PHYS 102 Lab Project Proposal

The Capacitance of Parallel Plate Capacitor with Dielectric Slab

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Section: 03

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Table of Contents:

3) Calculating Capacitance of Partially Filled Capacitor

Objective

Theory

Setup of Experiment

Procedure and Data

Table 3.1

Table 3.2

Table 3.3

Conclusion

Part A Calculating Dielectric Constants of Some Materials:

Objective:

This part of the experiment aims to find dielectric constants of materials used in both Part B and C. This part will assume found dielectric constants will be correct since there is no reference value to be compared. Therefore, no error will be calculated for this part.

Theory:

1) $C = \epsilon_0 \frac{A}{d}$ [1]
2) $C = \kappa\, C_0$ [1]
3) $E = \frac{V}{d}$ [1]
4) $\kappa_{\text{air}} = 1.00059 \approx 1 = \kappa_{\text{vacuum}}$ [1]

(ϵ_0 is the permittivity of free space, A is the area of the single plate in meters, d is the distance between the plates in meters, C_0 is capacitance of the capacitor filled with vacuum, κ dielectric constant, E is the electric field, V is the potential difference between plates)

The capacitance of the parallel plate capacitor depends only on the area of one plate and distance between the plates with constant ϵ_0 (formula 1). When the plates are bigger, they will store more charge and when the plates are closer, the opposite charges will attract each other more. However, when d is very small, E may be high enough that the breakdown may occur between the plates, thus losing the capacitance feature (formula 3). One may solve the problem by putting an insulating material between the plates to increase the resistance of the capacitor to electric field changes [1]. Thus, capacitance value will be increased with insulator material with dielectric constant κ (formula 2). Four homemade parallel plate capacitors will be prepared in advance and the distance d between the plates will be kept stable while and the area of plates A will be changed. That way, the effects of different materials will be directly observed at the capacitance value of the capacitor. Using formula 4 and knowing C and C_0, κ can be easily calculated.

Setup of Experiment:

Equipment List:

1) 4 pairs of plates with different areas
2) Aluminium Foil
3) Ruler
4) Multimeter
5) Scientific Calculator
6) Paper block
7) Wood block
8) Foam block

Procedure and Data:

1) Cover the plates with aluminum foil
2) Create four conductors by keeping the distance between the plates constant
3) Using the feature of multimeter, measure the capacitance of every pair of plates while there is air, paper, wood, and foam between the plates, respectively.
4) Plot 3 C vs C graph whose x line is C_{air} and y line is $C_{material}$. (Plot 1.1, 1.2, 1.3)
5) Draw the best line for each graph whose slope should give $\kappa_{\mathrm{material}}$. (y = mx + b ⇔ $C_{material} = \kappa_{\mathrm{material}} * C_{air} + b$)
6) Save dielectric constants to Table 1.2 for later usage.

Table 1.1:

A_n= Area of one plate of nth conductor

C_n = Capacitance of nth conductor filled with given material

Material	$C_1(A_1)$(µF)	$C_2(A_2)$(µF)	$C_3(A_3)$(µF)	$C_4(A_4)$(µF)
Air				
Paper				
Wood				
Foam				

Plot 1.1:

Plot 1.2:

Plot 1.3:

Table 1.2:

Material	Dielectric Constant
Paper	
Wood	
Foam	

Conclusion:

Part B Calculating Capacitance of Half-Filled Capacitor:

Objective:

The purpose of this part of the experiment is to indicate the behaviour of the capacitor when it is partially filled. The distance between the plates will be half-filled in first vertical and then horizontal direction, respectively. The expected result proves that a single partially filled capacitor acts like multiple capacitors connected in series or parallel. The error will be found by comparing the experimental and theoretical results. The result will be the fundamental assumption of Part C.

Theory:

1) $\frac{1}{C_S} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + \cdots$ [2]
2) $C_p = C_1 + C_2 + C_3 + \cdots$ [2]
3) $C = \kappa\, \epsilon_0 \frac{A}{d}$ [1]
4) $V = V_1 + V_2 + V_3 + \cdots$ [2]
5) $V = \frac{Q}{C}$ [2]
6) $C_p V = C_1 V + C_2 V + C_3 V + \cdots$ [2]

(ϵ_0 is the permittivity of free space, A is the area of the single plate in meters, d is the distance between the plates in meters, C_0 is the capacitance of the capacitor filled with vacuum, Q charge, κ dielectric constant, C_s and C_p are total capacitances in series and parallel respectively)

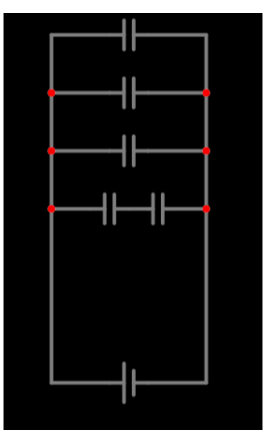

Figure 1

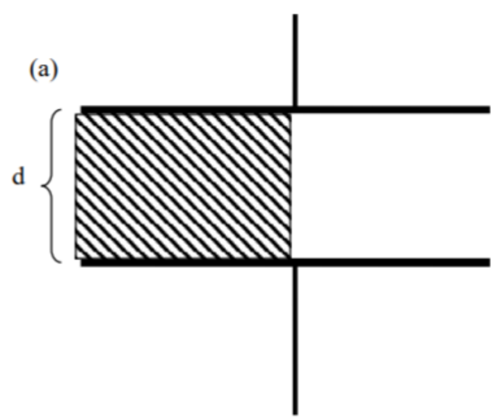

Figure 2

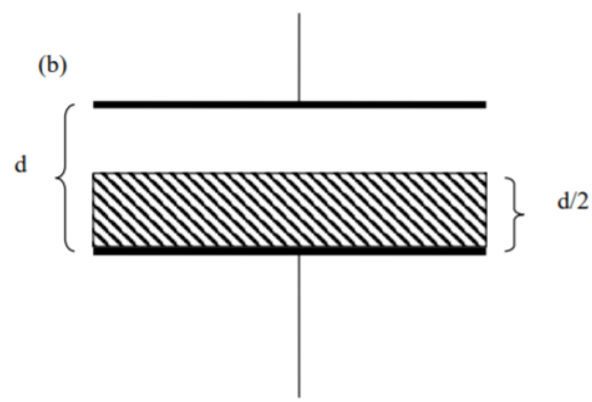

Figure 3

Since capacitances in series share total voltage between them, using formula 4 and 5, one can get formula 1. On the other hand, capacitances in parallel have same voltage values that, writing formula 5 for Q; formula 6 is obtained. Eliminating V from formula 6, formula 2 is received.

For figure 2, since the capacitor plates are at the same potential, the capacitor is similar to two capacitors connected in parallel with half area each.

For figure 3, the inner boundary of the inductor can be thought of as a new plate. Thus, the capacitor is similar to two capacitors connected in series with half the distance between the plates each.

From experimental results, we should get formulas 1 and 2, respectively.

Setup of Experiment:

Equipment List:

1) 1 conductor from the previous part
2) Ruler
3) Multimeter
4) Scientific Calculator
5) Paper block
6) Wood block
7) Foam block

Procedure and Data:

1) For each material:
    a. Insert material as in figure 2
    b. Measure capacitance of the conductor
    c. Calculate theoretical result
    d. Save both theoretical and experimental results in table 2.1
    e. Insert material as in figure 3
    f. Measure capacitance of the conductor
    g. Calculate theoretical result
    h. Save both theoretical and experimental result in table 2.2
2) For each table:
    a. Find errors in every row
    b. Take the average of the errors of three materials values

Table 2.1:

For Capacitances in Series

Material	C_{exp}(μF)	C_{theo}(μF)	Error (%)
Paper			
Wood			
Foam			

Table 2.2:

For Capacitances in Parallel

Material	C_{exp}(μF)	C_{theo}(μF)	Error (%)
Paper			
Wood			
Foam			

E_s = ... %

E_p = ... %

Conclusion:

Part C Calculating Capacitance of Partially Filled Capacitor:

Objective:

This part of the experiment aims to find a general formula for calculating the capacitance of the partially filled capacitor. The experiment will be restricted to partial fullness as in figure 2 (there will be no air between plate and the edge of the insulator). The result of this part is to find linear dependence between partial fullness and capacitance of the capacitor.

Theory:

1) $C_p = C_1 + C_2 + C_3 + \cdots$ [2]
2) $C_1 = (1 - \mathrm{f})\, \mathrm{C}_0$ [3]
3) $C_2 = f\kappa \mathrm{C}_0$ [3]
4) $C(f) = C_0 * (1 - f + f\kappa)$ [3]

(C_0 is capacitance of the capacitor filled with vacuum, κ dielectric constant, C_s and C_p are total capacitances in series and parallel respectively, 0 <= f <= 1)

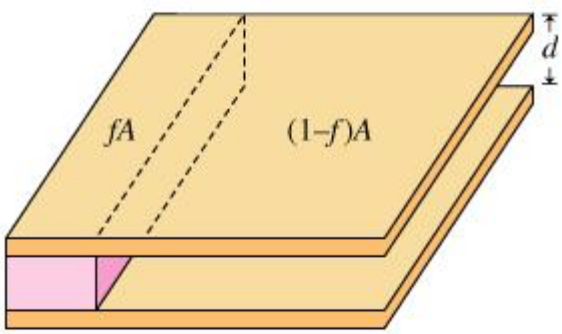

Figure 4

Part B proves that the configuration like Figure 4 divides the capacitor into two capacitors in parallel. For individual parts, the capacitance can be found by multiplying them with the division ratio f (formula 2 and 3). Summing the two leads us to formula 4. Using certain fractions, $C_{theo}(f)$ can be calculated and be compared with $C_{exp}(f)$. Th error will show the correctness of the general formula, formula 4.

Setup of Experiment:

Equipment List:

1) 1 conductor from previous parts
2) Ruler
3) Multimeter
4) Scientific Calculator
5) Paper block
6) Wood block
7) Foam block

Procedure and Data:

1) For each material:
    a. Insert material as in figure 4 by f = next value in table 3.x where x in {1, 2, 3} respectively.
    b. Measure capacitance of the conductor
    c. Calculate theoretical result
    d. Save both theoretical and experimental results in table 3.x
2) For each table:
    a. Find errors in every row
    b. Take the average of the errors of five values
3) Take the average of the errors of three materials

Table 3.1:

Paper

f	C_{exp}(μF)	C_{theo}(μF)	Error (%)
1/20			
1/16			
1/12			
1/8			
1/4			

E_{paper} = … %

Table 3.2:

Wood

f	C_{exp}(μF)	C_{theo}(μF)	Error (%)
1/20			
1/16			
1/12			
1/8			
1/4			

E_{wood} = ... %

Table 3.3:

Foam

f	C_{exp}(μF)	C_{theo}(μF)	Error (%)
1/20			
1/16			
1/12			
1/8			
1/4			

E_{foam} = ... %

E_{avg} = ... %

Conclusion:

References:

[1] "Capacitors and Dielectrics | Physics", Courses.lumenlearning.com, 2022. [Online]. Available: https://courses.lumenlearning.com/physics/chapter/19-5-capacitors-and-dielectrics/. [Accessed: 03- Mar- 2022].

[2] "Capacitors in Series and Parallel | Physics", Courses.lumenlearning.com, 2022. [Online]. Available: https://courses.lumenlearning.com/physics/chapter/19-6-capacitors-in-series-and-parallel/. [Accessed: 03- Mar- 2022].

[3] "Capacitor with Partial Dielectric", openvellum.ecollege.com, 2022. [Online]. Available: Mastering Physics Homework 3 Question 7. [Accessed: 03- Mar- 2022].