UNIT G482	Module 2	2.1.1	Charge and Current

- ***Candidates should be able to :***

  - *Explain that electric current is a net flow of charged particles.*
  - *Explain that electric current in a metal is due to the movement of electrons, whereas in an electrolyte the current is due to a movement of ions.*
  - *Explain what is meant by conventional current and electron flow.*
  - *Select and use the equation* $\boxed{\Delta Q = I\,\Delta t}$
  - *Define the* ***COULOMB****.*
  - *Describe how an ammeter may be used to measure the current in a circuit.*
  - *Recall and use the elementary charge* $\boxed{e = 1.6 \times 10^{-19}\ C}$
  - *Describe* ***KIRCHHOFF'S first law*** *and appreciate that this is a consequence of* ***conservation of charge.***
  - *State what is meant by the term* ***MEAN DRIFT VELOCITY*** *of charge carriers.*
  - *Select and use the equation* $\boxed{I = Anev}$
  - *Describe the difference between* ***CONDUCTORS, SEMICONDUCTORS*** *and* ***INSULATORS*** *in terms of the number density n.*

- ## *ELECTRIC CHARGE (Q)*

- ***Electric charge*** *is a property possessed by* ***protons*** *and* ***electrons.***

- *The charges carried by the electrons and protons within atoms are* ***equal in size (= 1.6 x 10^{-19} C)*** *and* ***opposite in sign (positive in protons and negative in electrons).***

- *In an atom with equal numbers of protons and electrons, the total positive charge = the total negative charge, so the* ***net charge = 0.***
  The atom is said to be ***electrically neutral.***

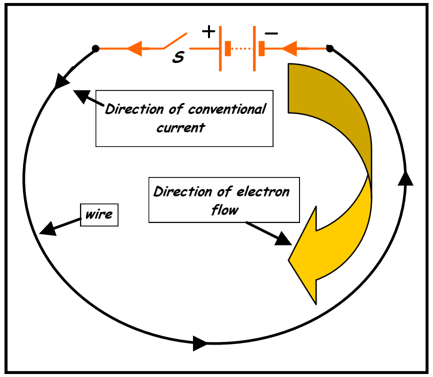
- ***Positive ions*** *are atoms which have* ***lost*** *one or more electrons.*
  Negative ions *are atoms which have* ***gained*** *one or more electrons.*

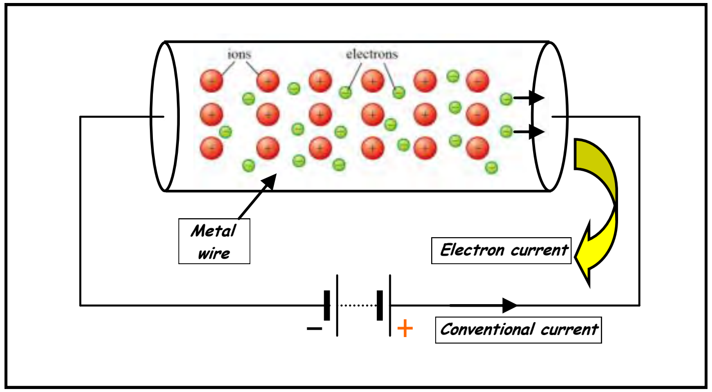
- ## *ELECTRIC CURRENT (I)*

An ***ELECTRIC CURRENT*** *is due to a net flow of charge due to the passage of charged particles (sometimes referred to as* ***charge carriers).***

Consider the circuit shown opposite. When switch (S) is closed, a current flows in the direction shown, from the positive terminal to the negative terminal.

This is the ***CONVENTIONAL CURRENT FLOW direction****, but in reality the charge carriers* ***(ELECTRONS)*** *flow in the opposite direction (i.e. from the negative terminal to the positive terminal).*





- *Inside the metal wire there are some negatively charged* ***electrons*** *which are free to move about.*

  These electrons which are not tightly bound to the metal atoms are called ***FREE*** *or* ***CONDUCTION*** *electrons.*

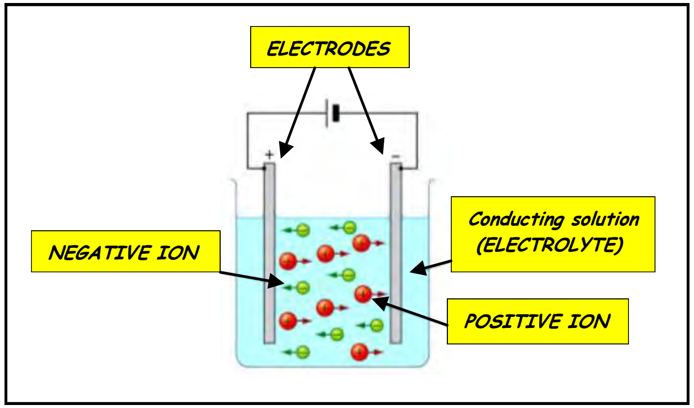
  When a battery is connected to the wire as shown above, the ***FREE electrons*** *experience an electric force which causes them to drift between the metal ions towards the positive terminal. It is this electron drift which constitutes the* ***ELECTRIC CURRENT****.*

- ***NOTE***

  - *The* ***ELECTRON FLOW*** *direction is opposite to that of the* ***CONVENTIONAL CURRENT****.*

  - ***There is current at all points in a circuit as soon as the circuit is complete****. This is because the charge carriers (i.e. the electrons) are present all around the circuit before a battery is connected and causes them to move.*

- *Sometimes a current can be due to a flow of* ***positively charged particles*** *(proton beam in a particle accelerator). The particle flow direction and the current direction are then the same.*



- *A current can also be due to* ***positive*** *and* ***negative*** *charges moving in opposite directions.*

  An ***ELECTROLYTE*** *contains both positive and negative* ***IONS*** *and when electrodes connected to a cell are placed in such a solution, the negative ions move towards the positive electrode and the positive ions towards the negative electrode.*

- *CURRENT AND CHARGE*

- ***ELECTRIC CURRENT (I)*** *is the rate of flow of electric charge (Q) measured in* ***AMPERES (A)***.

- ***ELECTRIC CHARGE (Q)*** *is measured in* ***COULOMBS (C)***.

- *CHARGE = CURRENT x TIME*
  (C) (A) (s)

- ***1 COULOMB (C) is the quantity of charge which flows past a point in a circuit in a time of 1 SECOND (s) when the current is 1 AMPERE (A).***

*So a current of **1 AMPERE** means that charge is flowing at the rate of **1 COULOMB/SECOND**.* ***(1 A = 1 C s^{-1}).***

- ***The charge on an electron, -e = -1.6 x 10^{-19} C.***

  The charge on a proton, +e = +1.6 x 10^{-19} C.

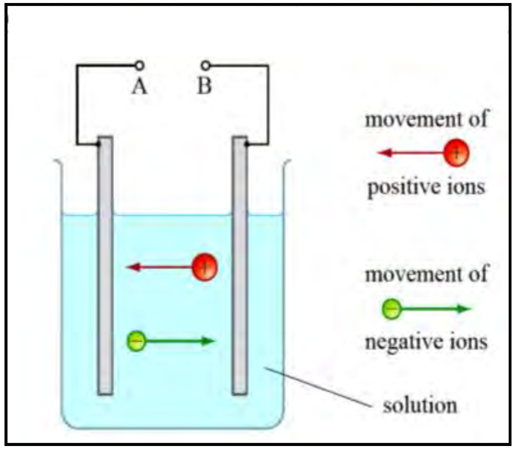
- *The amount of charge **(ΔQ)** flowing past a given point in a time **(Δt)**, when the current is **(I)** is given by :*

$$\Delta Q = I\,\Delta t$$

1 The diagram opposite shows a circuit in which an electric current is passed through a solution which contains both positive and negative ions.

A cell is connected between A and B.

Copy the diagram and complete it as follows :



(a) Use an arrow to show the direction of the current ***in the solution.***

(b) Use an arrow to show the direction of the current ***in the wires.***

(c) Add ***a cell between A and B***, indicating the positive and negative terminals of the cell.

2 (a) A lamp has a current of ***3.5 A*** for a time of ***45 minutes.*** How much ***charge*** has flowed through the lamp in this time ?

(b) Calculate the ***current*** through a component if ***2400 C*** of charge passes through it in ***32 minutes.***

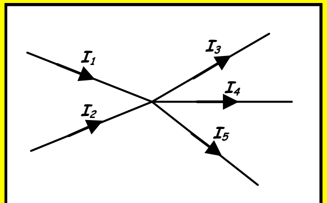
3 A wire forms part of a circuit. Calculate :

(a) The ***steady current*** through the wire if a charge of ***400 μC*** passes a point in the wire in ***8 ms.***

(b) The ***number of electrons*** which pass through the wire in ***8 ms. (charge on an electron, e = 1.6 x10^{-19} C).***

- ***KIRCHHOFF'S FIRST LAW***

At a junction in a circuit, the sum of the currents entering the junction is equal to the sum of the currents leaving the junction.



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

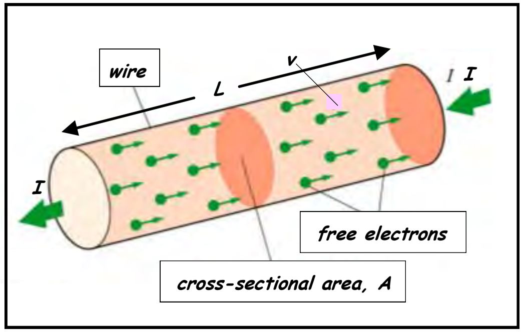
- ***KIRCHHOFF'S FIRST LAW*** *is a consequence of the principle of the* ***CONSERVATION OF CHARGE*** *(i.e. that the total amount of charge which exits a point in a circuit must equal the total amount of charge which enters the point).*

- *Kirchhoff's First Law may be verified by connecting* ***AMMETERS*** *at different points in a circuit where the current divides.*

  The ammeter is connected ***IN SERIES*** *so that the current being measured flows through it.*

- ***EQUATION FOR CURRENT IN A CONDUCTOR - I = nAve***

The diagram opposite shows a section of a conductor, of ***length (L), cross-sectional area (A),*** *carrying a* ***current (I).***



The current is carried by free electrons, each having a ***charge (e)*** *and moving with an* ***average drift velocity (v)*** *through the conductor.*

The ***number density (i.e. the number of electrons per m³) = n.***

Then, number of free electrons in the section = nAL

And, total charge flowing in the section = nALe

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

So,
$$\text{current, } I = \frac{\text{charge}}{\text{Time}} = \frac{nALe}{L/v}$$

$$\boxed{I = nAve}$$

(Current/A) *(number density/m^{-3})* *(cross-sectional area/m^2)* *(drift velocity/m s^{-1})* *electron charge/C*

NOTE

- ***n is different for different metals*** *(e.g. for copper, $n = 8 \times 10^{28}$ m^{-3}).*

- ***v is very small*** *(typically, <**1 mm s^{-1}**). The reason for this is that as the free electrons move along the wire, they have numerous, random collisions with the vibrating metal ions, which makes their motion very haphazard. Thus, even though the actual velocity of an electron between collisions is ≈ **10^6 m s^{-1}**, the average drift velocity ≈ **10^{-3} m s^{-1}**.*

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

So :

- $v \propto I$

  If the current increases, the drift velocity increases.

- $v \propto 1/A$

  The thinner the conductor, the greater the drift velocity. There are fewer electrons in a thinner conductor, so individual electrons must travel faster.

- $v \propto 1/n$

  The greater the number of electrons per m3, the smaller the average drift velocity will be.

• *CONDUCTORS, SEMICONDUCTORS AND INSULATORS*

- ***CONDUCTORS (metals)***

  *Have a **very high electron density (n)** (≈ 10^{29} m^{-3} = 10^{20} mm^{-3}). That is what makes them good conductors.*

- ***INSULATORS (rubber, plastic)***

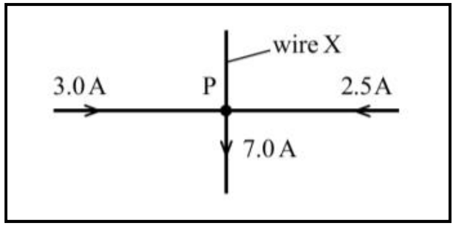
  *Have a **much lower electron density (n)** (≈ 10^{9} m^{-3} = 1 mm^{-3}). This means that there is only 1 electron which is free to move per mm^3 and that is why insulators cannot conduct.*

- ***SEMICONDUCTORS (silicon, germanium)***

  *Have an **electron density (n)** (≈ 10^{19} m^{-3} = 10^{10} mm^{-3}) which lies between that of a conductor and an insulator. The value of n increases with increasing temperature, which means that it behaves as an insulator when it is cold and as a conductor when it is warm.*

• PRACTICE QUESTIONS (2)

1 Use ***Kirchhoff's first law*** to determine the ***size*** and ***direction*** of the current in wire ***X*** shown in the diagram opposite.



2 A copper wire has a diameter of ***0.50 mm.*** Copper has ***8.5 x 10^{28} free electrons per m^3.*** Calculate the ***mean drift velocity*** of the free electrons when the wire is carrying a current of ***2.5 A.*** ***(Charge on an electron, e = 1.6 x10^{-19} C).***

3 Calculate the ***current*** in a gold wire of diameter ***0.84 mm***, given that the mean drift velocity of the conduction electrons in the wire is *0.08 mm s^{-1}* and that the electron number density for gold is ***6.0 x 10^{28} m^{-3}.*** ***(electronic charge, e = 1.6 x 10^{-19} C).***

• HOMEWORK QUESTIONS

1 A rechargeable battery can supply a current of ***0.25 A*** for ***5000 s,*** before its voltage drops and it needs to be recharged.

Calculate : (a) The ***total charge*** which the battery can deliver before it needs to be recharged.

(b) The ***maximum amount of time*** it could be used for without being recharged, if the current through it were :

(i) ***0.40 A,*** (ii) ***0.10 A.***

2 (a) A charge of ***4900 μC*** flows past each point in a wire in a time interval of ***70 s***. Calculate :

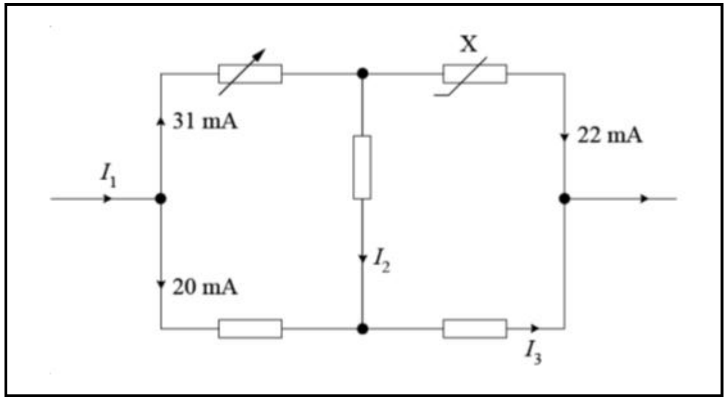
(i) The ***current*** in the wire,

(ii) The ***number of electrons per second*** passing each point in the wire ***(electron charge, e = 1.6 x 10^{-19} C).***

(b) A cathode-ray tube produces a beam of fast-moving electrons which strike a fluorescent screen. When the beam current is ***250 μA,*** calculate the number of electrons which strike the screen in ***2.5 s***. ***(electron charge, e = 1.6 x 10^{-19} C).***

3 (a) State ***KIRCHHOFF'S FIRST LAW.***

(b) The diagram below shows part of an electrical circuit.



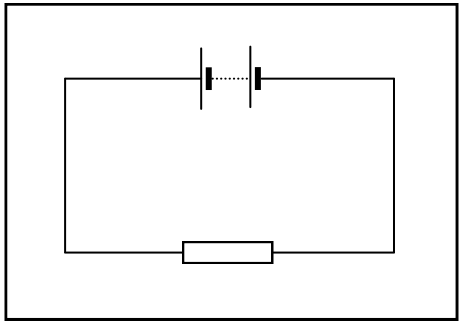
Use ***Kirchhoff's first law*** to determine the magnitude of the currents ***I_1, I_2 and I_3.***

(OCR AS Physics - Module 2822 - January 2004)

4 (a) (i) State what is meant by an ***electric current.***

(ii) A mobile phone is connected to a charger for ***600 s***. The charger delivers a constant current of ***350 mA*** during this interval. Calculate the ***total charge*** supplied to the mobile phone.

(b) The diagram opposite shows a resistor connected to a d.c. supply.



State the ***direction of electron flow*** in this circuit.

(OCR AS Physics - Module 2822 - May 2002)

5 The length of a copper track on a printed circuit board has a cross-sectional area of ***5.0 x 10^{-8} m^{2}.*** The current in the track is ***3.5 mA.*** You are provided with the following useful information about copper.

- ***1 m^{3} of copper has a mass of 8.9 x 10^{3} kg.***
- ***54 kg of copper contains 6.0 x 10^{26} atoms.***

In copper there is roughly one electron liberated from each atom.

(a) Show that the ***electron number density (n)*** for copper is about ***10^{29} m^{-3}.***

(b) Calculate the ***mean drift velocity*** of the free electrons.