# LABORATORY 3
# ELECTRIC POTENTIAL

## Objectives

- to be able to discuss the relationship between work and potential difference

- to be able to calculate the potential difference between two points in space for the case of a constant electric field

- to be able to identify equipotential lines

- to be able to use measurements of potential difference to calculate the electric field at a point

- to be able to discuss the relationship between equipotential lines and the electric field

- to be able to use measurements of potential difference to determine equipotential lines

**Overview:** In this lab, we will explore the concept of electric potential, including the relationship between work and potential difference, equipotential lines and the relationship between the electric field and potential difference. We will use measurements of potential difference to determine equipotential lines and to calculate the magnitude of the electric field at a particular point.

**Exploration 1: Electrical Potential**

**Exploraton 1.1** Take the pre-test for this lab.

**Exploration 1.2 Electrical Potential**

Since the electric force is a conservative force, we can define an electric potential energy at each point in space, such that the work done by the electric force in moving a charge from an initial point, $i$, to point, $f$, is equal to the change in electrical potential energy. In equation form:

$$W_{elec} = -\left(PE_f - PE_i\right)$$

The work done by the electric force depends on the electric field and must be calculated using calculus. However, for the case of a constant electric field, the electric work is

where q is the charge, E is the magnitude of the electric field, $d = x_f - x_i$ is the displacement from point $x_i$ to point $x_f$ and $\theta$ is the angle between the electric field and the displacement.

The sign of the work depends on the charge and it is useful to define an electrical potential, which is the potential energy divided by the charge. The potential does not depend on the charge and the change in potential is then defined as the negative of the work per unit charge done by the electrical force in moving from an initial point $x_i$ to a final point $x_f$. The symbol for electrical potential is V and the change in electrical potential is written mathematically as

$$\Delta V = \left( V_f - V_i \right) = -\frac{W_{elec}}{q}$$

For the special case of a constant field,

It is also true that for any electric field (constant or non-constant), the field is constant over a small region of space and a field at a given point can be found by measuring the potential difference between two closely spaced points in the direction of the electric field. Then

$$\overline{\phantom{xxxx}}$$

where $\Delta V$ is the potential difference between two closely spaced points $x_i$ and $x_f$ and $\Delta x = x_f - x_i$ is the displacement between those points. The displacement is measured in the direction of the electric field.

The zero of electrical potential energy and the zero of electrical potential, like the zero of the gravitational potential energy is arbitrary. The zero can be chosen at any particular point.

It turns out that it is much harder to measure an electric field than to measure the potential difference between two points. The electric field is then often determined by measuring the potential difference between points.

**a.** Consider a region in space with a constant electric field, as in the diagram below. Points A and B represent points in space a distance $x_1$ apart.
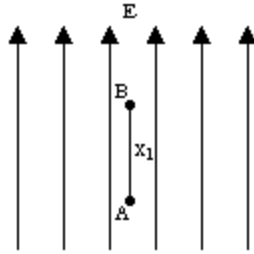
Calculate the potential difference between A and B in terms of E, $x_1$ and any relevant angles.

**b.** Now consider a third point C, as in the diagram below.
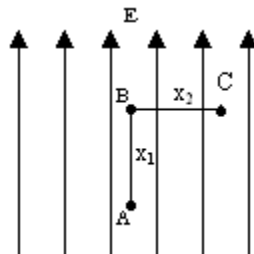


Calculate the potential difference between points B and C. Show your work.

How much work is done by the electric field in moving a charge from point B to point C? Show your work or explain your reasoning.

Calculate the potential difference between points A and C.

How does the potential difference between points A and C compare to the potential difference between points A and B? Explain.

**Exploration 2.2 Equipotential Lines**

If no electric work is done in moving a charge from one point to another, there is no change in the electrical potential between those points. It is useful to map out lines along which a charge can move with no electrical work being done. These are called *equipotential* lines.

Consider two large plates, one charged positively and one charged negatively, as in the diagram below.

———————————————————

———————————————————

**a.** Draw the charge distribution on the plates.

**b.** Draw the electric field lines in the diagram.

**c.** Predict the lines of equal potential by drawing them in the diagram. Discuss why you drew them the way you did and how they are related to the electric field lines you drew.

**Equipment:**
      1 voltmeter
      1 power supply
      sheets of conducting paper

**Investigation 1 Equipotential Lines and Electric Field of a Capacitor**

We are now going to measure the potential difference between points in a plane between "2D- capacitor plates". We are going to map out the equipotential lines and then use measurements of potential difference to calculate the magnitude of the electric field between the two plates.

Potential difference is measured by an instrument called a voltmeter. If you want to find the potential difference between two points, you need to place one of the voltmeter leads on one point and the other on the other point. The voltmeter will read the potential difference between the two points.

On your lab table is a sheet of conducting paper. It has two capacitor plates drawn on it. It is possible to put charge on the capacitor plates by attaching each plate to one end of a power source. If the positive (+) terminal of the power source is connected to one of the plates, the plate will be charged positively. If the negative (-) terminal of the power source is connected to a plate, that plate will be charged negatively.

When the plates are charged, you can place the leads of the voltmeter at points on the conducting paper to find the potential difference between those points.

**Investigation 1.1 Equipotential Lines of a Capacitor**

    **a.** Set the power supply for 20.0V. Connect one end of the power supply to one capacitor plate and the other end to the other capacitor plate.

       Consider the points indicated in the diagram below.
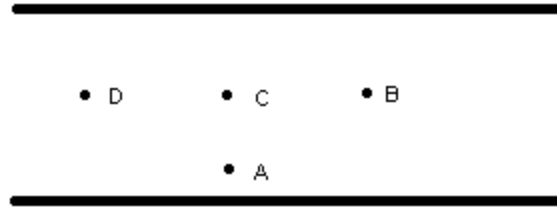
Use the voltmeter to determine the potential difference between points A and B, A and C and A and D.

Also determine the potential difference between points B and C and C and D and B and D.

Record your results here.

**b.** Which points are at the same potential?

**c.** Use the voltmeter to map out lines of equipotential. Remember, you can set the zero of potential anywhere you want. It is common to set the zero of potential at the negative plate and measure the potential relative to that plate. Mark the lines of equipotential on the sheet at the end of the lab.

**d.** How do the equipotential lines compare to your prediction?

**Investigation 1.2 Electric Field lines of a Capacitor**

    **a.** Consider the points indicated in the diagram below.
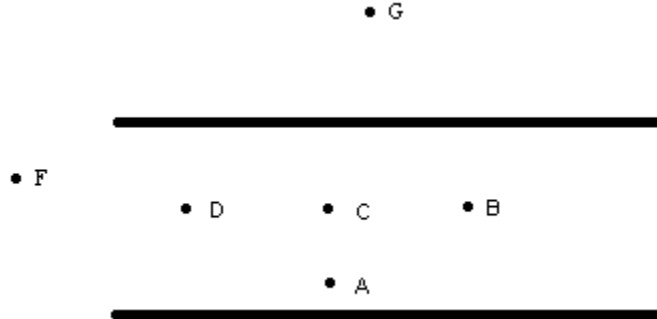


If the bottom plate is charged positively and the top plate is charged negatively, rank the values of the electric field at each of these points from highest to lowest. This is a prediction. (It is not right or wrong.) Each person in your group may make a different prediction.

    **b.** Discuss with your lab partners and devise a method to determine the magnitude of the electric field at point C in the picture above. Record your method below.

       Discuss your method with a TA.

    **c.** Use your method to determine the magnitude of the electric field at point C. Record your value for the magnitude of the electric field at point C below.

**d.** Determine the value of the electric field at each of the points A, B, C, D, F and G and record those values in the table below.

|  | Magnitude of the electric field |
|---|---|
| A |  |
| B |  |
| C |  |
| D |  |
| F |  |
| G |  |

**e.** Do you expect the magnitude of the electric field to be the same at any of the points? Explain your reasoning.

**f.** Are your data consistent with your predictions? Discuss.

**Exploration 2.3 Electric Field and Equipotential Lines for a Point Charge**

**a.** Draw the electric field lines for a point charge in the space below.

**b.** Predict the equipotential lines for a point charge, based on your knowledge of the relationship between the electric field lines and the equipotential lines. Draw your prediction for the equipotential lines in the diagram above.

**Equipment:**
        1 voltmeter
        1 power supply
        sheets of conducting paper

**Investigation 2 Equipotential Lines for a Point Charge**

**Investigation 2.1 Equipotential Lines for a Point Charge**

**a.** Check your prediction for the equipotential lines for a point charge using the 2D set-up with a point in the middle and a ring around the point. You may take the ring as the zero of potential. Draw the equipotential lines on the sheet at the end of the lab.

**b.** Use the EM field program to determine the equipotential lines for a point charge.

**c.** Are your measurements consistent with your prediction?

**Investigation 2.2 Equipotential Lines for a Point Charge Off Center Inside a Ring**

    **a.** Suppose the point charge was not centered in the ring. Draw a prediction for

            (i)       the electric field lines and
            (ii)     the equipotential lines in the diagram below.

Remember, the ring is a charged conductor.
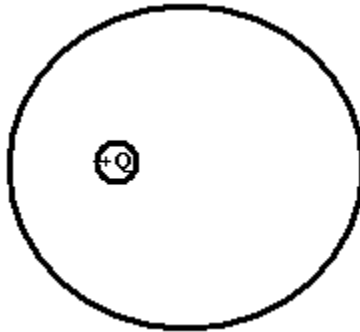


    **b.** Determine the equipotential lines using the conductive paper to test your predictions. Record your results on the sheet at the end of the lab.

**Equipment:**
    EKG sensor
    EKG electrodes (3 for each person)
    LabPro computer interface
    Logger Pro software
    Excel program
    EM Field program

## Application 1: EKG

**Application 1.1** An *electric quadrupole* is a set of four charges, two positive and two negative, as in the diagram below.
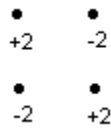


a. Use the EM filed program to plot the electric field and equipotential lines for an electric quadrupole.

b. It is also possible to us the EM field program to determine the potential difference between two points. In the EM field program, choose *potential difference* under *field and potential* on the tool bar. Click on one point, drag the cursor (while holding it down) to another point, and release. Choose any two points anywhere on the screen you want. The EM field program will give you the potential difference between the two points.

c. If the charges were in motion, what do you expect would happen to the potential difference between those two points. Explain.

d. Move the charges to a different position and check your prediction.

## Application 1.2

a. Your heart is like an electric quadrupole, with the charges constantly moving around. The electric field lines and the equipotential lines around your body due to your heart are constantly changing. It is possible to measure the electric potential difference between any two points on your body and see how it is changing. This is called an electrocardiogram (EKG or ECG).

We will measure your EKG.

Obtain an EKG sensor, EKG electrodes, and a LabPro computer interface. Open the File *EKG sensor*. Follow the directions on page 5 of the EKG instructions for connecting the EKG sensors to a person.  Record the EKG for one person in your group. (You can take an EKG for everyone in your group, if there is time.) Save your EKG to a file, so you can print it out.

> **b.** You may want to read the details of how the heart works in the EKG sensor instructions.

**Summary.** Summarize how you would use potential difference measurements to calculate the electric field at a point.
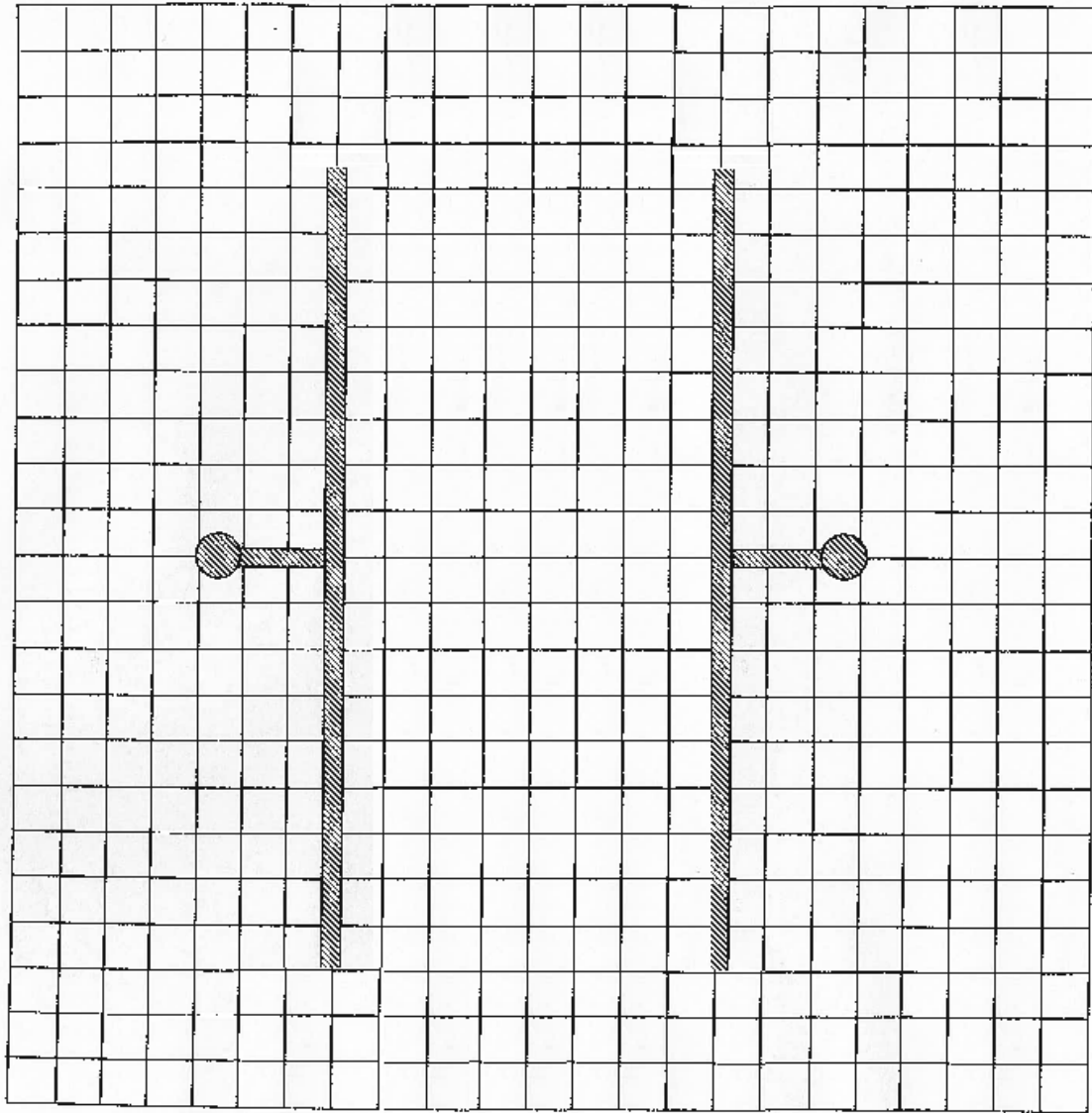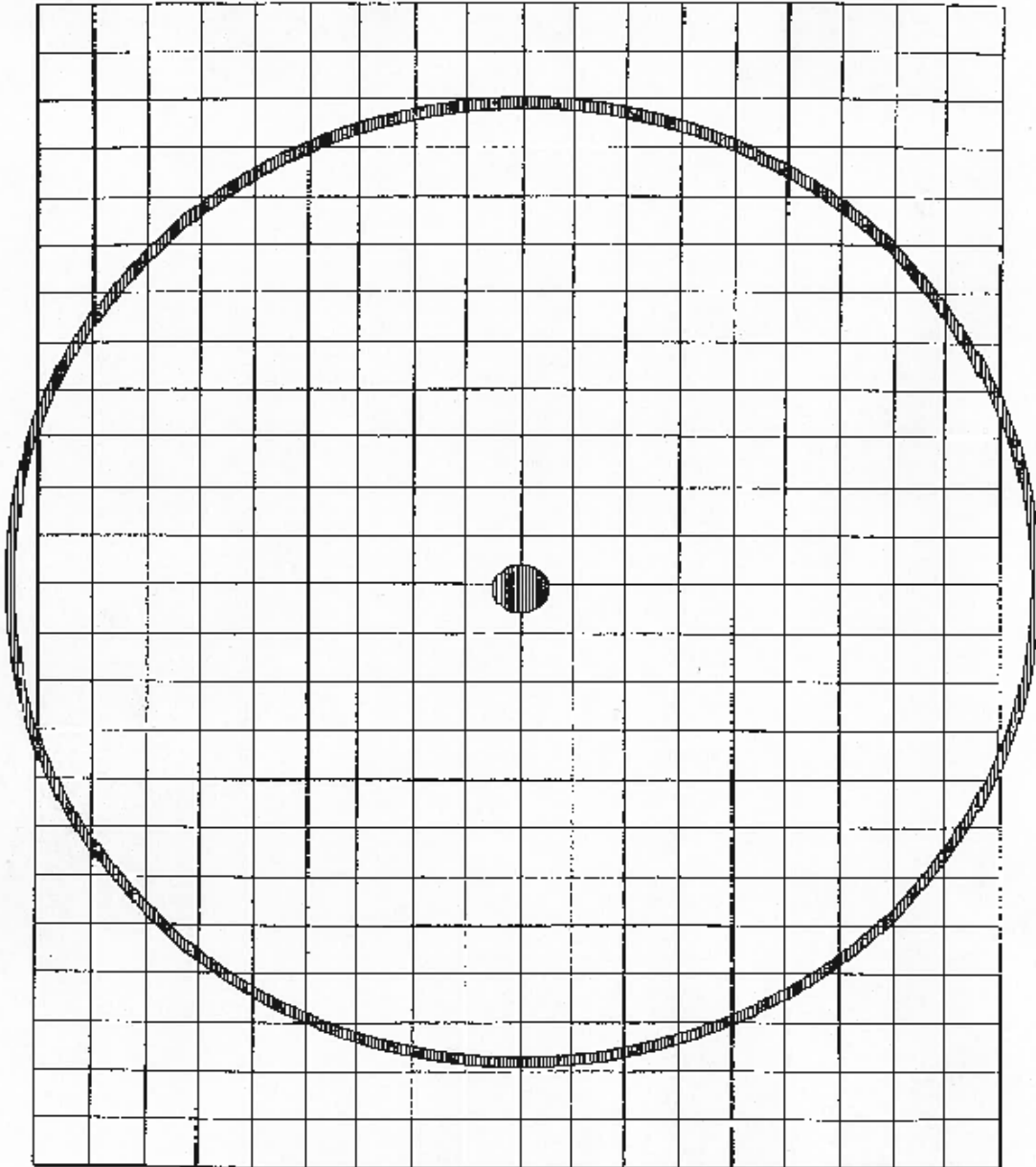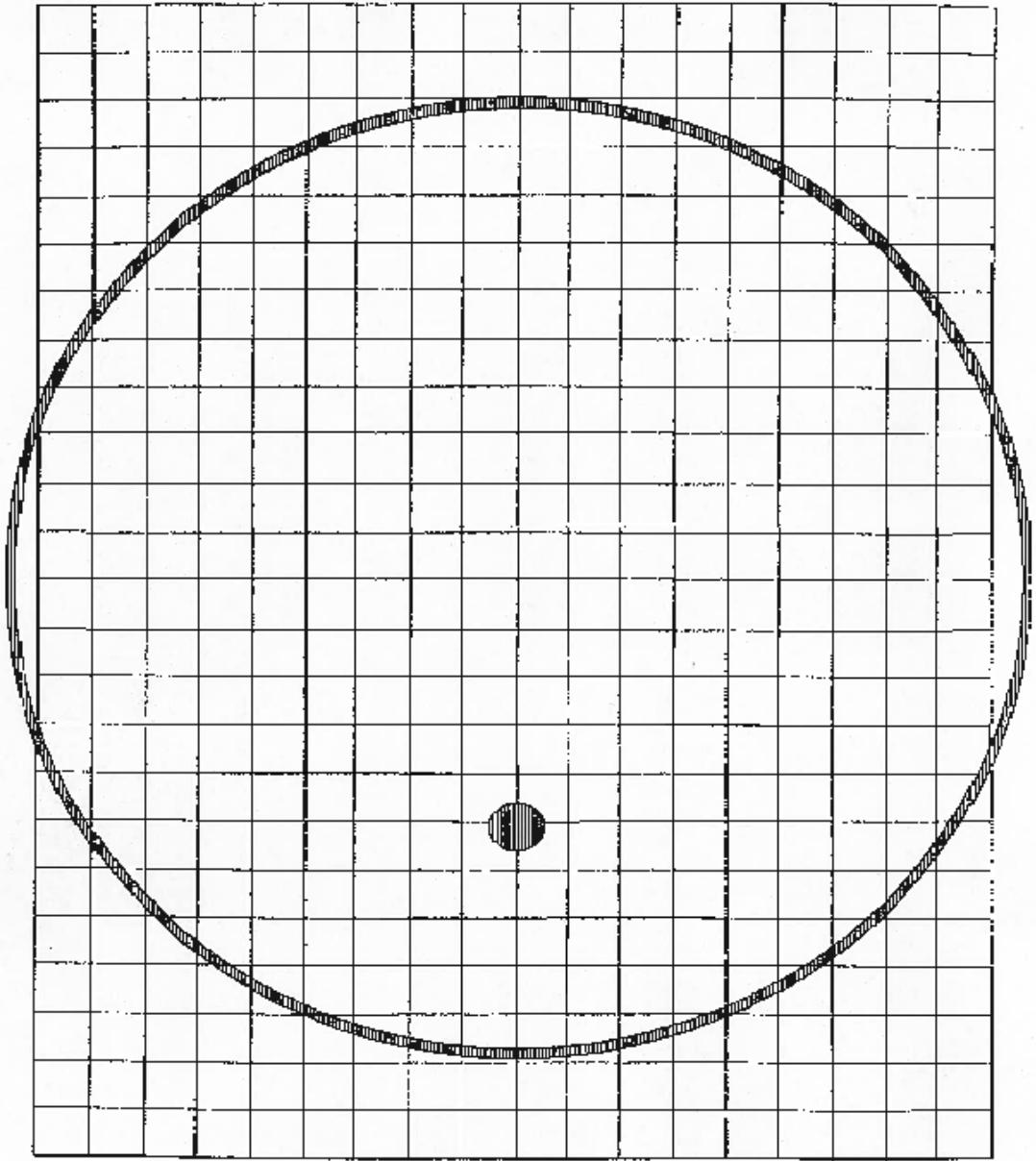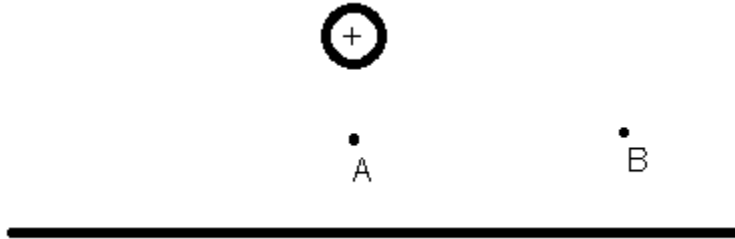
## Laboratory 3 Homework
## Electric Field and Potential

1) A large negatively charged metal plate is lying horizontally, as in the picture below. A positively charged conducting ball is located, as shown, above the plate. Points A and B are points in space, not charges.



a) Draw possible electric field lines in the diagram. Explain why you drew the field lines the way you did. Is the field stronger, at point A or point B? Explain your reasoning.

b) Draw possible equipotential lines in the diagram. Explain why you drew the equipotential lines the way you did.