

Capacitance Physics Lab VI

Objective

In this set of experiments, the properties of capacitors will be explored. In particular, the effect of the distance between the plates on the capacitance of a parallel plate capacitor will be examined. The effect of filling the space of a parallel plate capacitor on the capacitance will also be examined. Finally, the properties of combinations of capacitors (i.e. series and parallel combinations) will be explored.

Equipment List

PASCO Basic Variable Capacitor ES-9079, Multimeter, Various Dielectric slabs (Wood and Plexiglass), Four 1 Farad Capacitors, 2 miniature Light Bulbs, 2 D Batteries, 1 double battery holder (size D), 1 Double Pole/Single Throw switch, 1 digital caliper, 2 Stopwatches, Various connecting leads and alligator clips.

Theoretical Background

When electric charge is placed on an object, the charge on the object will create an electric field. This field will attract or repel other charges around the object. Suppose that charges of equal magnitude and opposite sign were placed on two conducting surfaces (i.e. the positive charge on one surface and the negative charge on the other). Since the charges are on conductors, they will spread out over the surface of the conductor. These oppositely charged plates will be attracted to each other. If the charged plates are held apart, then placing charge on them will cause energy to be stored on them much like energy is stored in lifting a book above a table.

Another way of saying energy is stored on the conductors as more charge is placed on the conductors is to stay that the potential difference, or voltage, between the conductors is increasing. Voltage, V, is the energy stored by placing charges on the conductors, U, divided by the amount of charge placed on the conductors, Q,

$$V = \frac{U}{Q}.$$
 (1)

As more charge in placed on the conductors, the voltage between the conductors increases. The relationship between the amount of charge on the conductors and the voltage between the conductors is known as the *capacitance* of the conductors. The capacitance is the charge on the conductors, Q, divided by the voltage between the conductors, V,

$$C = \frac{Q}{V}.$$
 (2)

Because of the way it is defined, capacitance is independent of the charge or the voltage on the conductors. It depends strictly on geometric properties of the conductors, such as how far apart, what shape they are, or how large they are, as well as various other physical constants. The capacitance tells us what the potential difference between the conductors would be for a given amount of charge placed on two conductors (equal in magnitude and opposite in sign). Alternatively, if the conductors are connected to a battery with a certain voltage, then the capacitance tells us how much charge will flow onto the conductors as a result of being connected to the battery. Since capacitance relates charge to voltage, the capacitance equation is typically written as

$$Q = CV. (3)$$

The simplest type of capacitor would be a set of conducting plates with equal area separated by some distance. The capacitance for this type of capacitor is given by

$$C_{\parallel} = \frac{\epsilon_0 A}{d},\tag{4}$$

where A is the area of the conducting plates, d is the distance between the plates, and ϵ_0 is a constant known as the permittivity of free space. If the area of the plates and distance between the plates is measured in meters, then ϵ_0 is $8.854 \times 10^{-12} C^2 / (Nm^2)$.

In this series of experiments, several properties of parallel plate capacitors, such as the effect of the plate separation on the capacitance and the effect of inserting an insulator between the plates, will be explored. In addition, the effects of combining capacitors in various ways will also be explored.

Procedure and Data Analysis

The Parallel Plate Capacitor

Dependence of Capacitance on Plate Separation

In this portion of experiments, the relationship between the capacitance of a parallel plate capacitor and plate separation will be tested.

1. If it is not already done, attach the variable capacitor (i.e the object with the silver colored plates that is attached to the black rail) to the multimeter. This is done by first attaching leads with alligator clip to metal posts that protrude from the back of each plate. Small wires should be inserted in two holes of the column of small holes on the upper right side of the multimeter (any two holes should work). The leads attached to the capacitor plates should then be attached to the wires

from the multimeter. If you have trouble with this setup, consult with your lab instructor or the lab TA.

2. Measure and record the diameter of the capacitor plate. Calculate record the area of the plate on your data table. Use the following equation:

$$A = \frac{\pi d^2}{4} \tag{5}$$

- 3. Record the theoretical value of the permittivity of free space ϵ_0 on the space provided of your data table. Recall, $\epsilon_0 = 8.854 \times 10^{-12} C^2/(Nm^2)$.
- 4. Set the multimeter to measure capacitance by turning the dial to the 200 pF setting on the multimeter.
- 5. Observe how the capacitance changes as the plate separation is increased and decreased. Record your observations in the space provided.
- 6. Using the caliper, adjust the distance between the plates of the variable capacitor to 5.0 mm. Record the capacitance indicated on the multimeter and the distance between the plates in the space provided. Be sure to convert capacitance measurements to Farads!
- 7. Calculate ϵ_0 experimental using the following equation:

$$\epsilon_{0\,exp.} = \frac{Cd}{A} \tag{6}$$

- 8. Repeat this capacitance measurement for plate separation of 10.0 mm, 15.0 mm, 20.0 mm, and 25.0 mm. Convert separation distances to meters!
- 9. Calculate and record the percent differences between ϵ_0 theo and $\epsilon_0 exp$. Use the following equation:

$$\% \ difference = 100\% \times \frac{Theoretical \ Value \ - \ Experimental \ Value}{Theoretical \ Value}$$
(7)

10. **Graph** the capacitance of the capacitor C as a function of the ratio between the area and the distance of plate separation $\frac{A}{d}$. Draw the best fit line of the data points, and determine the slope and y-intercept of the plot. This graph can be done after all other measurements in this set of experiments have been completed.

Dependence of Capacitance on "Filling"

In this portion of experiments, the effect of filling the space between the plates of a parallel plate capacitor with an insulator will be examined.

- 1. With the capacitor still attached to the multimeter, place the square wood piece into the space between the capacitor plates. Adjust the plate spacing so that the wood completely fills the space between the plates of the capacitor.
- 2. Record the capacitance of the capacitor filled with the wood as C_{filled} .

- 3. Carefully lift the wood from between the plates of the capacitor so that the plate separation is not changed. Record the new capacitance of the capacitor as C_{empty} on the data sheet.
- 4. Repeat this process for the plexiglass sheet.
- 5. After completing these measurements, turn the multimeter off.
- 6. After completing these experiments, calculate the dielectric constant, κ , of wood and plexiglass by dividing the filled capacitance by the empty capacitance of the variable capacitor,

$$\kappa = \frac{C_{filled}}{C_{empty}} \tag{8}$$

Capacitors in Series and Parallel: Capacitors and Light Bulbs

In this portion of this series of experiments, the effects of combining capacitors together will be examined by observing the effect of combinations of capacitors on lighting a light bulb. The capacitors used in this set of experiments will be the large, 1 Farad capacitors.

<u>Note:</u> For this part of the experiment, two properties of the light bulb connected to a set of capacitors will be used:

(1) The length of time the bulb is lit by the combination of capacitors. The longer the bulb remain lit, the larger the total capacitance of the combination of capacitors.

(2) The brightness of the bulb. The brighter the bulb, the larger the stored energy, or voltage, in the combination.





Figure 1: Capacitors in Series Comparison Experiment

- 1. Connect a single capacitor to a light bulb using one side of the switch. Connect two capacitors together and then to the switch and light bulb as indicated in the Figure 1. The capacitor should have a set of dark lines on one side near one of the terminals. This is the negative terminal of the capacitor. Be careful of the polarity of the capacitors; The negative terminal of one capacitor should be connected to the positive terminal of the capacitor next to in the circuit. The two capacitors connected together are said to be connected in *series*.
- 2. Charge the single capacitor (not the two in series) by attaching leads to the battery terminals and then touching these leads to the capacitor. The capacitor should have a set of dark lines on one side near one of the terminals. This is the negative terminal of the capacitor and should be charged with the negative terminal from the battery. The positive terminal on the other side of the capacitor should be charged from the positive terminal of the battery. Hold the two leads from the battery to the capacitor terminal for about 10 seconds, then remove the leads and close the switch. Note how the light bulb is lit up by as the capacitor discharges.
- 3. Open the switch and then charge the single capacitor by connecting the battery terminals to the terminals of the capacitor for about 10 seconds . Be careful about the polarity of the capacitor.
- 4. Charge the two capacitors in series. The capacitors in series should be charged as a group (i.e. <u>not</u> individually). To charge them as a group, connect the positive terminal from the batteries to the positive terminal of one of the capacitors the negative terminal from the batteries to the negative terminal of the <u>other</u> (second) capacitor.
- 5. Close the switch and use the stopwatches provided to time the length of discharge of the capacitors (i.e. how long the light bulbs are lit). Record the discharge time in the space provided. Also record your observations about the relative brightness of the bulbs. Repeat the experiment if necessary.
- 6. Open the switch. Charge each of the capacitors using the battery (as opposed to charging the series combination as a group).
- 7. Close the switch. Observe and record the length of time each bulb remains lit. In addition, observe and record the relative brightness of the two bulbs.
- 8. Open the switch. Insert a third capacitor into the two connected in series. Be careful of the polarity of the capacitors; The negative terminal of one capacitor should be connected to the positive terminal of the capacitor next to in the circuit. Have your lab instructor or a lab TA check your circuit.
- 9. Charge the three capacitors in series. The capacitors in series should be charged as a group (i.e. <u>not</u> individually). To charge them as a group, connect the positive terminal from the batteries to the positive terminal of one of the capacitors the negative terminal from the batteries to the negative terminal of the <u>third</u> (not the middle) capacitor.

- 10. Close the switch and use the stopwatches provided to measure the discharge time of the capacitors (i.e. how long the light bulbs are lit). Record the discharge time in the space provided. Also record your observations about the relative brightness of the bulbs. Repeat the experiment if necessary.
- 11. Open the switch and charge the capacitors individually, rather than as a group. Charge both the series combination and the single capacitor.
- 12. Close the switch and use the stopwatches provided to measure the discharge time of the capacitors (i.e. how long the light bulbs are lit). Record the discharge time in the space provided. Also record your observations about the relative brightness of the bulbs. Repeat the experiment if necessary.

Capacitors in Parallel

1. Connect a single capacitor to a light bulb using one side of the switch. Connect two capacitors together and then to the switch and light bulb as indicated in the Figure 2. The capacitor should have a set of dark lines on one side near one of the terminals. This is the negative terminal of the capacitor. Be careful of the polarity of the capacitors; The negative terminal of one capacitor should be connected to the negative terminal of the capacitor next to it in the circuit. The two capacitors connected together are said to be connected in *parallel*.





Figure 2: Capacitors in Parallel Comparison Experiment

2. Open the switch and then charge the single capacitor by connecting the battery terminals to the terminals of the capacitor for about 10 seconds. Be careful about the polarity of the capacitor.

- 3. Charge the two capacitors in parallel. The capacitors in parallel should be charged as a group (i.e. <u>not</u> individually). To charge them as a group, connect the positive terminal from the batteries to the positive terminal of one of the capacitors the negative terminal from the batteries to the negative terminal of the <u>other</u> (second) capacitor.
- 4. Close the switch and use the stopwatches provided to measure the discharge time of the capacitors (i.e. how long the light bulbs are lit). Record the discharge time in the space provided. Also record your observations about the relative brightness of the bulbs. Repeat the experiment if necessary.
- 5. Open the switch. Charge the capacitors individually, rather than in a group. Charge both the single capacitor and the parallel combination.
- 6. Close the switch and use the stopwatches provided to measure the discharge time of the capacitors (i.e. how long the light bulbs are lit). Record the discharge time in the space provided. Also record your observations about the relative brightness of the bulbs. Repeat the experiment if necessary.
- 7. Open the switch. Connect a third capacitor into the two connected in parallel. Be careful of the polarity of the capacitors; The negative terminal of one capacitor should be connected to the <u>negative</u> terminal of the capacitor next to it in the circuit.**Have your lab instructor or a lab TA check your circuit.**
- 8. Charge the three capacitors in parallel. The capacitors in parallel should be charged as a group (i.e. <u>not</u> individually). To charge them as a group, connect the positive terminal from the batteries to the positive terminal of one of the capacitors the negative terminal from the batteries to the negative terminal of the <u>third</u> (not the middle) capacitor.
- 9. Close the switch and use one of the stopwatches provided to measure the discharge time of the capacitors (i.e. how long the light bulb is lit). Record the discharge time in the space provided. Also record your observations about the relative brightness of the bulbs. Repeat the experiment if necessary.
- 10. Open the switch and charge the three capacitors individually with the battery, rather than as a group. Charge the single capacitor as well.
- 11. Close the switch and use one of the stopwatches provided to measure the discharge time of the capacitors (i.e. how long the light bulb is lit). Record the discharge time in the space provided. Also record your observations about the relative brightness of the bulbs. Repeat the experiment if necessary.

Capacitors in Combination: Complex Case I

1. Connect a single capacitor to a light bulb using one side of the switch. Connect three capacitors together and then to the switch and light bulb as indicated in the Figure 1. The capacitor should have a set of dark lines on one side near one of the terminals. This is the negative terminal of the capacitor. Be careful of the polarity of the capacitors; The negative terminal of one capacitor should be connected to the positive terminal of the capacitor next to in the circuit.



Figure 3: Capacitors in Series Comparison Experiment

- 2. Discuss with your lab group what effect connecting three capacitors as shown in figure 3 would have on the total capacitance using the observations made about the series and parallel combinations. Make a prediction of how the brightness of the bulb and the length of time the bulbs are lit will differ between the single capacitor and the three capacitors wired together and charged as a group. Your predictions should answer the following questions:
 - (a) Does connecting the three together increase or decrease the total capacitance? Remember that a larger capacitance means the light bulb will be lit for a longer period of time. Based on this, will the bulbs go out at the same time, or will one of the bulbs burn longer than the other? If so, why?
 - (b) Will one of the bulbs be brighter than the other? Remember that the brightness of the bulbs is an indication of the energy stored in the capacitors. Is the amount of energy stored the same for the single capacitor and the two capacitors in series, or does one of the configurations store more energy? If so, why?

Briefly summarize your prediction in the space provided. Be sure to include a brief explanation of the your lab groups reasoning about your prediction.

- 3. Open the switch and then charge the single capacitor by connecting the battery terminals to the terminals of the capacitor for about 10 seconds. Be careful about the polarity of the capacitor.
- 4. Charge the three capacitors. These capacitors in should be charged as a group (i.e. <u>not</u> individually). To charge them as a group, connect the positive terminal from the batteries to the positive terminal of one of the capacitors the negative terminal from the batteries to the negative terminal of the <u>other</u> capacitors. If you are unsure how to do this, consult with your lab instructor or lab assistant.

- 5. Close the switch and use the stopwatches provided to time the length of discharge of the capacitors (i.e. how long the light bulbs are lit). Record the discharge time in the space provided. Also record your observations about the relative brightness of the bulbs. Repeat the experiment if necessary.
- 6. Reevaluate your prediction compared with the actual experimental results with of your lab group. In the space provided, briefly summarize the results of your discussion. Check your reevaluation with your lab instructor or with the lab TA.
- 7. Discuss with your lab group what effect connecting three capacitors as shown in figure 3 would have on the total capacitance using the observations made about the series and parallel combinations. Make a prediction of how the brightness of the bulb and the length of time the bulbs are lit will differ between the single capacitor and the three capacitors wired together and *charged individually*. Your predictions should answer the following questions:
 - (a) Does connecting the three together increase or decrease the total capacitance? Remember that a larger capacitance means the light bulb will be lit for a longer period of time. Based on this, will the bulbs go out at the same time, or will one of the bulbs burn longer than the other? If so, why?
 - (b) Will one of the bulbs be brighter than the other? Remember that the brightness of the bulbs is an indication of the energy stored in the capacitors. Is the amount of energy stored the same for the single capacitor and the two capacitors in series, or does one of the configurations store more energy? If so, why?

Briefly summarize your prediction in the space provided. Be sure to include a brief explanation of the your lab groups reasoning about your prediction.

- 8. Open the switch and then charge the single capacitor by connecting the battery terminals to the terminals of the capacitor for about 10 seconds. Be careful about the polarity of the capacitor.
- 9. Charge the three capacitors. These capacitors in should be charged as a individually (i.e. <u>not</u> as a group). To charge them as a individually, connect the positive terminal from the batteries to the positive terminal of one of the capacitors the negative terminal from the batteries to the negative terminal of the <u>same</u> capacitor. Complete this process for all four capacitors in both circuits. If you are unsure how to do this, consult with your lab instructor or lab assistant.
- 10. Close the switch and use the stopwatches provided to time the length of discharge of the capacitors (i.e. how long the light bulbs are lit). Record the discharge time in the space provided. Also record your observations about the relative brightness of the bulbs. Repeat the experiment if necessary.
- 11. Reevaluate your prediction compared with the actual experimental results with of your lab group. In the space provided, briefly summarize the results of your discussion. Check your reevaluation with your lab instructor or with the lab TA.

Capacitors in Combination: Complex Case II

1. Connect a single capacitor to a light bulb using one side of the switch. Connect three capacitors together and then to the switch and light bulb as indicated in the Figure ?? . The capacitor should have a set of dark lines on one side near one of the terminals. This is the negative terminal of the capacitor. Be careful of the polarity of the capacitors; The negative terminal of one capacitor should be connected to the positive terminal of the capacitor next to in the circuit.



Figure 4: Capacitors in Complex Case II Experiment

- 2. Discuss with your lab group what effect connecting three capacitors as shown in figure 4 would have on the total capacitance using the observations made about the series and parallel combinations. Make a prediction of how the brightness of the bulb and the length of time the bulbs are lit will differ between the single capacitor and the three capacitors wired together and charged as a group. Your predictions should answer the following questions:
 - (a) Does connecting the three together increase or decrease the total capacitance? Remember that a larger capacitance means the light bulb will be lit for a longer period of time. Based on this, will the bulbs go out at the same time, or will one of the bulbs burn longer than the other? If so, why?
 - (b) Will one of the bulbs be brighter than the other? Remember that the brightness of the bulbs is an indication of the energy stored in the capacitors. Is the amount of energy stored the same for the single capacitor and the two capacitors in series, or does one of the configurations store more energy? If so, why?

Briefly summarize your prediction in the space provided. Be sure to include a brief explanation of the your lab groups reasoning about your prediction.

- 3. Open the switch and then charge the single capacitor by connecting the battery terminals to the terminals of the capacitor for about 10 seconds. Be careful about the polarity of the capacitor.
- 4. Charge the three capacitors. These capacitors in should be charged as a group (i.e. <u>not</u> individually). To charge them as a group, connect the positive terminal from the batteries to the positive terminal of one of the capacitors the negative terminal from the batteries to the negative terminal of the <u>other</u> capacitors. If you are unsure how to do this, consult with your lab instructor or lab assistant.
- 5. Close the switch and use the stopwatches provided to time the length of discharge of the capacitors (i.e. how long the light bulbs are lit). Record the discharge time in the space provided. Also record your observations about the relative brightness of the bulbs. Repeat the experiment if necessary.
- 6. Reevaluate your prediction compared with the actual experimental results with of your lab group. In the space provided, briefly summarize the results of your discussion. Check your reevaluation with your lab instructor or with the lab TA.
- 7. Discuss with your lab group what effect connecting three capacitors as shown in figure 4 would have on the total capacitance using the observations made about the series and parallel combinations. Make a prediction of how the brightness of the bulb and the length of time the bulbs are lit will differ between the single capacitor and the three capacitors wired together and *charged individually*. Your predictions should answer the following questions:
 - (a) Does connecting the three together increase or decrease the total capacitance? Remember that a larger capacitance means the light bulb will be lit for a longer period of time. Based on this, will the bulbs go out at the same time, or will one of the bulbs burn longer than the other? If so, why?
 - (b) Will one of the bulbs be brighter than the other? Remember that the brightness of the bulbs is an indication of the energy stored in the capacitors. Is the amount of energy stored the same for the single capacitor and the two capacitors in series, or does one of the configurations store more energy? If so, why?

Briefly summarize your prediction in the space provided. Be sure to include a brief explanation of the your lab groups reasoning about your prediction.

- 8. Open the switch and then charge the single capacitor by connecting the battery terminals to the terminals of the capacitor for about 10 seconds . Be careful about the polarity of the capacitor.
- 9. Charge the three capacitors. These capacitors in should be charged as a individually (i.e. <u>not</u> as a group). To charge them as a individually, connect the positive terminal from the batteries to the positive terminal of one of the capacitors the negative terminal from the batteries to the negative terminal of the <u>same</u> capacitor. Complete this process for all four capacitors in both circuits. If you are unsure how to do this, consult with your lab instructor or lab assistant.

- 10. Close the switch and use the stopwatches provided to time the length of discharge of the capacitors (i.e. how long the light bulbs are lit). Record the discharge time in the space provided. Also record your observations about the relative brightness of the bulbs. Repeat the experiment if necessary.
- 11. Reevaluate your prediction compared with the actual experimental results with of your lab group. In the space provided, briefly summarize the results of your discussion. Check your reevaluation with your lab instructor or with the lab TA.

Selected Questions

- 1. Based on your observations of the change in the capacitance of the variable capacitor as the plate separation was increased and decreased, what would you expect the mathematical relationship would be between the two quantities? Explain your reasoning.
- 2. Determine what change, if any would occur when a dielectric is removed from a variable capacitor. Assume the plates are charged by a battery that is then removed so that the charge on the plates of the capacitor remains constant and the plate separation remains fixed. If the quantity changes, indicate how it changes (increases or decreases) and why you think this change occurs. (a) Capacitance of the capacitor. (b) Potential drop across the plates of the capacitor. (c) Electric field between the plates. (Hint: Consider the following relationship for the parallel plate capacitor: Q = CV, $E = \frac{\Delta V}{d}$)
- 3. Determine what change, if any, would occur when a dielectric is inserted into a variable capacitor. Assume the capacitor is connected to a battery, and remains connected to a battery, so that the voltage between the plates of the capacitor remains constant and that the distance between the plates remains fixed. If the quantity changes, indicate how it changes (increases or decreases) and why you think this change occurs. (a) Potential drop across the plates of the capacitor.(b) Capacitance of the capacitor. (c) Charge on the capacitor. (d) Electric field between the plates. (Hint: Consider the following relationship for the parallel plate capacitor: Q = CV, $E = \frac{\Delta V}{d}$)