

Capacitors

Capacitance

The capacitance of an object is the amount of charge it is able to store per unit potential difference across it.

Capacitance is measured in farads

1 farad (F) = 1 coulomb per volt (CV⁻¹)

$C = \text{capacitance in F} \rightarrow C = \frac{Q}{V}$

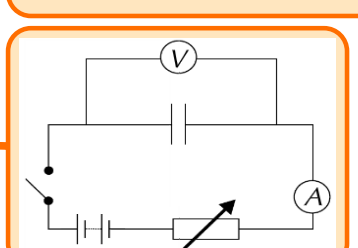
$Q = \text{charge in C}$
 $V = \text{potential difference in V}$

Investigating V and Q

$C = Q/V$
 $Q = CV$
Q is directly proportional to V

Experiment

Charge a capacitor using a constant current.



Permittivity

Permittivity is a measure of how difficult it is to generate an electric field in a medium.

The higher the permittivity of a material, the more charge is needed to generate an electric field of a given size.

Relative Permittivity

is the ratio of the permittivity of a material to the permittivity of free space

$\epsilon_r = \text{relative permittivity of material 1} \rightarrow \epsilon_r = \frac{\epsilon_1}{\epsilon_0}$

$\epsilon_1 = \text{permittivity of material 1 in Fm}^{-1}$
 $\epsilon_0 = \text{permittivity of free space} = 8.85 \times 10^{-12} \text{ Fm}^{-1}$

Sometimes called the dielectric constant.

Polar molecules

Permittivity can be explained by the motion of the molecules inside a dielectric.

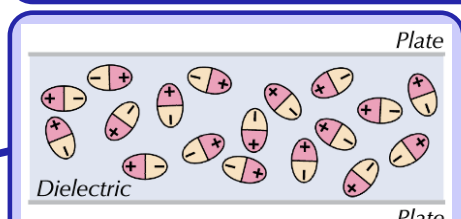


Figure 1: The alignment of molecules in a dielectric when no electric field is present.

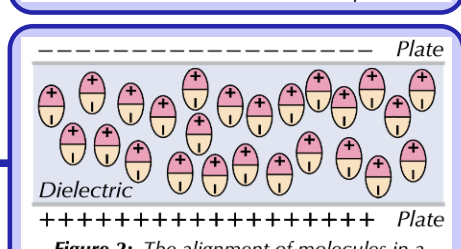


Figure 2: The alignment of molecules in a dielectric when an electric field is present.

The molecules each have their own electric field, which in this alignment now opposes the applied electric field of the capacitor.

The larger the permittivity, the larger this opposing field is. This reduces the overall electric field between the parallel plates, which reduces the potential difference needed to transfer a given charge to the capacitor thus the capacitance increases.

Calculating capacitance

The capacitance of a capacitor depends on the dimensions of the capacitor as well as the dielectric inside it.

$A = \text{effective area of a plate, in m}^2$
 $\epsilon_0 = \text{permittivity of free space, in Fm}^{-1}$
 $\epsilon_r = \text{relative permittivity}$
 $C = \text{capacitance, in F} \rightarrow C = \frac{\epsilon_0 \epsilon_r A}{d}$

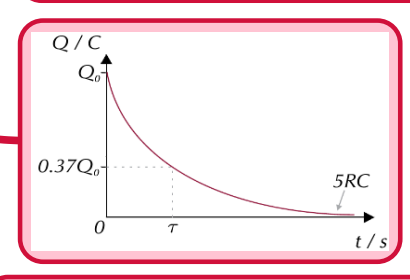
$d = \text{distance between the capacitor plates, in m}$

Time Constant and Time to Halve

RC

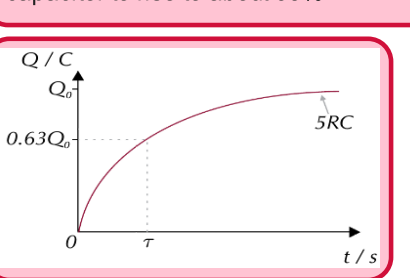
Discharging capacitor

Time taken for the charge on a discharging capacitor to fall to about 37%.



Charging capacitor

Time taken for the charge of a charging capacitor to rise to about 63%.



Time to halve

The time to halve is the time taken for the charge, current or potential difference of a discharging capacitor to decrease to half of the initial value.

$t = \ln(2)RC$

Energy Stored

Like charges, so when each plate of a capacitor becomes charged, the charges on that plate are being forced together. This requires energy, which is supplied by the power source and stored as electric potential energy for as long as the charges are held.

When the charges are released, the electric potential energy is released.

$E = \text{energy stored in J} \rightarrow E = \frac{1}{2}QV$

$V = \text{potential difference across capacitor in V}$
 $Q = \text{charge on capacitor in C}$

Capacitors

A capacitor is an electrical component that can store electrical charge. They are made up of two electrical conducting plates separated by an electrical insulator (a dielectric).

When a capacitor is connected to a direct current power source, charge builds up on its plates - one plate becomes negatively charged and one becomes positively charged. The plates are separated by an electrical insulator, so no charge can move between them. This means that a potential difference builds up between the plates of the capacitor.

The capacitor is the charge that the capacitor can store per unit potential difference across it. The voltage rating of a capacitor is the maximum potential difference that can be safely put across it. A capacitor will only charge up to the voltage of the power source it is connected to.

Capacitors can only store relatively small amount of charge, so they aren't used instead of batteries.

Capacitors are usually only used to provide power for a short amount of time as the amount of voltage through the circuit decreases as the capacitor discharges.

Uses of capacitors

Camera flash

The camera battery charges up the capacitor over a few seconds, and then the entire charge of the capacitor is dumped into the flash almost instantly. This allows the camera flash to be very bright for a very short time.

Ultracapacitors

can be used in back-up power supplies to provide reliable power for short periods of time.

Smooth out variations in d.c. voltage

A capacitor absorbs the peaks and fills in the troughs.

The electrons flow from the negative terminal of the supply onto the plate connected to it, so a negative charge builds up on that plate.

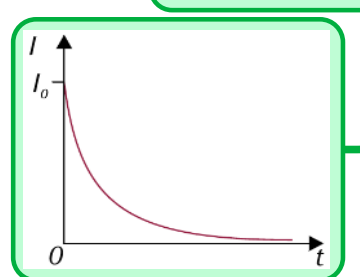
At the same time, electrons flow from the other plate to the positive terminal of the supply, making that plate positive. These electrons are repelled by the negative charge on the negative plate and attracted to the positive terminal of the supply.

The same number of electrons are repelled from the positive plate as are built up on the negative plate. This means an equal but opposite charge builds up on each plate, causing the potential difference between the plates.

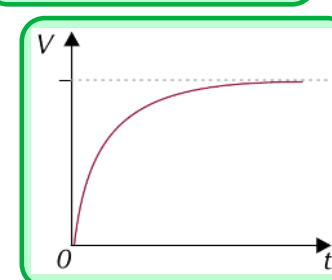
Charging

Initially the current through the circuit is high. But, as charge builds up on the plates, electrostatic repulsion makes it harder and harder for more electrons to be deposited. When the p.d. across the capacitor equals the p.d. across the supply, the current falls to zero. The capacitor is fully charged.

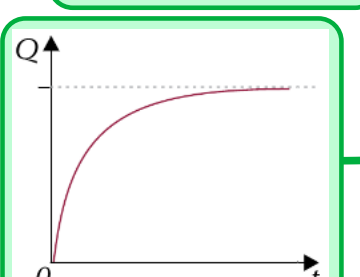
the resistance of the resistor will affect the time taken to charge the capacitor.



Current against time



P.d. against time



Charge against time

$Q_0 = \text{charge of the capacitor in C when fully charged}$
 $Q = \text{charge of the capacitor at time t, in C} \rightarrow Q = Q_0(1 - e^{-\frac{t}{RC}})$
 $R = \text{resistance of fixed resistor in } \Omega$
 $C = \text{capacitance of capacitor in F}$
 $t = \text{time since charging began in s}$

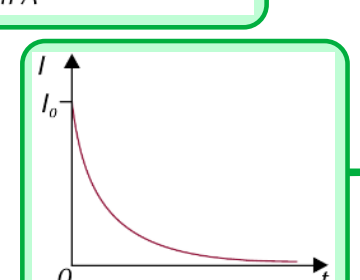
Equation

$V_0 = \text{potential difference across the capacitor when fully charged, in V}$
 $V = \text{potential difference across the capacitor at time t, in V} \rightarrow V = V_0(1 - e^{-\frac{t}{RC}})$

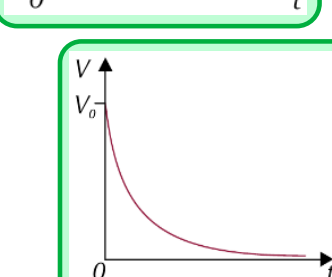
P.d.

$I_0 = \text{initial current, in A}$
 $I = \text{current at time t, in A} \rightarrow I = I_0 e^{-\frac{t}{RC}}$

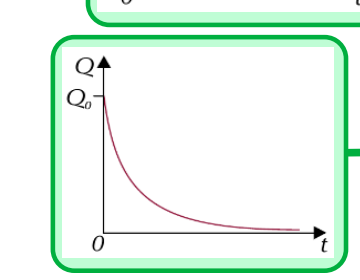
Current



Current against time



P.d. against time



Charge against time

$Q_0 = \text{charge of the capacitor in C when fully charged}$
 $Q = \text{charge of the capacitor at time t, in C} \rightarrow Q = Q_0 e^{-\frac{t}{RC}}$
 $R = \text{resistance of fixed resistor in } \Omega$
 $C = \text{capacitance of capacitor in F}$
 $t = \text{time since discharging began in s}$

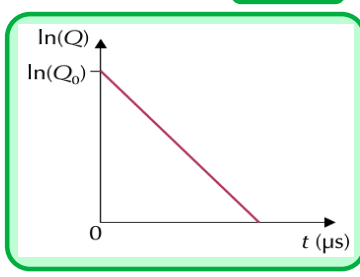
Equation

$\ln(Q) = \left(-\frac{1}{RC}\right)t + \ln(Q_0)$

gradient

$-\frac{1}{RC}$

Graph



Charging and Discharging