<u>NATIONAL UNIVERSITY OF TECHNOLOGY</u>

<u>COMPUTER ENGINEERING DEPARTMENT</u>

Applied physics Lab (PHY13002)

<u>Experiment No:2</u>

Title: Experiment to investigate how capacitance of a parallel plate capacitor varies.

Submitted to: Prof Ayesha

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Date of experiment performed: 22 October 2024

Objective:

- Study the effect of capacitance of a parallel plate capacitor under the presence of a Dielectric Material.

Apparatus:

1. Basic Electrometer
2. Basic Variable Capacitor
3. Electrostatics Voltage Source
4. 850 Universal Interface
5. PASCO Capstone
6. Paper

Theoretical explanation:

A simple capacitor with two parallel plates has capacitance calculated as $C=\kappa\epsilon_0 A/d$.

Variables in the formula:

- κ: dielectric constant of the insulating material.
- ϵ: permittivity constant, valued at 8.85×10^{-12} F/m
- A: area of each plate.
- d: distance between the plates.

In complex systems, additional components, such as wires and electrometers, contribute extra capacitance, represented by C_{sys}. The modified capacitance formula for such systems becomes $C= \kappa\ \epsilon_0\ A\ /d + C_{sys}$.This is checked in the first part of the experiment by varying distances and recording the voltages.

In the second part of the experiment dielectric materials are placed between plates, which increase capacitance by a factor κ. If the charge remains constant while inserting a dielectric, the voltage across the capacitor decreases to $V=V_0/\kappa$ (where V_0 is the initial voltage without the dielectric). This experiment involves adjusting a variable capacitor to measure how capacitance changes with plate separation and dielectric insertion. By positioning parallel plates at precise distances and connecting them to an electrometer, we monitor the voltage changes as separation distances vary. Using a PASCO Capstone interface, we record data to analyze the relationship between plate distance, dielectric constant, and capacitance.

Procedure for Task 1:

a) Remove any charge from the capacitor by momentarily touching both plates at the same time with your hand.
b) Turn on the electrometer and set the range button to the 100 V scale.
c) Connect the wire to the stud of the capacitor plates for 1 minute to store maximum charge.
d) Set the initial distance between the plates to 8 cm and record the first voltage reading using the "Keep Sample" button.
e) Gradually decrease the distance between the plates to 7 cm and record the voltage reading.
f) Continue decreasing the plate distance by 1 cm for each , recording the voltage at each step, until the distance reaches 0.3 cm.
g) Once all measurements are recorded, save the samples for analysis

Procedure for Task 2:

a) After completing Task 1, ensure the plates remain charged.

b) Set the distance between the plates to 8 cm.

c) Record the initial voltage reading with no material between the plates.

d) Insert a sheet of paper between the plates and note the new voltage reading.

e) Repeat the process, taking multiple readings at the same 8 cm distance with inserting and removing the paper between the plates.

Observations and Calculations:

1.Measurements:
The experiment was conducted at decending distance from 8cm to 0.3cm. For each result, the distance was varied,and the voltages were recorded. The voltage decreased as the distance decreased, as expected.

2.Graphing the Results:
Graph was plotted for Voltage vs Seperation.As Seperation decreased voltage decreased but the decrease was not linear because conditions were not ideal.

3.Observation:

As the distance between the capacitor plates was decreased, the measured voltage across the plates also decreased. This inverse relationship indicates that reducing the separation increases the capacitance, which in turn requires less voltage to maintain the same charge. The graph demonstrates a gradual decrease in voltage as the plate separation becomes smaller, highlighting the dependency of capacitance on plate distance.

Task1:

Separation (cm)	Voltage (V)
8.0	53.22
7.0	51.50
6.0	49.73
5.0	47.56
4.0	44.61
3.0	41.90
2.0	38.78
1.0	34.92
0.5	31.92
0.3	28.02

Result and Analysis:

$V = Q/ (\kappa\, \varepsilon_o\, A/d + C_{sys})$ and we made C_{sys} subject hence, $C_{sys} = \frac{\epsilon * A}{d}$

We analyzed the relationship between voltage (V) and plate separation (d) in a capacitor system where an additional system capacitance, C_{sys}, is present.To verify the Equation, we calculated $\kappa\epsilon_0 A$ as 2.18×10^{-11} F and used it to estimate initial values of the charge Q and system capacitance C_{sys} by fitting the model to our data.

$$Q = V_{0.3}\, (\kappa\, \varepsilon_o\, A)/d = (28.02\ V)*(2.18x10^{-11} F\ cm)/(0.003\ m) = 2.0x10^{-9}\ C.$$

$$C_{sys} = Q/V_8 \sim 2.0x10^{-9}\ C/53\ V = 3.8x10^{-11}\ F$$

Using this method, we calculated C_{sys} at different distances. According to the Equation mentioned above, if C_{sys}=0, voltage should be directly proportional to the separation, resulting in a straight line on the Voltage vs. Separation graph. However, our data showed a curved relationship, suggesting C_{sys} is not zero.

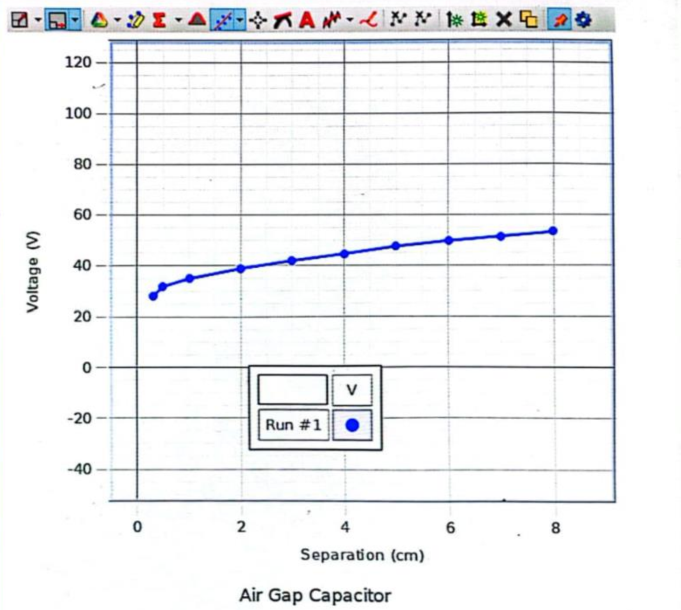
C_{sys} represents the system capacitance essentially, any extra capacitance in the circuit outside of the main capacitor plates. This includes capacitance from connecting wires, surrounding materials, and any other components in the setup that store electrical charge.

In a perfect setup, only the main capacitor plates would contribute to capacitance. However, in real experiments, these additional elements also hold some charge, contributing to a small but noticeable capacitance, which we call C_{sys}. This extra capacitance affects the voltage readings, especially at larger distances between the plates when the parallel plate capacitance is smaller and C_{sys} becomes a larger part of the total capacitance. The fitted values showed that at larger distances, C_{sys} contributed more significantly, while at smaller distances, the parallel plate capacitance had a stronger effect on the voltage.

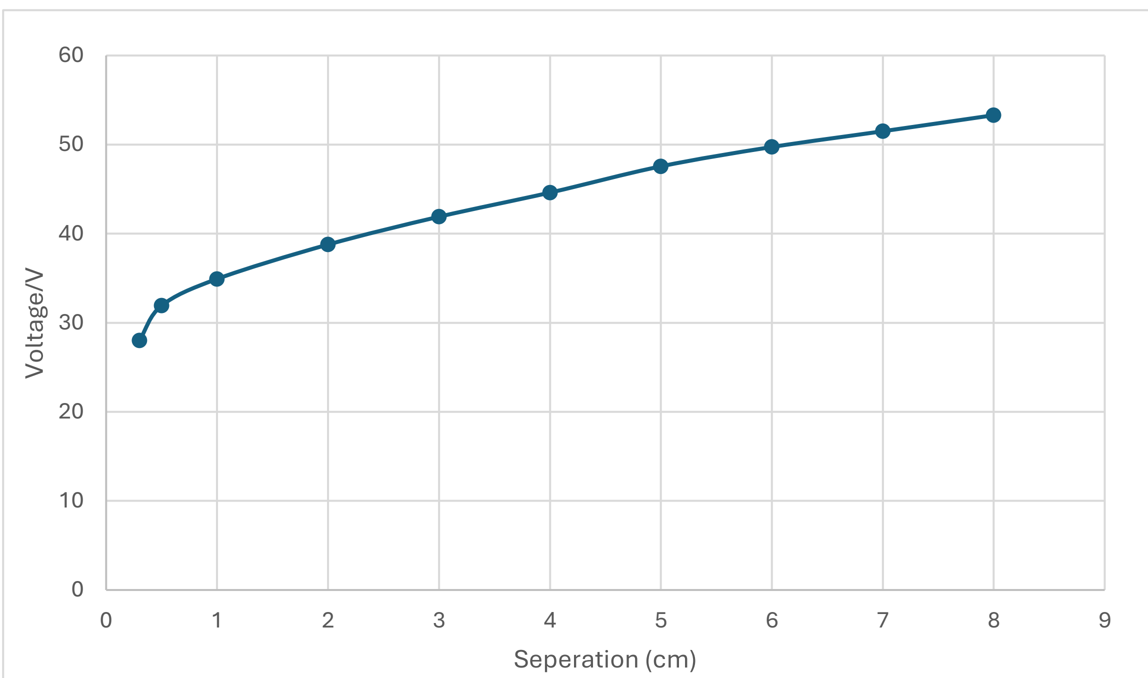
Result shown on PASCO Software:

Air Gap Capacitor Data

Set: Separation (cm)	Run #1: Voltage (V)
8.0	53.22
7.0	51.50
6.0	49.73
5.0	47.56
4.0	44.61
3.0	41.90
2.0	38.78
1.0	34.92
0.5	31.92
0.3	28.02



Graph:



Task 2:

	Paper Position	Voltage (V)
1	out	35.22
2	in	31.76
3	out	33.93
4	in	29.62
5	out	32.00
6	in	29.56
7	out	31.84
8	in	29.10
9	out	31.30

Result and Analysis:

- The voltage drops each time the paper is inserted between the plates, indicating that the dielectric material (paper) reduces the potential difference across the capacitor.
- This aligns with the concept that a dielectric material increases the capacitance by reducing the electric field for a given charge, resulting in a lower voltage.
- The presence of a dielectric material increases the capacitance C of the capacitor by a factor of the dielectric constant κ. Since $V=Q/C$, an increase in capacitance C (while Q is constant) leads to a decrease in voltage V.
- Each time the paper was inserted, it acted as a dielectric and effectively lowered the voltage by increasing the capacitance between the plates.
- Variations in voltage with repeated inserting and removal of the paper may be due to slight changes in voltages, but the overall trend demonstrates the impact of the dielectric material on capacitor behavior.

- The decrease in voltage when the paper is between the plates suggests that the dielectric constant of paper is greater than that of air. This higher dielectric constant allows the capacitor to store more charge at a given voltage, effectively enhancing its capacitance.
- Repeated cycles of inserting and removing the paper confirm the consistent effect of the dielectric on the voltage, validating the concept that introducing a dielectric between the plates of a capacitor reduces the voltage for a fixed charge by increasing the capacitance.

Result shown on PASCO Software:

Paper Dielectric Data

	Set	Run #2
	paper position	Voltage (V)
1	out	35.22
2	in	31.76
3	out	33.93
4	in	29.62
5	out	32.00
6	in	29.56
7	out	31.84
8	in	29.10
9	out	31.30
10		
11		
12		

Procedure B: The Effect of a Dielectric between the Plates

1. You will use paper as the dielectric to be inserted between the plates. Get a stack of paper about 1 cm thick.

2. Position the movable plate of the capacitor at 8 cm.

3. Turn on the electrometer and set the range button to the 100 V scale.

4. Remove any charge from the capacitor by momentarily touching both plates at the same time with your hand.

5. Zero the electrometer by pressing the 'ZERO' button. The needle must be at zero.

6. Momentarily connect a cable from the +30-V outlet in the voltage source to the stud on the back of the movable capacitor plate. This will charge the capacitor. Remove the charging cable.

7. Click on the PREVIEW button below.

8. One student holds the stack of paper directly above the gap between the capacitor plates so that the long side of the paper is vertical. Hold the paper with one hand and keep the other hand on the metal connector attached to the signal input of the Electrometer so that there is no static charge on the student holding the paper. Press the Keep Sample button to record the voltage when the paper is not between the plates.

9. Lower the paper between the two plates and well away from either plate until it touches the base. Do not let the paper get close to either plate! Keep your hand as far above the plates as possible. Press the Keep Sample button to record the voltage when the paper is between the plates.

10. Pull the paper back above the plates and repeat steps 8 and 9 several times.

11. Click the STOP button to stop monitoring the data.

12. If the final voltage with the paper out is much different from the initial paper out value, you probably got too close to a plate and should repeat the experiment.

Precaution:

- Handle Materials Carefully: Avoid touching the capacitor plates and the paper dielectric directly, as oils or moisture from hands can affect readings. Ensure the paper remains clean, dry, and free from creases to maintain consistent dielectric properties.
- Ensure Proper Setup and Positioning: Keep the capacitor plates parallel at each separation distance and position the paper accurately when placing it between the plates. This prevents any uneven distribution or measurement errors.
- Minimize Interference: Keep metallic objects, cables, and hands away from the experimental setup to avoid interference. Static charges from hands or nearby objects can impact the readings, so grounding the electrometer and handling equipment with care is essential.
- Zero and Check Equipment: Before starting, zero the electrometer and confirm all connections are secure. Repeat this step if any disturbances occur during the experiment to ensure accuracy.

Comments:

1. **What happened to the voltage as the plates got closer together (d decreasing)?**

As the plates of a capacitor are brought closer together, the distance decreases. Since capacitance C is defined as C=Q/V (where Q is the charge and V is the voltage), if the charge Q remains constant, a decrease in distance leads to an increase in capacitance, which results in a decrease in voltage V.

2. **What were your best fit values for the charge Q and C_{sys}?**

The capacitance of the air gap capacitor, C_{sys}, is calculated using the formula:

$$C_{sys}=\frac{\epsilon * A}{d}$$

Where $Q=2.0\times10^{-9}$ C is assumed (constant charge) and V is the measured voltage. Based on the data, the best value for C_{sys} is 4.48×10^{-11}, which occurs at a separation of 4.0 cm. This is the highest capacitance, indicating maximum charge storage at lower separations, aligning with the expected behavior of capacitors.

3. **How well did your model fit the data? Try to explain any discrepancy. Hint: What approximations are made when deriving the parallel plate capacitance ($C = \kappa\, \varepsilon_0\, A/d$) from Gauss' Law?**

The model fits the data well, showing the expected inverse relationship between capacitance and separation. Discrepancies arise due to approximations in the capacitance formula: it assumes no edge effects, perfect plate alignment, uniform air dielectric ($\kappa\approx1$), and smooth plate surfaces. In reality:

Edge effects: The ideal formula assumes a uniform electric field, but real capacitors have non-uniform fields at the edges, reducing capacitance.

Plate misalignment: The formula assumes perfectly parallel plates; any tilt or misalignment causes uneven spacing, affecting capacitance.

Air variability: Assumes $\kappa\approx1$, but variations in temperature, humidity, or pressure can slightly change the dielectric constant.

Surface roughness: The formula assumes smooth plates, while actual roughness creates uneven separation and field distribution, impacting capacitance.

These issues cause slight deviations, leading to lower measured capacitance than predicted.

4. Briefly discuss the value of computer modeling.

The ability to accurately simulate complex systems by computer modeling makes it possible to forecast behavior under a variety of scenarios, which makes it valuable. It saves time and money, optimizes designs, helps find possible discrepancies, and offers insights that can be hard to get from manual testing alone. Additionally, modeling enables quick testing of many scenarios, increasing understanding and efficiency.

5. Examine Table II. Does the data agree with Equation 5? What does a dielectric do?

Yes, the result agrees with the equation 5 that $\mathbf{V<V_0}$, where V_0 is the voltage without the dielectric (paper) and V is the voltage with the dielectric inserted.

Dielectric material, such as paper, increases the capacitance of a capacitor by reducing the electric field strength between the plates for the same charge. This results in a lower voltage for the same amount of charge, as the dielectric constant (κ) of the material is greater than 1. Basically, the dielectric allows the capacitor to store more charge at a given voltage, hence decreasing the voltage observed when it is inserted.

Conclusion:

In these experiments, we explored how plate separation and dielectric materials affect a capacitor's voltage. In the first experiment, as the distance between the plates decreased, the voltage also decreased. This inverse relationship demonstrates that reducing separation increases the capacitance, allowing the capacitor to hold more charge at a lower voltage.

In the second experiment, placing a dielectric (paper) between the plates resulted in a lower voltage compared to when the dielectric was absent. The dielectric increases capacitance by reducing the electric field strength, enabling the capacitor to store more charge at a lower voltage.

Overall, both experiments highlight key aspects of capacitor behavior, decreasing plate distance and adding a dielectric both increase capacitance. This allows a greater charge to be stored at a reduced voltage, supporting fundamental principles in capacitor design and application.