PHY 152/252

Equipotential Surfaces and Electric Field Lines – Laboratory 1

Objective:

The objective is to illustrate the relationship between charged conducting surfaces and electric field lines by mapping equipotential surfaces.

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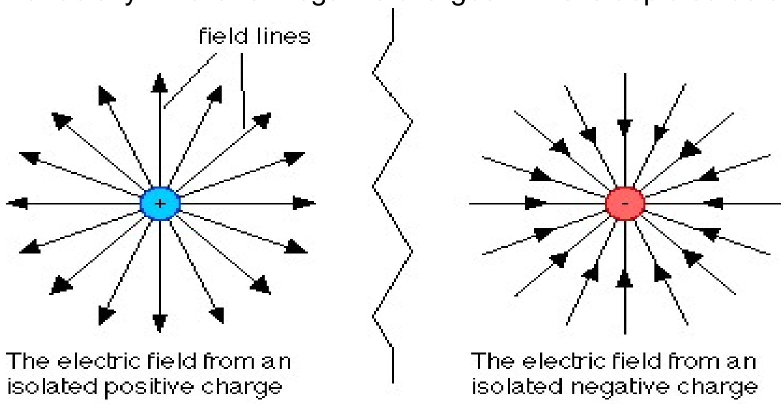
Theory:

An electric field is the way that we describe how one electric charge affects another charge near it. The equation for the electric field due to a point charge is $E = \frac{kQ_{source}}{r^2}$ where r is the distance from the charge, Q is magnitude of the charge, and k a constant. The electric field is a vector quantity that points in the direction a positive charge would move if placed in that electric field. We know that the electric field for a point charge points radially outward for positive charges and radially inward for negative charges. This is depicted below.



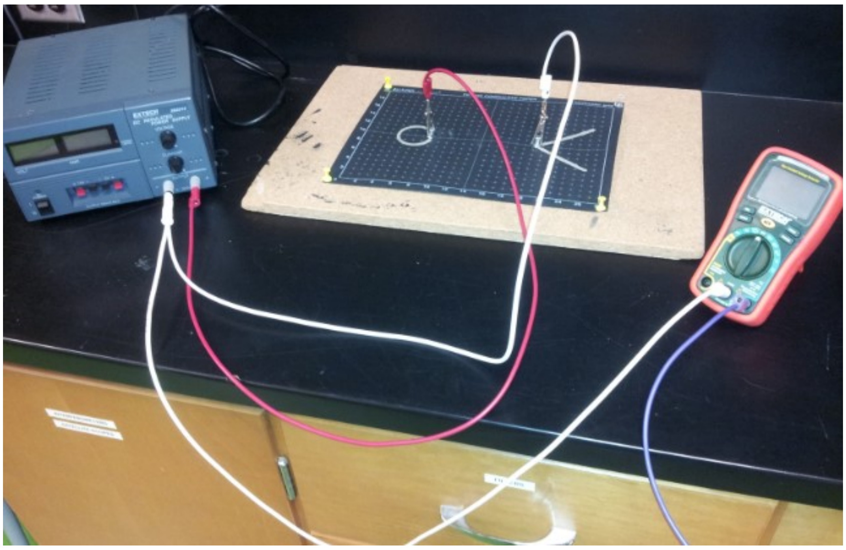
How do we know what the electric field for different charge geometries look like? This will require some background into electric potential, more commonly called voltage.

Electric potential or voltage is defined as the electrical potential energy per charge: $V = \frac{PE}{q}$, and represents the amount of work that would be needed in order to move charge from point a to point b. Voltage can be related to gravitational potential energy. If a ball is placed on top of a hill it has high potential energy and wants to roll down to a state of lower potential energy. Likewise a charge that is in a high potential region wants to move to a place of lower potential. The electric potential around an electrode, which is just a conductor, can be represented by a series of closed, imaginary surfaces. These are called equipotential surfaces, and at every point on an equipotential surface, the voltage value is the same. We can simulate equipotential surfaces on a sheet of conducting paper by applying a voltage difference between two electrodes. A voltmeter can be used to find specific voltage values on the paper. The equipotential surface (or line) can be drawn by finding a series of points on the paper where the voltage value is the same (equipotential) and then connecting them with a smooth curve.

Electric field lines and equipotential surfaces are related in that electric field lines always intersect equipotential surfaces perpendicularly. This is true because the electric field does **no work** when a charge moves along an equipotential surface. This allows electric field lines to be drawn by going from equipotential surface to equipotential surface knowing that the field lines intersect the equipotential surfaces perpendicularly.

Procedure

1. Set up the lab configuration as shown below. Use the plastic push pins to fasten your black conducting paper to the cork board. The silver-colored metal push pins are to be used as contacts between the electrodes (the silver painted patterns) and the power supply. These two pins may need to be pressed repeatedly into the paper during the experiment.



2. The first pattern you will use is the **parallel lines** (or parallel electrodes) pattern. Connect the red (positive) terminal of the power supply to the left electrode by placing the alligator clip around the metal push pin. Connect the black (negative) terminal of the power supply to the right electrode. The negative side is defined as the "ground" (V = 0). Connect one side of a provided wire into the COM terminal of the voltmeter and the other side into the negative terminal of the power supply. Connect another wire into the right port of the voltmeter to be used as a probe. You can measure voltage at any point on the conducting paper simply by touching the end of the connecting lead to the paper and reading the meter.

3. Ask the lab instructor to check your circuit. After approval, turn the large knob on the voltmeter 2 "clicks" clockwise to the V_{DC} position, turn the voltage control knob (the upper knob) fully counter-clockwise, turn the current-limit knob fully clockwise, turn on the power supply and set the voltage value to 12.0 V using the voltage control knob. Verify 12.0 volts using your voltmeter (and not the meter on the power supply). Do this by plugging the probe into the back of the stackable plug which is plugged into the positive terminal of the power supply.

4. Before you begin mapping, check the connections between the metal pushpins and the silver patterns on the black carbon paper by touching the probe to both patterns. The meter must read 12 volts on the left pattern and read 0 volts on the right pattern.

5. Map equipotential surfaces (in this 2-dimensional case, "equipotential lines") by moving the probe along the conducting paper until the desired voltage values are found. You should map 7 different equipotential lines at 1 V, 2 V, 4 V, 6 V, 8 V, 10 V, and 11 V. You can map an equipotential line by finding at least 6 points for the specific voltage value and transferring the coordinates from of the conducting paper onto the provided graph paper. One lab partner should find the equipotential points and another should transfer them to the graph paper. Each lab partner must have his/her own graph paper diagram of the surfaces to include with his/her lab report. Complete each of the 7 equipotential lines by connecting the coordinate points with smooth curves. On the graph paper, label each equipotential line with its corresponding voltage

value. Note that, by definition, the electrodes (the silver painted shapes) are equipotential surfaces (or lines).

6. Repeat the above steps using the sheet of black conducting paper having two points or small solid circles. Be sure to draw the electrodes on your graph paper diagrams at their correct locations for both configurations.

Calculations:

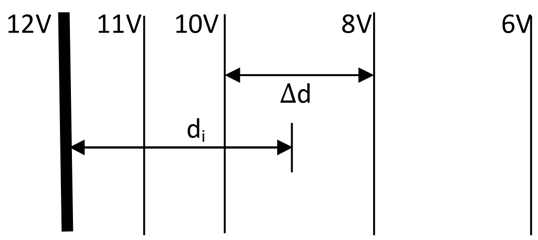
1. For both configurations, use the perpendicular relationship between field lines and equipotential surfaces (or lines) to draw 5 to 7 electric field lines, starting at one electrode and ending at the other. Draw arrows on the field lines to indicate the field's direction.

The remaining calculations are to be performed **only** for the first configuration (the parallel electrodes configuration).

2. Calculate the electric field strengths (magnitude of **E**) between each of the equipotential lines you drew. Do this calculation for one of the electric field lines, preferably one that is directly between the electrodes. .Start at the positive electrode and follow along this chosen field line, measuring the distance on your graph paper between each equipotential line. Use the voltage difference between adjacent equipotential lines (either 1 or 2 volts) and the distance between the lines, which is Δd, to calculate the electric field strength between each equipotential line. You should have 6 electric field values when you go from one electrode to the other. Use the equation $E = \frac{|V_2 - V_1|}{\Delta d}$ for your electric field calculations. The above equation comes from the general equation: $\boldsymbol{E} = -\nabla V$. For the simple geometry of this experiment, this equation reduces to: $E = -\partial V/\partial x$ which further reduces to: $-\Delta V/\Delta x$ and finally to: $|V_2 - V_1| / \Delta d$. You are not required to understand how this equation is derived.

3. Create a data table for the same field line that you used to calculate values for E. In the table, make two columns, one for the values of E and the other for the distances, d_i, from the left electrode to each point where the associated values of E were found. To find the value of d_i for an associated E value, calculate the average distance (Δd / 2) between the two equipotential lines used in that calculation and then add the distance from the left electrode to the left equipotential line used for your E-value calculation. You should have 6 such calculations for the selected field line. This calculation is shown graphically and described below.

In the figure shown here, d_i is obtained by adding the distance from the 12V electrode to the 10V equipotential line, to ½ of the distance (Δd) between the 10V and the 8V equipotential lines. In the case shown to the right, this would be d_2, the distance to put in the 2[nd] row of your table. d_1 would be measured between the 11V and the 10 V equipotential lines.



4. Using your data table from calculation 3, graph the magnitude of the electric field using Excel. Put the average distances, d_i, from the positive electrode on the x-axis and the magnitudes of the electric field on the y-axis.

Question: Is the value of the electric field strength what you expect it to be, moving from the positive to the negative electrode? Use the graph of the electric field strength (magnitude of **E**) <u>versus</u> the distance to help you with your explanation. Also, remember that the strength of the electric field is proportional to the "density" of the electric field lines.

5. Identify and discuss sources of error. Can you explain why you were not required to perform the above calculations for the second configuration?