Lab-3: Equipotential Surface Plotting

Purpose

a. To map the *equipotential surfaces* by two charged conductors of various shapes.

b. To draw *electric field lines* produced by the two charged conductors of various shapes from equipotential surfaces. For simplicity, we will work with two-dimensional systems.

Theory

There are a few fundamental concepts from electrostatics that are involved in this lab:

Electric field lines: A convenient way of visualizing the electric field produced by a given charge distribution is by drawing lines called electric field lines. An electric field line starts at a positive charge and ends at a negative charge. The strength of the field is proportional to the density of the field lines. The tangent direction of the electric field line at any point gives the direction of the corresponding electric field, as shown in Fig. 1.

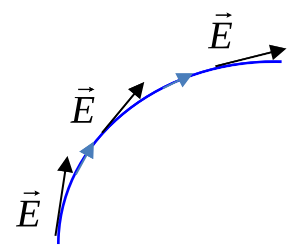
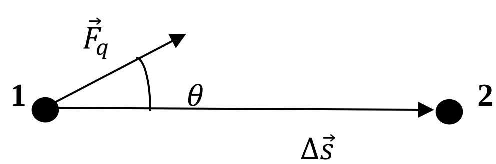


Fig. 1. Electric field line and Electric field

Electric potential (or simply, potential): The electrostatic force is a conservative force and hence, one can define a potential energy U associated to this force. For a given point charge q in the presence of an electric field $\vec{E}$, the *electrostatic potential energy* difference between two points in space "1" and "2" infinitesimally close to each other is defined by

$$\Delta U = U_2 - U_1 = -|\vec{F}_q||\Delta\vec{s}|\cos\theta \qquad (1)$$

where $\vec{F}_q = q\vec{E}$, $\Delta\vec{s}$ is the displacement vector connecting points "1" and "2", and θ is the angle between $\vec{F}_q$ and $\Delta\vec{s}$:



The *electrostatic potential* difference between points "1" and "2" is defined by $\Delta V = \Delta U/q$. In other words,

$$\Delta V = V_2 - V_1 == -|\vec{E}||\Delta\vec{s}|\cos\theta \qquad (2)$$

It follows that for any point charge q, the electrostatic potential energy difference between two close points is $\Delta U \sim q\Delta V$. While the potential energy depends on both the point charge q and the charge distribution that generates $\vec{E}$, the electric potential only depends on the source charge distribution. Note that Eq. (2) implies that the maximum value of ΔV occurs for $\theta = 180°$, i.e. when one "moves" along the direction anti-parallel to the electric field. Similarly, the minimum value of ΔV occurs for $\theta = 0°$, i.e. when one "moves" along the direction of the electric field

Equipotential surfaces: Surfaces where V is constant are called "equipotential surfaces". It follows from Eq. (2) that the (infinitesimally close) points "1" and "2" are on the same equipotential surface (i.e., $V_2 = V_1$) if and only if $\theta = 90°$. This implies that the electric field is perpendicular to $\Delta\vec{s}$ and hence, to the equipotential surface containing points "1" and "2". Therefore, we conclude that equipotential surfaces must be perpendicular to the electric field *lines* at all points.

Calculation of the magnitude and direction of the electric field is difficult in the presence of complicated charge distributions. However, if it is possible to map the equipotential surfaces, then one can obtain information about the electric field based on the fact that the direction of the field at every point is normal to the equipotential surface passing through that point. The magnitude of the electric field can be obtained from the separation of the equipotential surfaces.

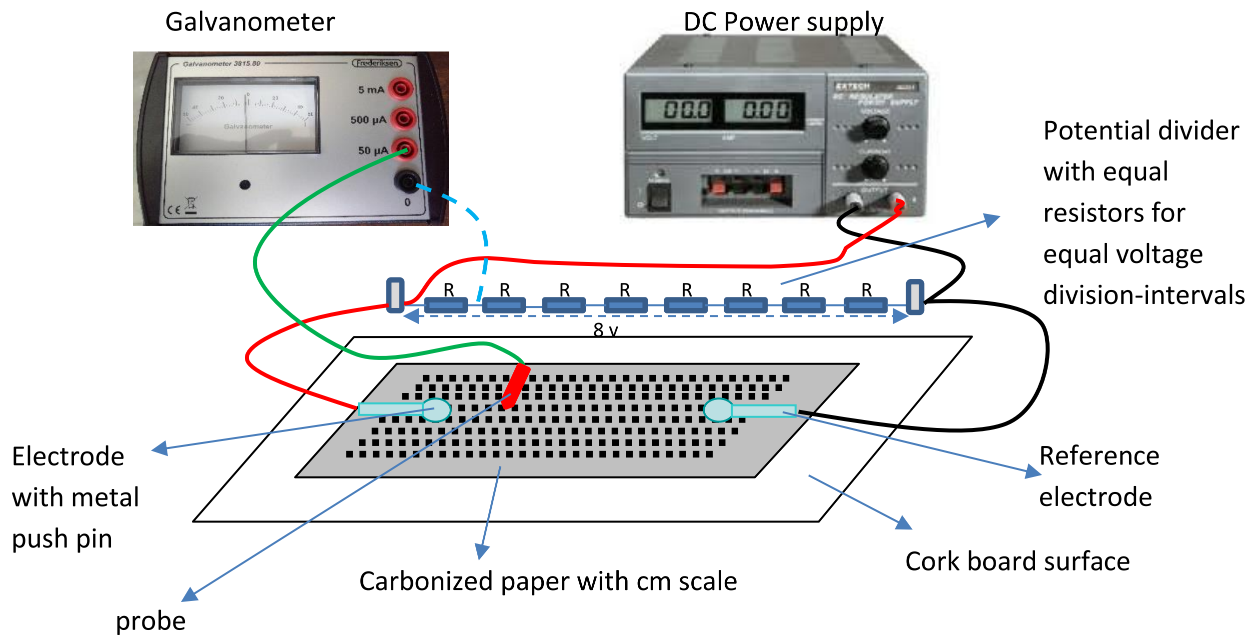
In this experiment, you will plot two-dimensional equipotential surfaces (actually lines!) generated by two charged conductors of various shapes. From these equipotential surfaces, you will be able to draw the corresponding electric file lines and estimate the magnitude of the electric field.

Apparatus

Sheets of carbonized paper (each sheet includes a pair of electrodes made of conducting silver ink), Corkboard working surface, potential divider, Galvanometer, Push-pins, three banana wires with clips at one end, Multimeter, power supply, and connecting wires.

Description of Apparatus

Experimental set up for this lab is shown in the figure below in Figure 2.



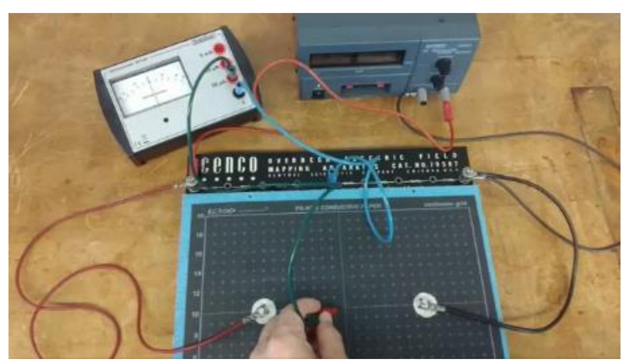


Figure 2: Setup used in the lab. The power supply sets a potential difference between the two electrodes that are connected to the terminals of the potential divider and to the silver drawn conductors on the carbonized paper with metal push pins. The Galvanometer reads zero current when the probe (red probe and green wire in diagram) voltage matches the voltage to which the other terminal of the galvanometer is connected to at the potential divider (blue wire). **CAUTION: Make sure the power supply is off before setting up the lab equipment.**

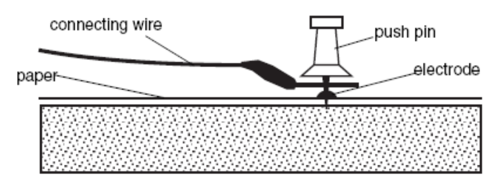
You will use carbonized paper sheets with conductors of different shapes painted using conducting silver ink. There are four different configuration of the electrodes on the carbonized paper sheets in this lab: (a) two point electrodes (b) two parallel electrodes (c) one line and a point electrodes and (d) two line electrodes with a conducting circular area between them. A power supply will be used to create a potential difference between the two conductors. This two-dimensional setup can be used to simulate the patterns of equipotential surfaces and electric field lines that are generated by two metal electrodes in three-dimensions.

At the end of this manual there are graph papers that include a grid similar to the grid printed on the carbonized paper. You will have to measure the potential on the carbonized sheet and ***map the equipotential surfaces on the graph sheet*** attached at the end of this manual. These sheets are your data sheet for this lab. Once you complete plotting the equipotential surfaces, you will be able to draw electric field lines for all four configurations of electrodes.

Procedure

Setting up the apparatus

1. Make sure the power supply is OFF and the "voltage" and "current" control knobs are set at zero position (i.e. turned completely counter clockwise).
2. Use the carbonized paper with two "point" electrodes made of conductive silver ink. Set up the apparatus as shown in Fig. 2. Connect the positive (red) and negative (black) terminals of the power supply to the terminals of the potential divider as shown in the diagram in figure 2 above and to each of the "point electrodes" on the carbonized paper. For proper contact with the electrodes, use push-pins as shown in the figure (in case of wires with a clip at the end, you can simply clip the push pin).



3. Connect a banana plug wire (blue dashed wire in diagram in fig. 2) into the galvanometer 0 and to the 7 V position on the potential divider (the first banana socket after the 1st resistor from the left end). Connect another banana wire (green wire in diagram in fig. 2) to the 50 μ A socket of the galvanometer. At the opposite terminal of this wire you should have the red probe.
4. You will use the red probe (connected to the green wire in fig. 2) to find points on the carbonized paper that has same electric potential voltage as the other terminal of the galvanometer connected to the potential divider voltage.

Part I. Mapping of Equipotential surfaces for two "point" electrodes

1. Make sure that both knobs of the power supply are all the way counter clock wise (zero position). Now turn the power supply on and rotate the current limit knob very slightly clock wise till the small red light turns off. Set the voltage to 8 V.
2. **Test the circuit if the wire connections are correct:**

   a. Use the multimeter as a voltmeter and place the tip of its black probe on the reference electrode (the one on your right hand in fig. 2) on the carbonized sheet & place the red probe of the voltmeter on the black (reference) electrode. What is the reading on the voltmeter? Place the probe at different points on the line. Do they read the same voltage on the voltmeter?

b. Keeping the black probe of the voltmeter on the reference electrode on the carbonized sheet, place the tip of the red probe of the voltmeter on the opposite electrode (the electrode on your left side in fig. 2). What is the reading on the voltmeter? Place the probe at different points on the line. Do they read the same voltage on the voltmeter?

3. On one of the graph papers **attached at the end of this lab manual** draw the "point" electrodes at the same location using the scales on graph paper and the carbonized paper.
4. Place the tip of the red probe (not the voltmeter probe, but the red probe attached to the green wire that is attached to the galvanometer, as shown in fig. 2) on the carbonized sheet. Now poke around with the red probe to find points that are at potential of 7 V. These are the points for which the galvanometer, as shown in fig. 2, reads zero current, indicating equal voltages at its two terminals. **DO NOT touch the carbonized sheet** with your hand while doing this. Tilt the probe tip a little bit to get a stable reading and DO NOT drag the probe tip on the sheet. **Mark the location of these points on your graph paper. <u>Note that:</u>** because the resistors have tolerance in their values, they are not exactly equal to each other, so the values of the voltages of the potential divider might be different from the ideal case of 7 V, 6 V, 5 V, 4 V, 3 V, 2 V & 1 V. So, for example, the first voltage of the potential divider might be 7.3 V or 6.8 V instead of exactly 7 V. So, you need to first use the voltmeter to measure the actual values of the voltages of the potential divider and then accordingly label the equipotential curves that you will trace on the carbonized sheet with the values of these actual voltages; for example; if the actual voltage of first point of the potential divider is 7.3 V, then the first equipotential curve you will trace on the carbonized sheet should be labelled as equipotential curve of value 7.3 V. For this same reason (resistors tolerance), the center of the potential divider might be different from exactly 4 V. It might be 4.3 V or say 3.5 V. But the center of the carbonized sheet is at 4 V. Therefore, the corresponding equipotential curve (of say 4.3 V or 3.5 V) on the carbonized sheet will be off from the center of the grid of the carbonized sheet.
5. Trace the equipotential line corresponding to 7 V by connecting the points just found (use the actual value of the voltage that you measured with the voltmeter on the potential divider at the point between the 1^{st} & 2^{nd} resistor from your left-hand side). Label the line with actual value voltage, (the actual value you measured with the voltmeter on that point of the potential divider, for example; you might have measured it on the potential divider as 7.3 V instead of 7 V, then label the equipotential curve as: the 7.3 V equipotential curve).
6. Repeat the previous step for 6 V, 5 V, 4 V, 3 V, 2 V and 1 V (actually, use the actual values you measured using the voltmeter on the corresponding points of the potential divider as explained in step 4 above) and trace the corresponding equipotential curves. The equipotential curves you obtained are analogous to the equipotential surfaces of two point charges q and –q in three-dimensions.

   Are the equipotential curves as you expected? Is there any two equipotential curves crossing each other?
7. Once you complete plotting your equipotential curves (sometimes called equipotential lines), please rotate the knobs of the power supply counter clock wise to zero and **turn off** the power supply.

Part II. Mapping of Equipotential surfaces for two "parallel line" electrodes

1. Remove the previous carbonized sheet and replace by the carbon sheet paper with two **"parallel line" electrodes** made of conducting silver ink.

2. Reconnect the wires as before. Turn on the power supply and test the connection.
    a. Place the tip of the red probe of the multimeter (voltmeter) on the black (reference) electrode. What is the reading on the multimeter? Place the probe at different points on the line. Do they read the same voltage on the multimeter?
    b. Place the tip of the red probe on the opposite electrode. What is the reading on the multimeter? Place the probe at different points on the line. Do they read the same voltage on the multimeter?
3. Now, repeat the steps 3 - 7 in Part I. The resulting equipotential lines are analogous to the equipotential surfaces of two parallel, uniformly charged plates with charges *q* and –*q* in three-dimensions.

Part III. Mapping of Equipotential surfaces for one "point" and one "line" electrodes

1. Remove the previous carbonized sheet and replace by the carbon sheet paper with **one "point" electrode and one "line" electrode** made of conducting silver ink.
2. Reconnect the wires as before. Turn on the power supply and test the connection.
3. Now, repeat the steps 3 - 7 in Part I. The resulting equipotential lines are analogous to the equipotential surfaces of one point charge in the presence of a uniformly charged plate with charges *q* and –*q* in three-dimensions.

Part IV. Mapping of Equipotential surfaces for two "line electrodes" with a conducting area between them

In this part of the lab we will repeat Part II but using a slightly modified configuration. In this case, there is a small circular area of conducting ink between the line electrodes. The line electrodes are connected to the power supply, as in Part II, but the small conducting ink area is **<u>not</u>** connected to the power supply. You will learn how potential and hence electric field behave in the presence of an uncharged conductor placed in an external electric field.

Repeat the steps in Part II. The resulting equipotential lines are analogous to the equipotential surfaces of two parallel and uniformly charged plates, with charges *q* and –*q*, in three-dimensions, in the presence of an uncharged conducting sphere between them.

Computation

For all **four** configurations of electrodes in the lab, draw electric field lines on the sheets with the equipotential lines you plotted. You may use a different color pen to draw the field lines. Make sure to put arrows on the electric field lines to indicate the direction of the electric field.

Using the values on the equipotential lines and measuring the distance between them, estimate the magnitude of electric field at three different places for each configuration.

Questions

1 How much work is done by the electrostatic force on a point charge that is moved on an equipotential surface (line)? Explain.

2. If the electric field lines are not normal to the equipotential surfaces, what would happen?