Chapter 26

Capacitance and Dielectric

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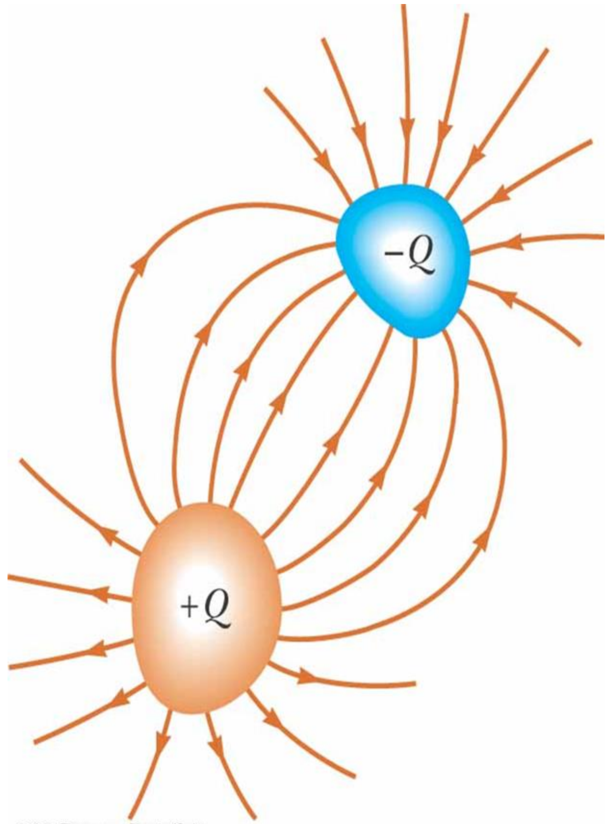
26.1 Definition of capacitance

PhET Capacitor Lab: Visualize Charging, Voltage, Capacitance, and Electric Fields

https://phet.colorado.edu/sims/html/capacitor-lab-basics/latest/capacitor-lab-basics_en.html



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In the front figure, you can see two conductors. Such a system is called a capacitor. Due to the different charges on the two plates, a difference in potential ΔV exists between the two plates. It has been found that,

$$q \propto \Delta V$$

So, $$q = C \ \Delta V \qquad 26.1$$

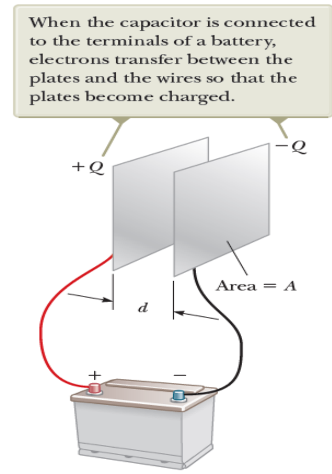
Where C is the capacitance. The capacitance is defined as the ratio between the charge and the difference potential.

$$C = \frac{q}{\Delta V}$$

The unit of the capacitance is Farad (F). In practical, the devices have capacitance ranging from microfarad ($\mu F = 10^{-6}$ F) to picofarad ($pF = 10^{-12}$ F).

How a capacitor charges when connected to a battery.

Step 1: Connecting the Capacitor to a Battery



- A capacitor consists of **two conductive plates** separated by an **insulating material** (dielectric).
- When the capacitor is **connected to a battery**, one plate is linked to the **positive terminal**, and the other plate is linked to the **negative terminal** through conducting wires.

Step 2: Battery Creates an Electric Field

- The battery maintains a **potential difference (voltage, V)** between its terminals.
- This creates an **electric field** inside the wires, pushing **free electrons** to move.

Step 3: Electron Movement from the Negative Terminal

- Electrons from the **negative terminal** of the battery move through the wire **toward one plate** of the capacitor.
- As electrons accumulate, this plate **gains a negative charge**.

Step 4: Electron Removal from the Positive Plate

- At the same time, the **battery pulls electrons** away from the **other plate**, leaving it with a **positive charge**.
- The removal of electrons is driven by the attraction of positive ions inside the battery.

Step 5: Charge Accumulation and Electric Field Formation

- As the capacitor charges, the **potential difference** between its plates **increases**, opposing further electron flow.
- Inside the capacitor, an **electric field** forms **between the plates**, storing **electrostatic energy** in the dielectric material.

Step 6: Charging Stops When Equilibrium is Reached

- The capacitor continues charging until its voltage **matches the battery's voltage**.
- At this point, **no more current flows**, and the capacitor is **fully charged**.
- The charge stored is given by **Q=CV**, where:

- Q is the charge,
- C is the capacitance,
- V is the battery voltage.

Comments:

- **A capacitor does not "store" electrons**, but rather **separates charge** across its plates.
- **Electrons flow through the wires but do not pass between the plates** due to the dielectric.
- **Energy is stored in the electric field** between the plates, which can later be discharged to power a circuit.

Example 1: A capacitor stores charge Q at a potential difference ΔV. What happens if the voltage applied to the capacitor by a battery is doubled to 2ΔV?

(a) The capacitance falls to half its initial value, and the charge remains the same.
(b) The capacitance and the charge both fall to half their initial values.
(c) The capacitance and the charge both double.
(d) The capacitance remains the same, and the charge doubles.

26.2 Calculating Capacitance

❖ Parallel-plate capacitors:

In the figure, two parallel plates carry different types and equal charges (±Q) and are separated by a distance d. As we discussed in chapter 24, the surface charge σ is $\frac{q}{A}$. Then, the electric field between the two plates is given by:

$$E = \frac{\sigma}{\varepsilon_0} = \frac{q}{\varepsilon_0 \ A} \qquad 26.2$$

Also, the electric potential can be written as,

$$V = \int_0^d E \ dx = E \ d \qquad 26.3$$

Comparing Eq. (26.2) and (26.3), we can derive an expression for the capacitance of the parallel-plate as follows,

$$V = \frac{q}{\varepsilon_0 \, A} d = \frac{d}{\varepsilon_0 \, A} q \qquad 26.4$$

$$q = \frac{\varepsilon_0 \, A}{d} V$$

==➔ $$C = \frac{\varepsilon_0 \, A}{d} \qquad 26.5$$

Then, the capacitance of the parallel plate depends on:

1- **The distance between the two plates,**
2- **The area of each plate, and**
3- **The material between the two plates.**

Example-2

A parallel-plate capacitor with air between the plates has an area $A = 2.00 \times 10^{-4}$ m^2 and a plate separation $d = 1.00$ mm. Find its capacitance.

Example-3

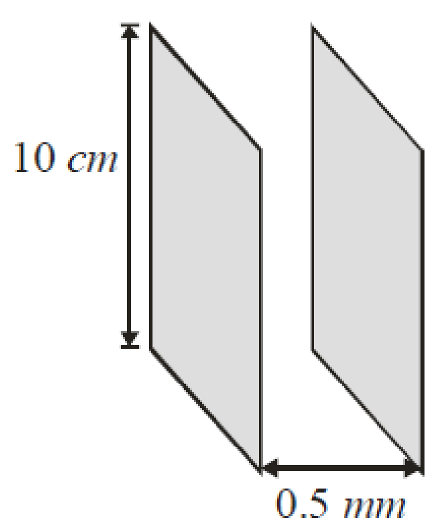
An air-filled capacitor consists of two parallel plates, each with an area of 7.60 cm^2, separated by a distance of 1.80 mm. A 20.0 V potential difference is applied to these plates. Calculate (a) the electric field between the plates, (b) the surface charge density, (c) the capacitance, and (d) the charge on each plate.

Example-4:

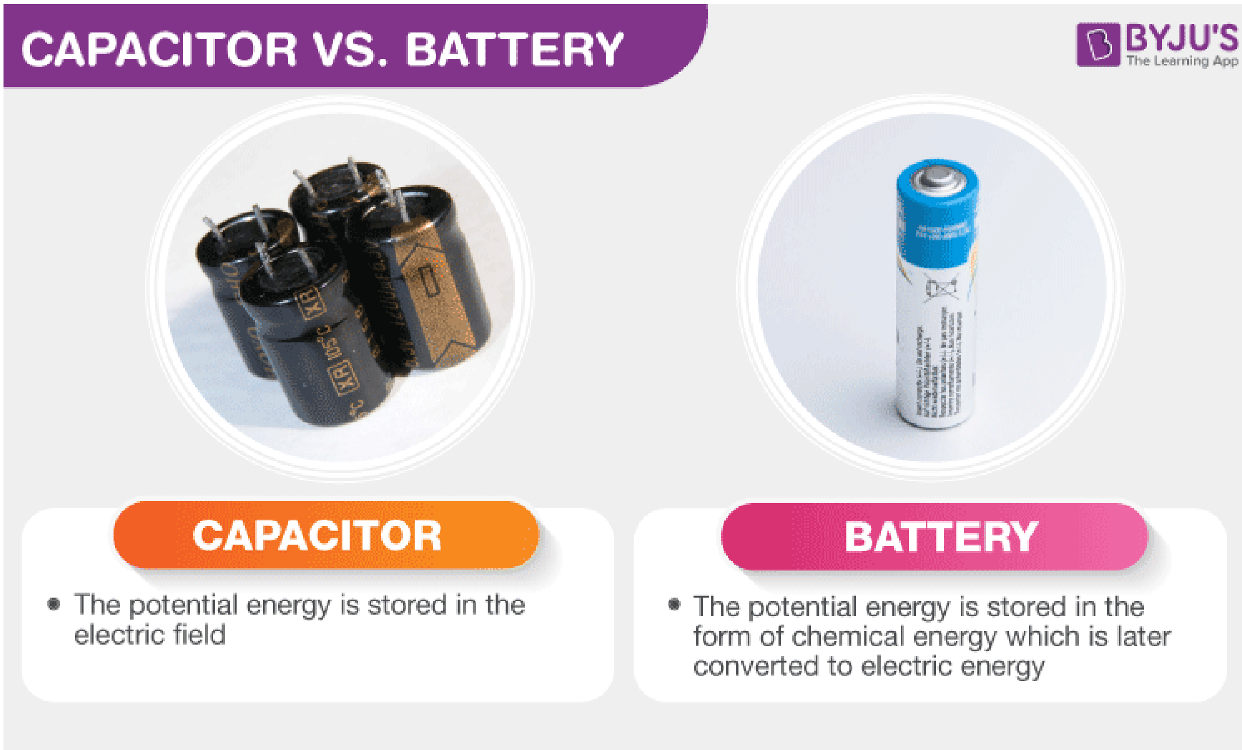
When a potential difference of 150 V is applied to the plates of a parallel-plate capacitor, the plates carry a surface charge density of 30.0 C/m^2. What is the spacing between the plates?

Example-5:

What is the capacitance of the capacitor shown below, knowing that the plates are square in shape?



Think about it: What is the difference between a battery and a capacitor?



Think about it !!

How Can Capacitors Significantly Reduce Costs and Improve Train Efficiency?

Think about it: Why are multiple capacitors used in electric circuits?