LAKE FOREST COLLEGE
Department of Physics

Physics 115 **Experiment #4: Equipotentials and Electric Fields v2** Spring 2025

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Date: 02/11/2025
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Table number:

Preliminary Instructions
Create a folder for you and your lab partner on Teams. Save a copy of these instructions for each student to that folder. Include your name in the filename. As you edit this document put your text in a different color. Save one copy of the *Excel* template with both your and your partner's name included in the filename.

Pedagogical purpose:
Study the relationship between electric fields and electric potentials.

Experimental Purpose:
Measure the electric potential at various positions between two conductors and calculate the electric field between the conductors. Also, explore the geometric relationship between equipotentials and electric field lines.

Background and operational definitions:
Calculation of the magnitude and direction of the electric field is difficult for complicated charge distributions. A useful way to study such distributions is to visualize the electric fields they produce by drawing the electric field lines. These lines start at a positive charge and end at a negative charge, and the strength of the electric field is proportional to the density of the field lines. Alternatively, it is possible to map the equipotential surfaces, which are lines that connect points of the same electric potential, and from these obtain information about the electric field. This is based on the fact that the electric field lines point along the direction of the greatest rate of change in the electric potential and that the electric field lines are perpendicular to the equipotential surface passing through that point. The magnitude of the electric field can be obtained from the separation of the equipotential surfaces.

In this experiment, you will map out two-dimensional equipotential surfaces (actually lines) generated by charged conductors. From these equipotential surfaces, you will be able to draw the corresponding electric file lines and estimate the magnitude of the electric field.

Place the negative probe of the DMM through the center of the plastic disk. Then the outside of the disk defines a constant distance in all directions. Move the positive probe around the disk to find the direction of the most negative voltage (greatest decrease in potential) at the edge of the disk. The electric field points in this direction.

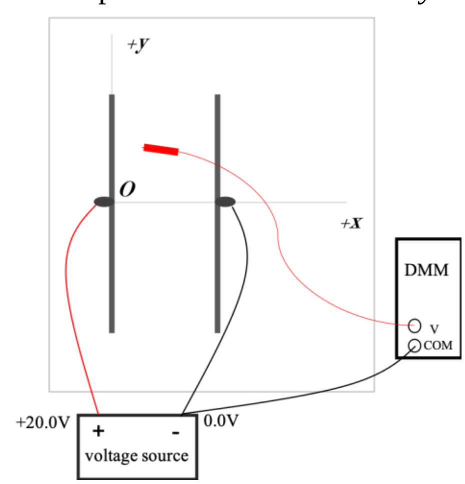
The Pasco black paper is slightly conducting. The silver paint is a very good conductor. This arrangement allows a very small amount of current to flow between two conductors when a potential difference (voltage) is applied to them. Use a gel ink pen to draw directly on the conducting sheets to record the location of the equipotential points.

Equipotential lines connect points that have the same electric potential. Set the dial on the digital multimeter (DMM) to "$\overset{\overline{\cdots}}{V}$" in order to measure "DC voltage." Press the button in the middle of the dial to display two decimal places. The negative (or COM) lead of the DMM is connected to the negative lead of the power supply. This establishes a reference potential of 0 V. The positive probe for the DMM is used to find points on the paper with the same voltage reading. These are points of equal potential.

Procedural summary:
Part I. Equipotential lines and electric field lines between two conducting plates

1. The first arrangement has two parallel silver lines, 20 cm long, 4 cm apart. Orient your conductive paper as shown. Connect the wires as shown using the conducting pushpins. Set the power supply to give +20.0 volts (as measured by the DMM) on the left conductor. Place the pins on the outside of the pads as far apart as possible. Use a gel pen to label the +20 V conductor. Call the position of the left line x=0; the vertical midpoint of the lines will be y=0. The axes should not be drawn.

2. Use the DMM probe to measure the potentials every 0.5 cm from $x = 0.0$ cm to $x = 4.0$ cm along $y = 0.0$ cm (the x axis). DO NOT PUNCTURE THE PAPER. Record your data in a table. **Insert Table I here; include a table caption.**



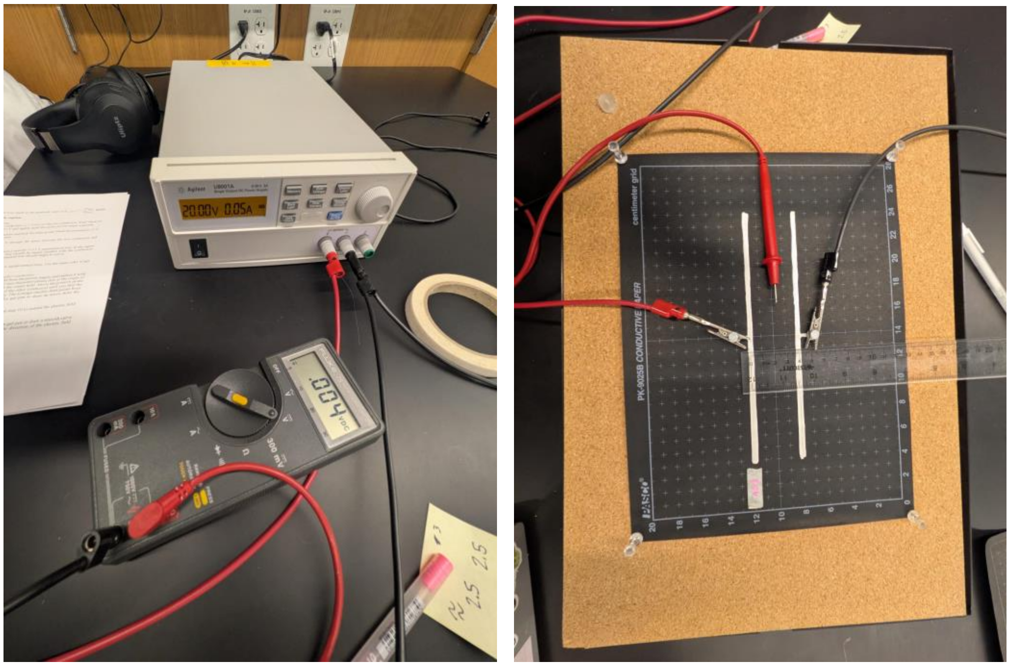


Figure 1. Voltage Apparatus. The Agilent Single Output DC Power Supply Outputs 20V. The red cord is the positive side and the black cord is the negative side. The cords from the power supply connect the metal push pins connected to the metallic strips in the Pasco Scientific conductive paper. The Fluke multimeter is used the measure the charge. The red cord is the positive side and the black cord is the negative side. When the black cord of the multimeter is connected to the black cord of the power supply then the negative side is 0V.

x (cm)	*x* (m)	*V* (V)
0.0	0	19.38
0.5	0.005	17.02
1.0	0.01	14.12
1.5	0.015	11.44
2.0	0.02	9.08
2.5	0.025	6.38
3.0	0.03	3.99
3.5	0.035	1.833
4.0	0.04	0.163

Table 1. DMM Probe Measurements. With the power suppy negative charge and the measured negative equally set to 0V, the voltage was measured between the positive and negative metallic strips. 0.0cm is the positive metallic strip and 4.0cm is the negative metallic strip. The highest voltage of 19.38 was on the positive strip and the lowest voltage of 0.163V was at the negative strip. The voltage changed an average of 2.4V per 0.5cm.

3. Use Logger Pro to plot the voltage as a function of the *x*-position (in meters) and fit a line

($y = mx + b$) to your points. **Insert your plot here; include a caption.**

Explain how to determine E_x **from the slope of your graph**. (Recall that $E_x = -\dfrac{\Delta V}{\Delta x}$). Make sure the sign of E_x is correct.

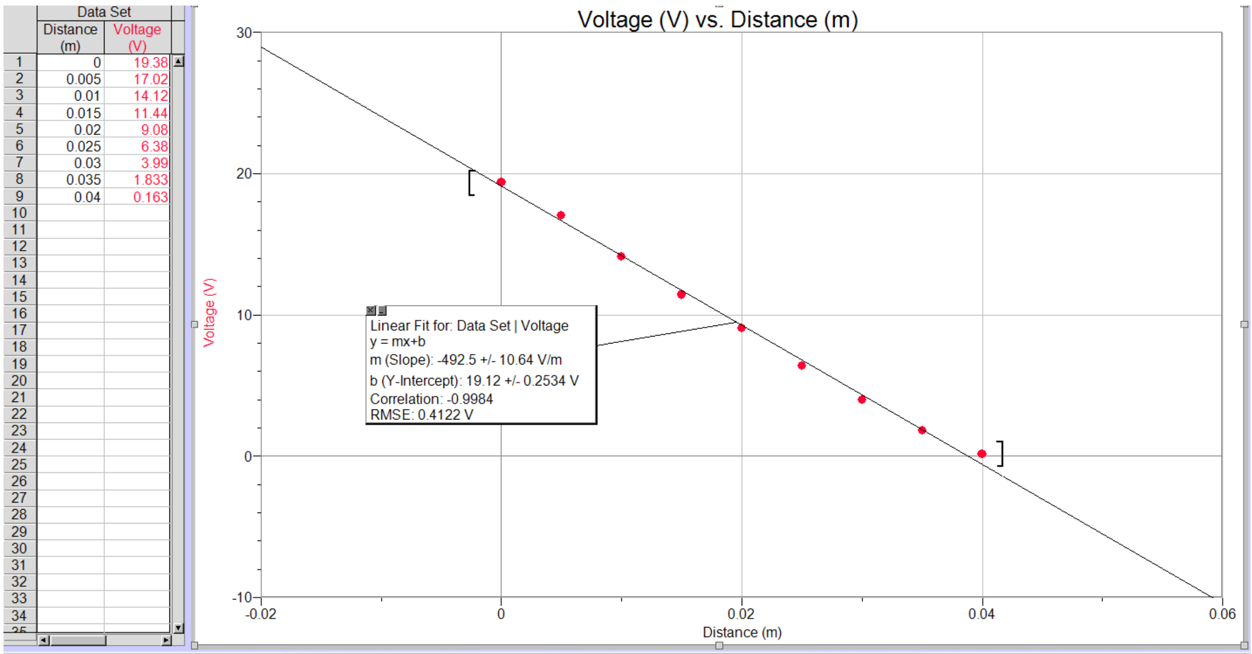


Figure 2. LoggerPro Voltage Graph. The distance from the positive metallic strip in meters is on the x-axis. The voltage is on the y-axis. As the probe was moved further from the positive strip the voltage decreased. The slope of the fitted line, -492.5V/m, is ΔV/Δx which is equal to $-E_x$, 492.5V/m. The uncertainty of the slope, 10.64V/m, is the same as the uncertainty of E_x.

4. Use the ratio test to compare your result to the predicted value of $E_{x\ \text{predicted}} = -\dfrac{\Delta V_{\text{plates}}}{\Delta x_{\text{plates}}}$. **Insert Table II here; include a table caption.**

slope (V/m)	unc slope (V/m)	measured E_x (V/m)	measured unc E_x (V/m)	rel measured unc E_x
-492.5	10.64	492.5	10.64	2.2%

ΔV_{plates} (V)	unc ΔV_{plates} (V)	rel unc ΔV_{plates}	Δx_{plates} (m)	unc Δx_{plates} (m)
19.22	0.09	0.47%	-0.04	0.002

rel unc Δx_{plates}	predicted E_x (V/m)	rel unc predicted E_x	unc predicted E_x (V/m)
5.0%	480.425	5.5%	26

Ratio Test
0.33

Table 2. Calculations. The slope of -492.5 V/m and the slope's uncertainty of 10.64V/m comes from the fitted line of the change is voltage over the change in distance from the positive metallic strip. The measured E_x is the negative slope. The measured uncertainty of E_x is the same as the uncertainty of the slope. ΔV was calculated by subtracting the voltage at one side, 0.163Vm, from the voltage at the origin, 19.38V. Δx was calculated by subtracting the distance of one side, 4.0cm, from the origin, 0.0cm. The measured and predicted values agree according to the ratio test.

Mapping the V=15 V *equipotential line*

5. Start on the line connecting the midpoints ($y = 0$ cm) of the two conductors. Find where on this line the potential is equal to 15 V and lightly mark this point on your paper a gel pen.

6. Move roughly parallel to the conductors and look for other points where the potential is 15 V. Mark several such points with a gel pen.

7. Continue to find points where V=15 V through the space between the two conductors and beyond.

8. Using a gel pen, connect your points to form a smooth V=15 V equipotential line. In the region near the midpoints of the conductors this line should be nearly parallel with the conductors. Near the edges of the conductors the equipotential line should begin to curve.

Mapping other equipotential lines

9. Repeat steps 5-8 to find the V=10 V and V=5 V equipotential lines. Use the same color of gel pen to draw all of these equipotential lines.

Mapping the electric field line in the center of the parallel conductors

10. Disconnect the negative (or COM) lead of the DMM from the power supply and replace it with a pointed probe. Place the center of the SMALL (12 mm diameter) plastic disc at the origin (0 cm, 0 cm) and put the negative DMM probe through the center hole. Move the positive probe around the edge of the disk (in the general direction of the other conductor) until you find the most negative voltage (the largest <u>decrease in potential)</u>. The average electric field points from the center of the disk to this point. Use a different color gel pen to draw an arrow from the negative probe position to the positive probe position.

11. Center the disc on the tip of your previous arrow and repeat step 10 to extend the electric field line.

12. Repeat steps 10-11 until you reach the other electrode. Use the gel pen to draw a smooth curve through your electric field arrows. Draw arrows indicating the direction of the electric field along this line.

Mapping other electric field lines

13. Repeat steps 10-12 to draw two additional electric field lines at other regions between the two conductors: start at $(0.0 \text{ cm}, 5.0 \text{ cm})$ and go to the other plate; start at $(0.0 \text{ cm}, 9.5 \text{ cm})$ and go to the other plate. Use the same colored gel pen to draw all of the electric field lines.

14. **Insert a photo of your work here.**

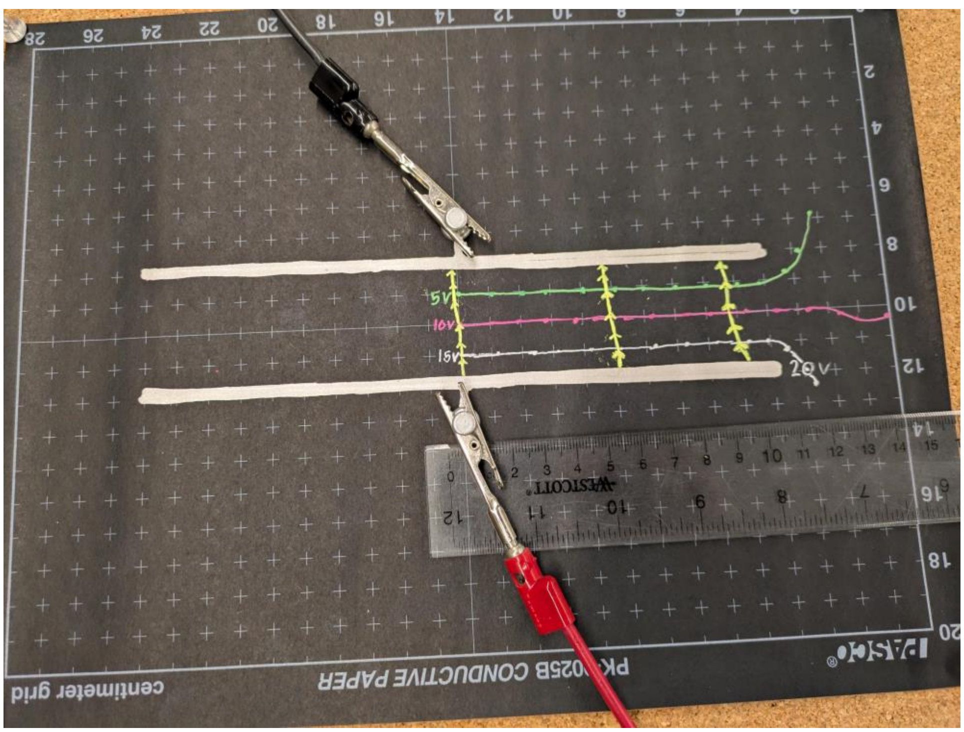


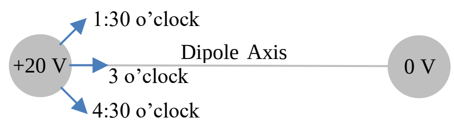
Figure 3. Line Electric Fields. The 15V. The Red cord connects to the positive metallic strip and the black cord connects to the negative electric strip. The 15V equipotential line is marked in white. The 10V equipotential line is marked in pink. The 5V equipotential line is marked in green. The yellow lines represent the electric field lines at 0.0cm, 5.0cm, and 9.5cm, along the y-axis. As the equipotential lines get to the end of the strips, they begin to curve. As the electric field gets closer to the end of the strips, it begins to bow.

Part II. Equipotential lines and electric field lines of a dipole

15. The second arrangement uses two circular conductors. Put the left circle at +20V and the right at 0 V. Use a gel pen to label the +20 V conductor. Place the pushpins on the outside of the pads, as far apart from each other as possible.

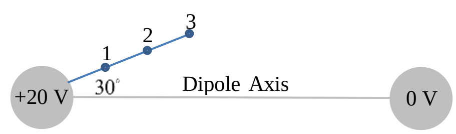
16. Following the general procedure of steps 5-8 above, map out the equipotential lines for 7, 10, and 13 V.

17. Following the general procedure of steps 10-12 above, map out three electric field lines.
    a. Start one line at the 3 o'clock position on the +20 V circle and go to the 0V circle. Start two other lines on the +20 V circle at the 1:30 and 4:30 positions and go to the 0 V circle.



    b. Draw arrows on your lines to indicate the direction of $\vec{E}$.

18. Estimate the strength of the electric field at three positions. Do this by measuring ΔV from the center of the plastic disk to the edge of the disk in the direction that gives the greatest decrease of *V*. The magnitude of the electric field at this position is approximately $E = \dfrac{|\Delta V|}{d}$, where the radius of the disk is $d = 0.0064\ \mathrm{m}$. Draw a straight line at about ~30º to the **dipole axis** that passes through the center of the 20 V conductor. Determine the magnitude of the electric field at three locations: 1 cm, 2 cm and 3 cm from the edge of the conductor. Note the location of the largest field magnitude. **Insert Table III and a photo of your work here**. **Include captions.**



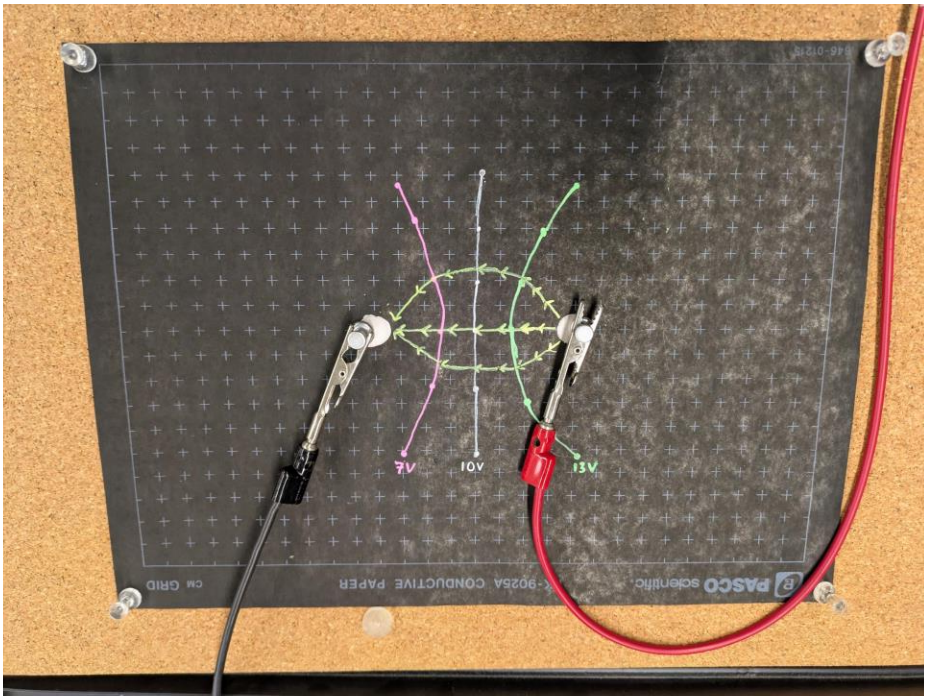


Figure 4. Point Charge Electric Field. The red cord connects to the positive metallic strip. The black cord connects to the negative metallic strip. The 7V equipotential line is marked in pink. The 10V equipotential line is marked in white. The 13V equipotential line is marked in green. The yellow lines represent the electric field between the points. As the field gets further from the point charges the magnitude of the field decreases.

Table III
(Step 18)

d (m)		
0.0064		
Dist from Cond (cm)	Δ*V* (V)	*E* (V/m)
1.0	16.8	2625
2.0	14.21	2220
3.0	12.07	1886

Table 3. Dipole Table. The raduius of the point d, is 0.0064m. The electric field magnitude E, was calculated by dividing the voltage, ΔV, but the radius of the point. The voltage was measured 3 distances from the positive charged point. The voltage changed 2.54V between 1.0cm and 2.0cm and 2.14V between 2.0cm and 3.0cm. The distance from the conductor increased, the strength of the electric field decreased.

19. **You may have learned in lecture that electric field lines and equipotential lines should cross at right angles. Do your lines show this?**

Yes, both the lines and the points the equipotential lines intersect the electric field lines at an approximately 90° angle.

20. **What is the relationship between the density of the equipotential lines, the density of the electric field lines, and the strength of the electric field? Do you diagrams show this?**

    The equipotential lines show where voltages are equal. When electric field lines are densely packed, it represents that the electric field is stronger and has a larger magnitude. The lines create a uniform electric field between them, so the electric field lines are equally spaced. The points show this relationship better as the electric field lines spread out as they get further from the points. It is possible to have dense electric field lines but a low voltage equipotential line.

21. **Write an analysis of the experiment here.**

The measured electric field E_x of 492.5±10.6 V/m agrees with the predicted value of 480±26V/m. The lines create a uniform electric field between them but as the end of the line is reached, they begin to warp. The ends of the lines act similar to the non-uniform electric field of the points.

22. **Write a brief conclusion here.**

The higher voltage equipotential lines are closer to the positive charge. Electric field lines go from negative to positive charge. **Equipotential lines intersect electric field lines at a 90° angle meaning the product of them is 0. The density of the electric field lines is equivalent to the strength of the electric field but independent of the electric potential.**
It would be interesting to increase the number of charged points and observe the electric field when there are 3 or more points.

Final remarks
Adjust the formatting (pagination, margins, size of figures, etc.) of this report to make it easy to read. Save this report as a PDF document. Upload it to the course Moodle page. Ensure that your Excel file, Logger Pro file, and all pictures are saved to the Team.

Clean up your lab station. Put the equipment back where you found it. Remove any temporary files from the computer desktop. Make sure that you logout of Moodle and your email, then log out of the computers. Ensure that the laptop is plugged in. Check with the lab instructor to make sure that they received your submission before you leave.