

Electric Field and Equipotential

OBJECT: To plot the equipotential lines in the space between a pair of charged electrodes and relate the electric field to these lines.

APPARATUS: Two different plastic templates (opaque and either cardboard, transparent, or plastic) digital voltmeter (DVM), graph sheets, BK Precision Power Supply/Battery Eliminator 3.3/4.5/6/7.5/9/12V, 1A Model#1513 potential source (with 6 Volts selected), and connecting wires.

THEORY: Electric field is an important and useful concept in the study of electricity. For an electric charge distribution, the electric field intensity or simply the electric field at a point in space is defined as the electric force per unit charge:

$$\vec{E} = \frac{\vec{F}}{q}. \quad (1)$$

From the knowledge of an electric field, we can determine the force on any arbitrary charge at different points.

Theoretically the electric field is determined using an infinitesimally small positive test charge q_0 . By convention the direction of the electric field is the direction of the force that the test charge experiences. The electric field (which is a vector field), may therefore be mapped or displayed graphically by lines of force. A line of force is an imaginary line in space along which the test particle would move under the influence of the mapped electrostatic field; at any point, the tangent to the line of force gives the electric field at that point.

For a simple case of an isolated positive charge, the electric field is directed radially outward, as shown in the Fig. 3.1, since a positively charged test particle would be repelled radially.

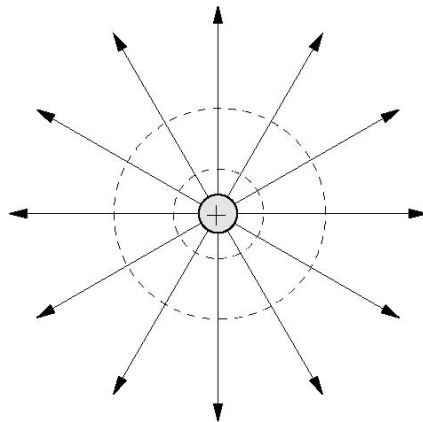


Figure 3.1: Lines of force (Solid Lines Radially Outward) and Equipotentials (Dashed Lines Concentric Circles)

For the case of an isolated negative charge, the force lines are radially directed inward, as a positively charged test particle would be attracted radially. The force lines are crowded together where the field is stronger and are further apart where the field is weaker. The field has a $(1/r^2)$ behavior; that is, it decreases inversely as the square of the distance from the isolated charge.

Experimentally we cannot truly map the field because of difficulties in placing the test charge at a point in space and determining the force acting on the test charge. However, it is possible to map the electric field indirectly from the equipotential lines. (In three dimensions, electric field is mapped from equipotential surfaces.)

The potential difference ΔV between two points is defined as the work required to move a unit positive charge from one point to the other in the electric field:

$$\Delta V = \frac{W}{q_0} \quad (2)$$

If the test charge q_0 is moved perpendicular to the electric field or the force lines, no work is done or $W = 0$. This implies that $\Delta V = 0$; that is, the potential remains constant along a path that is perpendicular to the force lines. Such a path that has the same value of potential at all points on it is called an equipotential line in two dimensions, and an equipotential surface in three dimensions.

It can be easily shown that the electric field is given by the negative gradient of the potential. The magnitude of the field is

$$\Delta E = \frac{dV}{ds} \quad (3)$$

where s is a coordinate in the direction of the electric field.

Two equipotential lines or two force lines from a given charge distribution never cross each other, since both the potential and the electric field at any point other than the point-like charges themselves always have unique values. At the location of a point-like charge, the equipotential lines collapse to that point, and the lines of force diverge from a positive point-like charge and converge into a negative point-like charge; see Fig. 3.1.

PROCEDURE:

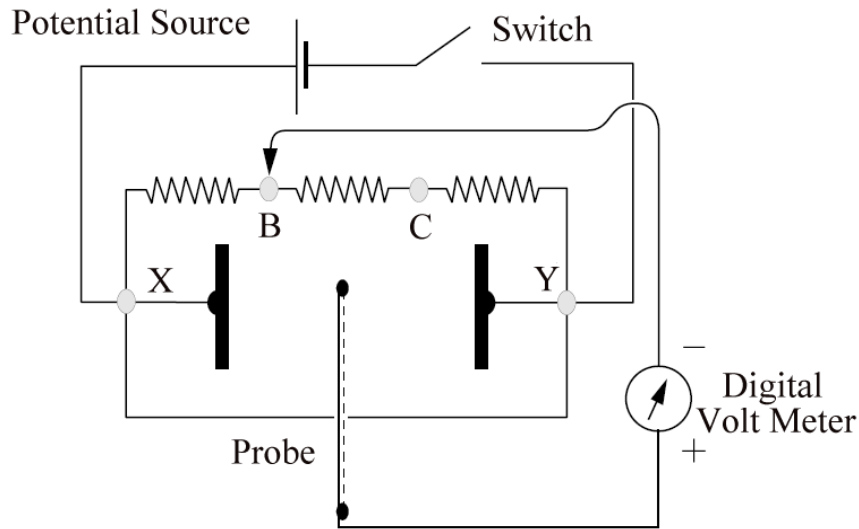


Figure 3.2: Experimental Setup.

1. Place the opaque template (for example, parallel-plate capacitor shown in the figure as dark region) at the bottom of the field mapping board.
2. Fasten a piece of graph paper on the upper side of the mapping board by pressing on the springs (located at the four corners) and push paper under the rubber stops and release the springs.
3. Place the transparent/cardboard template on the graph sheet and align according to the tiny holes located at the top of the template.
4. Turn the board upside down to ensure that the opaque template and the transparent/cardboard template on the opposite side of the board are both aligned.
5. Carefully, slide the U-shaped probe into the board, with the ball end facing the underside of the board.
6. Connect the potential source to the conducting terminals X and Y and make the connections for the digital voltmeter (DVM) with the terminal B as shown in the Fig. 3.2.
7. Turn on the potential source. Move the probe over the graph sheet to find a zero reading position. This point must be at the same potential as B. Move the probe to another null point and continue this procedure to find a series of these points.
8. Connect these equipotential points with a smooth curve to display the equipotential line as B.
9. Move the digital voltmeter (DVM) connection to C now, and find the corresponding equipotential line. (The DVM should indicate zero voltage).
10. Make a mark to identify this location.
11. Repeat the above procedure for all terminals (E1, E2, E3, etc) of the series of resistors.
12. Draw in, using dashed lines, the lines of force which are everywhere perpendicular to the equipotential lines.
13. Repeat the experiment for the second template.