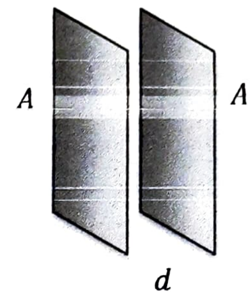
| Section | Group | Name | Signature |
|---|---|---|---|
| | 6 | | |
| Grade | | | |
| | | Jacob Hawkins | [illegible] |

**Materials:** • *Web browser*

**After this activity you should know:** • *capacitance of a parallel plate capacitor.* • *potential energy stored in a capacitor.* • *how a capacitor charges* •. *how to find the power dissipated by a circuit element.* • *the meaning of dielectric strength and dielectric breakdown.*

1. **Parallel Plate Capacitor** is a capacitor with an especially simple geometry consisting of identical flat plates arranged parallel to each other and separated by a gap. We will use a PhET simulation to explore the properties of a parallel plate capacitor.




   a. Goto https://phet.colorado.edu/sims/html/capacitor-lab-basics/latest/capacitor-lab-basics_en.html. Double click on the light bulb on the right.

   You should now be in the PhET capacitor simulation. Click on "Top Plate Charge" and "Stored Energy" to show bar graphs of the charge on the top plate and the electrical potential eneryg stored in the capacitor. Click on "Electric field" so you can view the electric field lines between the capacitor.

   b. Click on and slide the titled green arrow to increase the area of the plates. What happens to the capacitance of the capacitor, i.e., does it increase, decrease, or is unchanged?

   Increases

   c. Use the vertical green arrow to increase the gap between the plates. What happens to the capacitance?

   decreases

   d. Return the plate area to its smallest value. Move the voltmeter leads so the red lead touches the top capacitor plate and the black lead touches the bottom capacitor plate. The voltmeter reads the voltage difference between the red and black leads: $V_{reading} = V_{red} - V_{black}$

   Use the yellow slide bar to increase the voltage of the battery. What happens to the charge on the top plate, the electric field between the plates, the voltage across the capacitor, the capacitance, and the energy stored in the capacitor as you increase the battery voltage? (Determine whether each quantity increases, decreases, or is unchanged.)

| | |
|---|---|
| $Q$ | Increases |
| $\|\vec{E}\|$ | Increase |
| $\Delta V$ | Increase |

| | |
|---|---|
| $C$ | Increases |
| $U_E$ | Increases |
| | |

e. Set the battery at is maximum voltage. Increase the area of the capacitor. What happens to above quantities as you increase the area?

| | |
|---|---|
| $Q$ | Increases |
| $\|\vec{E}\|$ | ~~const~~ ~~constant~~ Increase |
| $\Delta V$ | constant |

| | |
|---|---|
| $C$ | Increases |
| $U_E$ | ~~Increase~~ Increase |
| | |

f. Now with the area fixed, increase the gap between the plates. What happens to the above quantities as you increase the gap size? *You may need to move the voltmeter probes to make sure they maintain contact with the top and bottom plate.*

| | |
|---|---|
| $Q$ | decreases |
| $\|\vec{E}\|$ | decrease |
| $\Delta V$ | same |

| | |
|---|---|
| $C$ | decreases |
| $U_E$ | decrease |
| | |

g. Why did the voltage difference across the capacitor not change in the last two experiment (e) and (f)?

The Battery was a constant Voltage

h. Return the gap size and area to their minimum values. At the top of the circuit is a switch (black circles). Move the switch to the middle position so that the capacitor is no longer connected to the battery. Make sure the voltmeter leads are touching the top and bottom capacitor plates. Change the voltage of the battery. Why is the voltage across the capacitor not affected?

The plates aren't connected to the Battery

i. Increase the gap size. What happens to the following quantites when the gap size increases? *You may need to move the voltmeter probes to make sure they maintain contact with the top and bottom plate.*

| | |
|---|---|
| $Q$ | ~~[illegible]~~ ~~constant~~ constant |
| $\|\vec{E}\|$ | ~~[illegible]~~ constant |
| $\Delta V$ | Increases |

| | |
|---|---|
| $C$ | Decrease |
| $U_E$ | Increases |
| | |

j. Why did the charge remain the same in this case?

No new charge was added/subtracted.

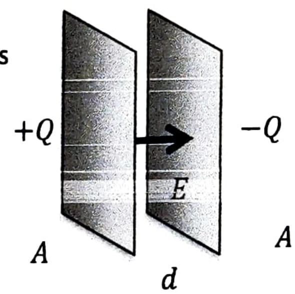
k. Now throw the switch over to the right so the capacitor is connected to the light bulb. How does the capacitor discharge, i.e., where do the charges go?

The charges flow from the bottom (negative) plate through the circuit to the positive plate

l. What happens to the energy stored in the capacitor as the capacitor discharges through the light bulb?

It is converted into light and heat.

2. **Capacitance of a Parallel Plate Capacitor.** We will now derive the capacitance of a parallel plate capacitor. We will do so by assuming a charge $Q$ and $-Q$ on the plates and then determining the voltage difference in terms of $Q$. The ratio will give the capacitance.




a. Assume a charge $Q$ on plates of area $A$ with a gap of width $d$. What is the magnitude of the electric field across the plates in terms of $Q$, $A$, $d$ and physical constants?

$$2 \cdot \frac{Q}{A\epsilon_0}$$

b. Since the electric field is uniform, it is easy to determine the voltage difference between the plates. What is the magnitude of the voltage across the plates $\Delta V_c$ in terms of $Q$, $A$, $d$ and physical constants?

$$\Delta V = E d = \cancel{2} \cdot \frac{Q}{2 \cancel{A} \epsilon_0} \cdot d$$

c. Use $C = Q/\Delta V_c$ to determine the capacitance of a parallel plate capacitor.

$$\frac{Q}{\cancel{2} Q d} \cdot 2A\epsilon_0 = \frac{2A\epsilon_0}{\cancel{2} d}$$

*Check that this expression is consistent with your first set of simulation experiments 1b and 1c.*

d. What happens to the capacitance of this capacitor if you double the charge on the capacitor? Please explain your answer.

Nothing, the capacitance does not rely on charge.

e. What happens to the capacitance if you triple the area and double the gap width?

$\frac{3}{2} \cdot C$

3. **Energy stored in a capacitor:** One application for capacitors is to store energy. Capacitors have the advantage over batteries in that they can deliver charge must faster than batteries can and also can be charged and discharged many more times than rechargeable batteries before degrading.

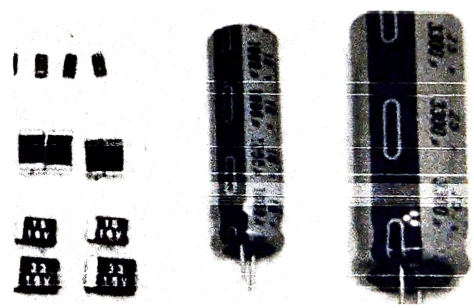
   The stored electrical potential energy is:

$$U = \frac{1}{2} Q \Delta V_c = \frac{1}{2} C (\Delta V_c)^2.$$

   What is the energy stored in a capacitor with capacitance of 8 $mF$ and a voltage difference of 12 V?

$\frac{1}{2}(0.008F)(12)^2 = 0.576 J$

4. **Dielectric Breakdown**. Capacitors are labeled with their capacitance (3300µF, 1000µF, etc) and a breakdown voltage (25V, 16V, etc). This is the maximum voltage that can be placed on the capacitor. If voltage exceeds the breakdown voltage, the electric field in the insulating gap may cause some electrons in the insulator to become mobile making the material a conductor. This leads to a spark across the gap and damage to the capacitor. The electric field at which an insulating material breaks down is called the dielectric strength.



   The dielectric strength of humid air is 1,500,000 $V/m$. Assume a lightning strikes occurs from the bottom of a cloud at 500 m to the ground. What is the voltage difference between the cloud and the ground? Treat the electric field as uniform betwen the cloud and the ground.

$1{,}500{,}000 \frac{V}{m} \cdot 500 m \approx 7.5 \cdot 10^8 V$