ELECTRICITY

There are two branches of electricity namely:

i) electrostatic electricity
ii) current electricity

ELECTROSTATIC ELECTRICITY

Is the study of electric charges at rest. An electric charge is a deficiency or surplus of electrons and therefore electric charges are either positive or negative.

ORIGIN OF CHARGES

Matter is made of atoms and atoms have three particles namely,

- Protons
- Electrons
- Neutrons.

The protons are positively charged and are located in the nucleus of an atom. The neutrons are neutral (no charge) and are also located in the nucleus of the atom while electrons are negatively charged and they move around the nucleus of the atom. Therefore the nucleus has a positive charge due to charge on the protons and the total number of protons in nucleus is equal to total number of electrons around the nucleus, hence the atom has no charge (neutral).

Any material that gains electrons becomes negatively charged and any material that loses electrons becomes positively charged, this is the origin of electric charges.

Note

- The charge is neither created nor destroyed during the charging but can be transferred from one body to another. This is the principle of conservation of charge.
- A negatively or positively charged atom is called an ion.

Law of electrostatics. (Law of charges)

It states that like charges repel and unlike charges attract each other.

Conductors and insulators.

❖ **Conductors.**

A conductor is a substance in which electrons are free to move and conducts heat and electricity easily.
Examples are all metals and carbon in form of graphite.

Properties of conductors.

- They have free electrons which are loosely held by the nucleus.
- They are good conductors of heat and electricity.

- They can lose or gain electrons
- Loss of electrons leaves the conductor positively charged.
- Gain of electrons leaves the conductor negatively charged.

❖ **Insulators.**

An insulator is a substance in which electrons are not free to move and does not conduct heat and electricity easily.

Examples include all non-metals like ebonite, plastic, rubber, polythene etc.

Properties of insulators.

- They don't have free electrons, electrons are tightly held by the nucleus.
- They don't conduct heat and electricity.
- They can lose or gain electrons.
- Loss of electrons leaves an insulator positively charged.
- Gain of electrons leaves an insulator negatively charged.

Methods of charging.

a) Charging by rubbing (friction).

- When two insulators are rubbed together, there is transfer of electrons.
- The insulator that gains electrons becomes negatively charged and an insulator that looses electrons becomes positively charged.
- The two insulators will therefore acquire equal but opposite charges.

Examples:

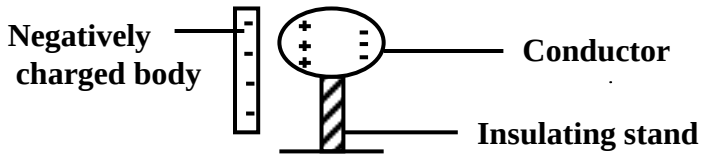
When glass and silk is rubbed together the glass atoms lose electrons to the silk atoms, as a result the silk acquires a negative charge due to excess electrons and the glass acquires a positive charge due to excess protons. The resulting electric force can attract small pieces of paper.

b) Electrostatic induction.

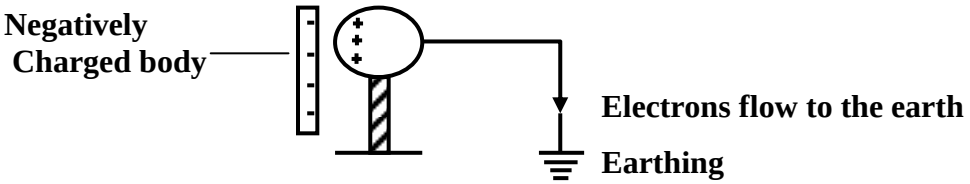
This is the production of temporary charge on a body or conductor due to its nearness / closeness to a charged body.

- **Charging a conductor positively by induction.**

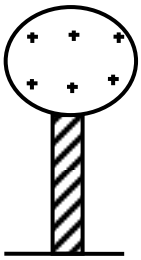
- A negatively charged body is brought near one side of the conductor supported by an insulator.
- Positive charges are induced on the side near the charged body and the negative charges are repelled to the other side.



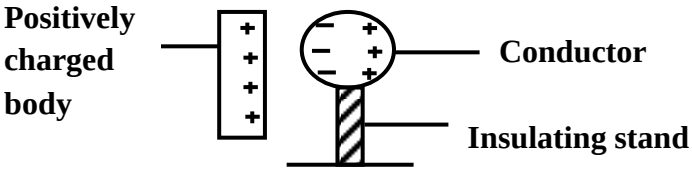
- With the negatively charged body still in place, the other side of the conductor is then earthed by connecting the wire to the ground or touching it momentarily with a finger, electrons will then flow to the ground leaving positive charges.



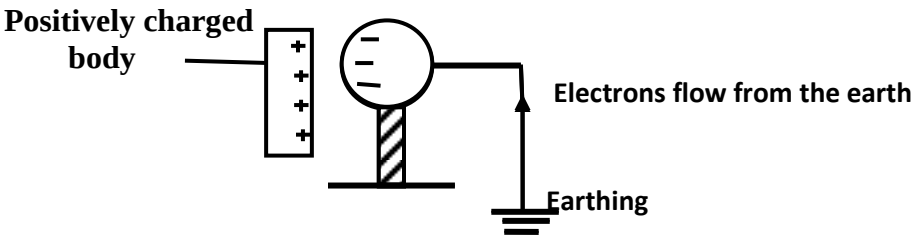
- With the negatively charged body still in place/its position, the earthing wire is removed.
- The negatively charged body is then removed and the positive charges will redistribute themselves over the whole conductor leaving it with a net positive charge.



- **Charging a conductor negatively by induction.**
  - A positively charged body is brought near one side of the conductor supported by an insulator.
  - Negative charges are induced on the side near the body and the positive charges are repelled to the other side.



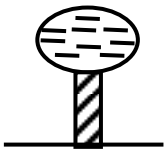
- With the positively charged body still in place, the other side of the conductor is earthed by connecting an Earth wire to the ground or by momentarily touching with the finger.



- Electrons will flow from the ground to neutralize the positive charge on the conductor leaving only negative charges.

- With the positively charged body still in its position, the earth wire is removed.

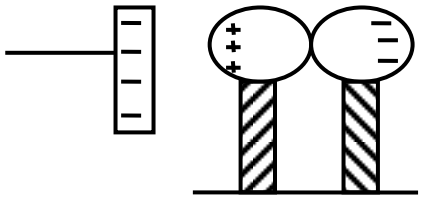
- The positively charged body is then removed and the conductor is left with a net negative charge.



Note. Charging by induction is more successful than charging by contact because when a body touches another the points of actual contact are extremely few and therefore transfer of charge by contact is limited to only few points where as in induction it is the nearness of the body that matters.

- **Charging two conductors simultaneously by induction.**
- Two metal spheres A and B in contact are placed on insulated supports. A negatively charged body is brought near sphere A.
- Positive charges are induced on A and negative charges are repelled to B.

Negatively charged body



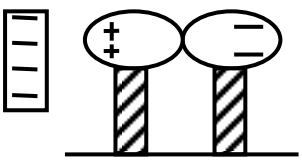
- With the negatively charged body still in place, the two spheres are separated and on removing the charged body sphere A acquires a positive charge and B acquires a negative charge.

A **B**

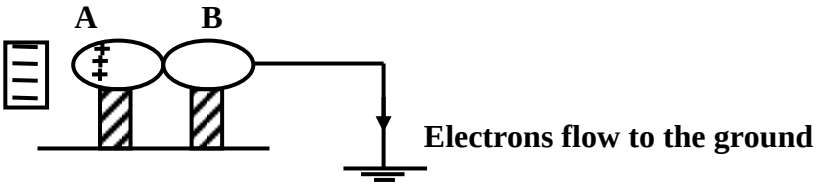


- **Charging simultaneously two conductors positively by induction.**
  - Two metal spheres A and B in contact are placed on insulated supports. A negatively charged body is brought near sphere A.
  - Positive charges are induced on A and negative charges are repelled to B.

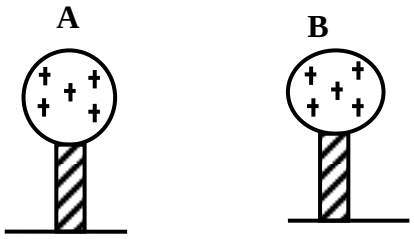
A **B**



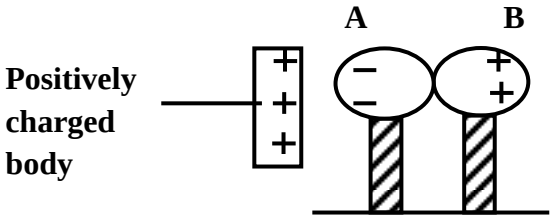
- With the negatively charged body still in place, sphere B is earthed and electrons flow to the ground.
- The earthing is removed and later the charged body is removed and positive charges in A distribute themselves over spheres A and B.



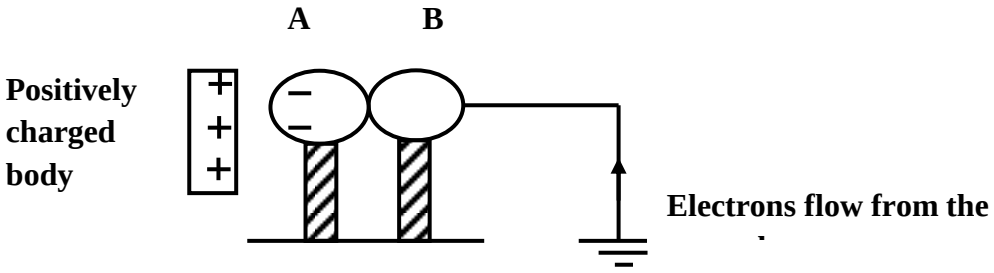
- The two spheres are then separated and both spheres A and B acquire a positive charge.



- **Charging simultaneously two conductors negatively by induction.**
  - Two metal spheres A and B in contact are placed on insulated supports. A positively charged body is brought near sphere A.
  - Negative charges are induced on A and positive charges are repelled to B.



  - With the positively charged body still in place, sphere B is earthed and electrons flow from the ground to neutralize the positive charge in B.
  - The earthing is first removed then the charged body is later removed and negative charges in A redistributes themselves over spheres A and B.



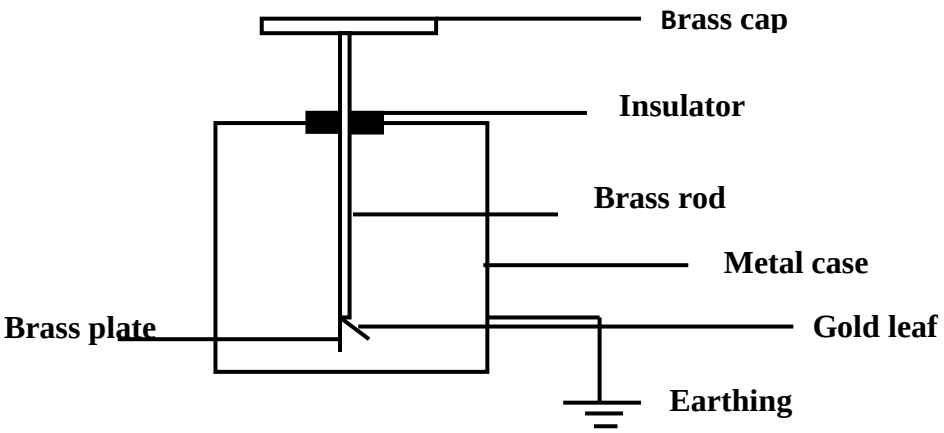
  - The two spheres are then separated and both spheres A and B acquire a negative charge.





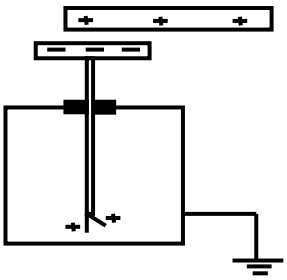
THE GOLD LEAF ELECTROSCOPE:

- This is an instrument which works on principle of electrostatics charges to detect the presence of the charge and differentiate between the charges.
- It consists of a metal case with glass window to protect it from draught.
- A metal cap is joined to the metal rod which is supported by an insulator so that charges are not conducted to the metal case.
- The rod is joined to a gold leaf on a plate and the metal case is earthed by the wire.

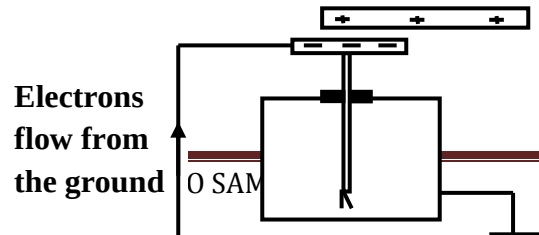


Charging a gold leaf electroscope negatively by induction.

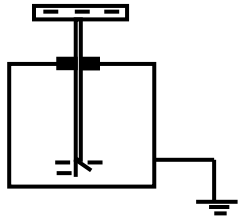
- A positively charged body is brought near the cap of uncharged electroscope.
- Negative charges are induced on the cap and positive charges are repelled to the plate and the gold leaf and the leaf diverges, because like charges on the plate and the leaf repel.



- With the charged body still in place, the cap is earthed by connecting the earth wire to the cap or touching the cap momentarily with a finger.
- Negative charges flow from the ground to neutralize the positive charges and a decrease in the divergence of the leaf is observed.

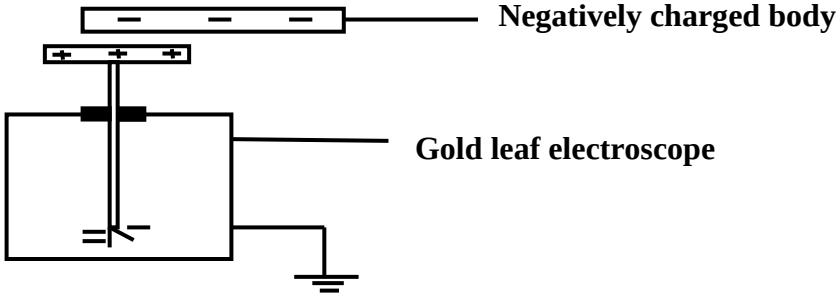


- The earthing is removed and subsequently the charged rod is removed.
- The negative charge on the cap redistributes itself onto the plate and the gold leaf. As a result the leaf diverges and the electroscope acquires a negative charge.

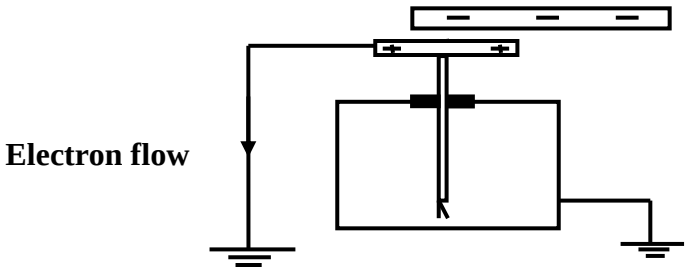


Charging a gold leaf electroscope positvely by induction.

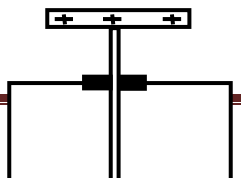
- A negatively charged body is brought near the cap of uncharged electroscope.
- Positive charges are induced on the cap and negative charges are repelled to the plate and the gold leaf and the leaf diverges, because like charges on the plate and the leaf repel.



- With the charged body still in place, the cap is earthed by connecting the earth wire to the cap or touching the cap momentarily with a finger.
- Negative charges flow to the ground and a decrease in the diverges of the leaf is observed.



- The earthing is removed and subsequently the charged rod is removed.
- The positive charge on the cap redistributes itself onto the plate and the gold leaf, as a result the leaf diverges and the electroscope acquires a positive charge.



NB. When a glass rod (charged body) is brought near a gold leaf electroscope, the leaf diverges but falls again when the rod is removed.

- This is because similar charges like that of the glass rod /charged body are induced on the metal plate and the leaf causing divergence. When removed the opposite charges from the cap and those on the leaf and the plate neutralize each other hence the leaf collapses.

Uses of the gold leaf electroscope

The following are the uses of gold leaf electroscope.

- **To detect charge on the body.**
  When a charged body is brought near the cap of an uncharged gold leaf electroscope, the gold leaf is seen to diverge indicating that a charge has been induced on the plate and the leaf which results into repulsion between them. If the body is not charged, there is no divergence of the gold leaf.

- **To test the sign of the charge on the body.**
  A charged electroscope is used to test the sign of the charge on a body.
  - When a negatively charged body is brought near the cap of a negatively charged electroscope, an increase in the divergence of the leaf is observed and if a positively charged body is used, a decrease in the divergence of the leaf is observed.
  - When a positively charged body is brought near the cap of a positively charged electroscope, an increase in the divergence of the leaf is observed and if a negatively charged body is used, a decrease in the divergence of the leaf is observed.
  - When an uncharged body is brought near the cap of a negatively or positively charged electroscope, a decrease in the divergence of the gold leaf is observed.
  - This shows that the only way of confirming the kind of charge on the body is by an increase in divergence of the leaf.
  - The table below shows a summary of the results obtained when we test the sign of the charge on a body using different charged electroscopes.

Charge on the electroscope	Charge on the body	Effect on the divergence
+	+	Increase
-	-	Increase
+	-	Decrease
-	+	Decrease
+ or -	No charge	Decrease

- **To test for insulation and conduction properties.**
  A body under test is brought near the cap of a charged electroscope.

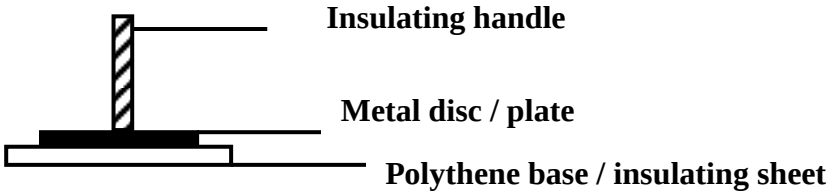
- If the leaf collapses immediately then the body is a conductor because conductors have free electrons hence rapid loss of electrons. If there is no divergence of the leaf then the body is an insulator. If the leaf collapses slowly then the body is a semi conductor.

- **To test the magnitude of the charge on a body.**
  Two spherical balls of different sizes are charged simultaneously and each is brought near the cap of a charged electroscope. It's observed that the small ball shows a slight change in divergence of the leaf and the large ball shows a greater change in divergence of the leaf.

THE ELECTROPHORUS.

This is a device used for producing charges by electrostatic induction and it's used in transfer of charge.

It consists of circular metal plate with an insulating handle placed on an insulating sheet previously charged by rubbing.



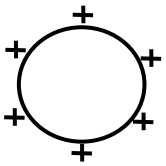
When the plate is earthed by touching with a finger and then removed, it acquires a charge opposite to that on insulating sheet. This charge can be transferred to another conductor and the electrophorus recharged again as before.

Distribution of charge on a conductor.

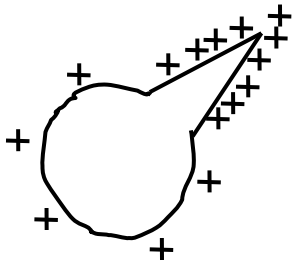
The distribution of charge on the surface of the conductor depends on the shape of the conductor that is charge is concentrated at sharply pointed edges of the conductor hence there is high charge density at sharp edges of the conductor. The high charge density causes ionization of air around the conductor leading to positive and negative ions. Ions opposite to the charge on the conductor are attracted and neutralize the charge hence loss of charge by the process called corona discharge.

Charge density is the amount of charge per unit area.

- For a uniform spherical conductor the charges are evenly distributed and therefore the charge density is uniform for a spherical conductor.

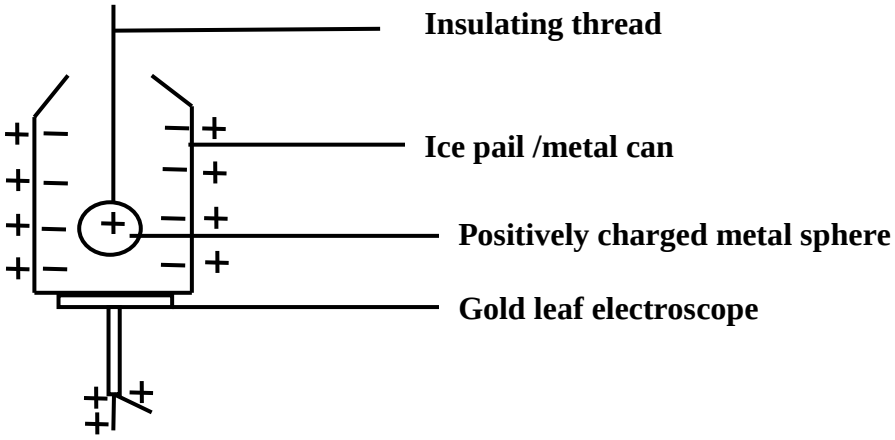


- For pointed conductors there are more charges at the sharp points and therefore the charges density is high at the sharp point.

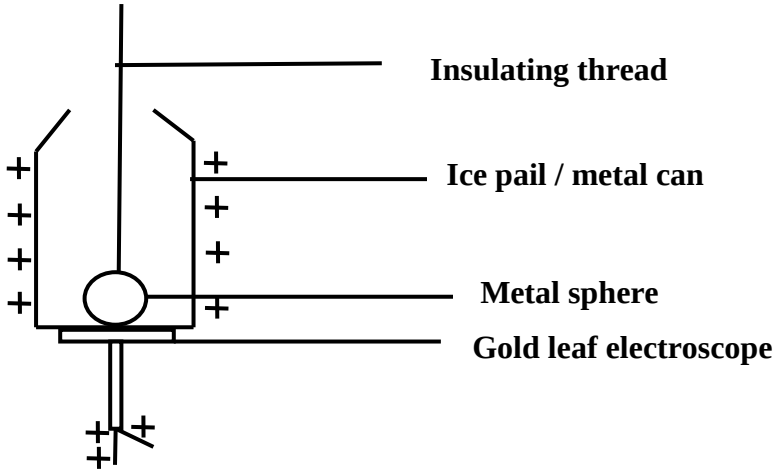


FARADAYS ICE PAIL EXPERIMENT

- An Ice pail is place on top of the cap of a neutral gold leaf electroscope.
- A positively charged metal sphere attached to an insulating thread is lowered into the pail without allowing it to touch the inner surface of the pail.
- Negative charges are induced inside and positive charges are induced outside the pail hence the gold leaf diverges.



- When the sphere is moved in different positions inside the pail without touching the inside, the magnitude of divergence does not change.
- When the sphere is removed the divergence of the gold leaf collapses and when the sphere is tested for the charge it is found to have had its charge.
- The sphere is again lowered into the pail and allowed to touch the pail. The magnitude of divergence remains the same as before, when removed and tested for the charge it had no charge.
- This shows that there is no charge residing inside the hollow conductor. Since the divergence of the gold leaf remained, it means charge resides outside the hollow conductor.



Action of sharp points

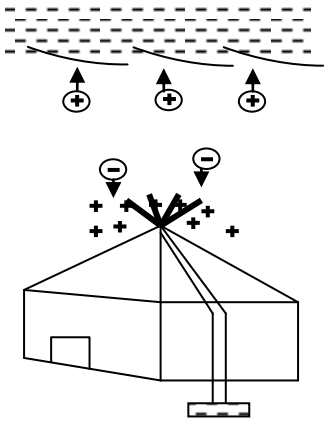
The sharp points of a conductor have high charge density which results in production of strong electric fields. The strong electric field causes the air molecules around the sharp points to be ionized. Ions of opposite sign to the charge at the sharp points are attracted to the sharp point neutralizing some of the charge there.

LIGHTNING.

This is a result of sudden neutralizing of electric charges which occurs between the clouds and the earth when charges build up in the clouds. Lightning occurs when a negatively charged cloud meets a positively charged cloud resulting in a spark which is seen as lightning.

LIGHTNING CONDUCTOR.

Lightning conductors are used to protect buildings from being struck by lightning. It consists of a thick copper stripe with spikes at the top and copper plate buried in the earth.



When a negatively charged cloud passes over a lightning conductor, positive charges are induced on the spikes and negative charges are repelled to the plate. Due to high charge density on the spikes, the air around the spikes is ionized and the negative ions are attracted to the spikes and neutralize some of the charges and positive ions are repelled to the cloud and neutralize some of the charges on the cloud. Hence the house is protected from lightning.

NB. The following **precautions** should be observed when working with an electrostatic device.

- Avoid damp conditions
- Use of insulator as a base stand or hanging with thread
- Avoid sharp points
- Earthing

Dangers of lightning

- Flow of a large current may occur between the charged cloud and the earth.
- Large current may cause fire (burns houses)
- Causes electrocution
- Causes death (kills cows, people, crops etc)
- Damages electronics
- Causes power surge
- Damages buildings

ELECTRIC FIELD.

This is an area around a charge where an electric force can be experienced. The electric field is represented by electric field lines (lines of force). An electric field line is a line drawn such that its direction at any point is the direction of the electric field at that point.

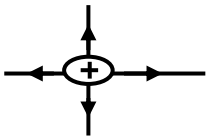
Properties of electric field lines

- They do not intersect or cross each other
- They originate from the positive charge and end at the negative charge
- They are in a state of tension

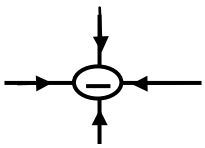
Representing electric fields.

It's represented by lines with an arrow showing the direction of the field. The following are examples of electric field patterns.

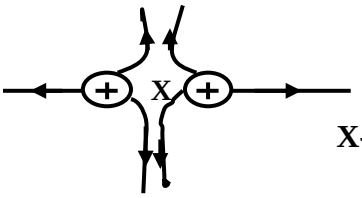
(i) Isolated positive charge.

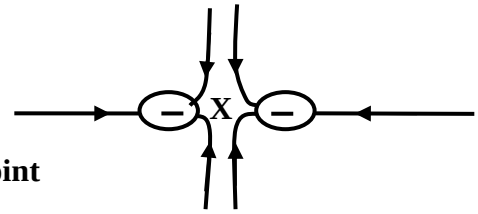


(ii) isolated negative charge



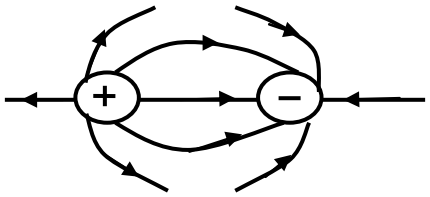
(ii) Like charges near each other



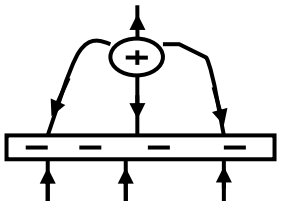


X- Neutral point

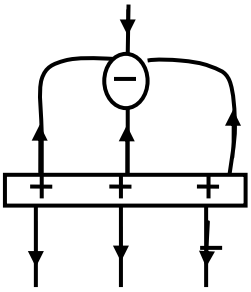
(iii) Un like charges near each other



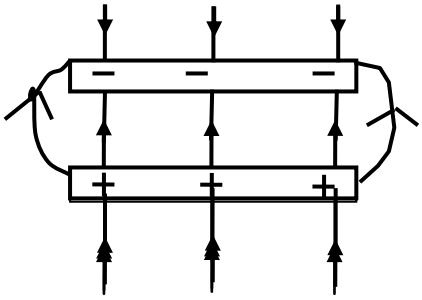
(iv) A positive charge near a negative plate



(iv) Negative charge near a positive plate

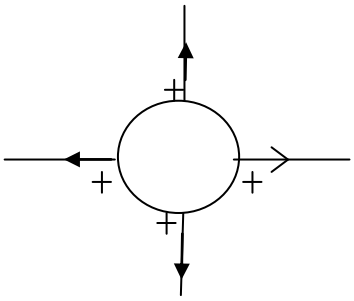


(vi) Two oppositely charged plates



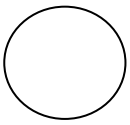
X-a neutral point is the area where the resultant electric force is zero.

(vii) A positively charged hollow sphere



(viii) A negatively charged hollow sphere

(Sketch the field pattern for this)



SOURCES OF E.M.F (SOURCES OF ELECTRICITY)

The major sources of electromotive force (electricity) are;

1. Dry cell
2. Thermocouples
3. Photocells/solar panels
4. A.c generators
5. D.c generators
6. Battery/ accumulators

1. ELECTRIC CELL

An electric cell is a device that drives an electric charge around a circuit in form of current.
Therefore electric cells are sources of electricity (electrical energy).
It converts chemical energy to electrical energy

Types of Electric Cells

There are two major classes of Electric cells;

(a) Primary Cell

This is one that cannot be renewed or recharged when it is used up. This is because the chemical reactions producing electric current are **irreversible**

Examples of primary cells are:-

- Simple cell
- The dry cell (Leclanche cell)

(b) Secondary Cell

This is one that can be renewed or recharged when it is used up

This is because the chemical reactions producing electric current are **reversible**

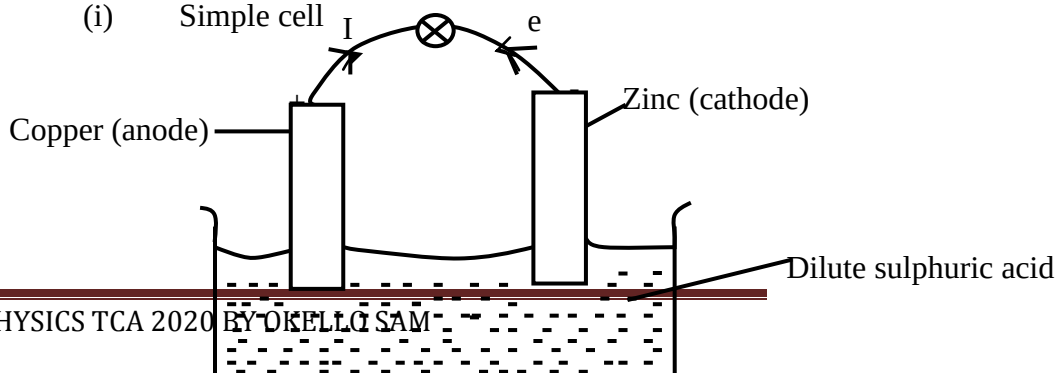
Examples of secondary electric cells are;

- Lead-acid battery, the Nife cell
- Nickel-Cadnium alkaline cell

NB: An electric cell is made by dipping two dissimilar electrodes in a solution of a salt or acid or a base

Example of primary cell

(i) Simple cell



A simple cell is made up of copper plate and zinc plate dipped in dilute sulphuric acid as an electrolyte. The most reactive metal is made cathode and less reactive, an anode hence zinc is made cathode while copper is an anode. When copper and zinc plates are joined with a wire, zinc begins to slowly dissolve in H_2SO_4 and bubbles of hydrogen gas are formed at the copper plate. Dilute sulphuric acid is ionized by water hence ions present are $2H^+$, SO_4^{2-} from sulphuric acid and H^+, OH^- from water. At the zinc plate (cathode)

$Zn(s) \rightarrow Zn^{2+}(aq) + 2e$

$Zn^{2+}(aq) + SO_4{}^{2+}(aq) \rightarrow ZnSO_4(aq)$

The two electrons lost by zinc on dissolving to Zn^{2+} flow to the positive plate (copper anode). The two electrons are gained by displaced hydrogen ions from the acid hence at the copper anode.

$2H^+(aq) + 2e \rightarrow H_2(g)$

Hydrogen gas is given off at the copper anode.

When the two electrodes are joined together by a wire, current flows through for a short time, falls quickly to a very small value and eventually stops flowing. This is brought about by defects of a simple cell.

Defects of a simple cell.

There are basically two defects of a simple cell;

1. **Polarization**
   Is the formation of hydrogen bubbles in the positive electrode (copper plate) of a cell. This is because when the simple cell is in use the zinc plate dissolves giving out electrons which move to the copper plate and combine with hydrogen ions forming hydrogen bubbles around the copper plate hence insulating it from electrolyte reducing the flow of current.
   This always:
   - Increases internal resistance of a cell
   - It sets up back electromotive force (e.m.f)

   How polarization can be minimized:

   - By using an oxidizing agent that oxidizes hydrogen gas to water such as potassium dichromate ($K_2Cr_2O_7$) also called a depolarizer.
   - By occasional brushing of the plates.

2. **Local action**
   This is the formation of tiny local cells at the zinc electrode due to some impurities contained by zinc electrode. This results in the zinc being used up even when current is not supplied. These impurities may include; iron, sulphur, carbon, etc.
   Local action is always minimized by;
   - Coating of zinc surface using mercury

- Using pure zinc
- Using ammonium chloride as an electrolyte instead of dilute sulphuric acid.

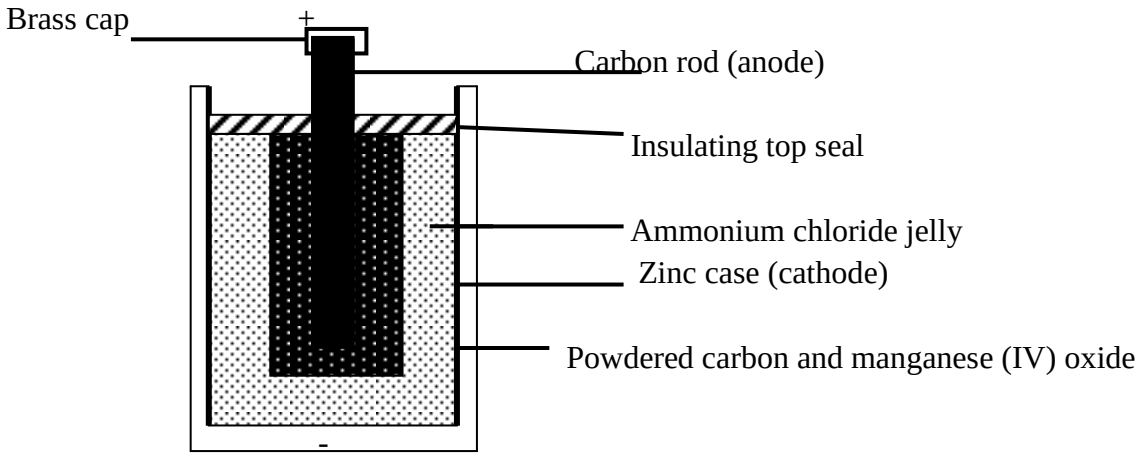
(ii) Dry cell (leclanche cell)

This is a cell used in torches and transistor radios and has an emf of 1.5V. This type of cell has no liquid hence a dry cell.
The electrolyte used is ammonium chloride jelly instead of a solution. The source of energy is the chemical action between zinc and ammonium chloride but as a result hydrogen is produced which collects at the carbon rod and polarizes the cell.

Manganese dioxide acts as a depolarizer so that the hydrogen produced is oxidized to water which makes the cell wet after being used up.
Powdered carbon reduces the internal resistance of the cell.

The zinc case acting as the negative electrode reacts with ammonium chloride and an emf is set up from the produced electrons of zinc. This emf keeps on reducing due to local action.
A brass cap prevents mechanical wear, carbon rod acts as a positive electrode and the insulating seal prevents drying up of the jelly.

Dry cell (leclanche cell)



Precaution when using dry cells

- Large currents should not be drawn from the dry cell within a short time
- Short circuiting its terminals can ruin the cell
- The cell should be stored in dry places.

Advantages of dry cells

- It gives large amount of current
- It is portable
- It uses a jelly as an electrolyte instead of a solution

SECONDARY CELLS

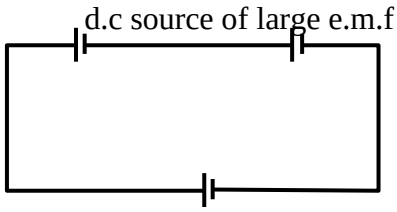
Examples of secondary cells

(a) Lead-acid accumulator:

Lead-acid accumulator consist of lead as a negative electrode and lead(II) oxide as a positive electrode.

Dilute sulphuric acid is used as an electrolyte. It is used in ignition and lighting system of motor vehicles.

Charging of lead-acid accumulator



- The tops of the accumulator are removed.
- The accumulator is connected positive to positive and negative to negative to a d.c source of greater e.m.f.
- This is left for some time and the accumulator is fully charged when bubbles in the electrolyte are formed.

NB. A charged accumulator can be discharged by connecting a wire across its terminals.

Electrons from the negative terminal will flow through the wire to neutralize the positive charge from the positive terminal. This continues for some time until the accumulator is fully discharged.

How to prolong the life of the lead-acid accumulator

- Avoid putting on bare floors
- Top up electrolyte with distilled water to compensate any loose of water in accumulator
- Recharge regularly
- Avoid over discharging
- Charged accumulators should not be examined with naked flames
- Grease/greasing the terminals
- Avoid shorting of the terminals

(b) Nife/Alkaline cell

It consists of nickel hydroxide as an anode and cadmium as the cathode.

Electrolyte used is an alkaline such as potassium hydroxide dissolved in water. The common types are nickel cadmium and nickel iron accumulators.

Advantages of a Nife cell over lead-acid accumulator

- They last longer
- Provides a large current without affecting the cell
- It can be left in a discharged state for a long period of time without harm
- It has greater e.m.f (electromotive force)
- Are not affected by over charging
- Are portable compared to lead acid accumulators.

Disadvantages of a Nife cell over lead-acid cell

- It has high resistance than lead-acid cell
- It is expensive
- It is bulky
- They have high internal resistance.

CURRENT ELECTRICITY

Current electricity involves movement of electric charges. The charges that are involved in movement are the electrons.

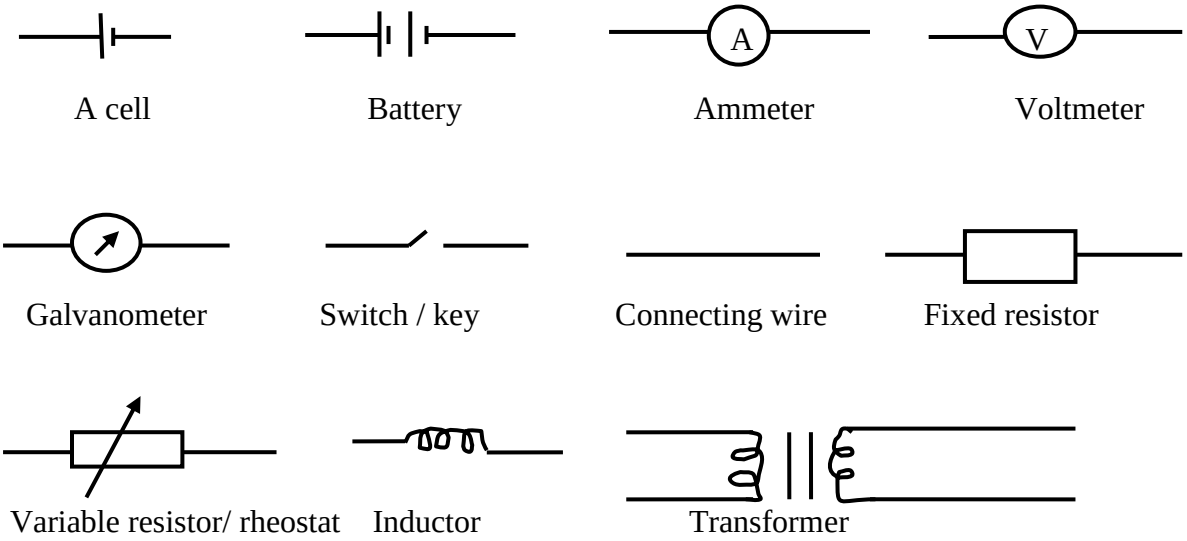
Electricity is thus flow of electrons / charge.

Current is the rate of flow of charge.

Electrical symbols

When describing or drawing circuit diagrams the exact instrument is not drawn. Symbols that represent various electric instruments /devices are drawn.

The following are the commonly used symbols.



A group of cells is called a battery.

Conductors and insulators

A conductor is a material that allows electricity to flow through it. This is because they have free mobile electrons.

Examples include;

- Metals such as silver, copper, constantan
- Salts
- Inorganic solutions

Insulators are materials that do not allow electricity to pass through them.

Examples include rubber, plastics, wood, paper, glass, ebonite etc

CURRENT

Is the rate of flow of charge.

Charge is the quantity of electricity that flows from one point of the conductor to another. In metals the charges that constitutes a current are the electrons, in salts and acid solutions the charge carriers are the ions.

From definition of current;

Current I = $\frac{charge\ (Q)}{time\ (t)}$

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

$$Q = It$$

The SI unit of current is Ampere (**A**)

An ampere is an electric current in a circuit when one coulomb of charge passes through every point in one second.

The SI unit of charge is a coulomb (**C**)

A coulomb is the quantity of charge that passes through a given point of the conductor in one second when a steady current of one ampere flows.

NB: The alternative unit of current is a coulomb per second.

Examples

1. Find the electric current flowing through the wire when 0.8 C of charge passes a point in 2 seconds.

Solution

$$I = \frac{Q}{t} = \frac{0.8}{2} = 0.4\,A$$

2. A self starter of a vehicle uses a current of 20 A in 10s. Calculate the quantity of electricity that flows through the starter.

Solution

$$Q = It = 20x10 = 200C$$

3. A current of 5 A passes in a circuit for 25 seconds.

(i) Find the amount of charge that passes any one point in a circuit at this time.

(ii) How long must a current of 10 mA flow in order to pass the same amount of charge.

Solution

(i) $Q = It = 5x25 = 125C$

(ii) $t = \frac{Q}{I} = \frac{125}{10x10^{-3}} = 125000\,s$

RESISTANCE OF A CONDUCTOR.

Is the opposition to the flow of current through the conductor.

The SI unit of resistance is ohm (Ω).

An ohm is a resistance of a conductor such that when a p.d of one volt is connected across its ends a current of one ampere flows through it.

Factors that affect resistance of a conductor.

The following physical properties affect the resistance of a conductor

- Length of the conductor. Increasing length of the conductor increases its resistance.
- Cross sectional area (thickness) of the conductor. Increase in cross sectional area reduces on the resistance of the conductor.
- Temperature. Increasing the temperature of the conductor increases it resistance.

It follows that $R \alpha l$ …….. (i)

$$R \alpha \frac{1}{A} \text{ ……} \quad \text{(ii)}$$

Hence combining equations (i) and (ii)

$$R \alpha \frac{l}{A}$$

$$R = \frac{\rho l}{A}$$

Where ρ *is the resistivity of the conductor*.

Potential difference (p.d)

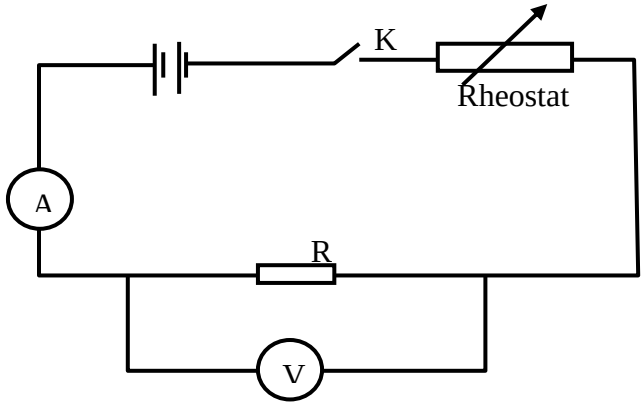
Is the work done in moving one coulomb of charge from one point to another in a circuit**.**

Potential difference thus work done per coulomb of charge.

$$P.d\ (V) = \frac{Work\ done, W}{Charge, Q} \ldots\ldots\ldots\

It states that the current through a resistor is directly proportional to the potential difference (P.d) across its ends provided temperature and other physical conditions are kept constant.

Experiment to verify ohm's law



- Switch K is closed and the rheostat adjusted to give the smallest current readable on the ammeter.
- The current ***I*** and the voltage, **V** are read from the ammeter and voltmeter respectively.
- The procedure is repeated for different values of ***I*** and **V** by adjusting the rheostat.
- Results are recorded in a suitable table
- A graph of **V** against **I** is plotted and a straight line graph through the origin obtained.
- This shows that I is proportional to V hence verifying OHM'S law.

It implies that I αV and similarly $V \alpha I$

$I \alpha V$
$V \alpha I$
$V = KI$
Where K is the constant of proportionality. But K=R (Resistance)
Therefore V=IR

V=IR

Examples

1. A 2v accumulator is connected to a 10 Ohm resistor. Find the current flowing in the resistor.

Solution

From $V = IR$

$$I = \frac{V}{R} = \frac{2}{10} = 0.2\ A$$

2. A current of 6mA flows in a radio with resistance of 2kΩ . Calculate the p.d across the resistance.

Solution

From V=IR

I=6mA = $\frac{6}{1000} = 6 \times 10^{-3} A$

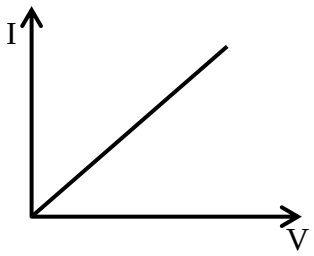
R=2kΩ = 2x1000 = 2000 Ohm

V= $6 \times 10^{-3} x\ 2000 = 12V$

OHMIC AND –OHMIC CONDUCTORS

Ohmic conductors are the conductors that obey Ohm's law. The graph of current, I against voltage, V is a straight-line through the origin since current is directly proportional to voltage. Examples include; metals, Alloys such as constantan wire.

Current – voltage characteristics for ohmic conductors

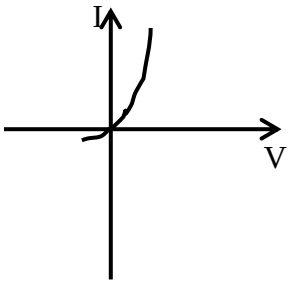


Non-ohmic conductors are those conductors that do not obey Ohm's law. Examples include; Semi-conductor diode, filament lamp, thermionic diode, ironic solution e.g. dilute sulphuric acid, Neon gas.

Current-voltage characteristics for Non-ohmic conductor

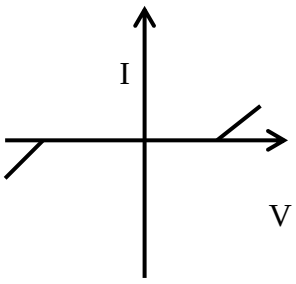
Semi-conductor diode

(i)

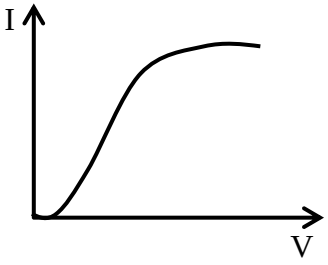


Dilute sulphuric acid

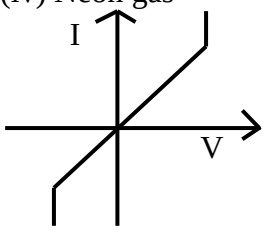
(ii)



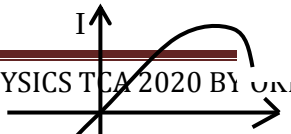
(iii) Thermionic diode



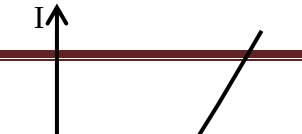
(iv) Neon gas



(v) Filament lamp



(vi) Gas discharge tube



V

V

ELECTRICAL POWER

Is the rate of transfer of electrical energy.

Electrical power = $\frac{energy\ transfered}{time}$

P = $\frac{Energy}{Time}$

But energy is the same as the work done

Therefore P = $\frac{Work\ done}{Time}$

Also power = VI

But V = IR

Therefore P = (IR)I

= I^2R

Also I = $\frac{V}{R}$

Power = $\left(\frac{V}{R} \times R\right)\frac{V}{R}$

Power = $V\left(\frac{V}{R}\right)$

Power = $\frac{V^2}{R}$

From power = $\frac{work\ done}{time(\ t)}$

VI = $\frac{Work\ done}{t}$

Therefore work done = VIt

Where V=voltage

I=current

t=time

Examples

1. A current of 2A flows through a bulb for 10s. If the P.d across the bulb is 6V, calculate the work done.

Solution

From Work done = VIt

But V=6V, I=2A and t=10s

Therefore work done = 6x2x10

= 120J

Hence work done = 120J

2. A charge of 40C flows through an ammeter in 20s. What is the reading of the ammeter?

   solution

   From Q = It

   Therefore I=$\frac{Q}{t} = \frac{40}{20} = 2A, hence\ reading\ of\ ammeter\ is\ \mathbf{2A}$

3. When a 12V lamp is connected to a car battery, a current of 3A passes through the filament. Calculate the energy transferred by the lamp in 20s

   Solution

   From power = $\frac{work\ done}{time,t}$

   But energy is equal to work done

   Therefore work done/energy = VIt

   = 12x3x20

   = 720J

   Hence the energy transferred by the lamp in 20s is 720J

RESISTORS

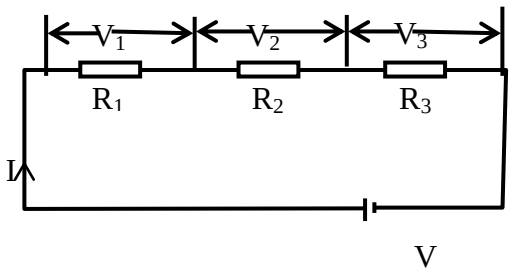
Resistors are electrical devices used to control the size of current and voltage in a given circuit.

Resistors are either fixed or variable

Resistor arrangements.

Resistors can be arranged either in series or in parallel depending on the purpose for which they are intended for.

(i) Series arrangements



Characteristics of resistors in series

- Same current, I flows though each of the resistors.
- The total P.d, V is equal to the sum of individual P.d's

i.e. $V=V_1 + V_2 + V_3$

by Ohm's law, V = 1R

$V_1 = IR_1$

$V_2 = IR_2$

$V_3 = IR_3$

Therefore $V = IR_1+IR_2+IR_3$

$V = I(R_1 + R_2 + R_3)$

$\frac{V}{I} = R_1 + R_2 + R_3$

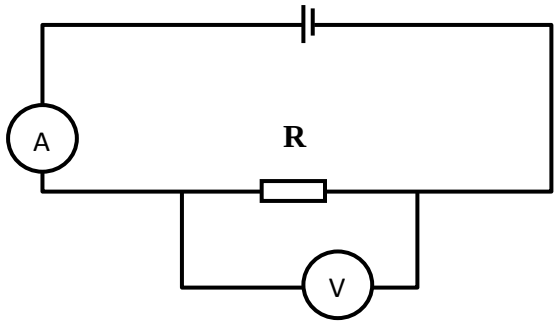
$But\ \frac{V}{I} = R(effective\ resistance)$

$therefore\ R = R_1 + R_2 + R_3$

The total resistance for resistors in series is equal to the total sum of individual resistors.

Measurement of resistance ,R , of a resistor

A dry cell in a holder, an ammeter and a resistor of resistance **R** are connected is series as shown below.

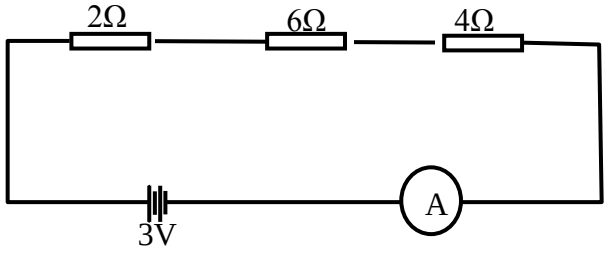


The ammeter reading I and voltmeter reading V are read and recorded.

The resistance of the resistor R is now calculated from $R = \frac{V}{I}$

Example:

1. The figure below shows three resistors connected in series to a battery of 3V



Calculate:

(i) Total/effective resistance
(ii) Reading of the ammeter
(iii) P.d across each resistor
(iv) Power dissipated in a 6Ω resistor

Solutions

(i) Total resistance, $R = R_1+R_2+R_3$

$= 2+6+4$

$R=12\Omega$

(ii) Reading of ammeter

$V = IR$

$I=\frac{V}{R} = \frac{3}{12} = 0.25A$

Therefore I=0.25A

(iii) P.d across 2Ω resistor

$V_1 = IR$

$V_1 = 0.25x2$

$= 0.5V$

P.d across 6Ω resistor

$V_2 = IR$

$=0.25x6$

$= 1.5V$

P.d across 4Ω resistor

$V_3=IR$

$=0.25x4$

$=1.0V$

(iv) Power (rate of transfer of energy) in 6Ω resistor

power = $\frac{V^2}{R} = \frac{1.5^2}{6} = 0.375W$

OR $P=VI = 1.5x0.25$

$= 0.375W$

OR $P=I^2R = (0.25)^2x6$

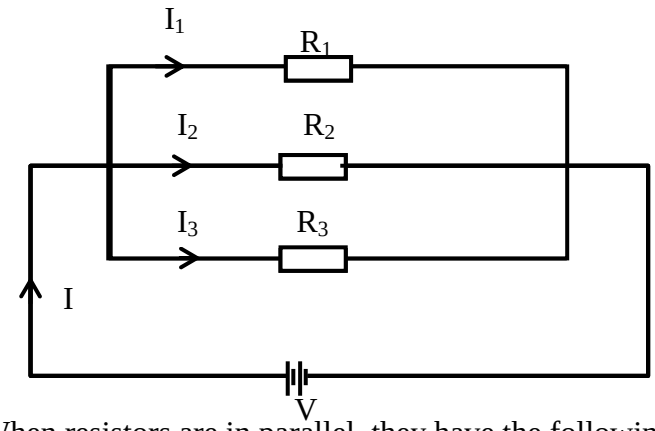
$=0.375W$

NB. If bulbs are connected in series;

- If one bulb blows, others stop working
- Bulbs do not use the same P.d
- The battery runs down easily
- Bulbs are not managed separately

These are the disadvantages of connecting bulbs in series

RESISTORS IN PARALLEL



When resistors are in parallel, they have the following characteristics

- P.d across each of them is the same
- Total current, I is equal to the sum of individual current flowing through each resistor
  From $I=I_1+I_2+I_3$

V=IR

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

$I_1 = \frac{V}{R_1}$

$I_2=\frac{V}{R_2}$

$I_3 = \frac{V}{R_3}$

Therefore $I = \left(\frac{V}{R_1} + \frac{V}{R_2} + \frac{V}{R_3}\right)$

$\frac{I}{V} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$

But $\frac{I}{V} = \frac{1}{R}$

$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$

Where R is the effective resistance

NB: For any two resistors in parallel,

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2}$$

$$\frac{1}{R} = \frac{R_1 + R_2}{R_1 R_2}$$

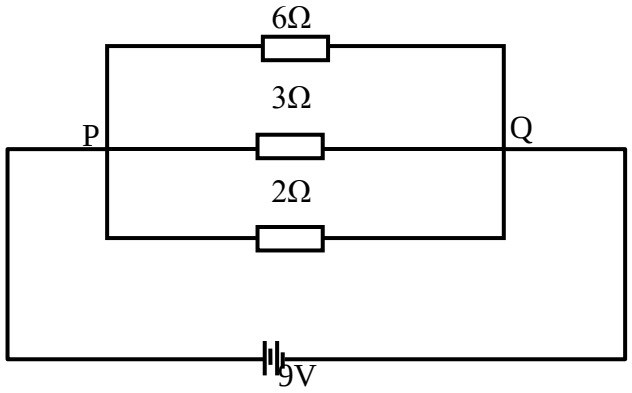
$$R = \frac{R_1 R_2}{R_1 + R_2}$$

$$\boxed{R = \frac{R_1 R_2}{R_1 + R_2}}$$

NB. For any two resistors in parallel the effective resistance R = $\frac{Product\ of\ the\ two\ resistors}{Sum\ of\ the\ two\ resistors}$

Examples.

1. The figure below shows arrangement of resistors connected to a battery of 9V.



Calculate:

(i) Effective (total) resistance in the circuit
(ii) Total current supplied by the battery
(iii) Current through each resistor
(iv) Power dissipated in the circuit.
(v) Power (rate of transfer of energy) dissipated in each resistor

Solution

For parallel resistors,

(i) $\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$

$$\frac{1}{R} = \frac{1}{2} + \frac{1}{3} + \frac{1}{6}$$

$$\frac{1}{R} = \frac{3 + 2 + 1}{6}$$

$$\frac{1}{R} = \frac{6}{6}$$

$$R(6) = 6 \times 1$$

$$\frac{6R}{6} = \frac{6}{6}$$

$$\boldsymbol{R = 1\Omega}$$

(ii) Total current supplied

$V = IR$

$I = \frac{V}{R} = \frac{9}{1}$

$I = 9A$

(iii) Current through 6Ω $I_1 = \frac{V}{R} = \frac{9}{6} = 1.5A$

Current through 3Ω, $I_2 = \frac{V}{R} = \frac{9}{3} = 3.0A$

Current through 2Ω, $I3 = \frac{V}{R} = \frac{9}{2} = 4.5A$

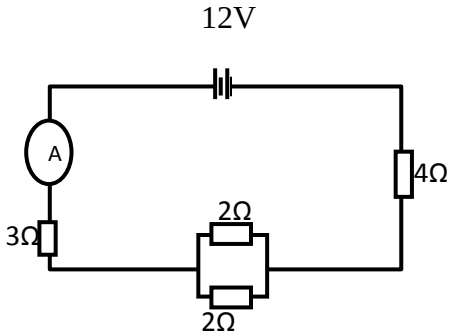
(iv) P=VI = 9x9=81W

(v) Power dissipated in 6Ω ; $P=I^2R=1.5^2x6 =13.5W$

Power dissipated in 3Ω; $P=I^2R=3^2x3=27W$

Power dissipated in 2Ω; $P=I^2R= 4.5^2x2=40.5W$

2. Four resistors are connected across a 12V battery of negligible internal resistance as shown below



Calculate;

(i) Reading of the ammeter

(ii) P.d across parallel combination of resistors

Solution:

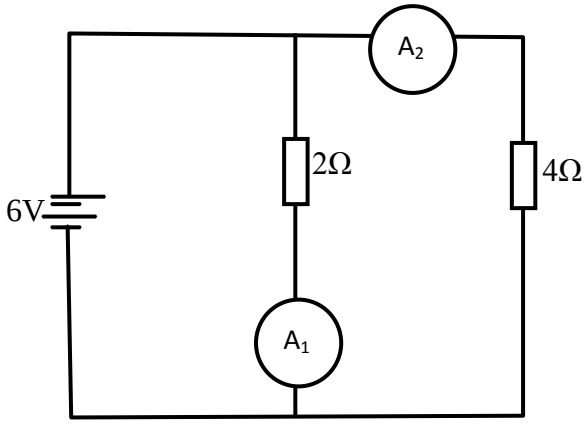
(i) $I = \frac{V}{R}$

$but\ R = \frac{(2\times2)}{2+2} + 4 + 3 = 8\Omega$

$I = \frac{12}{8} = 1.5A$

(ii) $V = IR = 1.5 \times 1 = 1.5V$

3. The figure below shows two resistors connected to a battery of negligible internal resistance.



Find the:

(i) Readings of ammeters A_1 and A_2
(ii) Total power dissipated in the resistors

Solution

(i) Reading of Ammeter A_1

current through A_1, $I_1 = \frac{V}{R_1} = \frac{6}{2} = 3A$

Current through A_2, $I_2 = \frac{V}{R_2} = \frac{6}{4} = 1.5A$

Total current flowing through the circuit = 3+1.5 = 4.5A

(ii) Total power dissipated in the resistor

$P = VI\ or\ P = I^2R\ or\ P = \frac{V^2}{R}$

$P = 6 \times 4.5$

$P = \mathbf{27W}$

4. When two identical heating elements of a kettle connected in series to a 240V, the power developed is 400W. Determine;

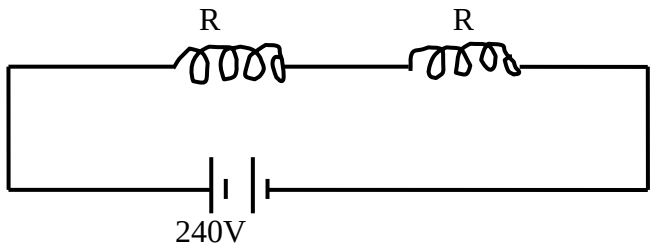
(i) Resistance of either elements

(ii) Power developed when connected in parallel to the same supply.

Solution

(i) For two identical heating elements their resistances are the same

$R_1=R_2=R$



Effective resistance $R=R_1+R_2$

$= R+R$

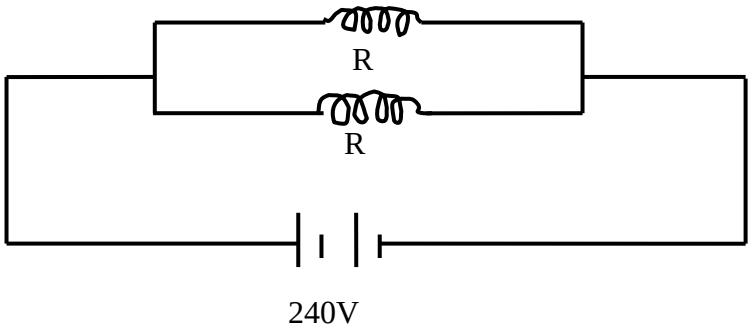
$= 2R$

But $P=\frac{V^2}{R}$

$400=\frac{240^2}{2R}$

$R=\frac{240x240}{2x400}=72\Omega$

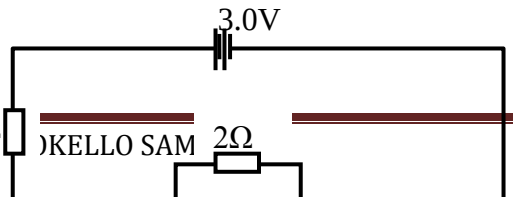
(iii)



Effective resistance $R=\frac{RxR}{R+R}=\frac{R^2}{2R}=\frac{R}{2}=\frac{72}{2}=36\Omega$

But Power $P=\frac{V^2}{R}=\frac{240x240}{36}=1600W$

5. A battery of e.m.f 3.0V and negligible internal resistors is connected across 3 resistors of 5Ω, 2Ω and 2Ω as shown below.



Calculate:

(i) Current supplied by battery

(ii) Power dissipated in 5Ω resistor

(iii) The P.d across 5Ω resistor

(iv) Current through each of the two resistor

Solutions

(i) Current supplied by battery

Total Resistance in parallel R = $\frac{R_1R_2}{R_1+R_2} = \frac{2\times2}{2+2} = \frac{4}{4} = 1\Omega$

$R_{effective}$ = 5Ω + 1Ω = 6Ω

$$I = \frac{V}{R} = \frac{3}{6} = 0.5A$$

(ii) Power dissipated in 5Ω resistor

$P=I^2R$

$P=(0.5)^2 \times 5$

P= 1.25W

(iii) P.d V=IR

V=0.5x5

V=2.5 V

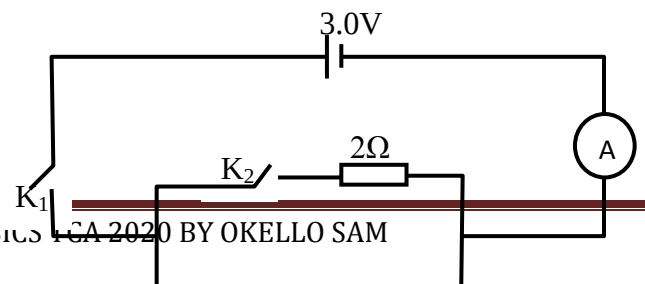
(iv) P.d across 2Ω resistors in parallel

V=3.0-2.5

= 0.5V

Current through 2Ω resistors, $I=\frac{V}{R} = \frac{0.5}{2} = 0.25A$

6.The figure below shows two resistors connected to a battery



What will be the reading of the ammeter if switch K_2 is

(i) Open and K_1 closed
(ii) Closed and K_1 closed

Solution

(i) If K_2 is open and K_1 closed
Current, I = $\frac{V}{R_2} = \frac{3.0}{4} = 0.75A$

(ii) K_2 closed and K_1 closed
Resistance in parallel, R = $\frac{R_1R_2}{R_1+R_2} = \frac{2\times4}{2+4} = \frac{8}{6} = 1.33\Omega$

$$I = \frac{V}{R}$$
$$I = \frac{3.0}{1.33}$$
$$I = 2.25A$$

Electromotive force (E.m.f):

Is the P.d across the cell when it is not delivering current or is the pd across the terminals of a cell in an open circuit.

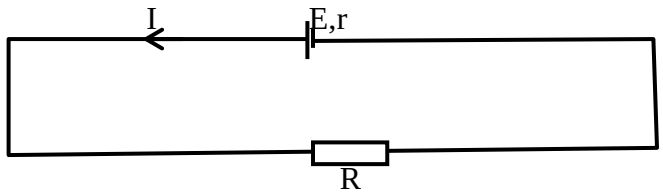
A cell that delivers current in a circuit has resistance that it offers to current flow in a circuit. This resistance is called the internal resistance of a cell(r)

Internal resistance of a cell/battery

Internal resistance of a cell/battery is the opposition to flow of current within a cell or battery itself.

NB: Internal resistance of a cell behaves like a small resistor connected in series with a cell.

Consider a cell with internal resistance, r connected in series with the resistor, R as shown below.



The total resistance in the circuit = $R_{effective}$

$R_T = R + r$

But e.m.f, $E = IR_T$

E=I(R+r)

E=IR+Ir

IR is the P.d dropped across R, the external resistance

Ir is the P.d dropped across r, the internal resistance

From ohm's law

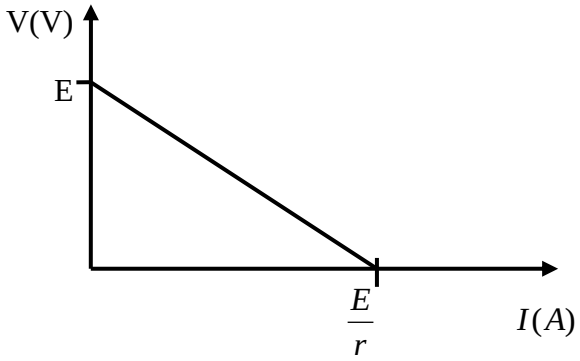
V=IR

E=V+Ir

V=E-Ir

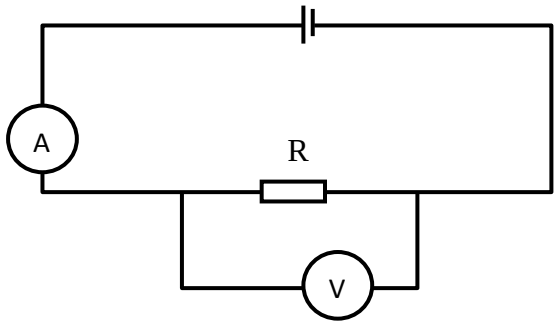
V=-Ir+E

When a graph of V against I is plotted, the slope of the graph is the internal resistance of a cell while the intercept on the V-axis is the E.m.f of a cell,E



Experiment to determine internal resistance of a cell

- A voltmeter is connected across a cell and its reading, E noted. This is the e.m.f of the cell.
- The cell is now connected in series with a resistor of resistance, R and an ammeter.
- The voltmeter is now connected across the resistor .
- The values of I and V are read and recorded from the ammeter and voltmeter respectively when the circuit is complete as shown below.



Internal resistance of a cell, r is now calculated from $\boldsymbol{r = \frac{E-V}{I}}$

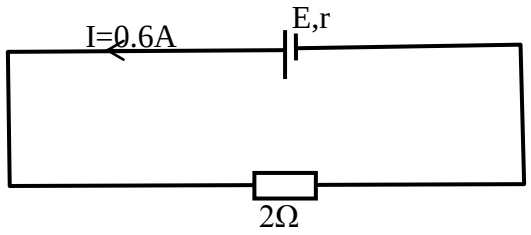
EXAMPLES

1. A cell drives a current of 0.6A through a 2Ω resistor. If the resistance is increased to 7Ω, a current of 0.2A flows through it. Calculate;

   i. The e.m.f of a cell, E
   ii. The internal resistance, r of a cell

Solution

Case I

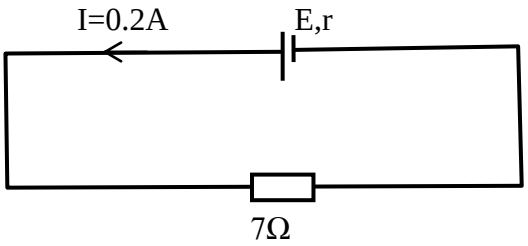


E = I(R+r)

E=0.6(2+r)

E=1.2+0.6r----------(i)

Case II



E = I(R+r)

E=0.2(7+r)

E=1.4+0.2r----------(ii)

But eqn (i) = eqn(ii)

1.2 + 0.6r = 1.4 + 0.2r
1.2 -1.4 = 0.2r-0.6r

$$\frac{-0.2}{-0.4} = \frac{-0.4r}{-0.4}$$

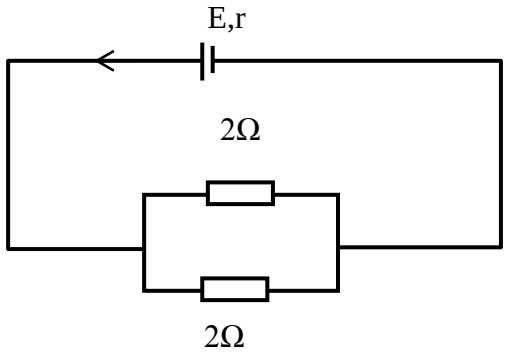
$$r = \frac{0.2}{0.4}$$

$$r = 0.5\Omega$$

2. A dry cell supplies a current of 1.2A through two 2Ω resistors connected in parallel. When the resistors are connected in series, the current flowing in a circuit is 0.4A. Find the electromotive force (e.m.f) of the cell

Solution

Case I



E=I(R+r)

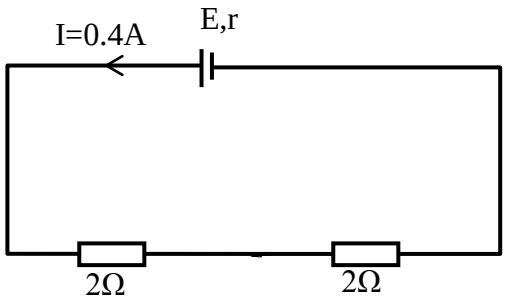
E=1.2$\left(\left(\frac{2\times2}{2+2}\right)+r\right)$

E=1.2$\left(\left(\frac{4}{4}\right)+r\right)$

E=1.2(I+r)

E=1.2+1.2r--------(i)

Case II



E=I(R+r)

E=0.4$((2+2)+r)$

E=0.4(4+r)

E=1.6+0.4r----------(ii)

But eqn(i) = eqn(ii)

1.2+1.2r=1.6+0.4r

1.2r-0.4r = 1.6-1.2

$$\frac{0.8r}{0.8} = \frac{0.4}{0.8}$$
$$r = 0.5\Omega$$

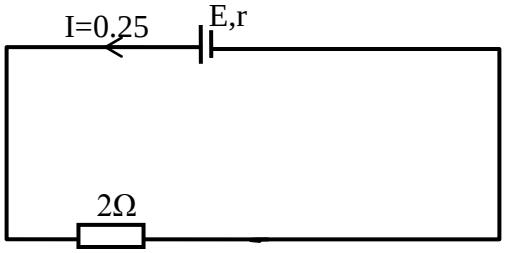
But E=I(R+r)
= 1.2 (1+0.5)
= 1.2 x1.5
= 1.8 V

3. A cell is joined in series with a resistor of 2Ω and a current of 0.25A flows through it. When a second resistor of 2Ω is connected in parallel with the first, the current increases to 0.3A. Calculate;

(i) Internal resistance, r of a cell
(ii) E.m.f of a cell, E

Solutions:

Case I



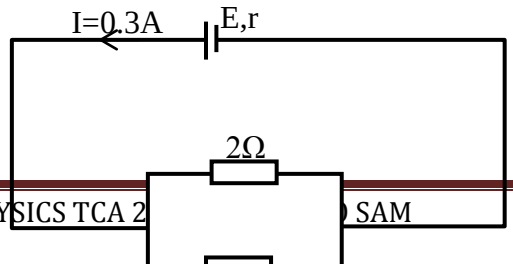
From;

E=I(R+r)

E=0.25(2+r)

E=0.5+0.25r---------(i)

Case II



2Ω

From;

$E = I(R + r)$

$E = 0.3\left(\left(\frac{2 \times 2}{2 + 2}\right) + r\right)$

$E = 0.3\left(\left(\frac{4}{4}\right) + r\right)$

$E = 0.3(1 + r)$

$E = 0.3 + 0.3r - - - - - - - - (ii)$

But eqn (i)=eqn(ii)

$0.5 + 0.25r = 0.3 + 0.3r$

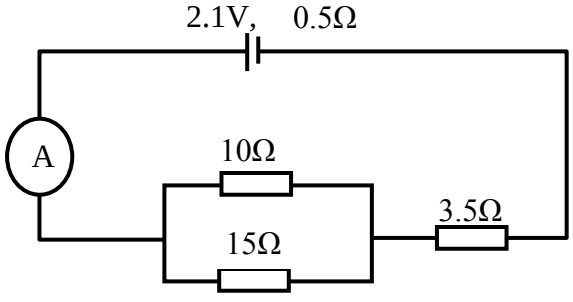
$0.5 - 0.3 = 0.3 - 0.25r$

$\frac{0.2}{0.05} = \frac{0.05r}{0.05}$

$\boldsymbol{r = 4\Omega}$

(ii) E.m.f, E
From; E=I(R+r)
Using the Second eqn: 0.3+0.3r = E
E=0.3+(0.3x4)
= 0.3 + 1.2
E=1.5V

4. A diagram below shows a cell of e.m.f, 2.1V and internal resistance, 0.5Ω



Determine the reading of ammeter (current flowing in the circuit)

Solution:

$R_{effective} = \frac{R_1 R_2}{R_1 + R_2} + R_3$

$= \frac{10 \times 15}{10 + 15} + 3.5$

$=\frac{150}{25} + 3.5$

$R = 6 + 3.5 = 9.5\,\Omega$

$E = I(R + r)$

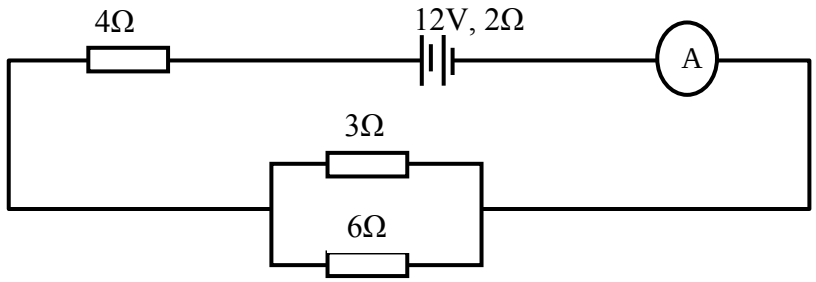
$2.1 = I(9.5 + 0.5)$

$2.1 = I(10)$

$\frac{2.1}{10} = \frac{10I}{10}$

$\boldsymbol{I = 0.21A}$

5. The figure below shows a battery of e.m.f, 12V and internal resistance, 2Ω connected in series with an ammeter.



Calculate;

(i) Reading of the ammeter
(ii) P.d across each resistor
(iii) Current flowing through 3Ω resistor
(iv) Power dissipated across 6Ω resistor

Solution:

(i) For parallel resistors, $R = \frac{R_1 R_2}{R_1 + R_2}$

$$R = \frac{3\times6}{3+6} = \frac{18}{9} = 2\Omega$$

$R_{effective} = (4 + 2) + 2$
$= 6+2$
$= \mathbf{8\Omega}$

From;

V=IR

12=I(8)

$\frac{12}{8} = \frac{8I}{8}$

I=1.5A

(ii) P.d across each resistor

- P.d across 4Ω
  V_1=IR
  V_1=1.5 X 4
  V_1= 6V

- P.d across internal resistor
  V_2 = Ir
  V_2 = 1.5x2
  V_2 = 3V

- P.d across parallel resistors
  V_3 = IR
  V_3 = 1.5x2
  V_3 = 3V

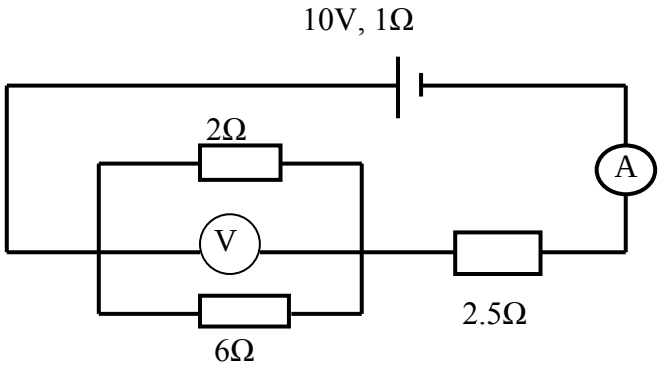
(iii) Current through 3Ω resistor
From;
V = IR
I = $\frac{V}{R}$
$I = \frac{3}{3}$
I = 1A

Current through 6Ω
$I = \frac{V}{R}$
$I = \frac{3}{6}$
I = 0.5A

(iv) Power dissipated across 6Ω resistor
P = VI
P = 3x0.5 = 1.5W
Or
P = I^2R
P = $(0.5)^2$ x 6
P = 0.25 x 6
P = 1.5W
Or
$P = \frac{V^2}{R}$

$P = \frac{3^2}{6} = \frac{9}{6} = 1.5W$

6.A battery of emf 10Vand internal resistance 1Ω is connected to resistors of 6Ω, 2Ω and 2.5Ω as shown below.



(i) Calculate the ammeter and voltmeter readings
(ii) Calculate the current through the 2Ω resistor
(iii) Find the rate at which electrical energy is converted to heat energy in a 6Ω resistor

Solution

(i) For parallel resistors

$$R=\frac{R_1R_2}{R_1+R_2}=\frac{2x6}{2+6}=\frac{12}{8}=1.5\Omega$$

$$R_{eff}=1.5+2.5+1=5\Omega$$

$$I=\frac{V}{R}=\frac{10}{5}=2A$$

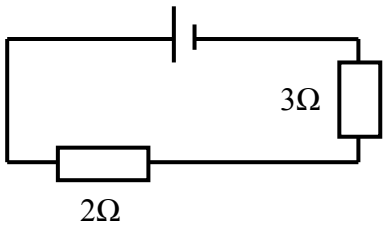
$$V=IR=2x1.5=3V$$

(ii) $$I=\frac{V}{R}=\frac{3}{2}=1.5A$$

(iii) Rate of conversion of electrical energy to heat energy is the same as power

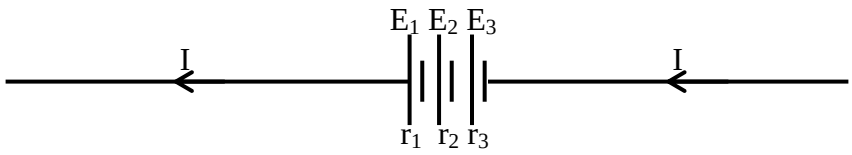
$$P=\frac{V^2}{R}=\frac{3^2}{6}=\frac{9}{6}=1.5W$$

Exercise



A cell of emf E and internal resistance 1.0Ω is connected in series with resistor 2 Ω and 3 Ω as shown above. If the potential difference across the 3 Ω resistor is 1.5 V, calculate the emf of the cell.
Ans : 3.0 V

CELLS IN SERIES:
A group of cells connected in series together constitutes a battery. When the cells are in series, the total e.m.f, E of a battery is equal to the sum of e.m.f of individual cells and internal resistance is also equal to the sum of internal resistances of individual cells.
Consider 3 cells of e.m.f, E_1, E_2, E_3 each of internal resistances, r_1, r_2, r_3 arranged in series as shown below.



Total e.m.f, $E= E_1+E_2+E_3$

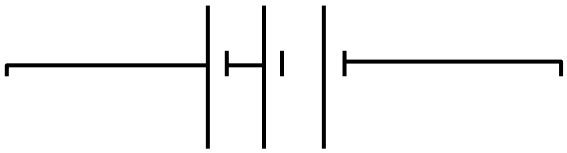
Total internal resistance, $r = r_1+r_2+r_3$

NB: When cells are connected in series

- Total e.m.f is maximum
- Total internal resistance is high (maximum)
- Current delivered is small

Examples

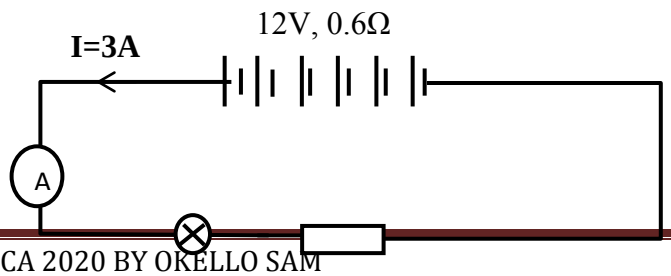
1. 3 cells each of 1.5V and internal resistance 1Ω are to be arranged in different ways. Draw the diagram to show how the cells can be arranged to deliver the least current.



2. A battery is made up of 6 cells each having the e.m.f of 2V and internal resistance of 0.1Ω connected in series with an ammeter of negligible resistance, 1.4Ω resistor and a filament lamp. If the ammeter reads 3A, calculate;

(i) Resistance of the lamp
(ii) P.d across the lamp

Solution



R_s 1.4Ω

(i) Total e.m.f, E = 2x6 = 12V
Total internal resistance = 0.1x6 = 0.6Ω
From E = I(R+r)
But R= (R_s+1.4)Ω
Where E = 12V
I = 3A
r=0.6Ω
R_s =?

12 = 3(R_s=1.4+0.6)

12=3(R_s+2)

12=3R_s+6

12-6 = 3R_s

$$\frac{6}{3} = \frac{3R_s}{3}$$

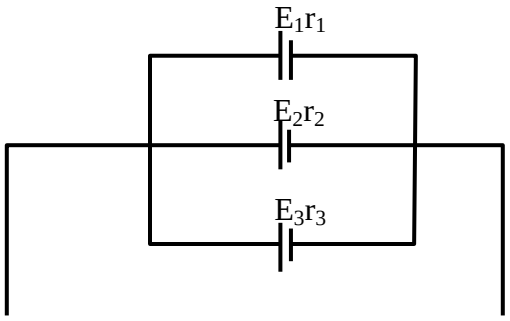
R_s = 2Ω

(ii) **V=** $IR_S = 3x2 = 6V$

CELLS IN PARALLEL

When identical cells are connected in parallel, the resultant e.m.f of a battery is equal to the e.m.f of one of the cells and internal resistance is obtained using the formula of resistors connected in parallel.

Consider 3 identical cells each of e.m.f, E=E_1 =E_2=E_3 and internal resistance, r=r_1, r_2 and r_3 connected in parallel as below:



NB: When cells are connected in parallel

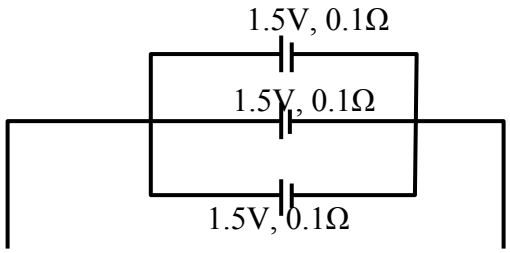
(i) Total e.m.f is minimum

(ii) Total internal resistance is minimum
(iii) Current delivered is maximum
(iv) Their life span is prolonged.

Examples

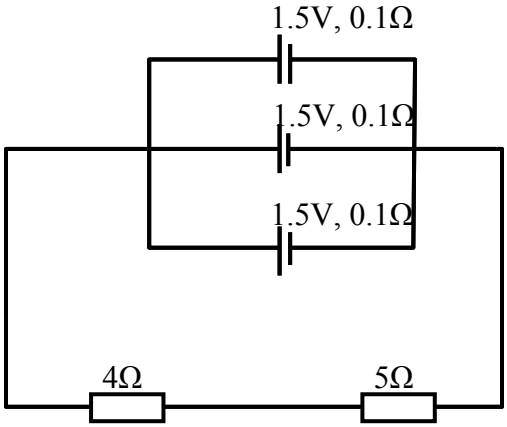
1. Use a diagram to show how 3 identical cells each of e.m.f, 1.5V and internal resistance 0.1Ω can be arranged to give minimum e.m.f

Solution



ii) Calculate the current flowing in the circuit of the arrangement in one above if two resistors of resistances 4Ω and 5Ω are included in series in the circuit.

Solution



Total e.m.f = 1.5V

Total internal resistance, $\frac{1}{r} = \frac{1}{r_1} + \frac{1}{r_2} + \frac{1}{r_3}$

$$\frac{1}{r} = \frac{1}{0.1} + \frac{1}{0.1} + \frac{1}{0.1} = \frac{1+1+1}{0.1}$$

$$\frac{1}{r} = \frac{3}{0.1}$$

$$\frac{3r}{3} = \frac{0.1}{3}$$

$$\boldsymbol{r = \frac{0.1}{3} = 0.033}$$

$R_{effective}$ = 4+5 = 9Ω

From, E = I(R+r)

Where, E=1.5

I =?

R=9

r=0.033

1.5 = I(9+0.033)

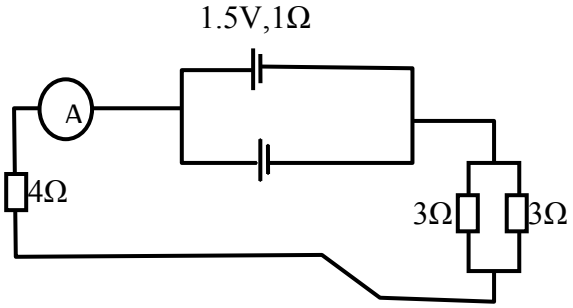
1.5 = I(9.03)

$$\frac{1.5}{9.03} = \frac{9.03I}{9.03}$$

$$I = \frac{1.5}{9.03} = 0.166A$$

$$\boldsymbol{I = 0.166A}$$

2. The diagram below shows two cells each of e.m.f 1.5V and r=1.0Ω connected to a circuit with resistors of 3Ω, 4Ω and 6Ω



Calculate

(i) Reading of the ammeter

(ii) Power dissipates in 4Ω

Solution

(i) Emf, E=1.5V

Total internal resistance $r = \frac{r_1 r_2}{r_1 + r_2} = \frac{1x1}{1+1} = 0.5\Omega$

$E = I(R + r)$

$$1.5 = I(\frac{3x6}{3+6} + 4 + 0.5)$$
$$1.5 = I(2 + 4 + 0.5)$$
$$I = \frac{1.5}{6.5} = 0.23A$$

(ii) Power $= I^2R = 0.23^2 x4 = 0.21W$

Advantages of connecting bulbs in parallel with the battery

- When one bulb blows others continue working
- Bulbs use the same p.d
- Battery does not run down easily (there is less resistance)
- Each bulb is managed separately

COST OF ELECTRICITY

Electricity is rated at a fixed price per unit.
The meter records units in Kilowatt (kW) hours consumed.
Separate meters may be used for power and lighting circuits if different rates are charged
A cost paid on electricity depends on the total consumption
A kilowatt hour is the energy supplied at a rate of working of 1000W for 1 hour. Or it is the energy used in 1 hour when power is 1kW (Kilowatt)

Calculation of cost of electricity
Steps:

1. Calculate the total power in watts
2. Calculate power used in kilowatts (convert power in watts to kilowatts)
3. Calculate power in kilowatt hours (simply multiply power in kilowatts by the hours you have used power to get kilowatt hours)
4. Relate power in Kilowatt hours to the cost of one unit of electricity. The unit of electricity is always charged in terms of kilowatt hours used.

Examples:

1: Find the cost of running 5 bulbs of 60W and 4 bulbs of 100W for 8 hours, if electrical energy costs 5 shillings per unit.

Solution:
Total power used:
For 5 bulbs each 60W, (5x60) = 300W
For 4 bulbs each 100W, (4x100) = 400W
Total power used = (300+400) = 700W
So 1000W = 1kW

700W = $\left(\frac{1}{1000} \times 700\right)$

$\frac{700}{1000} = 0.7kW$

So power in kilowatt hours = (0.7x8) = 5.6kW hr

1kWhr = 5/=

5.6kWhr = $\left(\frac{5}{1} \times 5.6\right)$

= 28/=

2: The cost of running a lamp rated 7.2V, 3.0A for 5 hours is shs. 2.16. Find the cost per unit of electricity

Solution:

Total power = VI = (7.2x3.0)W

Converting (7.2x3.0)W in to kW

= $\left(\frac{7.2\times3.0}{1000}\right) kW$

Power in kWhr = $\left(\frac{7.2\times3.0}{1000}\right) 5$

$\frac{7.2 \times 3.0 \times 5}{1000} = \frac{2.16}{1}$

1kWhr = x

$X = \frac{2.16\times1000}{7.2\times3.0\times5}$

$\boldsymbol{X = 20/=}$

3: A man has a 40W, 60W and two 150W bulbs in a house. How much will it cost him to keep the bulbs lighting for six hours if the cost of electricity is 1200 shillings per unit.

Solution:

Total power used

For 40W bulb, 40x1 = 40W

For 60W bulb, 60x1 = 60W

2 bulbs of 150W, 2x150 = 300W

Total power = 300+60+40

= 300+100

= 400W

Converting in kW

1000W = 1kW

400W = $\left(\frac{400}{1000}\right) = 0.4kW$

So power in Kilowatt hours = (0.4x6) = 2.4kWhr

1kWhr = 1200/=
2.4kWhr = (1200x2.4) = 2880/=
Therefore cost of electricity is shs. 2880/=

4. A house hold has two bulbs each rated 100W and an electric iron rated 2000W. If the bulbs are left on for 3 hours and an electric iron used for 30 minutes, find the number of units of electricity consumed.

Solution:
For 2 bulbs each 100W = (2x100) = 200W
For an electric iron; (1x2000) = 2000W
Converting 200W in kW

$$\frac{200}{1000} = 0.2kW$$

Power in kWhr = 0.2x3
= 0.6kWhr

Converting 2000W in kW

$$\frac{2000}{1000} = 2kW$$

Power in kWhr = 2x½hrs = 1kWhr
Total number of units of electricity consumed
= sum of power consumed by 2 bulbs + power consumed by iron
= 0.6+1
= 1.6kWhr

Exercise
1.Five equal electric bulbs are switched on for 8 h a day for thirty days. If each unit costs Shs600 and the total monthly bill is Shs 43,200, find the power rating of each bulb.
Ans 60W

2.A household uses two security flood lights each rated 1000W, one flat iron rated 1500Wand two electric coils each rated 1800W for five hours. Calculate the total cost of electrical energy used if each unit of electricity costs shs.650.
Ans 23,075=

SAFETY PRECAUTIONS WHEN WIRING BULDINGS:

- House hold wires must be covered with insulated materials.
- Switches must be placed on live wires of the main.
- Fuse wires must be used in fuses.

A fuse:
A fuse is a short-thin piece of wire with a very low melting point normally connected in the live cables which passes to the appliance.

When a fault develops and current is exceeded, the fuse melts and breaks the circuit. This stops the flow of current in the circuit hence it acts like a switch.

Hazards that can be caused by electricity

Causes electric shock resulting from touching of live wires.

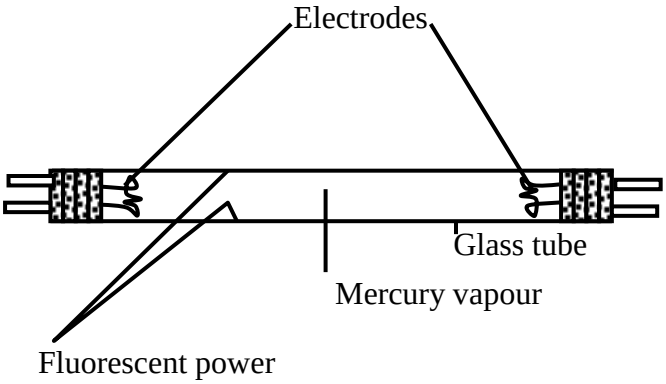
Causes electric fires as a result of faulty appliances, short circuits and overload cables.

NB: A short circuit is a direct connection of terminals of the source of e.m.f

Further questions

1. With the aid of a diagram, explain how a fluorescent tube works.

Solution:



How it works:

When the tube is switched on, mercury vapour emits ultra violet radiations. The radiations strike the powder and the powder glows emitting light.

The colour of light emitted depends on the colour of the powder.

Advantages of fluorescent tubes over filament lamps

- They are more efficient
- Have cheap running costs
- Don't produce a lot of heat
- Long lasting

Disadvantages

- Require high installation costs
- May not start when the supply voltage is low

2. (a) A lamp is marked 240V, 60W. What does this statement mean?
   (b) How much current does the lamp draw when connected across a 240V supply?

   Solution:

(a) When a lamp is connected to 240V supply, it dissipates 60 joules of energy in one second.

(b) From P = VI

Where P = 60Wor 60 Js^{-1}

V = 240

I = ?

$$\frac{60}{240} = \frac{240I}{240}$$

$$I = \frac{60}{240} = \frac{1}{4} = 0.25A$$

3. Explain why a wire heats up when a current passes through it.

When current flows through a conductor, electrons collide with the atoms of the conductor hence giving up their kinetic energy to the atoms. Their vibrational energy increases leading to increase in internal energy which results into rise in temperature.

4. An electric bulb rated 60W is connected to a power supply. If a current of 0.25A flows through the bulb when it is operating, find the resistance of its filament.

Solution:

From $P = I^2R$

Where: $P = 60Js^{-1}$

I = 0.25A

R = ?

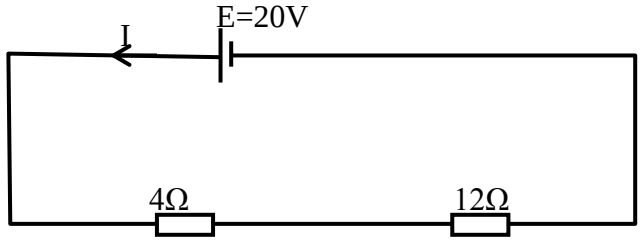
$60 = (0.25)^2 \times R$

$$\frac{60}{0.0625} = \frac{0.0625R}{0.0625}$$

R = 960Ω

5. Two resistors of 4Ω and 12Ω are connected in series with a battery of e.m.f 20V and negligible internal resistance. Calculate the current that flows through a 4Ω resistor.

Solution



From $I = \frac{V}{R}$

Where V = 20V

R = ?

I = ?

$R_{effective} = 4\Omega + 12\Omega$

$R = 16\Omega$

$$I = \frac{V}{R} = \frac{20}{16} = 1.25A$$

6. Explain why
(a) the space in the bulb of a filament lamp is filled with an inert gas.
(b) the filament of a filament lamp is made of tungsten.

Solution

(a) It prevents vapourization of the filament which leads to darkening of the filament.
(b) The temperature of the filament is so high that it requires a high melting point material and Tungsten is such a material.

MAGNETIC EFFECT OF ELECTRIC CURRENT

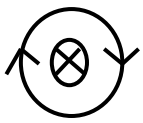
When current flows through a conductor, a magnetic field is produced around a conductor.

The relationship between the direction of lines of force and current is expressed by "Maxwell's Corkscrew rule.

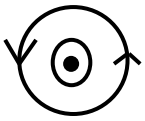
The rule states that, "Imagine yourself driving a corkscrew in the direction of current, then the direction of rotation of the corkscrew is the direction of lines of force."

Illustration of the corkscrew rule

fig (i)



current into a page

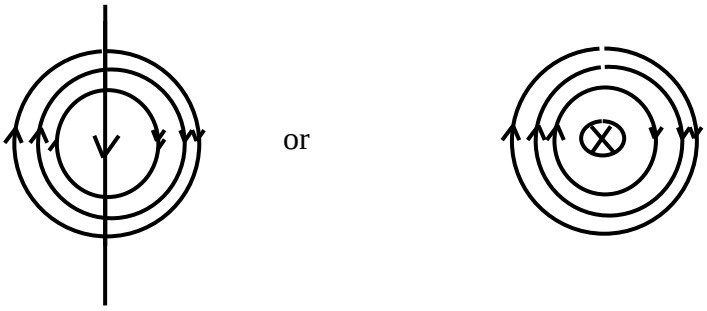
fig. (ii)  current out of a page

In figure (i) above, a cross represents a wire carrying current into paper/page.

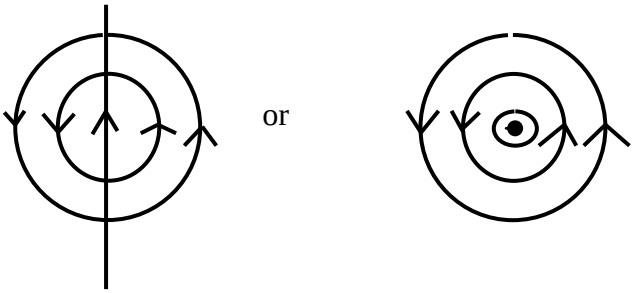
In figure (ii), a dot represents a wire carrying current out of a paper/page

Magnetic field patterns for:

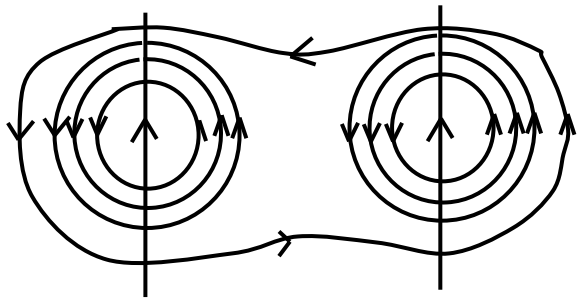
(i) A wire carrying current into a page



(ii) a wire carrying current outwards

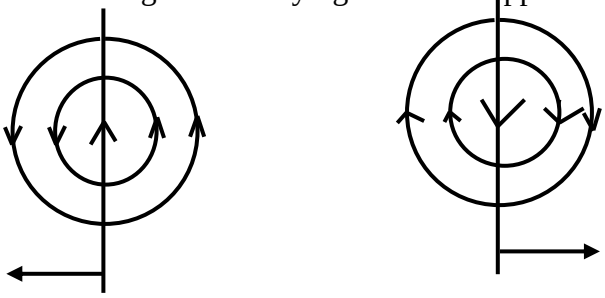


(iii) Two long wires carrying current into the same direction (upwards)



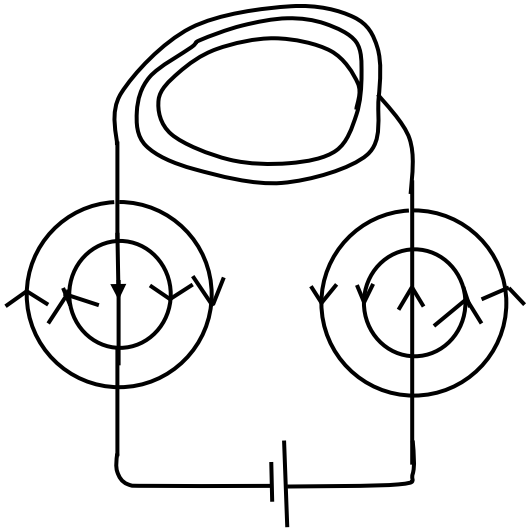
When two conductors or wires are carrying current in the same direction, the wires are pushed to a region of a weaker field hence experiencing an attraction force.

(iv) Two long wires carrying current in opposite directions.

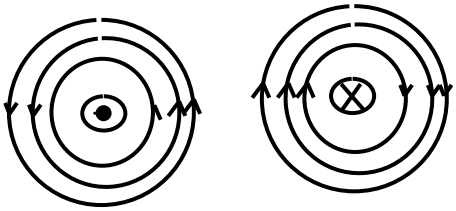


When two wires or carrying current in opposite direction, they are pushed away from a region of stronger field hence repelling each other.

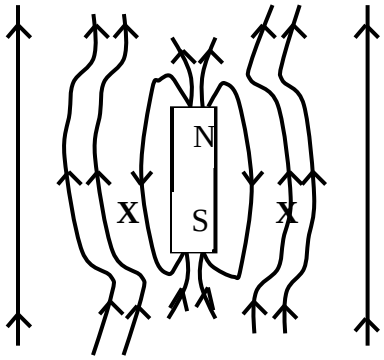
(v) A circular coil carrying current



or

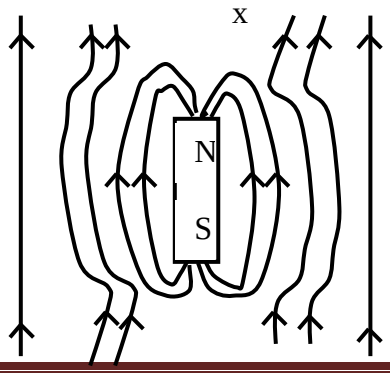


(vi) A bar magnet with its north pole facing north in the earth's magnetic field



x-neutral point

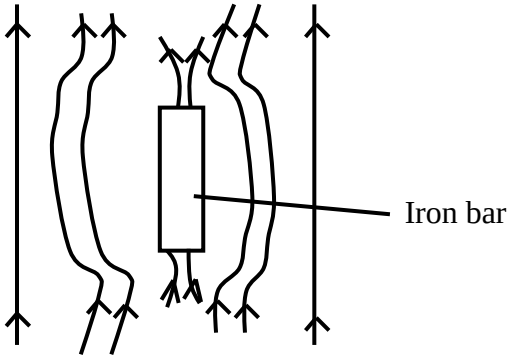
(vii) A bar magnet with its south pole facing north in the earth magnetic field



x

x-neutral point

(viii) A bar of un magnetized iron placed along the axis of the earth field



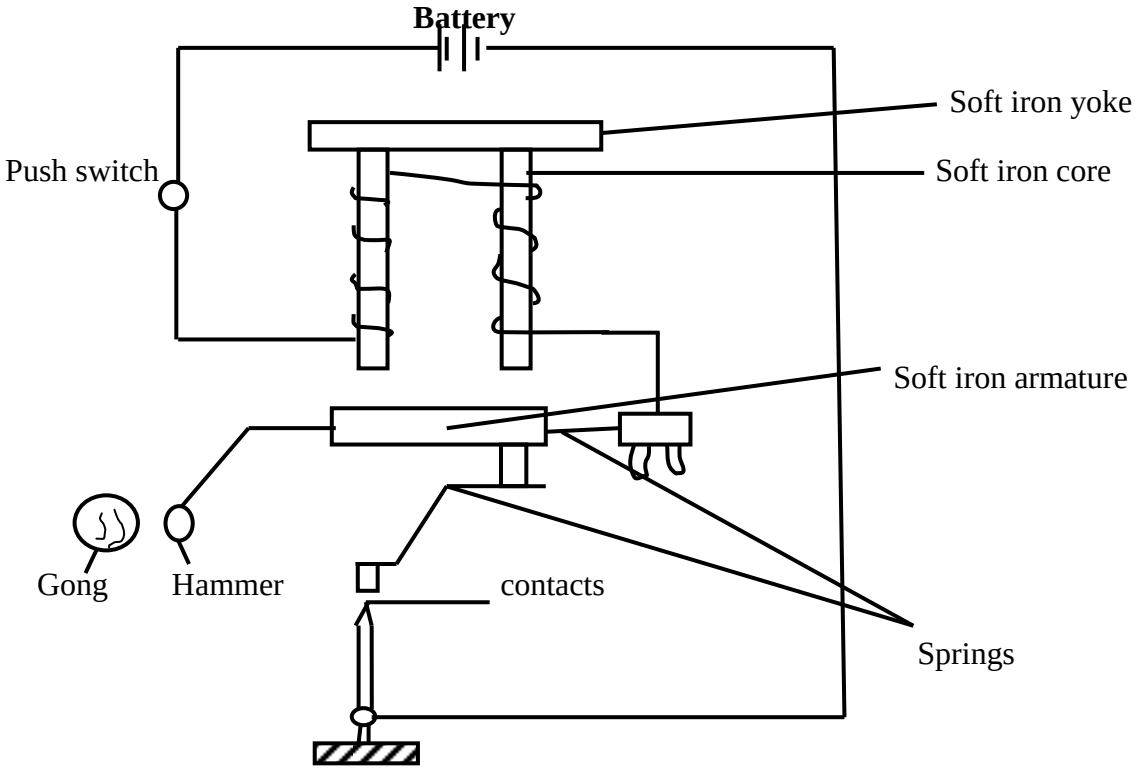
ELECTRO MAGNETS

An electro magnet is a piece of soft iron which gets magnetized when electric current is passed through a coil surrounding it.

Uses of an electro magnet

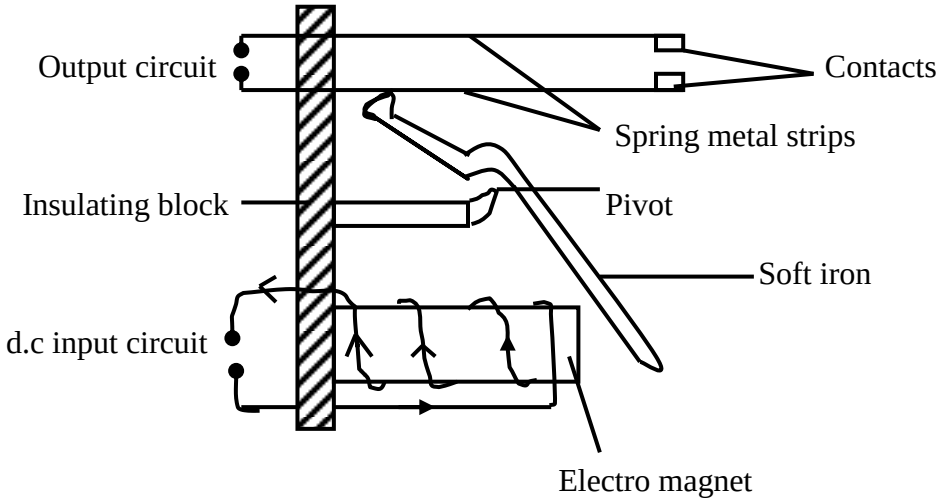
- Lifting heavy pieces of metal
- Used in hospitals for removing bits of iron or steel from eyes.
- Used in several electric devices e.g. electric bell, magnetic relay, telephone receivers etc.

(a) Electric Bell



- When a switch is pressed, current flows through the circuit and the soft iron get magnetized.
- The soft iron armature is then attracted, the hammer hits the gong and a loud sound is heard.
- Contacts are broken and magnetism in the cores is lost.
- The soft iron armature is returned by the spring to its original position and contacts are remade and the cycle repeats.

(b) Magnetic relay:

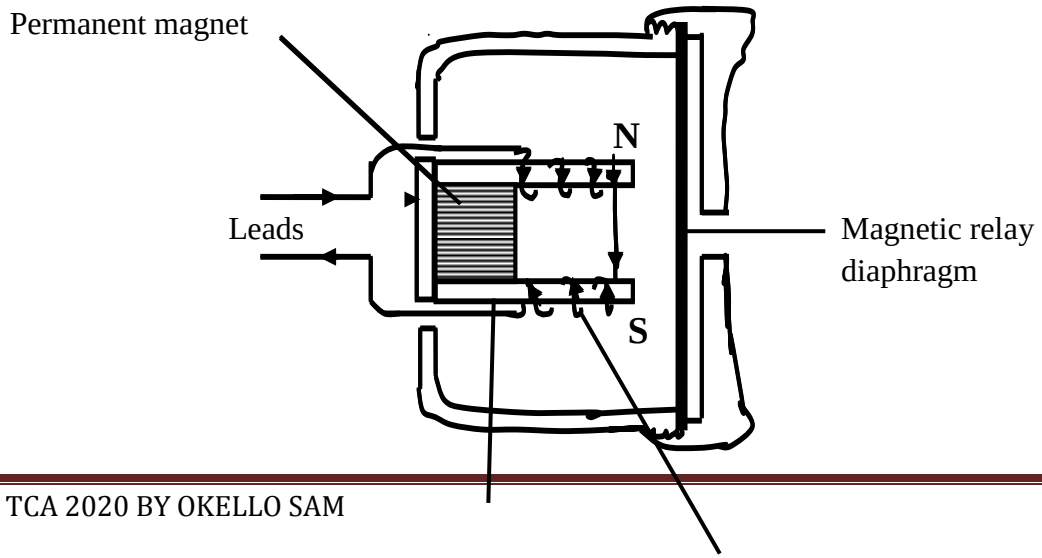


- The input circuit supplies current to the electro magnet.
- It gets magnetized and the electro magnet attracts one end of soft iron armature which is pivoted so that its other end acts as a lever.
- The lever opens and closes contacts in the output circuit by a spring metal strip.
- The spring strips and contacts are arranged in such a way that they can open and close easily.

Advantages of magnetic relays:

- Small current in the input circuit is used to control a large current in the output circuit.
- One circuit can be used to control another circuit without any direct electrical connections between them.

3. Telephone receiver.



Soft iron pole piece

Solenoid

The telephone receiver contain a U-shaped magnet formed by placing a short permanent bar magnet across the ends of two soft iron bars. This is placed so that it exists as a pull on a spring magnetic alloy diaphragm. Two solenoids are wound in opposite directions on the soft iron bar.

When a person speaks into the microphone at the other end of the line varying current is set up having the same frequency as the sound waves. A similar electric current is caused to pass through the solenoid in the ear piece. This alters the strength of the magnetic flux in the U-shaped magnet and produces a corresponding variation in the pull of the diaphragm. The latter therefore vibrates and produces a copy of the sound waves which entered the microphone.

Factors that affect the strength of an electro-magnet

(i) Number of turns/coils wound around electro-magnet
(ii) Current flowing in the coil

Force on a conductor carrying current in a magnetic field

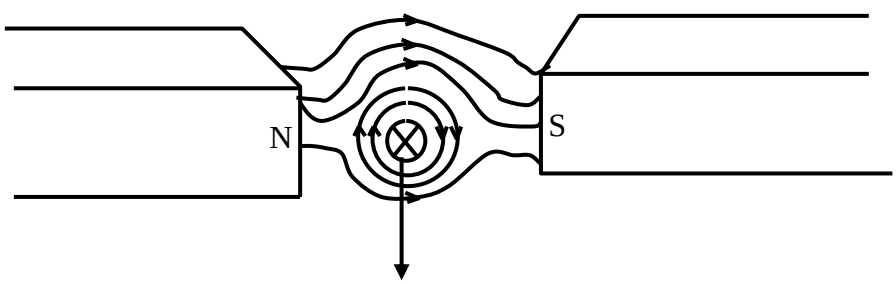
A conductor carrying current in a magnetic field experiences a force.

The direction of force is tressed by ***Fleming's left hand rule***

The rule states that; if the middle finger, fore finger and thumb of the left hand when held at right angles to each other; the fore finger represents the field, middle finger represents current and the thumb represents force/motion.

QN: Explain why when a conductor carrying current placed in a magnetic field experiences a force.

- When a conductor is carrying current, magnetic fields consisting of concentric circular lines of force are created around it
- The original magnetic fields due to the magnet superimposes with the fields due to the conductor/wire.
- This creates a region of a weaker field and a region of a stronger field-hence the wire is pushed from a region of a stronger field to a region of a weaker field as shown below.



Force

The figure, F experienced by the conductor is given by $F = BIl$

Where; B – Magnetic flux density (strength of magnetic field)

I – Current

L – Length of a conductor

Force on a conductor carrying current in magnetic field is always affected by:

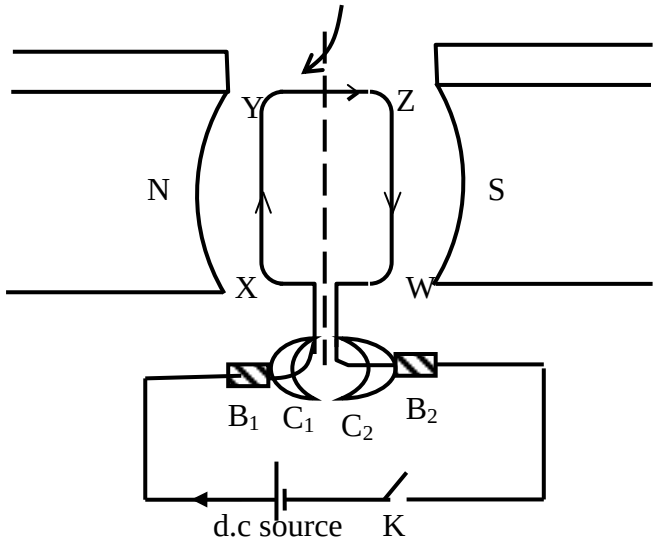
- Strength of magnetic field/flux
- Current flowing
- Length of the conductor

Applications of force on a conductor

- Applied in d.c motor
- In moving coil galvanometer
- Loud speaker

(a) A d.c motor

It converts electrical energy to mechanical energy.



WXYZ - Rectangular coil

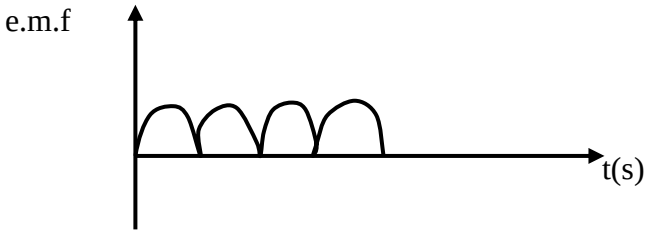
C_1C_2 – split ring commutators

B_1B_2 – Carbon brushes

N, S – Pole pieces of a permanent magnet

- When switch, K, is closed current flows through the rectangular coil WXYZ
- XY experiences a downward force and Z,W- an equal upward force.
- YZ and WX experience no force because they are carrying current parallel to the magnetic field.
- The two forces constitute a couple that causes the coil to rotate in the direction shown.
- The commutators, C_1C_2, change contacts with the carbon brushes hence current in the coil is reversed but the force in the coil continues acting in the same direction hence the coil continues to rotate in the same direction.

Graph of e.m.f against time:



Energy losses in electric motors

- Resistance of windings: minimized by using wires of low resistance
- Loss due to friction in the moving parts of motor. Minimized by lubrication of the removing parts.
- Loss due to Eddy current. Minimized by laminating the coil.

Examples:

1. A motor has an armature resistance of 4Ω and draws a current of 10A when connected to 200V supply. Calculate;
   (i) Power wasted in the windings
   (ii) Efficiency of the motor

   Solutions

   I = 10A

   V = 200V

   R = 4Ω

   (i) Power wasted = I^2R

   $P = (10^2 x 4)$

   $P = 100x4$

P = 400W

(ii) Efficiency of the motor

Efficiency = $\frac{Power\ output}{Power\ input} \times 100\%$

Power input = Power output + Power lost

From power = VI

Power input = 10x200

= 2000W

Power output = Power input – power lost

= (2000-400)W

Power output = 1600W

Therefore ŋ = $\frac{1600}{2000} \times 100\%$

ŋ= 80%

2: A motor is marked 3W, 6V and is 20% efficient. Calculate:

(i) Current flowing
(ii) Energy it supplies in 10s

Solution

P = 3W

V = 6V

I = ?

(i) Power, P = VI

P = VI

I = $\frac{P}{V}$

I = $\frac{3}{6}$

Therefore I = 0.5A

(ii) ŋ = $\frac{power\ output}{power\ input} \times 100\%$

ŋ = 20%

Power output = ?

Power input = 3

Therefore $\frac{20}{100} = \frac{power\ output}{3} \times \frac{100}{100}$

0.2 = $\frac{power\ outut}{3}$

0.2 x 3 = power output

Power output = 0.6W

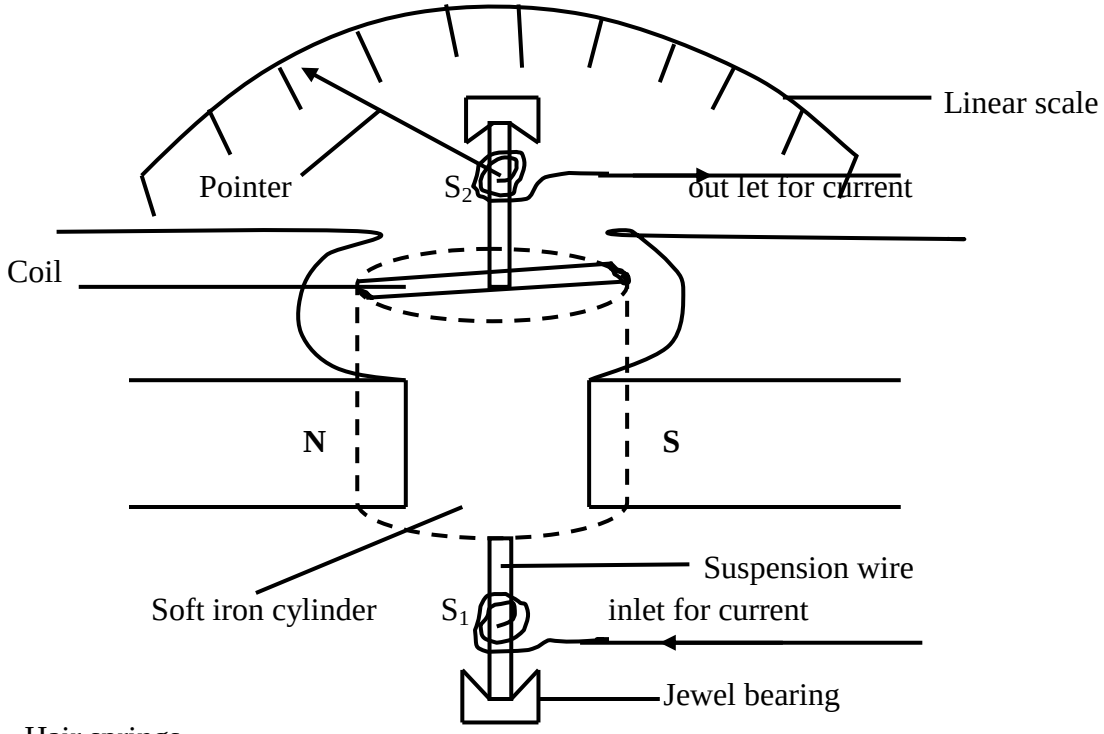
Power = $\frac{Energy}{time}$

0.6 = $\frac{Energy}{10}$

The Energy supplied = 6J

(b) A moving Coil galvanometer:

This is an instrument used for measurement of small currents and potential differences.



S_1,S_2 – Hair springs

N,S- Pole pieces of a permanent magnet.

- When current enters the coil, a couple acts on the coil causing it to rotate due to the torque.
- The suspension wire is twisted and the pointer attached to it also turns until the torque due to the hair springs balances with the torque due to current.

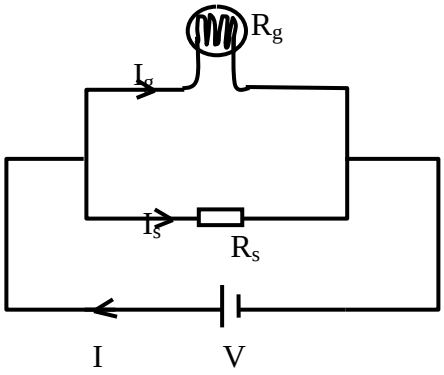
  It can be converted to an ammeter to measure current and can also be converted to a voltmeter to measure voltage.

NB: The sensitivity of moving coil galvanometer can be improved by:

- Using a strong magnet
- Increasing number of coils (using a coil of many turns)
- Using fine hair springs

CONVERSION OF MOVING COIL GALVANOMETER TO AN AMMETER

In order to convert a moving coil galvanometer to an ammeter, a low resistance called a shunt is connected in parallel to the terminals of galvanometer and the shunt diverts most of the current to be measured away from the coil hence nearly all current flows through the shunt.



R_s – Resistance of the shunt

I_s – current through the shunt

I_g – current through galvanometer

I – Current to be measured

V – Voltage of battery supplying current

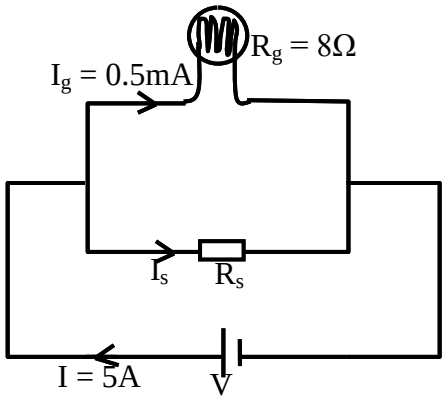
NB: For parallel resistors, P.d across the galvanometer is the same as the P.d across the shunt

Therefore $I_sR_s = I_gR_g$

Examples

1. A galvanometer has a coil resistance 8Ω and given a full scale deflection when a current of 0.5mA is supplied. Calculate the resistance that can be used to convert it to an ammeter measuring up to 5A

Solution



$I = I_s + I_g$

$5 = I_s + \left(\frac{0.5}{1000}\right)$

$5 = I_s + 0.0005A$

$I_s = 5 - 5x10^{-4}$

$I_g = 4.9995A$

But $I_gR_g = I_sR_s$

$$\left(\frac{0.5}{1000}\right) \times 8 = 4.9995R_s$$

$5x10^{-4}x8 = 4.9995R_s$

$$\frac{0.004}{4.9995} = \frac{4.9995R_s}{4.9995}$$

$R_s = 0.0008\Omega$

2. A moving coil galvanometer has a coil of resistance 4Ω and gives a full scale deflection when a current of 25mA passes through it. Calculate the value of resistance required to convert it to an ammeter which reads 15A at full scale deflection.

Solution

$I = I_s + I_g$

$I_g = 25mA = 25x10^{-3} = 2.5x10^{-2}\,A$

$15 = I_s + 2.5x10^{-2}A$

$I_s = (15 - 2.5x10^{-2})A$

$I_s = 14.975A$

But $I_sR_s = I_gR_g$

$(14.975)xR_s = \left(\frac{25}{1000}\right) \times 4$

$14.975R_s = 0.1$

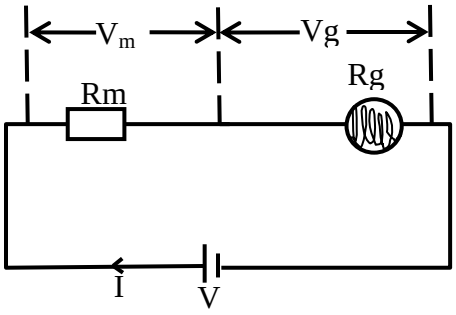
$R_s = 0.00668 = 6.68x10^{-3}\Omega$

NB: An ammeter is used for measurement of current. It is constructed with a very low resistance coil so that a large current passes through it.

Conversion of a moving coil galvanometer to a voltmeter

A galvanometer can be converted to a voltmeter by connecting a resistor called a multiplier in series with the coil.

A large P.d is dropped across a multiplier leaving a small P.d only to be dropped across a galvanometer.



V_m – Voltage across multiplier
V_g – Voltage across galvanometer
R_g – resistance of galvanometer
R_m – Resistance of multiplier

$V = V_m + V_g$

But $V_m = IR_m$
$V_g = IR_g$

$V = IR_m + IR_g$

$V = I(R_m + R_g)$

Examples

1. The resistance of a galvanometer is 10Ω and gives a full scale deflection when a current of 20mA flows through it. Calculate the value of the resistor that should be connected so that it reads up to 3V.

   Solution

   From $V = I(R_m + R_g)$

   $3 = \frac{20}{1000}\ (Rm + 10)$

   $3 = 0.02R_m + 0.2$

   $R_m = \frac{2.8}{0.02} = 140\Omega$

2. A galvanometer of resistance, R gives a full scale deflection when a current of 10mA flows through it. When a resistor of resistance 170Ω is connected in series with the galvanometer, it reads 2V, calculate the value of R.

Solution:

From $V = I(R_m+R_g)$

$2 = \left(\frac{10}{1000}\right)(170 + R_g)$

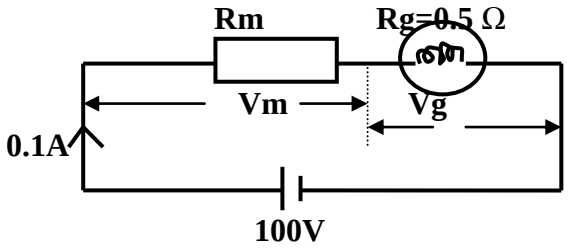
$2 = 0.01\ (170 + R_g)$

$\frac{2}{0.01} = (170 + R_g)$

$R_g = 200 - 170 = 30\Omega$

3. A galvanometer gives full scale deflection for a current of 0.1 A and its resistance is 0.5Ω. Determine the value of the resistance necessary to convert it into a voltmeter which reads up to 100V.

Solution



P.d across the galvanometer

$V_g = IR_g = 0.1x0.5 = 0.05V$

But $V = V_m + V_g$

$100 = 0.05 + V_m$

$V_m = 99.95V$

$V_m = IR_m$

$R_m = \frac{V_m}{I} = \frac{99.95}{0.1} = 999.5\Omega$

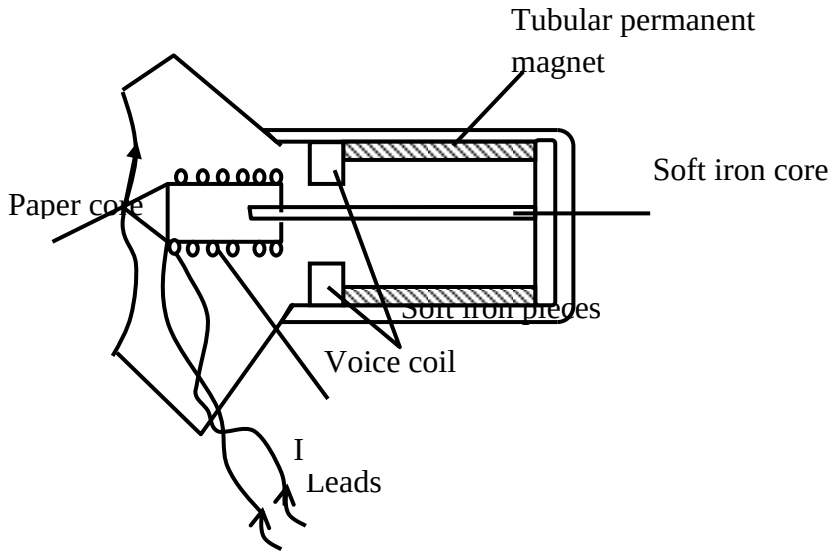
NB: A voltmeter is used for measurement of voltage.

It is constructed such that its coil has a very high resistance so that negligible current flows through it.

How to improve on the sensitivity of electrical metres

- By using a strong electro-magnet
- Using a coil of many turns
- Using weaker hairspring
- Using a coil of large cross sectional area.

(c) Moving coil loud speaker



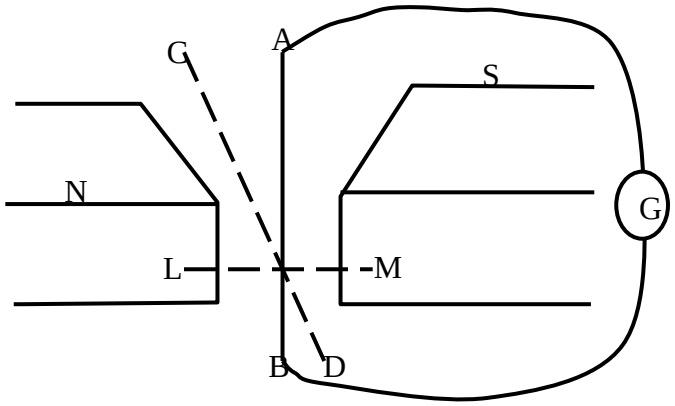
I = current

The loud speaker changes electrical energy to sound energy
When electrical signals (pulses) corresponding to sound enter through the leads, it ends up in the voice coil.
A force acts on the coil which causes it to vibrate in accordance to Fleming's left hand rule.
These vibrations are extended to the paper core to which the voice coil is connected.
The surrounding air is set into vibration producing the required sound.
NB: Pitch and loudness of sound produced in a loud speaker depends on;

- Magnitude of current in the voice coil
- Strength of magnetic field

ELECTROMAGNETIC INDUCTION

This is the production of e.m.f in a wire by a magnetic field.
When an e.m.f is induced in a wire, current that circulates in a wire is called induced current. This current is always induced in the wire whenever magnetic lines of force are cut by the wire.



G = galvanometer

When the wire is moved upwards towards C, it cuts the magnetic field lines and an e.m.f is induced in the wire.

Induced e.m.f results to flow of induced current in the wire. Along BA and the pointer of the galvanometer deflects in one direction.

When the wire is moved downwards towards D, it also cuts the magnetic field lines hence causing an induced current (e.m.f). In this case, current flows in opposite direction along AB and the galvanometer deflects in opposite direction.

If the wire is moved along the field (along LM), the wire does not cut the magnetic field lines because it moves parallel to the magnetic field lines hence no induced current is produced and the pointer of the galvanometer does not deflect.

NB: The magnitude of induced current (e.m.f) can be increased by:

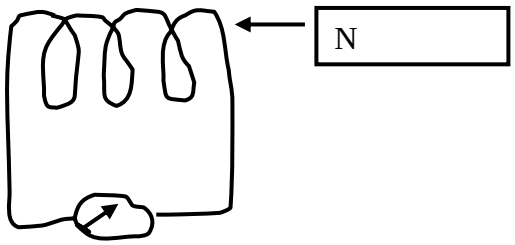
- Increasing speed of motion of the wire
- Increasing strength of the magnetic field
- Using a coil of many turns
- Increasing cross-sectional area of the wire/coil

LAWS OF ELECTROMAGNETIC INDUCTION

(a) Lenz's law

It states that, the direction of induced current is such as to oppose the change causing it.

The figure below shows a cable connected to a centre of zero galvanometer.



(i) State what is observed when the north pole of the magnet is moved towards the cable

(ii) State ways in which the effect observed in (i) above can be increased

i) The pointer of the galvanometer deflects.

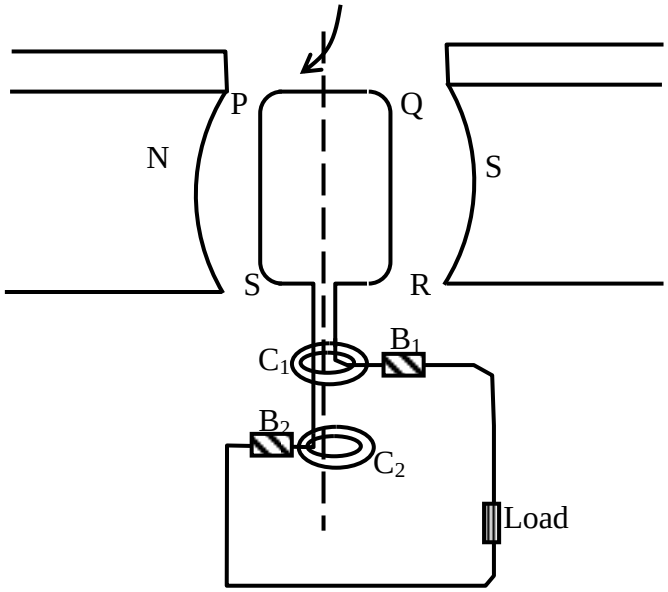
ii) - Increasing strength of magnetic field
- Increasing number of turns of the coil
- Moving the magnet faster

- Winding the coil on soft iron

(b) Faradays' law:

It states that, the magnitude of induced e.m.f is directly proportional to the rate of change of magnetic flux through the coil.

A.C GENERATOR (Simple dynamo)

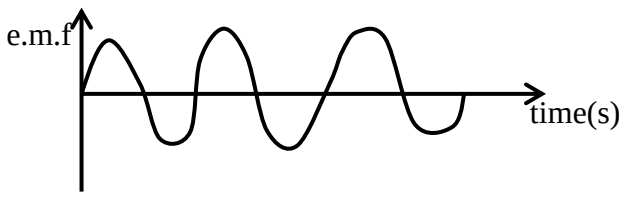


PQRS – rectangular coil
C_1C_2 – Slip ring commutators
NS – Poles of permanent magnet

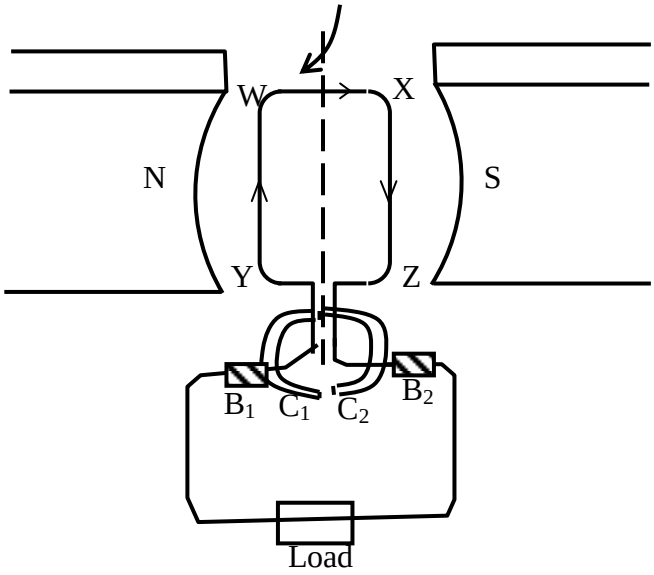
- The rectangular coil is connected to the slip rings, as shown above.
- When the coil is rotated in a magnetic field, it cuts the magnetic field and an e.m.f is induced.
- When the coil is in the vertical position, it does not cut the flux and thus the e.m.f is zero.
- When in the horizontal position, the coil cuts the flux and the e.m.f induced is maximum
- During the second half of rotation, e.m.f induced is reversed since the side of the coil which was initially moving upwards will then be moving downwards.
- The e.m.f induced is therefore alternating.

NB: In electrical study a load is any device that consumes electrical current

Graph of e.m.f against time (alternating e.m.f)



A D.C GENERATOR (Simple dynamo)



WXYZ - Rectangular coil

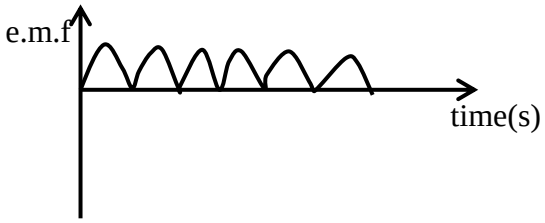
C_1C_2 – split ring commutators

B_1B_2 – Carbon brushes

N, S – Poles of a permanent magnet

- A rectangular coil, WXYZ is connected to the split ring commutators.
- When a coil is rotated about an axis in a magnetic field, magnetic flux is cut and an e.m.f is induced.
- In the vertical position, the coil does not cut the magnetic flux and the e.m.f is zero.
- In the horizontal position, e.m.f induced is maximum.
- During the second half of rotation, the two halves of the commutator change contacts with the carbon brushes and the e.m.f reverses but current flows in the external load in one direction hence direct current.

Graph of e.m.f against time



NB: The e.m.f produced by a dynamo can be increased by/depends on;

- Strength of magnetic field
- Number of turns in the coil
- Cross-sectional area of the coil
- Speed of rotation of the coil

SELF AND MUTUAL INDUCTION

(a) Self induction:

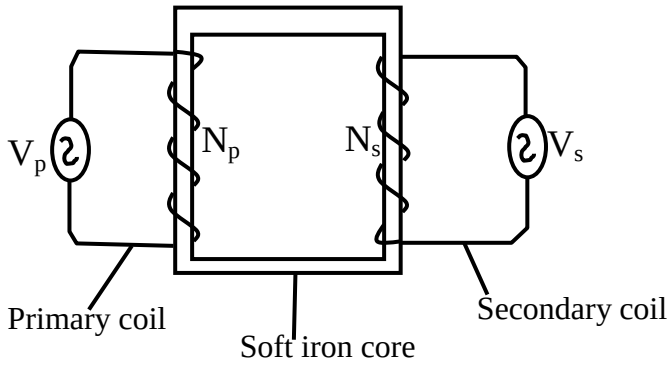
Is the production of an e.m.f in a coil or circuit due to change of current in the same coil or circuit.

(b) Mutual induction:

Is the process by which an e.m.f is induced in one coil or circuit due to change of current on another nearby circuit or coil.

Mutual induction is always applied in working of a transformer.

A TRANSFORMER:



N_s – Number of turns in the secondary coil

N_p – Number of turns in the primary coil

V_p – voltage in primary coil (in put voltage)

V_s – Voltage in secondary coil (out put voltage)

NB: A transformer is a device that uses the principal of mutual induction to produce an e.m.f in one coil due to changing current in another nearby coil.

How it works

An alternating voltage, V_p (alternating current) is applied to the primary coil, it sets up an alternating flux in the soft iron core hence inducing an alternating voltage in the secondary coil.

If the transformer is a set up transformer, then $N_s > N_p$, if it a step-down transformer, then $N_s < N_p$

Types of transformers

There are basically two types of transformers

(i) Step down transformer

Is one in which the output voltage is less than the input voltage ($V_s < V_p$).

Is one in which the number of turns in the secondary coil is less than the number of turns in the primary coil ($N_s < N_p$).
A device that reduces alternating voltage

(ii) Step up transformer

Is one in which the input voltage is less than the output voltage.
Is one in which the number of turns in the primary coil is less than the number of turns in the secondary coil.
A device that increases alternating voltage.

TURN RATIO EQUATION

This is an equation that relates the voltage in primary and secondary coils to number of turns in primary and secondary coils.

$$\boxed{\frac{V_p}{V_s} = \frac{N_p}{N_s}}$$

Efficiency of a transformer

This is the ratio of power output to power input expressed as a percentage.

Efficiency $\eta = \frac{power\ output}{power\ input} \times 100\%$

Power output = V_sI_s

Power input = V_pI_p

Efficiency = $\frac{V_sI_s}{V_pI_p} \times 100\%$

NB: If efficiency of a transformer is 100%, then power output should be the same as power input. Such that;

$V_sI_s = V_pI_p$

$\frac{V_s}{V_p} = \frac{I_p}{I_s}$ This equation can only be used when the efficiency of the transformer is 100%

Examples:

1. A transformer has 100 turns on a primary coil. Calculate the number of turns on a secondary coil if 240V is stepped to 400V.
   Solution

   From: $\frac{V_p}{V_s} = \frac{N_p}{N_s}$

   $\frac{240}{400} = \frac{100}{N_s}$

$N_s = \frac{40000}{240} = 166.67$ turns

2. A transformer steps up voltage from 12V to 48V. If the current flowing in primary coil is 2A, calculate the current in the secondary coil if the transformer is 100% efficient.

   Solution:
   From $V_s I_s = V_p I_p$
   $48xI_s = 12x2$
   $I_s = \frac{24}{48} = 0.5A$

3. The voltage and current in the primary coil of a transformer are 120V and 1.5 A and that in the secondary coil are 24V and 14A respectively. Calculate the power.
   (i) Supplied to the primary coil
   (ii) Supplied to the secondary coil
   (iii) Wasted in the transformer

   Solution:

   (i) Power supplied to primary coil = power input

   From; Power input = $V_p I_p$

   = 240 x 1.5

   Therefore power input = 360W

   (ii) Power supplied to secondary coil = power output
   From, power output = $V_s I_s$
   = 24 x 14
   = 336W
   (iii) Power wasted = power input – power output
   = 360 – 336
   = 24W

4. A transformer is designed to work from a 240V a.c mains and to give a supply at 8V to ring a house bell. If the primary coil has 4800 turns, calculate the number of turns in the secondary coil

Solution:

From $\frac{V_p}{V_s} = \frac{N_p}{N_s}$

$\frac{240}{8} = \frac{4800}{N_s}$

$N_s = 160$ turns

5. A transformer which is 80% efficient has an output of 12W. Calculate the input current if the input voltage is 240V

Solution:

Power output = $V_s I_s$

Power input = $V_p I_p$

From: $\eta = \frac{power\ output}{power\ input} \times 100\%$

$$\eta = \frac{V_s I_s}{V_p I_p} \times 100\%$$

$$\eta = \frac{12}{240 I_p} \times 100\%$$

$$\frac{80}{100} = \frac{12}{240 I_p} \times \frac{100}{100}$$

$$80 \times 240 I_p = 12 \times 100$$

$$I_p = \frac{1200}{80 \times 240} = 0.0625A$$

6. 240V step down mains transformer is designed to light ten 12V, 20W ray box lamps and draws a current of 1A in the primary coil. Calculate;

(i) Power supplied to the primary coil
(ii) Power developed in the secondary coil
(iii) Efficiency of the transformer

Solution:

(i) Power supplied to primary coil = power input
But Power input = V_pI_p
= 240x1
= 240W

(ii) Power developed in the secondary coil = power output
Power output = V_sI_s
If each of the 12V lamps consumes power of 20W
Then 10, 12V lamps will consume (20x10) = 200W
Therefore power output = 200W

(iii) Efficiency of transformer, $\eta = \frac{power\ output}{power\ input} \times 100\%$

$$\eta = \frac{200}{240} \times 100\%$$

$$\eta = \frac{200}{240} \times 100\%$$

$\eta = 83.3\%$

7. The numbers of turns in the primary and secondary coils of a transformer are **N** and 300 respectively. If the output voltage is 120 V when the input is 40 V, find the value of **N.**

Solution.

$$\frac{N_S}{N_P} = \frac{V_S}{V_P}$$

$$\frac{300}{N} = \frac{120}{40}$$

$$N = \frac{300\,x\,40}{120} = 100\,turns$$

ENERGY LOSSES IN TRANSFORMERS:

- Loss due to resistance of the windings. Minimized by using thick cables of low resistance.
- Loss due to eddy currents. Minimized by laminating the core
- Flux leakage. Minimized by winding primary coil on top of a secondary
- Hysteresis (magnetization and demagnetization of soft iron core). Minimized by using soft iron core

Transformer oil

Transformers that are always in use are submerged in oil. This is because;

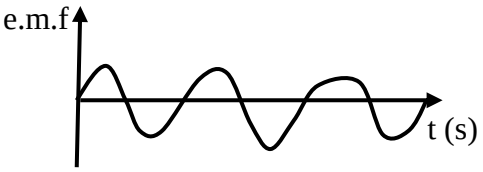
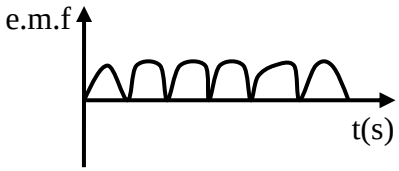
- When the transformer is in use heat is generated. If this heat is not removed it would damage the transformer.
- Oil is put in order to absorb heat and lose it to the surrounding hence cooling the transformer.
- Oil is used because it is a poor conductor (an insulator).
- Oil has a high specific heat capacity.

Advantages of A.C over D.C

- Alternating voltage in an A.C can be stepped up or down by a transformer while a D.C cannot.
- Less power is lost in A.C transmission
- A.C can be transmitted for longer distances at high voltage.
- A.c can easily and cheaply be generated in large amounts than d.c

Differences between alternating current (A.C) and direct current (D.C)

a.c	d.c
A.C (alternating current) moves both in forward and backward (taken as negative) direction	Flows in only one direction

For A.C, a graph of e.m.f against time is as follows	For D.C, a graph of e.m.f against time is as follows
	

Differences between a.c generator and d.c generator.

A.C generator	**D.C generator**
Ends of the coil are joined to slip rings	Ends of the coil are joined to split rings
The output is A.C	The output is DC
There is no change over of the two halves of the commutators during rotation of the coil	There is changeover of the two halves of the commutators during rotation of the coil

LONG DISTANCE POWER TRANSMISSION.

For power to be transmitted over long distances, the voltage at the generating power station must be stepped up to a very high value so that a small current is transmitted.

This is because cables that transmit power have resistance and therefore power is lost due to production of heat in the cables as current flows through them. The power loss $P = I^2R$. Hence to reduce power loss current supplied must be small.

From P=VI

$$I=\frac{P}{V}$$

For small currents the voltage must be high.

Explain why voltage is first stepped up before transmission?

Stepping up voltage means there is small current in transmission. This minimizes power/ energy losses as heat.

Disadvantage of transmission at high voltage

- High voltage is dangerous because it ionizes air molecules around the wires which causes health hazards e.g blood cancer.
- It needs high installation costs in terms of material.

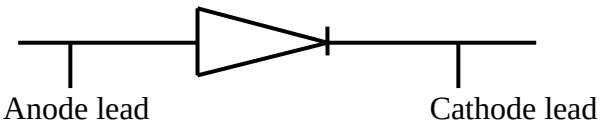
Explain why power cables of cookers are thicker than the ones of lighting

Electric cookers draw more current than lighting systems hence resistance of cables must be low / reduced than that of lighting cables. This will allow current to flow through the cables without melting or overheating.

RECTIFICATION OF ALTERNATING CURRENT (A.C)

This is the process of converting an alternating current (voltage) to direct current (voltage).

This is done using; semi – conductor diodes; that allow current to flow in only one direction

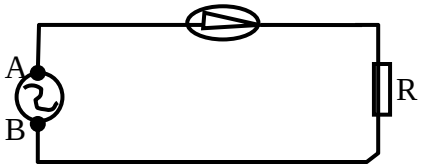


The arrow is in the direction of convectional current. Since current flows from the anode to cathode, electrons are attracted to the anode which is at a positive potential during a positive half cycle.

NB: There are two types of rectifications of A.C to D.C

i. Half wave rectification of A.C to D.C
ii. Full wave rectification of A.C to D.C

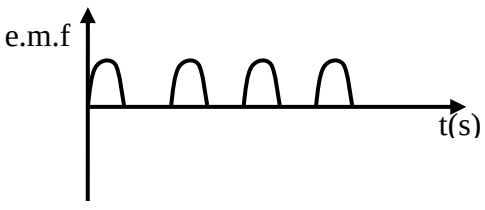
(i) Half wave rectification:
This is done using one diode i.e.



During the first half circle when A is positive, the diode conducts current and current flows through resistors.

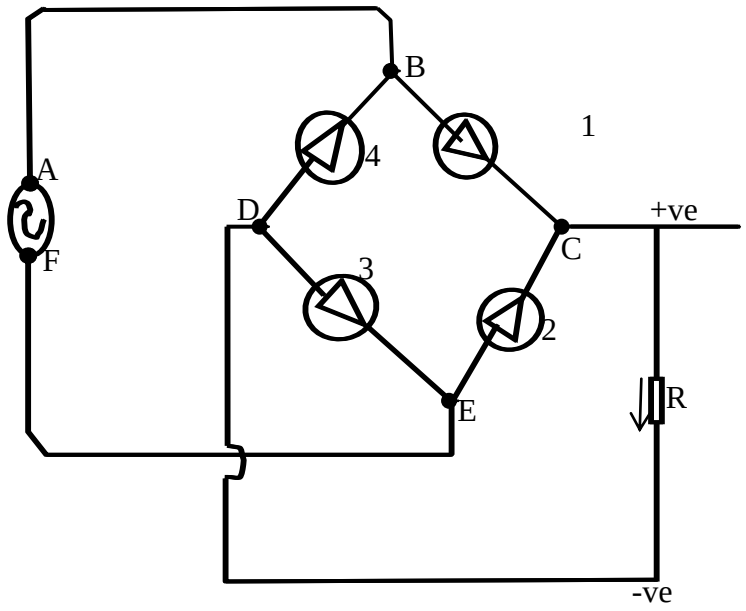
In the second half circle when B is positive, the diode does not conduct current hence no current flows through the resistor. Since the diode conducts in only one direction current flows through the resistor in only one direction hence direct current.

A graph of e.m.f against time, during half wave rectification



(ii) Full wave rectification

This is done using four diodes arranged in a bridge circuit.



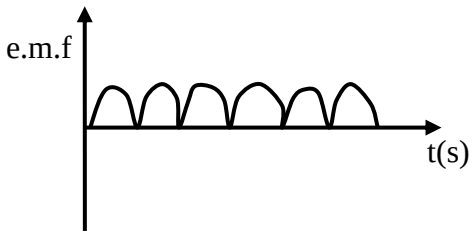
Diodes; 1, 2, 3, 4 are arranged as shown above.

If A is positive, diodes 1 and 3 conduct current and current flows through A, B, C, R, D, E, F.

On the next half circle, when F is positive, diodes 2 and 4 conduct current and current follows path F, E, C, R, D, B, A

During both half circles, current flows through the resistor in one direction hence A.C is fully rectified.

A graph of e.m.f against time for full wave rectification



ATOMIC STRUCTURE

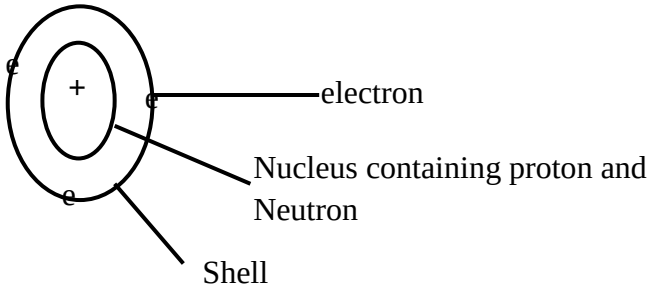
All matter consists of atoms

The atoms of any one element are all identical and different from the atoms of any other element

The nucleus consist of protons and neutrons

Protons are positively charged while neutrons are not charged (neutral) hence the positive charge on a proton makes the nucleus positive.

Electrons orbit around shells



Properties of protons:

- They are positively charged
- Deflected by electric and magnetic fields
- It is a hydrogen nucleus
- Has a mass similar to that of hydrogen

Particle	**Symbol**	**Mass**	**charge**
Protons	P; ${}_{1}^{1}H$	1	+
Electrons	e; ${}_{-1}^{0}e$	0	-
Neutron	n; ${}_{0}^{1}n$	1	Neutral

Definitions:

1. **Atomic number (Z):**
   Is the total number of protons in the nucleus of an atom.
   Atomic number is also called proton number
   A neutral atom has exactly the same number of protons and neutron

2. **Mass number (A):**
   Is the total number of protons and neutrons in the nucleus of an atom.
   Mass number is also called nucleon number (or number of nucleons) in the nucleus of an atom.
   Number of nucleons is the total number of protons and neutrons
   An element, X, can be represented as; ${}_{Z}^{A}X$, where;
   X – element
   A – mass number
   Z – atomic number

An element is composed of protons and neutrons

3. **Isotopes**
   Are atoms of the same element with the same atomic number but different mass numbers.
   Are atoms of the same element with same number of protons but different number of neutrons

QN: An element X is represented by $^{235}_{92}X$

(a) Determine
   (i) Atomic number
   (ii) Mass number
   (iii) Number of neutrons
(b) Determine the composition of element X.

Solution

(a) (i) Atomic number =92

(ii)Mass number =235

(iii)Sum of protons and neutrons = mass number

P + n = 235
92+n = 235
n = 235 – 92
Therefore number of neutrons in atom, $n = 143$

(b) Element X has 92 protons and 143 neutrons in its nucleus.

RADIOACTIVITY

Is the spontaneous decay (disintegration) of a radioactive material in which radiations are emitted.

The radiations emitted are;

(i) Alpha particles
(ii) Beta particle and
(iii) Gamma particle/rays

Radioactive decay is a random process hence it is difficult to ascertain which atom will decay first.

It is always shown by a few elements with large mass numbers such as Uranium 235, Uranium 238 and Thorium 232; that finally decay to lead; hence the greater the mass number, the greater the chances of radioactive decay.

Radioactive decay is not affected by physical conditions like temperature and pressure

NB:

1. When the mass of radioactive element is increased, chances of radioactive decay also increase

2. When temperature is increased, radioactive decay will remain constant hence increase in temperature has no effect on the activity of a material.

Properties of radiations emitted during radioactivity.

1. **An alpha particle (α)**
    - It is a helium nucleus represented as ${}^{4}_{2}H_e$
    - It is positively charged
    - Deflected by electric
    - Deflected by magnetic fields
    - Ionizes gases (highest ionizing power of gases)
    - Penetrates matter (has the least penetrating power)
    - Darkens photographic films (plates)
    - It has mass of four times that of hydrogen

NB: Loss of an alpha particle from the nucleus of an atom reduces its mass number by 4 and atomic number by 2. This is illustrated below.

$$ {}^{A}_{Z}X \rightarrow {}^{A-4}_{Z-2}Y + {}^{4}_{2}H_e $$

Examples

1. A radioactive substance ${}^{238}_{92}X$ undergoes decay by emission of an alpha particle to form substance Y. Determine atomic and mass numbers of Yand write a balanced equation for the decay process.

Solution

Let a $and\ b$ be the atomic and mass number of Y respectively

$$ {}^{238}_{92}X \rightarrow {}^{b}_{a}Y + {}^{4}_{2}H_e $$

For atomic C number:

92 = a+2

a = 92-2

a= 90

For mass number;

238 = b+4

b=238-4

b=234

2. Uranium $^{235}_{92}U$ undergoes decay by emission of two alpha particles to form Thorium (Th). Determine the atomic and mass number of Thorium and write equation for the decay process.
Solution

Let a and b be atomic and mass numbers of Th respectively.

$$^{235}_{92}U \rightarrow 2^{4}_{2}He + {}^{b}_{a}Th$$

For atomic number,

92=a+ 4

a=92-4

a=88

for mass number,

235=b+8

b=235-8

b=227

Therefore atomic and mass numbers of thorium are 88 and 227 respectively.

$$^{235}_{92}U \rightarrow 2^{4}_{2}He + {}^{227}_{88}Th$$

2.Beta particle (β)

Are high speed electrons represented by $^{0}_{-1}e$

Characteristics of beta particles

- Are negatively charged
- Ionize gases (low ionizing power of gases)
- Penetrates matter than alpha particles
- Causes fluorescence
- Deflected by both electric
- Deflected by magnetic fields
- Darken photographic plates

NB. Loss of a beta particle from the nucleus of an atom has no effect on the mass number but atomic number is increased by one (1) as illustrated below,

$$^{A}_{Z}X \rightarrow {}^{A}_{Z+1}Y + {}^{0}_{-1}e$$

Qn . State the similarities and differences between alpha and beta particles

Similarities

- Both are charged
- Both penetrate matter

- Both ionize gases
- Are both deflected by electric fields
- Are both deflected by magnetic fields

Differences

Alpha particle	**Beta particle**
Positively charged	Negatively charged
It's a helium nucleus	High speed electron
Deflected to negative plate in an electric field	Deflected to positive plate in an electric field
Low penetrating power of mater	High penetrating power of mater
High ionizing power of gases	Least penetrating power of gases compared to alpha particle

Example

A radioactive nuclide ${}^{234}_{90}X$ undergoes decay by emission of a beta particle to form nuclide Y. Find the atomic and mass numbers of Y and write a balanced equation for the decay process.

Solution :

Let a and b be atomic and mass numbers of nuclide Y

${}^{234}_{90}X \rightarrow {}^{0}_{-1}e + {}^{b}_{a}Y$

For atomic numbers

90= a-1

a= 91

For mass numbers

234=0+b

$\Longrightarrow$b =234

Atomic numbers of Y is 91 and mass number is 234.

Hence equation ${}^{234}_{90}X \rightarrow {}^{0}_{-1}e + {}^{234}_{1}Y$

3.Gamma rays (γ)

- They are electromagnetic radiations
- Travel through a vacuum
- Travel at the speed of light i.e. $3x10^8$ ms^{-1}
- Carry no charge
- Not deflected by electric and magnetic fields
- Penetrates matter (hightest penetrating power)
- Are transverse waves
- Ionizes gases (least ionizing power)

- Undergo interference
- Undergo diffraction
- Undergo polarization.

NB: Loss of a gamma ray has no effect on the mass numbered and atomic number of a radioactive substance ${}^{A}_{Z}X \rightarrow {}^{A}_{Z}Y + 8$

QN. A radioactive nucleus is denoted by the symbol ${}^{288}_{92}Y$. Write down how you would expect the nucleus to be composed and state the composition of the nucleus at the end of each of the following stages of disintegration.

(i) Emission of an alpha particle
(ii) Further emission of beta particle
(iii) Further emission of some gamma radiation

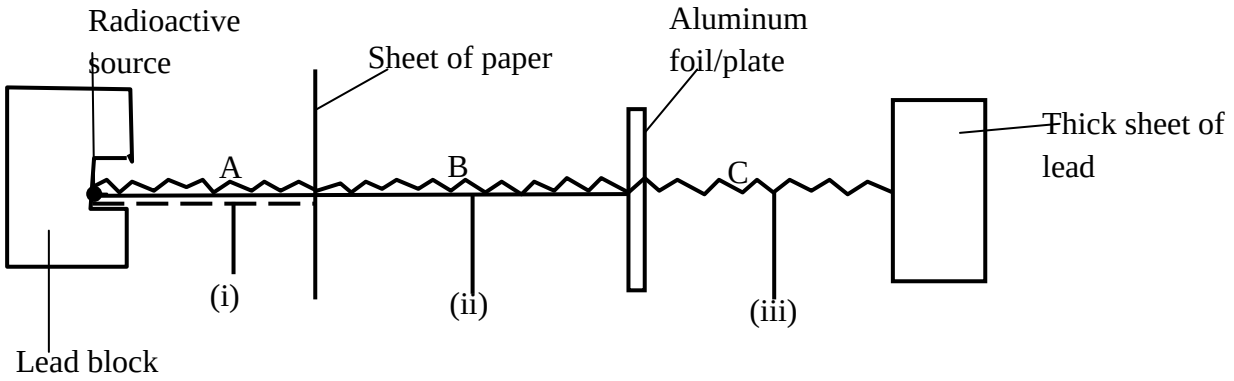
Solution

(i) ${}^{288}_{92}Y \rightarrow {}^{b}_{a}A + {}^{4}_{2}He$
For atomic number
a+2 = 92
a = 90
For mass number
288 = b+4
B = 284
${}^{288}_{92}Y \rightarrow {}^{284}_{90}A + {}^{4}_{2}He$
Composition: The nucleus consists of 90 protons and 194 neutrons

(ii) ${}^{284}_{90}A \rightarrow {}^{284}_{91}B + {}^{0}_{-1}e$
Composition: it consists of 91 protons and 193 neutrons

(iii) ${}^{284}_{91}B \rightarrow {}^{284}_{91}C + \gamma$
It consists of 91 protons and 193 neutrons

ABSORBERS OF RADIOACTIVE PARTILCES



Absorption of radioactive particles always depends on the penetrating power of the particles.

(i) An alpha particle; absorbed/stopped by a sheet of paper

(ii) A beta particle; absorbed/stopped by aluminum foil/plate
(iii) Gamma ray; absorbed/stopped by a thick sheet of lead

NB: In region A;

Alpha, beta and gamma rays exist

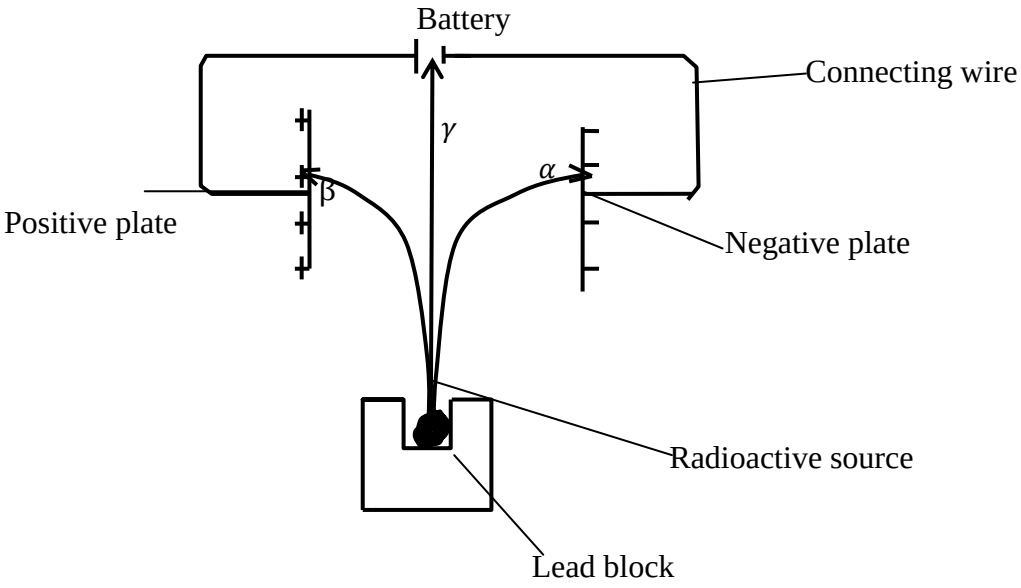
In region B;

Beta and gamma rays exist

In region C;

Only gamma rays exist

Effects of electric field on radioactive particles



When a radioactive source is placed in a region where there is an electric field, some particles are deflected towards the negative plate showing that they are alpha particles.

Others are deflected towards the positive plate-showing that they are beta particles.

While others are not deflected showing that they are gamma rays.

Hazards/effects/danger caused by radio-activity

- Destroys body cells e.g. white cells hence reducing body immunity
- Causes genetic mutation
- Causes skin burn
- Causes sterility
- Destroys retinal cells hence causing night blindness

Precautions:

- Keep radioactive substances in lead boxes
- Avoid being in direct exposure to radioactive substances
- Wear protective gear
- Handle radioactive substances with forceps

Uses of radioactivity

(a) Medical/Biological use

- Sterilization of medical equipment
- Treatment of cancer/destroys cancer cells
- Determination of blood volume in animals
- Treatment of brain teumous
- Used in diagonization of diseases using mercury 197
- Used to investigate heart and lung conditions using oxygen 15

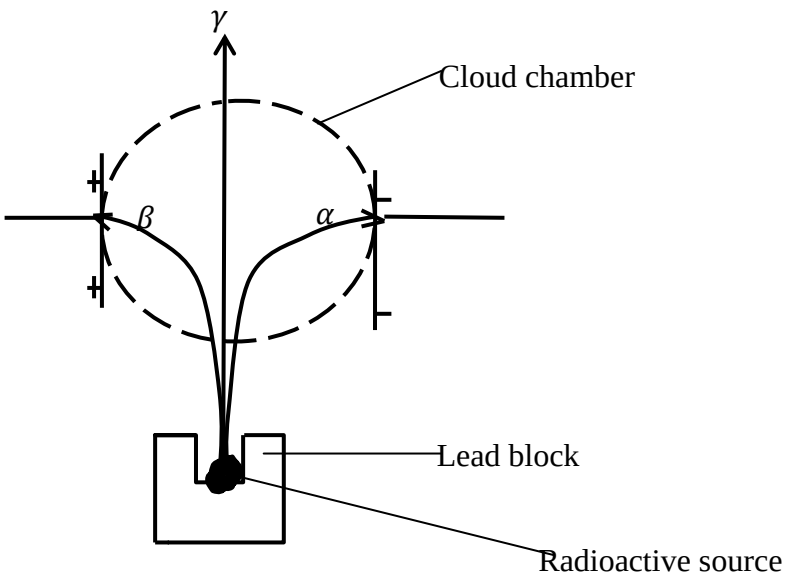
(b) Agricultural use:

- Sterilization of pests
- Study of uptake of fertilizers by plants
- Carbon dating(when one is able to determine the ages of fossils)
- Production of new varieties of crops

(c) Industrial use

- Detection of cracks
- Used in hardening of rubber by exposing rubber to gamma rays
- Thickening of lubricant oils done by exposing oils to gamma rays
- Used as a thickness gauge done by using beta particles
- Used in manufacture of explosives
- Detection of flaws in metals

Experiment to detect the three kinds of radiations emitted during radioactivity

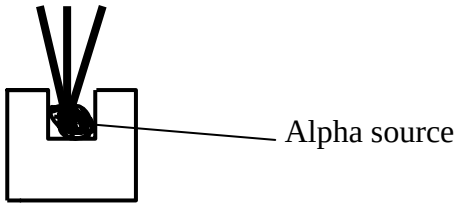


The three radiations from a radioactive source are directed into a cloud chamber placed in an electric field.

Some radiations are deflected to the positive plate showing that they are beta particles. Some are deflected to the negative plate showing that they are alpha particles; while others are not deflected showing that they are gamma rays.

Appearance of tracks trapped by radiations in a cloud chamber

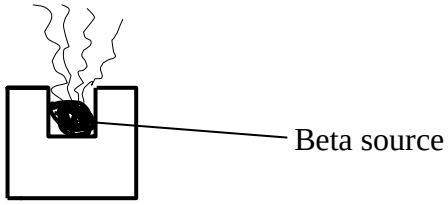
(i) Alpha particle:



An alpha source produces thick and straight short tracks. This is because alpha particles are good ionizers of air hence thick tracks

They make straight short tracks because they are heavy hence not easily deflected by collisions with air molecules.

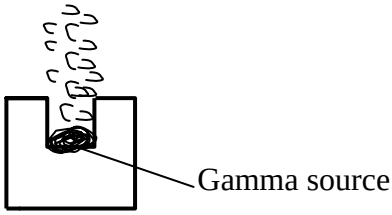
(ii) beta particle:



A beta source produces long and thin wavy tacks. This is because beta particles are poor ionizers of air hence thin tracks.

They form long wavy tracks because they are light hence easily deflected by collisions with air molecules.

(iii) Gamma rays



A gamma source produces dotted wavy tracks because; they are very poor ionizers of air.

QN: Explain the nature of the tracks of alpha particles and beta particles in air

Solution

- Alpha particle; produces thick and straight short tracks. This is because alpha particles are good ionizers of air hence thick tracks. They make straight short tracks because they are heavy hence not easily deflected by collisions with air molecules.
- Beta particles; produces tracks which are long and thin wavy. This is because; beta particles are poor ionizers of air hence thin tracks. They form long wavy tracks because they are light hence easily deflected by collisions with air molecules.

Uses of radioactive Tracers

(i) Medical/Biological use:
- To detect cancer
- To detect brain teumous
- To detect blood volume
- To detect kidney stones
- To detect blood clot

(ii) Non-medical uses
- Monitor uptake of fertilizers by plants (Agriculture)
- In carbon dating
- Detect leakage in pipes (industrial)
- Used to detect flaws in metals

HALF LIFE

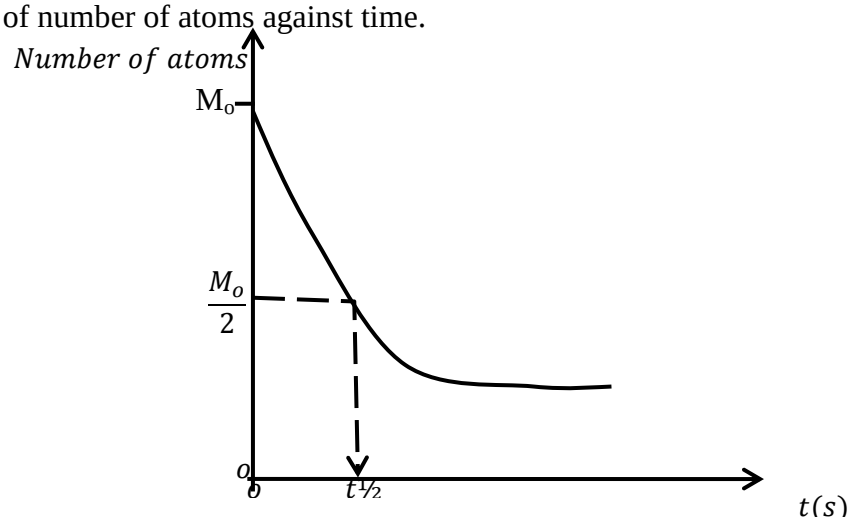
Is the time taken for the mass of a radioactive material to decay (reduce) to half its original/initial value.

Half life is always measured in; seconds, minutes, hours, days, weeks, months, years.

Half life is also the time taken for the count rate of a radioactive substance to reduce to half its original values.

Half life of a radioactive substance can be determined using a graph

If M_o, is the original number of atoms of a radioactive substance, its half line can be determined by plotting a graph of number of atoms against time.



$t½$ - half life of a radioactive material.

A radioactive element with original sample, M_o and half line, $t_{½}$ undergoes decay so that the remaining sample is M_T the remaining sample, M_T can be obtained from the formula.

$M_T = M_o \left(\frac{1}{2}\right)^{\frac{T}{t_{½}}}$, where T is the time taken for the material to decay.

NB:

(i) The mass of a radioactive substance that has decayed is given by, $M_o - M_T$; where M_o –original mass /initial mass, M_T – Remaining mass.

(ii) The fraction of the sample that has not decayed after a time, T, is given by $\left(\frac{1}{2}\right)^{\frac{T}{t_{½}}}$; where $\frac{T}{t½}$ = Number of half lives, n

Questions

1. A radioactive substance of mass 60g takes 400 years for its mass to reduce to 15g. Find its half life

Solution:

$M_T = M_o \left(\frac{1}{2}\right)^{\frac{T}{t_{½}}}$

$15 = 60\left(\frac{1}{2}\right)^{\frac{400}{t½}}$

$\frac{15}{60} = \left(\frac{1}{2}\right)^{\frac{400}{t½}}$

$\frac{1}{4} = \left(\frac{1}{2}\right)^{\frac{400}{t½}}$

$\left(\frac{1}{2}\right)^2 \left(\frac{1}{2}\right)^{\frac{400}{t½}}$

$2 = \frac{400}{t½}$

So, $t_2^1 = 200\ years$

OR

$60g \xrightarrow[t½]{} 30g \xrightarrow[t½]{} 15g$

$2t½ = 400$

$\boldsymbol{t½ = 200\ years}$

Mass that has decayed

$M = M_o - M_T$

$M = 60 - 15$

$\boldsymbol{M = 45g}$

2.The mass of a radioactive substance decays to $\frac{1}{32}$ of its original mass after 20 days. Determine:

(i) Its half life

(ii) Fraction of the original mass that will have decayed after 32 days.

Solutions:

From: $M_T = M_o \left(\frac{1}{2}\right)^{\frac{T}{t_{½}}}$

(i) $\frac{1}{32} = \left(\frac{1}{2}\right)^{\frac{T}{t_{½}}}$

$\left(\frac{1}{2}\right)^5 = \left(\frac{1}{2}\right)\frac{20}{t½}$

$5 = \frac{20}{t½}$

$t½ = 4\ days$

(ii) Fraction undecayed

$\left(\frac{1}{2}\right)^{\frac{T}{t_{½}}} = \left(\frac{1}{2}\right)^{\frac{32}{4}}$

$\left(\frac{1}{2}\right)^8$

$\frac{1}{256}$

Fraction that will have decayed =

$\frac{1}{1} - \frac{1}{256} = \frac{256-1}{256} = \frac{255}{256}$

QN: The half-life of the isotope is $3x10^3$ years. What fraction of the isotope remains after 6000 years

Solution:

$t½ = 3 \times 10^3$

$t½ = 3 \times 10^3$

$t½ = 3000$

Fraction undecayed = $\left(\frac{1}{2}\right)^{\frac{T}{t½}}$

$= \left(\frac{1}{2}\right)^{\frac{6000}{3000}}$

$= \left(\frac{1}{2}\right)^2 = \frac{1}{4}$

QNS:

1. A radioactive element has half-life of 4 hours. If the initial mass of the sample is 9.6g. Calculate the time taken for the element to decay to 0.15g (24 hours).
2. A radioactive element has half-life of 5 minutes. If the initial mass of material is 120g, calculate the mass that decays after 20 minutes (112.5g)
3. The mass of a radioactive substance decays to $\frac{1}{16}$ of its original value after 36 days. Find its half life (9 days)
4. A radioactive sample decays to $\frac{15}{6}$ $after\ 8\ minutes$. Find the half life of the sample (2 minutes)

Solutions:

1. $9.6 \underset{t½}{\rightarrow} 4.8 \underset{t½}{\rightarrow} 2.4 \underset{t½}{\rightarrow} 1.2 \underset{t½}{\rightarrow} 0.6 \underset{t½}{\rightarrow} 0.3 \underset{t½}{\rightarrow} 0.15$

   = 6 half lives
   n= 6

   $\left(\frac{1}{2}\right)^6 = \left(\frac{1}{2}\right)^{\frac{T}{4}}$
   $6 = \frac{T}{4}$
   T = 6x4
   T = 24 hours

2. From $M_T = M_o \left(\frac{1}{2}\right)^{\frac{T}{t½}}$

   Mass remaining $M_T = 120 \text{ x } \left(\frac{1}{2}\right)^{\frac{20}{5}}$

   $= 120 \text{ x } \left(\frac{1}{2}\right)^4$

   $= \frac{1}{16} \times 120$

$M_T = 7.5g$

Mass decayed = $M_o - M_T$

$= 120 - 7.5$

$= 112.5g$

3. T = 36 days, $M_T = \frac{1}{16} \times M_o$

So, from: $M_T = M_o \left(\frac{1}{2}\right)^{\frac{T}{t_{½}}}$

$$\frac{1}{16} \times M_o = M_o \times \left(\frac{1}{2}\right)^{\frac{36}{t_{½}}}$$

$$\frac{M_o}{16 \times M_o} = \frac{M_o}{M_o} \left(\frac{1}{2}\right)^{\frac{36}{t_{½}}}$$

$$\frac{1}{16} = \left(\frac{1}{2}\right)^{\frac{36}{t_{½}}}$$

$$\left(\frac{1}{2}\right)^4 = \left(\frac{1}{2}\right)^{\frac{36}{t_{½}}}$$

$$4 = \frac{36}{t_{½}}$$

$$t_{½} = \frac{36}{4}$$

$\boldsymbol{t_{½}\ 9\ days}$

4. $M_T = M_o \left(\frac{1}{2}\right)^{\frac{T}{t_{½}}}$

$Fraction\ undecayed = \frac{1}{16}$

$$\left(\frac{1}{16}\right) = \left(\frac{1}{2}\right)^{\frac{8}{t_{½}}}$$

$$\left(\frac{1}{2}\right)^4 = \left(\frac{1}{2}\right)^{\frac{8}{t_{\frac{1}{2}}}}$$

$\boldsymbol{t_{½} = 2\ minutes}$

5. A radioactive substance takes 5600 years for 93.75% of its mass to decay. Calculate the half life of the substance.

Solution

$\frac{93.75}{100} M_o = M_o \left(\frac{1}{2}\right)^{\frac{T}{t_{½}}}$

$$\frac{93.75}{100} = \left(\frac{1}{2}\right)^{\frac{5600}{t_{½}}}$$

$fraction\ that\ decayed$

$$\frac{93.75}{100} = \frac{15}{6}$$

Fraction undecayed

$$1 - \frac{15}{16} = \frac{16-15}{16} = \frac{1}{16}$$

$$\frac{1}{16} = \left(\frac{1}{2}\right)^{\frac{T}{t_{½}}}$$

$$\left(\frac{1}{2}\right)^{4} = \left(\frac{1}{2}\right)^{\frac{5600}{t_{½}}}$$

$$4 = \frac{5600}{t½}$$

$$t½ = \frac{5600}{4}$$

$$\boldsymbol{t½ = 1400\ years}$$

Or

Percentage which remained = original percentage – percentage that decayed

100% - 93.75%

= 6.25%

From:

$100\% \xrightarrow{t½} 50\% \xrightarrow{t½} 25\% \xrightarrow{t½} 12.5\% \xrightarrow{t½} 6.25\%$

$$4\ t½ = 5600$$

$$t½ = \frac{5600}{4}$$

$$\boldsymbol{t½ = 1400\ years}$$

Or

Percentage which remained, M_T

= 100% - 93.75%

= 6.25%

M_o, original % = 100%

Percentage decayed, 93.75%

From: $M_T = M_o \left(\frac{1}{2}\right)^{\frac{T}{t_{½}}}$

$$6.25 = 100\left(\frac{1}{2}\right)^{\frac{T}{t_{½}}}$$

$$\frac{6.25}{100} = \left(\frac{1}{2}\right)^{\frac{5600}{t_{½}}}$$

$$\frac{1}{16} = \left(\frac{1}{2}\right)^{\frac{5600}{t_{½}}}$$

$$\left(\frac{1}{2}\right)^{4} = \left(\frac{1}{2}\right)^{\frac{5600}{t_{½}}}$$

$$4 = \frac{5600}{t_{½}}$$

$$t½ = \frac{5600}{4}$$

$$\boldsymbol{t½ = 1400\ years}$$

NUCLEAR REACTIONS

These are reactions that involve only the nucleus of an atom.

(i) Nuclear fission:

Is a nuclear reaction in which a heavy nucleus splits into two smaller nuclei with release of energy.

A heavy nucleus splits up when it is bombarded by a high energy neutron.

A neutron is used because it does not have a charge hence penetrates deeply into the nucleus.

The nucleus absorbs the neutron and as a result its mass number increases by 1 hence the energy content of the nucleus also increases which then makes it unstable and breaks up into two smaller lighter nuclei. E.g.

$^{235}_{92}\cup + {}^{1}_{0}\cap \rightarrow {}^{144}_{56}Ba + {}^{90}_{36}Kr + 2\,{}^{1}_{0}\cap + energy$

Nucleaar fission occurs naturally in the nucleus of an atom

Uses of Nulear fission:

- Formation of atomic bombs
- Results in production of energy used to generate power (used to generate electricity)

Conditions for nuclear fission to occur

- Occurs at ordinary temepratures
- Presence of high energy neutron in order to bombard the heavy nucleus
- There must be a heavy nucleus with large mass number

QN: Explain the processes involved in generation of electricity using Uranium 235

Nuclear fission of Uranium 235 produces a lot of heat in the nuclear reactor. The heat energy is used to boil water in order to produce steam at high temeprature and pressure. This steam is used to turn turbines in a dynamo or generator in order to produce electricity.

(ii) Nuclear fission:

Is a nuclear reaction in which lighter nuclei combine to form a heavy nucleus with release of energy.

NB: it occurs natually in the sun

Conditions for nuclear fussion to occur

- Occurs at very high temepratures

- Presence of light nuclei approaching each other at high speed to overcome the repulsive force

Uses of nuclear fussion

- Source of solar energy
- Used in production of hydrogen bombs

CATHODE RAYS

Cathode rays are a stream of fast moving electron.

OR: cathode rays are high speed electrons

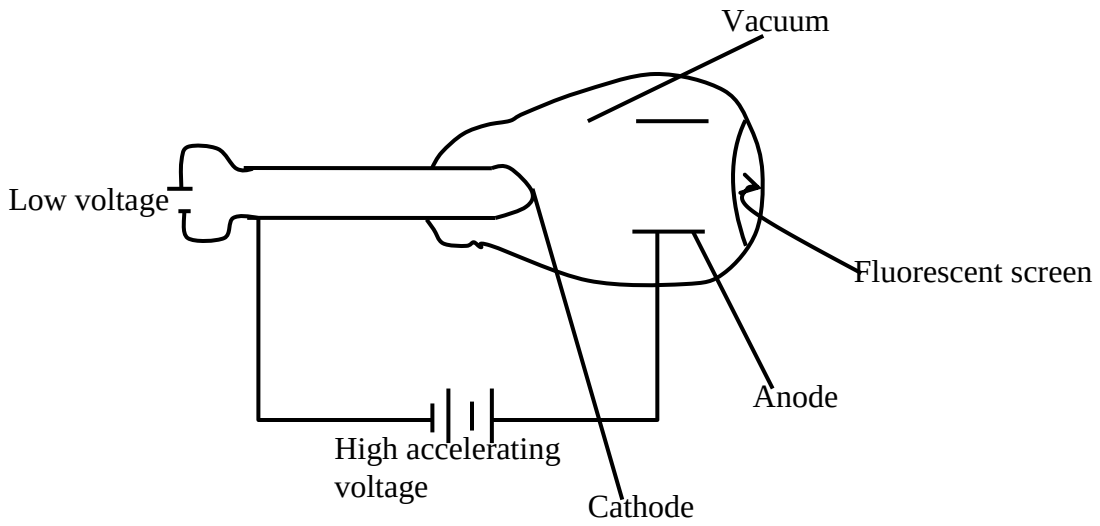
Properties of cathode rays

- Are negatively charged
- Deflected by an electric
- Deflected by magnetic fields
- Travel in a straight line (Forms a shadow)
- Posses energy (carry momentum)
- Can produce X –rays when stopped by a metal target
- Ionises gases
- Affect phototgraphic plates (darkens photographic plates)
- Produces flourescence

PRODUCTION OF CATHODE RAYS

Cathode rays can be produced in a Cathode Ray Tube (C.R.T)

Structure of a Cathode Ray Tube (C.R.T)



- The cathode filament is heated by a low voltage and electrons are emitted (produced)
- A high voltage is connected between the cathode and the anode.
- Electrons are therefore accelerated towards the anode by this high voltage (E.H.T) hence constituting cathode rays that are focused onto the fluorescent screen.

QN: Briefly explain how cathode rays are produced in a cathode ray tube.

QN: Why is a cathode ray tube always made of a vacuum in it

- To prevent unnecessary ionization of particles in the tube since the electrons ionize gases.
- To prevent unnecessary collision of moving electrons with the particles inside which will reduce the speed of moving electrons.

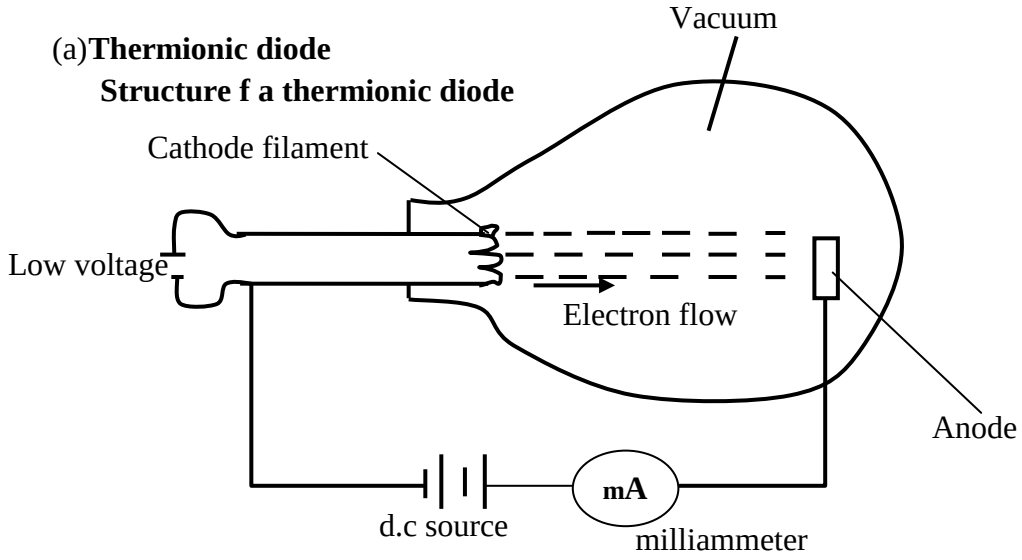
Methods of producing electrons:

1. (i) Thermionic emission

   Is the emission of electrons from a metal surface when heated to sufficiently high temperature. As a metal losses electrons, it acquires a net positive charge.

(a)**Thermionic diode**

Structure f a thermionic diode



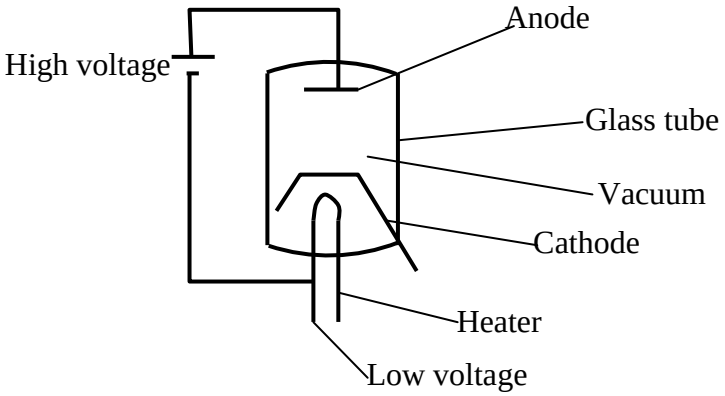
The cathode is heated by a low voltage and produces electrons by thermionic emissions.

Electrons are accelerated by a high positive anode to a high speed thus forming cathode rays.

When electrons are released from the cathode, the pointer of the milliammeter deflects. This is because motion of electrons constitutes a complete circuit where current flows.

NB: A thermionic diode allows electrons to flow or pass in only one direction.

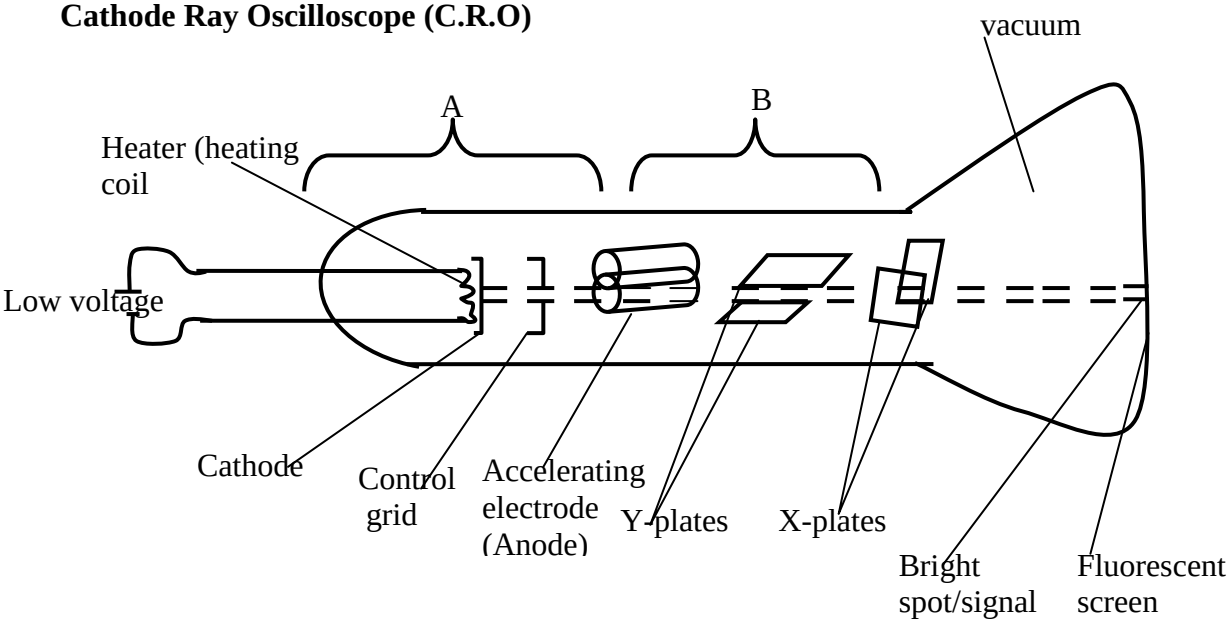
(b) Diode value



A diode is a device that allows current to flow in only one direction.

A diode valve consists of an anode and the cathode inside an evacuated glass tube. It conducts when the anode is positive relative to the cathode and has high resistance when the anode is negative relative to the cathode.

Cathode Ray Oscilloscope (C.R.O)



A – Electron gun

B – Deflecting system

NB:

- The Cathode Ray Oscilloscope consists of three major component parts i.e. Electron gun, deflecting system and fluorescent screen.
- Electron gun comprises of; heater, Cathode, control grid and anodes
- Deflecting system comprises of; Y-plates and X-plates.

How C.R.O works

- The cathode is heated by a low voltage and emits electrons by thermionic emission.
- The emitted electrons are accelerated and focused into a fine beam by use of anodes at a high positive potential relative to the cathode.
- The control grid controls (alters) the brightness of the spot formed on the screen
- In the deflecting system, the Y-plates deflects electron beam vertically and X-plates deflects electron beam horizontally.
- When the beam strikes a fluorescent screen, a bright signal/spot is formed.

QN: (a)

(i) State the three major component parts of a C.R.O

(ii) Describe the functions of each component part you have named in a(i) above

(iii) With the aid of a labeled diagram, describe how a C.R.O works

SIGNALS FORMED ON C.R.O

A C.R.O consists of a time base circuit which applies a certain voltage to the X-plates so that the bright spot moves horizontally.

When an alternating voltage is connected to the Y-plates, the spot is deflected vertically; hence the time base is to produce an alternating current.

Signals produced are in wave form as shown below:

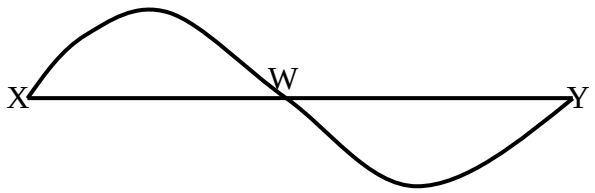
(i) ⊙ ; this wave form is formed when there is no voltage connected to both X and Y-plates hence both X and Y-plates should be switched off.
(ii) ∿ ; this wave form is obtained when an alternating current is applied to the Y-plates and the time base switched on.
(iii) ⊖ ; obtained when the Y-plates are switched off i.e. no voltage connected to Y-plates but a d.c source connected to the X-plates causing a horizontal deflection.
(iv) ⊕ ; this wave pattern is obtained when the X-plates are switched off i.e. no signal is connected to the X-plates but A.C is applied to the Y-plates causing vertical deflection only.

Uses of C.R.O

- Used to display wave forms of various electrical signals
- Used in televisions
- Used as a voltmeter to measure voltage
- Used in computers
- Used to measure frequency of waveforms
- Used in measurement of time and phase difference

Examples on applications of a C.R.O

1. A wave W is obtained on the screen of a Cathode Ray Oscilloscope when an a.c. voltage is applied to the Y-plates. If length $\overrightarrow{XY}$ on the time base of a C.R.O represent 0.002s. Find the frequency of the voltage.



Solution:

Time taken for wave, W to move from X to Y is the period

Therefore period = 0.002s

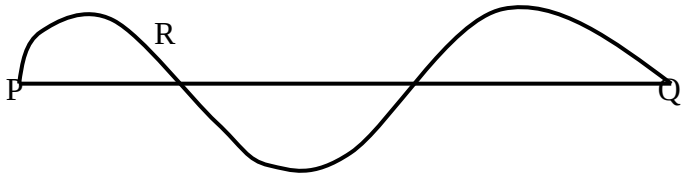
But, frequency is a reciprocal of the period

$f = \frac{1}{T}$

$f = \frac{1}{0.002}$

Therefore frequency f = 500Hz

2.



The length $\overrightarrow{PQ}$ on the time base of a C.R.O represents a time of $1.5x10^{-3}$s. A wave, R is obtained on the screen when an a.c voltage is connected to the Y-plates. Find the frequency of the a.c supply.

Solution

Between P and Q there are 1½ cycles = $\frac{3}{2}\ cycles$

$\frac{3}{2}\ cycles\ is\ produced\ in\ 1.5\ \times 10^{-3}s$

1 cycle is then produced by, T (period)

$\frac{3}{2} = 1.5 \times 10^{-3}$

1 = T

$\frac{3T}{2} = 1.5 \times 10^{-3}$

$3T = 1.5 \times 10^{-3} \times 2$

$T = \frac{1.5\ \times 10^{-3} \times 2}{3}$

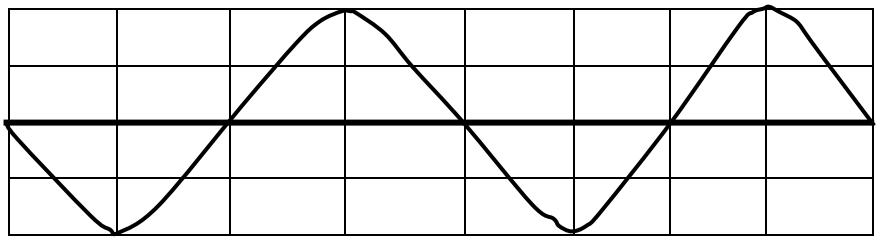
$T = 1.0 \times 10^{-3}s$

Therefore f = $\frac{1}{T} = \frac{1}{1.0x10^{-3}} = 1000Hz$

OR

$f = \frac{Number\ of\ cycles}{time} = \frac{n}{t} = \frac{1.5}{1.5\ \times 10^{-3}} = 1000Hz$

3.



The C.R.O with its time base switched on was connected across a power supply and a wave form shown above was displayed on a screen. If the distance between any two successive lines is 2cm.

(i) Identify the type of voltage generated by the power supply

(ii) Find the amplitude (peak value) of the voltage generated if the voltage gain is set at 5V per centimeter ($5Vcm^{-1}$)

(iii) Calculate the frequency of the power source if the time base setting on a C.R.O $5*10^{-3}$s /cm

Solution

(i) An a.c voltage

(ii) Amplitude occupies a distance of 4 cm, But Y-gain is 5V cm^{-1}

If 1cm=5V

4cm = $\left(\frac{5}{1}\right) \times 4 = 20$ V

(iii) From: $f = \frac{n}{t}$

$n = 2$

$t = 5 \times 10^{-3} scm$

1cm = 5×10^{-3}

$(8 \times 2)cm = 5 \times 10^{-3} \times (8 \times 2)cm$

Therefore $t = 5 \times 10^{-3} \times 16$

So $f = \frac{n}{t} = \frac{2}{5 \times 10^{-3} \times 16} = \frac{2}{0.005 \times 16}$

$= \frac{2}{0.08} = 25Hz$

$therefore\ f = 25Hz$

4. In a C.R.O, explain the effect of the following on the brightness of electron spot on the screen:

(i) Increasing the filament current

(ii) Decreasing the anode voltage

Solution:

(i) Increasing filament current increases temperature of the cathode and the number of electrons emitted increases, hence increase in brightness of electron spot.

(ii) Decreasing anode voltage decreases the speed hence number of electrons reaching the screen also decreases. This leads to decrease in brightness of electron spot on the screen.

Advantages of a C.R.O as a voltmeter over a moving coil voltmeter

- A C.R.O measures both a.c and d.c voltages while voltmeter measures only a d.c voltage.
- Electron beam in a C.R.O acts as a pointer of negligible inertia and responses instantly.
- It draws negligible current from the circuit being measured.

2. PHOTOELECTRIC EMISSION

This is the emission of electrons from a metal surface when electromagnetic radiation of high enough frequency falls on it.

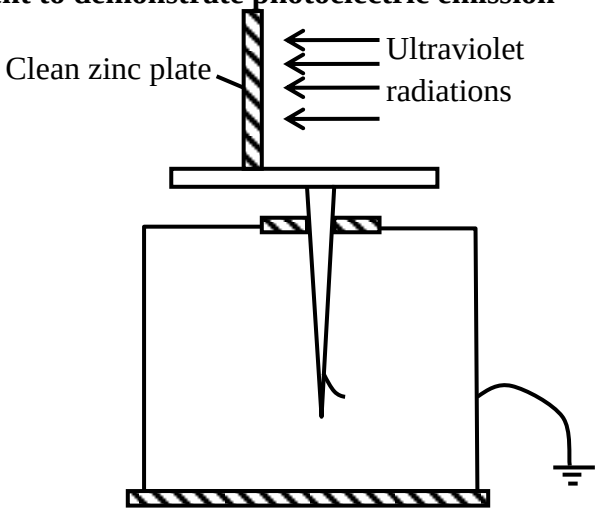
A radiation of ***short wave length*** has a high frequency

The ***commonly used*** radiations is an ***ultra violet radiation***

The frequency of a radiation should be above a certain value called Threshold frequency, f_o; hence below this frequency, no electrons will be emitted from the metal surface.

NB: If an electromagnetic radiation of low frequency such as radio wave is incident on a metal surface (zinc plate), the radiations will not be able to eject electrons from the zinc surface hence no photoelectric emission occurs.

Experiment to demonstrate photoelectric emission



A zinc plate is placed on the cap of a charged gold leaf electroscope.

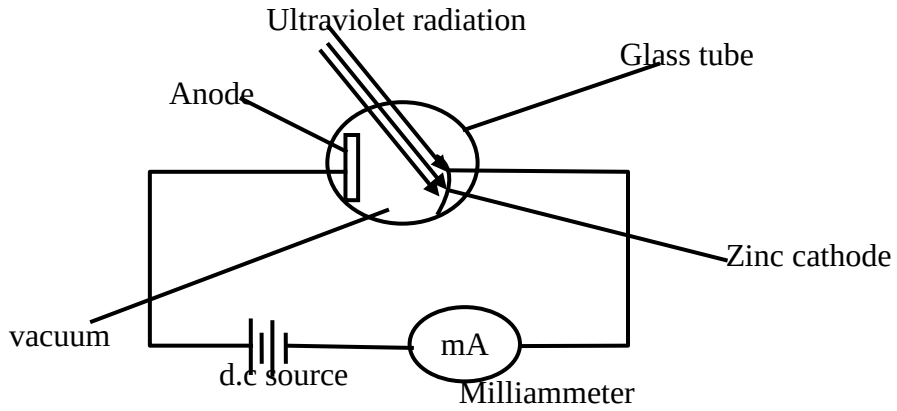
Ultraviolet radiations are incident on a clean zinc plate.

(i) If the gold leaf electroscope is negatively charged, the zinc plate emits its electrons because ultraviolet radiation has a high loss of charge.

(ii) If the gold leaf electroscope is positively charged, no further divergence of the leaf is observed when ultraviolet radiation is incident on the zinc plate. This is because, ultraviolet radiations ejects electron from the zinc plate but electrons are immediately attracted back hence, no loss of charge.

NB: If a radio wave is directed on the zinc plate, the radiation will not be able to eject electrons from the zinc surface hence no effect will be observed in a gold leaf electroscope (divergence remains the same)

Photo Emission Cell



When ultra violet radiation of high frequency is incident on a zinc cathode, electrons are emitted.

Emitted electrons are accelerated to the anode since electrons flow in the circuit, they constitute a current which flows through the milliammeter hence the pointer of the milliammeter gives a deflection.

The flow of current increases when the intensity o the incident radiation is increased

NB: When gas is introduced into a glass tube, the deflection in the pointer of the milliammeter decreases. This is because gas molecules collide with electrons hence reducing their kinetic energy (speed) as they move from the cathode to the anode, hence very few electrons will be flowing in the circuit.

Factors that affect photoelectric emission

(i) Frequency of the incident radiation
(ii) Nature of the metal surface used as the cathode

X-RAYS

These are electromagnetic radiations produced when fast moving electrons are stopped by matter.

They are produced in a modern x-ray tube by firing high energy (speed) electrons towards a metal target inside an evacuated glass tube.

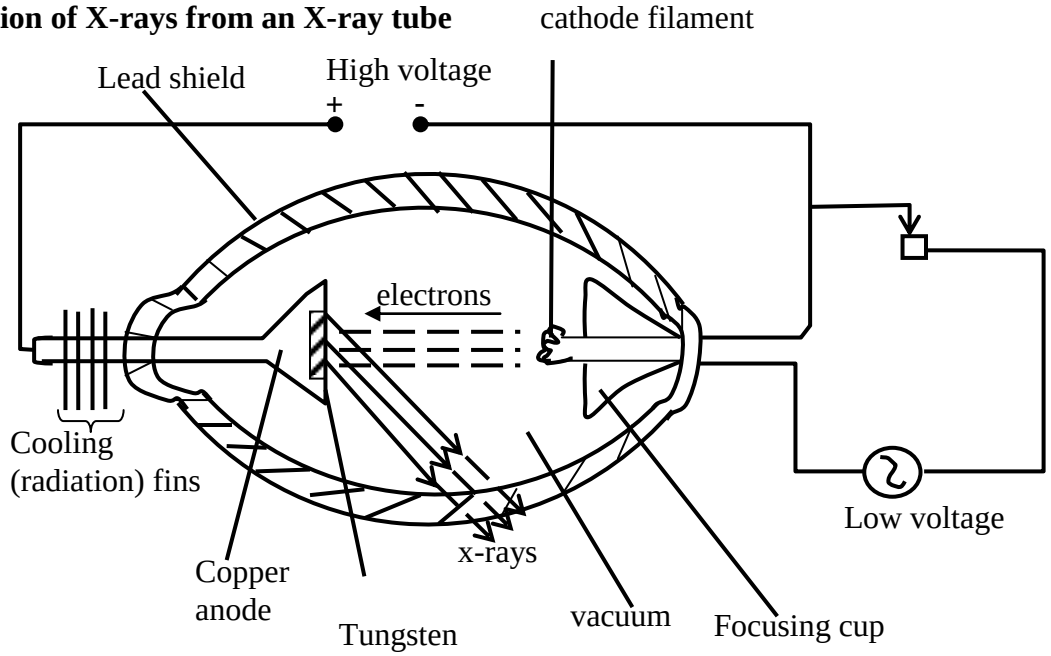
NB: <u>For electrons to produce x-rays, the following conditions must be satisfied.</u>

(i) Electrons must be accelerated to a high speed
(ii) Electrons must be accelerated through a vacuum
(iii) Electrons must strike a metal target

Properties of X-rays

- Travel through a vacuum
- Carry no charge
- Not deflected by electric and magnetic fields
- Travel at a high speed of $3x10^{8}ms^{-1}$ (speed of light)
- Penetrate matter
- Travel in straight line
- Darken photographic plates
- They are transverse waves
- They ionize gases
- Undergo diffraction
- Undergo interference
- Undergo polarization

Production of X-rays from an X-ray tube



- The cathode is heated by a low voltage and an electron beam is emitted.
- Electrons are accelerated towards the anode by a high voltage and are focused onto the tungsten target by a focusing cup.
- On hitting the target, electrons are instantly brought to rest thus giving up their Kinetic energy.
- A small fraction or percentage of energy is converted to x-rays while the rest is converted to heat which is removed away by the cooling fins.

Types of x-rays

1. **Soft x-rays**
   These are x-rays with the following properties
   - Have longer wave length (low frequency)
   - Have least penetrating power (carry lower energy)
   - Produced at a low accelerating voltage

NB: Soft x-rays are always used in taking photographs of internal parts of patients in hospital.

2. **Hard x-rays**
   These are x-rays with the following characteristics /properties
   - Have short wavelength (high frequency)
   - Are more penetrating (carry more energy)
   - Produced at high accelerating voltage

NB: Soft x-rays are always preferred to hard x-rays in taking photographs of internal parts of patients because soft x-rays are less penetrating to body tissues and carry low energy while hard x-rays have high energy compared to soft x-rays hence more penetrating to body tissues.

QN: State three differences between soft x-rays and hard x-rays

NB:

In an x-ray tube, the tungsten target is always embedded on a copper anode, because copper is a good conductor of heat. When electrons strike the target, a lot of heat is produced which would affect the machine hence copper quickly conducts this heat away.

The x-ray tube is evacuated (made up of a vacuum) in order to prevent loss of energy by electrons due to collisions with air molecules. This is because air molecules are massive and large compared to electrons. If they are not removed, they will obstruct movement of electrons towards the anode hence a few electrons that would be able to reach the anode would be too weak to produce x-rays on impact with the target.

The cooling fins are used to remove the excess heat produced when electrons strike the target.

Uses of x-rays

(a) Medical/Biological uses:

- Used to burn cancer cells
- Used to reveal chest infections (Detection of T.B)
- Treatment of brain teumous
- Detection of foreign objects in the body
- Sterilization of medical equipment
- To detect fractures in bones

NB: x-rays are used to detect fractures in bones because;

- They travel in straight lines
- They darken (affect) photographic plates
- X-rays do not penetrate bones but only penetrate flesh

(b) Industrial use

- Detection of cracks in metals
- To investigate structures of crystals
- Checking of luggage

Dangers (Hazards) of x-rays

- Causes skin burn
- Causes cancer
- Causes genetic mutation or hereditary effects
- Causes sterility
- Destroys body cells e.g. white blood cells hence reducing body immunity
- Destroys retinal cells hence causing night blindness

Precautions

- Keep x-rays in lead boxes
- Wear protective gears

- Handle x-rays with forceps
- Avoid being in direct exposure with x-rays

In x-ray tubes, heat energy is changed to electrical energy to Kinetic energy and to heat energy which is lost and some turned to x-rays.

Penetration power of x-rays

This is the ability of x-rays to enter into matter hence the penetrating power of x-rays can be increased by increasing the accelerating voltage. This in turn increases the kinetic energy of electrons making them more penetrating.

When the accelerating voltage is high, hard x-rays are produced and when the accelerating voltage is low, soft x-rays are produced.

Intensity of x-rays

The intensity of x-rays depends on the filament current.

When the filament current is increased, the rate of electron emission also increases, hence more electrons strike the target per second and this increases the intensity of x-rays.