Student's name ____

Experiment E1

STUDY OF ELECTRIC FIELD BY PROBE METHOD

Objective: to work out a theoretical model of electrostatic field using equipotential contours and electric field lines of electric dipole.

1 EQUIPMENT

1) Galvanometer;
2) metallic probes;
3) two electrodes;
4) bench insulator for electrodes and paper sheet;
5) e.m.f. surce;
6) metallic leads;
7) ruler, pencil, paper, water.

2 THEORY

An electric charge create an electric field in space around. If the charge is immobile, the field does not vary in time and is called electrostatic field. On any charge placed in the field, an electrical force is exerted. Such an action is a manifestation of the field and allows to estimate its strength. The strength of the field in a point is characterized by a vector $\vec{E}$, which is called electric field. Numerically, magnitude of electric field $\boldsymbol{E}$ in some point is equal to the force acting on unitary positive charge placed in this point.

$$\vec{E} = \frac{\vec{F}_e}{q_0}. \quad (2.1)$$

Direction of the vector $\vec{E}$ coincides with direction of the force acting on the charge. In practice, magnitude of the probing charge $\boldsymbol{q_0}$ has to be small enough not to disturb the measured field.

If electric field in vacuum is created by point-like charge $\boldsymbol{q}$ then the force, acting on the probing charge $\boldsymbol{q_0}$ is determined by **Coulomb's law**:

$$F_e = \frac{qq_0}{4\pi\varepsilon_0 r^2}, \quad (2.2)$$

where $\boldsymbol{r}$ is the distance between centers of the charges; ε_0=8,85·10^{-12} Ф/м is the electric constant. **Electric field, created by the point charge** $\boldsymbol{q}$ on distance $\boldsymbol{r}$, is expressed by formula

$$E(r) = \frac{q}{4\pi\varepsilon_0 r^2}. \quad (2.3)$$

Within a dielectric medium the electric field is reduced:

$$E = \frac{E_0}{\varepsilon},$$

here $\boldsymbol{E_0}$ is electric field in a vacuum; ε is known as dielectric permittivity of the medium ($\varepsilon \geq 1$).

A convenient way of visualizing electric field patterns is to draw lines that follow the same direction as the electric field vector at any point. These lines, called **electric field lines**, are related to the electric field in any region of space in the following manner. The electric field vector E is tangent to the electric field line at each point. The number of lines per unit area through a surface perpendicular to the lines is proportional to the magnitude of the electric field in that region. Thus, E is great when the field lines are close together and small when they are far apart. If the lines at different locations point in different directions than the field is nonuniform.

The rules for drawing electric field lines are as follows. The lines must begin on a positive charge and terminate on a negative charge. The number of lines drawn leaving a positive charge or approaching a negative charge is proportional to the magnitude of the charge. No two field lines can cross.

Electric potential is an energy characteristic if electric field. Work done to move a charge $\boldsymbol{q_0}$ between two points of the field, created by the point charge

$$A_{12} = \int_{r_1}^{r_2} \vec{F} d\vec{r} = \int_{r_1}^{r_2} \frac{q_0 q}{4\pi\varepsilon_0 r^2} dr = \frac{q_0 q}{4\pi\varepsilon_0}\left(\frac{1}{r_1} - \frac{1}{r_2}\right) = q_0(\varphi_1 - \varphi_2),$$

is dependent only on the magnitude of charge $\boldsymbol{q_0}$ and electric potentials of initial point $\varphi_1 = \dfrac{q}{4\pi\varepsilon_0 r_1}$ and final point $\varphi_2 = \dfrac{q}{4\pi\varepsilon_0 r_2}$ but independent on the way along which the charge is moved.

For any electrostatic field one obtains that the difference of potentials $\varphi_1 - \varphi_2$ (a voltage $\boldsymbol{V}$) determines the change in energy, which is equal to the work done, so that

$$A_{12} = q_0(\varphi_1 - \varphi_2) = q_0 V\ , \tag{2.4}$$

In a field one can find a surface, all points of which have the same potential. This surface is known as **equipotential surface** (surface of constant potential).

Electric field lines are always perpendicular to equipotential surfaces. Electric force moving a unitary charge is equal in magnitude to $\boldsymbol{E}$ so the elementary work equals

$$\Delta A = E\Delta l \cos\alpha\ , \tag{2.5}$$

where $\Delta\boldsymbol{l}$ is a trajectory segment and α is angle between trajectory an force applied.

From the other side the work needed to move positive unitary charge from the point with potential φ to the point with $\varphi + \Delta\varphi$ equals to

$$\Delta A = \varphi - (\varphi + \Delta\varphi) = -\Delta\varphi\ , \tag{2.6}$$

where $\Delta\varphi = \boldsymbol{V}$ is an increase of potential.

If the charge is moved along equipotential surface, the work done by electric field equals zero, because $\Delta\varphi$=0. Comparing two above formulas for $\Delta\boldsymbol{A}$ we obtain that cosα=0 where from α=90°; that means the electric fiels lines are perpendicular to equipotential surface.

One can express the value of electric field $\boldsymbol{E}$ through a gradient of potential $\dfrac{\Delta\varphi}{\Delta l}$ (change of potential $\Delta\varphi$ corresponding to the unit of displacement in direction normal to equipotential surface):

$$E_l = -\frac{\Delta\varphi}{\Delta l}\ , \tag{2.7}$$

where $E_l = E \cdot \cos\alpha$. One can see from formula (2.7) that electric field vector directed towards lower potential: the condition $\Delta\varphi$<0 is to be fulfilled in order to get $\boldsymbol{E_l}$>0.

Experimental setup for determining electric lines and equipotential contours is shown in figure 2.1.

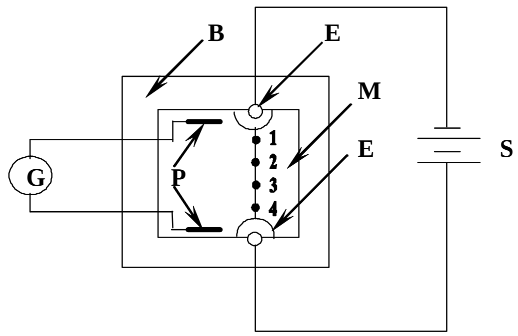

Figure 2.1

The insulating bench **B** is used to fasten a sheet of wet paper **M** (being a conducting medium) and electrodes **E** connected to source of direct current **S**. Prior to be fastened, the sheet of paper is to be moistened to make it conducting.

In this setup the electric field of a dipole is modeled by stationary electric field of direct current between electrodes in weakly conducting medium (wet paper). The source of e.m.f. maintain a constane voltage across electrodes and through the sheet of paper the constane current flows along the electric field lines. Measuring probes **P,** connected to galvanometer **G** allows one to determine voltage across chosen points and investigate the distribution of electrical potential.

3 PROCEDURE AND ANALYSIS

3.1 Draw an axis on a sheet of paper and divide the axis into segments each 3 cm long.

3.2 Moisture the paper and fasten it with electrodes to the insulating bench.

3.3 With help of galvanometer determine the distribution of potential along the axis. For this purpose press one of measuring probes to point 1 on axis and touch point 2 by the second probe. Read the voltage from galvanometer. After this, repeat the measurement with points 2 and 3 and so on.

Do not ever touch electrodes with measuring probes to avoid breakage of galvanometer.

3.4 Using formula (2.7) calculate the magnitude of electric field between points. Difference of potentials can be calculated by formula:

$$\Delta\varphi = n \cdot c \cdot R,$$

where ***n*** in deflection of galvanometer, ***c*** is graduation mark of the galvanometer, ***R*** is galvanometer's resistance. Fill the table 3.1 with results of measurements and calculations:

Таблиця 3.1

Distance between points, Δl	**Galvanometer reading, *n***	**Galvanometer's graduation mark, *c***	**Resistance of the galvanometer, *R***	**$\Delta\varphi$, V**	**E_l, V/m**

3.5 To determine the form of equipotential contour, touch point 1 with one of the measuring probes and find 5-6 points aside the axis with the same value of potential (the galvanometer's pointer will point zero in this case). Connect all these points by a smooth line. This line represents an equipotential contour. Repeat this procedures for other points of the axis.

3.6 Having determined the form of equipotential contours, draw the electric field lines starting on the plus and anding on the minus (ground) electrode. Each of lines is to intersect the equipotential contours at right angles. Indicate voltage between next nearest equipotential contours.