AS Level Physics

Chapter 7 – Electrons, Waves and Photons

7.1.1 Charge and Current

Notes

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ELECTRIC CURRENT

An ELECTRIC CURRENT is a flow of charge due to the passage of charged particles. These charged particles are referred to as charge carries.

A current is a flow of charge. In metals, this charge is carried by electrons, which are negatively charged. A battery is responsible for pushing charge around a circuit.

However, before electrons were discovered, it was assumed that positive charge flows from the positive to the negative terminals, and we still use this convection today.

Direction of Conventional Current

wire

Direction of Electron Flow
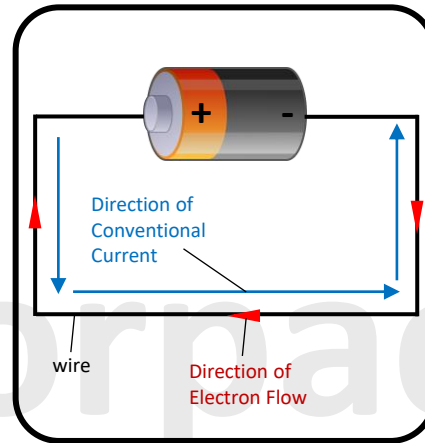
The conventional current is a flow of charge from the positive terminal to the negative terminal.

But in actual fact the charge carriers are electrons and electron flow is in the opposite direction (i.e. from the negative terminal to the positive terminal).

ELECTRIC CURRENT

Ions

Electrons

Metal wire

Electron Current

Conventional Current
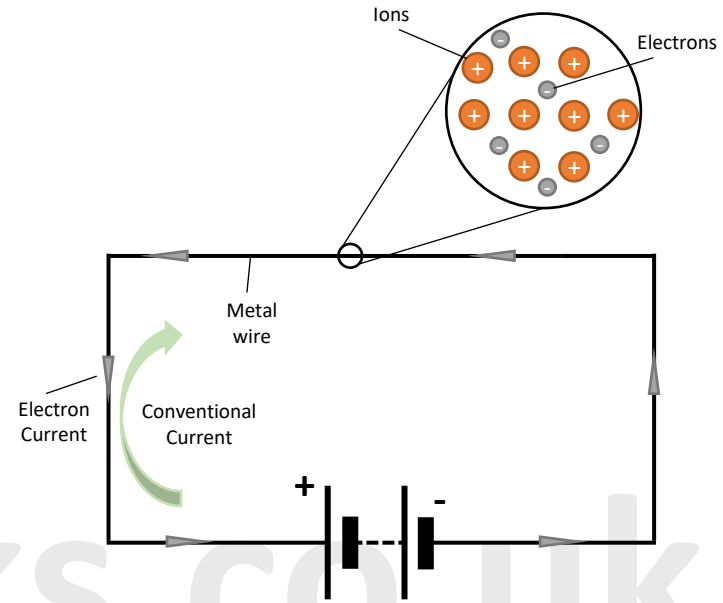
- In metal wires there are free moving negatively charged electrons. These electrons are not tightly bound to the metal atoms and are known as CONDUCTION or FREE electrons.

- These FREE electrons experience an electric force, when a battery is connected to the wire, causing them to drift between metal ions. They drift from the negative terminal towards the positive terminal, while colliding with each other and to the fixed positive ions inside the metal wire. It is this electron drift that creates the Electric Current.

- The electron flow direction is in the opposite direction to conventional current.

- Current is present at all points in a circuit when it is complete. This is because electrons (i.e. charge carriers) are all around the circuit before a battery is even connected and causes them to drift.

ELECTRIC CURRENT

- In comparison to a closed circuit, when an electric current is passed through a salt solution, the charge is carried by ions (i.e. charged atoms or molecules).

- The charge carriers in an electrolyte (a conducting solution) are positive and negative ions. As soon as a voltage is applied to the electrodes, the positive ions are attracted to the cathode (i.e. the negative electrode) and the negative ions are attracted to the anode (i.e. the positive electrode). The ions are discharged when they have reached the relevant electrode.

- A current passes through in an electrolyte due to positive and negative charges moving in opposite directions.
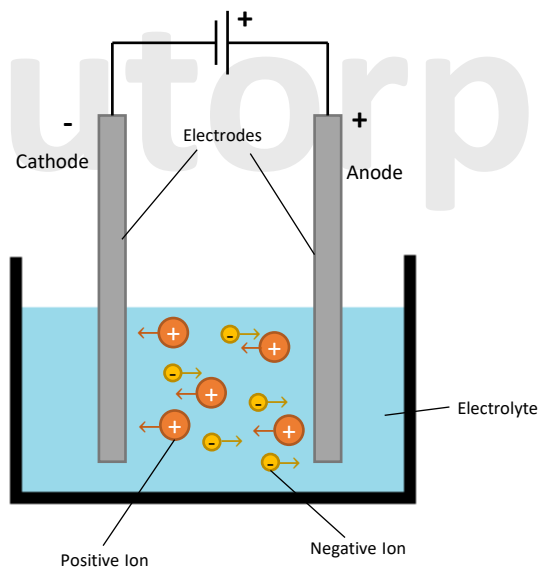
CHARGE AND CURRENT

Current (I) is the rate of flow of charge (Q).

To calculate the current (I) flowing when charge ΔQ passes a point in time interval Δt:

$$I = \frac{\Delta Q}{\Delta t}$$

where:
I = **Current** measured in **Amperes or Amps, A.**
Q = **Charge** measured in **coulomb, C.**
t = **Time** measured in **seconds, s.**

To calculate the charge:

$$\Delta Q = I \times \Delta t$$

The bigger the current, and the longer it flows, the more the charge passes.

Coulombs and Amperes (Amp)

1 AMP is 1 COULOMB per second: $1\,A = 1\,Cs^{-1}$

1 COULOMB (C) is the charge which flows, past a point in a circuit, when a current of 1 AMP (A) flows for 1 second (s).

Charge is represented by the letter e.
The charge on an electron, $-e = -1.6 \times 10^{-19}\,C$.
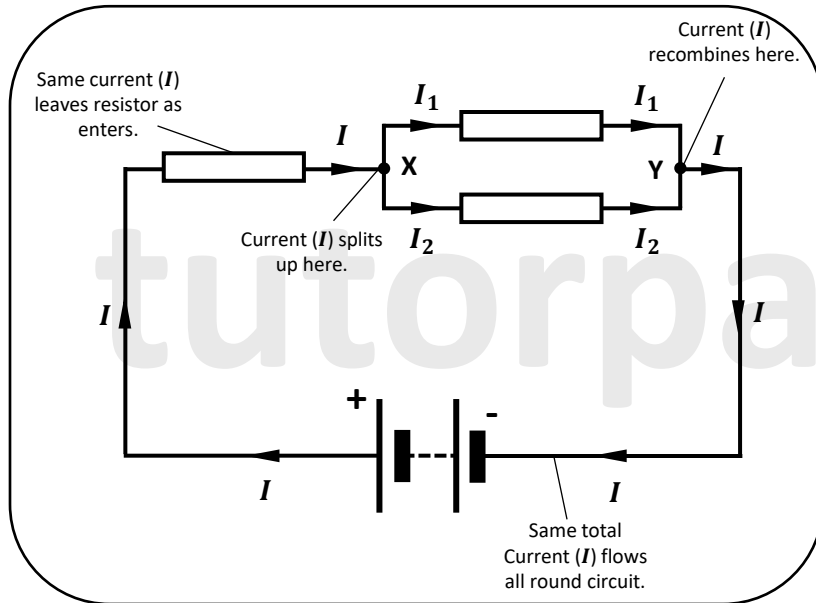**The charge on a proton, $+e = +1.6 \times 10^{-19}\,C$.**

CONSERVATION OF CURRENT

Current is the flow of charge.

> **Conservation of charge states that electric charge can neither be created nor destroyed. In a closed system, the amount of charge remains the same. Charge can only be transferred from one system to another.**

This means that charge cannot be used up or disappear and as a result we say that current is conserved.

Same current (I) leaves resistor as enters.

Current (I) recombines here.

Current (I) splits up here.

Same total Current (I) flows all round circuit.

At point X, current splits up:
$$I = I_1 + I_2$$

At point Y, current recombines:
$$I_1 + I_2 = I$$

These equations describe the conservation of current. They are an example of **Kirchhoff's first law**.

CONSERVATION OF CURRENT
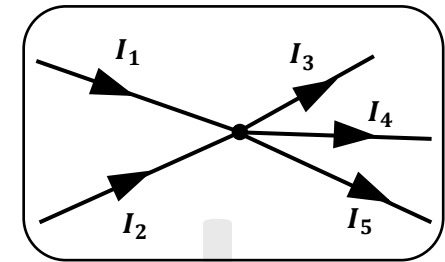
Kirchhoff's First Law

> **Kirchhoff's First Law states that the sum of the currents entering a point in a circuit is equal to the sum of the currents leaving a point.**

For example:

$Sum\ of\ current\ in = Sum\ of\ current\ out$

$$\sum I_{in} = \sum I_{out}$$

$$I_1 + I_2 = I_3 + I_4 + I_5$$

An ammeter connected in series in a circuit can be used to measure the current.

Ammeters can be connected at different points, in a circuit where the current divides, to verify Kirchhoff's first law.
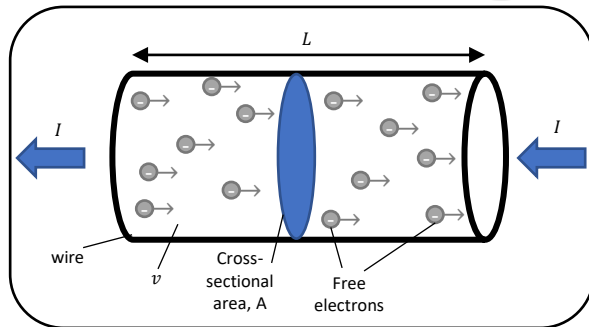
DRIFT VELOCITY (OCR only)

Free electrons move around in rapid, random directions (like air) in any conductor (such as a wire). But, without a battery, we cannot get a current in the wire and so the electrons randomly collide or keep moving around a metallic ion rapidly and do not drift/move along the wire. When a battery is used the electrons experience a force causing them to accelerate. They will still be in rapid random motion but overall all the electrons present in the wire will all move towards the direction of the force (i.e. to the left or right). This is what contributes to the electric current.

So, when a voltage is applied (i.e. battery) the electrons gain an additional velocity along the wire (causing them to drift in one direction). The average gain in additional velocity by the electrons is known as the mean drift velocity (v) and is constant for all electrons in the wire.

To increase the mean drift velocity (v), increase the current (I) (e.g. use a stronger battery).

How to relate current to the mean drift velocity?

Consider a wire of **length (L)**, **cross-sectional area (A),** carrying a **current (I).** The current is carried by free electrons, each having a **charge (e).**

DRIFT VELOCITY (OCR only)

Remember, current depends on the **cross-sectional area (A)**, and the number of electrons per m^3 (**number density, n**) of a wire.

So, the number of free electrons in a section of a wire = nAL

The total charge flowing in the section of a wire = $nALe$

Time taken for the electrons to flow through = L/v

Therefore:
$$current, I = \frac{charge}{time} = \frac{nALe}{L/v}$$

Which gives us:
$$I = nAve$$

To calculate drift velocity:
$$v = \frac{I}{nAe}$$

where:
I = **Current** measured in **Amperes or Amps, A.**
n = **number density** measured in m^{-3}.
A = **cross-sectional area** measured in m^2.
v = **mean drift velocity** measured in ms^{-1}.
e = **electron charge** measured in **couloumbs**, **C**.

DRIFT VELOCITY (OCR only)

$$v = \frac{I}{nAe}$$

where:
I = **Current** measured in **Amperes or Amps, A.**
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To understand the equation change one variable at a time:

- $v \propto I$

The mean drift velocity increases if the current increases.

- $v \propto \frac{1}{n}$

A large number of electrons per m^3 results in a small mean drift velocity.

- $v \propto \frac{1}{A}$

The thicker the conductor, the smaller the mean drift velocity because there a more electrons present and so individual electrons travel slowly.

Note:

- Number density, n, is different for different materials.

- Mean drift velocity, v, is very small due to the fact that free electrons move along the wire and have several random collisions with the vibrating metal ions. This makes their motion haphazard.

DIFFERENT MATERIALS HAVE DIFFERENT NUMBER DENSITIES, n

- **Conductors (metals)**

Metals have a very high electron density and so n is large and drift velocities are slow. This is because, in metals, there are many charge carriers present as a result of the free electrons from the outer shells of each atom.

- **Semiconductors (silicon, germanium)**

Semiconductors have fewer charge carriers compared to metals, therefore you will need to have a higher drift velocity in order to have the same current.

Semiconductors have an electron density that lies between that of a conductor and an insulator. A semiconductor behaves as an insulator when cold, and a conductor when warm. This means the value of n increases with temperature.

- **Insulator (rubber, plastic)**

Insulators usually have 1 electron which is free to move per mm^3 as it has a very small electron density. As a result insulators cannot conduct current.

A perfect insulator will have an electron density, n, equal to zero and therefore it wouldn't have an charge carriers to conduct current.

Please see **'7.1.2 Charge and Current worked examples'** pack for exam style questions.

For more revision notes, tutorials and worked examples please visit **www.tutorpacks.co.uk**.