

Electric Fields

Mapping the Potential Curves and Field Lines of an Electric Dipole

January 2014

Print Your Name

Print Your Partners' Names

Instructions

Before lab, read the *Introduction*, and answer the Pre-Lab Questions on the last page of this handout. Hand in your answers as you enter the general physics lab.

You will return this handout to the instructor at the end of the lab period.

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0. Introduction

Abstract. A brief introduction to the notion of the electric field, electric field lines, electric potential and equipotential lines for a given charge distribution. The relation between equipotential lines and electric field lines is also discussed.

0.1 *Electric field and electric field lines:* In the previous lab you explored some of the basic properties of electric charges. The experimental activities conducted in that lab led you to conclude that:

- (a) there are two types of charges in nature – positive and negative charges,
- (b) if charges are brought close to each other they exert an electrostatic force on one another.
- (c) the direction of the electric force depends upon the nature of the interacting charges – like charges repel each other while unlike charges attract each other.

A question that immediately pops up is: How does a charge exert a force on another nearby charge even though the two charges are not in contact with each other?

To answer this question, physicists in the 19th century hypothesized that with every electric charge one can associate an *Electric field* that permeates the space around that electric charge. The force experienced by a charge in the vicinity of another charge was explained in terms of the interaction between the charge experiencing the force and the electric field associated with the

other charge. To make the concept of an electric field more precise, the following properties were attributed to it:

- It is a vector quantity. One can associate a magnitude and a direction to the electric field for any point near a given charge.
- The magnitude or strength of the electric field at a given point is the electrostatic force experienced by a unit positive charge placed at that point.
- The direction of the electric field at any given point is the direction in which a positive test charge would move starting from rest if placed at that point.

The electric field of a given charge distribution can be visualized by drawing a series of lines called *electric field lines* that indicate the direction of the electric field. Examples of electric field lines for isolated point charges are shown Figure 1.

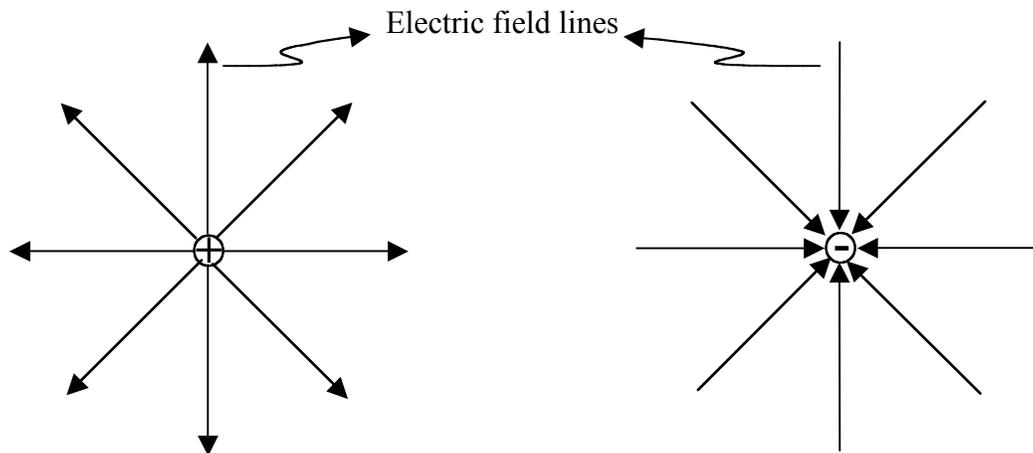


Figure 1 The electric field lines for an isolated positive charge (left) point radially outward and for an isolated negative charge (right) they point radially inward.

- The arrows on the electric field lines indicate the direction of the electric field. Thus in Figure 1, the positive charge has its field lines pointing outwards while the electric field lines of a negative charge point inwards.
- The number of electric field lines converging to or diverging from a charge is proportional to the magnitude of the charge. Thus greater the amount of charge greater are the number of electric field lines entering or leaving the charge distribution.
- The magnitude of the electric field in a give region near a charge is proportional to the density of the electric field lines. In Figure 1, the electric field is stronger close to the charges since the electric field lines are closer together while it is weaker as you move further away since the electric field lines get further apart.



Figure 2 Two equal but oppositely charged metal disks. The goal of this lab is to map their equipotential lines and field lines.

In the case where one has several charges, the electric field lines around the charge distribution can be quite involved since the net electric field at a given point is the vector sum of all the electric fields at that point.

The goal of this lab is to map the electric equipotential lines and the electric field lines surrounding two metal disks carrying equal and opposite charge (Figure 2).

0.2 Electric potential and equipotential lines

The method we follow to map the electric field lines surrounding a charge distribution involves the notion of the *electric potential*. Simply stated, the electric potential at a point near a charge distribution is the electric energy per unit charge that another charged particle would have when located at that point. The unit of the electric potential is the *Joules/Coulomb = Volt (V)*.

The probe that you will use in this lab, called a *Digital Multimeter*, directly measures the *electric potential difference* between two points near a charge distribution. If two points are at the same electric potential then the electric potential difference between the two points is zero. The two points are referred to as *equipotential points* and the locus (or set) of all points which are at the same potential define an *equipotential line*. One of the tasks in this lab is to trace out several equipotential lines surrounding the metal disks shown in Figure 2.

0.3 Given the equipotential lines, how do you find the electric field lines?

The electric field lines surrounding a given charge distribution are always perpendicular to the equipotential lines. Figure 3 shows the equipotential lines and the associated electric field lines for isolated metal disks carrying a net positive and a net negative charge.

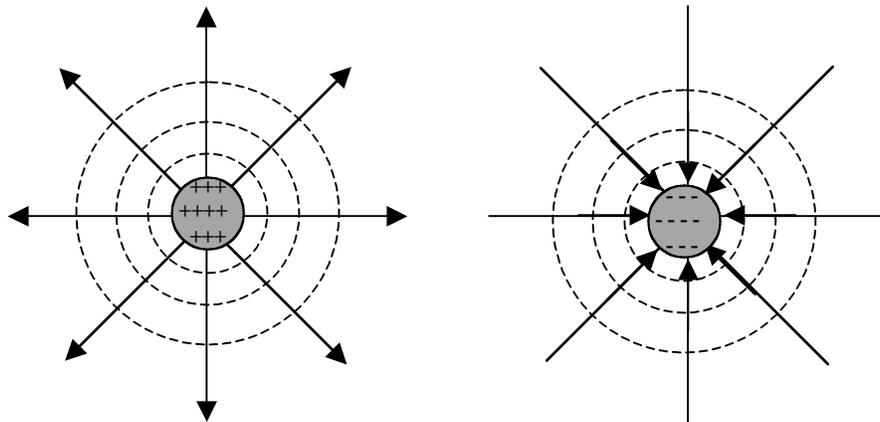
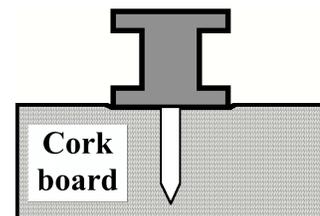


Figure 3 Equipotential lines (dashed lines) and the corresponding electric field lines for an isolated positively charged metal disk (left) and an isolated negatively charged metal disk (right).

Note that in Figure 1 the electric field lines leaving or entering the metal disks are perpendicular to the boundary of the disk. This is because the boundary of a charged metal disk is also an equipotential line.

0.4 How to properly align a push-pin

For reliable results in this lab, you need to press push-pins into a cork board so that the base of the push-pin is flat and tight against the surface of the cork board. The diagram to the right shows a side view of a correctly installed push-pin.



1. Activity #1: Instructor demonstration

The Lab Instructor demonstrates aligning and mounting the white graph paper and the black conductive paper on the cork board. Refer to the instructions under paragraph 2.2.

2. Activity #2: Experimental setup.

Abstract In this activity you set up the equipment in preparation for the measurements of Activity #3.

Equipment: 12 V DC Power supply
Multimeter set at 20 VDC or 30 VDC

PASCO conducting paper (PK-9025) with painted disks at (8,10) and (20,10) and with a 1/4" diameter hole punched at (1,10)

The painted disks are not absolutely necessary. (a) Without paint, there may be a poor connection, but a poor connection can be fixed by pressing hard on the push pin. (b) A small dot of paint works as well as a carefully drawn disk.

Cork board and seven pushpins

Graph paper (print the graph paper from file **ElectricFields-GraphPaper.doc**)

Circle template

Plastic ruler

Banana plug wires (2 red, 2 black)

Alligator clips (2) that fit on banana plug wires

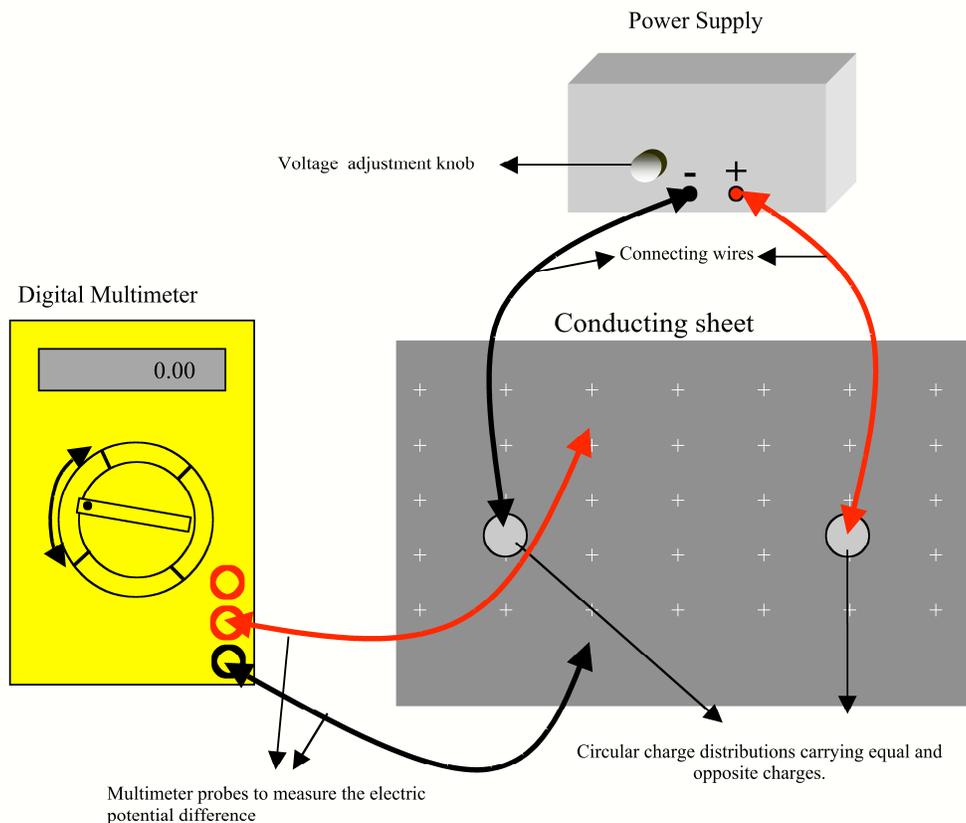


Figure 4 Experimental setup

2.1 Refer to the experimental setup shown in Figure 4.

2.1.1 On your table you will find a black conductive paper and a white graph paper.

2.1.2 Two silver-colored conductive disks are painted on the black conductive paper at locations (8,10) and (20,10).

2.1.3 On the white graph paper, the long axis is the horizontal x -axis, and the short axis is the vertical y -axis.

2.2 Your first task is to mount the black conductive paper and the white graph paper on the cork board so that their origins and axes are exactly aligned.

2.2.1 Place the white graph paper on the cork board and, using one of the metal pushpins, punch a hole passing through its origin at (0,0).

2.2.2 Remove the push pin and replace the white graph paper with the black conductive paper, and punch a hole passing through its center, located at (14, 10).

2.2.3 Now place the black conductive paper and the white graph paper on the cork board, the black conductive paper on top of the white graph paper and with their grids facing up. The origins of the two sheets must coincide. This is achieved by poking a pushpin through the holes you just made and then pressing the pushpin into the cork board.

2.2.4 You will notice that the black conductive paper has a 1/4" diameter hole located at the left end of its horizontal axis (the longer axis). You should be able to see the graph paper through this hole. Orient the two sheets such that the x -axis of the graph paper ***exactly coincides with the horizontal axis of the conductive sheet.***

2.2.5 Once you have achieved this alignment, fix the two sheets in place by sticking four pushpins at the four corners of the black conductive paper making sure that they also pass through the graph paper.

2.2.6 Remove the pushpin at the origin.

2.3 The metal disks on the conductive sheets can be "charged" with the power supply.

2.3.1 Notice that there are two wires originating from your power supply – one from the positive (red) terminal, the other from the negative (black) terminal.

2.3.2 Push one pushpin into each metal disk. Ensure the pushpin is flat and tight against the paper under it.

2.3.3 Clip the alligator clip from the black ground power supply terminal to the pushpin at (8,10) and the alligator clip from the red positive power supply terminal to the pushpin at (20,10), keeping the wires away from the middle of the conductive black paper.

2.4 Switch the power supply ON. This maintains a constant electric potential difference between the two metal disks.

2.4.1 This is equivalent to charging the disks with equal but opposite charges.

2.4.2 In particular, the disk connected to the positive terminal (red) of the power supply is charged positive and the disk connected to the negative terminal (black) is charged negative.

2.5 The electric potential difference between any two points on the conductive sheet is measured with the *Digital Multimeter* (refer Figure 4).

2.5.1 The multimeter should have two probes connected to it. A black probe connected to the jack marked **COM** and a red probe to the jack marked **V- Ω** .

2.6 Switch the multimeter ON by turning the selection dial counterclockwise and set it on the mark labeled 20 V or 30 V. The multimeter is now set to read a maximum potential difference of 20 V (20 joules per coulomb) or 30 V (30 joules per coulomb).

2.7 Place the metal tip of the black probe from the multimeter in contact with the pushpin on top of the disk charged negative. Similarly place the red probe on top of the disk charged positive. Your multimeter will display the electric potential difference between the two charged disks.

2.8 Adjust the voltage knob on the power supply (see Figure 4) so that the electric potential difference between the two disks is approximately 12.00 V.

2.9 Notice that if both probes are placed on the same disk your multimeter reading is 0.00V. This indicates that all points that make up each disk are at the same potential and hence are equipotential points.

3. Activity #3: Plotting equipotential points.

Abstract In this activity you measure the coordinates of the points that will determine the equipotential curves for an electric dipole.

3.1 Place one of the probes of the multimeter on the conductive paper at the location (6,6), which will here be referred to as the *reference point*.

3.2 Lightly press the metal tip of the probe on the reference point so that it leaves a visible dent on the conductive paper without poking a hole in the paper.

**Avoid poking holes in the black paper
until explicitly directed to do so.**

3.3 When placing a probe on the conductive paper, always hold the probe vertically, as shown in Figure 5.

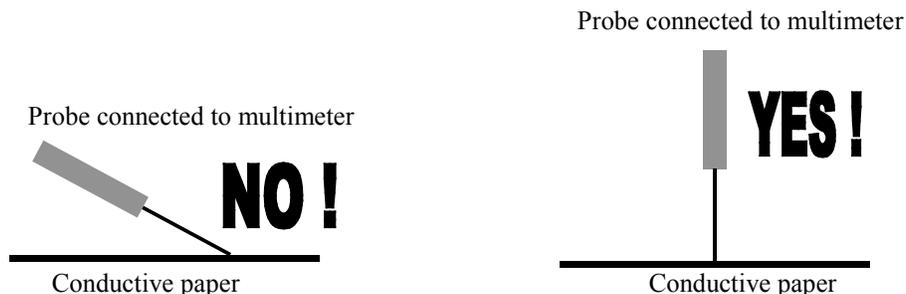


Figure 5 Placing the multimeter probes on the conductive sheet.

3.4 Use the other multimeter probe (the "search probe") to find an equipotential point relative to the reference point. The steps that follow explain how to do this.

3.4.1 At an equipotential point on the black conductive paper, your multimeter will read 0.00V, indicating the difference in potential between the location of the search probe and the location of the reference point is zero volts (*i.e., both points have the same voltage*).

3.4.2 The best way to find an equipotential point is to start with the search probe close to the grounded pushpin at (8,10). Then gently drag the search probe *directly away from* the pushpin while watching the DMM reading.

3.4.3 When the DMM reading is exactly 0.00 V, you have found an equipotential point relative to the reference point.

3.4.4 Restrict the search to the area enclosed by the vertical lines at (6,0) and (22,0) and the horizontal lines (0,4) and (0,16). Refer to Figure 6.

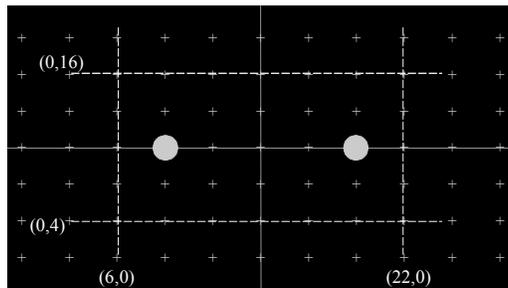


Figure 6 All equipotential points must lie in the rectangular region enclosed by the four lines.

3.5 For the given reference point, find *at least* six equipotential points (excluding the reference point). Restrict attention to the area mentioned in step 3.4.4.

3.5.1 One of the equipotential points *must* lie on the horizontal axis and another should lie on or near the vertical line on which the reference point lies. For example, if the reference point is (6,6) then one of the equipotential points must be on or near the vertical line at (6,0).

3.5.2 There must be equal number of equipotential points above and below the horizontal axis.

3.5.3 Spread the equipotential points evenly on the search area. Do not pack all the equipotential points in a small region.

3.5.4 On finding an equipotential point, press the probe firmly on the conductive paper to leave a visible dent on the paper but without poking a hole through the paper.

3.6 Once you have determined all the equipotential points for the given reference point, circle the points *lightly* with a pencil and write the number (1) next to these circles. This will help you identify the equipotential points later.

3.7 Before you proceed, show your work to your lab instructor and have him or her initial your lab handout here: **Instructor's initials** _____

3.8 Change the reference point to (10,4). Repeat steps 3.2-3.6, to obtain a new set of equipotential points. In step 3.6. replace the number (1) with the number (2) next to the circles.

3.9 Change the reference point to (14,4). Repeat steps 3.2-3.6, replacing the number (2) with the number (3) next to the circles.

3.10 Repeat steps 3.2-3.6 for the reference points (18,4) and (22,6) calling the set of equipotential points (4) and (5) respectively.

3.11 You have now determined points on five different equipotential lines.

Now you can poke holes in the black paper!

3.12 To mark the equipotential points on the graph paper placed below the conductive sheet, use the spare pushpin to punch holes through all the equipotential points on your conductive paper.

3.13 **Show the conductive paper to your instructor before proceeding.**

3.14 Switch the power supply and the multimeter OFF.

3.15 Remove the conductive sheet and the graph paper from the corkboard. On your graph paper, circle all the equipotential points and label them similar to the conductive sheet.

3.15.1 Notice that on the graph paper, each of the equipotential points corresponds to a point with a definite (x,y) coordinate.

3.16 **Please stick the pushpins on the corkboard to avoid injury.**

4. Activity #4: Plotting the equipotential points using Excel.

Abstract In this activity, you have MS Excel plot the points that define the equipotential curves, so you can print copies for each member of your group.

Equipment: Computer with MS Excel
Graph paper and Conductive sheet from Activity #3
Plastic ruler

4.1 Turn ON the computer and open an empty spreadsheet on Excel.

4.2 Enter the graph paper x and y coordinates of each of the equipotential points into the spreadsheet.

4.2.1 Use the coordinate system printed on the graph paper, not the coordinate system on the black conductive paper.

4.2.2 Enter the coordinates in centimeters accurate to one place past the decimal point. *Examples* -3.5, 2.0.

4.2.3 Enter all the equipotential points for a given reference point before entering the set of points for the next reference point. The figure to the right shows a sample spreadsheet.

4.3 Using the **Chart Wizard** option in Excel, obtain an **X-Y (Scatter)** plot of the x and y coordinates of the equipotential points.

4.3.1 Give a title to the plot. For example, "Plotting the equipotential points".

4.3.2 Uncheck all boxes in the menu item - **Gridlines**.

Partner #1: _____
 Partner #2: _____
 Partner #3: _____
 Partner #4: _____

Reference Point	Equipotential Points	
	x-coordinate	y-coordinate
1

2

3

4

5

Sample Spreadsheet

4.3.3 Remove any Legend by unchecking the relevant box in the **Legend** menu .

4.3.4 Place the chart in a new sheet.

4.4 Rescale the x - and y - axes of your plot by right clicking on any numeric label on the axis.

4.4.1 Choose **Format Axis...**

4.4.2 In the **Scale** menu, change the Maximum and Minimum values to spread the points as much as possible. Click OK.

4.4.3 Make sure that the range on the x - and y - axes are the same.

4.5 If your plot area (gray area) looks rectangular you may want to resize it to look square. To do this:

4.5.1 Click on the plot area, left click and drag the bottom right corner of your plot to resize it to a square. Use a plastic ruler if you need to.

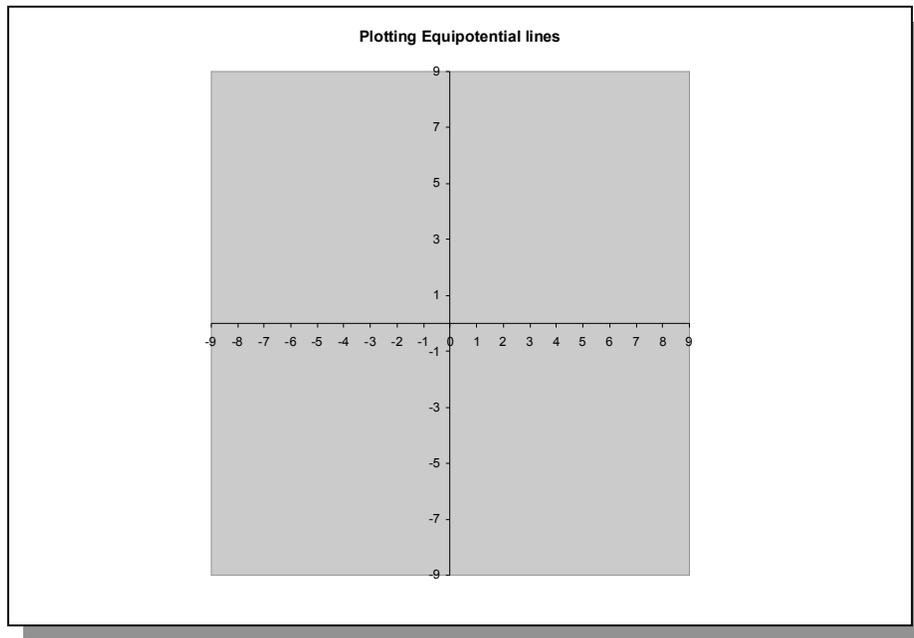


Figure 7 The plot area after rescaling and resizing (equipotential points not shown). Notice that the range on the x - and y - axes are the same and the plot area is approximately a square.

4.6 Figure 7 shows how the plot area (equipotential points not shown) should look after rescaling and resizing.

4.7 Follow these directions to obtain landscape-mode printouts of *the spreadsheet and the graph* for you and your partners (one set of printouts for each partner): **File** → **Print** → **Properties** → **Basics tab** → **Landscape** → **OK** → [Set Number of Copies] → **OK**.

4.8 Use the circle template to draw, on your Excel graphs, circles representing the charged disks. Label each circle with the appropriate sign of the charge.

5. Activity #5: Sketch the equipotential lines and electric field lines.

Abstract: Sketching the equipotential lines and the electric field lines on the Excel plot.

Equipment: MS Excel printout from Activity #4
Pencil

5.1 Use a pencil for all sketching activities.

5.2 The equipotential lines are obtained by drawing smooth curves passing through each set of equipotential points on your Excel plot. Since you plotted five sets of equipotential points, you should have five different equipotential lines.



Figure 8 Connecting the equipotential points

5.3 The curve passing through the equipotential points must be smooth with no sharp edges. Figure 8 demonstrates how to connect the equipotential points.

5.4 After sketching the equipotential lines, trace the electric field lines.

5.4.1 The electric field lines must be smooth curves and perpendicular to the equipotential lines where they cross.

5.4.2 Each electric field line starts at one of the charged disks and terminates at the other. Since the boundary of each disk is also an equipotential line, the electric field lines must be perpendicular to these boundaries.

Figure 9 (a) How to draw electric field lines near a positively charged conductor. Also note the arrows point from + toward -. (b) How to draw electric field lines where they cross equipotential lines.

5.4.3 The arrows on the electric field lines must be directed from the disk charged positive to the disk charged negative. Refer to Figure 9 part (a).

5.5 Sketch at least five electric field lines on your Excel plot. At least two lines must be above the horizontal axis and two below with one along the horizontal axis.

5.6 Show your Excel plot with the sketched equipotential lines and electric field lines to your instructor.

5.7 Close your Excel spreadsheet without saving and quit Excel.

6. Activity #6: Simulating equipotential lines and electric field lines.

Abstract Use the field simulations software EM Field 6.4 to plot equipotential lines, electric field lines, and electric field vectors.

Equipment: Computer
Field simulation software EM Field 6.4.

6.1 Double-click the **EM Field** icon, on your computer desktop.

This field simulator software package helps you visualize the equipotential lines and electric field lines for various charge distributions. You will use this software to further explore the equipotential lines and electric field lines of various charge distributions.

6.2 Maximize the window that opens so that it covers the entire screen.

6.3 On the main menu, click on **Sources** and choose **3D point charges**. The bottom part of your window displays an array of positive and negative charges.

6.4 Click on **Display** on the main menu and choose **Show grid**. Also choose **Constrain to grid** on the **Display** menu.

6.5 Click, drag and drop a +1 unit charge and a -1 unit charge into the plot region (the region with the grid).

6.5.1 Arrange the two charges approximately in the middle of the region a distance of six grid points from each other.

6.5.2 The distance on the monitor screen between the grid points is equal to about 2 cm, so the screen arrangement is similar to the two disks investigated in Activities #2 - #5.
Make sure you understand why.

6.6 On the main menu, click on **Field and Potential** and choose **Equipotentials**.

6.6.1 Clicking at any point in the plot region results in the software calculating and displaying an equipotential line passing through that point.

6.6.2 Determine the equipotential lines for the five reference points chosen in Activity #3.

Q1 Carefully compare the equipotentials displayed by EM Field with those you sketched on the Excel plot. List your observations and conclusions. (The computer draws equipotential curves as if the charges were in infinite space, with no boundaries. The equipotentials you drew on the Excel plot were from charges confined in a relatively small region – the black paper. Therefore, differences between the two plots are to be expected.)

6.7 Display a few more (not too many!!) equipotential lines for points of your choice.

6.8 On the main menu, click on **Fields and Potential** and choose **Field lines**.

6.8.1 EM Field is now programmed to calculate and display electric field lines passing through any point in the plot region.

6.8.2 Choose various points in the plot region and obtain the corresponding electric field lines.

6.8.3 The color of the field lines tells you the magnitude or strength of the electric field. The colors in the order of decreasing magnitude are: Red, Yellow, Green and Blue.

Q2 Do the electric field lines plotted here agree with those sketched on your Excel plot? List all your observations and conclusion.

6.9 Using the following sequence of mouse clicks, obtain a printout of the EM Field plot displaying the equipotential lines and electric field lines: **File → Print Screen → Setup → Landscape → OK** . Repeat this for as many partners as are in your group. (The option to print more than one copy at a time does not work, so you must print one copy at a time for each partner.)

6.10 The following directions clear all equipotential lines, electric field lines and charges from the screen. **Do not do this until everybody has printed copies of the screen!**

6.10.1 To remove all the field lines choose **Clean up screen** in the **Display** menu.

6.10.2 To remove the charges click, drag and drop the charges into the bottom part of the screen.

6.11 Place a +4 unit charge close to the middle of the plot region and a -1 unit charge one grid point to its right .

6.12 Choose **Field vectors** in the **Fields and Potential** menu.

6.12.1 Left clicking and dragging the mouse in the plot region displays the *direction and magnitude* of the electric field in the region surrounding the charges. If you release the left click button, a vector is displayed indicating the direction and magnitude of the electric field at the point of release.

6.12.2 To remove displayed Field vectors, choose **Clear up screen** in the **Display** menu.

Q3 Use the Field vectors tool to find a point on the line joining the two charges where the electric field vanishes. In the space below sketch the two charges and indicate the point where you think the electric field vanishes. Include a brief explanation of how you came to this conclusion.

Hint: Observe the behavior of the Field vectors and the Directional Arrows.

7. When you are done with this lab...

7.1 Exit **EM Field** . Please do not save anything on the hard drive.

7.2 Make sure the multimeter and the power supply are switched off.

7.3 Stick the pushpins on the corkboard to avoid injury.

7.4 Attach the following printouts to this handout:

7.4.1 the Excel spreadsheet (paragraph 4.7)

7.4.2 the Excel plot (paragraph 4.7), and

7.4.3 the EM Field plot(paragraph 6.9).

7.4.4 In addition, you or one of your lab partners must attach the conductive paper and the graph paper to their handout.

7.5 Turn in this lab handout before you leave the lab.

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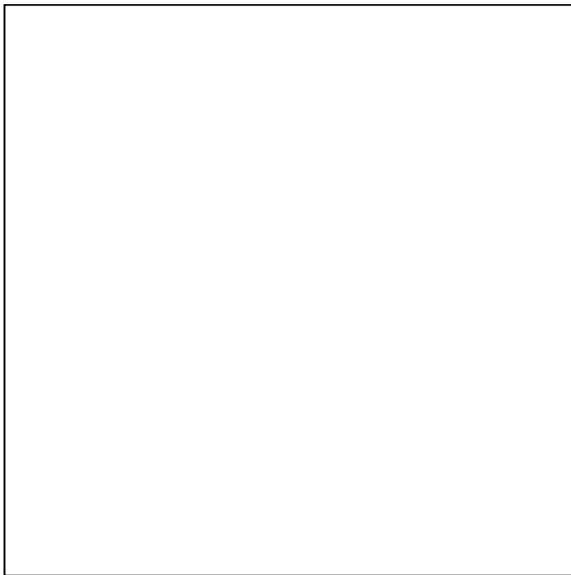
Pre-Lab Questions

Print Your Name

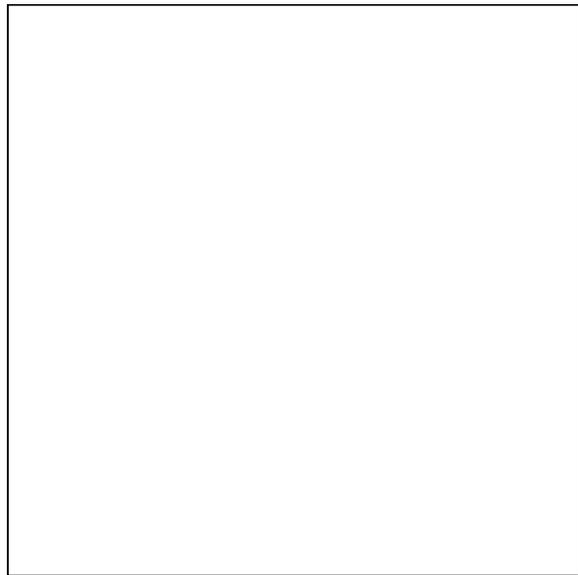
Read the *Introduction* to this handout, and answer the following questions before you come to General Physics Lab. Write your answers directly on this page. When you enter the lab, tear off this page and hand it in.

1. How does one define the magnitude and direction of the electric field?

2. In the boxes on the left, draw a copy of the positive charge from Figure 1. In the box to the right, draw a positive charge with the same diameter but twice as much charge. You need to have the correct number of field lines coming from both charges.



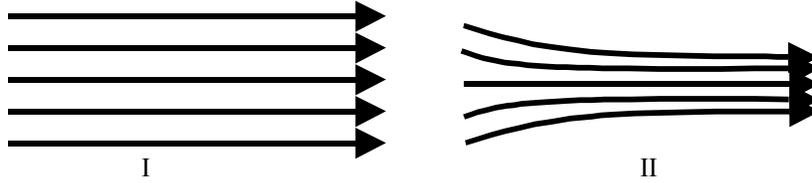
Copy of the charge from Figure 1



Twice the charge in Figure 1

3. Draw a picture showing the correct way – for this lab – to press a push-pin into the cork board.

4. Drawings I and II show two examples of electric field lines. Decide which of the following statements are true and which are false, explaining your choice in each case.



- a) In both I and II the strength of the electric field is the same everywhere.
- b) As you move from left to right in each case, the electric field becomes stronger.
- c) The electric fields in both I and II could be created by negative charges located somewhere on the left and positive charges somewhere on the right.

5. Is there any point on the line on which the two charges lie where the electric field is zero? Justify your answer.

