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Lab 3: Capacitors and Stored Energy

Objective: I will characterize the capacitance of parallel plates with the area and distance between plates by describing the relationships between voltage, charge, capacitance, and potential energy.

In this lab, you will be investigating the capacitance for a parallel plate system. These activities will allow you to gain an understanding of what capacitors are, what they can be used for, and how they are charged. You will be working with 2 simulations:
https://phet.colorado.edu/sims/html/capacitor-lab-basics/latest/capacitor-lab-basics_en.html
https://ophysics.com/em5.html

Pre-lab Questions:

1. How many meters is 1 picometer (pm)?

$$1\ pm = 10^{-12}\ m$$

Tasks

Below is a list of tasks that you must accomplish during this lab. Please summarize your results below as indicated.

1. Start on the "Capacitance" tab of the PhET simulation. Determine how the capacitance changes with plate separation and/or plate area by keeping the voltage constant. You can use raw data or graphs to determine these two relationships.
2. Repeat Task 1, but for determining how the stored energy changes with voltage and capacitance. You can use the voltmeter to get an exact voltage reading. You will need to create both a data table and a graph for this task.
3. Move to the "Light Bulb" tab. Charge the plates by increasing the voltage of the battery. Then, disconnect the plates from the battery. Connect the voltmeter across the light bulb, and then connect the capacitor to the light bulb. Comment on your observations about how the charge and potential difference change: do they increase or decrease? Is the increase/decrease linear or not? Formulate qualitative observations based on one or two trials.
4. *Not required*, but if you are curious on exploring Task 3 farther, check out the oPhysics link!

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Data

Table 1. Table showing how capacitance depends on plate separation and plate area while voltage is kept constant.

Voltage (V)	*Separation(mm)*	*Plate Area (mm^2)*	*Capacitance (pF)*
1.5	*2.0*	*200*	*0.89*
1.5	*5.0*	*200*	*0.35*
1.5	*10.0*	*200*	*0.18*
1.5	*5.0*	*100*	*0.18*
1.5	*5.0*	*300*	*0.53*

Capacitance is proportional to 1/separation but directly proportional to plate area when voltage stays constant.

Table 2. Table showing how stored energy changes with voltage and capacitance

Voltage (V)	*Capacitance (pF)*	*Stored Energy (pJ)*
1.5	*0.30*	*0.33*
1.5	*0.89*	*1.00*
1.5	*0.18*	*0.20*
1.0	*0.30*	*0.15*
0.5	*0.30*	*0.04*

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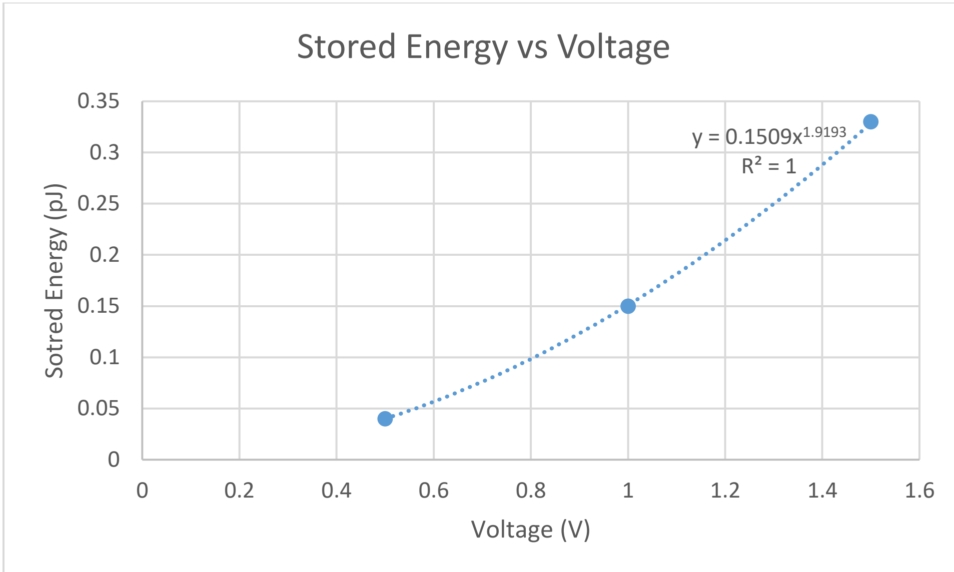

Fig 1. Power regression of stored energy vs voltage, with capacitance remaining constant

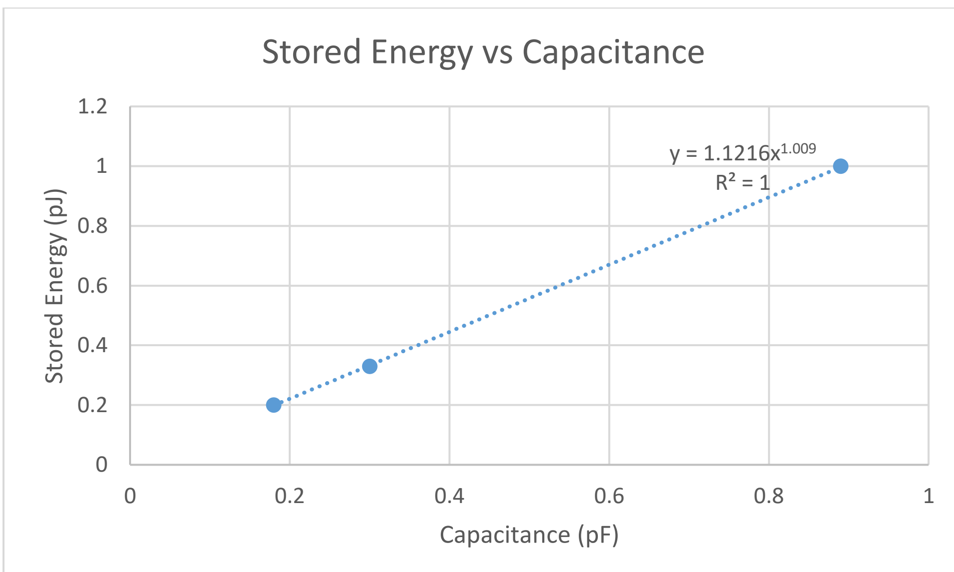

Fig 2. Power regression of stored energy vs capacitance, with voltage remaining constant

Stored energy has a quadratic proportionality with stored energy and a linear proportionality with capacitance.

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Results and Discussion

From task 1, we can see that capacitance is directly proportional to plate area but inversely proportional to separation. This can intuitively be seen from looking at the data without the use of graphs. As voltage and plate area remain constant, the capacitance increases as the separation of the plates decreases, suggesting an inverse proportionality. Moreover, the value of separation times capacitance stays constant, indicating that capacitance is proportional to 1/separation. Similarly, when separation and voltage stay constant, capacitance triples when plate area triples, implying direct proportionality. This correlation can be further verified by the formula $C = \epsilon A/d$.

From task 2, it is clear from the graphs that stored energy is proportional to voltage^2 and directly proportional to capacitance. This is known as in Fig 1, the graph of stored energy vs. voltage gives a power regression of $y = 0.1509x^{1.9193}$ with R^2 of 1, and the graph of stored energy vs capacitance gives a power regression of $1.1216x^{1.009}$ with R^2 of 1. This relation can be further verified as it is known that $U = \frac{1}{2}CV^2$.

As the light bulb is connected, the charge and potential difference both decreases. Energy is used to produce light and is slowly drained out of the system. The decrease is not linear, as the rate at which they both decrease decreases over time. As the system has less and less of a potential difference, less charge moves across the circuit, which means less charge goes through the lightbulb and causes a loss in charge. This loss in charge also contributes to the loss of potential difference, so its rate slows down as well.

In this lab, sources of error are unlikely due to the nature of simulations. However, if this lab was conducted in the real-world other sources of error may be possible. For instance, charge could escape from the system affecting measured values. Alternatively, it is assumed that the air between the capacitors is a perfect insulator, but in the real world that is not always the case.

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Post-lab Questions

1. In your own words, define "capacitance" without using formulas or referencing charge and electric potential/voltage.
   A measurement of how much total energy can be stored in a system.
2. In the first tab you used for this lab, the capacitor charged instantly. However, for the lightbulb, it discharged over time. Which scenario is feasible in the real world given your hypothesis? What might instantaneous charging/discharging represent about the system?
   The second scenario, as in real life, charge doesn't always move at an infinitely fast speed. Instantaneous charging/discharging just means that the system is closed and therefore nothing can affect the system, meaning the "speed" at which the charging is done can be set to be infinitely fast.
3. What might some real world examples of capacitors be?
   Earth's surface and the ionosphere, different types of capacitors used in circuits – dielectric capacitor, mica capacitor, film capacitor, etc - , capacitor for AC, capacitor for microwave.