

# EXPERIMENT 16

## Equipotential Lines and Electric Fields

### OBJECTIVES:

- 1) Determine the lines of constant electric potential for two simple configurations of oppositely charged conductors.
- 2) Determine the electric field from lines of constant electric potential.

### INTRODUCTION

Charged bodies exert forces on each other which they would not exert if they were uncharged. There are two types of electric charge, positive and negative. The symbol  $q$  is used to denote charge and the SI unit of charge is the Coulomb (C).

Charges having the same sign of charge will repel each other, whereas charges having opposite signs of charge will exert attractive forces on each other. The magnitude of the force between two charged bodies can be calculated from Coulomb's Law:

$$F_E = k \frac{|q_1||q_2|}{r^2} \quad (1)$$

In Coulomb's Law,  $r$  is the distance between the charges  $q_1$  and  $q_2$ . The constant  $k$  is Coulomb's constant and is equal to  $8.99 \times 10^9 \frac{N \cdot m^2}{C^2}$ .

If a small positive test charge,  $q_t$  is placed near a charge,  $q$  it will experience an electrostatic force from the charge. The electric field vector,  $\vec{E}$  is a property of the space around an electric charge and is given by:

$$\vec{E} = \frac{\vec{F}_E}{q_t} \quad (2)$$

The magnitude of the electric field is the ratio of the electric force exerted on a test charge to that test charge.

Recall that if a force,  $F$  acts over a over a displacement,  $\Delta s$ , work is done by the force. The amount of work done by the force is given by:

$$W = |F||\Delta s| \cos \theta \quad (3)$$

$|F|$  and  $|\Delta s|$  are the magnitudes of the force and displacement vectors, respectively and the angle,  $\theta$  is the angle between these two vectors. In SI units work is measured in joules (J).

If an electric field is present and it takes work,  $W$  to move a charge,  $q$  from point A to point B, then A and B are defined to have an electric potential difference:

$$\Delta V = V_A - V_B = \frac{W}{q} \quad (4)$$

The volt (V) is the SI unit of electric potential difference and  $1 \text{ V} = 1 \text{ J/C}$

If the displacement is chosen such it is in the same direction as the electric field, then the work required to move the charge  $q$  is:

$$W = -F \Delta s = -q \frac{F}{q} \Delta s = -qE \Delta s = -q \Delta V \quad (5)$$

From the definition of work, we can see that maximum work is required to move a charge directly against an electric field ( $W_{\text{REQUIRED}} = -W_{\text{FIELD}}$ ). Furthermore, no work is required to move the charge perpendicular to the field. If zero work is done when moving the charge perpendicular to the electric field, then the potential difference between two points along this path must also be zero. Such a path is along an equipotential (constant electric potential). In three dimensions, equipotentials are typically equipotential surfaces. In two dimensions, these equipotentials can be equipotential lines. It follows that equipotentials are perpendicular to the lines of electric force and therefore, to the electric field as well.

From equation (5), the magnitude of the electric field is given by:

$$|\vec{E}| = \left| \frac{\Delta V}{\Delta s} \right| \quad (6)$$

$\Delta V$  is the difference in electric potential between the two lines of equipotential and  $\Delta s$  is the distance between the lines of equipotential. The direction of the electric field is identical to the direction of the force acting on a positive charge placed at a point in space. As such, it points from higher electric potential to lower electric potential.

For electrostatics, all points on a conductor are at the same electric potential. Therefore, all points on an object made of metal (i.e. an ideal conductor) are at the same electric potential.

### Apparatus:

DC Power Supply  
Digital Multimeter  
Conducting Paper  
Metal Charge Distributions  
Banana Plug wires and connectors  
Electric Potential Probe

In this experiment we will measure the electric potential in the vicinity of two different charge distributions. Each charge distribution will consist of two metal objects mounted on conducting paper. We consider metals to be ideal conductors (same electric potential everywhere on the metal). Whereas, the conducting paper is non-ideal and the electric potential depends on the location of the point on the paper.

The first distribution will consist of two parallel bars (or plates). This can be thought of as a 2-D model of a parallel plate capacitor. A schematic of the parallel plate experiment is shown in Figure 1 below. In this configuration, one of the two plates will be electrically connected to the positive terminal of the power supply and held at a constant positive electric potential. The other plate will be electrically connected to the negative terminal, or the ground of the power supply. All electric potentials are measured with respect to this electric potential (i.e.  $V_{ground} = 0$  V). The ground terminal of the power supply will also be connected to the ground, or COM port of the multimeter. The probe used to measure the electric potential is connected to the “V” port of the multimeter.

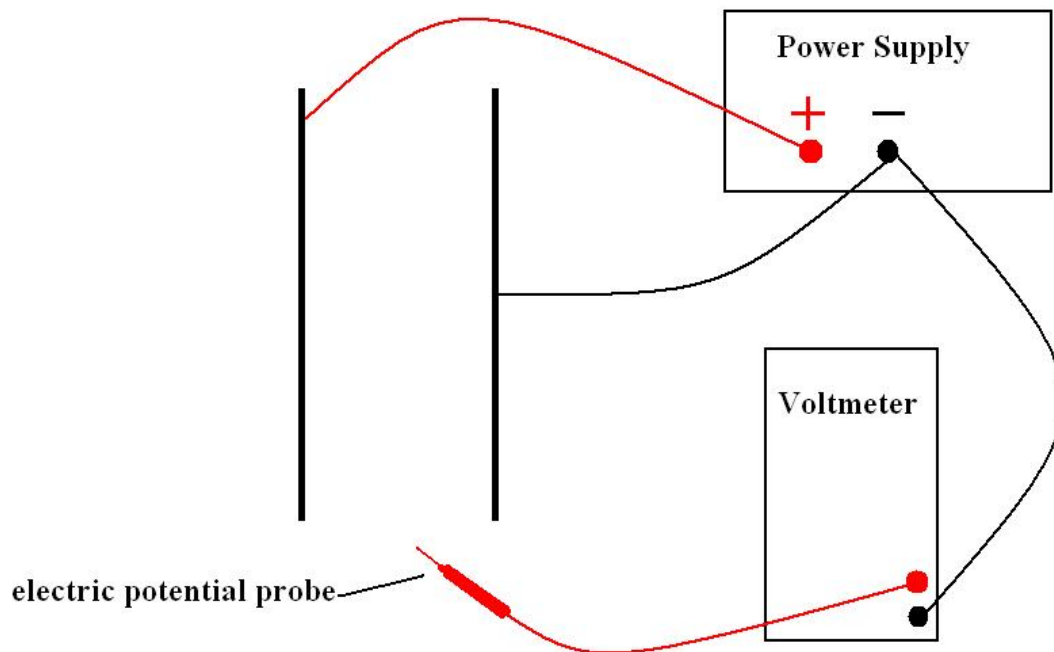


Figure 1

The second charge distribution will be a point source at the center of a ring. A schematic of this arrangement is shown in Figure 2 below.

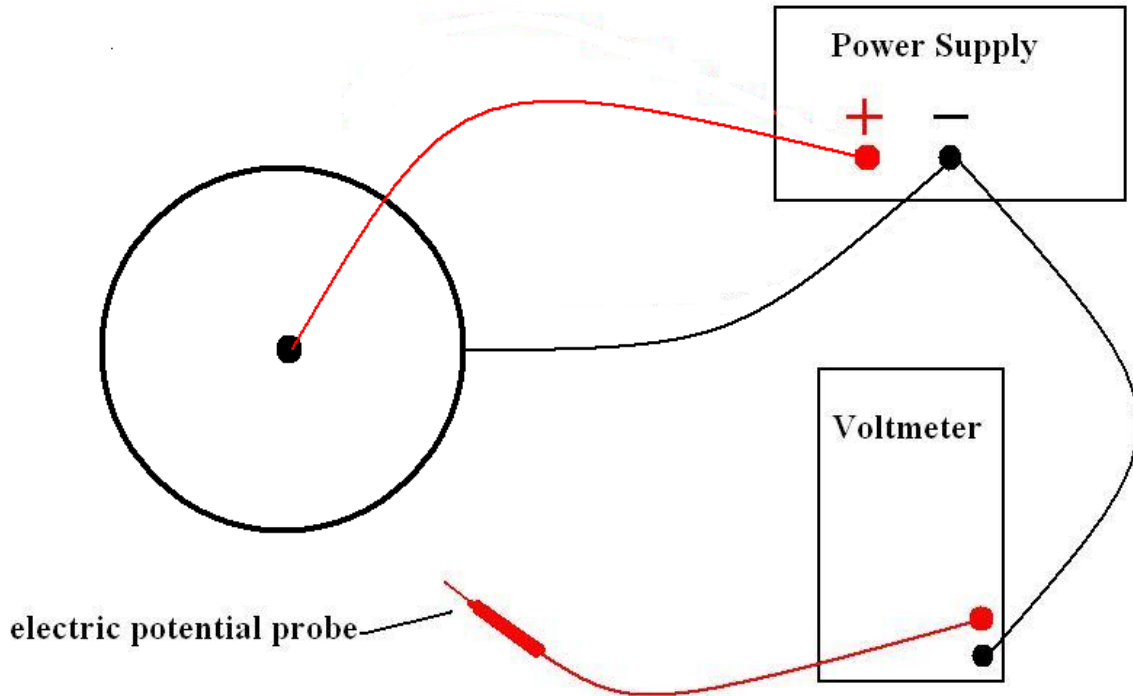


Figure 2

## Procedure

### Part 1: Two Parallel Conducting Plates (Figure 1)

1. Sketch the two conducting plates on a grid sheet (data sheet) provided by your lab instructor.
2. Use a banana plug wire to connect one of the parallel plates to the positive terminal of the power supply.
3. Use a second banana plug wire to connect the second plate to the negative terminal of the power supply.
4. Connect the COM port of the digital multimeter to the negative terminal of the power supply using a third banana plug connecting wire.
5. Connect the electric potential probe to the “V” port of the digital multimeter.
6. Adjust the power supply to an electric potential of 10 V.
7. Set the digital multimeter to measure DC electric potential (voltage).
8. Use the electric potential probe to find at least six points having the same electric potential in the region between the plates and record these points on your data sheet (to be provided in class); then find an additional four points extending beyond the region of the plates having the same electric potential.
9. Use a pencil to draw a smooth curve/line that best represents points in step 8.
10. Repeat steps 8 and 9 for at least four additional electric potentials.

11. Measure the distance between the parallel plates and assign a reasonable uncertainty to this measurement. Use this measured distance and the 10.0 V electric potential difference between the plates to calculate the electric field between the plates and its uncertainty (Question #1).
12. Measure the distance between two of your lines of equipotential; calculate the difference in electric potential between these two lines; calculate the electric field and its uncertainty using these measured values (Question 2).
13. Draw and label the electric field lines (at least eight of them) – you should include some near the edges of the parallel plates. Indicate the direction of the electric field with an arrow on each of your electric field lines.

**Part 2: Ring and Point (Figure 2)**

1. Sketch the ring and point on a grid sheet (data sheet) provided by your lab instructor.
2. Use a banana plug wire to connect one the point located at the center of the ring to the positive terminal of the power supply.
3. Use a second banana plug wire to connect the ring to the negative terminal of the power supply.
4. Connect the COM port of the digital multimeter to the negative terminal of the power supply using a third banana plug connecting wire.
5. Connect the electric potential probe to the “V” port of the digital multimeter.
6. Adjust the power supply to an electric potential of 10 V.
7. Set the digital multimeter to measure DC electric potential (voltage).
8. Use the electric potential probe to find at least eight points having the same electric potential inside the ring; record these points on your data sheet (to be provided in class).
9. Use a pencil to draw a smooth curve/line that best represents points in step 8.
10. Repeat steps 8 and 9 for at least four additional equipotentials.
11. Draw and label the electric field lines (at least eight of them). Indicate the direction of the electric field with an arrow on each of your electric field lines.



## Questions

1. Use the electric potential difference between the two parallel plates and equation (6) to calculate the magnitude of the electric field between the plates. In addition, calculate the uncertainty in the electric field (show your work). The fractional uncertainty in the electric field is given by:

$$\left| \frac{\delta E}{E} \right| = \left| \frac{\delta V}{V} \right| + \left| \frac{\delta s}{s} \right|$$

Electric potential between the plates:  $V \pm \delta V =$

Distance separating the plates:  $s \pm \delta s =$

Magnitude of the electric field:  $E \pm \delta E =$

2. Use the electric potential difference between two of your equipotential lines (between the parallel plates and not near the edge of the plates), the distance separating these two lines and equation (6) to calculate the magnitude of the electric field between the plates. In addition, calculate the uncertainty in the electric field. Do not use the plates themselves as the equipotentials in this question and show your work.

Electric potential between equipotentials:  $V \pm \delta V =$

Distance separating the equipotentials:  $s \pm \delta s =$

Magnitude of the electric field:  $E \pm \delta E =$

3. Compare your results for the electric field obtained in questions 1 and 2. What does this comparison lead you to conclude about the electric field between two parallel conducting plates, but not near the edge of the plates?

4. Is the metal ring an equipotential? This should be verified by measurement.

5. What is the magnitude of the electric field outside the circular ring in the second part? Justify your response.