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CONTENTS

1 INTRODUCTION

Basic goal of the laboratory work manual on Physics is to enable students to learn important physical phenomena by experience. Laboratory work description does not try to give students a complete picture of the studied phenomena. Such presentation can only be achieved as a result of study of lectures and textbooks.

Large attention in the laboratory work manual on Physics for the students of technical professions is devoted to the handling of the measured results. Prior independent preparation, above all theoretical, is needed for successful completion of the work.

Every laboratory work is supposed to take two academic hours. Before the class a student must prepare a protocol of laboratory work and learn appropriate theoretical material.

During the class students do the necessary measurements, execute calculations and take the report to the conclusion. Measured results are discussed with a teacher and confirmed.

Fully designed report on laboratory work should be given to the teacher before the end of the class. It must include: title sheet, laboratory work number and name, list of devices and installations, purpose of work, drawing of the setting, calculation formulae, table of the measurement results and calculations, conclusions, as the result of the work. Graphs must be done on a millimeters paper.

If a student does not have time to support the laboratory work before the end of the class, he/she is allowed to design a report (graph) with the use of the computer programs (Excel, Origin) for the next class.

Laboratory work is considered done after the successful speech in support in front of a teacher (report explanation + mark for theoretical material).

Support of report: purpose of work + experimental method + conclusions.

Theoretical material: knowledge of the physical phenomena, which was studied in this laboratory work (laws, formulas).

2 SAFETY AT WORK WITH ELECTRICAL CIRCUITS

In the laboratory of electricity and magnetism you must strictly observe safety rules, when you are working with electrical circuits.

1. You need to be careful using appliances. Before using the appliance, it is necessary to examine the structure and rules for dealing with it. If you found fault devices you must tell to a teacher or laboratory assistant.
2. The assembled electrical circuit can be connected to a power supply only after checking it by the teacher or laboratory assistant.
3. Do not make a switching in the circuit which is under electric voltage.
4. Do not leave circuit unattended, which is under electric voltage.
5. Do not touch bare parts of the circuit.
6. In identifying of individual heating parts of circuit or electrical parts, especially the appearance of a smell of burning, the current source should be immediately turned off and you must to inform a teacher about that occasion.
7. After the finishing of measurements it is necessary to disconnect power supply.
8. After the calculations and view the results obtained by the lecturer electric circuit must be dismantle, workplace must be tidy.

3 DEVICES FOR ELECTRICAL MEASUREMENTS

3.1 The sensitivity and value of a point for electrical measurement device

Sensitivity S of the device is the ratio of linear or angular displacement of pointer d*a* to change the measured value d*x*, which caused that move.

$$s = \frac{da}{dx} \qquad (3.1)$$

The dimension of sensitivity depends on the nature of the measured value (sensitivity of the device relative to the current to voltage and so on).

Value, opposite to the sensitivity, is called the point value of the device. It is determined by the electrical quantities, causing deviations in one division. In general, the value of a point is the difference of the measured values for the two neighbouring labels. Value of points depends on the top and bottom landmark measuring device and the number of divisions of the scale. For example, in Figure 3.1 shows the scale of the device, designed to measure the direct current from 0 mA to 300 mA, with 60 divisions.

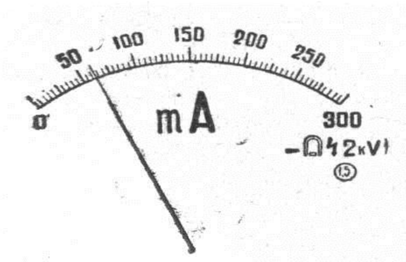

Figure 3.1

Value of this device is 300: 60 = 5 mA / division. Sensitivity s = 0,2 division. / mA.

3.2 Errors of measurement tools

To the means of measurements includes measuring instruments and installations. Each device provides error because it cannot be made perfect. Accuracy of measuring instruments does not exceed a certain value, called the main *permissible error limit of the measuring* device (PELM or МОДП). PELM (МОДП) is set by national standards and defined as absolute, relative and reduced errors.

Absolute error of instrumental X is a deviation $\delta = |a - X|$, where α is called an index of an instrument; X is the true value of the quantity measured. Typically, δ is quantity of the instruments minimum value scale. For example: the ruler error is δ = 1mm.

Relative error of measurement is the ratio

$$\varepsilon = \frac{\delta}{X}\,. \qquad (3.2)$$

Typically, it is defined as a percentage

$$\varepsilon = \frac{\delta}{X} \cdot 100\% \,. \tag{3.3}$$

Brought error or *precision class* determined by the ratio

$$\gamma = \frac{\delta}{D} \cdot 100\% \,, \tag{3.4}$$

D - maximum value of scale tool. For example, we have ammeter with scale of 0 ÷ 1 A, accuracy class 0.5. This means that γ = 0,5%, absolute error

$$\delta = \frac{\gamma \cdot D}{100} = \frac{0{,}5 \cdot 1A}{100} = 5 \cdot 10^{-3} A.$$

If the ammeter shows 0.3 A relative error is

$$\varepsilon \approx \frac{5 \cdot 10^{-3} A}{0{,}3A} \cdot 100\% = 1{,}7\% \,.$$

Under the *resulted error* of the device with two sided scale (zero in the middle) refers *error* attributed to the amount of the upper and lower limits of measurement.

The need to introduce *reduced errors*, because even at a constant absolute error for the entire instrument scale relative error with decreasing values of the measured value increases. Precision of instruments for electro-measurements is the most important characteristic and that underlies in the instrument division into classes. According to ГОСТ, with increasing precision, instruments are divided into seven classes as follows: 0.1; 0.2; 0.5; 1; 1.5; 2,5 and 4. The class index equals brought error of accuracy in percentage. Absolute error is given by

$$\delta = \frac{\gamma \cdot D}{100}. \qquad (3.5)$$

Instruments of classes 0.1, 0.2, 0.5 are used for accurate measurements and laboratory called precision. In technique is used devices with less accurate grade 1; 1.5; 2,5 and 4 (technical). Devices with an error greater than 4%, considered extracurricular. The class of the device is usually indicated on its scale.

3.3 Classification of devices for the principle of action

Magnetoelectric system. Devices of magnetoelectric system intended for measuring current and voltage in DC circuits. During applying various converters and rectifiers magnetoelectric devices can also be used for power measurements in the circuits of high frequency alternating current for measuring non-electrical parameters (temperature, pressure, movement and so on). Laboratory measurements in DC circuits are carried out mainly through magnet devices. Work of magnetoelectric system devices is based on interaction of field of immovable magnet and moving coil, on which flows the measured current. The torque acting on the coil is proportional to the strength of current passing through it. The linear relationship between the current and the deflection angle provides the uniformity of scale device. Corrector allows to change the position of the fixed end of one of the helical springs and thereby establish pointer to zero. Therewith the frame of moving coil is made of aluminium (i.e. of conductor) induction currents that occur when moving it in a magnetic field, creating a braking torque that causes rapid sedation of system during the measurement.

The advantages of magnetoelectric system are: high sensitivity and accuracy; immunity to external magnetic fields; low energy consumption; uniformity of scale; aperiodicity. The disadvantages of the devices of the system are: the possibility of measuring only DC; sensitivity to overload.

Electromagnetic system. Devices of electromagnetic system intended for measuring the current and voltage circuits in AC and DC.

The principle of action of devices of electromagnetic system based on the interaction of the magnetic field coils A, on which the measured current flows and movable iron core B (Fig. 3.2). Iron core B with a special form of holes fixed eccentrically on the axis O. Rotating around this axis, the core enters to the slit coil. Under the influence of the magnetic field of the coil core in an effort to settle so that the cross as the greatest number of power lines, involved into the coil by increasing the current strength in it. Counteracting the moment is created by coil springs K.

The devices of electromagnetic system is provided air damper D, which is a chamber in which the aluminium piston E moves. At the turn of the core piston encounters air resistance, as a result oscillation of moving part quickly fade.

The magnetic field is proportional to the coil current, the magnetization of the iron core is also increased with increasing current. Therefore, we can roughly assume that devices electromagnetic system torque is proportional to the square of the current. Counteracting moment, which is created by spring K, is proportional to the angle of rotation of the moving parts of the device. Thus, the scale of the electromagnetic device is uneven, quadratic.

With the change of current direction with the direction of the magnetic field changes polarity of magnetizing core. Therefore, electromagnetic system devices are used for measuring both direct and alternating currents of low frequency. The advantages of these devices are: the possibility of measuring direct and alternating currents; simple design; mechanical strength; endurance relatively to overloads.

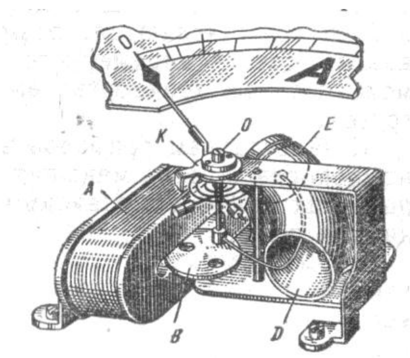

Figure 3.2

The disadvantages of the devices of the system include: uneven scale; less precision than the magnetoelectric devices; dependence on external magnetic fields.

Electrodynamic system. Electrodynamic measuring instruments are intended for measurement of current, tension and power in circuits of a direct and alternating current. The principle of operation of instruments of electrodynamic system is based on interaction of coils on which pass the measured current. Thus, instruments of electrodynamic system differ from instruments of magnetoelectric system in the fact that the magnetic field is created not by a permanent magnet, but the coil which is powered the measured current.

In a figure 3.3 is schematically figured the structure of the electrodynamic instrument. In the fixed coil 1 is the moving coil 2 to which is rigidly connected the arrow 3 that returns before a scale can rotate. The opposing moment is created by spiral springs 4. The measured current passes through both coils. As a result the interaction of a magnetic field of the fixed coil and current in mobile the torsion moment under the influence which moving coil aims to return so that the plane of its rounds became the parallel plane rounds of the fixed coil is created, and their magnetic fields would match in the direction. To it counteract springs therefore the moving coil is set in such situation where the torsion moment is equal I counteract.

Coils in electrodynamic instruments, depending on assignment, connect among themselves sequentially or parallel. If connect coils to the instrument parallel, then it can be used as the ammeter. If connect coils sequentially and connect added resistance, then the instrument can be used as the voltmeter.

Scale of the electrodynamic instrument non-uniform, however, selection of construction of coils it is possible to bring closer it to uniform. In case if change the direction of the current in both coils the direction of a torsion moment doesn't change. So it follows that instruments of this system are suitable for measurements of both: direct and alternating currents. Braking in these instruments as well as in electromagnetic, it is reached by the air damper.

In practice, the dynamometer wattmeter is applied to measurement of the power consumed in a circle. It consists of two coils - fixed, with a small number of rounds of a thick wire, joins sequentially with that section of a circle where it is necessary to measure power, and mobile which contains a large number of rounds of a thin wire and which contain in the fixed coil. The moving coil turns in a circle like the voltmeter – parallel to a customer. To increase its resistance, connect added resistance sequentially with it.

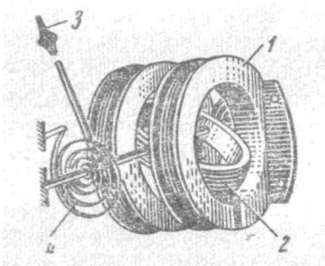

Figure 3.3

Advantages of instruments of electrodynamic system are: possibility to measurement of both direct, and alternating current; adequate accuracy. Treat shortcomings of instruments of this system: non-uniformity of a scale sensitivity to outside magnetic fields; big vulnerability in relation to overloads. Electrodynamic ammeters and voltmeters are used mainly as control instruments in alternating current circuits.

Thermal system. The principle of operation of instruments of thermal system is based on change of the length of the conductor on which there passes current, owing to its heating. The structure of the instrument of thermal system is schematically shown in a figure 3.4.

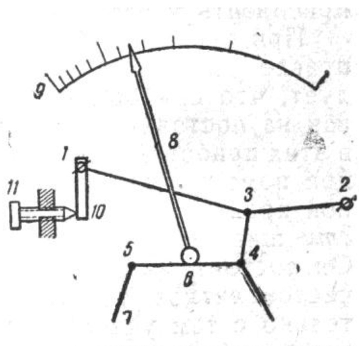

Figure 3.4

The measured current passes on a thin wire 1-2 which ends are fixed. This wire with a diameter about 0.1 mm is made of platinum alloy with iridium or silver. Approximately in the middle metallic thread 3-4 which is stretched by the thin silk thread 4-5 spanned via the unit 6 is soldered to it. The end of this thread is attached to steel a spring 7 which forms a thread tension. The arrow 8 is connected in the unit 6 and it can be turned in front of a scale 9.

When current is passing by a wire 1-2 it’s heating up owing to what it increases. The tension of threads 3-4 and 4-5 weakens a little, and the spring departs to the left that causes an arrow deviation. As amount of heat, selected by current, in proportion to a current intensity square also doesn't depend on the direction of current therefore instruments of thermal system are suitable for measurement of both direct, and alternating current. The instrument dial is non-uniform. For installation of an arrow on zero one of clamps to which thread is attached becomes mobile, in the form of the lever 10 capable to rotate around an axis. Twisting or unscrewing a micrometer screw 11 it is possible to strengthen or weaken thread tension and by that to give an arrow of the instrument on zero scale division.

Advantages of instruments of the thermal system are: possibility of measurement of both direct, and alternating current; independence of indications of frequency that allows applying them to measurement of high-frequency currents; non-sensitivity to outside magnetic fields. Treat shortcomings of instruments of this system: non-uniformity of a scale; existence of thermal inertia, in communication with what it is necessary to wait some time until the pointer of the instrument is finalized; dependence of indications on environment temperature.

Induction system. Operation of instruments of induction system is based on interaction of the current arising in a moving part of the instrument with a magnetic field of an immovable electromagnet. To induction system electrical counters of an alternating current belong, for example. Active power meters of this system are used, too.

Vibrational system. Operation of instruments of this system is based on a resonance which arises on condition of coincidence of the frequency of natural oscillations of a moving part of the instrument to the frequency of an alternating current. Instruments of this system are generally used to measurement frequency of the current.

Electrostatic system. Operations of instruments of this system are based on interaction of two or several charged conductors. Under the influence of electric field forces mobile conductors move rather fixed. Electrostatic instruments apply preferentially to direct measurement of a high tension.

Thermoelectric system. This system is characterized by using of one or several thermocouples. Under the influence of heat generated by the measured current, thermocouples make a direct current which is measured by the instrument of magnetoelectric system. Instruments of thermoelectric system are generally used to measurement the alternating currents of high frequency.

Detection (detector) system. Operations of instruments of this system are based on rectification of an alternating current by means of the rectifier which is built in in the instrument. The pulsating current received thus is measured by means of the sensitive instrument of magnetoelectric system.

Electronic system. Operations of instruments of this system are based on using one or several electron tubes and the measuring instrument of magnetoelectric system integrated in one diagram.

3.4 Instruments with several limits of measurements

These are measuring instruments which electric circuit can be switched for change the intervals of the measured value. For the ammeter change of boundaries is reached by connection of different shunts, for the voltmeter-switching on added resistances.

Use of instruments with several limits of measurements is connected to those circumstances that it is often necessary to measure electrical quantities in very wide limits with sufficient accuracy rating in each interval. In this case the instrument with several limits of measurements replaces several same instruments with different intervals of measurement. For example, when obtaining anode characteristics of the vacuum triode value of an anode current, depending on anode voltage (in case of the invariable potential of a grid), can change ranging from 0 to 30 mA. If do measurements by the instrument which scale is expected 30 mA then small currents will be measured with a big error.

In such cases the instrument with several limits of measurements is switched to a smaller edge that the arrow deviated on the maximum angle, but It didn't go beyond a scale. In other words, the instrument with several limits of measurements can be turned on so that the relative error of measurement was minimal.

3.5 Instructions for using instruments with several limits of measurements

1. In order to avoid damage of the instrument, at first turn on it in the maximum range.
2. Define roughly measured value. After that transfer to that range which upper bound is the closest to value of the measured value, but at the same time it is more then it. Define exact value of the measured value.
3. If the measured value increases, then measurements continue until the arrow approaches the end of a scale, and then transfer to the range following (bigger) range.
4. In case of reduction of value, measurement continue until the measured value reaches upper bound of the following smaller range then transfer to this range.

4 LABORATORY WORK № 21 THE STUDY OF PERIODIC PROCESSES WITH AN OSCILLOSCOPE

A purpose of the work is to study the principles of oscilloscope work.

Task 1: to measure amplitude and period of a signal studied by an oscilloscope and calculate the effective value of voltage and frequency.

Task 2: to observe Lissajous figures for various frequencies of voltage oscillation at X and Y oscilloscope inputs.

Instrumentation and appliances: an electronic oscilloscope, two audio-signal generators, wires for electrical connections.

Theoretical part

Cathode ray oscilloscope is a device for visual observation of electrical signals and measuring their parameters – amplitude and period. The presence in the oscilloscope periodic and waiting scanner gives the possibility to investigate single and periodic processes.

The oscilloscope consists of the following main components (blocks): cathode-ray tube (CRT), scanner (BR-1), block pre-amplification (BPP-1) and a power supply.

A cathode-ray tube. The primary node of the oscilloscope is cathode ray tube (CRT). With the help of the CRT receive the visible image signal that is investigated. Fig.4.1 schematically shows a device of the CRT.

The main element of the CRT is electron gun that creates the electron beam. The source of electrons is the heating oxide cathode positioned in the middle of the cylinder 2. This cylinder together with the cathode is called the control electrode, or modulator. To adjust the intensity of the electron beam on the modulator serves a negative potential U_{manag}. Varying the value of potential, one can change the brightness of the image on the screen.

The electron beam is focused by the first anode 3, on which positive voltage U_{a1} is served.

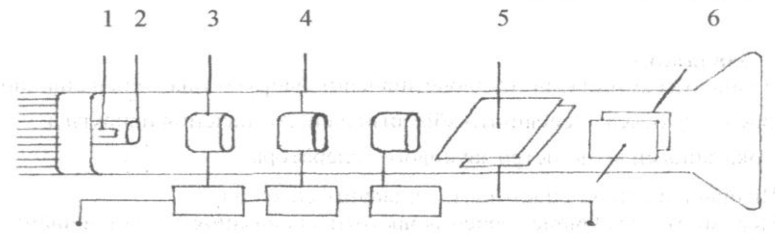

Figure 4.1

In order for the electrons reached the screen, their speed increase with the second anode 4. It is a positive voltage U_{a2}. A beam of electrons with a given velocity passes between two pairs of plates 5 and 6. Using these plates, the electron beam deflects vertically and horizontally. The angle of deflection of the beam depends on the voltage, applied to the plate, and the speed of the electrons.

One of the characteristics of the CRT is its *sensitivity* – the displacement of the beam on the screen vertically or horizontally at a voltage of 1V at a corresponding pair of plates. Sensitivity is measured in mm/V.

Scan. Usually the investigated AC voltage is applied to the vertically deflecting plates of the CRT (Y channel). If the horizontal deflection plates of CRT (X channel) has not voltage, the beam on the screen will move alternately up and down to draw a vertical line.

To expand the oscillations of the electron beam in time, you need to make it simultaneously with the movement of the vertically moving uniformly in the horizontal direction from the left edge of the screen to the right. The beam, reaching the right edge of the screen should (almost instantly) return to the left edge and again to start a uniform motion to the right edge. Such movement of the beam is called a *scan*. To get the scan on the horizontal deflecting plate serves the so-called saw-tooth voltage from the scan generator (Fig. 4.2). On the axis of ordinates deferred voltage, the abscissa shows the time.

At the minimum value of the scan voltage (point A) the beam is on the screen of the oscilloscope in the leftmost position. With the increase in voltage the beam moves with constant speed from left to right. When the voltage decreases from B to A, the beam makes a reverse. Reverse on the screen is not visible, because the oscilloscope has a device, blanking the beam during fly back. Scan period is defined as $T = t_{пр} + t_{зв}$.

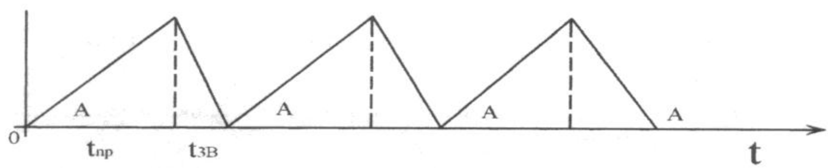

Figure 4.2

<u>Synchronization.</u> To obtain on the screen a clear image, you need to choose synchronization of the scan. The *synchronization* process is a forced external voltage to the generator scan, so that it begins to generate a voltage scan with a frequency that is equal to or a multiple of the frequency of the external voltage. In most cases, it is convenient to synchronize the scan the signal that examine, that is to use the internal synchronization.

Experimental part

<u>Order of carrying out the task 1</u>

1. Switch on the oscilloscope. Obtain a distinct sweep trace by tuning knobs "Яркость" and "Фокус". Set the sweep trace in the centre of the screen using knobs "↕" and "↔".
2. Switch on the generator 1. Supply the signal of 400 Hz frequency from terminal "Выход 600 Ом" of the generator to input Y of the oscilloscope (on the left-side panel) through electric cable.
3. Set the switch "V/дел." in the position with maximum signal within limits of oscilloscope's screen.
4. Locate within the screen 1-2 periods of the signal by the "ms/дел.", "µs/дел." switch.
5. Turn knob "Стаб" to the left reaching disappearance of the signal. Then turning knob "Уровень" to the right, get appearance of the signal on the screen.
6. Determine H and L in *large* scale graduations (Fig. 4.3). Be sure that knobs "Усиление" and "Плавно" are in the right limit position (after a click).

7. Repeat measurements setting up frequency of the generator signal to be 500 Hz; 1000 Hz.

8. Calculate amplitude and effective values of the signal for all three frequencies mentioned above.

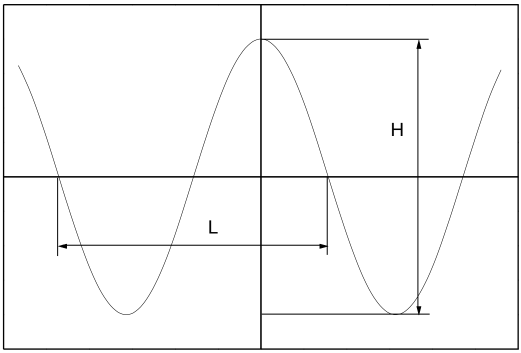

Figure 4.3

The amplitude value of the signal

$$U_a = (H/2)\alpha, \tag{4.1}$$

where α is the coefficient of vertical deflection (position of the switch "V/дел."). The effective value of voltage

$$U_{eff} = U_a / \sqrt{2}\,. \tag{4.2}$$

It has to be in accordance with the reading of the generator 1 voltmeter.

9. Calculate period and frequency of the signal for all three frequencies mentioned above.

The period can be found as

$$T = kL\,, \tag{4.3}$$

where k is the sweep coefficient (which corresponds to the position of the switch "ms/дел.", "μs/дел."). The frequency of the signal is calculated by the formula

$$\nu = 1/T \ . \qquad (4.4)$$

It is needed to compare the calculated values of frequency with ones set up on the scale of the generator 1.

10. Estimate an error for one of the appointed frequencies ν_1

$$\Delta\nu \approx (\Delta L/L_1)\ \nu_1, \qquad (4.5)$$

where $\Delta L = 0.2$ is the small scale graduation on the screen.

If the difference between ν_1 and the calculated frequency is more than $\pm 2\Delta\nu$, attempt to find some other source of an error that could explain such a divergence.

<u>Order of carrying out the task 2</u>

1. Switch on the oscilloscope. Obtain a distinct sweep trace by tuning knobs "Яркость" and "Фокус". Set the sweep trace in the centre of the screen using knobs "↕" and "↔".

2. Switch on the generator 1. Supply the signal of 3 kHz frequency from terminal "Выход 600 Ом" of the generator to input Y of the oscilloscope (on the left-side panel) through electric cable.

3. Set the switch "V/дел." in the position with maximum signal within limits of oscilloscope screen.

4. Set the switch "Разверт." on the right-side panel in the lower position.

5. Switch on the generator 2. Supply the signal of 0.9 kHz frequency from terminal "Выход 600 Ом" of the generator to input X of the oscilloscope (on the right-side panel) through electric cable.

6. Varying amplitude of the generator output signal by the knob above output terminals, get the signal not to pass the side boundaries of the screen.

7. Increase gradually frequency of the generator signal from 0.9 to 10 kHz and fix the values at which static figures (so-called Lissajous figures) are observed. Show these figures schematically in the report.

8. Make conclusion about an effect of the relationship between frequencies of generators 1 and 2 on an appearance of Lissajous figures.

Control questions

1. What is an oscilloscope application?
2. Describe construction of an electron-beam tube, give its schematic picture.
3. Give definition for the sensitivity of EBT.
4. What is a sweep?
5. How is the synchronization process performing?
6. What are Lissajous figures?
7. Show a block diagram of an oscilloscope and explain basic principles of oscilloscope work.
8. How to measure amplitude and period of a signal by an oscilloscope?
9. How to determine an effective value and frequency of voltage by using an oscilloscope?
10. How does an appearance of Lissajous figures depend on a relationship between frequencies of oscillations combined?

This instruction is translated out by S.P. Lushchin, reader of the physics chair,
completed by V.P. Kurbatsky, reader of the physics chair.
Reviewer: S.V. Loskutov, professor of the physics chair.

5 LABORATORY WORK № 22.1
THE STUDY OF THE LAWS OF DIRECT CURRENT

A purpose of the work is to measure resistance of a conductor by different methods, to calculate the specific resistance, to examine relation *Rp= f(1).*

Instrumentation and appliances: an experimental plant.

Theoretical part

1. The ordered motion of electric charges is called the electric current. An electric current in metals is the motion of the conductivity electrons. In conducting solutions (electrolytes) ions are the mobile charges. The ions and the electrons carry charges in gases.

Intensity and density are the quantitative characteristics of the electrical current. Intensity of current is the charge dq passes through a cross section of a conductor in a time dt:

$$I = \frac{dq}{dt}. \tag{5.1}$$

If the same amount of electric charges flows through any section of conductor at the equal period of time, the current intensity is constant value $I = dq/dt = const$. If the current changes by time, it is alternating current $dq/dt \neq const$. The intensity of current is a scalar value and measured in amperes in the SI system. Current intensity is measured in milliamperes **(**mA**)** and microamperes **(**μA**)** too.

If current is assigned irregularly along the surface S, then the current density j is defined in every point of the surface. The current density is the ratio

$$j = \frac{dI}{dS}, \tag{5.2}$$

where ***dS*** is an area perpendicular to the current direction ***dI*** which goes through this area.

The current intensity ***I*** through the given surface ***S*** can be found with the help of integration:

$$I = \int jdS\ .$$

If the current ***I*** is assigned regularly through the given surface ***S*** then the current density is ***j=I/S=const***. The current density is a vector value and in SI system measured in amperes divided by square meter **(**A/m^2**).**

The density of a charge ***j*** can be assigned by value of charge, concentration of the charges, and it's velocity

$$j = qn\upsilon\ .$$

2. There is relationship between the voltage ***U*** applied to the ends of the conductor and the current in it for each conductor if the condition of the conductor is invariable:

$$I = U / R\ . \tag{5.3}$$

It's the Ohm's law for the part of the electric circuit in integral form. According to the Ohm's law in the differential form ***j=σE*** the current density ***j*** in the conductor is directly proportionate to the electric intensity ***E*** in it, where **σ** is specific electrical conductivity of the conductor. The Ohm's law for the closed circuit is

$$I = \frac{\varepsilon}{R + r}, \tag{5.4}$$

where ***ε*** - electromotive force,

R - external resistance of the conductor,

r - internal resistance of current source.

When the current passes through the conductor, the latter is being heated. The quantity of the produced heat in the conductor is proportionate to its resistance, square value of current intensity and time:

$$Q = RI^2 t. \tag{5.5}$$

If the current intensity changes in time, then:

$$Q = \int_0^t RI^2 dt. \tag{5.6}$$

The formulas (8.2) and (8.3) represent the Joule-Lenz' law. The heat quantity ***Q***, which turns from the volume unit into the time unit of the conductor, is called the power of the current. The Joule-Lenz' law in differential form is:

$$\omega = jE = \sigma E^2.$$

3. Simple electric circuits are closed loops. The calculation of the ramified electric circuit is more complex but significantly simplified if we use Kirchhoff's laws.

The first law deals with the junction points and states: the algebraic sum of the currents at any junction point equals to zero (Fig. 5.1). For the junction point ***A***:

$$\sum I_k = 0$$

or $\boldsymbol{-I_1 - I_2 + I_3 = 0}$.

The second law deals with electric circuits: for any closed loop the algebraic sum of all incidences of voltage $\boldsymbol{I_i R_i}$ is equal to the algebraic sum of all the electromotive forces $\boldsymbol{\varepsilon i}$ in this circuit.

For the 1 circuit

$$I_1 R_1 - I_2 R_2 = \varepsilon_1 - \varepsilon_2.$$

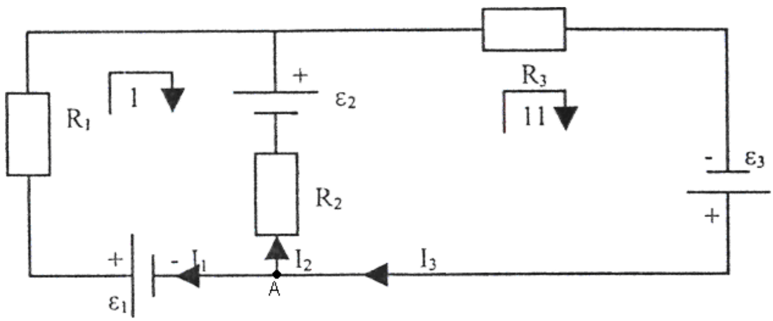

Figure 5.1

For the 2 circuit

$$I_2R_2 + I_3R_3 = \varepsilon_3 + \varepsilon_2 .$$

4. The conductor's resistance is directly proportional to its length and inversely proportional to its cross-section area

$$R = \rho\frac{1}{S} \quad , \tag{5.7}$$

where **ρ** - the specific resistivity of the conductor,

l - the length of the conductor,

S - cross-section area.

The conductors in the electric field can be connected in series and parallel.

When the conductors connected in series the current has the same value of ***I*** (Fig. 8.2).

Voltage drop in each resistance:

$$U_1 = IR_1; \qquad U_2 = IR_2; \qquad U_3 = IR_3.$$

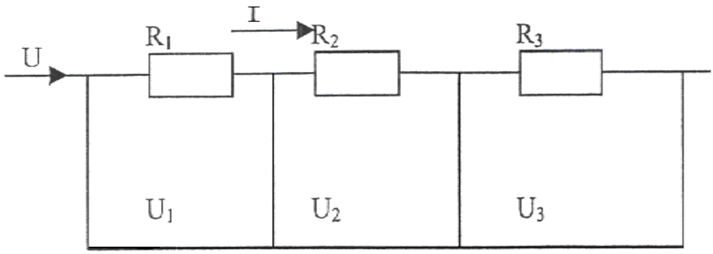

Figure 5.2

Adding right and left parts of these equations we obtain:

$$U_1 + U_2 + U_3 = I(R_1 + R_2 + R_3).$$

Hence it follows, that for any ***n*** amount of resistances connected in series there is a common resistance:

$$R_{ser} = R_1 + R_2 + ... + R_n \; . \qquad (5.8)$$

In case of parallel resistance the common current ***I*** is branched into $I_1, I_2 ... I_n$ currents.

Let us consider parallel connection for three conductors (Fig. 5.3):

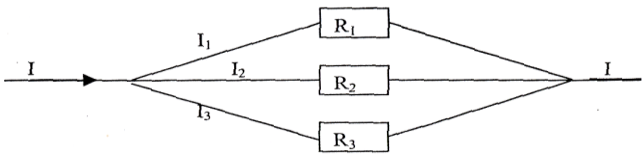

Figure 5.3

Voltage drop in each resistance is the same:

$$U_1 = U_2 = U_3 = U \, ;$$

$$I = I_1 + I_2 + I_3; \quad I_1 = U_1 / R_1; \quad I_2 = U_2 / R_2;$$
$$I_3 = U_3 / R_3; \Rightarrow$$

$$I = \left(\frac{U_1}{R_1} + \frac{U_2}{R_2} + \frac{U_3}{R_3}\right) = U\left(\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}\right).$$

In general for ***n*** amount of the conductors connected in parallel the total resistance may be expressed by the formula

$$\frac{1}{R_{par}} = \frac{1}{R_1} + \frac{1}{R_2} + \ldots + \frac{1}{R_n}. \quad (5.9)$$

Experimental part

An experimental device to measure the resistance consists of the column with wire and measuring block (Fig.8.4).

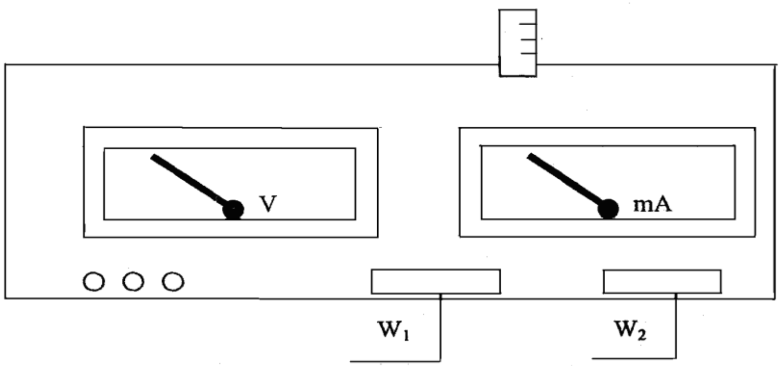

Figure 5.4

On the column there are two motionless brackets and a traveling one which can move along the column and be fixed in any position. The mark which is drawn between the upper and the lower brackets facilitates to define the length of the segment of resisting wire being measured.

The measuring part is placed in the separate block which has milliamperemeter, voltmeter and operating keys. Milliamperemeter is plugged in the resisting wire circle and used to measure the current and voltmeter to measure the voltage in the measured length of resisting wire. The switch $\boldsymbol{W_1}$ is used to choose the type of work and the switch $\boldsymbol{W_2}$ to choose the accuracy of current and voltage measurement.

1. Move the traveling bracket for 0,7 - 0,8 of length of the resisting wire, take it from the basis.
2. Press button $\boldsymbol{W}_1$ “МЕРЕЖА”.
3. Press button $\boldsymbol{W_3}$ “МІСТОК”.
4. When pressing button $\boldsymbol{W_2}$ the scheme works in the Fig. 8.5.

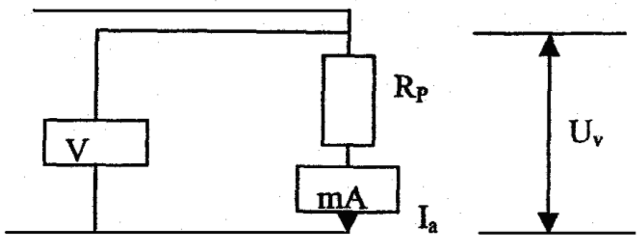

Figure 5.5

5. Write down the measurements which shows millliamperemeter and voltmeter and calculate $\boldsymbol{R}$ using the formula $R_p = \frac{U_v}{I_a} - R_a$,

   $\boldsymbol{R_a}$ = 0,15 Om, $\boldsymbol{R_a}$ = 2500 Om.
6. When pressing button $\boldsymbol{W_2}$, the scheme in the Fig. 8.6 works.
7. Make measurements of the millliamperemeter and voltmeter readings and calculate $\boldsymbol{R}$ using the formula:

$$R_p = \frac{R}{1 - R/R_v}, \qquad R = \frac{U_v}{I_a} .$$

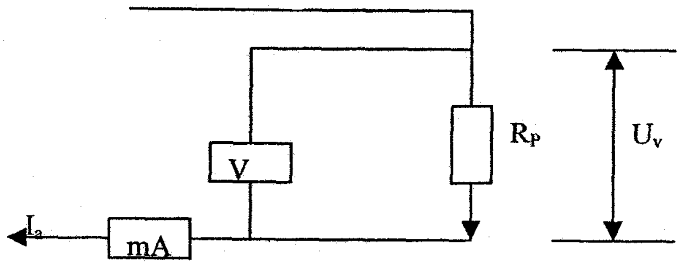

Figure 5.6

8. Measure with micrometer the diameter of the wire ***d***, the length of the wire from the basis to the traveling contact ***l***, calculate the specific resistivity ρ using the formula

$$R = \rho \, {}^{l}\!/_{S} \, .$$

9. Using one of the schemes of connection build up the constant value of the current ***I*** with the help of regulator. Moving the traveling contact of the resisting wire for a few marks find 8-10 values of the ***U.***

10. Count 8-10 values of ***R*** using the formula which correspond to the switching on scheme.

11. Fill in the table with data:

Table 5.1

№	1	2	3	4	5	6	7	8	9
I_a, A									
I, m									
U_v,V									
R_p, Om									

12. Build up the graph $\boldsymbol{R_p = f(I)}$.

13. Count the error for $\boldsymbol{R_p}$. Make a conclusion about the work done.

Control questions

1. What is an electric current? Write the formula for the direct current.
2. Write the definition and formula for the alternating current.
3. Write the definition and formula for the current density.
4. Write the relationship between the current intensity and its density.
5. Write the Ohm's law in integral form.
6. Write the relationship between the conductor resistance and conductor electrical conductivity.
7. Write the Ohm's law for the closed circuit.
8. Formulate and write the Joule Lenz' law.
9. Formulate and write the first and the second Kirchhoff's laws.
10. Write the dependence of the conductor resistance on its cross-section.
11. Deduce the formula for counting two resistors connected in series and parallel.

This instruction is translated out by S.P. Lushchin, reader of the physics chair.

Reviewer: S.V. Loskutov, professor of the physics chair.

6 LABORATORY WORK № 23
STUDY OF ELECTROSTATIC FIELD ON THE MODEL

A purpose of the work is to obtain equipotential lines and lines of force of an electrostatic field and determine its intensity.

Instrumentation and appliances: a power source; a potentiometer; a panel with electrodes and conducting paper; a probe; an oscilloscope.

Theoretical part

An electrostatic field is created by immobile charges and determined in each point of space by the force acting on a test charge.

The main characteristic of an electrostatic field is *the intensity*

$$\vec{E} = \vec{F} / q , \tag{6.1}$$

where $\vec{F}$ is the force acting on a point charge q placed into the point under consideration.

An energetic characteristic of an electrostatic field is *the electrostatic potential U*. It is measured by the work that is performed by an electric force when a unit positive charge is shifted from this point to the infinity.

When a charge shifts from arbitrary point 1 to arbitrary point 2, the work performed is independent of a trajectory and due to a difference of potentials:

$$A_{21} = -q(U_2 - U_1) . \tag{6.2}$$

Potential is a function of coordinates $U = U(x, y, z)$. If a potential distribution is known, an intensity can be found being

$$\vec{E} = -\,grad\,U , \tag{6.3}$$

where operator *grad* in the right side is called *the gradient*. It acts on scalar function of coordinates $f(x, y, z)$ by the rule

$$grad\ f = \vec{i}\,\frac{\partial f}{\partial x} + \vec{j}\,\frac{\partial f}{\partial y} + \vec{k}\,\frac{\partial f}{\partial z} . \tag{6.4}$$

$\vec{i}, \vec{j}, \vec{k}$ are unit vectors along axis x, y and z respectively.

An electrostatic field can be represented with equipotential surfaces (equipotential lines in two-dimensional case). *The equipotential surface (line)* is a locus of points with equal potential.

To represent an electrostatic field lines of force (lines of intensity) can be also used. *The line of force* is a line with tangent at each point coinciding with vector of intensity. Constructing lines of force, one can use their properties:

a) lines of force start from positive charges and finish at negative ones (or disperse in infinity);

b) crossing equipotential surfaces (lines), lines of force are directed perpendicularly to them;

c) lines of force come out (or come in) perpendicularly to electrodes since charged metallic surfaces are equipotential;

d) lines of force are concentrated in the places where intensity is higher;

e) lines of force are directed down in potential.

There is an analogy between of an electrostatic potential distribution in a homogeneous dielectric medium and a potential distribution in a homogeneous conductor with an electric current. It can be explained by the fact that both cases are described by the same equation which doesn't include any parameter of a medium

$$\frac{\partial^2 U}{\partial x^2} + \frac{\partial^2 U}{\partial y^2} + \frac{\partial^2 U}{\partial z^2} = 0 \cdot \qquad (6.5)$$

This equation can be applied to a dielectric as well as to a conductor. It is possible to study an electrostatic field in a dielectric medium by measuring a distribution of potential in a conductor although this potential distribution is of different origin.

Experimental part

A potential distribution in a thin conducting layer is used in this work as a two-dimensional model for an electrostatic field. To measure potential, a bridge is used (Fig. 6.1). Two metal electrodes A and B are pressed to the sheet of paper with a conducting layer. Voltage U_o = 6.3 V passes from the source to electrodes and lower terminals of the potentiometer. Probe P is connected to the sliding contact S through terminals of vertical deflection of the oscilloscope (input Y).

The oscilloscope is used in the work as an indicator of presence of a potential difference. When the probe touches the surface of the conducting paper we observe a signal on oscilloscope screen (as a vertical intercept, height of which is proportional to a potential difference between a point of contact and sliding contact S). If potential at the point of contact is equal to one at sliding contact, a dot is seen on the screen.

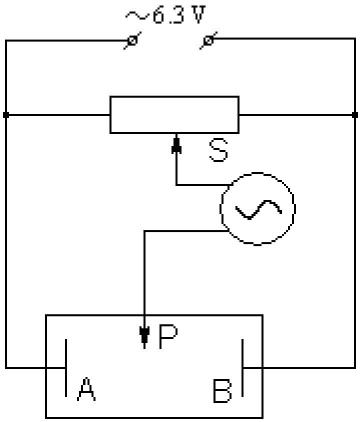

Figure 6.1

At the beginning two or three sheets of paper with outlines of electrodes in the position taking place during the work have to be inserted under electrodes and conducting paper.

We consider potential of the electrode A to be equal to zero U_A = 0. Then U_B = 6.3 V (only an amplitude value of the potential is taken into account). To obtain an equipotential curve for some value $0 < U_i < 6.3\text{V}$, first it is needed to place sliding contact *S* in the appointed position (Fig. 6.2)

$$d_i = d_0 \cdot \frac{U_i}{U_0} \quad . \tag{6.6}$$

Then it is necessary to move probe P along the conducting layer in direction of decreasing oscilloscope signal and stop the probe when the signal becomes zero. Potential at the stop point is equal to U_i. In order to fix position of this point pierce all the sheets by top of the probe.

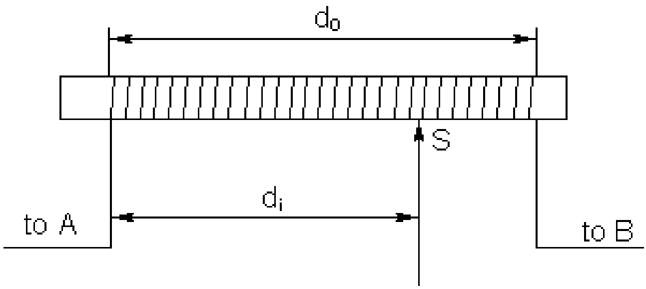

Figure 6.2

Near this point, another one with potential U_i has to be found and fixed. In such a way, moving from point to point, one can obtain the sequence of pinholes by which the equipotential curve can be drawn when the paper sheets are put out.

1. Obtain equipotential curves varying value of potential from 0 to 6.3 V with a step of 0.9 V. Take into consideration that outlines of electrodes are equipotential curves corresponding to potential values 0 and 6.3 V.

2. Build up a system of lines of force (not less than 7 in number).

3. Determine value and direction of an intensity at the points indicated by teacher. Value of intensity can be found by using the approximate formula

$$E = \frac{U_{n+1} - U_n}{D}, \qquad (6.7)$$

where U_n and U_{n+1} are potentials of two equipotential curves nearest to the point being considered; D is length of the shortest intercept joining these curves and coming through the point.

4. Estimate an error in location of equipotential curves

$$\Delta x \approx \frac{kd_0}{5U_0}, \qquad (6.8)$$

where k (in V/a scale graduation) is position of the voltage divider at the Y input of the oscilloscope.

Control questions and exercises

1. Give definitions for intensity and potential of an electrostatic field. In what units are they determined?
2. What is the relationship between intensity and potential of an electrostatic field?
3. Why is a surface of any conductor equipotential?
4. What are lines of force? What are their properties?
5. Prove that lines of force are perpendicular to equipotential surfaces.
6. Formulate the Ostrogradski-Gauss theorem.
7. Demonstrate that potential of a point charge $U = k \cdot q/r$ satisfies the equation (11.5).
8. Derive the approximate relationship (11.7) from the exact one (11.3).
9. Prove that an error in position of equipotential curves can be estimated by using the formula (11.8).

This instruction is translated out by V.P. Kurbatsky, reader of the physics chair. Reviewer: S.V. Loskutov, professor of the physics chair.

7 LABORATORY WORK № 24
MAGNETIC FIELD DISTRIBUTION ALONG AN AXIS OF A CIRCULAR CURRENT

A purpose of the work is to test relation between magnitude of a magnetic intensity and a distance along an axis of a circular current.

Instrumentation and appliances: a panel with two coils and scale; an audio-signal generator; a milliammeter.

Theoretical part

The main characteristic of a magnetic field in a medium is *the magnetic induction* $\vec{B}$ which is determined by the force acting on an element of a conductor with a current:

$$d\vec{F} = I\left(d\vec{l} \times \vec{B}\right), \tag{7.1}$$

where I is a current; $d\vec{l}$ is the vector which magnitude is equal to length of a conductor section and it’s direction coincides with a current direction. The boldface multiplication sign denotes the vector product.

Currents of any origin are sources of a magnetic field. Closed microscopic currents related to, for example, motion of electrons in atoms are always presented in a medium. Hence the total magnetic field in a medium $\vec{B}$ is the sum of the field produced by macroscopic currents in conductors $\mu_0\vec{H}$ and one produced by microscopic currents in a magnetized medium (a magnetic) $\vec{M}$:

$$\vec{B} = \mu_0\vec{H} + \vec{M}\ , \tag{7.2}$$

where $\mu_0 = 4\pi \times 10^{-7}$ H/m. $\vec{H}$ is called *the intensity* of a magnetic field, $\vec{M}$ is *the magnetic polarization*.

For a homogeneous isotropic medium (nonferromagnetic), relation between magnetic polarization and intensity is considered to be linear:

$$\vec{M} = \kappa\mu_0\vec{H}\ . \tag{7.3}$$

The proportionality coefficient κ is called *the magnetic susceptibility*. After substitution of (13.3) into (13.2), we obtain the relationship between induction and intensity

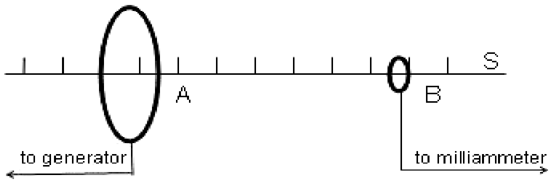

Figure 7.1

$$\vec{B} = \mu\mu_0\vec{H}\,, \qquad (7.4)$$

where $\mu \equiv \kappa + 1$ is called *the magnetic permeability* of the medium. In contrast to the dielectric permeability, the magnetic permeability can be either much or less than 1. Typical values of susceptibility for nonferromagnetic substances are 0.38×10^{-6} (air), -26×10^{-6} (silver), 300×10^{-6} (platinum).

Magnetic intensity at an arbitrary point is determined by a current distribution in conductors. If currents flow along wires, intensity at distances much more than a transverse size of the wires can be found by using *the Biot-Savart-Laplace formula*

$$\vec{H}(\vec{r}) = \frac{I}{4\pi}\int \frac{d\vec{l} \times (\vec{r} - \vec{r}\,')}{|\vec{r} - \vec{r}\,'|^3}\,. \qquad (7.5)$$

In this formula, $\vec{r}$ identifies position of the point where intensity has to be found; $\vec{r}\,'$ is the radius-vector of the wire element $d\vec{l}$ (this vector is defined in the same way as in (13.1)). The integration is performed over the whole length of the wire.

Using formula (13.5), it is easy to determine magnetic intensity on an axis of a circular turn with current (of magnitude I and radius R):

$$H = \frac{IR^2}{2(R^2 + l^2)^{3/2}}\,, \qquad (7.6)$$

where l is the distance from the point where intensity has to be found to the center of the turn.

Experimental part

The laboratory plant is shown in Fig. 7.1. The audio-signal generator is a source of an alternating current which flows in coil A connected to the generator. This coil (a circular current) creates a varying magnetic field.

The induction sensor B is also a small coil coaxial with coil A. The current induced in coil B by the variable magnetic field is measured by the milliammeter. Value of the milliammeter current is proportional to amplitude of magnetic field intensity. Shifting the sensor along scale S, change of milliammeter current reflects a change in magnetic intensity.

1. Check electrical connections. Set up 0.15 mA milliammeter range.

2. Switch on the generator. Set up frequency of generator's signal to be 10 kHz and maximum output voltage.

3. Place the indication coil B in the center of the circular current (h = 0). Make sure that pointer of the milliammeter is within the scale.

4. Varying position h of the indicating coil B from 0 with step of 2 scale graduations (2 cm, if using a scale rule), fix value of the milliammeter current H. Stop measurements when a change in current value becomes undetectable. Write down obtained results into table 7.1.

5. Using experimental data, examine theoretical dependence $H = f(h)$ by the linearization method.

This method implies a choice of new variables (a function and an argument) in relationship (13.6) in order to obtain a linear dependence between these variables. Such dependence can be easily verified since its plot is a straight line.

It is not difficult to demonstrate that making change

$$H^{-2/3} = y, \quad h^2 = x \tag{7.7}$$

in formula (13.6), relation gets the needed form

$$y = a + bx, \tag{7.8}$$

where $a = (I/2R)^{-2/3}$, $b = (IR^2/2)^{-2/3}$. Calculate y and x using data obtained in experiment and show graphically dependence between them. On account of the form of dependence $y = f(x)$, make a conclusion about results of the examination of relationship (13.6).

Table 7.1

h, см	H	$H^{2/3}$	$y=1/H^{2/3}$	$x = h^2$
0				
1				
2				
3				
…				

Control questions

1. Give definition for a magnetic induction.

2. What is a physical meaning of a magnetic intensity?

3. Explain relation between induction and intensity of a magnetic field.

4. Write down and explain the Biot-Savart-Laplace formula.

5. Obtain formula (13.6) for intensity of a magnetic field on an axis of a circular current using the Biot-Savart-Laplace law (13.5).

6. What is magnetic intensity in center of a circular current equal to?

7. Formulate the electromagnetic induction law. How does a phenomenon of electromagnetic induction manifest itself in the laboratory work?

8. How does value of the milliammeter current depend on frequency of the generator signal?

9. Show that value of the milliammeter current is proportional to amplitude of the magnetic field intensity at the point where the indicating coil is placed (if radius of this coil is much less radius of coil A).

10. What is the linearization method? Prove that change (13.7) transforms relationship (13.6) into linear dependence (13.8).

11. Explain why a noticeable deviation from linear dependence $y = f(x)$ can take place for large values x and small values x when the indicating coil is near the coil A.

This instruction is worked out by V. Kurbatsky, reader of the physics chair.
Reviewer: S. Loskutov, professor of the physics chair.

8 LABORATORY WORK № 25 MEASUREMENT OF SPECIFIC CHARGE OF AN ELECTRON

A purpose of the work is to study the relationship of anode current of electron tube on solenoid current $I_a = f(I_L)$; define the specific charge of electron e/m.

Instrumentation and appliances: electron tube, solenoid, microammeter, milliammeter, voltmeter, source of current.

Theoretical part

Fundamental characteristics of the electron are charge and mass. Relation of the charge of the electron to its mass is a specific charge of the electron:

$$\frac{e}{m} = \frac{1.6 \cdot 10^{-19} C}{9.1 \cdot 10^{-31} kg} = 1.7 \cdot 10^{11} \frac{C}{kg}.$$

This characteristic of the electron we can obtain by a magnetron method. This method makes use of the influence of a magnetic field on the electron that moves in a radial electric field. The electron tube is in the magnetic field of a solenoid. The electric field is perpendicular to the magnetic one. The electrons in the electron tube move from the cathode to the anode along a radius (1) if the magnetic field is absent (Fig.8.1).

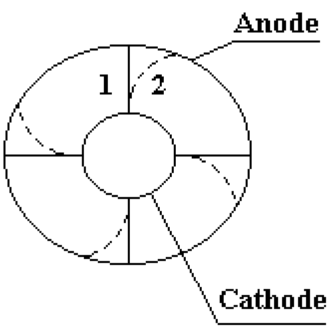

Figure 8.1

Lorenz's force acting on the electrons when they move in the magnetic field of the solenoid is $F_L = e[\mathbf{V}, \mathbf{B}]$, and therefore trajectory of motion will be distorted (curve 2 in the Fig.8.1).

The trajectory of the electron will be closed when intensity of the magnetic field is quit sufficiently high. In this case the specific charge of the electron is defined as:

$$\frac{e}{m} = \frac{8 \cdot U}{\mu_0{}^2 \cdot I_{cr}{}^2 \cdot n^2 \cdot R^2}, \qquad (8.1)$$

where U - potential difference of the cathode and anode; μ_0 - magnetic constant; I_{cr} - critical current of the solenoid; n - quantity of turns per unit of the solenoid length; R - radius of solenoid.

Experimental part

The wiring scheme is shown in Fig. 8.2:

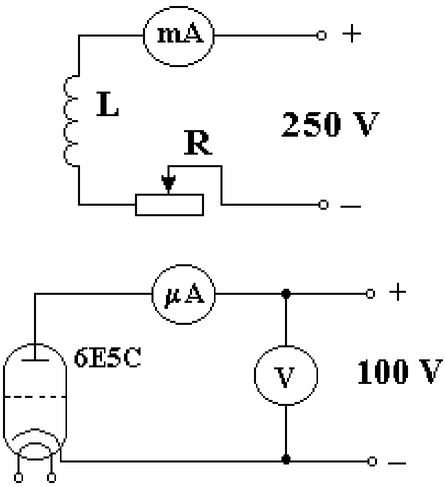

Figure 8.2

When current doesn't flow through the solenoid the anode current of the electron tube will be maximum. If current begins to flow through the solenoid and increases the anode current will decrease.

The anode current equal to zero corresponds to I_{cr} (Fig. 8.3).

2. The handle of voltage control is in the left position of the front panel of the current source ВУП-2. This handle must be in the position "0" when the source of current is turned off.

3. Switch on the source of current.

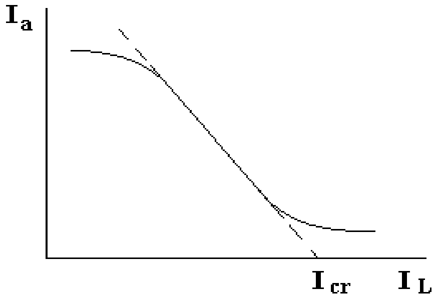

Figure 8.3

4. Write the value of the anode current I_a and voltage U when the solenoid current is absent and when the electron tube is being heated.

5. Increase the solenoid current from "0" to max value and write down the values of the anode current in the table.

6. Plot the graph of $I_a = f(I_L)$.

7. Define the I_{cr} on this graph.

8. Calculate *e/m* by the formula (8.1), where $\mu_0 = 4\pi \cdot 10^{-7}$ H/m, $n = 5 \cdot 10^4$ 1/m, $R = 5 \cdot 10^{-3}$ m.

Control questions

1. What is Lorentz's force?
2. What values depends on the Lorentz's force?
3. How to find the direction of the Lorentz's force?
4. What value is called the specific charge of the electron?
5. What is the idea of the method, which is used to calculate the specific charge of electron?
6. How the current in the lamp varies with the current increase in the solenoid?
7. What current of the solenoid is called the critical one?
8. Why the anode current does not decrease to zero?

This instruction is translated out by S. P. Lushchin, reader of the physics chair.
Reviewer: S. V. Loskutov, professor of the physics chair.

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