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:

(a) It is a vector quantity. One can associate a magnitude and a direction to the electric field for any point near a given charge.

(b) 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.

(c) 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 in Figure 1.

![Electric field lines](image)

*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, the greater the amount of charge, the greater are the number of electric field lines entering or leaving the charge distribution.
- The magnitude of the electric field in a given 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.

![Charge Diagram](image)

*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

![Experimental setup](image)

*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) or (6, 10) and (22, 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.
Electric Fields

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.

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.

Figure 5 Placing the multimeter probes on the conductive sheet.
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 LoggerPro.**

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

**Equipment:** Computer with LoggerPro

Graph paper and Conductive sheet from Activity #3

Plastic ruler

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

4.2 Create Manual Columns named X and Y.

4.3 Enter the graph paper \(x\) and \(y\) coordinates of each of the equipotential points into the spreadsheet.

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

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

4.3.3 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.

4.4 Obtain an X-Y plot of the \(x\) and \(y\) coordinates of the equipotential points.

4.4.1 Give a title to the plot. For example, “Plotting the equipotential points”.

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**Sample Spreadsheet**
4.5 Rescale the x- and y- axes of your plot.
   4.5.1 Make sure that the range on the x- and y- axes are the same.

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

![Plotting Equipotential lines](image)

*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.

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

4.8 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.

4.9 Use the circle template to draw, on your LP 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 LoggerPro plot.

*Equipment:* LoggerPro 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 LoggerPro plot. Since you plotted five sets of equipotential points, you should have five different equipotential lines.
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.

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 LP plot. At least two lines must be above the horizontal axis and two below with one along the horizontal axis.

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

5.7 Close your LP spreadsheet without saving and quit LP.

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

*Abstract* Use the field simulations software located at http://phet.colorado.edu/en/simulation/charges-and-fields to plot equipotential lines, electric field lines, and electric field vectors.

*Equipment:* Computer (at home or computer cluster)
Field simulation software http://phet.colorado.edu/en/simulation/charges-and-fields

6.1 Browse to: http://phet.colorado.edu/en/simulation/charges-and-fields
6.2 Click on Run Now!

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.

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

6.3 Check the boxes labeled ‘grid’, ‘Show numbers’, and then ‘tape measure’ (note: tape measure does not appear until you check numbers).

6.4 Click, drag, and drop a +1 nC unit charge and a –1 unit charge into the plot region (the region with the grid).
   6.4.1 Arrange the two charges approximately in the middle of the region a distance of 2 meters from each other.

6.5 Use the gray **equipotential box** to plot equipotential lines for your charges. *The pattern shown does NOT match your charges.*
   6.5.1 Clicking at any point in the plot region results in the software calculating and displaying an equipotential line passing through that point.
   6.5.2 Determine the equipotential lines for several points around and between EACH charge.
   6.5.3 Check the ‘Show E-field’ box to display the direction and strength of the electric field.
   6.5.4 **Bring printouts of your screen to lab.**
**Electric Fields**

Q1 Carefully compare the equipotentials displayed by the simulation with those you sketched on the LoggerPro 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 LP plot were from charges confined in a relatively small region—the black paper. Therefore, differences between the two plots are to be expected.)

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

6.6 The following directions will show you how to clear all equipotential lines, electric field lines and charges from the screen.

6.6.1 To remove all the field lines choose **Clear all**.

6.7 Place a $+4 \text{ nC}$ charge close to the middle of the plot region and a $-1 \text{ nC}$ unit charge two grids point to its right (1 meter).

6.8 Determine **Field vectors** for this charge distribution.

6.8.1 Left clicking on an **E-field sensor** and dragging the mouse to position the sensor 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.

6.8.2 To remove displayed Field vectors, drag them back into their storage bin.
**Electric Fields**

**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. Click **Clear all** and then create a continuous line distribution of positive charges. Create an exact copy of negative charges 1 m away.

7.1 Find the equipotential surfaces and electric field surrounding this distribution of charges.
   7.1.1 Drag the **equipotential** tool to several locations and click **plot**.
   7.1.2 Drag **E-field sensors** to the region between the line charges.
   7.1.3 Print your screen and bring this to your lab section with you.

**Q4** *What can you say about the electric field in the region between the line charges?*

8.0 **When you are done with this lab…**

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

8.2 Stick the pushpins on the corkboard to avoid injury.

8.3 Attach the following printouts to this handout:
   8.3.1 the LP spreadsheet (paragraph 4.8)
   8.3.2 the LP plot (paragraph 4.8), and
   8.3.3 the EM Field plot (paragraph 6.5.4).

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

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

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.