}$$

Simultaneously with the relation (19), there is a relation between U and I, expressed by the current-voltage characteristic

$$I = \begin{cases} I_0\sqrt{1-\left(\dfrac{U}{U_0}\right)^2}, & \left|\dfrac{U}{U_0}\right| \le 1 \\ 0, & \left|\dfrac{U}{U_0}\right| > 1 \end{cases}. \tag{20}$$

Solving jointly (19) and (20) with Ɛ = 0, we obtain

$$U = -U_0 \frac{1}{\sqrt{1+\left(\dfrac{2U_0}{I_0 R}\right)^2}} \tag{21}$$

$$I = I_0 \frac{\dfrac{2U_0}{I_0 R}}{\sqrt{1+\left(\dfrac{2U_0}{I_0 R}\right)^2}} \tag{22}$$

Thus, the voltmeter readings are equal

$$V_1 = -V_2 = U_0 \frac{1}{\sqrt{1+\left(\dfrac{2U_0}{I_0 R}\right)^2}} = 0.45V \tag{23}$$

The corresponding graphical construction is shown in the figure 4 below, on which the straight line corresponds to equation (19).

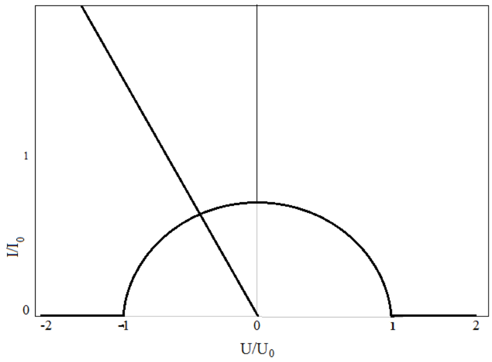

Figure 4. The current-voltage characteristic (the straight line corresponds to equation (19))

6) In the case of a voltage equal to Ɛ = 3 V, the construction yields the following figure 5

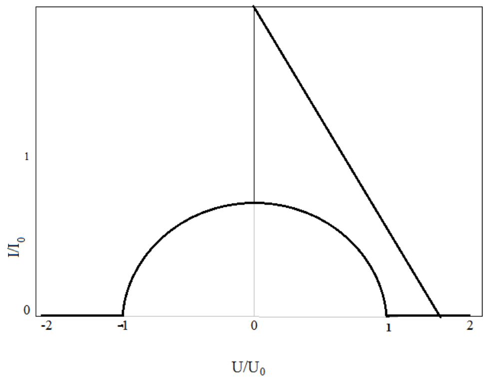

Figure 5. The current-voltage characteristic (voltage equal to Ɛ = 3 V)

from which it can be concluded that the current flowing through the black box is zero, and the voltage on it coincides with the voltage on the voltmeter:

$$V_2 = \frac{\varepsilon}{2} = 1.5V. \tag{24}$$

Hence the voltage across the voltmeter V_1 is

$$V_1 = \varepsilon - \frac{\varepsilon}{2} = \frac{\varepsilon}{2} = 1.5V. \tag{25}$$

7) The construction should give the following figure 6

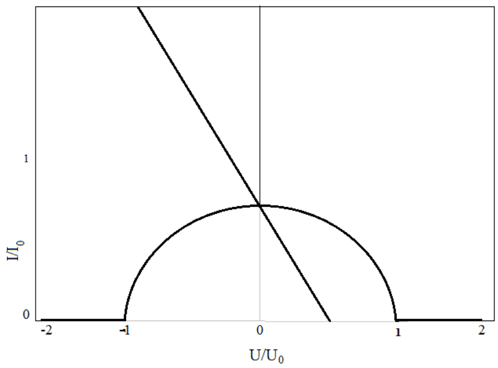

Figure 6. The current-voltage characteristic (voltage equal to Ɛ = 1 V)

from which we determine that the source voltage is equal to

$$\varepsilon = U_0 = 1V. \tag{26}$$

8) Solving jointly the system of equations (19) and (20), we obtain two roots

$$U = U_0 \frac{\frac{2\varepsilon U_0}{I_0^2 R^2} \pm \sqrt{1 + \frac{4U_0^2}{I_0^2 R^2} - \frac{\varepsilon_0^2}{I_0^2 R^2}}}{1 + \frac{4U_0^2}{I_0^2 R^2}} \tag{27}$$

This case corresponds to the construction shown in the figure7

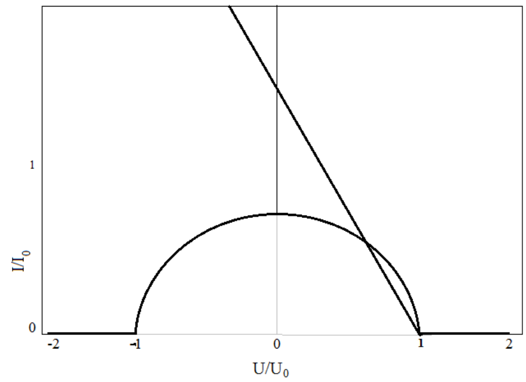

Figure 7. The current-voltage characteristic (the system of equations (19) and (20))

To a stable solution there corresponds a smaller of the roots, which is equal to

$$U = U_0 \frac{\frac{2\varepsilon U_0}{I_0^2 R^2} \sqrt{1 + \frac{4U_0^2}{I_0^2 R^2} - \frac{\varepsilon_0^2}{I_0^2 R^2}}}{1 + \frac{4U_0^2}{I_0^2 R^2}} = 0.69V \tag{28}$$

9) Not all points of intersection of line (19) and semicircle (20) correspond to stable values of current and voltage in the circuit. Let us determine which points are stable. Let the voltage on the black box increase by some small value δU, then the current through it decreases by a certain value of δI. The change in current through the voltmeter, which is connected in parallel to the black box, is equal to

$$\delta I_R = \frac{\delta U}{R}. \tag{29}$$

For the stability of the solution it is necessary to have a condition

$$-\delta I + \delta I_R > 0, \tag{30}$$

since in this case the current through the voltmeter V_1 increases, and this will cause a drop in voltage on the black box and voltmeter V_2

From (29) and (30) it follows that

$$\frac{\delta I}{\delta U} < \frac{1}{R}. \tag{31}$$

Condition (31) corresponds to line 1 in the figure 8, which is tangent to the circle and its slope to the x axis is $U_0 / I_0 R$.

Passing through the point of circle A straight line 2 from equation (19), we find the maximum voltage of the source

$$\varepsilon = \frac{U_0 + 2I_0R}{\sqrt{+\left(\frac{I_0R}{U_0}\right)^2}} = 2.12V. \qquad (32)$$

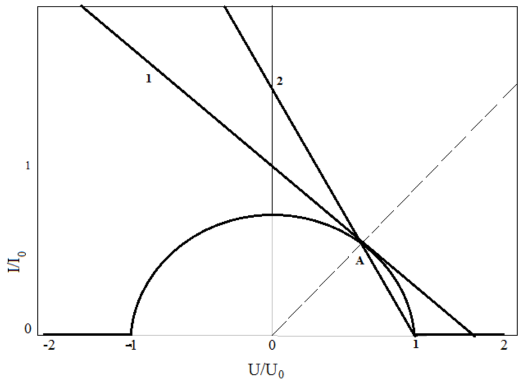

Figure 8. The current-voltage characteristic (the maximum voltage of the source)

Conclusion

Practical assignments can be used to introduce new concepts and formulas in the lesson, clarify the learning laws, and draw closer to the content of new materials. It is important to pay more attention to the ways in which it can be detected and not to pay attention to the ease or difficultness of the research. Thus, the student learns to work independently [2].

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