Physics Capacitor Notes

1 Introduction to Capacitors

A capacitor is a device used to store charge, constructed of two parallel metal gates near each other with an insulator in between. One conductor gains electrons and the other one loses them.
The charge on a capacitor with constant current is $Q = It$. Voltage across a capacitor is directly proportional to the current stored.
The unit of capacitance is the Farad, equal to one coulomb per volt. It will usually be given in μF, nF or pF.

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

2 Uses of Capacitors

- Smoothing circuits
- Back-up power supplies
- Timing circuits
- Pulse producing circuits
- Tuning circuits
- Filter circuits (remove unwanted frequencies)

3 Capacitor discharge through a fixed resistor

As a capacitor discharges through a fixed resistor the current reduces to zero. This is because as charge reduces, voltage reduces. Because $Current = \frac{pd}{resistance}$ and resistance is constant current decreases as voltage decreases. Current and voltage decrease exponentially over time, giving their graph with time a curve. If the initial charge is Q, and after t the charge is 0.8 Q then after nt the charge will be $0.8^n Q$.
This is because

$$I = \frac{V}{R} = \frac{Q}{CR}$$

$$\Delta Q = -I\Delta t$$

$$\frac{dQ}{dt} = -\frac{Q}{CR}$$

$$\int \frac{dQ}{Q} = -\int \frac{1}{CR} dt$$

$$lnQ = -\frac{t}{CR} + A$$

$$Q = e^{-\frac{t}{RC}+A} = e^{-\frac{t}{RC}} e^A = Qe^{-\frac{t}{RC}}$$

Time Constant = RC, unit=seconds

4 Charging a capacitor through a fixed resistor

As the capacitor charge increases the charging current decreases. When the capacitor is fully charged, its PD=Source PD and the current is 0. The time constant for the circuit is the time it takes for the capacitor to reach 63% charge.
Source PD = Resistor PD + Capacitor PD

$V_0 = IR + \frac{Q}{C}$ at any time

Initial current $(I_0) = \frac{V_0}{R}$ assuming the capacitor is initially uncharged.

At time t after the charging starts $I = I_0 e^{\frac{-t}{RC}}$

$V_0 = V_0 e^{\frac{-t}{RC}} + \frac{Q}{C}$
$\frac{Q}{C} = V_0(1 - e^{\frac{-t}{RC}})$
$V = \frac{Q}{C}$
$Q = CV_0(1 - e^{\frac{-t}{RC}})$
At time t=0:
$e^{\frac{-t}{RC}} = 1$ so Q=0 and V=0
As time $t \to \infty$:
$e^{\frac{-t}{RC}} = 0$
$Q \to Q_0$
$V \to V_0$

5 Dielectric action

The charge stored on the plates on a capacitor can be increased by inserting a **Dielectric** between the plates. These are electrically insulating materials that increase the charge storing ability. Polythene and waxed paper are examples of this.
When a dielectric is placed in a capacitor and connected to a battery the molecules become polarised, meaning that electrons are pulled slightly towards the positive plate.
This causes more charge to be stored on the plates as:

- The positive side of the dielectric attracts more electrons from the battery onto the negative plate
- The negative side of the dielectric pushed electrons back to the battery from the positive plate

6 Relative permittivity

Relative permittivity is the ratio of charge stored without a dielectric, compared to that with a dielectric.
Relative permittivitty $\epsilon_r = \frac{Q}{Q_0}$
Q = Charge stored when the area between the plates is completely filled with dielectric substances.
Q_0 = Charge without any dielectric.
For a fixed voltage $\epsilon_r = \frac{C}{C_0}$
The relative permittivity is also called the dielectric constant.

7 Capacitor design

Capacitance $= \frac{A\epsilon_0\epsilon_r}{d}$
A= Surface area
D = Distance between plates
A large capacitance can be achieved by:

- Making the area as large as possible
- Making the plate spacing as small as possible
- Filling the space between the plates with a dielectric which has a relative permittivity as large as possible.

8 Polarisation mechanisms

8.1 Orientation polarisation

For molecules where covalent bonds are formed between atoms of different elements. This forms a dipole as the electrons are shared unequally. When an electric field is applied the atoms are displaced in opposite directions, to align with the field.

8.2 Ionic polarisation

For substances where ions are held together by ionic bonds. Opposite direction displacement.

8.3 Electronic polarisation

Electrons in each atom are displaced relative to the nucleus when an electric field is applied. The electron distribution and the nucleus form a dipole.