Experiment 17
Electric Fields and Potentials Spring 2021 version

Equipment:
2 sheets of conductive paper
1 Electric Field Board
1 Digital Multimeter (DMM) & DMM leads
1 plastic tip holder w/ two 1cm spaced holes
1 power supply
1 grease pencil
2 (12 inch) banana-banana wire leads
2- point charge connectors
1- circular conductor ring
1-square conductor ring
6 (screw-type) binding posts

Objective:

The objective of this experiment is to map the equipotential surfaces and the electric field lines of 1) two equal and opposite point charges and 2) inside and outside of equal and oppositely charged hollow conductors *(technically, their analog)*.

Theory:

For a finite displacement of a charge from point A to point B, *the change in potential energy* of the system $\Delta U = U_B - U_A$ is

$$\Delta U = -q_0 \int_A^B \mathbf{E} \cdot d\mathbf{s}\,. \qquad \text{Equation 1}$$

The potential energy per unit charge U/q_0 is independent of the value of the test charge q_0 and has a unique value at every point in the electric field. The quantity U/q_0 is called the **electric potential** (or **potential**) V. Thus the electric potential at any point in an electric field is $V = U/q_0$.

The *electric potential difference* $\Delta V = V_A - V_B$ between two points A and B in an electric field is defined as the change in potential energy of the system divided by the test charge q_0:

$$\Delta V = \frac{\Delta U}{q_0} = -\int_A^B \mathbf{E} \cdot d\mathbf{s} \qquad \text{Equation 2}$$

To avoid having to work with potential differences, we can arbitrarily establish the potential to be zero at the point located at an infinite distance from the charges producing the field. Thus we can state that the *electric potential at an arbitrary point equals the work required (per unit charge) to bring a positive test charge from infinity to that point*. Potential difference and change in potential energy *are related* by $\Delta U = q_0 \Delta V$. The unit for potential difference is a joule/coulomb or a volt.

An equipotential surface is defined as any surface consisting of a continuous distribution of points all having the same electrical potential. If the potential is the same, then it takes no work to move a charge around on an equipotential surface. This is analogous to moving a mass around in the gravitational field.

The electric field at a point is defined as the force per unit charge at the point and has the units newtons/coulomb (N/C). It can also be shown to have the units volts/meter (V/m). The electric field is represented by lines of force drawn to follow the direction of the field. These lines are always perpendicular to the equipotential surfaces. (see figure 17-1).

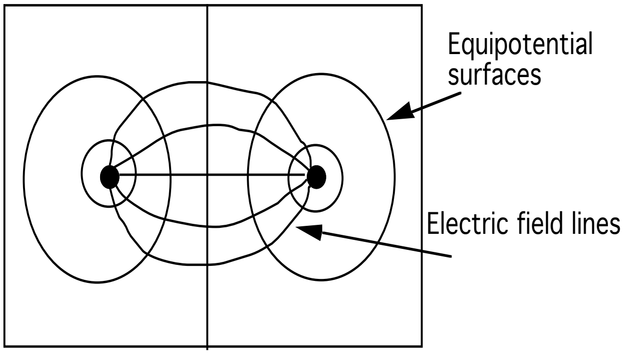

Figure 17-1

It is very important to realize that electric field lines radiate outwardly in all directions and are a three dimensional (3-D) phenomena. In this experiment you will map a cross section of the 3-D electric field by measuring equipotential lines on a plane of black paper. These lines are defined by the intersection of a plane with equipotential surfaces. *See section on euipotential surfaces in text*. Therefore you will examine the analogy that electric field lines are perpendicular to equipotential lines rather than surfaces

The electric field **E** and the electric potential V are related by Equation 2. The potential difference *dV* between two points a distance *ds* apart can be expressed as

$$dV = -\mathbf{E} \bullet d\mathbf{s} \qquad \text{Equation 3}$$

If the electric field has only one component E_x, then $\mathbf{E} \bullet d\mathbf{s} = E_x dx$. Equation 3 then becomes $dV = -E_x dx$ or

$$E_x = -\frac{dV}{dx} \qquad \text{Equation 4}$$

Using vector notation, equation 4 can be generalized and the electric field becomes the negative gradient of the potential or

$$\mathbf{E} = -\nabla V \qquad \text{Equation 5}$$

This says that the electric field points in the direction of the maximum decrease in electric potential.

Procedure:

Part 1: Two point charges Mapping Equipotentials

1. Attach the conductive sheet to the rubber covered board using two (screw-type) binding posts and two point charge connectors. See Figure 17-2.

2. Connect the power supply to the binding posts using banana leads. Connect the common ground lead from the DMM to the wire coming from the negative terminal of the power supply (the black terminal). Inserting the red DMM lead into the lead coming from the red terminal of the power supply. See figure 17-3.

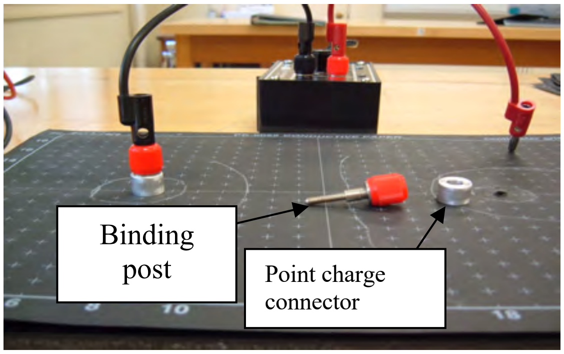

Figure 17-2 Point charge equipment

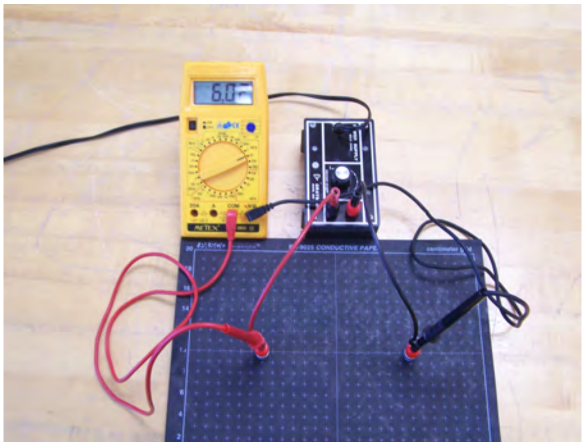

Figure 17-3 Point charge arrangement

3. Adjust the power supply until the potential difference between the terminals is 12 volts. Label the point charge (i.e., the connector ring) voltages using the grease pencil.

4. Map five equipotential lines(10, 8, 6, 4 & 2 volts) by moving the red DMM lead around on conductive paper. For example, there will be places on the paper where to voltmeter will read eight volts. Use the tip of the DMM leads to make a small indentation in the conductive paper. Do this for several points and then "connect the dots" with the grease pencil. Repeat this process for the other equipotential surfaces, labeling the voltage value of each one

Mapping Electric Field Lines

5. Electric field lines point in the direction of the maximum decrease in the potential (i.e., $\mathbf{E} = -\nabla V$). To map the field lines, you need to know the direction of maximum change. Place one tip of the DMM leads into the plastic discs.

6. Map **two electric field lines** on the conducting paper using the DMM and the grease pencil. Do this by placing both leads on the conductive paper. Rotate one of the leads until a maximum value appears on the DMM. **See figures 17-5 & 17-6 below to see how this is done.**

At this location, push the tips of the leads into the paper to make an indentation.

7. Move the lead so that the black lead is now in the indentation formerly occupied by the red lead. Repeat step six. Map two sets of field lines.

8. Since tips of the DMM leads are 1 cm apart when using the plastic disc, the field strength can be measured using the voltmeter. To do this, divide the potential difference between the ends of the probes by the distance between them.

Measure the field strength at a point half-way between the two point charges and record this value in V/m in your lab notebook.

Part 2: Hollow concentric conductors analog

9. Attach (i.e., plug) the negative lead from the power supply and the DMM to the outer circle. Attach the positive lead to the inner circle.

Adjust the power supply until the potential difference between the terminals is 12 volts. See Figures 17-3. See figure 17-4 below.

10. Map a few equipotential (8, 6 & 4 volts) surfaces between the conductors if possible. Verify the following statements by performing the appropriate actions with the DMM.

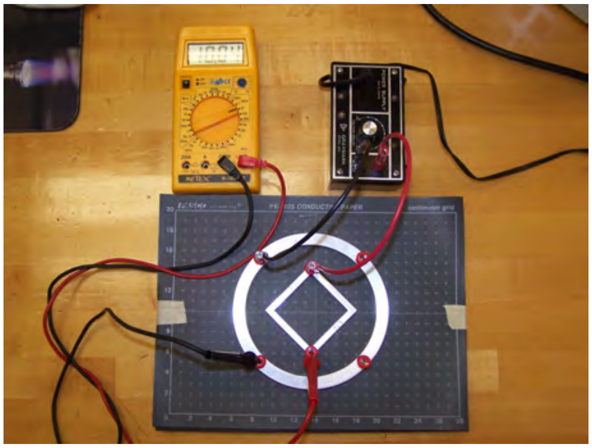

Figure 17-3 Concentric Conductors

(a) **The electric field inside a conductor is zero.** See Figure 17-7 below. Be sure and check voltage outside the conducting ring.

(b) **The electric field is never parallel to an equipotential conducting line/surface**. See Figure 17-8.

c) **The field is strongest at the points of greatest curvature.**

Place the black lead on the inner square and red lead inside the plastic disc.

See Figure 17-9 & Figure 17-10 below.

Record the voltages from the corner measurement and the flat part of square.

(d) **The potential difference is zero outside the conducting ring.**

No matter what the orientation of your power supply leads to the ring and square, you will still measure a potential difference of zero.

Show this by measuring the potential outside of the ring if you switch the power supply leads on the ring and square **while always keeping the black lead of the DMM with the black lead of the power supply.**

What voltage did the measure at all points outside of the ring? What is the potential difference?

Post Lab Questions:

1. In this lab you plotted 2 equipotential maps. Equipotential maps look (are) very similar to the topographical maps which are used in geology, hydrology, petroleum engineering & geological engineering to name a few areas. One of your plots was analogous to the Devil's Tower in the text. See figure below.

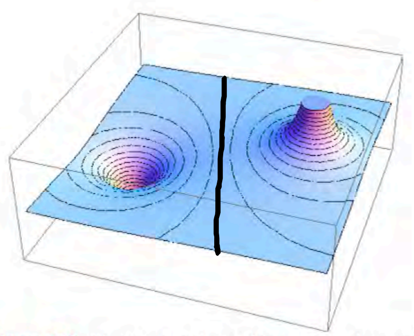

Figure 7.33 Electric potential map of two opposite charges of equal magnitude on conducting spheres. The potential is negative near the negative charge and positive near the positive charge.

Based upon this diagram, which of your **plots looks like the one half of the diagram above and why.**

Include a sketch of the figure above and show where the red and black power leads would be to duplicate either the right hand or left hand side of the potential plot(s) above. What happens (to the plot if you reverse the leads (See part 10d above.) Show with diagram.

2. **Compare the electric field you measured in step 8** above (i.e., the electric field midway between the two terminals) **to the electric field of the near the surface of the earth** . 'Google" this value. Include the ULR of the webpage used.

Calculate the % difference. Show all work and any suppositions.

3. Based upon what you observed in Part 2 of this lab, why is the inside of a car a relatively safe place to be in an electrical storm (i.e., lightening storm)? It's perfectly ok to "Google" the answer, but you must relate that answer to what you observed in this experiment.

4. The electric field you looked up in post lab question 2 above should be comparable to the magnitude of the **electric field you measured in the middle of conducting the paper (V_{middle}) in part 1, step 8 of procedure.**

a) Using this measured value calculate the amount of charge it would take to levitate 1 gram of a sheet of paper (~ ¼ of a sheet of 8 ½ by 11 inch sheet) if the paper was positively charged and your measured electric field was pointing upward.

b) The amount of charge that you calculated should be relatively small (~100 to 300 micro Coulombs).

Calculate the **force between two pieces of 1g paper located 1 meter apart** if they both had the amount of charge you calculated in part a) above. Convert from newtons to pounds. Show all work.

c) Calculate the force between the two pieces of paper if they both had one coulomb of charge and were located one meter apart. Very simple calculation.

d) The answer(s) above should convince you that most objects that you encounter in everyday life have very little net charge. Explain why.

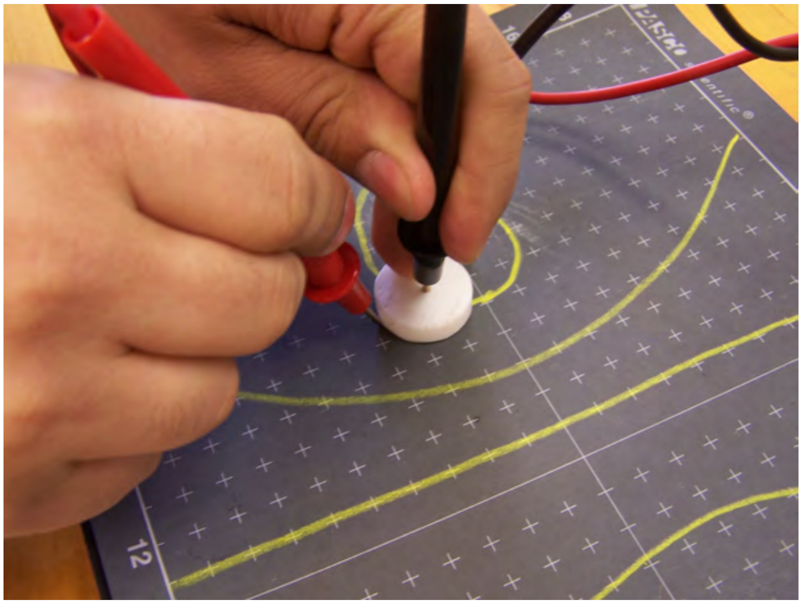

Figure 17-5

1) Place the red lead around perimeter of spacer (DMM value here is relatively low)

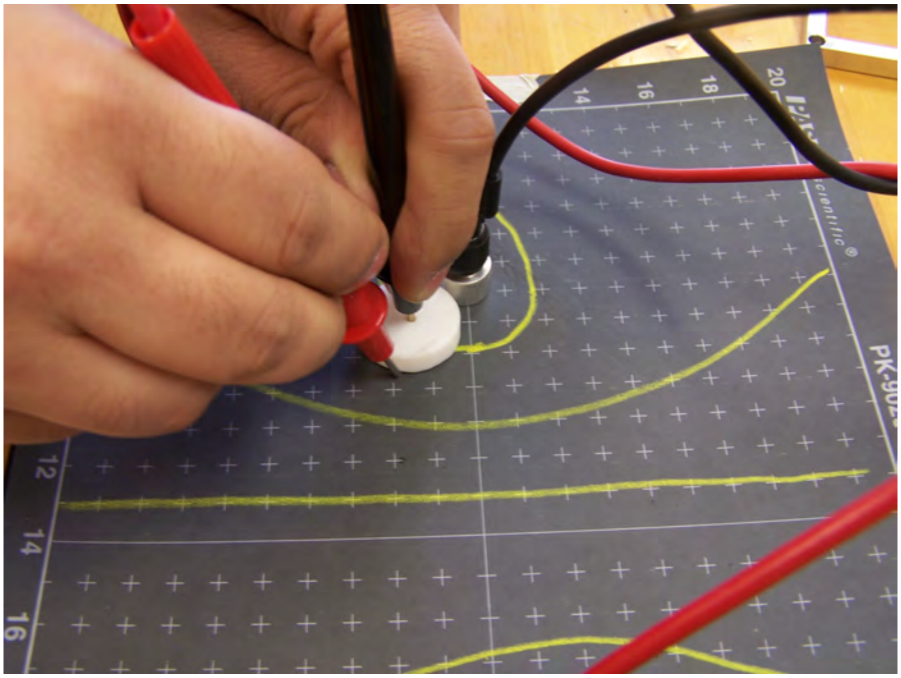

Figure 17-6

2) Move lead around perimeter of spacer until you find the maximum value.

3) Punch a small indentation with red lead.

4) Move spacer so that black lead is in the indentation above & repeat process

(i.e., find new maximum value using red lead)

Repeat above steps until you reach other pole.

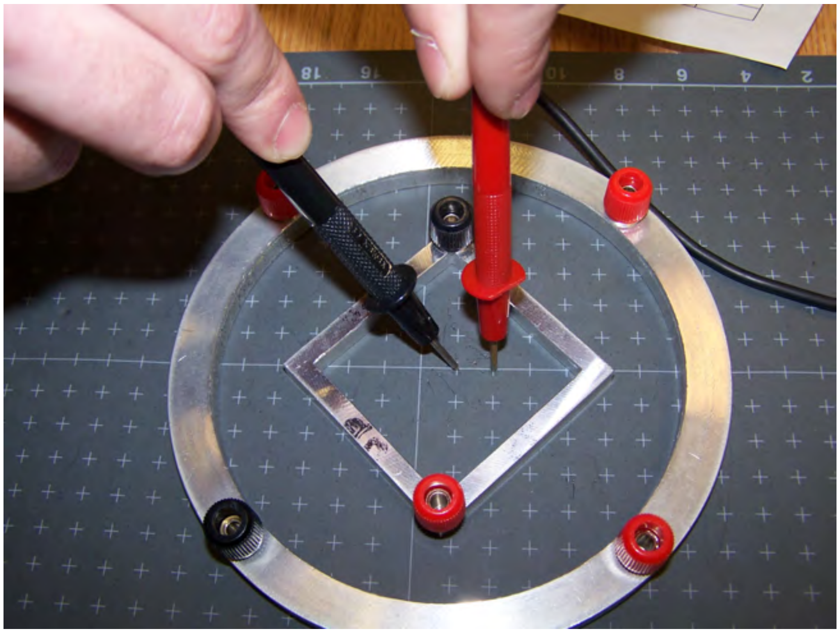

Figure 17-7 Measuring electric field inside of conductor

Figure 17-8 Determining orientation to measure zero electric field (Start like above and rotate spacer until DMM reads zero voltage & note orientation)

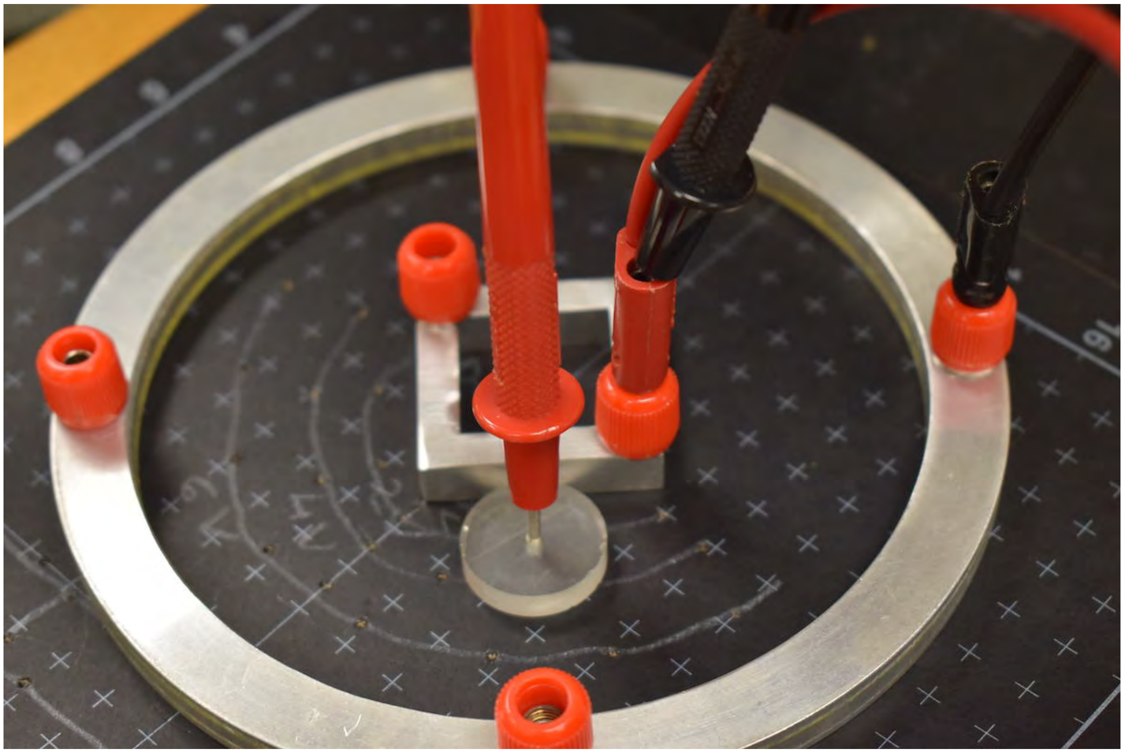

Figure 17-9 Measuring electric field at a zero curvature surface

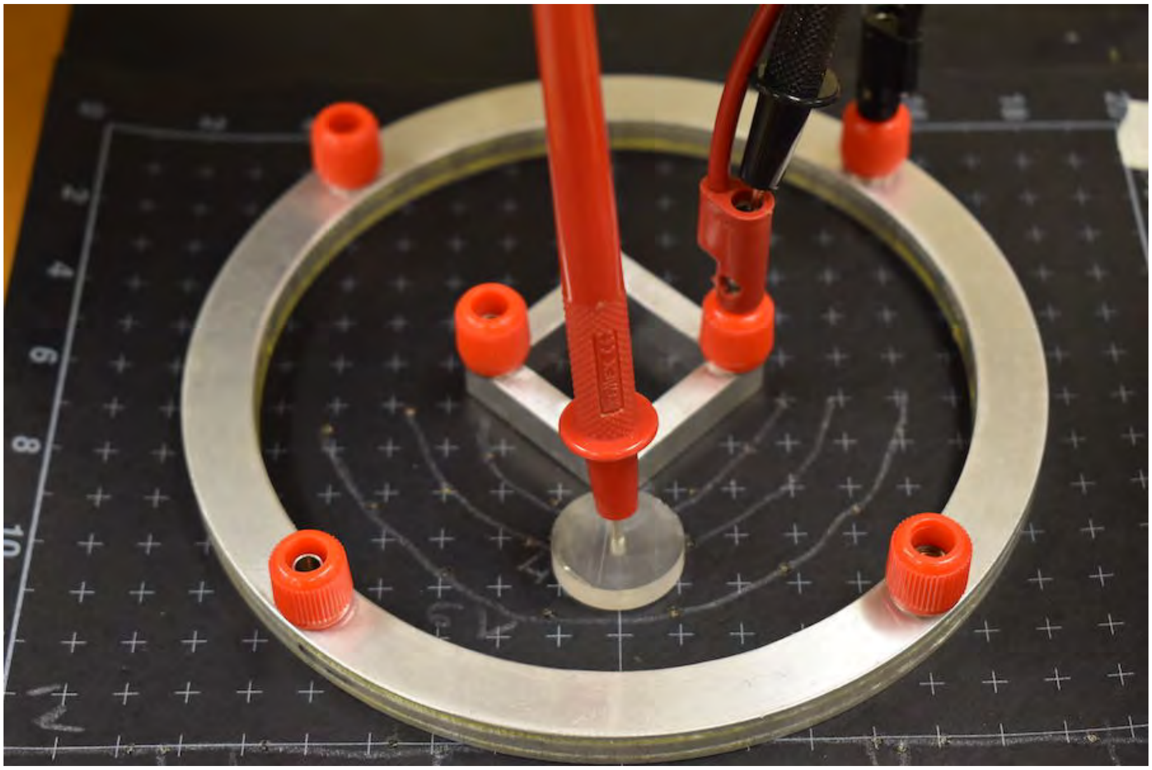

Figure 17-10 Measuring electric field a pointed (i.e., a non zero curvature) surface