

Experiment 3: Electric Fields and Electric Potential

Introduction

In this lab we will measure the changes in electric potential (V) using a digital multimeter. We will explore the relationship between equipotential surfaces and electric field \vec{E} lines and use this to construct a map of the electric fields surrounding various distributions of charge such as the electric dipole, parallel plate capacitor and coaxial cables.

An arrangement of electric charges exerts forces on one another by means of disturbances in their surrounding space called electric fields. From Coulomb's Law, the force that an electric field exerts on a charge q is simply $\vec{F} = q\vec{E}$. So in theory it is possible to calculate the electric field of various charge distributions by using Coulomb's Law and the superposition principle. In practice, however, it is rather difficult to calculate it due to the vector nature of the forces/fields.

The electric potential (or simply "potential") is defined as the electric potential energy U divided by the charge q : $V = U/q$. Thus the electric potential is a scalar quantity with SI units called the volt (V), where $1 \text{ V} = 1 \text{ joule/coulomb}$. If the electric field is known, we can calculate the electrostatic potential of any arbitrary point charge by using the formula

$$V = - \int_{P_0}^P E \cos(\theta) ds + V_0 \quad (1)$$

where θ is the angle between the electric field and the displacement ds . This electric field at a point in space depends on the rate of change of V over space at that point:

$$\vec{E} = \left(\frac{\partial V}{\partial x} \hat{i} + \frac{\partial V}{\partial y} \hat{j} + \frac{\partial V}{\partial z} \hat{k} \right) \quad (2)$$

So if you know the potential you can calculate the field and vice versa. Due to the scalar nature of the electric potential, it is easier to work with. The magnitude of the electric field in a region can be estimated by measuring the potential difference ΔV over a displacement Δd ,

$$|\vec{E}| = \left| \frac{\Delta V}{\Delta d} \right| \quad (3)$$

Equipotential regions are regions at a constant potential (or voltage). In three dimensions (3D), equipotential regions are often surfaces, providing a graphical 3D representation of the potential. In two dimensions (2D), equipotential regions are often lines or planes called contours. Electric fields and equipotentials have the following relations: The electric field \vec{E} is perpendicular to the equipotential surfaces, the field points in the direction of decreasing potential and equipotential lines never cross each other and electric field lines never cross each other.

Experimental Objectives:

- Measure the change in electric potential (voltage) between two conductors connected to a constant voltage (Power Supply).
- Draw the electric field lines in conjunction with the equipotential lines to observe and understand how field lines travel between multiple configurations of conducting surfaces.
- Analyze the shape of these electric field lines for two different configurations of conductors.

The following setup will produce a 2D electric field between two “point charges”. The two point charges are created by drawing a dipole configuration with conductive silver ink on a sheet of black conductive paper. We will use this dipole configuration to find the equipotential lines when you apply a ΔV of 10V the two point charges. A power supply will provide a constant ΔV , and the digital multimeter (DMM) can measure this ΔV . The potential on this surface will be measured with a DMM. Put the metallic push-pins into the center of the two point charges and connect the power supply to these pins using alligator clips and the red/black wires. Connect the point charge that represents ground to the DMM using a black cable with banana plugs at each end. Connect the red probing wire which has a pointed tip to the positive terminal of the DMM. This will act as your potential (voltage) probe. Set the DMM to measure voltage. The DMM will now measure ΔV relative to the negative electrode. That is, we will define $V=0$ at the negative electrode.

The two silver dots on the paper simulate two charges that make up an electric dipole. Use the DMM to find points on the paper where $V = +2V$. Use the grid paper intelligently so that you can transfer those points to the white grid paper for recording. **Do not mark the black conductive paper.** Locate enough points so that you can sketch the equipotential lines (contours) on the white grid paper. Repeat for $V = 4, 6$ and 8 Volts. Use the data marks on the white grid paper and your observations to answer the following questions as you perform the lab:

- Draw the four equipotential lines. Sketch some sample electric field lines using your acquired equipotential lines. Ensure equipotential lines and field lines are perpendicular to each other.
- Which way do the field lines point? That is, where do they start and end?
- If the power supply voltage was doubled, how would the equipotential lines and electric field strength change?
- How does the arrangement/shape of the conductors (electrodes) alter the \vec{E} ?
- Where is the field the strongest? Where is it the weakest?

Discuss these questions in the analysis section of your lab report. **Repeat** the above setup with another charge configuration selected from the collection in Figure 1. Use the conductive silver ink pen to trace out your design on a fresh page of black conductive paper (Note: the ink must be dry to be conductive -

it takes at least 3 minutes to dry!). Make sure that when you shake your pen hard enough so that the metal ball inside mixes up your ink by sliding back and forth inside the pen. You should hear it oscillate.

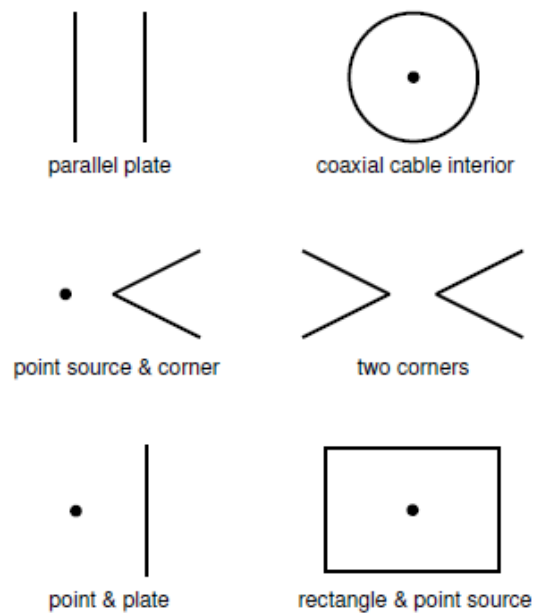


Figure 1: Sample electrode configurations.

Answer the following questions in your lab write-up:

1. How does the potential vary with distance on your plots?
2. Calculate the electric field strength at a few places with different characteristics using Eq. 2. Do your results agree with the idea that electric field line density is proportional electric field strength? Sketch neatly and clearly an appropriate amount of \vec{E} lines on your grid paper. You may want to use a different color.
3. Consider the following situation: An object with charge $q_0 = 1.5\mu\text{ C}$ and mass 0.7 g starts from rest at the $+6\text{V}$ equipotential line. Calculate its change in potential energy and speed when it reaches the $+2\text{V}$ line.