LAB - ELECTRIC FIELDS AND EQUIPOTENTIALS

The magnitude of the electrostatic force between two charges q and q' is given by:

$$F = \frac{kqq'}{r^2}, \text{ where } k = 9 \times 10^9 \text{ Nm}^2/C^2. \qquad \text{(Eq. 1)}$$

The force is either attractive or repulsive, depending on the signs of the charges. The electric force per unit charge, given by

$$E = \frac{F}{q} = \frac{kq'}{r^2}\ , \qquad \text{(Eq. 2)}$$

is called the electric field, E. By convention, the direction of the electric field produced by the source charge q' is determined by the direction of the force it exerts on a positive test charge q. Since the electrostatic force is an action-at-a-distance force, the electric field may be considered as the medium through which a source charge (or source charge distribution) exerts a force on external charges. By placing a test charge at various points near a source charge, and then determining the magnitude and direction of the force on this charge at each of these points, the electric field of the source charge may be mapped out. The electric field is everywhere tangent to the lines of force and the magnitude of the electric field can be determined using Eq. 2. Roughly sketch the electric field lines for a single negative charge and for a dipole. (An electric dipole consists of a positive charge q and an equal magnitude negative charge -q separated by a fixed distance). ***Include these sketches in your lab report.***

When a charge moves in an electric field, work is done on the charge. If a charge is moved from point 1 to point 2 under the influence of the electric force, the work done on the charge is

$$\text{work} = W = q(V_2 - V_1), \qquad \text{(Eq. 3)}$$

where V_2 and V_1 are the electric potentials at points 2 and 1, respectively. If a charge is moved in a direction perpendicular to the electric field lines, the work done is zero, since there is no component of the force in the direction of the displacement. This implies, using Eq. 3, that $V_2 = V_1$. The potential V is therefore constant along paths, called equipotentials, which are perpendicular to the electric field lines. ***Draw the equipotential lines on the sketch that you previously made for the negative charge.***

The electric field can be mapped by using either the electric field lines or the equipotentials. In this lab you will locate equipotential lines, and draw, by inference, the electric field lines. The apparatus consists of a tray containing a piece of corkboard, carbon impregnated paper, push pins, conductive ink, wires, a power supply, and a digital voltmeter. The conducting ink is used to draw three different electrode configurations on the carbon paper. The electrodes are then connected to a voltage source, the power supply, which pumps charge from one electrode to the other. The electrodes are conducting, and represent regions of constant potential. One electrode is at a positive potential +V, the other at a negative potential -V, which we will call zero for the sake of simplicity. Current flows between the electrodes in the direction of the electric field. The current flow cannot be mapped, but we can measure the change in potential experienced by the moving charge as it moves from point to point. There will be a drop in potential as the charge moves from the positive to "zero" potential

electrode, since the carbon paper has a high resistance. Points of equal potential can be identified, and connected to form the equipotentials.

Procedure -

Materials and equipment: tray containing a piece of corkboard, carbon impregnated paper, push pins, conductive ink, wires, a power supply, and a digital voltmeter.

I. Electrode Construction (may be skipped in some labs -- consult instructor)

STEP 1 - The carbon-impregnated paper has a centimeter grid drawn on its surface. Tape two sheets down to the lab table, and using a pencil, draw the following electrode pairs, one per sheet:

Electrode pair 1 **- Two dots representing the charges of an electric dipole. Place these dots about 6 cm apart (6 cm is edge-to-edge distance) with the axis of the dipole aligned with the long edge of the carbon sheet. Place the center of the dipole at the center of the sheet. Make the dots about 1 cm in diameter.**

Electrode pair 2 **- Two parallel line electrodes. Draw the lines so that they are parallel to the long edge of the carbon-impregnated sheet and centered on the sheet. Make the lines 10 cm long, 1.0 cm thick, and place them 6 cm apart, edge-to-edge.**

The group should verify that the electrodes are drawn correctly.

STEP 2 - Follow the instructions printed on the ink dispenser. Use the dispenser to fill in the electrodes with the conducting ink, taking care to draw smooth lines at the outside edges (you might want to practice on a scratch piece of paper first, but don't waste ink!). When you are finished, replace the cap on the ink dispenser and proceed to section II. The ink will take approximately one-half hour to dry.

II. Potential Measurements

STEP 1 - Each student should take two sheets of centimeter grid graph paper and draw the two electrode pairs with a pencil, just as described in section I. You should have exact copies of the ink electrodes.

STEP 2 - After the ink has dried, remove the dipole electrode configuration from the table top and transfer it to the corkboard in the plastic tray. Tack it down to the corkboard by using a push pin in each corner. Also put a push pin in the center of each of the dots. Do not remove these pins, since the pins will probably not make contact with the ink when they are re-inserted.

STEP 3 - You are now ready to make measurements. Connect the "high" side of the power supply (usually a red terminal) to one of the dots. This dot corresponds to the positive charge of the dipole pair. Connect the "low" side of the power supply (usually a black terminal) to the second dot. Turn on the power supply and set the voltage to 12 Volts. Verify that the power supply meter switch is set correctly. Turn on the digital meter and set it up for measurement of DC voltage. Select the 20 Volt scale. Attach a probe to the "low" (black) terminal of the meter and touch the probe to the "zero" potential electrode on the carbon sheet (the electrode connected to the "low" terminal of the power supply). This probe

is now at zero potential. Attach another probe to the "high" (positive) terminal of the meter and touch it to the carbon paper somewhere between the two dots. The voltage reading on the meter should be between 0 and +12 V. This voltage corresponds to the potential difference between the two probe locations. Draw a diagram that shows the electrodes, power supply, meter, and wiring, as set up for the potential measurements and *include this diagram in your lab report.*

STEP 4 - Next, touch the positive probe to the "high" electrode and read the voltage on the meter. If the voltage is different from 12 V, adjust the power supply until you obtain a 12 V reading.

STEP 5 - Use the positive probe to search for a location between the electrodes that is at 10 V. Mark the location on your graph paper. Continue to move the probe and identify and graph other locations at 10 V. Identify at least 10 such locations. You should have identified enough locations so that you can draw the equipotential.

STEP 6 - Repeat step 5 for voltage readings of 8, 6, 4, and 2 Volts.

STEP 7 - Draw the equipotentials on your graph paper that correspond to 10, 8, 6, 4, and 2 V. Now use the equipotentials to sketch the electric field. An electric field line is a line that leaves one of the electrodes, perpendicular to the electrode edge, and then passes through successive equipotentials at right angles to them. The line should terminate at the opposite electrode, intersecting it at right angles.

STEP 8 - Replace the dipole electrode configuration with the parallel electrode configuration. Place one electrode at 12 V and the other at 0 V, and map out the 10, 8, 6, 4 and 2 V equipotentials using the same procedure as in steps 5 and 6.

STEP 9 - Draw the equipotentials and sketch the electric field lines for the parallel electrode configuration. *Include the sketches from steps 7 and 9 in your lab report.*

III. ELECTRIC FIELD APPLET

Go to http://www.cco.caltech.edu/~phys1/java/phys1/EField/EField.html.

STEP 1 - Read the instructions for using the applet.

STEP 2 - Create a charge configuration that is two charges of equal magnitude but opposite sign (dipole). Draw the field lines and equipotentials for the pair of charges. Print your results.

STEP 3 - Repeat step 2 for a single charge of magnitude +6 and a line of six negative charges of magnitude -1, with the +6 charge centered above the line.

IV. QUESTIONS

(1) A uniform electric field is produced between two long, flat parallel electrodes carrying opposite charges. Check the field between your parallel electrodes for uniformity by completing the following: *Choose a line perpendicular to and between the electrodes, then measure the distance between each set of adjacent equipotentials intersecting this line. Record these distances in a table. You should measure separation distance between the 12 V and 10 V equipotentials, the 10 and 8 V equipotentials, etc.*

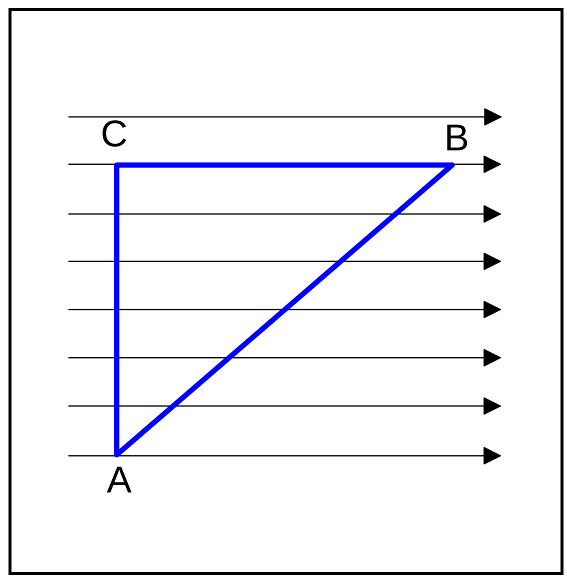
(a) Is the data in your table indicative of a uniform electric field? Explain.

(b) In a uniform electric field, the magnitude of the field can be calculated by dividing the change in potential by the distance over which the change takes place, i.e., $E = \frac{V_2 - V_1}{d}$. Calculate the electric field between the parallel electrodes.

(2) A uniform electric field points to the right as shown. If the change in electric potential in moving from point A to point B is -4 V, find the difference in potential between the following pairs of points (explain how you obtained your answers).

(a) A to C

(b) C to B



(3) Draw, by hand, a single positive charge of magnitude +8 placed at the center of eight negative charges of magnitude -1, as shown. Draw, <u>also by hand</u>, several electric field lines and equipotentials for this charge configuration.