Experiment Nr. 20

Electric field mapping

Theoretical part

An electric field is a vector field that is produced by electric charges. The source of the field may be a single charge or many charges. To visualize an electric field, we use lines of force. The arrows on the lines point in the direction of a force felt by a unit positive charge placed into such a field, so that lines of force enter negative charges and leave positive ones for simple one charge configurations such as seen in Fig. 1:

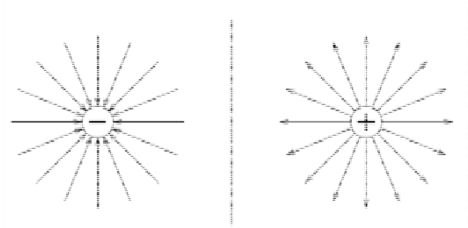

Fig. 1 Electric fields of negative and positive charges

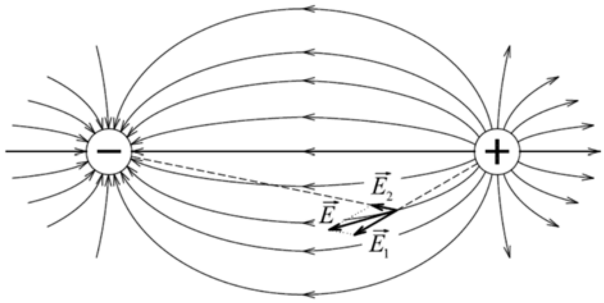

Fig. 2 Electric field near two equal charges of opposite sign

If the charge configuration has more than one member as in the configuration in Fig. 2, then the vector properties of the electric field must be considered. Here we see two charges of equal magnitude but opposite sign and want to see what would happen to a positive test charge introduced into the system. Let's imagine the test charge is introduced at a particular point (see Fig. 2). Generally, we must use vector analysis to predict the electric field on the charge. Let $\overrightarrow{E_1}$ be the electric field felt by the test charge because of the presence of the positive charge. Let $\overrightarrow{E_2}$ be the electric field felt by the test charge due to the negative charge. Here, using vector addition, the electric field vector is calculated for this system of two charges. The resultant, $\vec{E}$, is tangent to the electric field lines, thus the lines can be drawn in by calculating the resultant at each point in the diagram and sketching the electric field lines from these observed resultant vectors.

To maintain the charge at a specific position in the electric field or move it against the field requires an expenditure of energy. The work done to move a charge from infinity to a particular point in the field is called potential energy. It would become kinetic energy if the charge were free to move. The electric potential φ is the energy per unit charge. Lines of equal potential can be used to plot a force field, as lines of force are perpendicular to such equipotential lines (Fig. 3). This is because when a charge is moving along an equipotential line no work is done, and thus the electric field cannot have a component in this direction. If potentials can be measured and equipotential lines drawn, electric fields can be mapped. (Remember both potential lines and lines of force do not actually exist but are simply mental devices for thinking about force fields.)

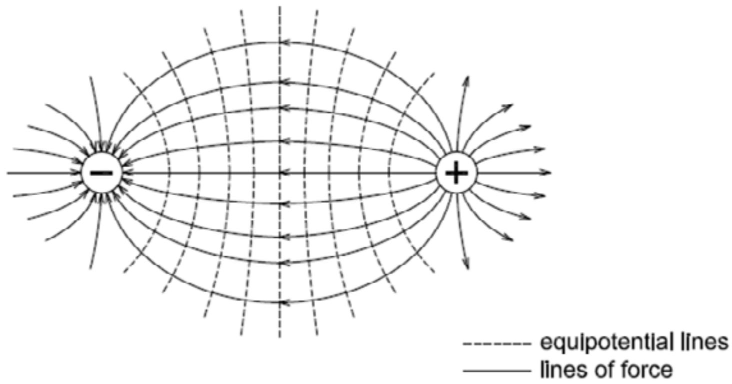

Fig. 3 Equipotential lines, and lines of force for the field of two charged points (electrodes)

The procedure below gives details of the apparatus used in this experiment to map out equal potential lines, and thus the electric field. Try to anticipate the features of the equipotential lines within your group before the experiment is completed. Use the ideas presented above to predict the field geometry from the plate geometry.

Theory of the measurement principle and measurement procedure

The measurement scheme is shown in Fig. 4. The measurement is carried out in an electrolytic bath, which is a large and shallow container with a printed grid on the bottom, filled with electrolyte (water). The container must be made of non-conductive material.

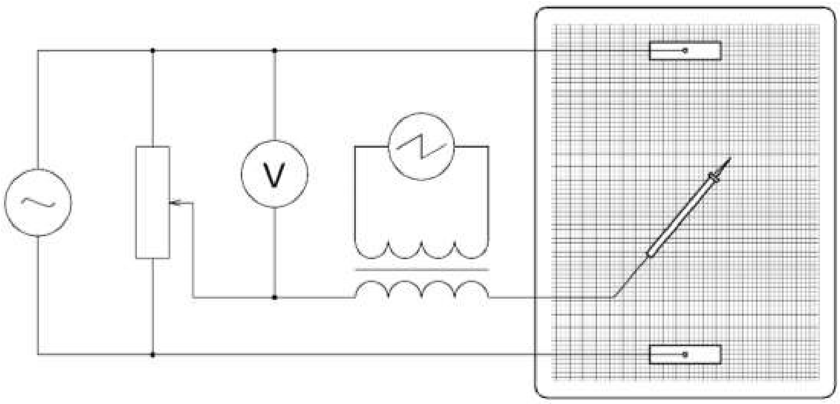

Fig. 4 Electric field mapping – measurement scheme

We insert two or more electrodes of different shapes into the bath. The electrodes should not be placed close to the walls of the bath, so that the walls do not influence the electric field.
Practically, a voltage source with direct current should power the electrodes located in the electrolytic bath. However, since polarization phenomena on the electrodes would greatly disturb the measurements, an alternating current of very low frequency is used. In our measurement, the power source of AC voltage with a sinusoidal waveform is represented by a function generator. Positions of the equipotential lines (the values of the potential we are looking for) are located in the bath with a help of a thin tip-probe, which we dip into the electrolyte at different points one after the other. The value of the desired potential is set by the slide resistor.

If a certain point is just at the potential set by the slider, the response on the oscilloscope, which is proportional to the potential difference between the slider and the measured point, will be zero.
After making the equipotential maps, the electric field lines (lines of force) should be drawn. These are lines which start from the positive electrode and travel to the negative one in such a way as to remain perpendicular to the equipotential lines where they cross the lines. In particular points of the field lines (but not in the intersections with the equipotential lines) the field intensity vector $\vec{E}$ should be determined.

Measurement objectives

1. Map the created electrostatic field and plot at least 5 equipotential lines.

2. With regard to the theory plot about 4 – 5 field lines (lines of force).

3. Determine the magnitude and direction of the field intensity $\vec{E}$ at 3 selected points.

4. Plot the vectors of the field intensity $\vec{E}$.

Comments

Ad 1. Fill the bath with electrolyte (water) to about two-thirds of the height of the electrodes. At the beginning of the measurement, set the maximum voltage of 3 V by changing the amplitude on the generator (check the voltage on the voltmeter) and select the desired potential value by moving the slider of the resistor. For the desired potential value find at least 6 points of the equipotential curve using the tip probe and read the coordinates of these points. Determine at least 5 equipotential curves by changing the voltage and repeating the procedure. The surfaces of the electrodes are also the equipotential lines.

Ad 3. The electric intensity field vector $\vec{E}$ is defined as

$$\vec{E} = -\frac{\Delta\varphi}{\Delta s}\overrightarrow{\tau_0},$$

where Δs is a distance measured on the curve of the field line between the nearest equipotential curves that corresponds to the potential difference $\Delta\varphi$. The unit vector $\overrightarrow{\tau_0}$ is tangent to the line of force and is oriented in the direction of increasing potential. When calculating the intensity of the electric field, take the plot scale into account.

Uncertainty calculation notes

The uncertainty of the electric field intensity depends on the inaccuracy $\Delta\varphi$ and Δs determination. Because the Δs inaccuracy is dominant, we can assume that

$$u_{rE} = u_{r\Delta s}$$

Note that the accuracy of the Δs determination is dependent on the minimum level of oscilloscope response and on the plot scale of the field map.