E2b: Electrostatic Potential, Potential Difference and Electric Field

Introduction:

The main objective of this experiment is to investigate the behavior of the electrostatic potential, potential difference, and electric field for two different charged configurations: a cylindrical capacitor, and a parallel plate capacitor.

The cylindrical capacitor and the parallel plate capacitor will be modeled using sheets of conductive paper and metallic ink. When connected to a DC power supply, these configurations generate a 2D electric field within the partially conducting paper that displays the same behavior as a cross-section of the two 3D capacitors.

A DC voltmeter can be used to measure the electrostatic potential difference between different points on the sheets of paper. The electric field can be determined from the obtained potential difference data. By measuring the electrostatic potential, determining the electric field, and then analyzing your data you will be able to observe the validity of Gauss's Law for electricity for the two configurations.

Apparatus:

- Conductive paper with two configurations
- Multimeter
- Power supply
- Plastic ruler
- Metal push-pins
- Connecting wires

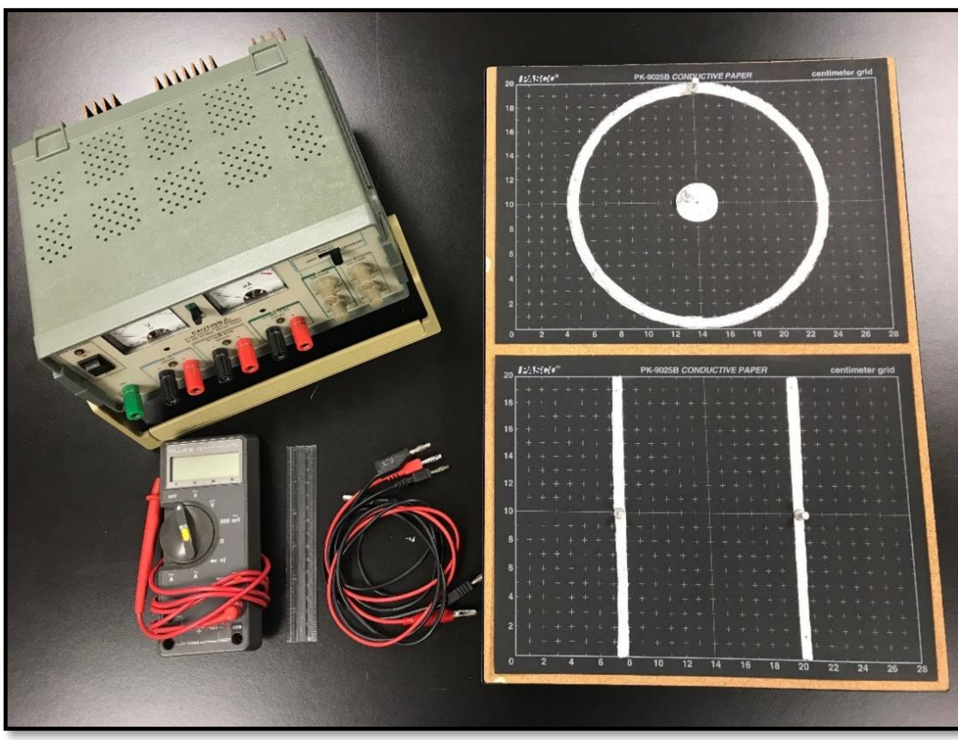

Figure 1

Theoretical background:

An electric field is generated by electric charges. Whenever a charged particle, *q*, is placed in a region where an electric field *E* is already present, there will be an electrostatic force F_e acting on this particle:

$$\vec{F_e} = q\vec{E} \qquad (1)$$

The potential difference, *ΔV*, is defined as the change in the electrostatic potential energy *ΔU* of a charge, *q*, when it is moved between two points in the presence of an electric field, divided by the value of the charge, *q*:

$$\Delta V = \frac{\Delta U}{q} \qquad (2)$$

If the electrostatic potential energy of a charge at some particular point is set to zero, then one can define the electrostatic potential at another point where the electrostatic potential energy of the charge is *U* as:

$$V = \frac{U}{q} \qquad (3)$$

Because the electrostatic potential energy of a charged particle is the negative of the work done by the electrostatic force on the particle, and this force is a product of the charge times electric field, the electric field and the electrostatic potential are related to each other as

$$\Delta V = -\int_a^b \vec{E} \cdot d\vec{s} \qquad (4)$$

and

$$\vec{E} = -\left\{\frac{\partial V}{\partial x}\hat{\imath} + \frac{\partial V}{\partial y}\hat{\jmath} + \frac{\partial V}{\partial z}\hat{k}\right\} \qquad (5)$$

The electric field depends on a geometrical distribution of charged particles, and can be predicted using Gauss' Law for electricity: ***The net electric flux through any closed surface equals the total charge enclosed inside the surface, Q_{enc}, divided by the free space permittivity***, $\varepsilon_0 = 8.85\times10^{-12}\,\frac{C^2}{N\cdot m^2}$, or:

$$\oint \vec{E} \cdot d\vec{A} = \frac{Q_{en}}{\varepsilon_0} \qquad (6)$$

Using Gauss's Law and a cylindrical Gaussian surface centered on the axis of the capacitor, one can show that the electric field between the two conducting surfaces inside a charged cylindrical capacitor is

$$E = \frac{\lambda}{2\pi\varepsilon_0 r}, \qquad (7)$$

where λ is the linear charge density and r is a radial distance from the central axis of the capacitor. The electric field outside of the conducting surfaces of the cylindrical capacitor is found to be zero.

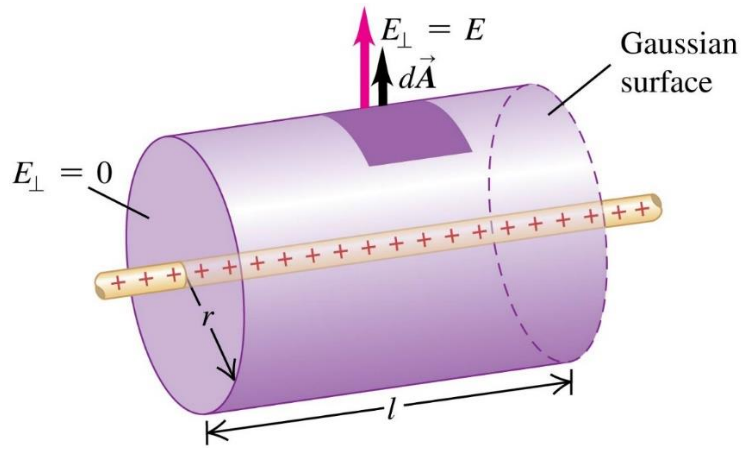

Figure 2. Applying Gauss's law to a cylindrical capacitor

Using Gauss's Law and a Gaussian "pillbox" or a cylindrical Gaussian surface for each parallel conducting plate then adding the two electric fields vectorially, one can determine that the electric field between the plates of a parallel plate capacitor is uniform and only depends on a surface charge density on the plates, $\boldsymbol{\sigma}$:

$$E = \frac{\sigma}{\varepsilon_0} \qquad (8)$$

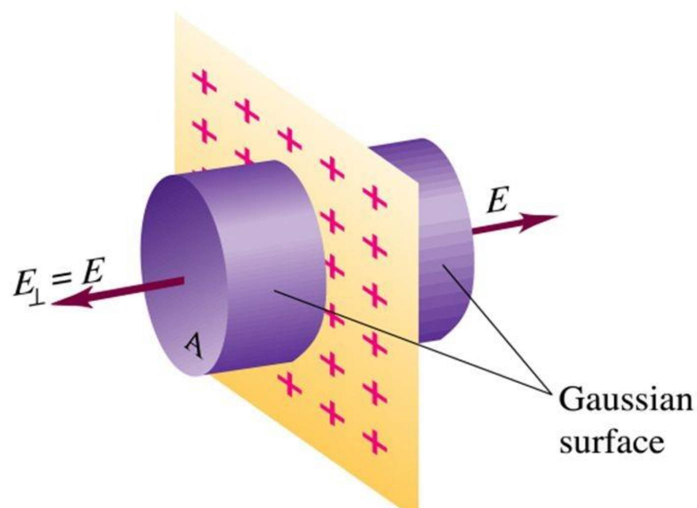

Figure 3. Applying Gauss's law to one plate of a parallel plate capacitor

Substituting equations (7) and (8) into equation (4) with the appropriate limits of integration, one can derive expressions for the electrostatic potential for each configuration which will be measured in the lab.

In the conditions of the experiment, equation (5) can be reduced to

$$E = \frac{\Delta V}{\Delta r} \qquad (9).$$

In the equation (9), *E* represents the magnitude of the electric field approximately in the middle between two closely located points, ΔV is the potential difference between these two points, and Δr is the distance between these two points. You are going to use equation (9) to obtain electric field data from measured electrostatic potential data.

By plotting the graphs of the electrostatic potentials and the electric fields as functions of the distance for the two configurations, and fitting them to the appropriate trend lines, one can observe the validity of Gauss' Law for electricity in the experiment.

More information on the relevant material can be found in you textbook.

Electric Field: Young & Freedman. **University Physics**, *Chapter* **21** *section* **4, 6**
Electric Potential: Young & Freedman. **University Physics**, *Chapter* **23** *section* **2, 4**

Do not begin this experiment without first checking with a lab instructor and reading through any supplemental reading material that the lab instructor provides.

Procedures:

This experiment consists of two parts. In the first part, you will measure and then plot the electrostatic potential difference as a function of radial distance from the center for a cylindrical capacitor configuration. In the second part, you will again measure and then plot the electrostatic potential difference as a function of distance from one plate (along a line perpendicular to the plate) for a parallel-plate capacitor. Subsequently, you will determine the electric field as a function of position from these electrostatic potential difference plots.

Part I

1. Place a partially conductive paper sheet with the drawn model of a cylindrical capacitor (a small metallic circle inside a metallic circumference/shell) on the cork board.
2. Push one metallic pushpin into the inner conducting central circle (any point different than the center), and another metallic pushpin into the outer conducting shell (anywhere as long as it's within the metallic portion of the outer conducting shell).
3. Attach the red (+) cable from the power supply to the metallic pushpin at the inner conducting circle. Attach the black (-) cable from the power supply to the metallic pushpin on the metallic shell. Turn on the power supply and set it to approximately 15 volts.
4. Connect the negative (black) probe from the voltmeter directly to the negative pole of the power supply. Touch the conductive paper *anywhere* **inside** the shell with the positive (red) probe from the voltmeter. You should be able to get some readings on your voltmeter.

5. Place the positive (red) probe at the center of the inner conducting circle. Record your reading in the **Table 1.** If everything is set correct, your reading should be the same as the voltage shown on the power supply.
6. Place the positive probe at 5 mm from the center of the circle. Record the reading on the voltmeter in the **Table 1**. Be precise with your positioning - exactly 5 mm from the center.
7. Repeat this procedure and measure the voltage along a radial line at 5 mm intervals from the center. Stop your measurements when you reach the metallic shell. Record your data in the **Table 1**.
8. Use Excel to plot a graph of the electrostatic potential (the voltage you measured) as a function of the distance from the center. Keep in mind that the potential is the dependent variable, and should be plotted along the y-axis.
9. You should observe a horizontal "plateau" and then a decrease in the electrostatic potential with distance. Later, in your post-lab, you'll need to explain the reason for this "plateau". Save your graph!
10. Make another graph using the same Excel spreadsheet, but excluding points inside the "plateau" (If you are familiar with the Excel, you can just exclude these points from the analysis and use the same graph as before). Use Excel to fit your data with a theoretical curve by choosing the appropriate trendline. Save your graph!
11. Remembering the relationship between the electric field and the electrostatic potential, determine how to use your data to obtain values for the electric field at different distances from the center of the inner conducting circle. Obtain these values and record them in the **Table 1**. Also, record in the same table the corresponding distances from the center for the calculated electric field.
12. Use Excel to plot a graph of the electric field as a function of the distance from the center and fit your data with a theoretical curve by choosing the appropriate trendline. Save your graph!
13. Show your data and the graphs (with trendlines and equations displayed on the graph) to a lab instructor.
14. Write a conclusion and reflect whether your experimental data are in agreement with the theoretical predictions.

Part II

1. Place a partially conductive paper sheet with the drawn model of a parallel plate capacitor (two parallel conducting bar lines) on the cork board.
2. Push one metallic pushpin into the board on each of the bar lines (anywhere within the lines).
3. Attach the red (+) cable from the power supply to the pushpin on the right bar and the black (-) cable from the power supply to the pushpin on the right bar. Turn on the power supply and set it to approximately 15 volts.
4. Touch the conductive paper in the middle between the conducting bars with the positive (red) probe from the voltmeter. The negative (black) probe from the voltmeter should still be connected directly to the negative of the power supply. You should get a reading on the voltmeter.
5. Place the positive (red) probe on the conductive paper, along a line perpendicular to the conducting bars near the center of the "capacitor", at precisely 5 mm from the negative conducting bar**.** Record the reading on the voltmeter in the **Table 2**.

6. Repeat this procedure and measure the voltage along the same middle line at 5 mm intervals from the negatively charged conducting bar. Stop your measurements when you reach the conducting bar connected to the positive terminal. Record your data in the **Table 2**.
7. Use Excel to plot a graph of the electrostatic potential (voltage you measured) as a function of the distance from the bar connected to the negative terminal. Keep in mind that the potential is the dependent variable, and should be plotted along the y-axis. Fit your data with a theoretical curve by choosing the appropriate trendline. Save your graph!
8. Remembering the relationship between the electric field and the electrostatic potential, determine how to use your data to obtain the data for the electric field as a function of position between the conducting bars. Obtain these data and record them in the **Table 2**. Also, in the same table, record the corresponding positions for the calculated electric field.
9. Use Excel to plot a graph of the electric field as a function of the distance from the negative charged bar and fit your data with a theoretical curve by choosing the appropriate trendline. Save your graph!
10. Show your data and the graphs (with the trendlines equations displayed on the graphs) to a lab instructor.
11. Write a conclusion and reflect whether your experimental data are in agreement with the theoretical prediction.

Experiment E2b: Electrostatic Potential, Potential Difference and Electric Field

Student Name____

*Lab Partner Name*____

*Lab Partner Name*____

Physics Course____

Physics Professor______________________________________

Experiment Start Date__________________________________

Lab Assistant Name	*Date*	*Time In*	*Time Out*

Experiment Stamped Completed

Data Sheets: E2b: Electrostatic Potential, Potential Difference and Electric Field

NAME: ____________________________ **DATE: _________________**

TABLE 1

Electrostatic Potential and Electric Field as a Function of Distance from Center of Cylindrical Capacitor

Distance from Center mm	Electrostatic Potential Volts

Distance from Center mm	Electric Field V/m

Data Sheets: E2b: Electrostatic Potential, Potential Difference and Electric Field

NAME: ______________________________ DATE: __________________

TABLE 2

Electrostatic Potential and Electric Field as Function of Distance from Negative Bar of Parallel-Plate Capacitor

Distance from the negative conducting bar mm	Electrostatic Potential Volts

Distance from the negative conducting bar mm	Electric Field V/m