

# Experiment 17

## Electric Fields and Potentials

### Advanced Reading:

Serway & Jewett - 8<sup>th</sup> Edition  
Chapters 23 & 25

### Equipment:

2 sheets of conductive paper  
1 Electric Field Board  
1 Digital Multimeter (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

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

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  $q_0$ :

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

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).

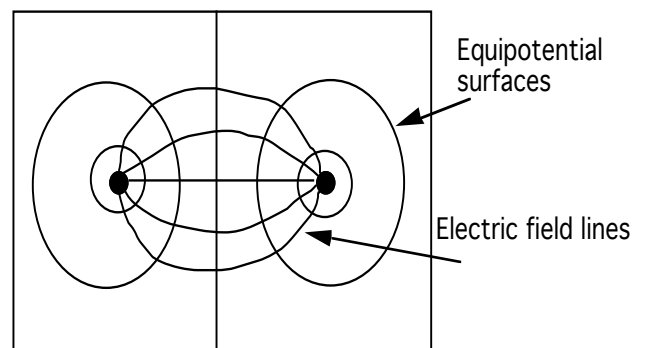


Figure 17-1

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 equipotential surfaces in text.* Therefore you will examine the analogy that electric field lines are perpendicular to equipotential lines rather than surfaces

The electric field  $\mathbf{E}$  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

$$dV = -\mathbf{E} \cdot d\mathbf{s} \quad \text{Equation 3}$$

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

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

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

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

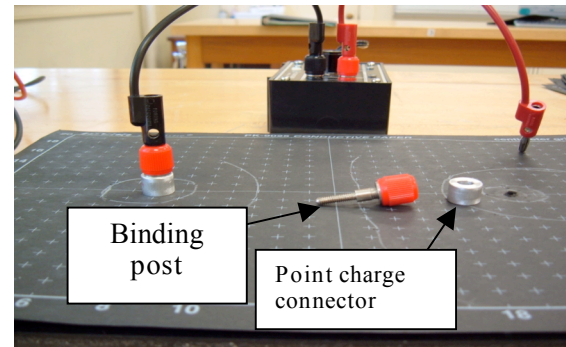
This says that the electric field points in the direction of the maximum decrease in electric potential.

## Procedure:

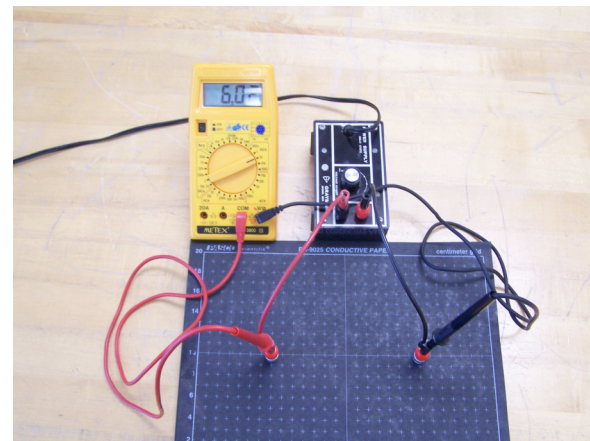
### Part 1: Two point charges Mapping Equipotentials

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 6 volts. Label the point charge (i.e., the connector ring) voltages using the grease pencil.

4. Map five equipotential surfaces (5,4,3,2,1 volts) by moving the red DMM lead around on conductive paper. For example, there will be places on the paper where the voltmeter will read five 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 the tips of the DMM leads into the plastic pin holders. The tips of the DMM leads are now 1 cm apart, so 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.
6. Map three lines of force on the conducting paper using the DMM and the grease pencil. Do this by placing both pins on the conductive paper. Rotate one of the pins until a maximum value appears on the DMM. At this location, push the tips of the leads into the paper to make an indentation.
7. Move the pins so that the black lead is now in the indentation formerly occupied by the red lead. Repeat step six. Map three sets of field lines.
8. 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 the negative lead from the power supply and the DMM to a conductive thumbtack placed on the inner square. Attach the positive lead to the outer circle. See Figure 17-3

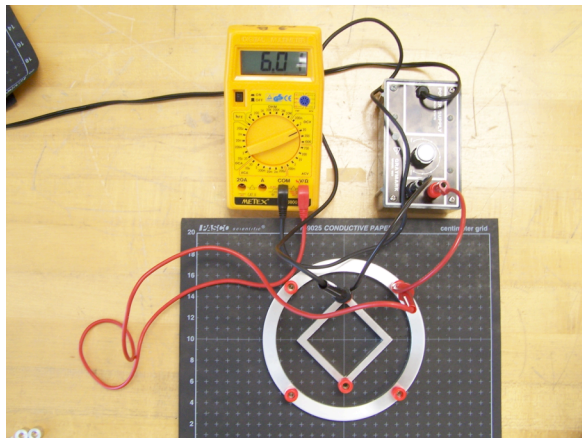


Figure 17-3 Concentric Conductors

10. Map four equipotential (two, three, four and five volts) surfaces between the conductors. Verify the following statements by performing the appropriate actions with the DMM.

- (a) the electric field inside a conductor is zero.
- (b) the electric field is always perpendicular to the conducting surface
- (c) the field is strongest at the points of greatest curvature
- (d) the field is zero outside the conducting surface

Explain how you proved these points in your lab report.

### Electric Field Program

11. Turn on the computer and open the field program called “**charges-and-field-en.jar**” in the software folder. Turn on grid. Add positive and a negative charges of equal magnitudes to the screen by dragging and dropping them. (This will make sense when you see the program.)
12. Map the field lines by clicking on “**Show E-field**”. Plot equipotentials using the tool with cross hair icon. Move icon to a location and click on “**plot**” to generate equipotential line.

### Questions/Conclusions:

1. Show that the electric field units of N/C is equal to V/m.
2. Explain the difference between electrical potential and electrical potential energy.
3. How does the computer version of the electric field lines compare with the one done by hand?
4. What are the possible sources of error in this experiment?