Parallel Plate Capacitors

OBJECTIVES

- To define capacitance and to learn to measure it with a digital multimeter
- To discover how the capacitance of conducting parallel plates is related to the separation distance between the plates and the surface area of the plates.
- To determine the dielectric constant for paper

INTRODUCTION

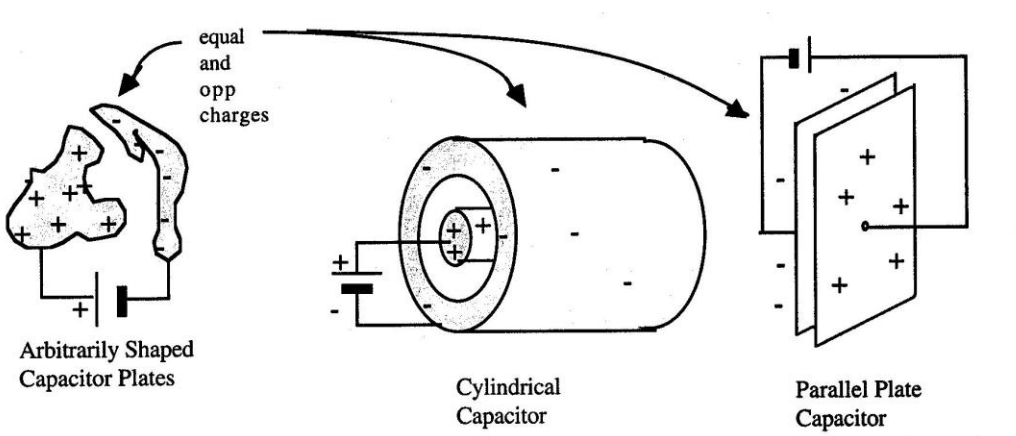
Capacitors are widely used in electronic circuits where it is important to store charge and/or energy or to trigger a timer electrical event. For example, circuits with capacitors are designed to do such diverse things as setting a flashing rate of Christmas lights, selecting what station a radio picks up, and string electrical energy to run an electronic flash unit. Any pair of conductors that can be charged electrically so that one conductor has positive charge and the other conductor has negative charge on it is called a capacitor.

The capacitance of a given capacitor is defined as the ratio of the magnitude of the charge (on either one of the conductors), q, to the voltage (potential difference), V, applied across the two conductors, thus:

$$C = \frac{q}{V} \quad \text{or} \quad C = \frac{dq}{dV}$$

Capacitance is a measure of the amount of net or excess charge on either one of the conductors per unit potential difference. The more charge a capacitor can store at a given voltage, the larger the capacitance.

A capacitor can be made up of two arbitrarily shaped blobs of metal or it can have any number of regular symmetric shapes such as one hollow sphere inside another, or a metal rod inside a hollow cylinder …



The type of capacitor that is easiest to analyze is the parallel plate capacitor. We will focus exclusively on the study of the properties of parallel plate capacitors because the behavior of such capacitors can be predicted using only simple mathematical calculations and basic physical reasoning. Also, parallel plate capacitors are easy to construct.

MATERIALS

- 2 sheets of aluminum foil
- Pages in a "fat" textbook
- Multimeter w/ capacitance mode
- Connecting wires
- Graphical Analysis
- Ruler with centimeter scale
- Vernier caliper or micrometer
- clip leads

PRELIMINARY QUESTIONS (ADDRESS IN THE DISCUSSION SECTION)

1. Capacitance represents the relationship between accumulated charge induced between a set of conductors and the applied potential difference. How would you expect the capacitance for a parallel plate capacitor to change as the area of the plates is increased? Explain your answer.

2. Since capacitance represents a coupling or communication between 2 associated conductors, how would you expect the capacitance between 2 parallel conducting plates to vary as the separation between the plates is increased? Explain your answer.

PROCEDURE

1. Obtain 2 sheets (same size) of aluminum foil. The sheets should be just small enough to barely fit inside your physics textbook (or another "fat" textbook of convenience). Measure the length and width of the sheets then determine their surface area.

Width: ______________

Length: ______________

Surface Area: ______________

2. Place the aluminum sheets inside the "fat" textbook. The sheets should be separated by 2 pages.
3. Record the number of pages between the aluminum sheets (this is the separation distance between the plates in "pages") in Table 1.
4. Place a heavy mass on top of the textbook to press the sheets tightly together (this step is very important for reliable results!).
5. Using the digital multimeter, measure the capacitance. Be sure the multimeter leads do not make contact with each other.
6. Record the measured capacitance in Table 1.
7. Increase the number of pages between the aluminum sheets. Repeat steps 3 through 6 for a total of 5 data points.
8. After you have collected all of your data, open the Graphical Analysis software. Use this program to create a graph of Capacitance vs. Separation Distance.

DATA TABLE 1 (SEPARATION DISTANCE VS. CAPACITANCE)

Separation (# pages)	Separation (m)	Capacitance (F)

9. If your graph looks like a straight line, use the Linear Fit function to obtain a best fit line and the corresponding linear regression equation (with standard deviations for the fit). If the graph does not look linear, try other functional fit equations until you find the best fit.
10. Cut-and-paste the graph, with the calculated curve fit, into Microsoft Word.

    Question: Which function best describes the relationship between separation distance and capacitance?

Question: How do your results compare with your prediction (in the Preliminary Questions) based on physical reasoning?

11. Separate the 2 aluminum sheets by 2-5 pages within the "fat" textbook. *You will keep this distance constant throughout the remainder of this experiment.* Record the number of pages and determine the separation distance between the sheets.

Number of pages: ____________

Separation Distance: ____________

12. Record the length and width of the aluminum sheets in Table 2. Determine the surface area of the sheets. Record this value.
13. Place a heavy mass on top of the textbook to press the sheets tightly together (this step is very important for reliable results!).
14. Using the digital multimeter, measure the capacitance. Be sure the multimeter leads to not make contact with each other.
15. Record the measured capacitance in Table 2.

16. Decrease the surface area of the aluminum sheets (remember the area of both sheets should be the same).
17. Repeat steps 13 through 16 for a total of 5 data points.
18. After you have collected all of your data, open the Graphical Analysis software. Use this program to create a graph of Capacitance vs. Surface Area.

DATA TABLE 2 (SURFACE AREA VS. CAPACITANCE)

Width (m)	**Length (m)**	**Surface Area (m^2)**	**Capacitance (F)**

19. If your graph looks like a straight line, use the Automatic Fit Routine (or Linear Fit Routine) to obtain a best fit line and the corresponding linear regression equation. If the graph does not look linear, try other functional relationships until you find the best fit.
20. Cut-and-paste the graph, with fit, into Microsoft Word. Print out the graphs.

    Question: What function best describes the relationship between surface area and capacitance?

Question: How do your results compare with your prediction based on physical reasoning?

ANALYSIS

The actual mathematical expression for the capacitance of a parallel plate capacitor of plate area, A, plate separation d, and dielectric constant, κ, is derived in your textbook. The result is

$$C = \frac{\varepsilon A}{d} \quad \text{or} \quad C = \frac{\kappa \varepsilon_o A}{d}$$

where $\kappa = \varepsilon/\varepsilon_o$ and ε_o is 8.85×10^{-12} $C/N{\cdot}m^2$. {Note: $\kappa = 1$ for air.}

1. Do your predictions and/or observations on the variation of capacitance with plate area and separation seem to agree <u>qualitatively</u> with this result? Explain.

2. Using the slope value from the C vs. A graph, calculate the dielectric constant, κ.

3. Using the fit constant value from the C vs. d graph, calculate the dielectric constant, κ.

4. What is the average value for κ? Calculate the % range for your κ value.

5. Use one set of the measured values of area, separation distance and average dielectric constant to calculate a value of C using the equation above. Show your calculations.

6. How does the calculated value of C compare with your measured value? Calculate the % Error.