Practical 2.6.

Power Supply Characterization

INTRODUCTION

Power supply is a device in which a spatial separation of electric charges occurs under the influence of external (not of the electrostatic nature) forces, that is, one electrode is continuously provided with the positive charged, and the other – with the negative one. If the electrodes (also referred to as called poles or clamps) are connected by a conductor, then there is an electric field created in the conductor whose carriers are influenced. Hence, there exist a current in the conductor. Note: power supply is a general term; depending on the configuration, it may serve either as a *current source* or as a *voltage source.*

Thus, the power supply must ensure the movement of charges as inside the source, to maintain spatial separation charges, and at the outer part of the chain relative to the source. This ability of sources is usually characterized by the "*electromotive force*" - **ε** (*emf, e.m.f.).* It is numerically equal to energy, which the source is able to supply to a single positive charge for its movement along the full chain. The unit of measurement of *emf* is volt: "1 volt" - **1V = 1 J / C**. This energy is dissipated by the resistance ***R*** on the external section of the circuit (called the *load*) and the internal resistance of the source ***r***. From Ohm's law for the *complete chain* it follows that:

$$\varepsilon = IR + Ir = U + Ir = U_{p.s.} + Ir, \qquad (1)$$

with I being the current, U – voltage across the load, which usually coincides with the voltage across the power supply clamps – $U_{p.s.}$

From the relation (1) it follows that the emf of a power supply can be measured as the voltage at the terminals of the source $U_{p.s.}$, when the current in the circuit is zero. This can be implemented in two ways. Firstly, by connecting to the terminals of the power supply a voltmeter with a large (more than 10^6 Ohm) input resistance and designed to measure the corresponding voltage with the required accuracy. Secondly, by compensating the current through the source under investigation using a special electrical circuit which has been previously calibrated using a reference source. The latter method is referred to as the "compensation method" and is used in this work.

It is important to ensure an efficient use of the power supply energy, which is dependent on both the R_{load} and on internal resistance of the power supply r. In accordance with the Joule-Lenz law, the total power of the source (P) and the “useful” power (P_u) released in the load are:

$$P = \varepsilon \cdot I, \quad P_u = U \cdot I. \qquad (2)$$

Expressing the strength of the current through Ohm's law, we can write:

$$P = \varepsilon^2 / (R + r), \quad P_u = I^2 R = \varepsilon^2 \cdot R / (R + r)^2. \qquad (3)$$

Accordingly, the efficiency of the source is:

$$\eta = P / P_u = R / (R + r). \qquad (4)$$

It follows from (3) that as R increases, the total power decreases monotonically, while the useful power first increases and then decreases, that is, it has a maximum. Differentiating P_u with respect to R, one can obtain that the useful power is maximal at $R = r$ and equals to $P / 2$. As to η, it increases monotonically with increasing R, tending to 1, and at R = r equals to 0.5.

Experimental tasks:

1) measurement of the electromotive force of the power supply by the compensation method;
2) obtaining data needed for total and useful power investigation and efficiency investigation depending on the load resistance;
3) Determination of the power supply optimal operating regime.

EXPERIMENTAL SETUP

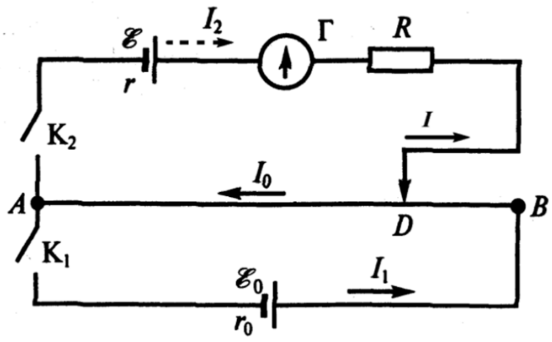

Figure 6. 1

Experimental setup is depicted in figure 6.1. As an auxiliary source ε_0, the rectifier BC4-12 is used, to the terminals of which the rheochord AB is connected. Compensating voltage is taken between the point *A* and the rheochord wiper (point *D*) and is applied to the source of interest *ε* in the opposite polarity.

A galvanometer (Γ) is used for observation of the compensation: when the voltage provided by the power supply is completely compensated the current through the galvanometer is zero. Then the unknown *emf* will be equal to the compensating voltage which is set by changing the position of the rheochord wiper. Since the rheochord is used as a voltage divider, then:

$$U_{AD} = \varepsilon_0 \cdot R_{AD} / (R_{AB} + r_0), \text{ with } (R_{AB} + r_0) << R$$

Although the values of ε_0, R_{AB} and r_0 are not known in advance, they do not change during the measurement. Therefore, for each measuring setup, we can assume that U_{AD} is proportional to R_{AD} or L_{AD} (AD section length), that is, $\boldsymbol{U_{AD} = C \cdot L_{AD}}$.

Thus, in fact the measurement of the *emf* can be done by measuring the length of the section AD, at which compensation occurs. Of course, first it is necessary to determine the value of the calibration factor ***C***, that is, in the final analysis, to calibrate the rheochord scale in Volts. To do this, instead of the source being investigated use a reference source, *emf* of which is known with a high accuracy. As such, the normal element of Weston (ε_n = 1,018V) may be used. Find a position of the rheochord wiper L_n, at which compensation occurs, and determine ***C*** as $\boldsymbol{\varepsilon_n / L_n}$. When the normal element is switched on, it must be protected against overload. For this purpose, a resistance *R*, limiting current is used. After replacing the Weston element with the source under investigation, this resistor is not removed from the circuit so as not to disrupt the calibration.

As the power supply under investigation, "AA" batteries are used in the work, installed in a common housing. In order to compose a battery for **Task 2**, it is necessary to connect them to each other by opposite poles. The theoretical value of the *emf* of such a battery equals to the sum of the *emf* of the sources.

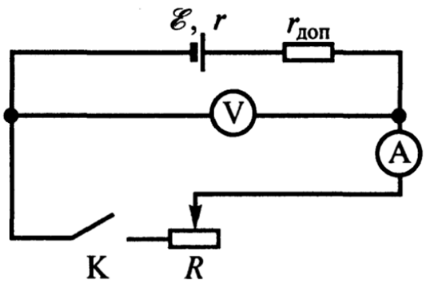

Figure 6. 2

In contrast, *opposite connection* (*subtractive polarity*) is realized by connecting them with the same poles. The polarity of the battery in this case is determined by the polarity of the free terminal from a source with a higher *emf* value, and the polarity of the free terminal from the other source is considered to be opposite. Theoretically the value of the total *emf* of such a battery equals to the difference of the *emf* of the sources.

Experimental setup for study the influence of the load resistance on the energy efficiency of the power supply is shown in Fig. 6.2. An additional external resistance r_{add} is used in series with the internal resistance of the source *r*.

MEASUREMENT AND DATA PROCECCING

Task 1. Determination of the calibration factor C

Table 1		
measurement	L_n, mm	C, V/mm
1		
2		
3		
C_{avg}		

After obtaining a practical permission, assemble experimental setup according to Fig. 6.1 using the normal Weston element. In this case, the normal element and the rectifier must be connected through the corresponding keys to the common terminal of the rheochord with the same poles **(!)**. Pay attention to the fact that the key which must be closed first, is connected to the rectifier. As the limiting resistance R use the resistance "ДВТ". To move the wiper of the rheochord use a rotating handle on its right side. After checking the assembled setup, turn on the rectifier.

Press the key and set the rheochord wiper to the position at which the current through the galvanometer becomes zero. Release the key. To avoid rapid discharge of batteries, do not keep the key pressed for too long.

Write down the 1st L_n value in Table 1. Slide the rheochord wiper in the same direction. Press the key again. Find a new position of the rheochord wiper, at which the compensation condition is obtained. Release the key. Record the new L_n value, slide the wiper arbitrarily and perform the measurement for the 3rd time. Calculate the factor C, as well as its average value C_{avg}, required further. Fill in Table 1.

Task 2. Determining *emf* of a battery

Table 2			
Battery	L_1, mm	$\varepsilon_{expected}$, V	$\varepsilon_{measured}$, V
1		(use nominal value)	
2			
1+2		(use calculation based on the voltage measurement on the batteries individually)	
1-2			

Disconnect the Weston element and connect one of the batteries instead, with regard to its polarity. Measure L_1, write it down in Table 2, calculate ε_1.

Repeat the measurement for the second battery, as well as for the serial and opposite connections of these batteries. Compare the experimental and calculated values of the *emf* of the two batteries connected in series and opposite to each other.

Task 3. Study of the total and useful power dependence on the load resistance

Assemble the experimental setup in accordance with Fig. 6.2. Here, rectifier BC-24 is used as the source, For r_{add} resistance *"P34"* is used, and a resistance box is used as the load resistance. The voltage is measured with help of a digital multimeter, and for measuring the amperage, an analog multimeter "Ц4511" is implemented.

Set the resistance switch of P34 to the "200 Ω" position. Turn on the multimeter and set the measurement limit to 20 V DC. Turn on the source. Without closing key K, record the voltmeter readings as ε = ... and use the resulting value in the future as the *emf*.

!Note: Despite the illegitimacy of such a substitution, in this case it is completely permissible, since the investigated quantities do not depend on of the absolute value of the *emf*.

Set the load resistance to R = 50 Ω. Set the milliammeter to the DC measuring mode and the measurement limit of 30 mA. Close the key and take the first measurement.

Table 3						
#	R, Ohm	U, V	I, mA	P_{total}, W	P_{useful}, W	η
1	50					
2	100					
…	…					
6	300					
7	400					
8	500					
9	700					
10	1000					

If necessary, change the measurement limit of the milliammeter so that the arrow would be on the right side of the scale, but not off the scale. Write down the values of *U* and *I* in Table 3. Repeat the measurements, increasing the resistance *R* in accordance with Table 3. From the measurement data, calculate the total and useful power and efficiency η.

Plot on a sheet of the graph paper $P_{total}(R)$, $P_{useful}(R)$, $\eta(R)$. Compare result with the theoretical prediction.

After the work is done, clean up the workspace disassembling the setup.

QUESTIONS AND EXERCISES

1. What direction of electric current is considered to be positive?
2. What is *emf* ?
3. Which part of the chain is called homogeneous, and which is not homogeneous?
4. Write down Ohm's law for the portion of the circuit containing a source of the *emf*.
5. What is the rule of signs?
6. Formulate Ohm's law for the complete chain.
7. What is electrical conductivity? In what units is it measured?
8. How does the total resistance of conductors connected in series (or in parallel) corresponds to that of each of them? Is it greater or smaller?
9. Two types of chemical current sources are known: galvanic cell and accumulator. What is a difference between them?
10. How the characteristics of chemical sources change over time the current?
11. What other types of current sources, besides chemical ones, do you know?
12. Why is the voltage at the source terminals equal to the *emf* ?
13. Draw a potential diagram of a circuit in Task 3 of Practical 5, if the sources are interchanged.
14. Draw a potential diagram of a circuit in Task 3 of Practical 5, if you change the polarity of one of the sources.
15. How to connect two identical supplies in order to get the maximum voltage on the load?
16. What is the potential danger of a non-working, but connected to the electrical network equipment?
17. Is it possible to compensate the *emf* ε if $|\varepsilon_0| < |\varepsilon|$(Figure 6.1)?
18. Is the multiplier C the same for different setups available in laboratory?
19. Formulate the law of Joule-Lenz.
20. Derive the condition for obtaining the maximum useful power in the circuit.
21. Under what conditions a maximum current can be obtained assuming a given power supply? How this current is called?
22. Formulate the rules of Kirchhoff.
23. From what fundamental law follows the first Kirchhoff's rule?
24. Formulate the rule of signs for *emf* and voltage drop for the second Kirchhoff's rule.
25. Apply the Kirchhoff rules to explain the operation of the setup presented in Fig. 6.1.