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The role of research tasks in teaching physics

The aim of the study is to prove the relevance of research tasks in teaching physics on the example of the «black box». The ability to use basic formulas, to know the units of measure and their ability to influence logical and abstract thinking is improving students' knowledge during the Physics Olympiad. 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. Solving the experimental tasks it is necessary to choose the theoretical proof, the method of its solution and evaluate the process of measurements, estimate the errors and analysis of received results.

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

Introduction

Undergraduate instructional labs in physics generate intense opinions [1]. 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 [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 [3].

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, and further identification and proof of attitudes.
– 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.

Method

The importance of organizing experimental research work is comprehended 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. The black box method in organization of experimental research works in following algorithm can be carried on:

1. Formulation and justification of a hypothesis that can be used as the basis for an experiment.
2. Determination of the purpose of the experiment.
3. Clarification of the conditions necessary to achieve the goal of the experiment.
4. Planning an experiment.
5. Selection of the necessary devices and materials.
6. Collecting installation.
7. Conducting an experiment, accompanied by observations, measurements and recording their results.
8. Mathematical processing of measurement results.
9. Analysis of the results of the experiment, formulation of conclusions.

Process skills are fundamental to science, allowing everyone to conduct investigations and reach conclusions [4].

As an example we present the solution of the following task:

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 $\varepsilon = 9.00$ V is connected to them.

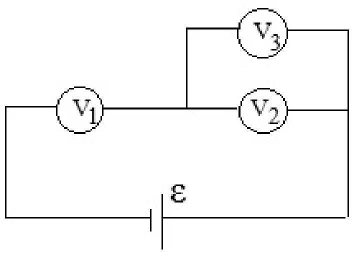

Figure 1.The circuit diagram

A black box is connected instead of one of the voltmeters, the current-voltage characteristic of which have the form shown in the Figures 2 and 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.

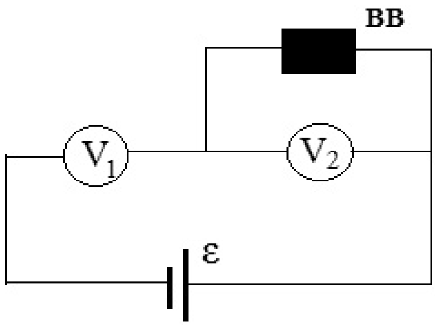

Figure 2. The circuit diagram of with black box

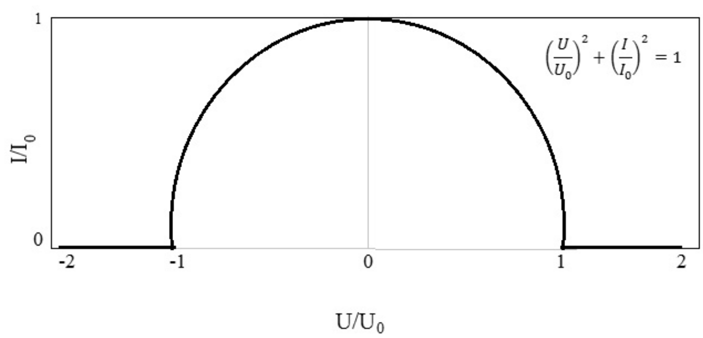

Figure 3. The current-voltage characteristic of the circuit

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 ε, 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 $\varepsilon = 3.00$ 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 ε = 2.10 V.
9) Find the maximum source voltage at which the 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

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

and is

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

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

$$\varepsilon = \frac{U}{\sqrt{2}} + I_1 R = U_0 + \frac{I_0}{\sqrt{2}}R. \tag{12}$$

In this case, the voltmeter readings are equal

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

$$V_1 = \frac{U_0}{\sqrt{2}} = 0.71V. \tag{14}$$

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 $\varepsilon = 0$, 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).

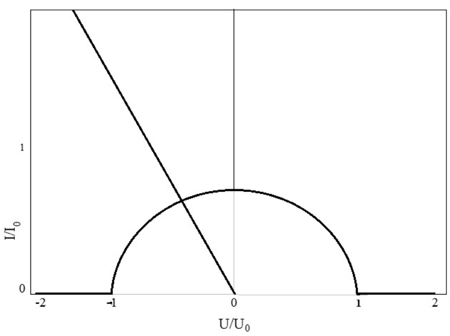

Figure 4. The current-voltage characteristic of the corresponding graphical construction

6) In the case of a voltage equal to ε = 3 V, the construction yields the following in the Figure 5

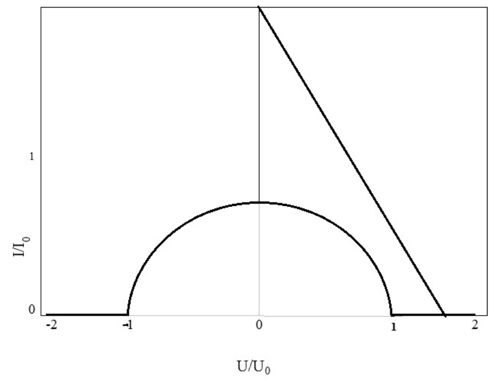

Figure 5. The corresponding graphical construction with a voltage equal to ε = 3 V

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 as in Figure 6.

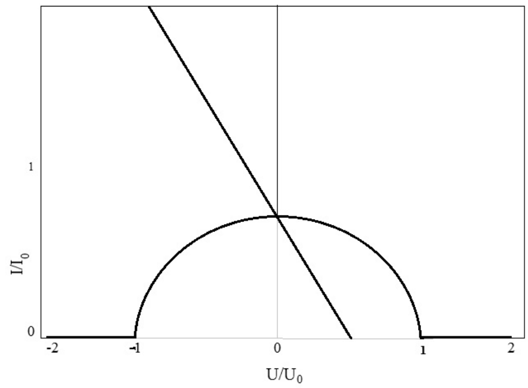

Figure 6. The corresponding graphical construction with a voltage equal to ε = 1V

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 Figure 7.

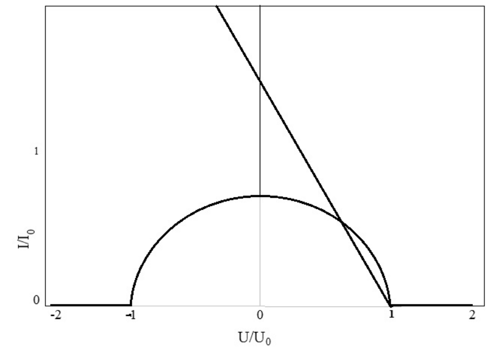

Figure 7. The current-voltage characteristic of the construction

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

$$U = U_0 \frac{\frac{2\varepsilon U_0}{I_0^2 R^2}\sqrt{1+\frac{4U_0^2\varepsilon_0^2}{I_0^2 R^2 I_0^2 R^2}}}{1+\frac{4U_0^2}{I_0^2 R^2}} = 0.69V. \quad (28)$$

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

$$\delta I_R = \frac{\delta U}{R}. \quad (29)$$

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

$$-\delta I + \delta I_R > 0, \quad (30)$$

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

$$\frac{\delta I}{\delta U} < \frac{1}{R}. \quad (31)$$

Condition (31) corresponds to line 1 in the figure, 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

$$\varepsilon = \frac{U_0 + 2I_0 R}{\sqrt{+\left(\frac{I_0 R}{U_0}\right)^2}} = 2.12V. \quad (32)$$

The construction should give the following Figure 8.

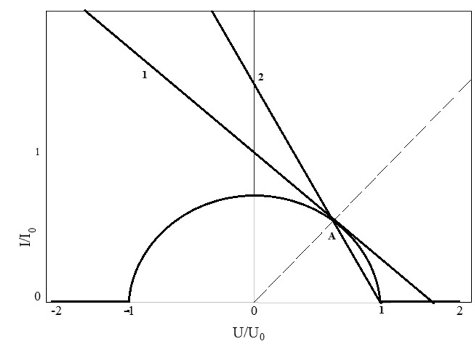

Figure 8. The construction of the final diagram

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. These can be adjusted to target the development of a wide range of specific skill sets as well as deepen students understanding of different physics principles and concepts [5–7]. Black box method enhances students' interest in learning, which in turn promotes the development of personality as a future professional. In carrying out such research work, students acquire practical skills in experimentation, the ability to put forward hypotheses and find ways to test them. Students learn to analyze and process the information received, present it in the form of graphs, diagrams. Undoubtedly, research work by students forms the independence and creativity of thinking.

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Физиканы оқытудағы зерттеу тапсырмаларының рөлі

Зерттеудің мақсаты «қара жәшіктің» мысалында физиканы оқытудағы зерттеу тапсырмаларының маңыздылығын дәлелдеу. Негізгі формулаларды қолдана алу, өлшем бірліктерін білу, олардың логикалық және абстракті ойлау қабілетіне әсер ету физика пәнінен олимпиада кезінде студенттердің білімінің негізгі көрсеткіштері болып табылады. Тапсырманы орындау кезінде есептерді шығаруда алгоритмдер мен қажетті нұсқаулар қолданылған. Білімді тәжірибеде қолдану оқу процесінде жетекші орын алады, өйткені студенттердің тапсырмаларды орындаудағы жан-жақты белсенділігі ақыл-ой жұмысы арқылы жүзеге асырылады. Олимпиадалық тапсырмалар шығармашылық әлеуетті пайдалануға және сол арқылы оларды қолдану аясын кеңейтуге мүмкіндік береді. Олимпиада тапсырмаларын орындау үшін қажетті теориялық және тәжірибелік дағдыларды талдау негізінде студенттер нақты ақыл-ой әрекетінсіз жасай алмайтындығын ескеру қажет. Эксперименттік есептерді шешкен кезде оны іске асырудың теориялық негіздемесі, оны шешу әдісі таңдалады, өлшеу процесі, қателіктерді бағалау және нәтижелер талдауы бағаланады.

Кілт сөздер: логикалық ойлау, эксперименттік зерттеу жұмысы, қара жәшік, олимпиадалық тапсырмалар, физика.

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Роль исследовательских задач в обучении физике

Цель исследования — доказать весомость исследовательских задач в обучении физике на примере «черного ящика». Умение использовать основные формулы, знание единиц измерения и их способность влиять на логическое и абстрактное мышление являются основными показателями знаний студентов во время предметной олимпиады по физике. Для расчета задач использованы алгоритмы и необходимые инструкции; применение знаний на практике занимает ведущее место в учебном процессе, поскольку всесторонняя деятельность учащихся при выполнении заданий осуществляется посредством большой умственной работы. Олимпиадные задания позволяют использовать творческий потенциал и тем самым расширить сферу их применения. Необходимо учитывать, что студенты не могут обойтись без реалистической мыслительной деятельности на основе анализа теоретических и практических умений, необходимых для выполнения олимпиадных заданий. При решении экспериментальных задач выбирается теоретическое обоснование их выполнения, метод решения, оценивается процесс измерений, оценки погрешностей и осуществляется анализ полученных результатов.

Ключевые слова: логическое мышление, экспериментально-исследовательская работа, черный ящик, олимпиадные задания.

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