



Electric Field and Equipotentials

Physics Lab V

Objective

In this set of experiments, the electric field from a charged set of conductors, on a two dimensional plane, is mapped out. The equipotentials between the conductors is also mapped out, and the relationship between the electric field and the equipotentials for each set of charged conductors is explored.

Equipment List

Multimeter, Power Supply, Conducting Paper with conducting surfaces (surfaces are constructed with 20 gauge copper wire), Voltage probes (red and black), Rubber Bands, Metal Thumbtacks, Connecting Leads, Colored Pencils.

Theoretical Background

A collection of charges, which are fixed in place (i.e. they can not move), produces an electric field that can affect another charge, free to move around, placed in their midst. The electric field produced by this fixed collection of charges is just the sum of the individual fields from each charge:

$$\vec{E} = \frac{kQ_1}{r_1^2}\hat{r}_1 + \frac{kQ_2}{r_2^2}\hat{r}_2 + \dots = \sum_{i=1}^n \frac{kQ_i}{r_i^2}\hat{r}_i. \quad (1)$$

The force on a free charge can then be written as:

$$\vec{F} = q\vec{E}. \quad (2)$$

From this force, the acceleration of this free charge can be found from Newton's Second Law ($\vec{F} = m\vec{a}$), and integrating acceleration gives the velocity of the particle. Likewise integrating velocity gives the position of the particle as a function of time. Knowing the electric field is important to be able to describe how a free charge will be affected by the fixed charges. In the first part of this lab, you will do a series of experiments to determine what the electric field between a set of charge conductors looks like.

Another way to get the velocity of the free charge is by using Energy methods. From Conservation of Energy we have the following equation:

$$K_f - K_i = U_i - U_f. \quad (3)$$

In this equation, K_i and K_f is the initial and final kinetic energy, and U_i and U_f is the initial and final potential energy. If the potential energy does not change, then neither does the kinetic energy (i.e. $U_f = U_i$ and $K_f = K_i$). No change in the kinetic energy, in turn, means that the charge's velocity would not change, since $K = \frac{1}{2}mv^2$. These places of constant potential energy are know as equipotentials. As part of this lab exercise, you will map out the equipotentials between the conductors.

The potential energy of the free particle in a field created by the charges on the conductors is given by

$$U = qV. \quad (4)$$

In this equation, q is the amount of charge on the free charge, and V is the potential between the conductors. The potential is to the potential energy what the electric field is for calculating the force on q in that both E and V are created by the fixed charges and independent of q . The SI unit of the electric potential is the *Volt*. The electric field and the potential are related to each other in that the magnitude electric field (in one dimension) is the derivative of the potential. The following equations shows this relationship.

$$E = -\frac{dV}{dx} \approx -\frac{\Delta V}{\Delta x}. \quad (5)$$

In this lab, you will make measurements to check this relation.

Procedure/Data Analysis

For each of the set of silver conducting surfaces, on each page of the black conducting paper, follow the following set of procedures.

Electric Field Plotting

In this section, the electric field between the two conducting surfaces will be mapped out.

1. Begin by attaching a silver thumbtack onto each copper wire strip. The wire should be fastened to the paper with several push pins. Be sure the silver thumbtack is placed on the center of the wire.
2. *With the power supply turned off*, plug the power supply into the wall outlet and connect a lead from the positive and ground terminals of the power supply to the thumbtacks. The lead from the positive terminal should be attached to one of the silver thumbtacks while the lead from the ground is attached to the other silver thumbtack.
3. Before turning the power supply on, make sure that the voltage control is turned down to zero. With the voltage turned down to zero, turn on the power supply and turn the voltage up to 15 volts.

4. Plug the red probe into the positive terminal of the multimeter and the black probe into the negative terminal of the multimeter.
5. Set the multimeter so that it reads voltage with a maximum of 20 volts (It should be set to read DC, not AC, voltage).
6. Measure the voltage between the conducting surfaces by placing the positive (red) probe tip on the conducting surface that is connected to the positive terminal of the power supply and the grounded (black) probe tip on the conducting surface that is connected to the ground terminal of the power supply. Record the measured voltage (it should be around the 15 volts) as ΔV_T .
7. Measure the distance between the conducting surfaces. Record this distance as Δd_T . From this distance and the voltage measured in the previous step, determine the *magnitude* of the *average* electric field by using the formula:

$$E_{ave} = \frac{\Delta V_T}{\Delta d_T} \quad (6)$$

8. Place the probes side by side and wrap a rubber band around the probes to hold them together. Measure the distance between the probe tips and record it on your data sheet as Δd_P .
9. With the probe tips connected together in this fashion, map out the electric field between the conducting surfaces by placing the probe tips at some arbitrary position between the conducting surfaces so that the line connecting the probe tips is perpendicular to the conducting surfaces. With the grounded probe tip fixed, rotate the positive probe in 45° increments. Note at which orientation the voltage between the probes is a maximum.
10. On your data sheet, draw an arrow at the position of the probe tips with a length equal to the distance between the probe tips, which points in the direction of maximum voltage. The arrow head should be located at the ground (black) probe tip. The arrow represents the direction of the electric field at this point. Place a small “1” beside the arrow to distinguish it from other arrows you will draw.
11. Record the voltage difference on your data table ΔV_1 . Use Equation 6 to calculate the magnitude of the electric field. For this calculation, d should be the distance between the probe tips.
12. Repeat this process nine more times at various positions between the conducting surfaces to get 10 electric field measurements. Make sure that these positions are scattered enough to get a good idea about how the electric field behaves between the two conductors.
13. Calculate the average value of the magnitude of the electric field vectors. Calculate the percent variation in the magnitude of the electric field vectors.

$$\% \text{ variation} = 100 \times \frac{\text{Largest Measured Value} - \text{Smallest Measured Value}}{2 \times \text{Average Value}} \quad (7)$$

14. Estimate the experimental uncertainty in the distance and voltage measurements. Use this uncertainty estimate and the smallest measure value of each quantity to determine the percent uncertainty in each quantity. Record the largest percent uncertainty in the space provided.

$$\% \text{ uncertainty} = 100 \times \frac{\text{Experimental Uncertainty}}{\text{Smallest Measured Value}} \quad (8)$$

Equipotentials Mapping

In this section, the equipotentials between the conducting surfaces will be mapped out.

1. Starting with the configuration used in the previous section, remove the rubber bands and connect the negative probe tip to the ground of the power supply. The positive probe tip, hereafter referred to as the equipotential probe, will now measure the potential relative to the grounded potential from the power supply on the multimeter.
2. First use the positive probe to measure the potential of each of the conducting surfaces (i.e. the copper wire) at four positions on each conductor. Record the value of each surface's potential beside each surface on the data sheet for the positive conductor ($V_{+ \text{ conductor } 1}$ through $V_{+ \text{ conductor } 4}$) and for the negative conductor ($V_{- \text{ conductor } 1}$ through $V_{- \text{ conductor } 4}$). Calculate the percent variation in the potential for each conducting surface.
3. Next, place the equipotential probe at a position between the conducting surfaces that would correspond to the tail of one of your electric field vectors on your data sheet. Record the potential at this position on your data sheet as V_A .
4. Proceed to find 5 more places between the conductors that have this same voltage. Record each position, and the value of the potential, on your data sheet. Connect each of these equipotential points together to form the equipotential surface.
5. Now place the equipotential probe tip at the head of electric field vector used in step 3 to measure the potential there as V_B .
6. Proceed to find 5 more places between the conductors that have this same voltage. Record each position, and the value of the potential, on your data sheet. Connect each of these equipotential points together to form another equipotential surface.
7. Repeat steps 3 and 4 for another of the electric field vectors to find a total of four equipotential surfaces.

Selected Questions

1. How does the average electric field between the conducting surfaces, $E_{ave\ T}$, compare with the average of the individual electric field vectors, E_{ave} , for each set of conductors?
2. What is the variance of the potential between each conducting surface? Consider both the positive and negative conducting surfaces for the parallel plates and the circular plate. Based on your observations and the definition of an equipotential surface as stated in the Theoretical Background section, what can be said about each of the conducting surfaces?
3. Choose any two of the equipotential surfaces you mapped. a) Calculate ΔV , the change in potential between the two equipotential surfaces. b) Measure Δd , the distance between the two equipotential surfaces. c) Calculate E_{ave} , the magnitude of the average electric field between the two equipotential surfaces using equation 6. Here ΔV_{T1} is the value found in a) and Δd_T is the value found in b). d) How does this average electric field compare to the magnitude of the electric field between the equipotentials? (hint: Compare the value from c) to the value of E_{ave} recorded on your data table.)
4. How are the electric field vectors oriented about equipotential surfaces?
5. Based on your measurements in step 2 of the Equipotentials Mapping section, which of the conductors is at a higher potential? In which direction, away from or towards, do electric field vectors point in relation to that equipotential surface at the higher potential?