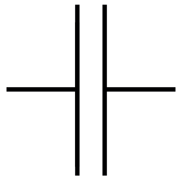
GCE Physics Unit 4.1 Capacitance

Capacitor:



A capacitor consists of two parallel conducting plates, separated by an insulator.

A capacitor is used to store energy. When there is no p.d. across the capacitor the plates are neutral and they have an equal number of electrons and positive ions. When a p.d. is applied to the plates, electrons are forced to move and the plates acquire equal and opposite charge. This stores energy until the electrons can flow back.

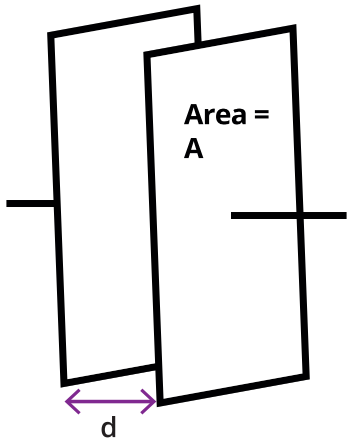
Capacitance:

$$\text{Capacitance} = \frac{\text{charge on a plate}}{\text{pd between plates}} \qquad C = \frac{Q}{V}$$

It is measured in units of F but more commonly will be given in μF or nF.

If the insulator separating the plates is a vacuum or air, the capacitance can be calculated using the following equation.

$$\boldsymbol{C = \frac{\varepsilon_o A}{d}}$$



Where ε_o is the permittivity of free space $= 8.85 \times 10^{-12}$ F m^{-1}.

The area required for a practical value of capacitance is very large, even when d is only a fraction of a mm. Therefore, instead of air or a vacuum a **dielectric** is used. This is an insulating material which **increases the capacitance without changing the dimensions**.

As one plate is positive and the other negative an **electric field** is created in the gap. (see unit 4.2) The strength of this E field can be calculated using this equation:

$$E = \frac{V}{d}$$

Energy:

An important difference to note is that the capacitor does not store charge, as the combined charge of both plates is 0, but it does store energy.

The energy can be calculated using this equation:

$$U = \frac{1}{2}QV$$

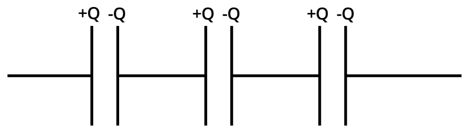
Combining this with the equation for capacitance gives two other equations for energy.

$$U = \frac{1}{2}CV^2 = \frac{Q^2}{2C}$$

Combining capacitors:

Series

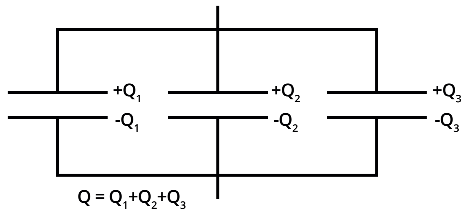
In series, the pd of the supply is shared (not always equally) across the capacitors but the charge on each capacitor is equal. This gives the following equation to calculate the total capacitance.



$$\boldsymbol{\frac{1}{C_{Total}} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + \cdots}$$

Parallel

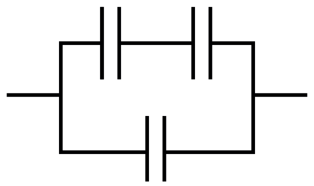
In parallel the pd across each capacitor is equal but the charge will be shared.



This gives the following equation:

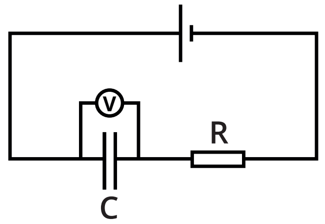
$$\boldsymbol{C_{Total} = C_1 + C_2 + C_3 + \cdots}$$

There may be examples where the total capacitance of a combination of series and parallel must be calculated.

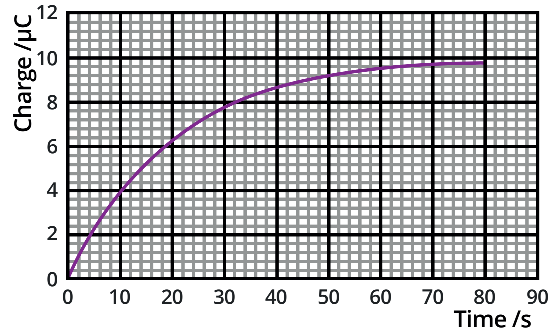


Charging:

When charging a capacitor, a current flows effectively causing electrons to move from one plate to the other.



This graph shows the how the charge increases when charging the capacitor.



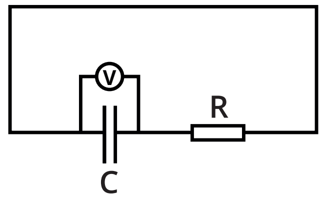
As Q ∝ V, the graph for p.d. will be the same shape.

This equation can be used to calculate Q at a time t.

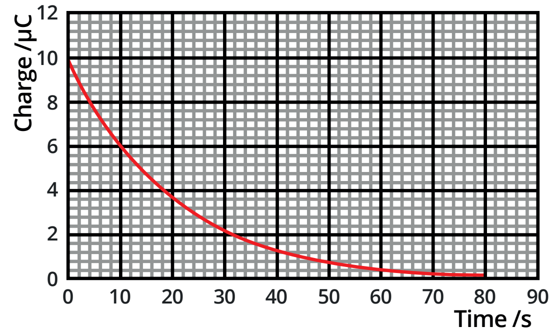
$$Q = Q_o\left(1 - e^{-\frac{t}{RC}}\right)$$

Discharging:

When discharging, the current will flow the opposite direction, effectively moving the electrons back.



This graph shows discharging a capacitor.



This equation can be used to calculate Q at a time t when discharging.

$$Q = Q_o\left(e^{-\frac{t}{RC}}\right)$$

RC is known as the **time constant**, τ. This is the time for the charge to decrease to $^1/e$ = 37% of its original value.

C = capacitance in Farad (F) | V = potential difference in V | I = current in A | R = resistance in Ω | U = energy in J

Q = charge in C | d = plate separation in m | t = time in s | E = electrical field strength in V m^{-1}