Lab 205: Parallel Plate Capacitor

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Course: PHYS 121A 016 **Instructor: Subodh Dahal**

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1. INTRODUCTION

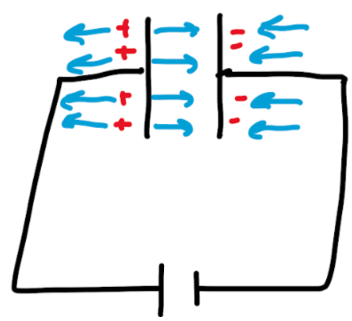
1.1 OBJECTIVES

The objective of this experiment is to use a potentiometer and distance sensor to verify the linear relationship between charge and distance on a parallel plate capacitor, as well as the relationship of dielectrics to capacitors.

1.2 THEORETICAL BACKGROUND

The two parts that made up this lab were capacitors and dielectrics. Capacitors are circuit components which store charges. A capacitor is created when two surfaces of opposite charges are put a distance away from one another, creating an electric field which is able to store a charge. Capacitance can be calculated using the following formula:

$$C = \frac{Q}{V}$$



The unit for Capacitance is the Farad (F), which is equal to Coulombs per Volt. Capacitors have a unique quirk in that they cancel out the outside electric charge since the direction of the internal electric field runs against the electric field of the whole circuit.

Capacitors are dependent on two factors to increase or decrease its effects. The first factor is the area of the plates which has a proportional relationship to capacitance. The second factor is the distance between the two plates, which is inversely proportional. This can be described in the following equation:

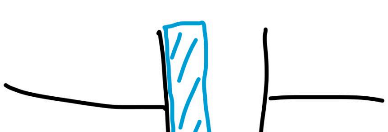
$$C = \frac{\varepsilon A}{d}$$

Capacitors when put into a circuit can either be put in series or in parallel. When in series, they have an inverse relationship, getting the following equation:

$$\frac{1}{C} = \frac{1}{C1} + \frac{1}{C2}... + \frac{1}{Cn}$$

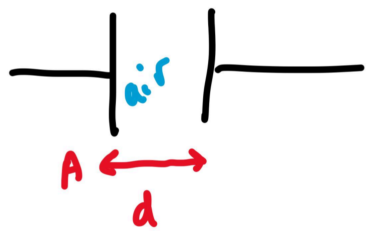
This is in contrast to when capacitors are placed in parallel, whereby they will have the following formula:

$$C = C1 + C2... + Cn$$



The second important concept is that of

dielectrics, which are materials put in the space in between the capacitor plates to create another electric field. It has the effect of reducing the total electric field since the electric field generated internally within the material runs opposite to the electric field from the plates. The material is what determines how much of the electric field is canceled out, which was what part two of the lab was about.

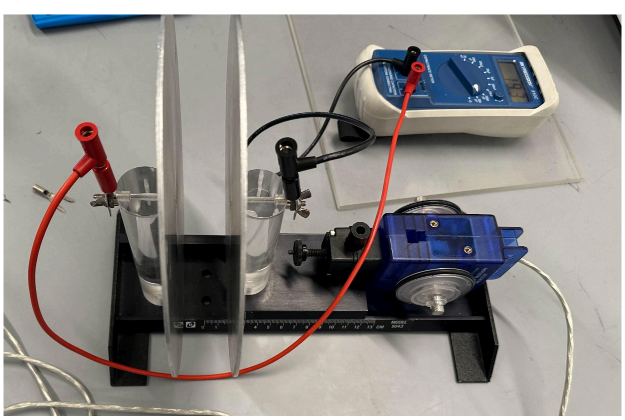


In the figure on the right, we see a diagram for a capacitor with the air acting as a dielectric. This is in contrast to when there is no dielectric, such as when assuming experimentation in a vacuum. The formula for such a situation is mostly the same, with one addition with a constant "k" which is multiplied by ϵ to get the permittivity through a specific material, including that of air. In experiment two, we use glass as a dielectric.

2. **EXPERIMENTAL PROCEDURE**

The capacitance findings might differ from the real capacitance, therefore first and foremost, keep the region surrounding the parallel plate capacitor clean. Use the appropriate banana cables to connect the positive feed and negative feed of the parallel plate capacitor to the positive and negative ports of the LCR meter, respectively, for the first phase of the setup. Aim for 200 pF on the LCR meter. In order to obtain an accurate reading, the parallel plate capacitor's ruler must next be calibrated. To do this, use calipers to measure the thickness of each plate and the starting distance between them.

There were two experiments that made up this lab. In experiment one, our objective was to find the value of ϵ_0 which is a constant value. Using both a digital sensor and capacitance meter, we measured an experimental and theoretical capacitance. a) With the battery attached, compare the charges on the plates when the dielectric is between the plates and when the material is not between the plates in order to compute the dielectric constant. This is the aim of the first lab. b) Comparing the voltage between the plates with and without the dielectric when the battery is removed.

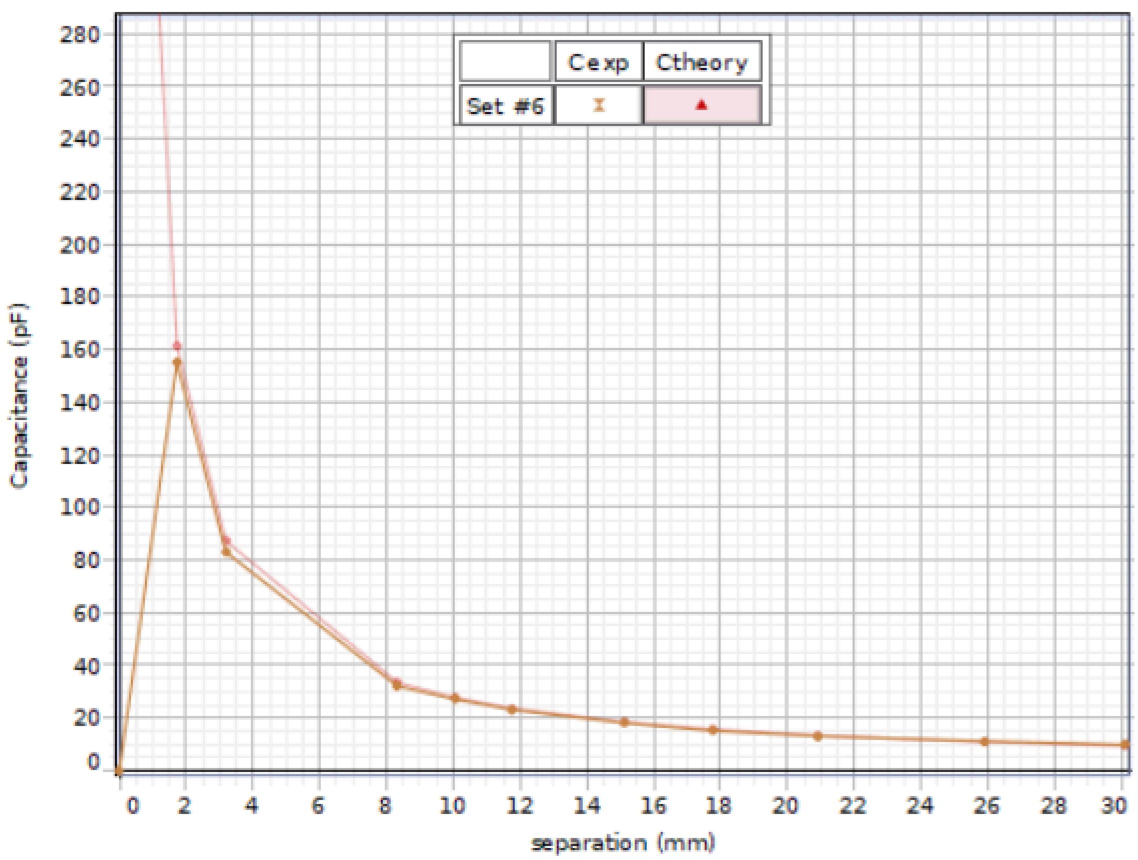


3. **RESULTS**

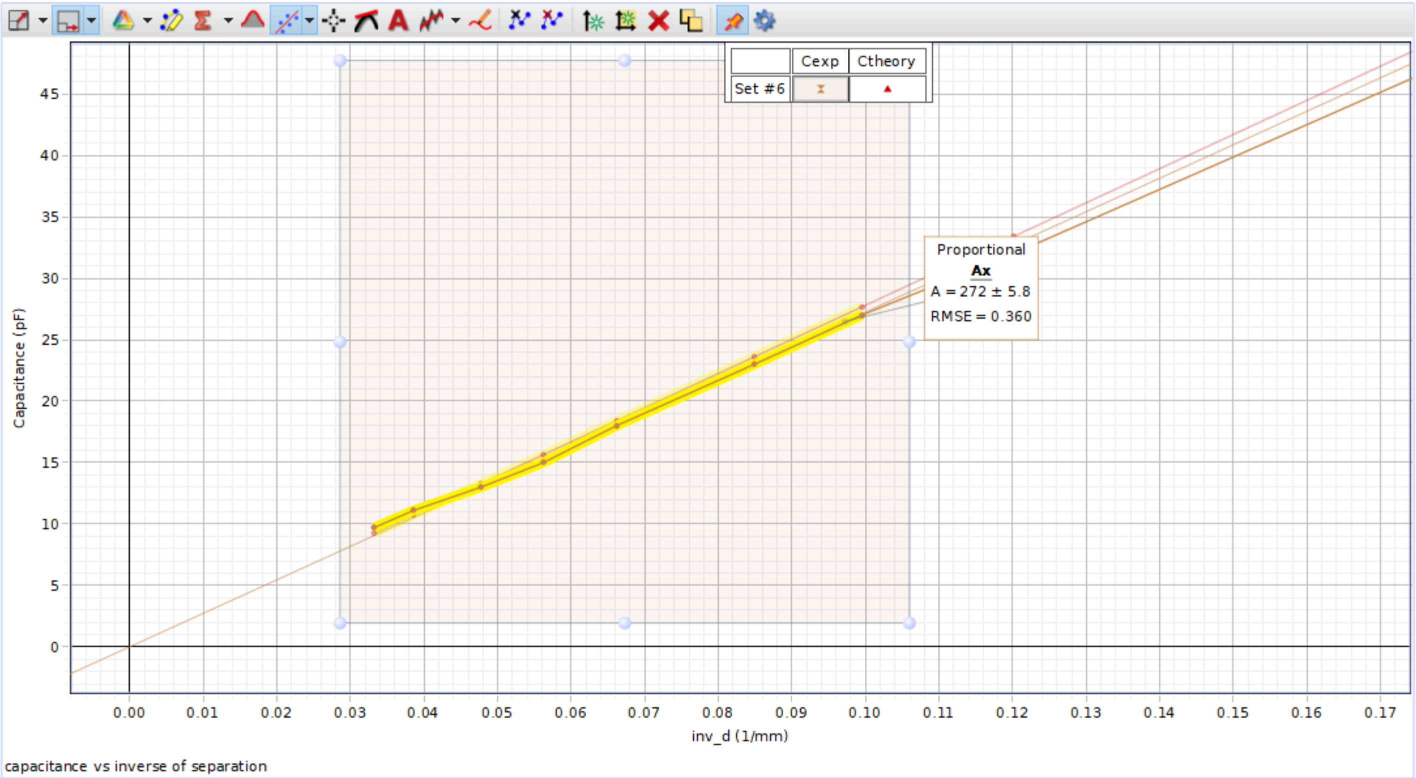
3.1 **EXPERIMENTAL DATA**

Experiment One

#	Separation (mm)	Experimental C (pF)	Theoretical C (pF)
1	0.0000	0.00	∞
2	1.7250	155.00	161.18
3	3.1875	83.00	87.23
4	8.3250	32.00	33.40
5	10.0500	27.00	27.66
6	11.7750	23.00	23.61
7	15.1125	18.00	18.40
8	17.7750	15.00	15.64
9	20.9325	13.00	13.28
10	25.9125	11.10	10.73
11	30.1125	9.70	9.23

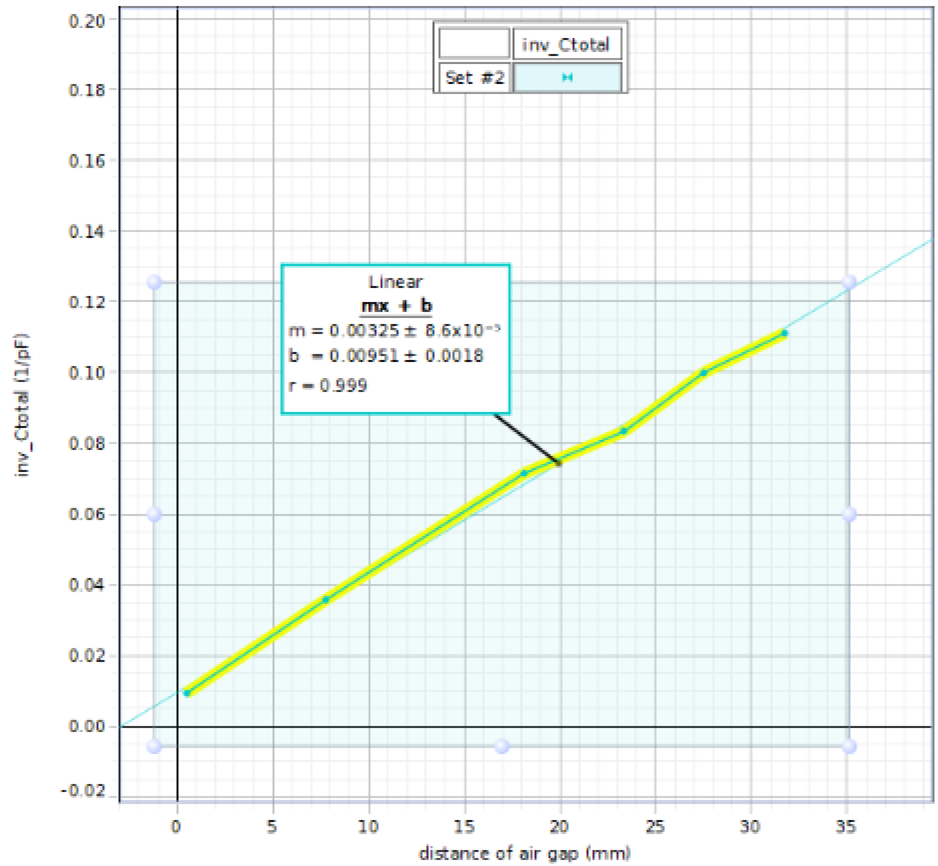


capacitance vs separation



Experiment Two

#	Air Gap (mm)	Total Capacitance (pF)	Inverted C (pF)
1	0.488	107.00	0.0093
2	7.762	28.00	0.0357
3	18.113	14.00	0.0714
4	23.362	12.00	0.0833
5	27.525	10.00	0.1000
6	31.762	9.00	0.1111



Inverse of total capacitance vs. distande of air gap in Part II

3.2 **CALCULATION**

Experiment One

$$m = 272\,pF \times mm = 0.272 \times 10^{-12} Fm$$

$$m = A \times \epsilon 0$$

$$A = \pi(\frac{0.2}{2})^2 m^2$$

$$\epsilon_0 = \frac{m}{A} = \frac{0.272\times10^{-12} Fm}{\pi(0.1)^2 m^2}$$

$$\epsilon_0 = 8.66 \times 10^{-12} \frac{C^2}{Nm^2}$$

Experiment Two

$$b = 0.00951$$

$$b = \frac{\Delta}{k\epsilon A}$$

$$\frac{1}{k} = \frac{b\epsilon A}{\Delta}$$

$$k = \frac{\Delta}{b\epsilon A} = \frac{6.22\times10^{-3} m}{(0.00951 \frac{1}{pF})(8.85\times10^{-12} \frac{C^2}{Nm^2})(\pi(0.1)^2 m^2)}$$

$$k = 2.35$$

4. **ANALYSIS and DISCUSSION**

The set-ups used in this experiment allowed us to empirically determine both the electric permittivity of a vacuum (ϵ_0) and the dielectric constant for an acrylic plate. Both of these experimentally determined values were found to be very close to their accepted values. The empirical ϵ_0 had a percent error of only 2.2% ($8.66 \cdot 10^{-12}$ vs. $8.854 \cdot 10^{-12}$). While the empirical dielectric constant of acrylic was clearly in the ballpark of the accepted value, however, it had a higher percent error of 6% (2.35 vs. 2.5).

A number of factors could have contributed to the error present in the results. The use of a rotary motion sensor to measure the distance the mobile plate was moved, while clever, introduced a number of potential inaccuracies. It was assumed that the wheel was pulled completely parallel to the movement of the plate, and that no slipping of the wheel occurred. If the wheel was pulled at a slight angle or if slippage occurred, this would skew any measurement taken. It also proved difficult to reliably set the zero point of the potentiometer prior to taking measurement; this may also have introduced slight error into the measurements presented. However, the clear similarity between the constants calculated and their expected values suggests that the methods used to collect measurements were carried out fairly accurately.

5. **CONCLUSIONS**

My understanding and visualization of the idea of series and parallel capacitors and how it affects their capacitance have greatly improved thanks to this lab. The dielectric constant and capacitance of several materials were predicted and confirmed by us using the simulations. For the dielectric constants of every material we examined, our predicted values and the actual results agreed almost exactly. Overall, this research on websites and the internet was quite beneficial. I was able to learn more about capacitors and the idea underlying its utilization in this lab. Additionally, the theory behind capacitors and their dependency on the type of insulator and separation distance is applied with the help of Matlab comprehension.

The results of this experiment successfully verify the relationship of the charge stored in a parallel-plate capacitor to the distance between the plates, the area of the plates, the constant ϵ_0, and the presence of any dielectric. Knowing that capacitors are impacted by these factors allows designing capacitors to take on any desired amount of charge given design constraints. This aids in the design of electronic components, as the behavior of capacitors on the current in a circuit makes them useful in controlling current flow predictably. The results presented here, however, are technically limited to capacitors constructed as two large metal plates of equal shape and size separated by some material. It may be of interest to develop more general results that apply to different capacitor types or to all capacitors generally, to better inform their construction and use.

6. **RAW DATA**

Experiment One

$$m = 272 \frac{pF}{mm} = .272 \times 10^{-12} \frac{F}{m}$$

$$m = A \cdot \mathcal{E}_0$$

$$A = \pi \left(\frac{0.2}{2} m\right)^2$$

$$\mathcal{E}_0 = \frac{m}{A} = \frac{.272 \times 10^{-12} \ F/m}{\pi \ (0.1)^2 \ m^2}$$

$$\mathcal{E}_0 = 8.66 \times 10^{-12} \frac{F}{m} = \frac{C^2}{Nm^2}$$

(M is supposed to be F*m, not F/m)

$$\frac{F}{m} = \frac{C}{Vm} = \frac{C}{\frac{J}{C} m} = \frac{C^2}{Jm} = \frac{C^2}{N m^2}$$

Experiment Two

$$b = 0.00951$$

$$b = \frac{\Delta}{k \varepsilon_0 A}$$

thickness

from pt 1

dielectric constant

from pt 1

from pt 1

$$\left(\frac{b \varepsilon_0 A}{\Delta} = \frac{1}{k} \right)^{-1}$$

$$\frac{\Delta}{b \varepsilon_0 A} = k$$

$$k = \frac{(6.22 \times 10^{-3}\ m)}{\left(0.00951 \frac{1}{pF}\right)\left(8.85 \times 10^{-12} \frac{C^2}{Nm^2}\right)\left(\pi (0.1)^2 m^2\right)}$$

$$k = 2.35$$

$$\frac{m}{\frac{1}{pF} \cdot \frac{C^2}{Nm^2} \cdot m^2} = \frac{F\, m N}{C^2} = \frac{\frac{\cancel{C}}{V} m N}{C^{\cancel{2}}} = \frac{mN}{VC} = \frac{mN}{\frac{J}{\cancel{C}} \cancel{C}} = \frac{mN}{mN} = 1$$