23 Capacitors

23.1 Capacitance

A **capacitor** is a device designed to store charge.

Two parallel metal plates placed near each other form a capacitor.

- When the plates are connected to a battery, electrons move through the battery.
  - Electrons are forced from the negative terminal of the battery onto one of the plates.
  - An equal number of electrons leave the other plate to return to the battery via its positive terminal.

  So each plate gains an **equal and opposite charge**.
- When we say the charge stored by the capacitor is Q, we mean one conductor stores charge $+Q$ and the other conductor stores charge $-Q$.

Charging at Constant Current

This can be achieved using a **variable resistor**, a switch, a microammeter, and a cell in series with the capacitor.

- When the switch is closed, the variable resistor is continually adjusted to **keep the microammeter reading constant**.
- At any given time t after the switch is closed, the charge Q on the capacitor.

$$Q = It$$

The **capacitance** C of a capacitor is defined as the **charge stored per unit pd**.

The unit of capacitance is the **farad** (F), equal to one coulomb per volt.

$$C = \frac{Q}{V}$$

23.2 Energy Stored in a Charged Capacitor

When a capacitor is charged, energy is stored in it because electrons are **forced onto one of its plates** and taken off the other plate. This energy is stored in the capacitor as **electric potential energy**.

1. To increase the charge on the plates by a small amount Δq from q to $q + \Delta q$. The energy stored ΔE in the capacitance is equal to the work done to force the extra charge onto the plate.
$$\Delta E = v\Delta q$$
2. $v\Delta q$ is represented by the area of the vertical strip of width Δq and height v under the line. Therefore the area of this strip represents the work done ΔE in this small step.

3. **Consider all the steps** from zero pd to the final pd V, the total energy stored is obtained by adding up the energy stored in each small step.

   E is represented by the total area under the line from zero pd to pd V, which is a triangle of height V and base length Q.

$$\begin{aligned}\text{Energy stored by the capacitor } E &= \frac{1}{2}QV \\ &= \frac{1}{2}CV^2 \\ &= \frac{1}{2}\frac{Q^2}{C}\end{aligned}$$

Energy in a Thundercloud

The thundercloud and the Earth below are like a pair of charged parallel plates.

1. Because the thundercloud is charged, an electric field exists between the thundercloud and the ground - the potential difference between the thundercloud and the ground is $V = Ed$.
2. For a thundercloud carrying constant charge Q.

$$E = \frac{1}{2}QV = \frac{1}{2}QEd$$

3. If the thundercloud raise up to a new height d', the new energy stored

$$E = \frac{1}{2}QEd'$$

4. The **increase in energy**

$$\Delta E = \frac{1}{2}QEd' - \frac{1}{2}QEd = \frac{1}{2}QE\Delta d$$

   where $\Delta d = d' - d$.

The energy stored increases because **work is done** by the force (of wind) to overcome the electrical attraction between the thundercloud and the ground. To make the charged thundercloud move away from the ground.