Electric Fields and Equipotentials

Note: There is a lot to do in this lab. If you waste time doing the first parts, you will not have time to do later ones. Please read this handout **before** you come to lab.

1 Equipment

In order to investigate electric fields you will need the following equipment

- Conducting graphite paper (pre-marked)
- DC voltage supply
- Connecting wires and probes
- Light (white) colored pencil
- Digital Voltmeter
- Graph paper and blank white paper

2 Introduction

The electric (Coulomb) force per unit charge is called the electric field intensity, or more simply "the electric field". It can be mapped by moving a test charge about a region and measuring the force on the test charge at each point. These measurements at individual points can be connected into **electric field lines.** The tangent of the electric field line at any point gives the *direction* of the electric field; the *density* of field lines (discussed below) is proportional to the strength of the electric field.

We will not actually measure forces on a microscopic test charge in this lab, but do something similar. You will be introduced to a new concept in this lab, the **electric potential.** Recall that the electric field gives the *force* a charge would experience if placed at that position:

$$\vec{F}(\vec{r}) = q\vec{E}(\vec{r})$$

If you move the charge from r_1 to r_2 , this will require doing work against the electric field. The work done is simply given by:

$$W = \int_{\vec{r}_1}^{\vec{r}_2} \vec{F}(\vec{r}) \cdot d\vec{r}$$

$$=q\int_{\vec{r}_1}^{\vec{r}_2}\vec{E}(\vec{r})\cdot d\vec{r}$$

We can define this integral of the electric field as the work done per unit charge in moving from r_1 to r_2 . Because the Coulomb interaction is a conservative force, the work done is independent of the path between the points. We can call this work/unit charge the electric potential energy or **electric potential** and it is similar to the "gravitational potential" you already know. The electric potential is measured in units of Joules/Coulomb which are also called volts.

A voltmeter is a device that measures the difference in electrical potential energy between two points. If those points are very close together, then this is much like taking the derivative of the potential, which is related back to the electric field itself.

3 Procedure

The apparatus consists of a flat board on which is placed a sheet of carbonized conducting paper imprinted with a grid. The sheet has an electrode configuration drawn with conducting metallic paint. The paint acts as electrodes creating a field when it is connected to the voltage source.

There will be three electrode configurations:

- Two dots representing an electric dipole configuration.
- Two parallel lines representing a cross section of a parallel plate capacitor.
- A random configuration of three or more dots and surfaces.

For each one you will map the electric field lines and equipotentials as described below.

Place the conducting sheet on the board and set the contact pins firmly through each metallic electrode. Connect the pins to the voltage supply with the wire clips. If there are only two electrodes then one should be connected to ground and one to the positive voltage lead. If there are more than two, you may elect to connect the others to the positive voltage or to ground as you see fit, but be sure to note to which one each was connected. Turn on the voltage supply and set it for 10 volts.

1. **Drawing Electric Field Lines:** Tape the two leads of the voltmeter together, so that the probe points are about 2 centimeters apart. You will use the pair of probes much like a drafting compass. Place one of the probe points near the electrode connected to ground; with this point planted on the paper, let the other point contact the conducting sheet, and swing it in an arc while looking at the voltmeter. You should find that there is point along the arc at which the reading on the meter is a maximum. Draw a line with the white pencil, connecting the pivot point to this point of maximal voltage.

Now move the first probe tip to the location of the second, and again swing the second tip in an arc, looking for the maximal voltage. In this way you will trace out a line in a series of small steps, stopping when you get either to the edge of the paper or the opposite electrode.

Repeat this procedure at equally spaced intervals around the electrode. You should draw from four to six of these lines.

2. Drawing equipotentials: Separate the probes that you had taped together in the previous procedure. Attach one of the voltage leads to the wire connected to the ground of the voltage supply. Place the other probe in contact with the conducting sheet, and move it about until you get a reading of two volts on the voltmeter. (You should check near the grounded electrode.) Now, slowly move the probe along the sheet in such a fashion that the voltmeter reads a constant value of two volts. Your partner should work with you, tracing the path of the probe using the white pencil. Label this contour line "2V".

Repeat the above procedure for tracing out lines with voltage readings of 4V, 6V and 8V, labeling each one. (You may trace out more of them if the time allows.)

3. Measuring **electric field values:** Again tape the probes together, but this time adjust the distance between the tips to a centimeter or less. Measure the distance between the tips as accurately as possible.

Choose any one equipotential contours (the 4V or 6V should work best), and place one end of the probe pair on the contour line. Again, using this point as a pivot point, swing the other probe tip in an arc on the paper, finding the direction of largest voltage change. Divide the voltage you measure by the distance between the probe tips, and record the number in units of volts/meter. This gives you a local measurement of the electric field. Mark the pivot point so as to keep track of what field values were recorded at which positions. Repeat this measurement in at least ten places around the contour. (You may do it more often and on more contours if you wish).

For the parallel line capacitor configuration you should also do the following: Draw a line midway between the conducting lines of the capacitor. Treat this line as you did the contour above, placing one of the probe points on the line and swing the other so as to get a maximal voltage, and divide this voltage by the distance between the probes to get a value for the strength of the electric field at a point on the midline of the capacitor configuration. Repeat this procedure every centimeter along the midline, to a region beyond the ends of the conducting lines that comprise the capacitor. Record these numbers, and the distance they were from the very center of the midline.

4. **Transferring your data:** Copy your drawings of electrodes, equipotentials and field lines to clean white pieces of paper, each one drawn in a different color. Label the voltages of each contour clearly. Draw each electric field vector you measured, making the vector proportional to the value you found. Write the value of the electric field you measured next to the arrow.

4 Questions

Discuss the following questions with your lab partners. You must all come to the same conclusions. Then write your answers to the questions in the space provided below.

1. Do you ever see two field lines cross?

2. Do you ever see two equipotential lines cross? Why is this the case?

3. What can you say about the angle at which field lines cross equipotential lines? Draw an example to illustrate what you saw.

4. What about the angle at which field lines start out from electrodes? How do they relate to this surface normal? Sketch an picture showing what you saw, and explain why the field lines act that way.

5. Plot the value of the electric field as a function of position along the midline of the parallel "plate" capacitor. How much does *E* vary between the center of the capacitor and the end points? How would you characterize the variation?

6. The expected value of the electric field between the plates should just be the voltage difference between the electrodes divided by the distance between them. Compare the measured value of E with the one you predict.

7. Do you see a relationship between the value of E written next to a line segment, and the spacing between the equipotential lines near that point? If so, describe it qualitatively.

5 Computer Simulations:

In the Physics directory on computers in the PC lab, there is a program called "E&M Fields". This program can do many different things. Start the program by double-clicking on the icon. You want to click the mouse under the menu-heading "Sources", and select "2D charged rods"¹ Drag two charges equal in magnitude but of opposite sign to the center of the screen, and place them about 5 centimeters apart. Now click on the menu-heading "Field and Potential" and select "Field Lines". When you click the mouse, the computer will draw the field line going through that point. Draw field lines that are roughly comparable to the ones you measured in the lab. Again click on the "Field and Potential" menu and select "Equipotentials". Try to reproduce the figure you obtained in your experiment. Sketch your result below:

Repeat the above process, hut now for two rows of equal and opposite charges. Again, use the computer to plot field lines and equipotentials. Sketch the result below:

Place a charge of +2 on the center of the screen. Next place two -1 charges on either

¹An infinite line of charge in 3D is like a point charge in 2D. There will be no component of the field parallel to the line, and each plane normal to the line will show an identical set of field lines.

If you are curious or bored, you might think about the equivalent of Coulomb's law in 2D. The force between charges in 2D does not fall off as $1/r^2$. Using the 2D equivalent of Gauss' law, can you determine the force between charges?

side of the +2 charge, so that all three are on a line as shown. On the left hands side sketch how you expect the fields lines and equipotentials to look. On the right hand side, sketch what you find from the simulation. Please try to reason out how the field lines look *before* you use the simulation!

You can also get a graphical representation of Gauss' Law by drawing a contour over which the computer will calculate the flux. One of the menus will allow you draw Gaussian surfaces by clicking the mouse and dragging it about in a closed loop. The computer puts a grey bar on each segment of the loop it draws; the bar indicates the magnitude and sign (in or out) of the electric flux. Place a number of different charges around the screen and give it a try.

Extra Credit The program has a challenge mode. You have to locate a set of invisible charges on the screen and determine their magnitude. Your only way to find them is to click the mouse at different points on the screen, where the computer will then draw the electric field vector. Try it first for a single charge. If you can do it for three or more charges show it to your TA for extra credit! (You must get the location and value of the charges to get credit.)

Possible standard electrode configurations

