14. Electric Field Mapping

Introduction

Positive and negative charges produce an *Electric Field*, ***E***, at every point in space. The force experienced by a charge, q, in such an electric field is ***F***=q***E***. Electric field lines begin and end on charges, since these are the sources of the electric field. We represent the electric field by vectors which point in the direction of the force on a positive test charge: away from other positive charges and towards negative charges. Electric Fields may be measured by looking at the acceleration of a charged particle in the field, but this can be difficult to do. It is easier in the lab to measure the electric *potential* or voltage.

Equipment

Shallow glass pan	Pads of graph or grid paper		4 electric leads
tap water (salt)	metal shapes	DC power supply	voltmeter or multimeter

Theory

As a charge moves along an electric field line, work is done by the electrical force. The energy gained or lost by this charge moving in the field is a form of *potential energy*, and so associated with the electric field is an *electric potential*, V, which has units of Energy per charge or Joules per Coulomb, which we also call Volts. Since voltage is potential energy per unit charge, voltage increases when going from a negative charge towards a positive charge. (The kinetic energy of a positive charge would increase when going from a higher potential to a lower potential.) A surface along which the potential is constant is called an *Equipotential*. On a piece of paper, the equipotential is represented by a line on which the voltage is constant. These equipotential lines may be mapped by using a voltmeter to find the lines of constant voltage. (If the constant voltage extends over a volume of space, then the equipotential on the two-dimensional surface may be an area rather than simply a line.) At the end of this section is a discussion of gravitational equipotentials and forces.

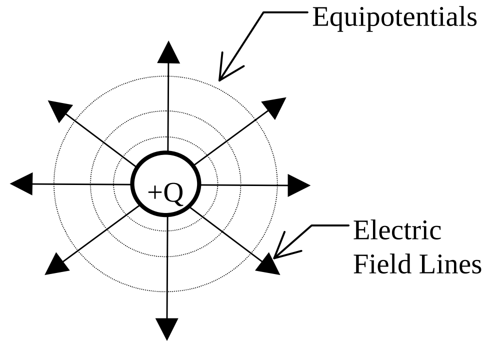

Figure 1: Equipotentials and Electric Field Lines around a spherical charge.

<u>Gravitational Equipotentials and Forces</u>

Since gravitational potential energy depends on height, lines of constant height would be gravitational equipotentials. A map of such lines is called a topographical map. Typically, a topographical map shows equally spaced lines of constant elevation. Where the lines are most closely spaced the elevation is changing most sharply, in other words the terrain is steep. <u>The</u>

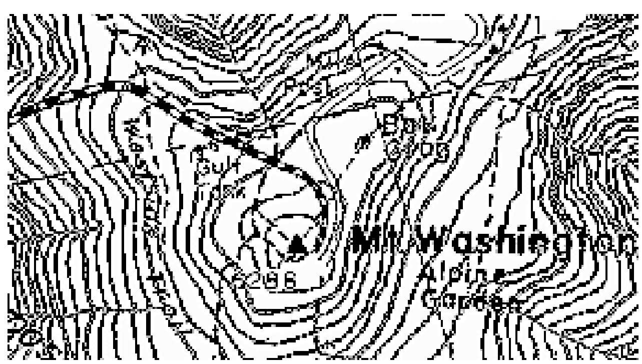

Figure 2: A topographical map. Lines of constant elevation (height) show how the gravitational potential energy is changing. (Some of the lines on this map are roads) The line of steepest descent is perpendicular to the equipotentials.

direction of the gravitational force (the component of gravity along the surface) would point down along the direction of steepest descent. The direction of the gravitational force is perpendicular to the gravitational equipotentials since the steepest downward slope is perpendicular to the lines of constant elevation.

Electric Field lines are also perpendicular to Equipotentials.

Since there is no work associated with moving in any direction along an equipotential, there can be no forces in any direction along the equipotential line or surface. Thus the vector ***E*** must have zero component along the equipotential surface: in other words it is perpendicular to the equipotential. Just as for the gravitational force, the electric force (and hence the electric field) points in the direction of the steepest change in electric potential.

In this lab you will look at the electric potential around different shapes of conductors. You will first use a voltmeter to map out lines of constant potential (the *equipotentials).* After you have found and sketched the equipotential lines you will draw the electric field lines which are perpendicular to the equipotentials.

Procedure

Your conducting shapes will consist of metal shapes, which you will place in a thin film of water. The conducting water (tap water generally has enough ions in it to conduct electricity, a *little* salt may be added if necessary) is needed in order to measure the *electric potential* (or *voltage*) at various points in space. If the negative terminal of the power supply is connected to one shape and also to the negative terminal of the voltmeter, then this shape will be at zero volts (Ground). The voltmeter will be able to measure the voltage difference between Ground and any point, which the voltage probe touches.

Your instructor will show you how to connect the circuit. Do not turn on the power supply until you are sure it is connected properly.

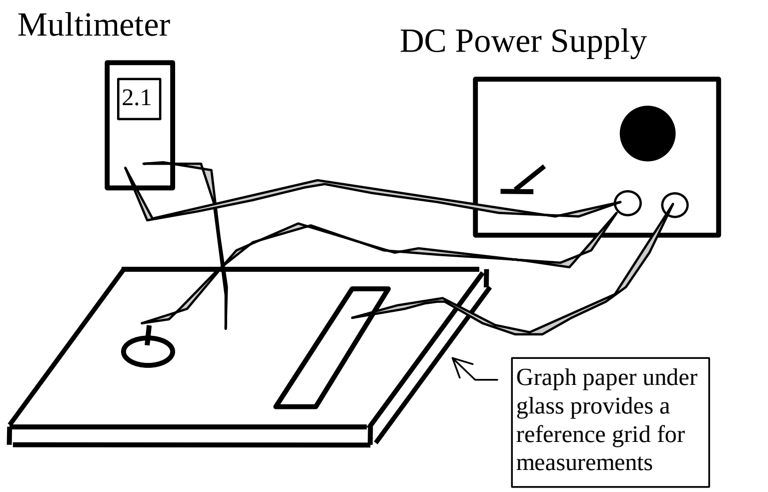

Figure 3: A DC power supply is connected to two conducting shapes, establishing a potential difference between them. A voltmeter is used to measure the potential (voltage) at various points between the two shapes.

Part A: Using the voltmeter

Connect the circuit as shown by your instructor. Use two bars for your conducting shapes. Place a piece or two of graph paper under the glass tray to make a reference grid. ***Be sure and connect the shapes to the output labeled DC voltage.*** Have your multimeter set to measure DC voltage. Practice using the voltmeter to:

Measure the voltage produced by the power supply. Calibrate the variable knob on the supply by finding the setting corresponding to zero volts and to ten volts. Leave the power supply set at ten volts.

Now measure the voltage of each of your two shapes. One shape should be at zero volts and the second at ten volts.

Verify that the entire conducting shape is at the same voltage. Because electrons are free to move within a conductor, the entire conductor must be an equipotential (in a static situation).

Measure the voltage at several points between the two shapes. Does it vary between zero and ten volts? If not, you may need to check your circuit or add a little salt to the water to increase its conductivity. ***If you are having difficulty measuring voltages or they do not seem to be correct, have your instructor check your setup***. It is important to get the circuit correct before proceeding.

For your report:

Make a sketch of your circuit. Label the positive and negative terminals of both the power supply and the meter.

Part B: Mapping equipotentials

Each lab partner should use an entire sheet of paper to make an overhead view sketch of your two conducting shapes. Use the same type of graph paper as you placed under the glass so that your sketch can be full scale and accurately drawn. You may wish to draw axes on both your graph paper and the paper under the glass. Label the shape connected to the positive terminal "10 Volts" and the shape connected to the negative terminal "0 Volts".

Use the voltmeter to find a point between the shapes, which is about 5 Volts. Draw an "X" on you sketch at the location of this point. You will now find an equipotential line by moving the voltage probe and tracing out a line, which is at a constant voltage (in this case, 5 Volts).

For the following one (or more) lab partners should be in charge of sketching while another moves the probe and another keeps track of the voltmeter. Have one partner move the probe about 1 cm keeping while keeping the reading on the voltmeter at 5 Volts. On your sketch make an X at the second point and connect to two by a line to indicate an equipotential.

Continue to move the probe and record on your sketch an X for the points at which you check the voltage and the lines of constant voltage, which connect them. The separation between X's may vary depending on how quickly the voltage changes. If the voltage is constant for a long straight line you might move the probe a longer distance before recording an X. If the voltage changes direction quickly you may need to record more X's in order to accurately sketch the equipotential lines.

Once you have sketched a line from the center between the two conductors out beyond the edges you may have to go back to the center and sketch the second half of the line in the opposite direction. If your shapes are symmetrical you may expect the field lines to be symmetrical as well. You may be able to make fewer X's: just check to see if the equipotential lines are indeed symmetric.

The line you have drawn is an equipotential with a value of 5 Volts. Label this line "5 Volts". For the two parallel bars make sure that you have investigated the areas out near (and beyond) the areas of the bars.

Lab partners should now switch roles so a different person measures the voltage or records the sketches. Now repeat the procedure to find *at least* two more equipotential lines: for voltages of 7.5 Volts and 2.5 Volts. Label them on your sketch.

For your report:

Each partner should have a sketch of the equipotential lines. Some of the sketches will be made during the voltage measurements. Additional copies can be made by tracing these sketches.

Part C: Drawing Electric Field Lines

You now have 5 equipotential lines (counting the surfaces of the conductors). You can now draw the electric field lines, which are perpendicular to the equipotentials using the following criteria:

The directions of the field lines go from high voltage to low voltage. (This is because high to low voltage would correspond to a decrease in potential energy (increase in kinetic energy) for a positively charged particle and so this is the direction of the electrical force on a positive charge).

The field lines should be perpendicular (90 degrees) to the equipotentials *The surfaces of the conductors themselves are equipotentials!* Start at one point on an equipotential line and draw a short line perpendicular to it. Then figure out how you would need to bend that line so that by the time it encounters the next equipotential line it is also perpendicular to that line.

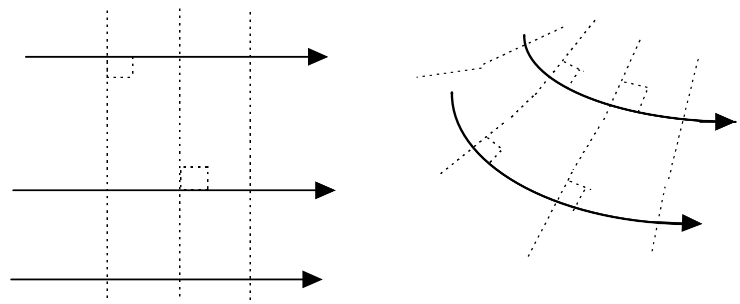

Figure 4: Equipotentials (dashed lines) and Electric Field Lines (solid). Electric field lines should be perpendicular to equipotentials at the points where they cross.

Draw a number of electric field lines which begin on the positively charged conductor (higher voltage) and end on the negatively charged conductor (lower voltage). You will want to sketch in a line lightly with a pencil and check with your instructor to make sure you understand the procedure.

For your report:

Draw the electric field lines on your sketch. Label the lines "E" and draw arrows along them to show the direction of an electric field. The arrows should go from higher voltage to lower voltage. At representative points draw a right angle symbol (   ) where the field lines meet the equipotentials.

Part D: More shapes.

Repeat for additional conducting shapes. ***Turn off the power supply while connecting and disconnecting the leads***. . You may try two round shapes or one round shape and one bar.

For your report:

Each partner should have a sketch of the equipotentials and field lines for the additional shapes.

Part E: Inside a hollow conductor.

Obtain a hollow metal ring and place it in the water to represent a hollow conductor. Place bar shaped electrodes on either side of the hollow ring. Investigate the change of potential at various points inside the hollow ring. Compare to the field without a ring.

For your report:

Make a sketch of your set-up and describe your results.

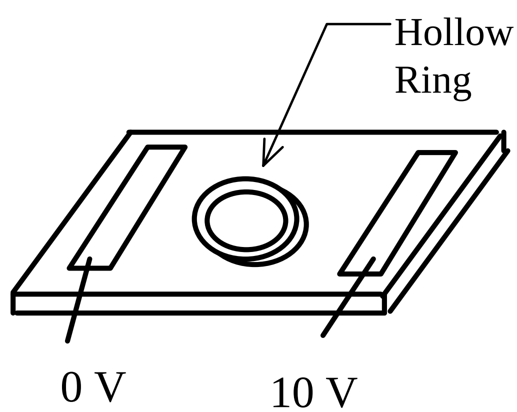

Figure 5: Hollow conducting ring placed between two electrodes.

Laboratory Report:

Your lab report should consist of an introductory cover page, which includes the title, names of lab partners, a paragraph or two (*in your own words*) describing the ideas behind the experiment and the basic procedures. The data for this lab will consist of the sketches you have made. Summarize your conclusions by answering the following questions in complete sentences with an explanation of your reasoning.

Questions:

Voltage is potential energy per unit charge. If you were a positive charge and you moved from a higher voltage (10 volts) to a lower voltage (0 volts) how would your kinetic energy change? What would the direction of the electrical force acting on you be?

How does your answer change if you are a negative charge?

What is the direction of the electric field in each case (is there any difference)?

How does the potential energy of a charge change as it moves *along* the surface of a conductor? What is the force on an electron along the surface of the conductor (in other words the component of force in the direction of the surface). What is the component of electric field along the surface of a conductor?

When the equipotential lines bend, what happens to the electric field lines?

Comment on the equipotential lines and the electric field between the two parallel bars. If the bars were infinitely long, what would you expect the electric field between them to look like?

Comment on the equipotentials and field lines for two spherical shapes or a sphere and a bar. How does the symmetry of the configuration show up in the equipotentials and fields?