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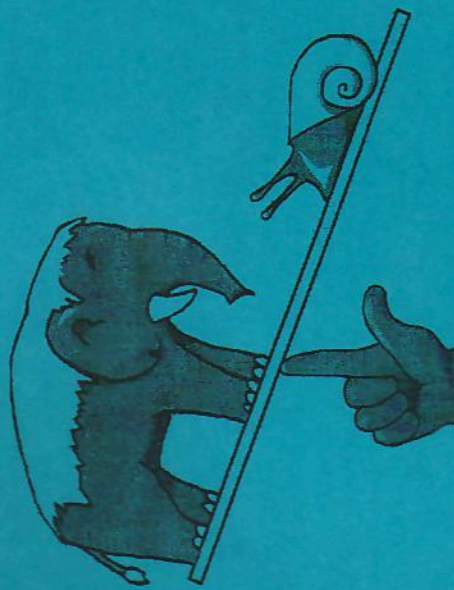
XV Международная олимпиада «Туймаада»



Физика

Экспериментальный тур

Методическое пособие



Якутск, 1–8 июля 2008 г.

Видим, что ёмкость довольно большая. При столь больших ёмкостях после зарядки конденсатора диод светился бы ещё довольно долго (порядка нескольких минут), в то время как в нашем случае он гаснет почти мгновенно (время его угасания менее полсекунды). Условие задачи допускает наличие в ящике реле и источников, поэтому можем нарисовать окончательную схему (рис. 12), где буквой P обозначены реле и его нормально разомкнутый контакт, а буквой K — ключ, выведенный наружу.

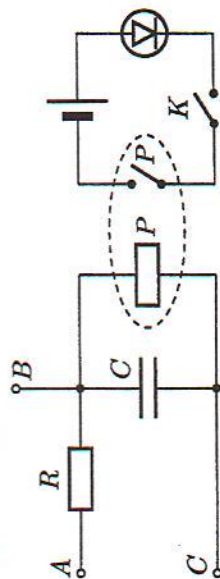


Рис. 12

Учитывая, что напряжение на ящике не поднимается выше 1,5–2 В, заключаем, что реле твердотельное, а назначение ключа K в том, чтобы воспрепятствовать постепенной разрядке источника через пульт и большое, но конечное сопротивление контакта твердотельного реле. Параметры элементов второй цепи определить в рамках задачи невозможно.

Примерная система оценивания

Снятие ВАХ между A и B , проверка на гистерезис и не менее 9 точек или не менее 15 точек	1
Значение $R = 5,45-5,75$ кОм	1
Погрешности	1
Анализ схемы, общие исследования	2
Объяснение наличия конденсатора	1
Предварительная схема	2
Идея линеаризации зависимости $t(U)$	1
График, не менее 6 измерений	1
Значение C	1
Погрешность	1
Окончательная схема	1
Её пояснение	1
Другие существенные выводы (например, полярность конденсатора)	1

Senior league

Problem 1. Salt density

Determine average density ρ of a salt crystal.

Equipment. Measuring-glass, syringe, plasticine, salt, water, thread.

Note. Water density is $\rho_0 = 1000$ kg/m³.

Problem 2. Black box with delayed response

Determine the simplest circuit design of a black box and parameters of elements it includes. Inside the black box there can be lineal elements, diodes, relays, current supplies.

Equipment. 9 V dc current supply, variable resistor, fixed-value resistor, multimeter, stop-watch, black box with three terminals (A , B and C).

ATTENTION! When making measurements do not connect terminal C to the positive side of the supply because this can damage the circuit. Take into consideration that the black box may include elements with voltage limits, so do not connect it directly to the supply but use a voltage divider — the variable resistor. Damage caused to the equipment may affect your mark.

Note. To return the circuit of the black box to initial condition short-circuit terminals B and C after each measurement. Before starting the experiment turn the black box on: switch the key over position «ON». Do not turn the black box off until the experiment is over.

Possible solutions

Senior league

Problem 1. Salt density

Pull out the syringe plunger, close the syringe fitting with plasticine to prevent water entry and tie up the syringe with the thread. Pour some water into the measuring-glass, put the syringe into it with its opened end facing upwards and measure volume V_1 . Put the syringe out with the thread, fill it with salt for about three quarters, put it again into the measuring-glass (the syringe must float) and measure volume V_2 . According to the condition of syringe floating determine mass of the salt in the syringe $m = \rho_0(V_2 - V_1)$.

Now determine volume of this mass of salt. One cannot measure salt volume by simply putting it into the measuring-glass without water because there is an air between salt crystals and its volume should not be taken into account. Also one cannot put salt into the measuring-glass with unsalted water because some amount of salt will dissolve. Therefore it is necessary to make saturated solution by dissolving some amount of salt (not the measured one), put down its volume V_3 , then put the measured salt into this solution and measure new volume V_4 . Then find the salt volume $V = V_4 - V_3$.

Thus, required salt density is

$$\rho = \frac{m}{V} = \frac{V_2 - V_1}{V_4 - V_3} \rho_0.$$

The participants were offered to carry out the experiment using syringes with volume $V_a = 20$ ml and measuring-glasses with volume $V_b = 100$ ml. By the results of measurements $V_1 = 57$ ml, $V_2 = 81$ ml, $V_3 = 53$ ml, $V_4 = 64$ ml find

$$\rho = (2.18 \pm 0.15) \text{ kg/m}^3.$$

Tabulated value of salt density is $\rho = 2.165 \text{ kg/m}^3$.

Grading system

Measuring V_1	1
Measuring V_2	1
Formula for salt mass	1
Understanding of what volume should be measured	1
Idea of saturated solution	3
Measuring V_3	1
Measuring V_4	1
Formula for salt density	1
Answer within limits $1800\text{--}2500 \text{ kg/m}^3$	1
Answer within limits $2000\text{--}2300 \text{ kg/m}^3$	1
Answer within limits $2100\text{--}2200 \text{ kg/m}^3$	1
Error estimate	2

Problem 2. Black box with delayed response

According to the statement of the problem, the circuit may include current supplies, so check for their availability. For this purpose connect the multimeter in voltmeter mode to each pair of terminals and check for voltage. In any case the voltage is zero. Thus, there are no obvious facts indicating that there are any current supplies.

Now check if there are any condensers. First connect a pair of terminals to the current supply for a while, then connect them to the multimeter in voltmeter mode. Doing this for four times (as far as terminal C must not be connected to the positive side of the supply), find out that there is no condenser between terminals A and B , but between B and C and between A and C there is, so it is no use measuring volt-ampere characteristics between these pairs of terminals.

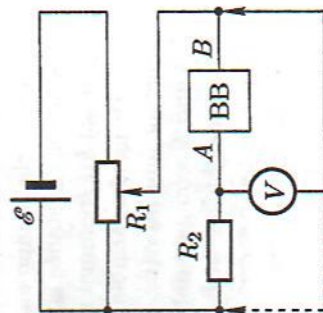


Fig. 13

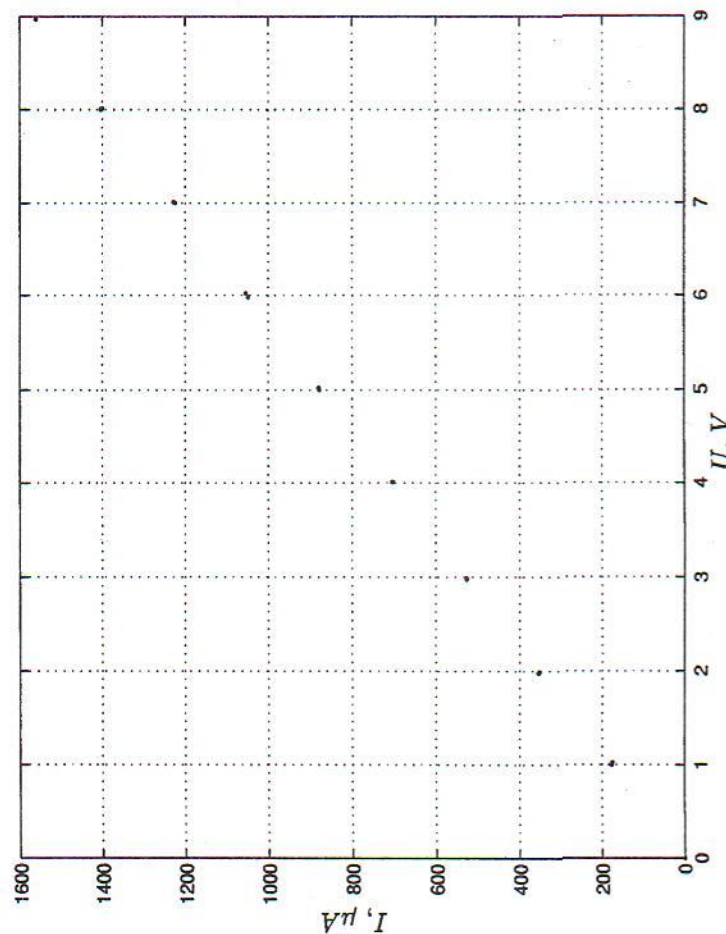


Fig. 14

With the multimeter in ohmmeter mode determine resistances of the resistors given in the equipment. Variable resistors with full resistance $R_1 = (4.9 \pm 0.5) \text{ k}\Omega$ (nominal resistance is $5 \text{ k}\Omega$) and fixed-value resistors with resistance $R_2 = (1.01 \pm 0.04) \text{ k}\Omega$ (nominal resistance is $1 \text{ k}\Omega$) were given.

Using the variable resistor as a voltage divider and the fixed-value resistor as a current indicator (fig. 13), measure volt-ampere characteristics between terminals A and B , compare data received at increasing and decreasing voltage. The diagram is a straight line with no hysteresis (fig. 14). So it can be concluded that a resistor is connected between terminals A and B . By angular coefficient its resistance can be determined. The black boxes include resistors with resistance $R = (5.6 \pm 0.1) \text{ k}\Omega$ (nominal resistance is $5.6 \text{ k}\Omega$).

Pay attention to the fact that if voltage supplied to terminals B and C is lower than some definite value the light-emitting diode (LED) does not light up, in the other case it lights up immediately. Besides, if voltage supplied to terminals A and B is lower than some definite value the LED also does not light up, in the other case it lights up after a while.

Taking what has been said into consideration, the circuit design may be supposed (fig. 15). According to the statement, terminal C must not be connected to the positive side of the current supply, therefore it can be proposed that condenser is polar.

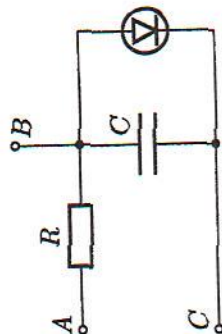


Fig. 15

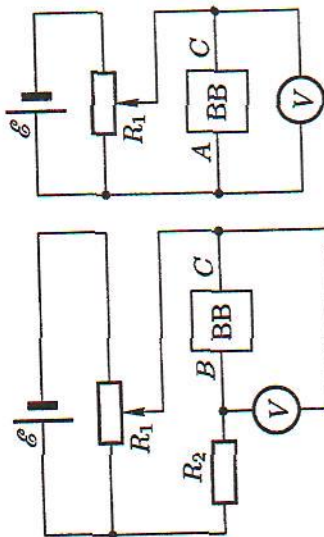


Fig. 16

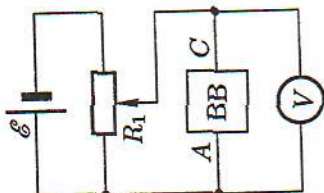


Fig. 17

Determine the open voltage of the LED (as will soon become evident, it is the barrier voltage of a solid-state relay). Wire up the circuit (fig. 16) and, turning the dial of the variable resistor very slowly, wait for the LED to light up. It must not be doing on a sudden because the condenser must have time to charge. Notice that the voltage across the black box does not rise above $1.5\text{--}2 \text{ V}$. Diodes (as will soon become evident, solid-state relays) in the black boxes open at voltage $U_o = (1.16 \pm 0.02) \text{ V}$.

Now wire up the circuit (fig. 17). Law of voltage variation across the condenser is:

$$U_c(t) = U_{in} \left(1 - e^{-t/(RC)} \right),$$

where U_{in} is the voltage between terminals A and B . This voltage should be measured in a steady state with complete circuit. It differs from the voltage between the middle and the end terminals of the voltage divider with open circuit, as far as the active resistance of the black box is comparable with the resistance of the part of the variable resistor with which the black box is multiplied. Determine a time needed to the LED to light up dependence on voltage supplied to the black box:

$$t = -RC \ln \left(1 - \frac{U_o}{U_{in}} \right).$$

Linearize this law: plot $t(\ln(1 - U_o/U_{in}))$ (fig. 18). Since resistance of the resistor in the black box is known, condenser capacity may be determined by angular coefficient of the plot. Nominal capacity of the condensers in the black boxes is $4700 \text{ }\mu\text{F}$.

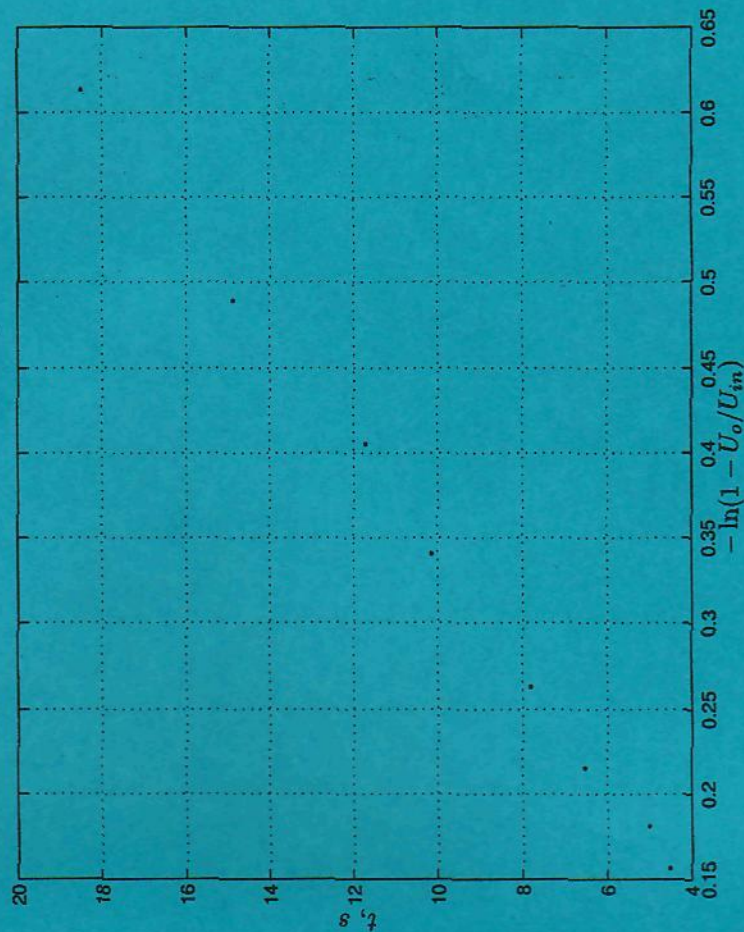


Fig. 18

Results of measurements made for one of the black boxes: $R = (5.7 \pm 0.3) \text{ k}\Omega$, $\alpha = (30 \pm 4) \text{ s}$ — angular coefficient, $C = (5300 \pm 700) \text{ }\mu\text{F}$.

The capacity is quite large. With such capacities the LED should light for about few minutes after charging the condenser, but in our situation it goes out

almost immediately (in less than half of a second). According to the statement of the problem, the black box may include relays and current supplies, so design the final circuit (fig. 19), where the relay and its normally open contact are lettered P and the brought-out key is lettered K .

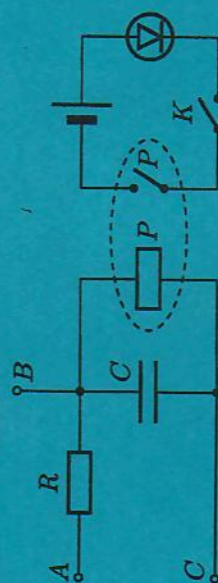


Fig. 19

Considering that voltage across the black box does not rise above 1.5–2 V, conclude that the relay is a solid-state relay and the key's assignment is to prevent current supply's gradual discharging through large but finite resistance of a contact of the solid-state relay. Parameters of secondary circuit elements can't be determined within this problem.

Grading system

Measuring volt-ampere characteristics between A and B , checking for hysteresis and at least 9 points or at least 15 points on the diagram	1
Value $R = 5.45\text{--}5.75\text{ k}\Omega$	1
Errors for R	1
Analysing the circuit, general investigation	2
Explaining presence of the condenser	1
Preliminary circuit design	2
Linearizing the plot $t(U)$	1
Diagram, at least 6 measurements	1
Value C	1
Errors for C	1
Final circuit design	1
Explanation	1
Other significant conclusions (for example, about polarity of the condenser)	1