13. CAPACITOR FUNDAMENTALS

STRUCTURED

Driving Question | Objective

How do physical properties of a parallel-plate capacitor affect its ability to store electric charge? Experimentally determine the relationship of the capacitor-plate area and the distance between plates to its ability to store electric charge (capacitance).

Materials and Equipment

- Digital capacitance meter/multimeter, 0.01-nF resolution
- 4-mm banana plug patch cord (2)
- 4-mm banana plug patch cord alligator clip (2)
- Aluminum foil sheets (4), approx. 8 1/2" × 11"
- Paper (6 sheets), 8 1/2" × 11"
- Scissors
- Ruler
- Heavy textbook

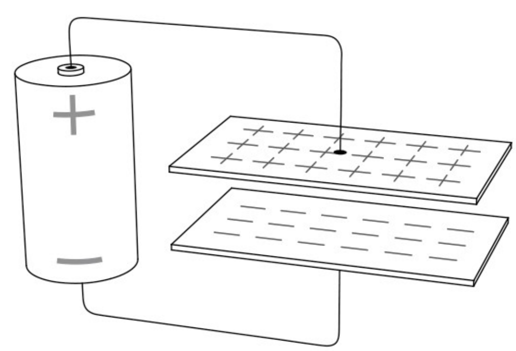
Background

The static electric effects of a Van de Graaff generator, of the laundry taken from the clothes dryer, and of a plastic wrapper pulled off a package are examples of positive and negative charges that have been separated from each other. Electrical potential energy is stored in those separated charges, since work has been done to separate them. Storing potential energy in the form of separated charges in an electric circuit is the function of a capacitor.

When allowed a conducting path, charges that have been separated readily flow back together. Charges in motion have kinetic energy. In a circuit, flowing charges are known as electric current.

The type of capacitor most easily analyzed consists of two parallel conductive plates separated by an insulating material. When a potential difference is applied (by a battery, for instance), the insulating material acts as a barrier to electrons and prevents them from jumping across the plates.

Instead, negative charges, attracted to the positive terminal of the battery, leave one plate with a net positive charge while the other plate is left with a net negative charge due to electrons forced onto the plate by the battery's negative terminal. As more and more electrons "crowd" on the negative plate, it gets more difficult to force them onto the plate. Once the potential difference between the two conductive plates equals the voltage source, electrons no longer flow. At this point, the capacitor is said to be "fully charged."



A 1.5 V battery acts as a source in a circuit with a capacitor.

The potential difference across the conducting wires causes charges to flow until the same potential difference exists across the two parallel plates of the capacitor.

A capacitor is used to separate and store charge that can be discharged through a circuit where it does useful work as electric current. A capacitor's ability to store charge is known as *capacitance* and is dependent on the physical properties of the capacitor. In this investigation you will construct several parallel-plate capacitors using aluminum foil as the plates to investigate how certain physical properties of the capacitor affect its capacitance.

Safety

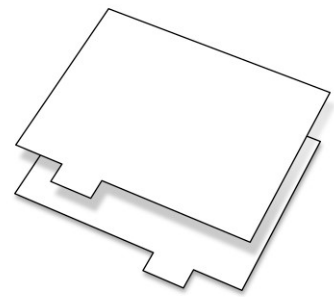
Follow these important safety precautions in addition to your regular classroom procedures:

- Follow the instructions in the user manual to correctly operate the digital multimeter (DMM).
- Use caution when working with sharp objects such as scissors, hobby knives, and serrated cutting edges.

Procedure

Part 1 – Varying the Area of Parallel Conducting Plates

Set Up


Cut sheets with offset tabs to prevent the tabs from touching when stacked.

1. Cut two rectangular sheets of aluminum foil each with dimensions slightly less than the size of a standard sheet of paper. It is important that each piece of foil be the same dimensions.

2. Cut a small tab into one side of each piece of foil. The tab will be used to make an electrical connection. The tabs should be offset from each other so they do not touch.

3. Insert one piece of paper between the two foil sheets. You now have a capacitor with parallel conductive plates separated by an insulator.

   NOTE: Make sure the two foil sheets have no contact with each other.

4. Place one textbook on top of the capacitor to press the layers together so they are flat. Do not cover the tabs with the textbook.

Collect Data

5. Measure the capacitance of the foil capacitor.

   a. Adjust the digital multimeter (DMM) to read capacitance in nanofarads (nF).

   b. Connect the two leads to the appropriate ports of the DMM.

   c. Connect one lead to one of the tabs on the foil sheets and connect the other lead to the other tab.

   d. Record the capacitance of the foil capacitor in Table 1 in the Data Analysis section below.

6. Remove the textbook and use the ruler to measure the dimensions of the foil sheets (excluding the tabs). Record the dimensions in Table 1.

7. Carefully fold each sheet of foil so the area of each sheet decreases by the same factor. For example, make each sheet half of its original area. Be sure not to fold over the foil tabs.

8. Cut the paper to be slightly larger than the capacitor plates. Insert the paper between the plates and use the same textbook to press the layers together.

   NOTE: Do not cover the tabs with the textbook.

9. Measure the capacitance and the dimensions of the foil capacitor. Record all values in Table 1.

10. Repeat the data collection steps three more times, decreasing the area of the capacitor's plates in each trial. Record the capacitance and dimensions for each trial in Table 1.

Part 2 – Varying the Plate Spacing Between Parallel Conducting Plates

SET UP

11. Cut two new rectangular sheets of aluminum foil each with dimensions slightly less than the size of a standard sheet of paper. The sheets should have the same dimensions and they should have offset tabs.

12. Insert one sheet of paper between the two foil sheets, and then place the textbook on top of the capacitor to press the layers together so they are flat. Do not cover the tabs with the textbook.

COLLECT DATA

13. Measure the capacitance of the aluminum foil capacitor with one sheet of paper between the plates. Record the result in Table 2 in the Data Analysis section below.

14. Increase the spacing between the parallel plates by adding a second sheet of paper between them.

15. Measure the capacitance of the foil capacitor and record the results in Table 2.

16. Repeat the data collection steps three more times, increasing the spacing between the parallel plates by adding one sheet of paper in each trial. Record each capacitance value in Table 2.

Data Analysis

Part 1 – Varying the Area of Parallel Conducting Plates

Table 1: Capacitance of a parallel-plate capacitor with varying plate area

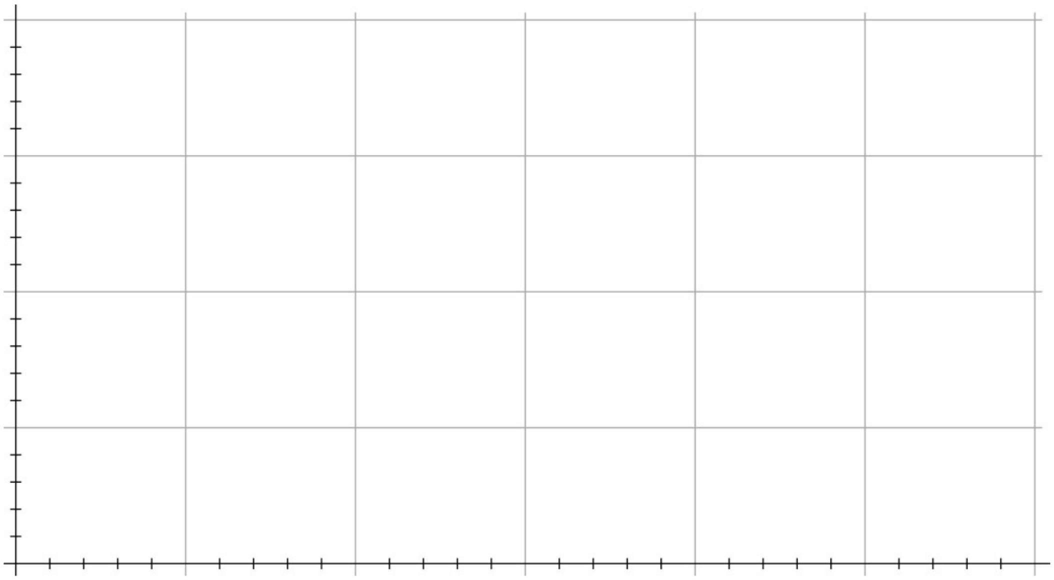
Length (cm)	Width (cm)	Area (cm^2)	Capacitance (nF)

1. Calculate the area of the capacitor plates used in each trial. Record the result for each trial in Table 1.

2. Qualitatively, what happens to the capacitor's ability to store charge (capacitance) as the area of each plate decreases?

3. Plot a graph of *capacitance* versus *area* in the blank Graph 1 axes. Be sure to label both axes with the correct scale and units.

Graph 1: Capacitance versus area for parallel-plate capacitor



4. How are the variables in Graph 1 related to each other mathematically? Use terms such as proportional, inversely proportional, linear, or quadratic in your response.

Part 2 – Varying the Distance between Parallel Conducting Plates

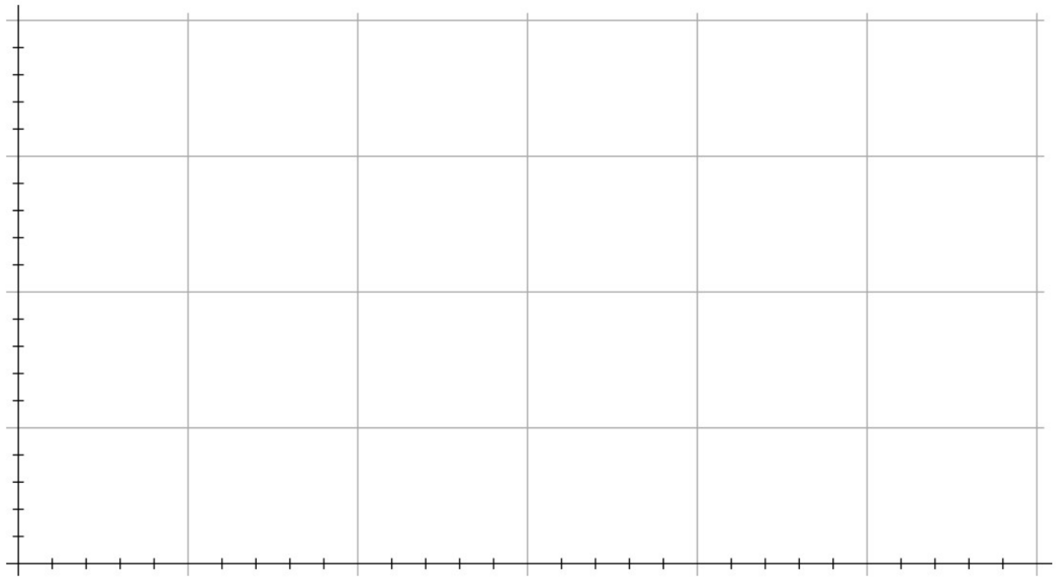
Table 2: Capacitance of a parallel-plate capacitor with varying plate spacing

Plate Spacing (sheets of paper)	Capacitance (nF)
1	
2	
3	
4	
5	

5. Qualitatively, what happens to the capacitor's ability to store charge (capacitance) as the spacing between the plates increases?

6. Plot a graph of *capacitance* versus *plate spacing* in the blank Graph 2 axes. For plate spacing, use the number of sheets of paper as the unit. Be sure to label both axes with the correct scale and units.

Graph 2: Capacitance versus plate spacing for parallel-plate capacitor



7. How are the variables in Graph 2 related to each other mathematically? Use terms such as proportional, inversely proportional, linear, or quadratic in your response.

Analysis Questions

1. Consider the materials you used to make your parallel-plate capacitor. Classify the materials as conductors or insulators and discuss the relative mobility of the electrons in each type of material.

2. What are the physical properties of a capacitor? In this experiment, which of these physical properties did you vary?

3. For each of the properties you varied, what was the effect on the capacitance you measured?

4. Why do you think the change in each of these physical properties changed the capacitance the way it did?

5. The capacitance C for a parallel-plate capacitor is given by the equation:

$$C = \kappa\varepsilon_0 \frac{A}{d} \tag{1}$$

where A is the area of each plate, d is the plate spacing, and κ and ε_0 are constants. How does your data support this definition of capacitance?

6. Consider the configurations you tested. Overall, what combination of conditions would yield the largest value for capacitance? What conditions would yield the lowest value?

Synthesis Questions

1. If you wanted to build a capacitor with twice the maximum capacitance you measured in this experiment, how would you design your new capacitor?

2. The SI unit of capacitance is a derived unit known as the farad (named after Michael Faraday). One farad is defined as one coulomb per volt: 1 F = 1 C/V. Based on the definition of this unit, write an equation that relates capacitance, charge, and potential difference and then solve this equation for charge.

3. An engineer needs a 1.0 μF parallel-plate capacitor with a spacing of 0.050 mm between its plates. She will use the capacitor in the design of a portable electronic device.

   a. What would the area of the plates need to be to make this capacitor? Assume that $\kappa = 1$ and $\varepsilon_0 = 8.85 \times 10^{-12}\ \mathrm{C^2/(N \cdot m^2)}$.

   NOTE: 1 V = 1 J/C

   b. Discuss the practicality of this capacitor in the context of its intended use.

   c. If the portable electronic device is designed to use a 1.5 V battery, what is the maximum charge the capacitor can store?