232/2

PHYSICS PAPER 2

TOPICS COVERED IN THIS PAPER / CONTENTS

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1. RECTILINEAR PROPAGATON OF LIGHT AND REFLECTION AT PLANE MIRRORS

RECTILINEAR PROPAGATION OF LIGHT

This is the property of light which suggests that light travels in a straight line

EVIDENCE FOR RECTILINEAR PROPAGATION OF LIGHT

i) **Formation of shadows**

ii) **Formation of images in a pin hole camera**

SHADOWS

A shadow is a shade cast whenever light is blocked by an opaque object

- There are ***two*** types of shadows

  (i) Umbra (total shadow)

  - *This is formed when **all** light from the source is blocked by an opaque object*

  (ii) Penumbra (partial shadow)

  - *This is formed when light from the source is **partially** blocked by an opaque object*

- The type of shadow formed depends on ***three*** main factors:

  (a) Size of the source of light

  - *If the light source is relatively bigger compared to the opaque object, penumbra is likely to be formed and vice versa*

  (b) Size of the opaque object

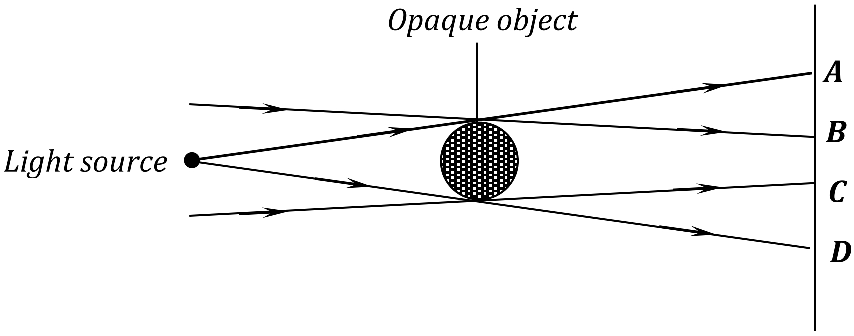
  - *If the object is relatively bigger compared to the opaque object, umbra will be formed and vice versa*

  (c) Distance between the opaque object and the source of light

  - *If the object is relatively far from the light source, penumbra is lkely to be formed*

Worked Example 1

The figure below shows three point sources of light with an opaque object placed between them and the screen. Explain the nature of the shadow formed long **B** and **C**



Answer

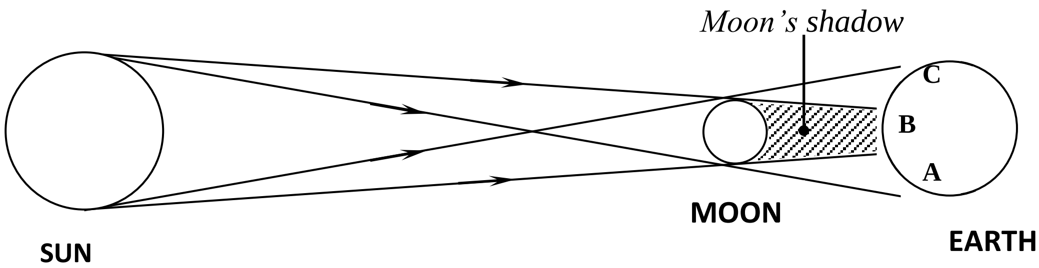
- *The shadow formed along **BC** is a umbra (total shadow)*
- *All the rays of light from the point sources towards the region **BC** are blocked by the opaque object and therefore cannot reach the screen*

ECLIPSES

- An eclipse is formed whenever there is a partial or total disappearance of either the sun or the moon
- There are ***three*** types of eclipses

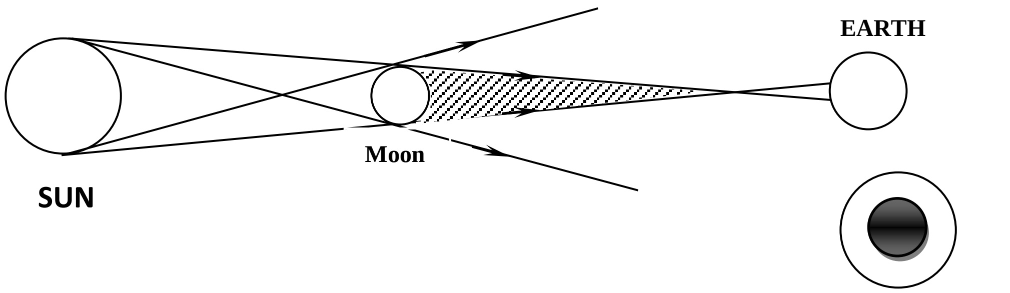
(i) ECLIPSE OF THE SUN (SOLAR ECLIPSE)

- *This occurs when the moon is in between the earth and the sun. The moon's shadow then falls on earth*



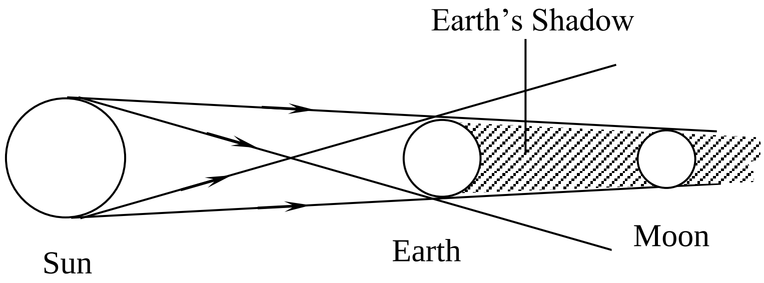
(ii) ANNULAR ECLIPSE (PARTIAL ECLIPSE OF THE SUN)

- *This is eclipse of the sun which occurs when the umbra of the moon is not long enough to reach the earth.*
- *The sun then appears as a bright ring with a black spot at the centre*

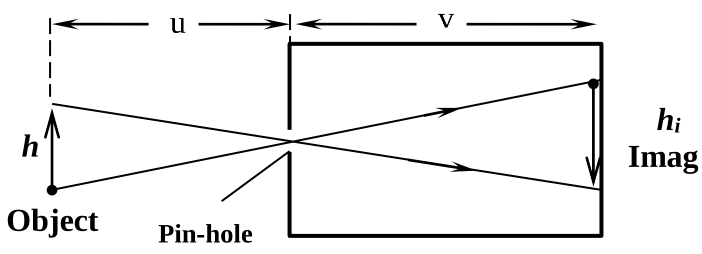


(iii) ECLIPSE OF THE MOON (LUNAR ECLIPSE)

- *This occurs when the earth is between the moon and the sun*
- *The earth's shadow then falls on the moon*



THE PINHOLE CAMERA



CHARACTERISTICS OF IMAGE FORMED BY PINHOLE CAMERA

- The image formed by the pinhole camera is:
  - **(i)** Diminished (smaller than the object)
  - **(ii)** Real
  - **(iii)** Inverted (upside down)

FACTORS AFFECTING IMAGE FORMED BY PIN-HOLE CAMERA

1. Object distance (distance from object to the pin hole)

- The bigger the object distance, the smaller the image formed in the camera

2. The image distance (distance from the pin hole to the screen)

- The bigger the image distance, the bigger the image formed on the screen

3. Size of the pin hole

- If the pin hole is made larger, the image formed becomes brighter but blurred (i.e. not clear)

Reason: *If the hole is enlarged, many overlapping images will be formed, thus giving a blurred image.*

MAGNIFICATION

- **This is the ratio of the size of image to the size of the object**

$$\text{Magnification} = \frac{\text{Image height } (h_i)}{\text{Object height } (h_o)}$$

ALSO:

$$\text{Magnification} = \frac{\text{Image distance from pin hole}}{\text{Object distance from pin hole}}$$

THEREFORE:

$$\frac{\text{Image height } (h_i)}{\text{Object height } (h_o)} = \frac{\text{Image distance from pin hole}}{\text{Object distance from pin hole}}$$

Worked Example 2

(a) A boy **1.4 m** tall stands **4.0 m** away from a pin-hole camera, **20 cm** long. Work out the height of the image formed on the screen.

Answer:

Image height = $\boldsymbol{h_i}$ *Image distance from pin hole* = *20 cm*

Object height = *1.4 m*   *Object distance from pin hole* = *4 m*

= *140 cm*   = *400 cm*

$$\frac{\text{Image height } (h_i)}{\text{Object height } (h_o)} = \frac{\text{Image distance from pin hole}}{\text{Object distance from pin hole}}$$

$$\frac{h_i}{140\text{ cm}} = \frac{20\text{cm}}{400\text{ cm}}$$

$$h_i = \frac{(140 \times 20)}{400}$$

$$h_i = 7\text{ cm}$$

(b) State the change that will be observed if:

(i) *the boy moves towards the camera*

Answer: *The image becomes bigger*

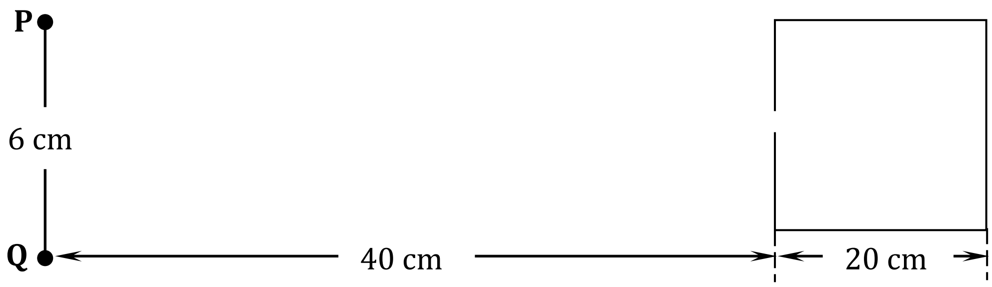
(ii) *the camera is made shorter*

Answer: *The image becomes smaller*

Practice Question

1. *How far away from a building of height* ***10 m*** *should a pin-hole camera be placed if an image of height* ***5 cm*** *is to be formed on the screen which is* ***12 cm*** *from the pin hole?*
(Answer: 24 m away from the building)

2. *A luminous point object took 3 sec to move uniformly from P to Q in front of a pin hole camera as shown in the figure below. Determine the speed of the image on the screen in cm/s* ***(Answer: 1 cm/s)***



ADVANTAGE OF THE PINHOLE CAMERA

- It does not require any focussing

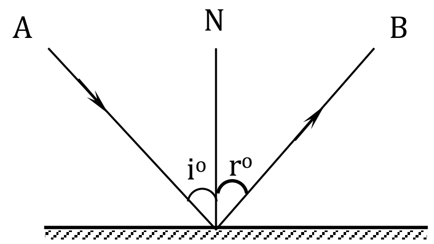
DISADVANTAGES OF THE PIN-HOLE CAMERA

1. The exposure time is too long due to the small size of the pin hole. *For this reason, the pinhole camera cannot be used to take pictures of moving objects*
2. It can only take one picture at a time

REFLECTION FROM PLANE SURFACES

LAWS OF REFLECTION OF LIGHT

1. **The angle of incidence is equal to the angle of reflection**
2. **The incident ray, the reflected ray and the normal all lie at the same plane and on the same side of the reflector**

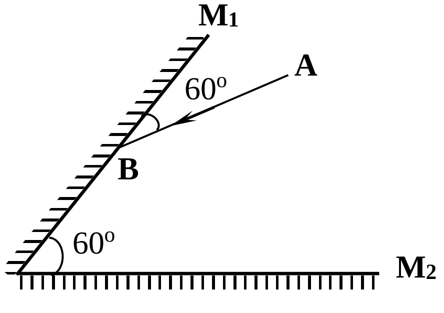


Angle i° = Angle r°

Practice Question

*Two plane mirrors, **M_1** and **M_2** are inclined at an angle of 60° to each other as shown below. A ray of light **AB** strikes mirror **M_1**, making an angle of 60° with the mirror as shown in the diagram. Complete the diagram by showing the path of ray **AB** from mirror **M_1** and after reflection from mirror **M_2** and hence determine the angle of reflection from mirror **M_2**?*

(Answer: 30°)



CHARACTERISTICS OF IMAGES FORMED BY PLANE MIRRORS

(i) The image is the same size as the object

(ii) The image is virtual (i.e. it is not formed by the actual intersection of the real rays)

(iii) The image is formed behind the mirror

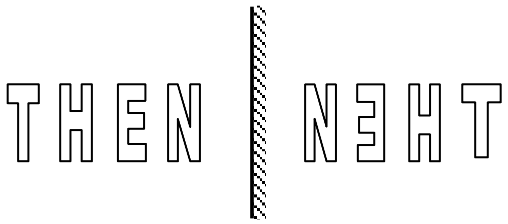
(iv) The image is erect (upright)

(v) Image distance is equal to the object distance

(vi) The image is **laterally inverted**.

Note: *Lateral inversion is the sideways turning effect in which the left side appears right and vice versa*

Example of lateral inversion



Differences between the images formed by the pin-hole camera and the plane mirror

Pin-hole camera	***Plane mirror***
Image is real	*Image is virtual*
Image is smaller than the object	*Image is the same size as the object*
Image is upside-down (inverted)	*Image is upright*
Image distance is shorter than the object distance	*Image distance is equal to the object distance*

IMAGES FORMED BY MIRRORS INCLINED AT AN ANGLE

- The number of images **N** formed by two mirrors inclined at an angle **θ** to each other is given by:

$$N = \left(\frac{360}{\theta}\right) - 1$$

Where: **N** – *Number of images formed* **θ** – *angle at which the two mirrors are inclined*

Worked Example 3

Two plane mirrors are inclined at an angle of 30° to each other. Determine the number of images observed

Answer

$$N = \left(\frac{360}{\theta}\right) - 1$$

$$= \left(\frac{360}{30}\right) - 1$$

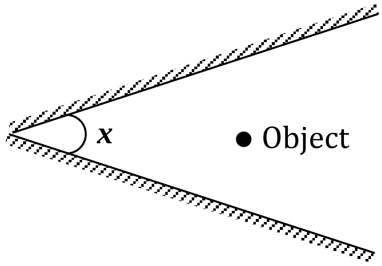
$$= 12 - 1$$

$$\underline{N = 11 \text{ Images}}$$

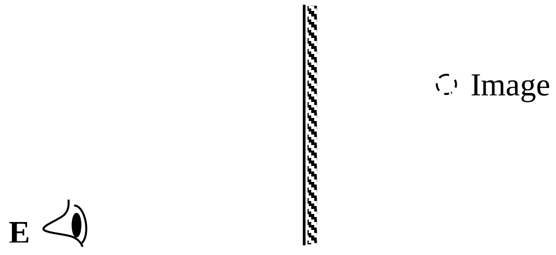
Practice Question

1. *At what angle must two plane mirrors be inclined for them to form 5 images?*
   (Answer: $\theta = 60^{o}$)

2. *The figure below shows two plane mirrors inclined at an angle* ***x*** *from each other. A viewer counts a total of seven images by looking directly from the object O. Determine value of* ***x***



3. *The figure below shows the position of an image in a plane mirror.* ***E*** *represents the eye of an observer. Complete the diagram to locate the position of the object*

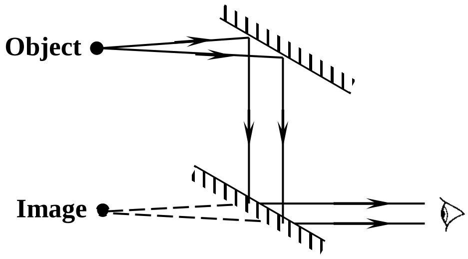


APPLICATIONS / USES OF PLANE MIRRORS

1. **Dental mirrors for observing dental problems**
2. **Plane mirrors for seeing oneself**
3. **Telescopes**
4. **Kaleidoscope**

5. Periscope

- *This is used to observe / view objects over obstacles*



- *The images formed are* ***upright*** *and* ***virtual***

Disadvantage of plane mirror periscope compared to prism periscope

- *Plane mirror periscope forms multiple images*
- *The paint on the plane mirror can pill off after some time*

2. ELECTROSTATICS 1 AND 2

- ***Electrostatics is the study of static (stationary) charges***
- **SI nit of charge is coulomb (C)**
- Some materials, mainly plastics acquire charges when rubbed. This enables them attract other smaller particles e.g. small pieces of paper, dust e.t.c.

Daily life examples

(i) Rubbing a plastic ruler on dry hair makes it to attract some small pieces of paper or dust

(ii) Household mirrors and windows attract dust and other small particles when wiped with dry duster

(iii) When a nylon dress is removed from the body, a cracking sound is heard

Worked Example 4

Inflammable liquids are not transported through plastic pipes. Give a reason for this.

Answer:

- *When a liquid flows through a pipe, its molecules become charged due to rubbing on the inner surface of the pipe.*
- *If the liquid is inflammable, it can cause sparks and explode.*

Practice Question

a) *Explain why a glass window when wiped with dry cloth on a dry day soon becomes dusty.*

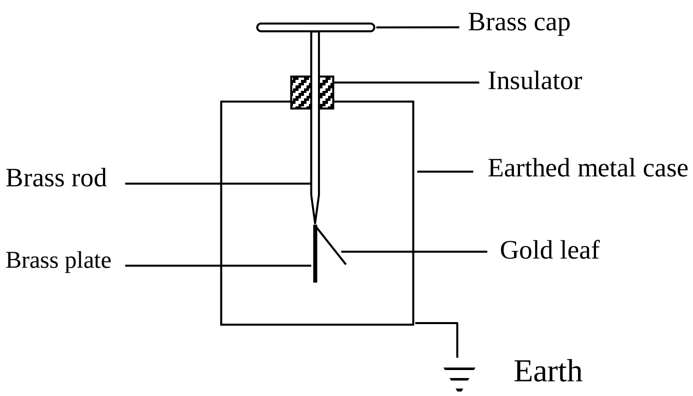
b) *It is not advisable to store highly inflammable liquids in plastic cans. Give a reason for this.*

BASIC LAW OF ELECTROSTATICS

The basic law of electrostatics states that unlike charges attract and like charges repel each other

THE GOLD LEAF ELECTROSCOPE

Main parts of the Gold Leaf Electroscope



- The cap acquires charge and spreads it through the rod to the leaf
- Presence of the charge makes the leaf to diverge. Absence of the charge makes the leaf to fall.
- Earthing is important in that it allows excess charge to flow to and from the earth.

Worked Example 5

Fuel tankers have a loose chain hanging under them to touch the ground as they move. Explain

Answer

- *The loose chain is used to earth the charges produced by friction between the moving parts of the vehicle.*

METHODS OF CHARGING THE ELECTROSCOPE

- There are ***two main*** methods of charging the electroscope:
  1) By contact
  2) By induction

1. CHARGING THE ELECTROSCOPE BY CONTACT METHOD

- A charged rod is rubbed several times on the cap of the gold leaf electroscope
- Charges are transferred to or from the cap of the electroscope and the leaf rises

Note:

When an electroscope is charged by contact, it acquires the same charge as that on the charging rod

2. CHARGING THE ELECTROSCOPE BY INDUCTION METHOD

1) A charged rod is brought near the cap of the electroscope
2) With the rod in that position, the electroscope is earthed by touching the cap
3) The finger is then first removed then the rod

Note:

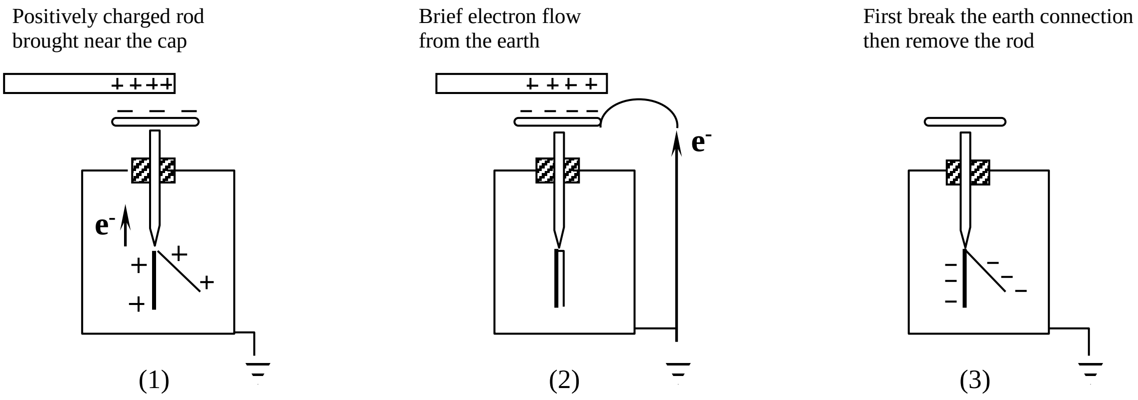
*When charging the electroscope by induction, the charge acquired is **opposite** to that on the charging rod.*

(a) CHARGING AN ELECTROSCOPE **NEGATIVELY** BY INDUCTION (*A **POSITIVELY** CHARGED ROD IS USED*)

Note: *When charging an electroscope negatively by induction a positively charged rod is used*

Procedure

- *A positively charged rod is brought near the cap of the electroscope. Electrons flow upwards from the brass plate and the leaf to the cap*
- With the rod in that position, the electroscope is earthed by touching the cap. *Electrons flow from the earth to the leaf and the brass plate to neutralise the positive charges there. The leaf then falls.*
- *The figure is then first removed then the rod*

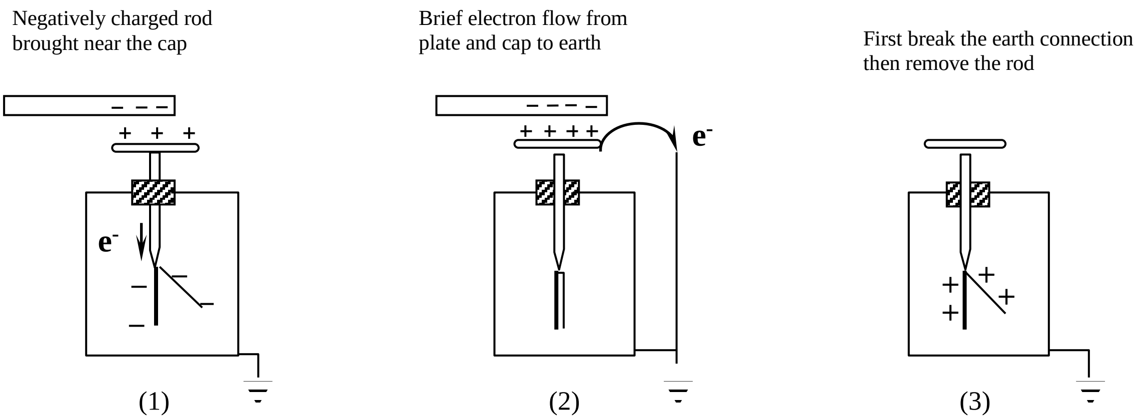


(b) CHARGING **POSITIVELY** BY INDUCTION (*A **NEGATIVELY** CHARGED ROD IS USED)*

Note: *When charging an electroscope positively by induction a negatively charged rod is used*

Procedure

- *A negatively charged rod is brought near the cap of the electroscope. Electrons flow downwards from the cap to the brass plate and the leaf*
- With the rod in that position, the electroscope earthed by touching the cap. *Electrons flow from leaf and the brass plate to the earth. The leaf falls.*
- *The finger is then first removed then the rod*



USES OF THE ELECTROSCOPE

1. To identify insulators and conductors
2. To test the quantity of charge on a charged object
3. To detect presence of charge on a body
4. To test sign of charge on a body

1. TO DETECT PRESENCE OF CHARGE ON A BODY

   - The material is brought close to the cap of the electroscope:
     - *(i) If the leaf rises (diverges) the material is charged*
     - *(ii) If the leaf does not rise (diverge) the material is not charged*

2. IDENTIFYING INSULATORS AND CONDUCTORS

   - The materials are brought near the cap of ***charged*** electroscope
     - *(i) If the leaf falls, the material is a conductor*
     - *(ii) If the leaf does not fall then the material is an insulator*

3. TESTING FOR THE QUANTITY OF CHARGE

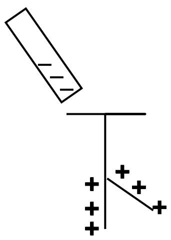
   - The quantity (amount of charge) is estimated by the leaf divergence. *The greater the divergence, the more the charges*

4. TO TEST SIGN OF CHARGE ON A BODY

   - The electroscope is first given a known charge e.g. positive of negative, then the charged material brought close to the charged electroscope.
     - *(i) If leaf divergence increases, it will mean similar charge*
     - *(ii) If leaf divergence decreases, it will mean opposite charge*

Worked Example 10

1. State and explain the observation on the leaf of a positively charged electroscope when a negatively charged rod is brought close its cap as shown in the below.



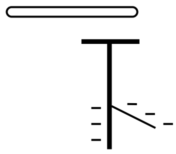
Answer

- *Leaf collapses // falls (leaf divergence decreases)*
- *Negative charges on the cap are repelled down and move to the leaf where they neutralize the positive charges there*

Practice Question

1. When a highly positively charged rod is brought from a high position towards a negatively charged electroscope, it is observed that the leaf divergence first decreases and then increases, when the rod nears the cap. Explain.

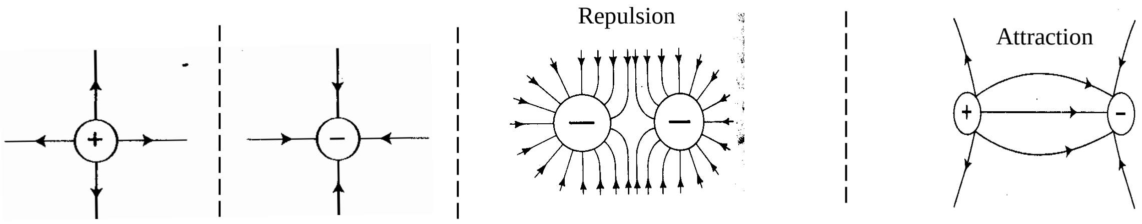
2. A charged rod was brought close to the cap of a negatively charged electroscope as shown below. It was observed that the leaf divergence increased as the rod was moved closer to the cap. Identify the charges on the rod.



ELECTRIC FIELD

An electric field is a region around an electric charge where the forces of attraction or repulsion are felt.

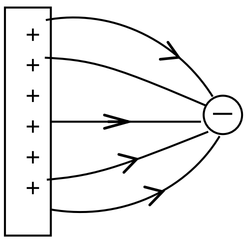
- An electric field is represented by a line of force, which:
  - **(i)** *Point outward from a positive charge*
  - **(ii)** *Point inwards to a negative charge*



Worked Example 12

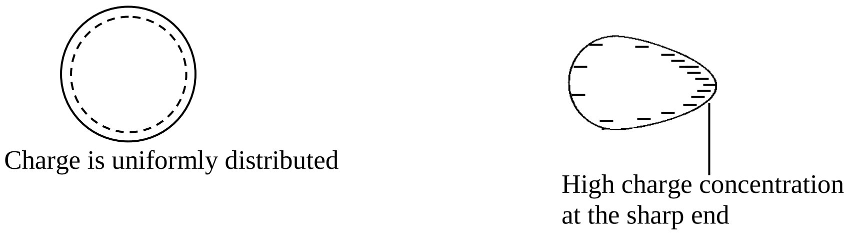
Sketch the electric field patterns for a negative point charge placed near a positively charged plate

Answer



CHARGE DISTRIBUTION ON THE SURFACE OF A CONDUCTOR

- The distribution of charge on the surface of a conductor depends on shape of the conductor.
  - *(i) For spherical conductor, charge is distributed uniformly on the surface*
  - *(ii) For pear shape conductor, charge is concentrated at the sharp point*



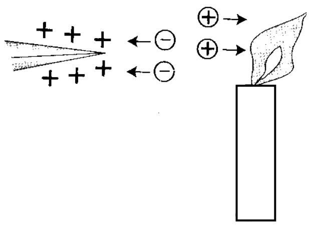
- No charges are found inside a ***hollow conductor.*** *For a hollow conductor, the charge resides on the outside the conductor.*
- Charge concentrations at sharp points make a conductor to gain or lose charges readily. ***This is known as point action.***

DEMONSTRATION OF POINT ACTION

- *A highly charged sharp point is brought close to a Bunsen flame.*

Observation

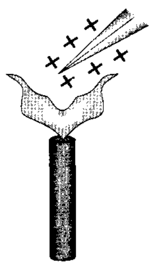
- *The flame is blown away.*



Explanation

- *Burning flame contains positive and negative ions*
- *When the sharp point is brought close to the flame, negative ions are attracted to the sharp point, while positive ions are repelled away from the rod*
- *As the positive ions are repelled, they create an "electric wind" which blows away the flame.*

NOTE: ***If the conductor is brought very close to the flame, the flame splits***



Worked Example 13

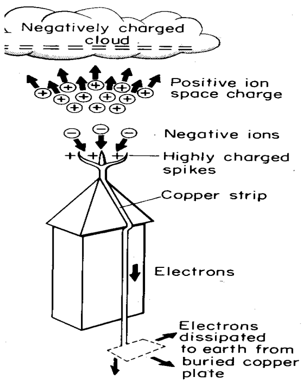
A candle flame is placed near a sharp pointed pin connected to the cap of a negatively charged electroscope. State and explain what is observed on the leaf of the electro scope.

Answer

- *The leaf collapses /falls*
- *The sharp point ionizes the air molecules around it.*
- *The electrons move to the sharp point to neutralize the positive charged air ions which attract the cap (or the positive air ions neutralize the negative charge on the sharp point.)*

APPLICATION OF POINT ACTION

- Point action is applied in the working of the lightning arrestor



- *When a negatively charged cloud passes over the arrestor it induces positive charges on the spikes and negative charges on the plate.*
- *The negative charges on the plate are immediately discharged to the surrounding ground.*
- *Negative ions are attracted to the spikes and are discharged by giving up their electrons*
- *At the same time positive ions are repelled upwards from the spikes*

Worked Example 14

It is dangerous to carry a pointed umbrella when it is raining. Explain

Answer

The sharp point / end of the umbrella acts to attract charges readily to neutralise the charge in the cloud which may electrocute the person holding the umbrella

Practice Question

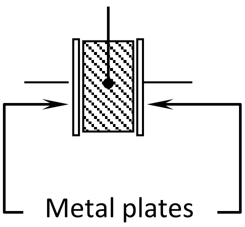
(a) *It is not advisable to take a shelter under a tree when it is raining. Explain.*

(b) *What is the purpose of the spikes on the lightning arrestor?*

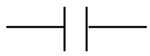
CAPACITORS

- ***A capacitor is a device used for storing charge.***
- A capacitor consists of two metal plates separated by an insulating material called ***a dielectric***.

Insulator (dielectric material)



Symbol for a capacitor



CAPACITANCE

- This is a measure of the charge storage ability of a capacitor, and is defined as:

The capacitance of a capacitor is the charge per unit voltage

$$\text{Capacitance} = \frac{\text{Charge}}{\text{Voltage}} \quad \text{OR} \quad C = \frac{Q}{V}$$

Q *– Charge in coulombs (C);* ***V*** *– potential difference in volts* ***C*** *– capacitance in farads (F)*

- SI unit of capacitance is the **farad (F)**
- Smaller units like the **microfarads (μF)** are most commonly used

NOTE: **(1)** 1 microfarad (μF) = 1×10^{-6}F

(2) If the capacitance is given in micro farads **(μ F)**, it must first be converted to farads **(F)**

Worked Example 15

A p.d of 10V is applied across the plates of a 2μF capacitor. Calculate the total charge stored in the capacitor

Answer:

$C = 2\,\mu F$
$= 2 \times 10^{-6} F$
$V = 10V$
$Q = CV$
$= 2 \times 10^{-6} \times 10$
$\underline{Q = 2 \times 10^{-5} C}$

Practice Question

A charge of 4×10^{-4} C was stored in a parallel plate capacitor when a p.d. of 5V was applied across the capacitor. Work out the capacitance of the capacitor.

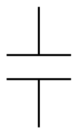
(Answer: 8×10^{-5}F OR 80 μF)

FACTORS AFFECTING THE CAPACITANCE OF A CAPACITOR

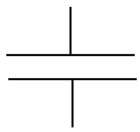
- The capacitance of a capacitor depends on ***three main factors***, which are:
  - **(a)** The area of overlap of the plates
  - **(b)** The distance of separation between the plates
  - **(c)** The nature of the dielectric material used

1. The area of overlap of the plates

- The bigger the area of overlap, the grater the capacitance, hence the charge stored



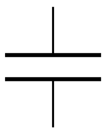
- *Less capacitance*
- *Less charge stored*



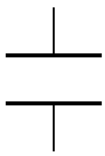
- *More capacitance*
- *More charge stored*

2. The distance of separation between the plates

- The shorter the distance of separation between the plates, the higher the capacitance hence more charge stored



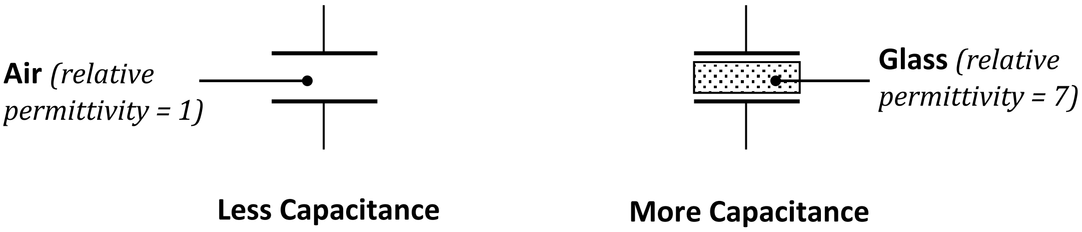
- *More capacitance*
- *More charge stored*



- *Less capacitance*
- *Less charge stored*

3. <u>The nature of the dielectric material used</u>

- The greater the **permittivity** of the dielectric material used, the greater the capacitance;



- These three factors are related by the formula**:**

$$C = \frac{\varepsilon A}{d}$$

Where:

C *– Capacitance in farads (F)*

A *– Area of overlap in metres squared (m²)*

d *– Distance of separation in metres (m)*

ε *– A constant known as permittivity*

<u>Worked Example 16</u>

Give any two ways of increasing the capacitance of a parallel plate capacitor

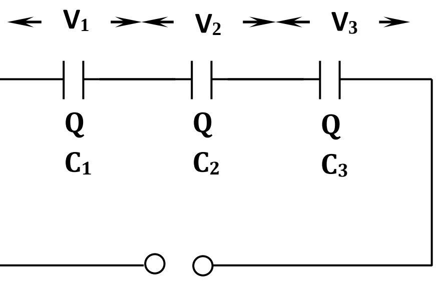
<u>Answer</u>

- *Reducing distance of separation between plates*
- *Increasing the overlap of the plates*
- *Using a good dielectric material*

ARRANGEMENT OF CAPACITORS

1. Series arrangement
2. Parallel arrangement

1) SERIES ARRANGEMENT OF CAPACITORS



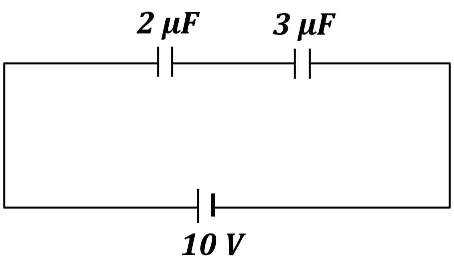
- Potential difference across each capacitor is **different**, but the **charge stored in each is the same**
- Effective capacitance is given by:

$$\frac{1}{C_T} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}$$

***C_T** – effective capacitance* ***C_1; C_2** and **C_3** – capacitance of individual capacitors in series*

Worked Example 17

The figure below shows two capacitors arranged in series. Find their effective capacitance



Answer

$$\frac{1}{C_T} = \frac{1}{C_1} + \frac{1}{C_2}$$

$$\frac{1}{C_T} = \frac{1}{2} + \frac{1}{3}$$

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

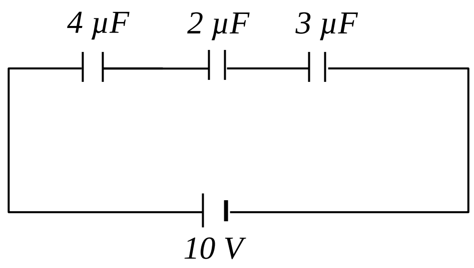
$$\frac{1}{C_T} = \frac{5}{6}$$

$$C_T = \frac{6}{5}$$

$$C_T = 1.2\ \mu F$$

Practice Question

Work out the effective capacitance for the circuit below. ***(Answer: 0.9231 μF)***



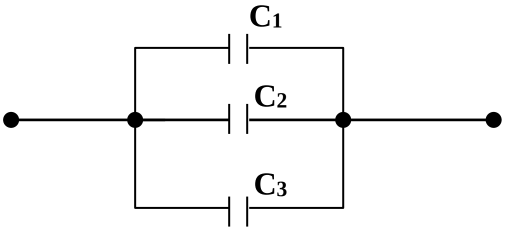
SPECIAL CASE OF TWO CAPACITORS IN SERIES

- For **two** capacitors connected in series, their effective capacitance can be calculated as:

$$C_T = \frac{\text{Product of capacitance}}{\text{Sum of capacitance}}$$

*Where C_T is the effective capacitance for the **two** capacitors in series*

2) PARALLEL ARRANGEMENT OF CAPACITOR



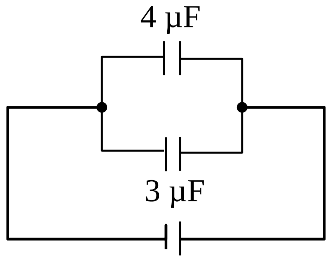
- The potential difference across each capacitor is the **same**, but the **charge stored on each is different**
- Effective capacitance is given by:

$$C_T = C_1 + C_2 + C_3$$

C_T – effective capacitance *C_1; C_2 and C_3 – capacitance of individual capacitors in parallel*

Worked Example 18

a) The figure below shows two capacitors arranged in parallel. Work out their effective capacitance



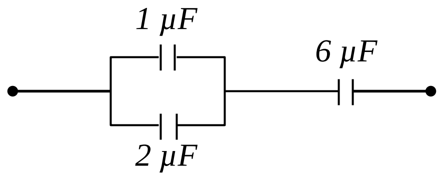
Answer:

$C_T = C_1 + C_2$

$C_T = 4\,\mu F + 3\,\mu F$

$\underline{C_T = 7\,\mu F}$

(a) Work out their effective capacitance for the circuit below



Answer: *For the two capacitors in parallel, the effective capacitance is given by:*

$C_T = C_1 + C_2$

$C_T = 1\mu F + 2\,\mu F$

$C_T = 3\,\mu F$

*This **3 µF** capacitance is in series with the **6 µF** capacitor, therefore, the effective circuit capacitance is:*

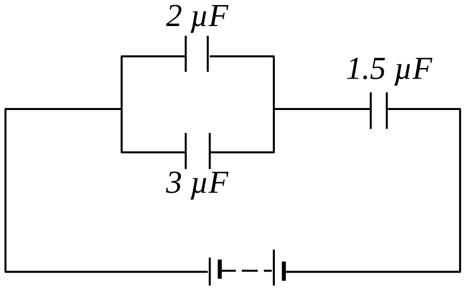
Effective circuit capacitance $= \dfrac{product}{Sum}$

$= \dfrac{(3 \times 6)}{(3+6)}\,\mu F$

$= \dfrac{18}{9}$

$\underline{C_T = 2\,\mu F}$

The figure below shows a capacitor network. Calculate the charge through the 1.5 μF capacitor



Answer *Effective capacitance of parallel capacitors* = (2μF + 3 μF)

= 5 μF

Effective circuit capacitance = $\frac{\textbf{product}}{\textbf{Sum}}$

= $\frac{(5 \times 1.5)}{6.5}$ μF

= 1. 1534 μF

= 1.1534×10^{-6} F

But, Q = CV

= 1.1534×10^{-6} F x 20V

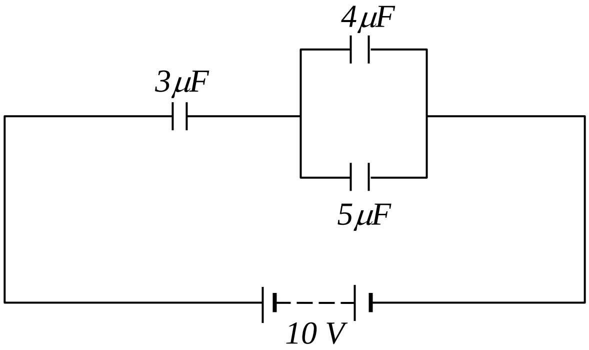
Q = 2.3068×10^{-5} C

Since the 1.5 μF is in series with the other capacitors, the charge stored is the same as the charge stored in the circuit = 2.3068×10^{-5} C.

Therefore, charge stored in the 1.5 μF = 2.3068×10^{-5} C

Worked Example 20

Three capacitors of capacitance 3μF, 4μF and 5μF are arranged as shown in the figure below with a 10V battery across it. Calculate the charge stored in the 5μF capacitor



Answer

For the parallel capacitors, effective capacitance, $C_T = C_1 + C_2$

$$C_T = 4\ \mu F + 5\ \mu F$$

$$C_T = 9\ \mu F$$

For the circuit, effective capacitance C_T is given by:

$$C_T = \frac{product}{Sum}$$

$$= \frac{(9 X 3)}{(9+3)}$$

$$C_T = \frac{27}{12}$$

$$C_T = 2.25\ \mu F = 2.25 \times 10^{-6} F$$

But Total charge $Q = CV$

$$= (2.25 \times 10^{-6} F \times 10)$$

$$Q = 2.25 \times 10^{-5} C$$

P.d, V, *across 3 μ F* $= \frac{Q}{C}$

$$= \frac{(2.25 \times 10^{-5})}{3 \times 10^{-6}}$$

P.d across 3 μ F = 7.5 V

Therefore, P.d. across the 5 μF capacitor $= (10 - 7.5)\ V$

$$= 2.5\ V$$

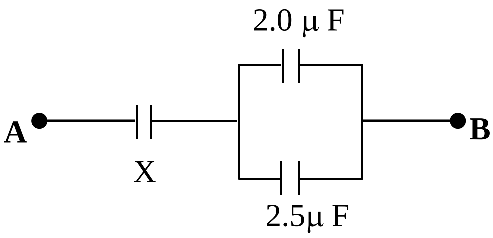
Therefore, charges stored in 5μF capacitor Q $= CV$

$$= (5 \times 10^{-6} \times 2.5)$$

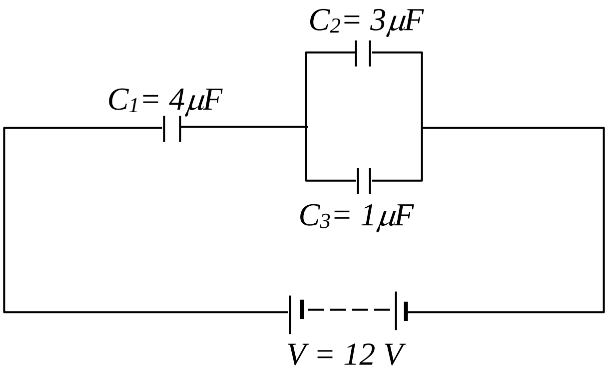
$$Q = 12.5 \times 10^{-6} C \quad OR \quad = 1.25 \times 10^{-5} C$$

Practice Question

1) Three capacitors are arranged as shown below. The total capacitance between **A** and **B** is 3.0μ F. Find the capacitance of **X**. **(Answer: X = 9.0 μF OR 9 x 10^{-6} F)**



2) In the circuit below C_1= 4 μF, C_2= 3 μF and C_3 = 1 μF. Given that V= 12 V, calculate the charge stored on the 3 μF capacitor, C_2 **(Answer: 1.8 x 10^{-5} C)**



ENERGY STORED IN A CHARGED CAPACITOR

- The energy stored in a charged capacitor is given by:

$$E = \frac{1}{2} CV^2$$

E *– Energy in joules* ***(J)*** ***C*** *– Capacitance in farads* ***(F)*** ***V*** *– Potential difference in volts* ***(V)***

NOTE: *If the capacitance is given in micro farads* ***(μ F)****, it must first be converted to farads* ***(F)*** *by using the relation:*

1 microfarad (μF) = 1 x 10^{-6}F

Worked Example 21

How much energy is stored by a 2.0 μF capacitor connected to a 200 V supply?

Answer

$$\boldsymbol{E = \frac{1}{2}CV^2}$$

$$V = 200\ V$$

$$C = 2.0\ \mu F$$

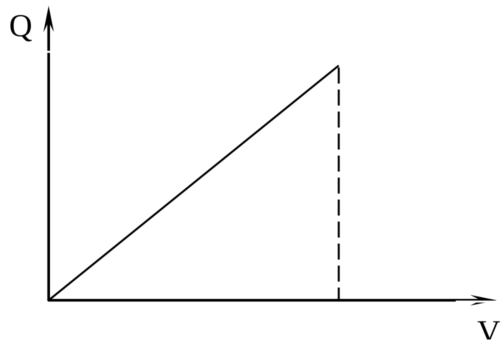
$$= 2.0 \times 10^{-6}\ F$$

$$= \frac{1}{2} \times 2 \times 10^{-6} \times (200)^2$$

$$= \frac{1}{2} \times 2 \times 10^{-6} \times 40000$$

$$\underline{\underline{E = 4 \times 10^{-2} J}}$$

- A graph of charge, **Q** against voltage, **V** is a straight line through the origin.



- For this graph:
  - (i) The gradient represents the capacitance; **C**
  - (ii) The area under the graph represents the energy stored in the capacitor

Practice Question

A capacitor was connected in a circuit and charged until it was full. The Potential difference (Pd) across it was measured using a voltmeter. The corresponding values of the charge stored was calculated and tabulated in the table below.

Pd across the Capacitor (V)	1.2	1.5	1.8	2.0	2.2
Charge stored (μF)	2.88	3.60	4.32	4.80	5.28

(a) Plot a graph of the charge stored against the Pd.

(b) Using the graph, determine:

(i) The capacitance of the capacitor ***(Answer: 2.4 x 10-6 F = 2.5 μ* F)**

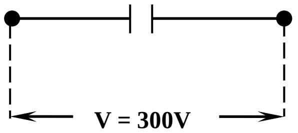
(ii) The energy stored by the capacitor **(Answer: 5.808 x 10^{-6}J)**

Worked Example 22

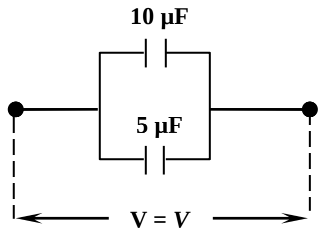
A 10 μF capacitor is charged to a potential difference of 300 V and isolated. It is then connected in parallel to a 5 μF capacitor.

(a) Find the resultant potential difference when the capacitors are connected in parallel.

*NOTE: By "**isolated**", we mean that the capacitor is not connected to anything else. i.e. it is just one and "alone"*



Isolated capacitor



Capacitors connected in parallel

$$\boldsymbol{Q = CV}$$

But for the isolated capacitor, $C = 10\ \mu F$

$= 10 \times 10^{-6}\ F$

Therefore, the charge, $Q = 10 \times 10^{-6} \times 300$

$$\boldsymbol{Q = 3.0 \times 10^{-3}\ C}$$

For the two capacitors connected in parallel capacitance, $C_T = 5\ \mu F + 10\ \mu F$

$= 15\ \mu F.$

Potential difference, $\boldsymbol{V} = \dfrac{\text{total charge stored, } \boldsymbol{Q}}{\text{Total capacitance, } \boldsymbol{C}}$

$= \dfrac{3.0 \times 10^{-3}}{15 \times 10^{-6}}$

$$\underline{\underline{\boldsymbol{V = 200\ Volts}}}$$

(b) The energy stored before connection of the two capacitors in parallel

$$\boldsymbol{E = \tfrac{1}{2} CV^2}$$

$= (\tfrac{1}{2} \times 10 \times 10^{-6} \times 300 \times 300)$

$$\underline{\underline{\boldsymbol{E = 0.45J}}}$$

(c) The energy in the two capacitors after connection

$$\boldsymbol{E = \tfrac{1}{2} CV^2}$$

Effective capacitance for the two capacitors in parallel, $C_T = 15\ \mu F$

$= 15 \times 10^{-6} F$

Potential difference across the two capacitors in parallel = 200 V

$E = \tfrac{1}{2} \times 15 \times 10^{-6} \times 200 \times 200$

$$\underline{\underline{\boldsymbol{E = 0.3J}}}$$

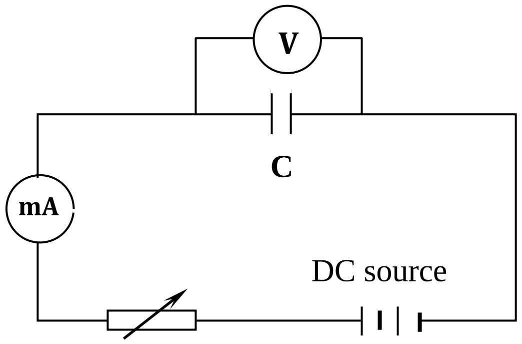
Practice Question

Two capacitors of capacitance 2 μF and 1μF are connected in parallel. A p.d. of 3V is applied across them. Find the energy stored in the combination. ***(Answer: 1.35 x 10^{-5}J)***

CHARGING AND DISCHARGING A CAPACITOR

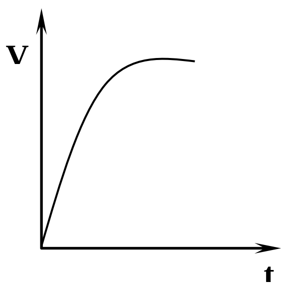
(a) CHARGING A CAPACITOR

- A capacitor is charged by applying a DC across its plates

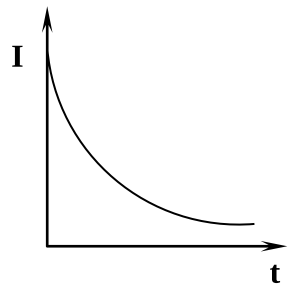


- As the p.d. is increased, the charge is increased up to a certain value.
- The capacitor is charged when the p.d. across its plates equals the p.d. of the source

Voltage against time when charging



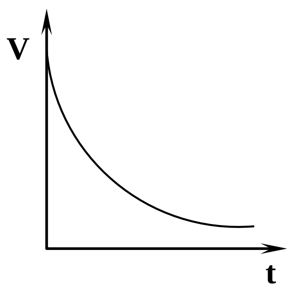
Current against time when charging



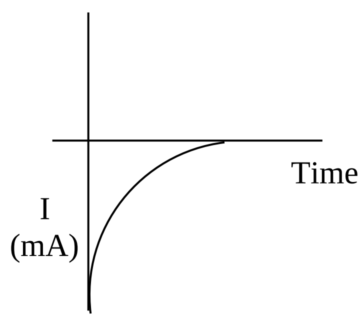
(b) DISCHARGING CAPACITOR

- A capacitor is discharged by connecting the plates of a charged capacitor across a load
- The capacitor discharges very fast across the load but in the opposite direction

Voltage against time when discharging



Current against time when discharging



3. CURRENT ELECTRICITY 1 AND 2

SOURCES OF ELECTRICITY

1. Generators
2. Solar cells
3. chemical cells

CHEMICAL CELLS

- **These are cells in which a chemical reaction generates electricity**
- There are two types of chemical cells

   1. *Primary cells*
   2. *Secondary cells*

Primary cells are chemical cells which cannot be recharged / renewed once they are exhausted

Examples of primary cells:

(i) Simple cell

(ii) Dry cell

Secondary cells are chemical cells which can be recharged / renewed when they are exhausted

Examples of secondary cells

(i) Lead acid accumulator

(ii) The alkaline battery

THE SIMPLE CELL

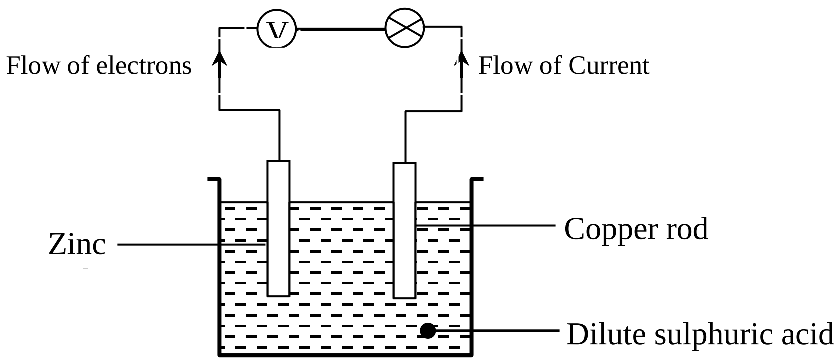
- This consists of:

   (i) Zinc metal as the negative electrode

   (ii) Copper metal as the positive electrode

   (iii) Dilute sulphuric acid as the electrolyte

- When the circuit is complete, *electrons flow from Zinc to copper*, while *current flows from copper to Zinc*.



- Simple cell cannot supply current for a long time because it suffers from ***<u>two defects</u>*** while in operation. These are:

  (i) POLARISATION

  (ii) LOCAL ACTION

(1) – **Polarisation** is the formation of hydrogen bubbles at the copper electrode

– These hydrogen bubbles form insulation around the copper therefore blocking the easy flow of current.

<u>REMEDY</u>:

- *Polarisation is minimised by adding a depolariser such as potassium dichromate*
- *The depolariser donates oxygen which combines with the hydrogen atoms to form water*

(2) – **Local action oc**curs when the Zinc metal is "eaten" away by the acid, this wastes Zinc

– Local action is caused by impurities on the Zinc metal

<u>REMEDY</u>:

- *Local action is minimised by either using pure zinc or by coating zinc with mercury (amalgamation)*
- *The mercury dissolves the Zinc metal leaving behind the impurities.*

<u>Worked Example 23</u>

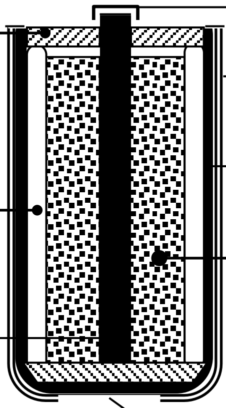
(a) A student using a simple cell to light a bulb observed that the bulb lit only for a short time then went off. Explain why the bulb went off after only a short time

- *The bulbs went off due to polarization effect, in which hydrogen bubbles were formed on the copper electrode which formed insulation around the copper electrode therefore blocking the easy flow of current*

(b) State a way in which polarisation reduces the current in a simple cell

- *The hydrogen layer insulates the copper plate increasing the resistance inside the cell*

THE DRY CELL (DRY LECLANCHE CELL)



- In this cell:
  - (i) Graphite rod is the positive terminal
  - (ii) Zinc metal is the negative terminal
  - (iii) Ammonium chloride jelly is the electrolyte
  - (iv) Polarisation is minimised by the manganese (IV) oxide

LEAD ACID ACCUMULATOR

- In this cell:
  - (i) Lead (IV) oxide is the ***Anode*** (*positive electrode*)
  - (ii) Lead metal is the ***Cathode*** (*negative electrode*)
  - (iii) Dilute sulphuric acid is the electrolyte

CARE FOR LEAD ACID ACCUMULATOR

(i) Topping up should be done using distilled water

(ii) Should not be short circuited

(iii) Terminals should be kept clean

(iv) Should be stored in a dry place and on wooden supports. Not on the floor

(v) Should not be left in a discharged state for a long time

(vi) When recharging direct current at low current should be used **AND NOT** alternating current

THE ALKALINE ACCUMULATOR

- This uses an alkaline solution as the electrolyte

Advantages of alkaline accumulator over lead acid accumulator

(i) It is portable

(ii) It requires little attention to maintain as compared to the lead acid accumulator

(iii) Can be kept in a discharged state for a long time

Disadvantages

(i) It is more expensive

(ii) It has a lower E.M.F per cell

ELECTRIC CURRENT AND POTENTIAL DIFFERENCE

Electric current is the rate of flow of charges through a conductor

- Electric current is measured in amperes (A) using the ammeter
- In a circuit, the ***ammeter is usually connected in series*** because it has a low resistance

Potential difference is the work done in moving charge between two points in an electric circuit

- Potential difference is measured in volts (V) using the voltmeter.
- The ***voltmeter is usually connected in parallel*** since it has a high resistance.

OHMS LAW

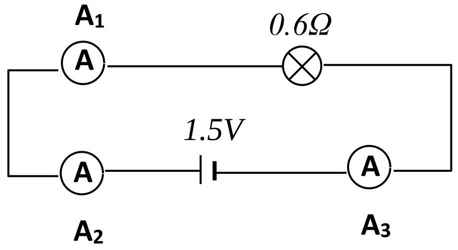
Ohm's law states that the current flowing through a conductor is directly proportional to the potential difference across the conductor provided the temperature is kept constant

$$V = IR$$

V – *Potential difference* **(V);** ***I*** – *current* **(A);** ***R*** – *resistance* **(Ω)**

Worked Example 24

The ammeters A_1, A_2, and A_3 are connected in a circuit as shown below. Given that the cell used has negligible internal resistance, work out the readings on the ammeters $A_1 - A_3$

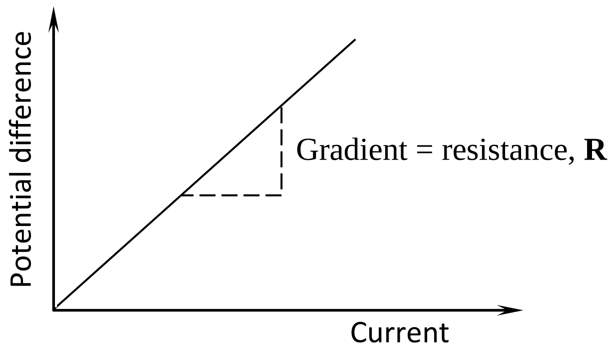


Answer

$$V = IR$$
$$1.5 = I \times 0.6$$
$$I = \frac{1.5}{0.6}$$
$$I = 2.5\ A$$

Since the three ammeters are all connected in series with the bulb and the battery, they will all give the same reading i.e. 2.5 A

- A graph of ***potential difference*** against ***current*** is a ***straight line through the origin***, whose ***gradient represents the resistance*** of the conductor.



Conditions for conductor to obey ohms law

- *Temperature must be kept constant*
- *Conductor should not be placed at right angle to a strong magnetic field*
- *Conductor should not be under tension*

OHMIC AND NON OHMIC DEVICES

- ***An ohmic conductor*** is a conductor which obeys ohms law
- For ohmic conductor, a graph of potential difference against current is a straight line through the origin
- *Examples of ohmic conductor:* ***Most Metals at Room Temperature***

- ***A non-ohmic conductor*** is a conductor which does not obey ohms law
- For a non ohmic conductor, a graph of potential difference against current is NOT a straight line through the origin
- *Examples of non-ohmic conductors:* ***Diodes; Thermistors; Lighted Bulb***

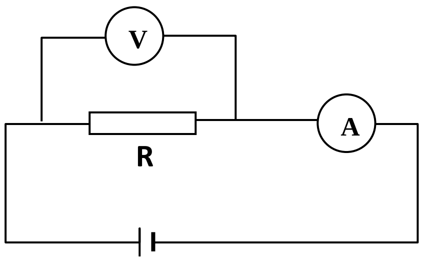
RESISTANCE

- ***This is the opposition to the flow of electric charges through a conductor*****.**
- Resistance is measured in ohms (Ω)
- Resistance is calculated as:

$$\text{Resistance} = \frac{\text{potential difference}}{\text{Current}} \quad \text{OR} \quad R = \frac{V}{I}$$

Worked Example 25

In the circuit below, the cell has negligible internal resistance. Given that the ammeter reads 0.5A and the voltmeter 1.2V, determine the resistance of the resistor R



Answer:

$$V = IR$$

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

$$= \frac{1.2}{0.5}$$

$$\underline{R = 2.4\ \Omega}$$

FACTORS AFFECTING THE RESISTANCE OF A METALLIC CONDUCTOR

1. Temperature

- **Increase in temperature increases the resistance of a conductor**

  Reason: *An increase in the temperature of a conductor causes its atoms to vibrate more vigorously, thus making it difficult for electrons to move easily through the conductor.*

2. Length of the conductor (*l*)

- **Resistance is directly proportional to the length of a conductor**

$$R \propto l$$

3. Cross sectional area (A)

- **Resistance is inversely proportional to the cross sectional area of a conductor**

  Reason: *A conductor with a bigger cross-sectional area has more free electrons per unit length therefore a better conductor.*

  Combining these three factors we get the formula:

$$R = \frac{\rho l}{A} \quad \text{OR} \quad \rho = \frac{R A}{l}$$

*ρ – Resistivity; **l** - length in **metres**; **A** – cross sectional area **in m^2** **R** – resistance in **(Ω)***

- SI unit for resistivity is ***ohm metre*** **(Ωm)**

Resistivity is the resistance of a wire of length 1 m and cross sectional area 1 m^2

Worked Example 26

A wire of length 64.3 cm and diameter 0.64 mm allows a current of 3.0A when a p.d. of 6 V is maintained at its ends. Calculate:

(a) Its resistance

(b) The resistivity of the wire

Answer

(a)

$$V = IR$$

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

$$= \frac{6\ V}{3\ A}$$

$$R = 2.0\Omega$$

(b)

$$\text{Diameter of wire} = 0.64\ mm$$

$$= \frac{(0.64)}{1000}\ m$$

$$= 0.64 \times 10^{-3} m$$

$$\text{Therefore radius of the wire, } r = \frac{0.64 \times 10^{-3} m}{2} = 0.32 \times 10^{-3} m$$

$$\text{Therefore cross-sectional area of wire, } A = \pi r^2$$

$$= 3.142 \times (0.32 \times 10^{-3})^2$$

$$= 3.142 \times 0.0000001024$$

$$= 0.0000003217\ m^2$$

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

$R = 2.0\ \Omega$ $A = 0.0000003217$ $l = 64.3\ cm$

$$= 0.643\ m$$

$$\text{Therefore, } \rho = \frac{(2.0 \times 0.0000003217)}{0.643}$$

$$\rho = 1 \times 10^{-6}\ \Omega m$$

Practice Question

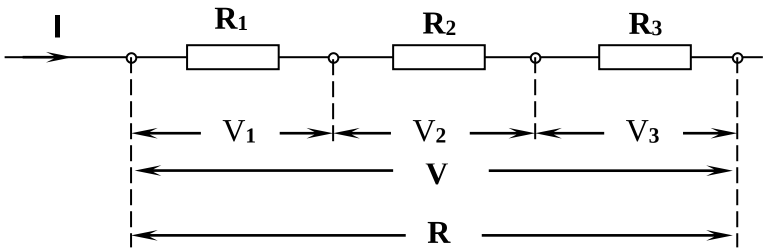
1. *A nichrome wire of diameter 0.46 mm is to be used in making a 70 Ω electric fire element. Find the length of the wire needed. Take resistivity of nichrome = 1.0×10^{-6} Ωm*
   (Answer = 11.635 m)

2. *22. A wire of diameter 0.42mm has a resistivity of 2.5×10^{-8}, how many metres should be cut to make a resistor of 10 ohms?* ***(Answer: 55.44 metres)***

ARRANGEMENT OF RESISTORS

1. Series arrangement
2. Parallel arrangement

(1) SERIES ARRANGEMENT OF RESISTORS



For resistors in series:

- Same current **I**, flows through each resistor

$$I = I_1 = I_2 = I_3$$

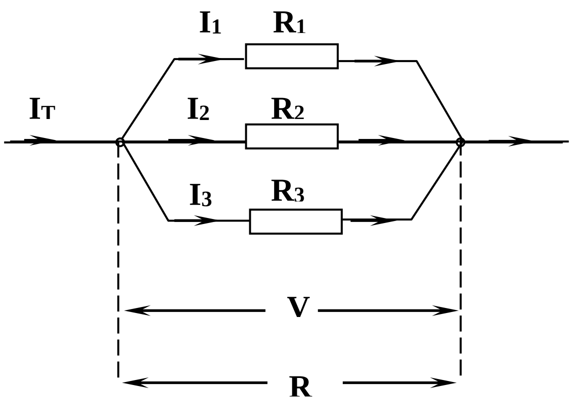
- Potential difference across each resistor is different

$$V_T = V_1 + V_2 + V_3$$

- Effective resistance is the sum of the individual resistances

$$R_T = R_1 + R_2 + R_3$$

(2) PARALLEL ARRANGEMENT OF RESISTORS



For resistors in parallel:

- Current through each resistor is different, main current divides; the amount through each resistor depends on the individual resistance.

$$I_T = I_1 + I_2 + I_3$$

- Potential difference across each resistor is equal to that of the source

$$V = V_1 = V_2 = V_3$$

- Effective resistance is given by:

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

SPECIAL CASE OF TWO RESISTORS TWO PARALLEL

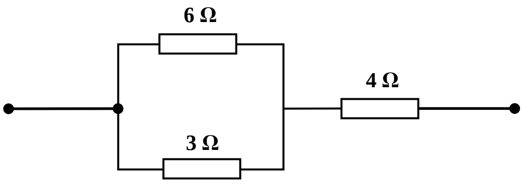
- For **two** resistors connected in parallel, their effective resistance, R_T, can be calculated as:

$$R_T = \frac{\text{Product of resistance}}{\text{Sum of resistance}}$$

Where R_T is the effective resistance for the **two** resistors in parallel

Worked Example 27

Work out the effective resistance for the circuit below



Answer:

For the two resistors in parallel, total resistance $R = \frac{Product}{Sum}$

$= \frac{(6 \times 3)}{(6 + 3)}$

$= \frac{18}{9}$

$R = 2\Omega$

This 2Ω resistance is in series with the 4 Ω resistor. Therefore total resistance in the circuit, R_T *is calculated as:*

$R_T = R_1 + R_2$

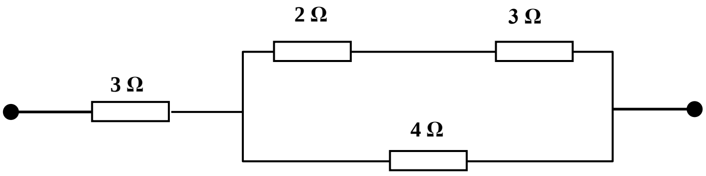
$R_T = 2\,\Omega + 4\,\Omega$

$R_T = 6\,\Omega$

Practice Question

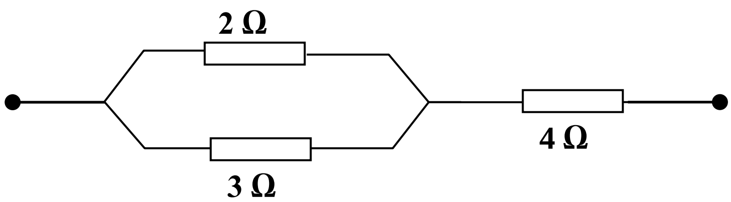
Work out the effective resistance for the circuits shown below

(a)



(Answer: 5.222 Ω)

(b)



(Answer: 5.2 Ω)

ELECTROMOTIVE FORCE AND INTERNAL RESISTANCE

1. **Electromotive force of a cell is the total work done in joules per coulomb of electricity conveyed in a circuit in which the cell is connected**
2. **Electromotive force is potential difference at the terminals of a cell when it is on open circuit**

- The voltage across a cell when it is supplying current is called **terminal potential difference** and is lower than the e.m.f.
- The difference between the e.m.f and the terminal potential difference is known as the "**lost volts**" and is due to the **internal resistance**, **r**.

E.M.F = P.D. Across R + Lost Volts

$$E = IR + Ir$$

$$E = I(R + r)$$

OR

$$E = V + Ir$$

Where:

__Ir__ – lost volts

__V__ – terminal potential difference

__r__ – Internal resistance

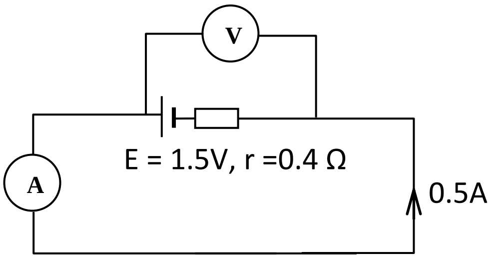
__R__ – external resistance

ALSO

$$\text{Current flowing in a circuit} = \frac{\text{Electromotive Force}}{\text{Total circuit resistance}}$$

Worked Example 28

The figure below shows a high resistance voltmeter connected across the terminals of a cell of e.m.f 1.5V and internal resistance 0.4 Ω



(a) ***Explain why the voltmeter reading is less than the e.m.f of the cell***

- *Some voltage is lost in overcoming the internal resistance of the cell*

(b) ***What would the voltmeter read if the cell drives a current of 0.5A***

$E = V + Ir$

$1.5 = V + 0.5 \times 0.4$

$1.5 = V + 0.2$

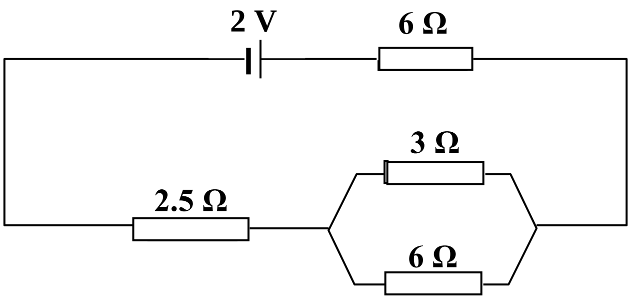
$V = 1.5 - 0.2$

$V = 1.3$ Volts

Practice Question

1. In the circuit below, determine the current through the **3 Ω** resistor

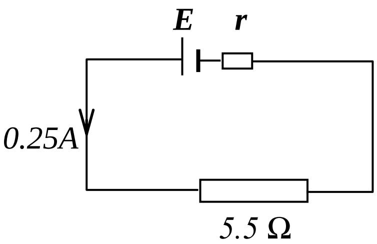
(Answer: = 0.127A)

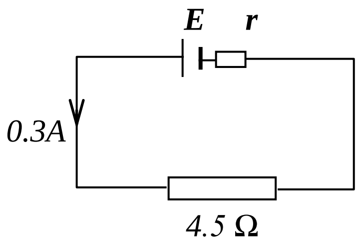


2. Two resistors of **4Ω** and **6Ω** in parallel are connected to the terminals of a battery consisting of four dry cells, each having an e.m.f of 1.5V in series. If the current in the 4Ω resistor is 0.6A, find:
   - **i)** The current in the **6Ω** resistor **(Answer: 0.4A)**
   - **ii)** The internal resistance of the battery **(Answer: 3.6 Ω)**

Worked Example 29

A dry cell of e.m.f, E, and internal resistance, r, drives a current of 0.25A through a resistor of 5.5 Ω and a current of 0.3A through a current of 4.5 Ω as shown in the figures below.





Determine:

a) The internal resistance of the cell

Answer

a) For the first diagram:

$$\mathbf{E = IR + Ir}$$

$$E = I(R + r)$$

$$E = 0.25\,(5.5 + r)$$

$$E = 1.375 + 0.25r \text{ ....(1)}$$

For the second diagram:

$$\mathbf{E = IR + Ir}$$

$$E = I(R + \mathbf{r})$$

$$E = 0.3(4.5 + \mathbf{r})$$

$$E = 1.35 + 0.3r \text{ ....(2)}$$

Since E is the same for both equations, then the two equations can be equated as follows:

$$1.375 + 0.25r = 1.35 + 0.3\mathbf{r}$$

$$1.375 - 1.35 = 0.3\mathbf{r} - 0.25\mathbf{r}$$

$$0.025 = 0.05\mathbf{r}$$

$$\mathbf{R} = \frac{0.025}{0.05}$$

$$\underline{\underline{\mathbf{r = 0.5\ \Omega}}}$$

b) The e.m.f of the cell

*Substituting for, **r**, in equation (1)*

$$E = 1.375 + 0.25r$$

$$E = 1.375 + 0.25 \text{ x } .5$$

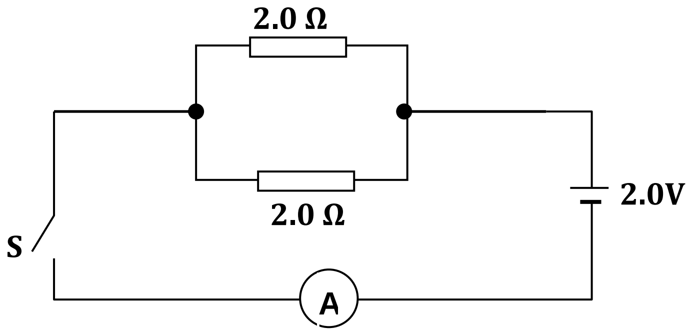
$$= 1.375 + 0.125$$

$$\underline{\underline{\mathbf{E = 1.5V}}}$$

Practice Question

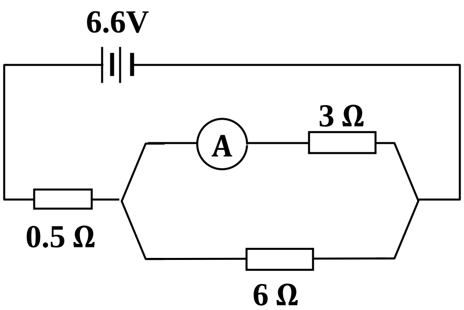
1. A cell supplies a current of 0.6A through a 2 Ω resistor and a current of 0.2A through a 7 Ω resistor. Calculate the e.m.f of the cell and the internal resistance
   (Answer: E.M.F = 1.5 V, r = 0.5Ω)

2. The reading of the Ammeter in the figure below is 0.5A when the switch, S is closed. Determine the internal resistance of the cell **(Answer: 3.0Ω)**



3. (a) What do you understand by the following terms
   (i) Electromotive force
   (ii) Open circuit
   (iii) Closed circuit

   (b) In the circuit shown below, the battery has an e.m.f of 6.6 V and internal resistance of 0.3 ohms. Determine the reading of the ammeter. **(Answer: 2.357A)**

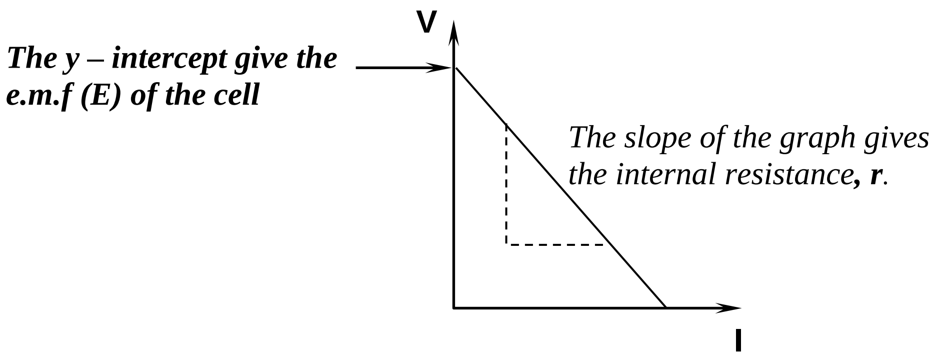


- From the equation:

$$E = V + Ir, \quad \textit{it follows that:}$$

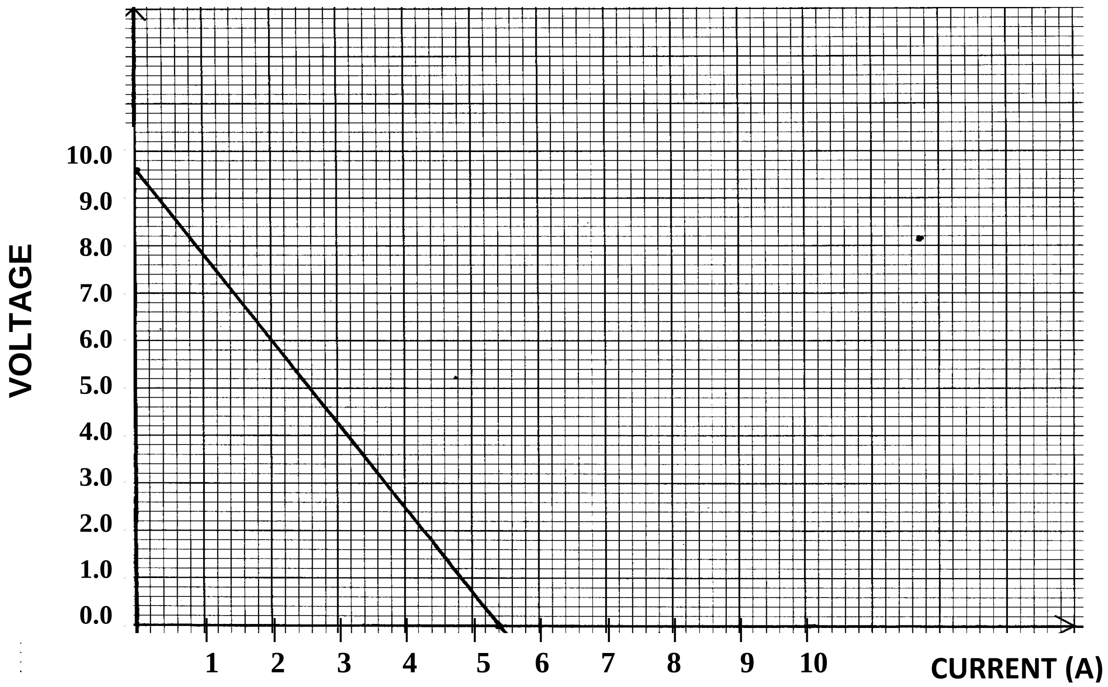
$$\mathbf{V = E - Ir}$$

- A graph of V against I is a straight line with a negative gradient



Practice question

The graph below shows the Voltage current relationship for a certain battery.



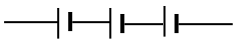
(i) Draw the circuit that could be used to obtain the results shown on the graph.

(ii) From the graph determine the e.m.f of the battery.

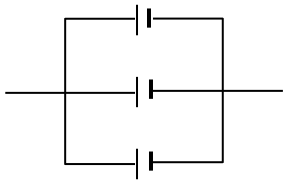
(iii) From the graph, determine the internal resistance of the battery.

(Answer: 1.818 ohms)

ARRANGEMENT OF CELLS



Series arrangement of cells



Parallel arrangement of cells

(a) When cells are arranged is series

- Total E.M.F of the arrangement is the sum of the of the separate E.M.F's
- Internal resistance of the battery is the sum of the internal resistance of the separate cells

(b) When cells of equal E.M.F's and internal resistance are arranged is parallel:

- The resultant E.M.F is the same as the E.M.F of one cell only
- The total internal resistance is calculated using the formula for resistors in parallel

ADVANTAGE OF PARALLEL ARRANGEMENT OF CELLS

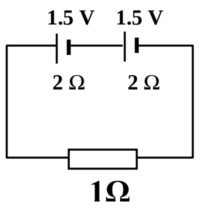
- *There is less drain on the cells since they share the total current, whereas with series connection the same main current is supplied by each cell*

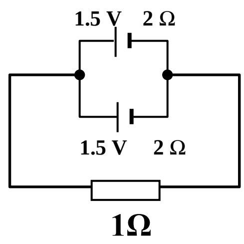
DISADVANTAGE OF PARALLEL ARRANGEMENT OF CELLS

- *If the E.M.F of one cell is slightly greater than that of another cell, current will circulate in the battery itself and cells become exhausted. This cannot happen when the cells are in series*

Worked Example 30

Two cells each having an e.m.f of 1.5 volts and an internal resistance of 2 Ω are connected (a) in series and (b) in parallel. Find the current in each case when the cells are connected to an external resistor of resistance 1 Ω





Answer

*For **(a)** Total E.M.F = 1.5 + 1.5*

= 3V

Total resistance = 2 + 2 + 1

= 5 Ω

Current = $\frac{\text{Total E.M.F}}{\text{Total resistance}}$

= $\frac{3}{5}$

Total current = 0.6A

*For **(b)** Total E.M.F = 1.5 V*

Total internal resistance = $\frac{\text{product of resistance}}{\text{Sum of resistance}}$

= $\frac{(2x2)}{(2+2)}$

= $\frac{4}{4}$

Total internal resistance = 1 Ω

Therefore total circuit resistance = (1 +1)

= 2 Ω

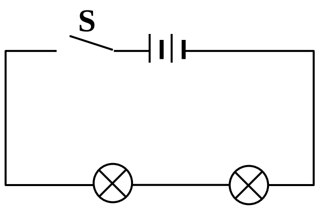
Current = $\frac{\text{Total E.M.F}}{\text{Total resistance}}$

Current = $\frac{1.5}{2}$

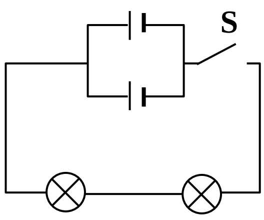
Total current = 0.75 A

Practice Question

In the figure below, the lamps in the two circuits are identical and the cells have the same e.m.f. Explain why the lamps in circuit B may be brighter than those in circuit A when the switches are closed simultaneously.



Circuit **A**



Circuit **B**

Answer

*In **A**, the resistance offered by the circuit is higher since the cells are in series In **B**, since the cells are in parallel the effective resistance of the cells is less, therefore more current in drawn.*

4. MAGNETISM

BASIC PROPERTIES OF A MAGNET

1. *A magnet has two poles. North Pole and South Pole*
2. *A suspended magnet tends to align itself in the north – south direction*

Worked Example 31

You are provided with two iron bars X and Y one is magnetized and the other is not. Explain how you would identify the magnetized bar.

Answer

- *Suspend each of them in the earth's magnetic field.*
- *Change their rest position and record the final direction.*
- *Repeat the procedure and record the directions.*
- *The magnetized rod will rest in the earth **N – S** direction each time.*

BASIC LAW OF MAGNETISM

The like poles of a magnet repel, while unlike poles attract each other

- The surest test for the polarity of a magnet is repulsion *since attraction can also occur between **any** pole of a magnet and a magnetic material, while repulsion can only occur between two like poles*.

Worked Example 32

Give a reason why attraction in magnetism is not regarded as a reliable method of testing for polarity.

Answer

All magnetic materials are attracted to the magnet but repulsion only occurs for polarities that are similar

Practice Question

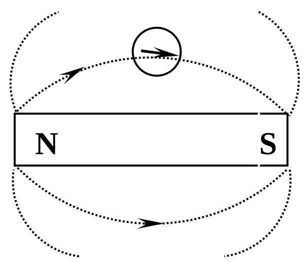
*You are provided with two iron bars **X** and **Y** one is magnetized and the other is not. Explain how you would identify the magnetized bar*

MAGNETIC FIELD

A magnetic field is the region around a magnet where the magnetic forces of repulsion or attraction are strongly felt

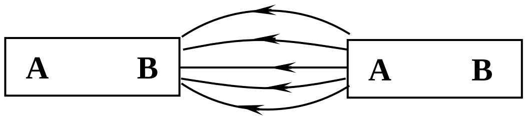
- Magnetic field is a vector quantity, i.e. it has both magnitude and direction.
- The direction of a magnetic field is the direction in which a freely suspended north pole of a magnet will tend to move if placed in that field

A magnetic line of force is the path along which the free north pole of a magnet will move in a magnetic field. The direction is from north to south



Worked Example 33

The diagram below shows the magnetic field patterns between two poles of magnet



*Identify the poles labelled **A** and **B**. Give a reason for your answer*

Answer

- ***A**: North Pole* *B**: South Pole*
- *The direction of the magnetic field is from North Pole to South Pole*

Practice Question

Sketch the magnetic field pattern around the arrangements shown below

(a)

(b)

Soft iron bar

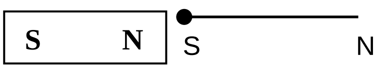
MAGNETISATION

- There are three main methods of making magnets

1. INDUCTION

- The polarity developed near the magnet is opposite that on the magnet

Example



Worked Example 34

Two similar razor blades were placed one on a wooden block and the other on an iron block as shown in the figure below.

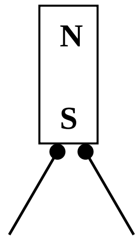
It was observed that the razor blade on the wooden block was attracted to the magnet while the other on the iron block was not. Explain.

Answer

- *In (a) the magnet induces magnetism into the razor blade which in turn induces the iron block to acquire opposite polarity. This causes the razor blade to remain attracted to the iron block.*
- *In (b) no magnetism is induced into the wooden block and so the razor blade is attracted;*

Practice Question

Two steel pins were attracted by a magnet as shown below.



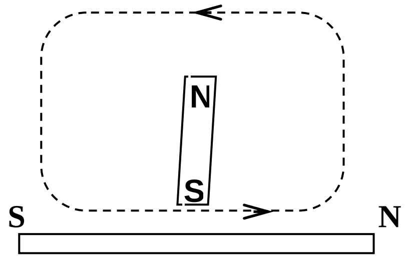
(a) *Give a reason why the ends of the two pins move apart instead of being parallel*

(b) *What observation would be made if a south pole of another magnet is brought between the two pins*

2. STROKING (SINGLE STROKE AND DOUBLE STROKE)

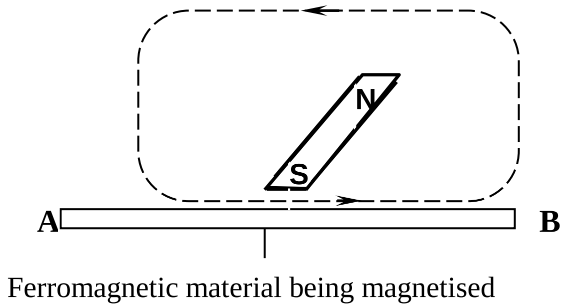
- In single stroke a single magnet is used, while in double stroke, two magnets are used
- *The end where the stroking ends acquires a pole opposite to that of a stroking magnet*

Example: *Single Stroke Method*



Worked Example 35

The figure below shows a method of magnetization of a ferromagnetic material.

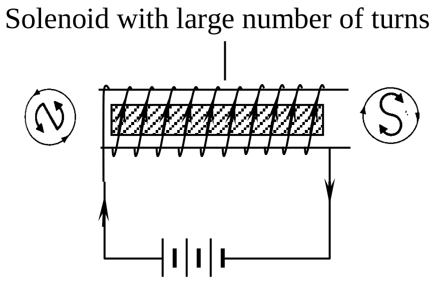


*What pole is acquired at end **B**?*

Answer: *North Pole*

3. USING ELECTRICAL METHOD

- *The material is placed inside a solenoid and a D.C. passed through.*

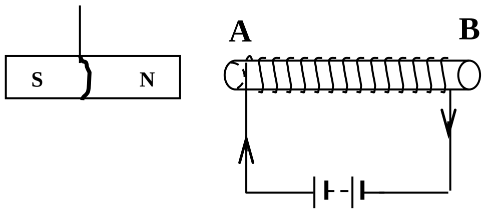


Rule for Polarity of a Coil Carrying a Current

When viewing one end of the coil, it will be of **N** polarity if the current is flowing in an a**N**ticlockwise direction and of **S** polarity if the current is flowing in a clockwi**S**e direction

Worked Example 36

A permanent magnet was suspended next to a solenoid in which an electric current flows as shown below



State and explain the observation made in this set up when the switch was closed

Answer

- *The suspended magnet was repelled away from the solenoid*
- *Current flows through the solenoid in such a direction that the end **A** of the solenoid close to the suspended magnet becomes a North Pole. This repels the N pole of the magnet*

DEMAGNETISATION

- The following methods can be used to demagnetise a magnet

(i) Heating the magnet while facing East – West direction (***heating method***)

(ii) Passing an **alternating current** though a solenoid in which the magnet is placed (***electrical method***)

(iii) Hammering while facing the East – West direction (***hammering method***)

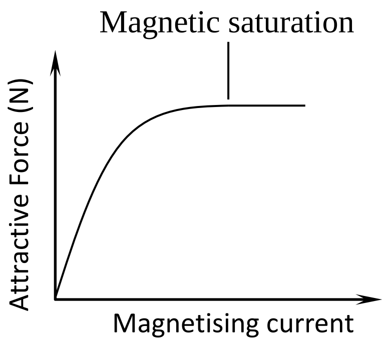
DOMAIN THEORY OF MAGNETISM

- **A magnetic material is made up of tiny atomic magnets (known as dipoles) which face different directions**

(a) ***During magnetisation***, *the dipoles are aligned to face one direction*

(b) ***During demagnetisation***, *the dipoles in the magnet are disturbed and disarranged then they settle back to their preferred directions.*

(c) ***Magnetic saturation*** *is attained when all the dipoles are fully aligned. The magnet can then not be magnetised any further*



Worked Example 37

(a) Explain using the domain theory of magnetism how an iron bar can be magnetized to saturation level by placing it in a magnetic field whose strength can be varied.

Answer

- *In an unmagnetised bar, the magnetic dipoles are facing in different direction hence the resultant magnetism of all the domains in this state is zero.*
- *When the bar is placed in a magnetic field whose strength can be varied during magnetization, most of the domains are aligned in one direction until all of them face in one direction .At this state the material is said to be magnetically saturated*

(b) Explain in terms of domain theory what happens when a bar magnet is placed in a solenoid in which an alternating current flows

Answer:

Altering current disarranges the dipoles; in the domain making them face in random direction, thus demagnetizing the magnet.

Practice Question

Using the domain theory, explain why a magnet may lose its magnetism on heating

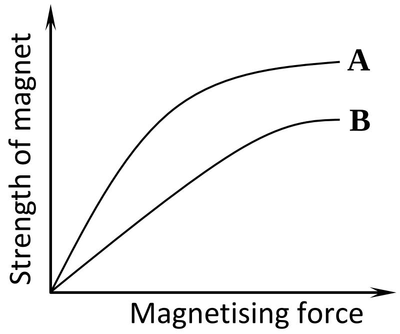
HARD AND SOFT MAGNETIC MATERIALS

- *A hard magnetic material is one which is not easily magnetised or demagnetised*

  Example: ***Steel***

- *A soft magnetic material is one which is easily magnetised and demagnetised*

  Example: ***Soft Iron***

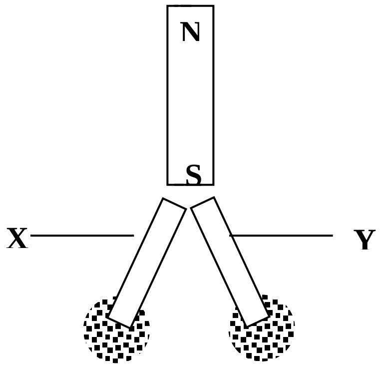


A – *Soft magnetic material*

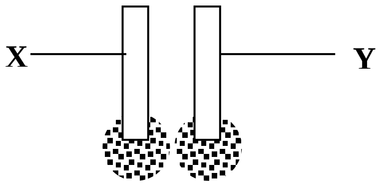
B – *Hard magnetic material*

Worked Example 38

The figure below shows a simple experiment using a permanent magnet and two metal bars X and Y. State with reason, which bar is a soft magnetic material



During attraction



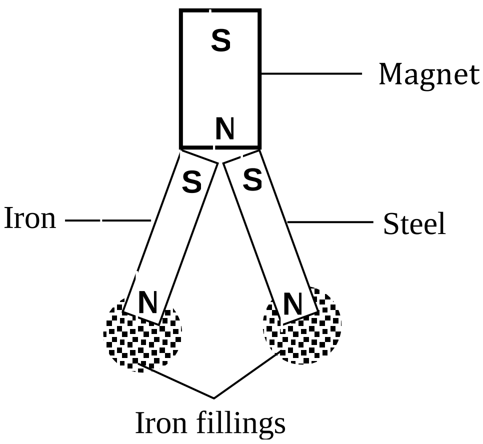
After attraction

Answer

- *None*
- *Each one of them retains its magnetism*

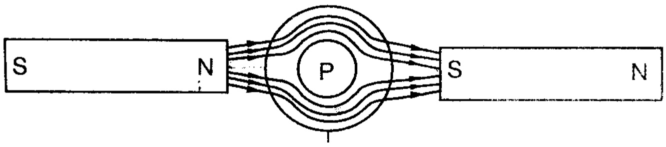
Practice Question

The figure below shows iron and steel rods placed in contact with a magnet. State with a reason what is observed when this magnet is removed from the rods.



MAGNETIC SHIELDING

- This is done by using a soft iron ring, which concentrates the magnetic field lines such that ***inside the ring there is no magnetic field / force***



USES OF MAGNETS

- Magnets are used:

  (i) *In Electric motors*

  (ii) *In Speakers*

  (iii) *In Telephone receivers*

  (iv) *To remove pieces of iron from the eye*

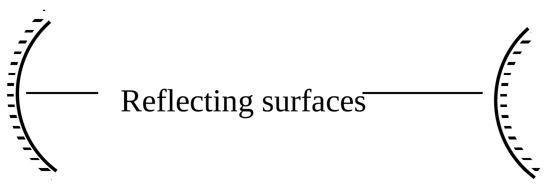
5. REFLECTION AT CURVED SURFACE

TYPES OF CURVED MIRRORS

- There are ***two*** type of cured mirrors

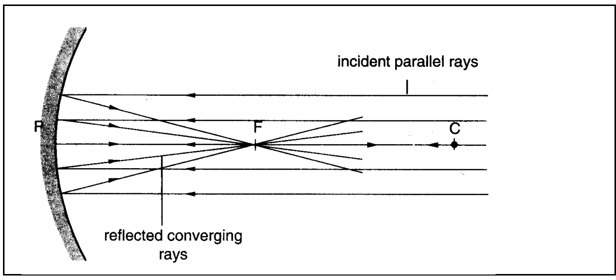
  1. **Concave mirror**: *In this the reflecting surface curves inwards*

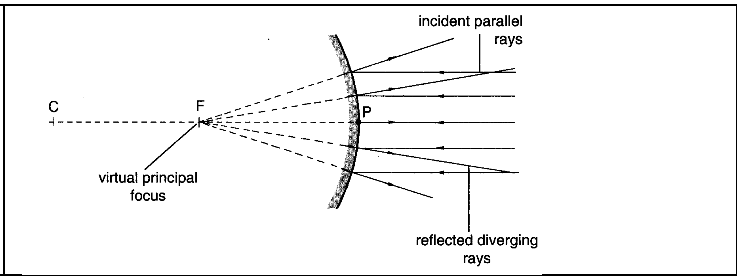
  2. **Convex mirrors**: *In this the reflecting surface curves outward*



Concave (converging) mirrors　　　　Convex (diverging) mirrors

TERMS USED





a) Centre of curvature (C)

- *This is the centre of the sphere from which the mirror is made*

b) Radius of curvature (r)

- *This is the radius of the sphere from which the mirror is made*

c) Aperture

- *This is the arc of the sphere which makes the mirror*

d) Pole (P)

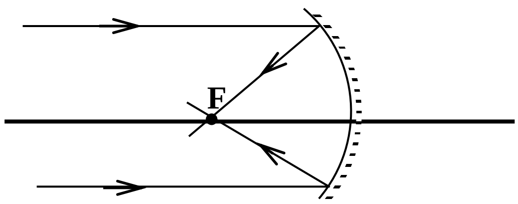
- *This is a point on the mirror surface, midway on the mirror*

e) Principal axis

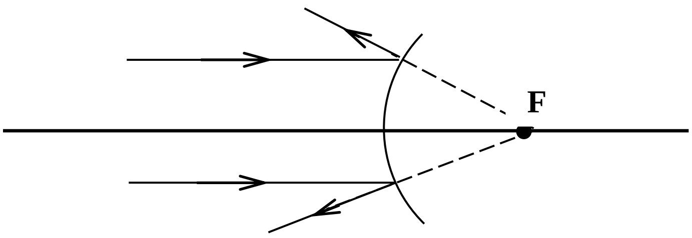
- *This is the line joining the centre of curvature to the pole of the mirror*

f) Principal focus (F)

(i) For a concave mirror, principal focus is the point on the principal axis where all rays originally parallel to the principal axis meet after reflection



(ii) For a convex mirror, principal focus is the point on the principal axis where all rays originally parallel to the principal axis ***appear*** *to come from after reflection*



g) The focal length (f)

- *This is the distance between the principal focus* **(F)** *and the pole of the mirror*
- Focal length is half the radius of curvature

$$f = \frac{1}{2}r$$

IMAGES FORMED BY CONCAVE MIRRORS

<table>
<tr>
<td>

1. Object between principal focus, F, and pole, P.

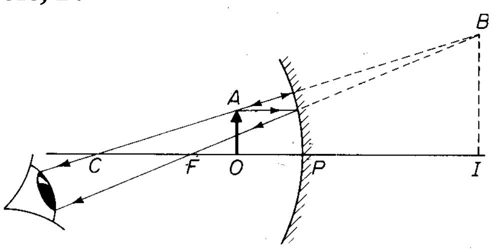


Image is:

– *Behind the mirror*
– *Virtual*
– *Upright*
– *Magnified i.e. larger than the object*

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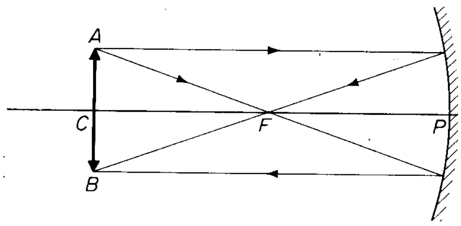
4. Object at C



– *Real*
– *Inverted*
– *Same size as the object*

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2. Object at principal focus, F.

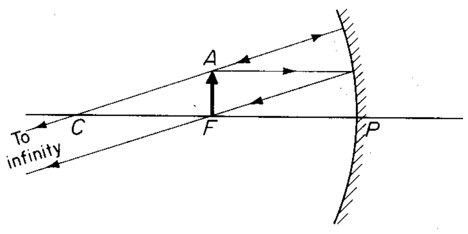

Image is at infinity

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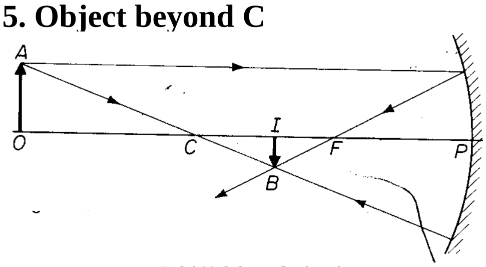
5. Object beyond C



– *Real*
– *Inverted*
– *Smaller than the object*

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3. Object between F and C

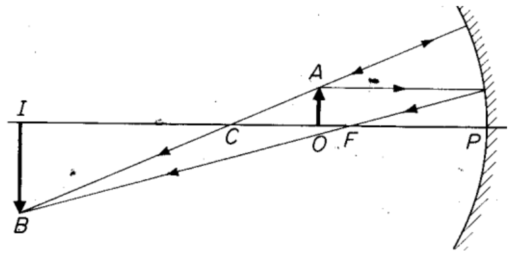

Image is:

– *Beyond C*
– *Real*
– *Inverted*
– *Magnified i.e. larger than the object*

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6. Object at infinity

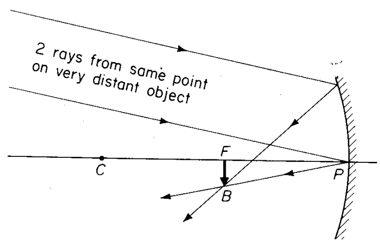

Image is:

– *At F*
– *Real*
– *Inverted*
– *Smaller than the object*

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</table>

Note:

(i) Real images are formed by the actual intersection of the reflected rays and they can be focussed on the screen.

(ii) Virtual images are formed by an apparent intersection of the reflected rays and they cannot be focussed o the screen

Worked Example 39

(a) State the condition under which a concave mirror forms:

(i) **A virtual image**

Answer

- *When the object is placed between the principal focus and the pole of the mirror*

(ii) **An image at infinity**

Answer

- *When the object is placed at the principal focus (F) of the mirror*

(iii) **An image at the principal focus of the mirror**

Answer

- *When the object is at infinity*

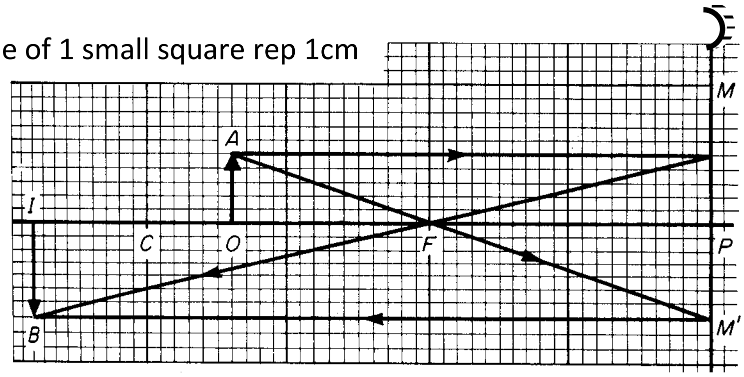
(iv) **A real magnified image**

Answer

- *When the object is between C and F*

(b) An object 5 cm tall is placed 34 cm from a concave mirror of focal length 20 cm. By means of an accurate graphical construction, determine the position, size and the nature of the image formed.

Scale: side of 1 small square rep 1cm



Position of image = (49 x 1)

= 49 cm from the mirror

Size of image = (7 x 1)

= 7 cm

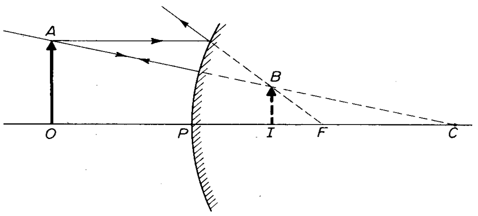
Nature of image: ***Image is real and inverted***

Practice Question

And object 5 cm tall is placed 12 cm in front of a convex mirror of focal length 20 cm. By means of accurate graphical construction, determine the position and nature of the image formed.

(Answer: The image formed is virtual and is formed 7.5 cm from the mirror)

IMAGES FORMED BY CONVEX MIRRORS



In all cases, images formed by convex mirrors are:

- *Virtual*
- *Smaller than the object*
- *upright*

THE MIRROR FORMULA

$$\frac{1}{f} = \frac{1}{v} + \frac{1}{u}$$

f *– focal length* ***v*** *– image distance* ***u*** *– object distance*

When using this formula:

a) *All distances are measured from the mirror as the origin*

b) *The distances of real objects, and real images are positive*

c) *The distances of virtual objects and virtual images are negative*

d) *Focal length of* ***concave mirror is a positive value*** *and that of* ***convex mirror is a negative value.***

MAGNIFICATION

- This is the ratio of image height to object height

$$\text{Magnification} = \frac{\text{height of image}}{\text{Height of object}}$$

Also,

$$\text{Magnification} = \frac{\text{image distance (v)}}{\text{Object distance (u)}}$$

And

$$\text{Magnification, m} = \frac{v}{f} - 1$$

Worked Example 40

(a) An object is placed 20 cm in front of a concave mirror of focal length 12 cm. Find the position and the nature of the image formed

Answer $u = 20\ cm$ $f = 12\ cm$ $v = v$

$$\frac{1}{f} = \frac{1}{v} + \frac{1}{u}$$

$$\frac{1}{12} = \frac{1}{v} + \frac{1}{20}$$

$$\frac{1}{v} = \frac{1}{12} - \frac{1}{20}$$

$$\frac{1}{v} = \frac{5 - 3}{60}$$

$$\frac{1}{v} = \frac{2}{60}$$

$$\frac{1}{v} = \frac{1}{30}$$

$$v = 30\ cm$$

- *A positive value of* ***v*** *means a real image is formed. Hence a real image is formed 30 cm away from the mirror on the same side as the object*

(b) A convex mirror of focal length 18 cm produces an image on its axis, 6 cm away from the mirror. Determine the position of the object

NOTE: For a convex mirror:

1. *The image formed is always virtual, therefore the image distance, v, is always assigned a negative value*
2. *The focal length, f, is always a negative value*

$u = u$ $f = -18\ cm$ $v = -6\ cm$

$$\frac{1}{f} = \frac{1}{v} + \frac{1}{u}$$

$$\frac{1}{-18} = \frac{1}{-6} + \frac{1}{u}$$

$$\frac{1}{u} = \frac{1}{6} - \frac{1}{18}$$

$$\frac{1}{u} = \frac{3 - 1}{18}$$

$$\frac{1}{v} = \frac{2}{18}$$

$$\frac{1}{u} = \frac{1}{9}$$

$$u = 9\ cm$$

- *A positive value of* ***u*** *means the object is real*

Practice Question

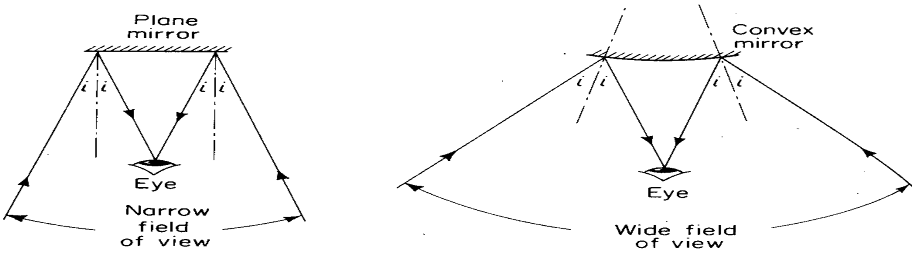
1. *An object placed 15 cm in front of a converging mirror form an image which is 9 times larger than itself. What is the image distance from the mirror?* ***(Answer: 135 cm)***

2. *A concave mirror has a focal length of 8cm. A real object of length 2cm is placed 12cm from the mirror. Calculate the distance of the image from the mirror. If the length of the image formed is 4cm.* ***(Answer: v = 24 cm)***

APPLICATIONS OF CURVED MIRRORS

1. DRIVING MIRRORS

- The driving mirrors of motor vehicles e.t.c are made of convex mirrors



Reasons

(i) They have a wide field of view unlike plane mirrors

(ii) They always give upright images

Disadvantage

- *The images formed are very small (diminished) in size*

OTHER APPLICATIONS:

2. ***Shaving mirrors***
3. ***By dentists when examining teeth***
4. ***As reflector behind lamps***

6. MAGNETIC EFFECT OF ELECTRIC CURRENT

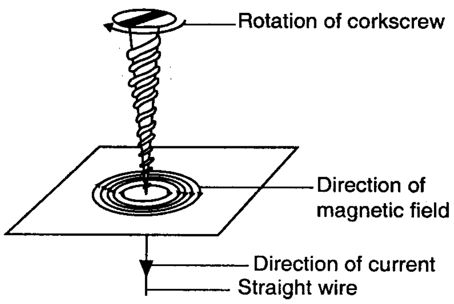
- A conductor carrying a current has a magnetic field around it.
- The direction of the magnetic field can be predicted by using either:

  a) *The Maxwell's cork screw rule* ***or***

  b) *The Flemings' right hand grip rule*

THE MAXWELL'S CORK SCREW RULE:

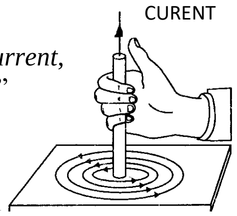
If a right-handed screw is driven forward in the direction of the current, then the direction of rotation of the screw is the direction of the field lines.



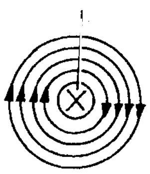
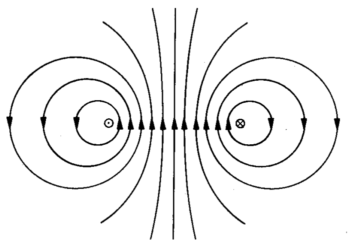
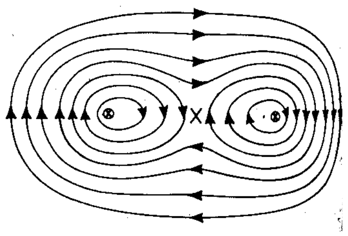
THE FLEMINGS' RIGHT HAND GRIP RULE

If a conductor carrying current is grasped in the right hand with the thumb pointing along the wire in the direction of the current, the fingers will point in the direction of the magnetic field.

"**Thumb** – *current*,
Fingers *field*"



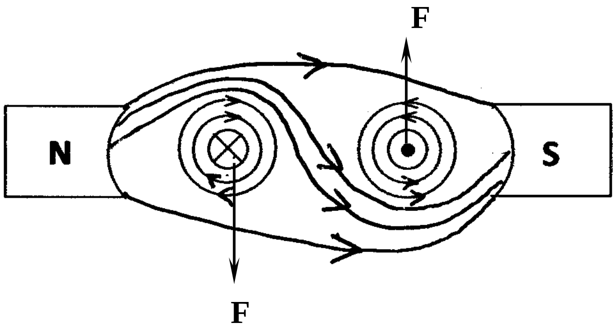
MAGNETIC FIELD PATTERNS AROUND CURRENT CARRYING CONDUCTORS

single conductor, current down	**parallel conductors with current in opposite directions**	**parallel conductors with current in same directions**
		
Current down	(repulsion exists between the two conductors)	Attraction exists between the two conductors

Worked Example 41

When viewed from the front the electric motor can be represented by the figure below. Draw the magnetic field pattern between the two poles of the magnet, showing the direction of the force on both ends of the coil

Answer



ELECTROMAGNETS

- *An electromagnet is a temporary magnet made by passing a direct current through soft iron core*
- *Soft iron is used because it is easy to magnetise and demagnetise. The soft iron concentrates the magnetic lines of force // magnetic field within the coils*
- The **North Pole** of the electromagnet can be predicted by using ***The Right Hand Grip Rule***

RIGHT HAND GRIP RULE

If a coil carrying current is held in the right hand such that the fingers encircle the loops while pointing in the direction of the current flow, then the thumb will point in the direction of the North Pole.

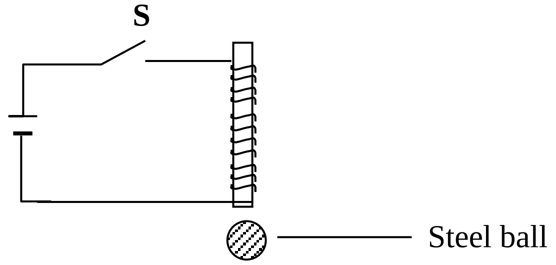
FACTORS AFFECTING THE STRENGTH OF ELECTROMAGNETS

1. **Number of turns of the coil**
   - *The more the number of turns of the coil, the stronger the electromagnet*
2. **Current flowing in the coils**
   - *The higher the current flowing through the coils, the stronger the electromagnet*
3. **Shape of the core**.
   - *U – Shaped cores make stronger electromagnets than straight cores.*

   Reason: *A U shaped core brings the poles closer together hence the lines of force get concentrated*
4. **Length of the solenoid.**
   - *The longer the solenoid, the weaker the electromagnet*

Worked Example 42

A small electromagnet for lifting and releasing a small steel ball is made in the laboratory as shown below



(a) **Explain why soft iron is better material to be used for the core than steel.**

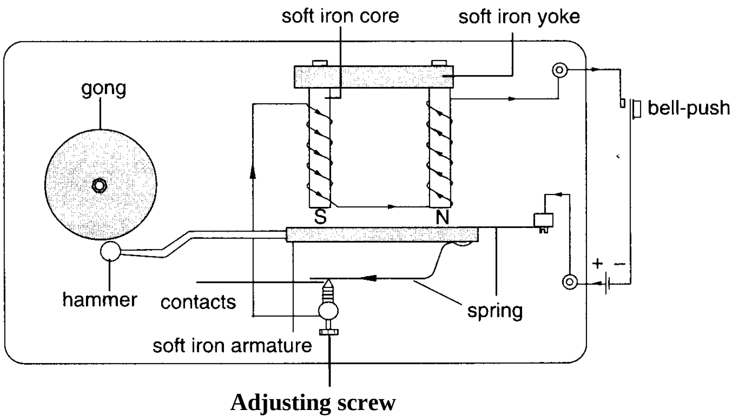
- *Iron can be easily magnetized and demagnetized*
- *Iron forms stronger electromagnet than steel under the same conditions*

(b) ***In order to lift a slightly larger ball, it is necessary to make a stronger electromagnet. State two ways in which electromagnet can be made more powerful.***

- *Increasing the current flowing through the solenoid*
- *Increasing number of turns in coil*

APPLICATIONS OF ELECTROMAGNETS

1. ELECTRIC BELL



- *When current flows through the solenoids, magnetisation of the iron bar occurs which attracts the soft iron armature. This in turn causes the hammer to strike the gong and the bell rings.*
- *The contact is broken and current stops flowing through solenoid. The soft iron core loses its magnetism and the spring pulls back the armature to its position. The contact is made once more and the process is repeated.*
- *The core and the armature are made of soft iron* ***and not steel****:*

Reasons*:*

1. *Steel forms a permanent magnet,*

2. *Steel is not easily magnetised and demagnetised*

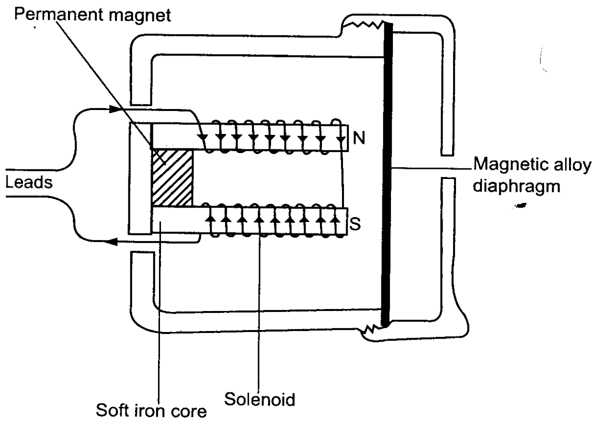
Worked Example 43

In the electric bell, explain what would happen if the armature is made of steel

- *If the armature is made of steel the hammer hits the gong and remains there / the bell rings once this is because steel acquires permanent magnetism*

2. TELEPHONE RECEIVER (EAR PIECE)

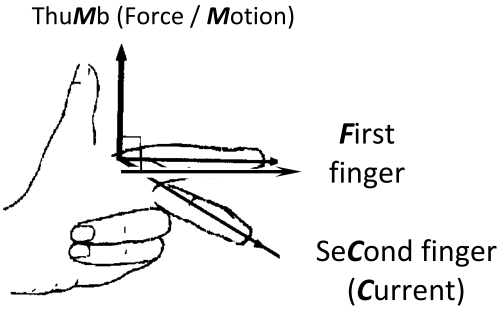
- When a person speaks in a microphone *on the other end* a varying electric current is set up in the ear piece.
- Since this current is varying, the diaphragm made of magnetic alloy vibrates. This in turn produces sound.

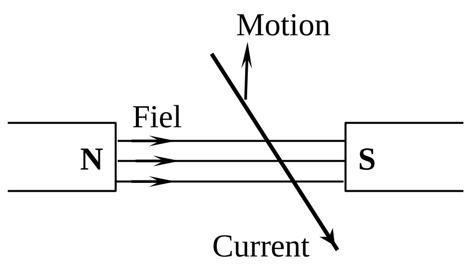


FORCE ON CURRENT CARRYING CONDUCTOR IN A MAGNETIC FIELD

- A conductor carrying current in a magnetic field experiences a force.
- The direction of the force can be predicted using ***Fleming's left hand rule***

If the left hand is held with the thumb, the first finger and the second fingers mutually at right angles so that the first finger points in the direction of the magnetic field and the second finger in the direction of the current, the thumb will point in the direction of motion

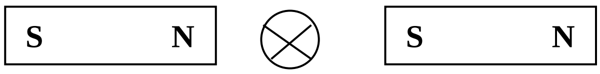




- **The size of the force produced depends on:**
  - ***(i)*** *Strength of the magnetic field*
  - ***(ii)*** *Magnitude of the current flowing*
  - ***(iii)*** *Angle between the conductor and the field. No force is produced when the conductor is parallel to the field*

Worked Example 44

The figure below shows a wire in a magnetic field. A current is switched on to flow through the wire in the direction shown. State the direction of motion of the wire.

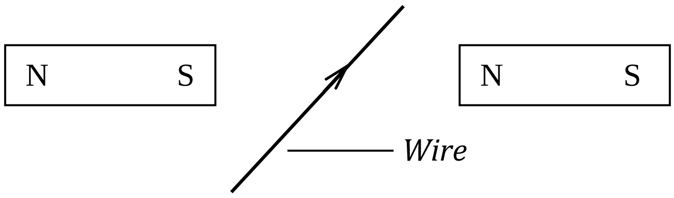


Answer

- *The wire moves downwards*

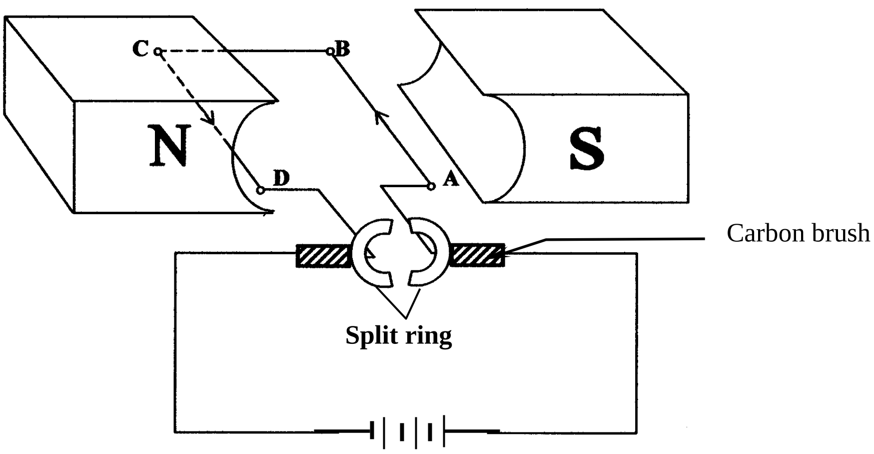
Practice Question

The figure below shows a conductor placed in a magnetic field. The current direction is shown. In which direction will the wire move?



APPLICATION

Electric motor



- *When current is passed through the coil a force is created on side **AB** in the upward direction and on side **CD**, in the downward direction. These cause the coil to turn in the anticlockwise direction.*
- *When the coil passes through the vertical position, no force acts on it, since the sides **AB** and **CD** are moving along the lines of force and are not cutting the lines. However, Due to its momentum, the coil continues with its motion.*
- The electric motor is used in things like:

  (i) *Electric shaving machines*

  (ii) *Electric drilling machines*

  (iii) *Electric fans*

Worked Example 45

State five ways by which the electric motor can be made to rotate faster

Answer:

(1) *By increasing the current flowing through the coils*

(2) *By using stronger magnets*

(3) *By using more turns of the coil of the wire*

(4) *By increasing the area of the coil in the magnetic field*

(5) *By using many coils with more split ring parts in many planes*

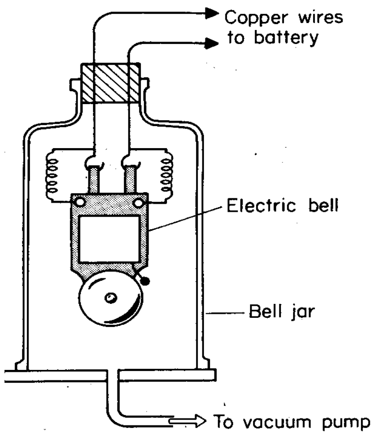
7. SOUND

- Sound is a form of energy produced by vibrating objects
- The human ear can hear sound whose frequencies are in the range of 20 Hz to 20 000Hz. ***This is known as the audible frequency range.***

TRANSMISSION OF SOUND

- Sound waves do not travel through a vacuum. They always require a material medium for transmission

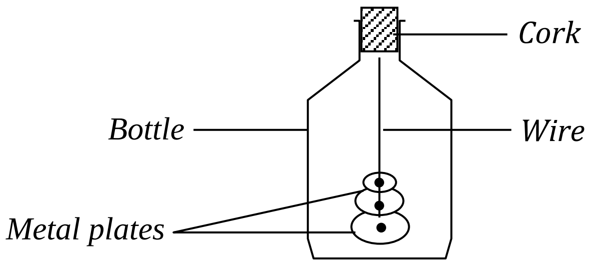
Experiment



- *The bell is set ringing and the air is gradually pumped out of the bell jar using the vacuum pump*
- *As the air is pumped out, the sound becomes fainter and fainter until a point is reached whereby no sound is heard*

Worked Example 46

(a) The figure below represents a set up used to study sound waves.



(i) **What would be observed when the bottle is shaken?**

Answer: *Sound will be heard*

(ii) **Explain the observation that would be made if a little hot water is poured into the bottle then cork is replaced and the bottle is shaken**

Answer: *A very faint sound is produced. Air is expelled by steam from hot water creating partial vacuum*

(iii) **What conclusion would you make from the above observations?**

Answer: *Sound needs material medium for transmission*

(b) A person watching a miner sees the miner strike the rock and hears the sound 2 seconds later. Determine the distance between the person and the miner. Speed of sound = 340m/s)

Answer:

Distance = Speed x time;

= 340 x 2

= ***680m***

Practice Question

1. *In a 100 meter race, the time keeper started the watch immediately after hearing the sound from the starter's pistol. Taking the speed of sound in air to be 320 m/s, determine:*

   (i) The error in his timing **(Answer: 0.3125 seconds)**

   (ii) The actual time taken by the first runner if by the end of the race the time keeper recorded a time of 11.60 seconds **(Answer: 11.9125 seconds)**

   (iii) The distance already covered by the first runner by the time the time keeper started the watch assuming that he was running at a speed of 8 m/s **(Answer: 2.5 m)**

2. *(a) State the reason why the sound of thunder is always heard sometime after the lightning flash is observed.*

   (b) A lightning flash is seen, followed by thunder 5 seconds later. How far is the storm from the observer? (take speed of sound in air = 330 m/s) **(Answer: 1650 m or 1.65 km away)**

SPEED OF SOUND BY ECHO METHOD

- Echo is reflected sound
- Speed of sound in air is determined by echo method by using the formula

$$\text{Speed of sound} = \frac{2 \times \text{distance in one direction}}{\text{Total time taken}}$$

- Echoes can be used to:

  (i) *Determine the depth of the sea*

  (ii) *Locate objects under water*

  (iii) *Under-water exploration of gas and oil*

  (iv) *Bats use echoes to detect the presence of obstacles in their flight path*

Worked Example 48

(a) **In determining the depth of an ocean an echo sounder produces ultrasonic sound. Give reasons why ultra sound is preferred for this purpose.**

Answer:

- *Ultra sound Penetrates deepest*
- *Ultra sound is reflected easily by tiny grains of sand*

(b) **An echo sounder produces a pulse and an echo is received from the sea- bed after 0.4 seconds. If the speed of sound in water is 1500 ms^{-1}, calculate the depth of the sea- bed**

Answer

$$v = \frac{2 \times \boldsymbol{s}}{\boldsymbol{t}} \qquad (\boldsymbol{s} - \text{depth of the sea})$$

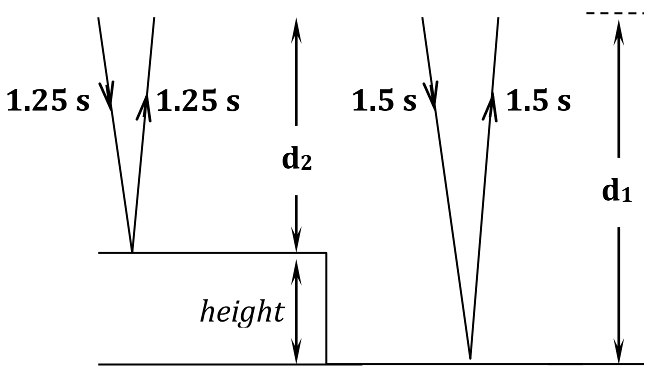
$$1500 = \frac{2 \times \boldsymbol{s}}{0.4}$$

$$2\boldsymbol{s} = (1500 \times 0.4)$$

$$\boldsymbol{s} = \frac{600}{2}$$

$$\underline{\boldsymbol{s = 300\ m}}$$

(c) **A fathometer produces sound in a ship and receives two echoes' where there is a raised sea bed one after 2.5 seconds and the other after 3.0 seconds. Find the height of the raised sea bed (Take speed of sound in water = 1460 m/s)**



$$d_1 = s \times t_1$$

$$= 1460 \times 1.5$$

$$\boldsymbol{d_1 = 2190\ m}$$

$$d_2 = s \times t_2$$

$$= 1.25 \times 1460$$

$$\boldsymbol{d_2 = 1825m}$$

$$\text{height} = (d_1 - d_2)$$

$$= (2190 - 1825)$$

$$\underline{\boldsymbol{\text{height} = 365m}}$$

Practice Question

(1) *A girl standing 200m from the foot of a high wall claps her hands and the echo reaches her 1.16 seconds later. Calculate the velocity of sound in air using this observation.*

(Answer: 344.8 m/s)

(2) *A gun is fired and an echo heard at the same place 0.6s later. How far is the barrier, which reflected the sound from the gun? Take Speed of sound in air = 330 ms^{-1}*

(Answer: 99 metres)

FACTORS AFFECTING THE SPEED OF SOUND IN AIR

- **Speed of sound in air depends on:**

1. DENSITY OF THE AIR

- *The denser the air, the lower the speed of sound*

2. TEMPERATURE

- *The higher the temperature, the higher the speed of sound in air*

Reason: *If temperature increases, the density of air decreases hence the speed increases*

3. WIND

- *If wind blows in the direction of the sound, then the speed of sound increases and vice versa*

4. HUMIDITY

- *Speed increases with humidity of air*

Reason: *If humidity increases, the density of air decreases hence speed of sound increases*

5. PRESSURE

- *Pressure change has no effect on speed of sound in air, provided the temperature is kept constant*

Worked Example 49

Student carried out an experiment to measure the speed of sound in air very early in the morning and found the speed to be 320 m/s. She repeated the same experiment at noon and found the speed to be 335 m/s. Give a possible explanation for the differences

Answer

- *Very early the morning the temperature was low therefore the speed of sound in air was low*
- *At noon, the temperature of the air had increased, leading to the increase in the speed of sound in air*

Practice Question

A student stands between two halls and 400m from the nearest hall. The halls are x metres apart. Every time the student claps, two echoes are heard by the student such that the first echo comes after 2.5 seconds while the second follows 2 seconds later. From this information calculate;

(a) *The speed of sound in air* ***(Answer: 320 m/s)***

(b) *The value of* ***x*** ***(Answer: X = 1120m)***

(c) *Explain the effect of pressure on the speed of sound in gases at a constant temperature.*

(Answer: *No effect because temperature is constant hence vibration of molecules is constant therefore transmission speed is constant)*

8. WAVES 1 AND 2

- A wave is a disturbance that transmits energy from one point to another
- Waves which require material medium for transmission are known as ***mechanical waves***

Example of mechanical waves

(i) Sound waves

(ii) Water waves

- Waves which don't require material medium for transmission are known as ***electromagnetic waves***

Examples of electromagnetic waves:

(i) Light waves

(ii) X – rays

(iii) Radio waves

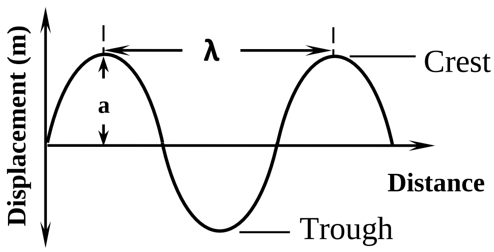
PULSE AND WAVE TRAIN

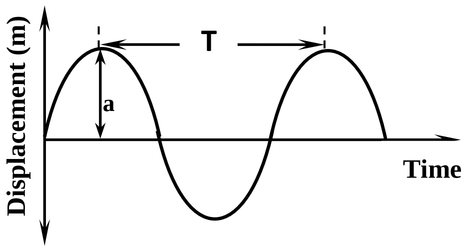
- ***A pulse is a single or short lived wave***
- ***A wave train is a continuous disturbance of a medium which arises due to regular pulse being produced***

TRANSVERSE AND LONGITUDINAL WAVES

(a) TRANSVERSE WAVES

A transverse wave is a wave in which the direction of vibration of wave particles is at right angle to the direction that the wave is travelling





- *Transverse waves are characterised by* ***crests*** *and* ***troughs***

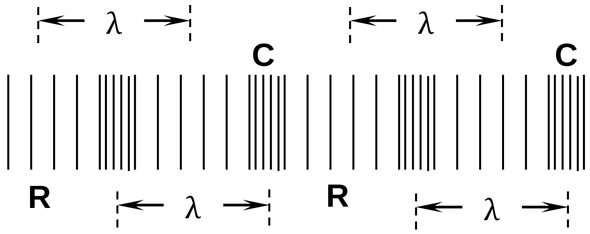
Examples of transverse waves

i) Water waves

ii) Light waves

(b) LONGITUDINAL WAVES

A longitudinal wave is a wave in which the direction of vibration of the particles is parallel to the direction that the waves are travelling



C – Compression; **R** – Rarefaction

- *Longitudinal waves are characterised by* ***compressions*** *and* ***rarefactions***

<u>**Examples of longitudinal waves**</u>

i) Sound waves

Worked Example 50

State <u>two</u> differences between sound waves and light waves

Answer

- *Sound waves requires materials medium while light waves don't require any*
- *Sound waves are longitudinal while light waves are transverse*

<u>**DEFINITION OF TERMS**</u>

1. <u>Amplitude (a)</u>

- *This is the maximum displacement of a particle from its rest position*

2. <u>Wavelength (λ)</u>

- *This is the distance between two successive particles which are in phase*
- *For a transverse wave, wavelength can be defined as the distance between two successive crests or troughs*

3. <u>Frequency (f)</u>

- *Frequency is the number of complete cycles or oscillation s in one second*
- Frequency is measured in hertz (Hz)

4. Periodic time (T)

- *This is the time taken to complete one* complete oscillation
- Periodic time is related to frequency by the formula

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

Where: ***T*** *– periodic time in seconds,* ***f*** *– frequency in Hz or cycles per second*

Worked Example 51

Sound waves have a frequency of 16 kHz. What is the periodic time for the waves?

Answer

$$f = 16 \text{ kHz}$$
$$= (16 \times 1000) \text{ Hz}$$
$$= 16\,000 \text{Hz}$$
$$T = \frac{1}{f}$$
$$= \frac{1}{16\,000}$$
$$T = 0.0000625 \text{ seconds}$$

Practice Question

Work out the frequency of water waves if their periodic time is 0.2 seconds ***(Answer: = 5Hz)***

5. Wave speed (v)

- *Wave speed is the distance travelled by the wave in one second*

THE WAVE EQUATION

- Wave speed (v), frequency (f) and wavelength (λ) of a wave are related by the formula:

$$v = f\lambda$$

v *– wave speed* ***in m/s*** ***f*** *– frequency* ***in Hz*** ***λ*** *– wavelength* ***in meters***

Worked Example 51

A radio station transmits waves at a frequency of 95.6 MHz. What is the wavelength of the waves transmitted? ($c = 3.0 \times 10^8$ m/s)

Answer:

$$v = f\lambda$$

$$v = 3.0 \times 10^8 m/s$$

$$f = 95.6\ MHz$$

$$= 95.6 \times 10^6\ Hz$$

$$3.0 \times 10^8\ m/s = 95.6 \times 10^6 \times \lambda$$

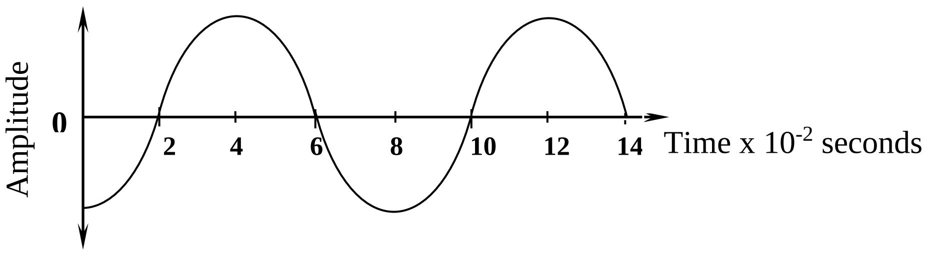
$$\lambda = \frac{3.0 \times 10^8\ m/s}{95.6 \times 10^6\ Hz}$$

$$\lambda = 3.14\ m$$

Practice Questions

1. *Calculate the wavelength of red light in air if the frequency of red light is 4.3×10^{14}Hz ($c = 3.0 \times 10^8$ m/s)* ***(Answer: 6.98×10^{-7} m)***

2. *The wave shown in the figure below has a velocity of 250m/s.*



Determine:

(a) *The period, T, of the wave* ***(Answer: 8×10^{-2} seconds)***

(b) *The frequency of the wave* ***(Answer: 12.5 Hz)***

(c) *The wavelength of the wave* ***(Wavelength = 20m)***

PROPERTIES OF WAVES

(i) REFLECTION

(ii) REFRACTION

(iii) DIFFRACTION

(iv) INTERFERENCE

1. REFLECTION

- This is where waves bounce back when they hit a barrier
- The nature of the reflected wave depends on two things:

  a) Shape of the reflector

  b) Shape of the incident waves

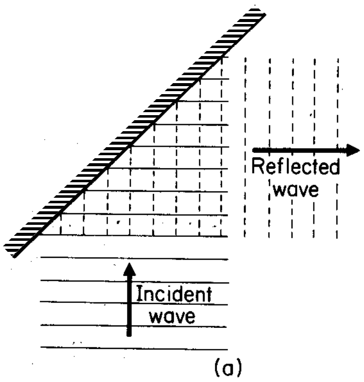
Examples:

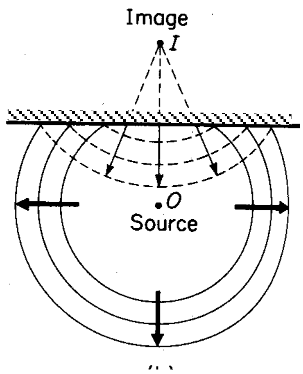
***Note*: In the diagrams below:**

1. The continuous lines (————) represent the incident waves

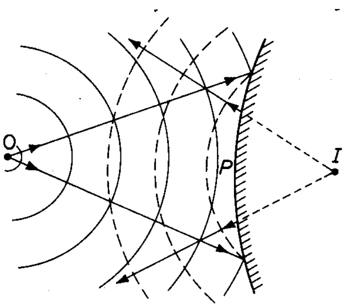
2. The dotted lines (– – – – -) represent the reflected waves

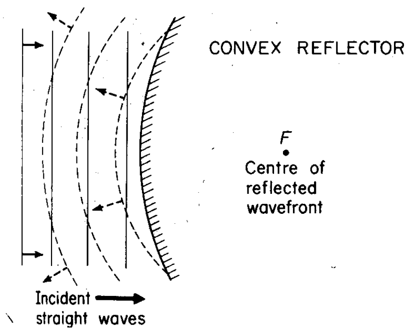
A. PLANE REFLECTORS



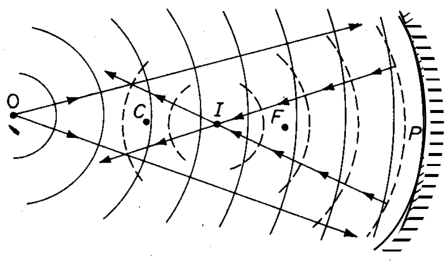


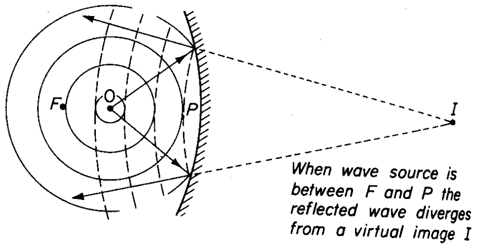
B. CONVEX REFLECTORS

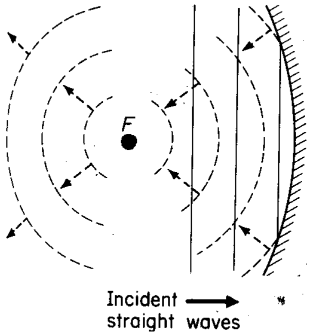


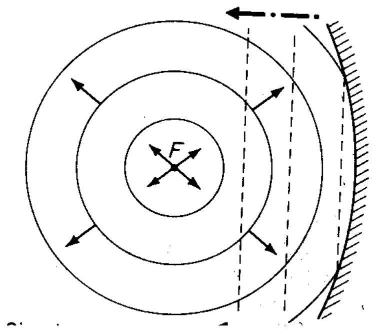


C. REFLECTION AT CONCAVE REFLECTORS



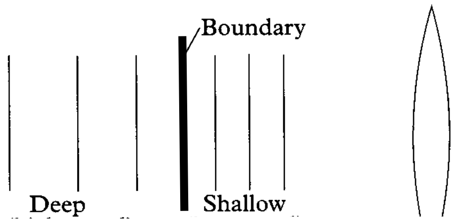


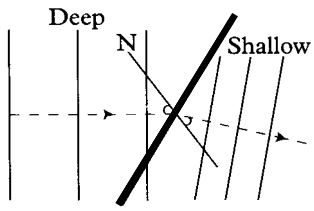




2. REFRACTION

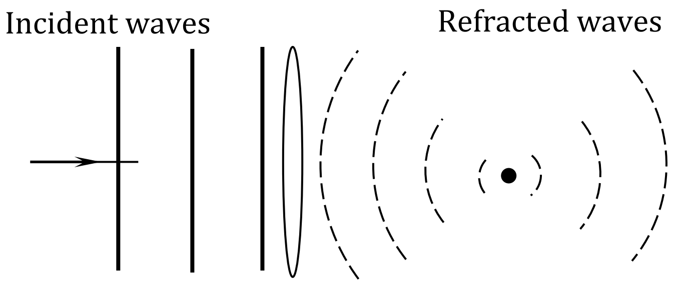
- **Refraction is the bending of waves as they pass from one medium to another**
- *Refraction of waves occurs due to change in speed of waves as they pass from one medium to another.*
- *The wave length of water waves in shallow water is usually shorter than in deep water*





Deep end
(***High speed, long wavelength but same frequency***)

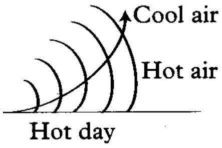
Shallow end
(***Low speed, short wavelength but same frequency***)

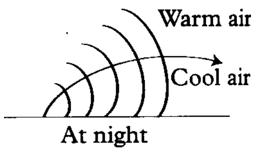


Daily Life Example

During the day sound from distant sources are not very clear unlike during the night.

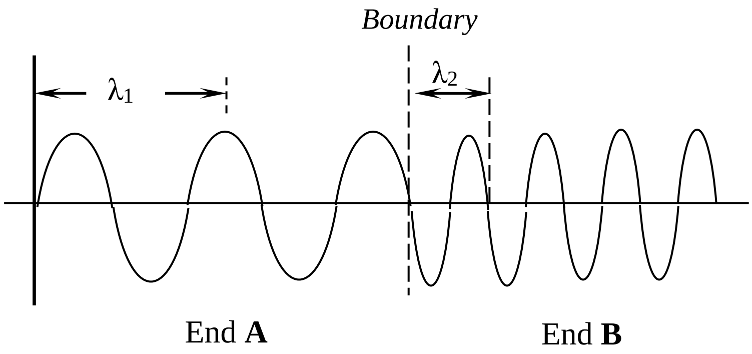
Reason: During the day sound waves are refracted upwards from the hot earth, while at night, sound waves are refracted downwards, hence are much louder.





Worked Example 53

The figure below shows the displacement of a particle in progressive wave incident on a boundary between deep and shallow regions.



(a) **Which of the two ends of the pond labelled A and B is shallow. Give a reason for your answer**

Answer

- *End **B***
- *The wavelength of the wave in end **B** (λ_2) is shorter than in end **A** (λ_1)*

(b) **Explain the observation above.**

Answer

- *As the wave passes through the boundary, their velocity reduces and wavelength decreases since the frequency remains the same.*

(c) **Give a reason why the amplitude of the wave does not change as it crosses the boundary**

Answer

- *There is no loss of energy therefore amplitude does not change.*

3. DIFFRACTION

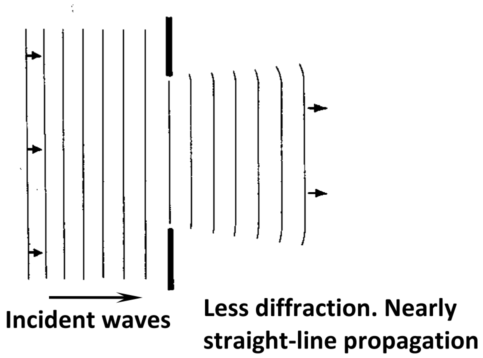
- *Diffraction is the spreading out of waves as they pass through obstacles or small openings*
- *The extent of diffraction depends on **two** factors:*

  (1) *Size of the openings*

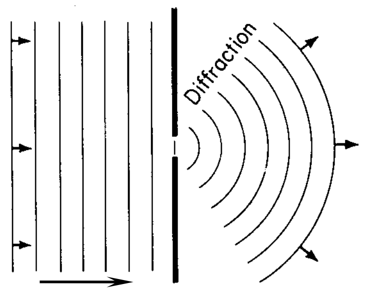
  (2) *Wavelength of the incident waves*

1. SIZE OF THE OPENINGS

- The ***smaller the openings*** in relation to the wavelength, ***the greater the diffraction***



BIG OPENING, LESS DIFFRACTION



SMALL OPENING, GREATER DIFFRACTION

2. WAVELENGTH OF THE WAVES

- *The longer the wavelength of the waves, the greater the diffraction. The shorter the wavelengths, the les the diffraction*

  <u>Daily Life Example</u>

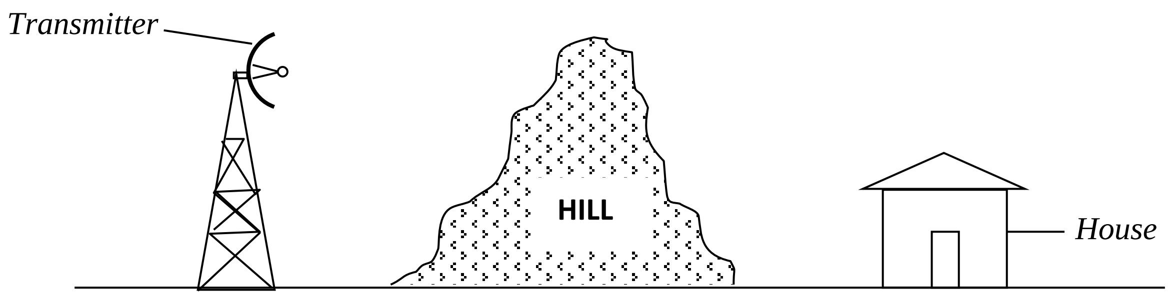
  It is possible to hear sound round obstacles but not possible to see light

  <u>Reason</u>

  Sound waves have longer wavelengths therefore are more readily diffracted unlike light waves, which have very short wavelengths therefore not readily diffracted

Worked Example 54

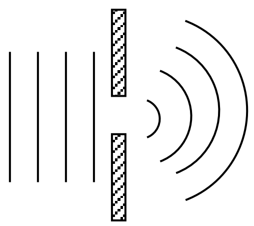
(a) **The figure shows a transmitter producing both TV and radio waves. Briefly explain why radio reception will be better than TV beyond the hill.**



Answer:

Radio waves have longer wavelengths than TV waves and therefore are diffracted (spread) more than the TV waves which have shorter wavelength, leading to better reception of radio than TV.

(b) **The figure below shows wavefront before and after passing through an opening as shown**



State what would be observed on the pattern after passing the opening if

(i) **Wave length is increased**

Answer: *Diffraction would be **more** pronounced*

(ii) **Gap is increased**

Answer: *Diffraction would be **less** pronounced*

4. INTERFERENCE

- ***Interference is the superimposition of waves***
- There are ***two*** types of interference

   (i) *Constructive interference* ***AND***

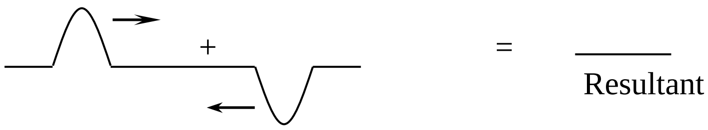
   (ii) *Destructive interference*

- ***Constructive interference*** *occurs* <u>*when the waves are in phase*</u> *and the overall effect is that they add up to bigger waves*

<u>Example</u>: *A crest meeting a crest leads to constructive interference*

- ***Destructive interference*** <u>*occurs when the waves are out of phase*</u> and the overall effect is that they cancel each other

<u>Example</u>: *A crest meeting a trough leads to destructive interference*



<u>CONDITIONS NECESSARY FOR THE OCCURRENCE OF INTERFERENCE OF WAVES</u>

- *The waves must be of the same frequency*
- *The waves must be of the same amplitude*

Waves which have the same frequency and the same amplitude are said to be ***coherent***

<u>Worked Example 55</u>

Two sets of transverse waves arrive at the same point at the same time. Under what conditions do they:

(a) Cancel out

- *Troughs from one arrive at the same time as crests from the other (destructive interference)*

(b) Produce a larger wave

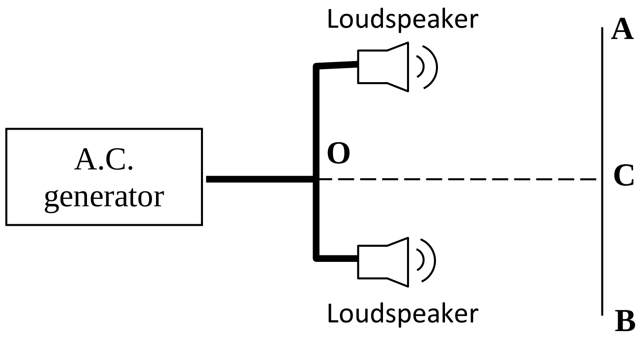
- *A crest from one arrive at the same time as a crest from the other (constructive interference)*

PRACTICAL EXAMPLES

a) Interference In Sound Leads To Soft And Loud Sound

(i) Soft sound occurs in regions where sound waves interfere destructively

(ii) Loud sound occurs where sound waves interfere constructively



- *An observer moving along the line **AB** hears loud sound at some point and soft sound at other points*

  Reason

  - *Regions where sound is loud are regions where constructive interference of sound waves occurs.*
  - *Regions where sound is soft are regions where destructive interference of sound waves occurs.*

- *An observer moving along the line **OC** hears loud sound only*

Worked Example 56

The figure below shows two identical speakers S_1 and S_2 connected to the same source of sound waves (audio signal generator). The line $\mathbf{AA_1}$ is the perpendicular bisector of the line joining $\mathbf{S_1}$ and $\mathbf{S_2}$, while the line $\mathbf{BB_1}$ is perpendicular to $\mathbf{AA_1}$. An observer walking along $\mathbf{AA_1}$ hears continuously loud sound while an observer walking along $\mathbf{BB_1}$ hears alternating loud and low sounds at different points.

(a) Explain how the loud and low sounds are produced along $\mathbf{BB_1}$

Answer:

- *At some points along* $\mathbf{BB_1}$ *waves from* $\mathbf{S_1}$ *and* $\mathbf{S_2}$ *meet in phase causing constructive interference and so a loud sound is formed.*
- *At the other points, waves meet out of phase causing destructive interference and so a low sound is formed*

(b) State why the observation made in **(a)** above along $\mathbf{BB_1}$, may not be observed if the speakers are connected to different sources of sounds

Answer:

- *If the sources of sound are different, they may be not coherent (i.e. the sounds may **not have the same frequency and same wavelength**)and so interference may not be observed*

(c) State and explain the effects on the sound heard along AA_1 and on the sound heard along $\mathbf{BB_1}$ one speaker is switched off

Answer:

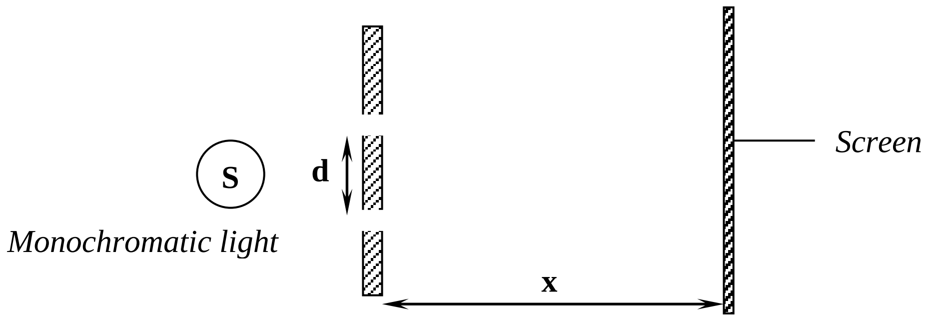
- *When one speaker is switched off the loudness would decrease as the observer moves further away from sources because the sounds along* $\mathbf{AA_1}$ *and* $\mathbf{BB_1}$ *are the same. There is no interference this time since there is no second wave to superimpose on the firsts*

b) Interference In Light Produces Bright And Dark Fringes If a Monochromatic Light Is Used

- *If white light is used, a central bright fringe is obtained at the centre and coloured bands on either side*

Worked Example 57

In an experiment to observe interference of light waves, a double slit is placed close to the source as shown below.



(a) What is meant by monochromatic light?

- *This is light consisting of one colour only / one wavelength*

(b) What is the purpose of the double slits?

- *To act as two sources of light which are coherent*

(c) Briefly describe what is observed on the screen

- *Bright bands and dark bands are observed*

(d) State what is observed on the screen when the

(i) Slit separation, d, is reduced.

- *Fringe separation is increased*

(ii) Distance, x, is increased.

- *Fringe separation is increased*

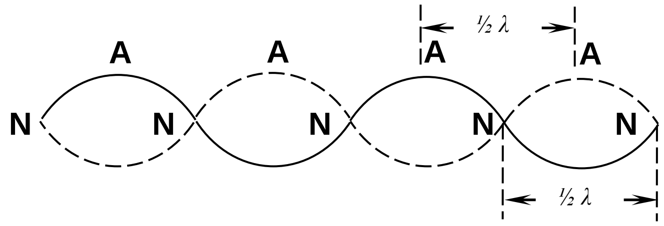
(iii) Monochromatic source is replaced with white light

- *A central white fringe will be formed followed by the other fringes taking the seven colours of the rainbow. This is because each colour of the rainbow will be diffracted differently because of the varying wavelength*

STATIONERY WAVE

- ***A stationary wave is formed when two progressive waves travelling in opposite direction meet and cancel each other***

Examples: *In stringed instruments such as the guitar*



- A stationary wave is characterized by ***Nodes* (N)** and ***Antinodes* (A)**
  - ***(i)*** *A **Node** is a region of zero displacement*
  - ***(ii)*** *An **Antinode** is a region of maximum displacement*

- ***The distance between successive nodes or antinodes is ½ λ***

Worked Example 59

What are the differences between stationary and progressive waves?

Answer

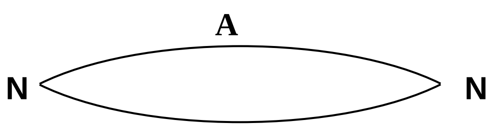
- *Stationary waves do not transfer energy away from source while progressive do*
- *Vibrations of particles at points between successive nodes in a stationary wave are in phase while in progressive phases of particles near each other out of phase*
- *In stationary waves distance between successive nodes or antinodes is $^{\lambda}/_{2}$ while in progressive distance between successive troughs or crest is **λ***

FUNDAMENTAL FREQUENCY AND OVERTONES

- ***A fundamental frequency is the lowest frequency produced by a vibrating string***
- ***Harmonics are sounds whose frequencies are whole number multiples of the fundamental***

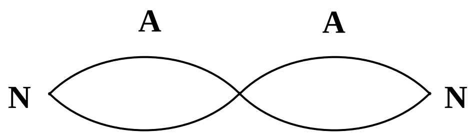
HARMONIC

- A harmonic is the simplest mode of vibration
- The first harmonic is when the string produces the fundamental i.e. sound of the lowest possible frequency



First harmonic

- The number of loops on a vibrating string is equal to the harmonic number

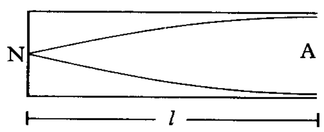


Second harmonic

> **<u>Worked Example 59</u>**
>
> **Explain what is meant by the terms: <u>overtone</u> and a <u>harmonic</u> in stationary waves.**
>
> - *Overtone is sound or note of different frequencies produced after fundamentals. i.e.* ***is any sound or note whose frequency higher than the fundamental frequency***
> - *Harmonic is a note whose frequency* ***is a whole number multiple*** *of the fundamental frequency*

<u>VIBRATING AIR COLUMNS</u>

- The simplest mode of vibration for air in a *<u>pipe closed on one end</u>* is shown below. This is the fundamental

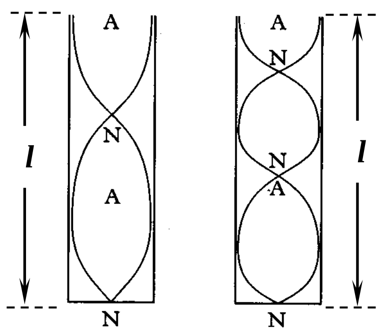


$$l = \frac{\lambda}{4}$$
$$\lambda = 4l$$
$$\text{but, } v = f\lambda$$
$$\text{therefore, } f = \frac{v}{\lambda}$$
$$f_o = \frac{v}{4l}$$

- Overtones are produced when air is blown strongly over the pipe

<u>FOR FIRST OVERTONE</u>

$$l = \frac{3\lambda}{4}$$
$$3\lambda = 4l$$
$$\lambda = \frac{4l}{3}$$
$$\text{but, } v = f\lambda$$
$$\text{therefore, } f = \frac{v}{\lambda}$$
$$\mathbf{f = \frac{3v}{4l}}$$

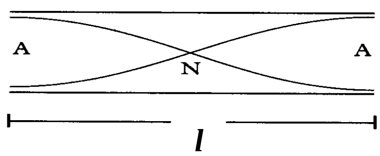


1st overtone 2nd overtone

<u>FOR SECOND OVERTONE</u>

$$l = \frac{5\lambda}{4}$$
$$5\lambda = 4l$$
$$\lambda = \frac{4l}{5}$$
$$\text{but, } v = f\lambda$$
$$\text{therefore, } f = \frac{v}{\lambda}$$
$$\mathbf{f = \frac{5v}{4l}}$$

- When an ***<u>open pipe</u>*** is used, the simplest mode of vibration producing the fundamental frequency is as shown below



9. REFRACTION OF LIGHT

Refraction of light is the bending of light when it passes from one transparent medium to another.

LAWS OF REFRACTION

1. The incident ray and the refracted ray are in the opposite sides of the normal and they lie in the same plane as the normal
2. **Snell's law** states that for a given pair of medium, the ratio of the sine of angle of incidence to the sine of angle of refraction is a constant

- **From Snell's law**:

$$\frac{\sin i^{o}}{\sin r^{o}} = \text{constant}$$

- The constant is known as the refractive index, **n**.
- Therefore:

$$\frac{\sin i^{o}}{\sin r^{o}} = n$$

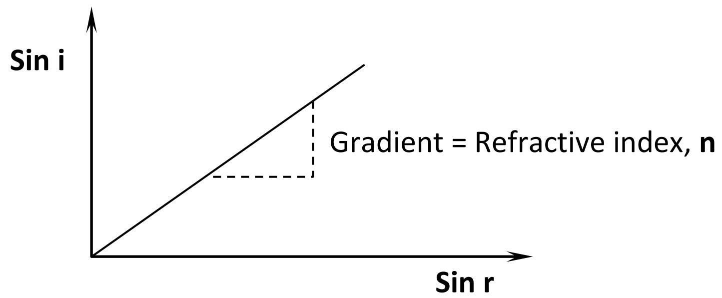
Where:

***i** – Angle of incidence;* ***r** – angle of refraction;* ***n** – refractive index*

- Refractive index is a measure of the extent to which radiation is refracted on passing through the interface between two media.

Refractive index can be defined as being ***the ratio of sine of angle of incidence to sine of angle of refraction for a given pair of medium***

- A graph of **sine i** against **sine r** is a straight line through the origin whose gradient gives the refractive index, **n**.



PRINCIPLE OF REVERSIBILITY OF LIGHT

- ***The principle of reversibility of light states that the paths of light rays can be reversed***

- *If the refractive index for a ray of light moving from air (**a**) to glass (**g**) is represented as* $_an_g$ *and the refractive index for a ray moving from glass to air is represented as* $_gn_a$*, then by principle of reversibility of light:*

$$_gn_a = \frac{1}{_an_g}$$

Worked Example 60

a) **The refractive index for a ray of light travelling from air to water is 1.33. what is the refractive index for a ray travelling from water to air**

Answer:

$$_wn_a = \frac{1}{_an_w}$$

$$_wn_a = \frac{1}{1.333}$$

$$_wn_a = 0.750$$

b) **The refractive index for a ray of light travelling from air to water ($_an_w$) is $^4/_3$, while that for a ray travelling from air to glass ($_an_g$) is $^3/_2$. What is the refractive index for a ray travelling from glass to water**

Answer:

$$_gn_w = {_gn_a} \times {_an_w}$$

But

$$_gn_a = \frac{1}{_an_g}$$

Therefore,

$$_gn_w = \frac{1}{_an_g} \times {_an_w}$$

$$= \frac{1}{\frac{3}{2}} \times {^4/_3}$$

$$= \left(1 \div \frac{3}{2}\right) \times \frac{4}{3}$$

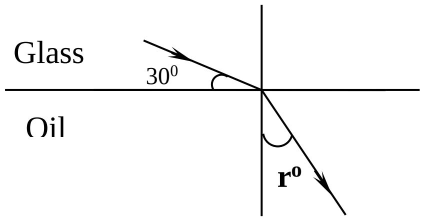
$$_gn_w = \frac{2}{3} \times \frac{4}{3}$$

$$_gn_w = {^8/_9}$$

Practice Question

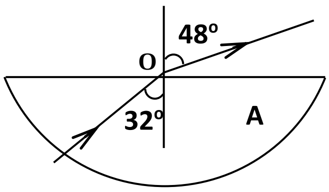
1. *The refractive index for a ray of light travelling from air to oil ($_an_o$) is $^5/_3$, while that for a ray travelling from air to glass ($_an_g$) is $^3/_2$. What is the refractive index for a ray travelling from glass to oil?* ***(Answer: $^{10}/_9$)***

2. *A ray of light is incident on a glass oil interface as shown in the figure Determine the value of **r**. Take refractive index of glass and oil as $^3/_2$ and $^6/_3$ respectively* ***(Answer: r = 41.8^0)***



Worked Example 59

The figure below represents a ray of light falling normally on the curved surface of a semicircular glass block A, at an angle of 32° at O and emerging into the air at an angle of 48°. Calculate the absolute refractive index of the glass of which the block is made



Answer

Method 1:

$$_an_g = \frac{\sin i}{\sin r}$$

$$= \frac{\sin 48^\circ}{\sin 32^\circ}$$

$$_an_g = 1.402$$

Method 2:

$$_gn_a = \frac{\sin i}{\sin r}$$

$$= \frac{\sin 32^\circ}{\sin 48^\circ}$$

$$_gn_a = 0.7131\,;$$

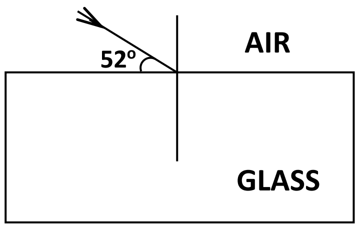
Now $_an_g = \frac{1}{_gn_a}$

$$= \frac{1}{0.7131}$$

$$_an_g = 1.402$$

Practice Question

Calculate the angle of refraction in glass for a ray travelling from air to glass as shown in the figure below. Take refractive index of glass = 1.5 ***(Answer: 20.69°)***



REAL AND APPARENT DEPTHS

- Refractive index can also be defined as the ratio of real depth to apparent depth

$$\text{Refractive index, n,} = \frac{\text{Real depth}}{\text{Apparent depth}}$$

Worked Example 62

A coin is placed at the bottom of a tall gas jar. When the jar is filled with paraffin to a depth of 32.4 cm, the coin is apparently seen displaced 9.9 cm from the bottom. What is the refractive index of paraffin?

Answer

$$\text{Apparent depth} = (32.4 - 9.9)\ \text{cm}$$

$$= 22.5\ \text{cm}$$

$$\text{Refractive index} = \frac{\text{Real depth}}{\text{Apparent depth}}$$

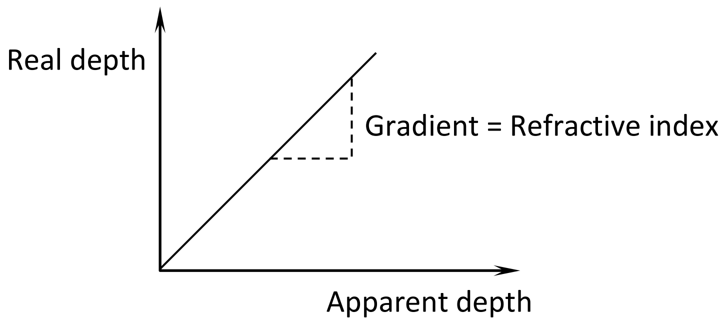
$$= \frac{32.4\ \text{cm}}{22.5\ \text{cm}}$$

$$\mathbf{n = 1.44}$$

Practice Question

A beaker of height 10 cm is filled with water. An optical pin which is at the bottom of the beaker is then viewed from the top of the beaker. How far does the pin appear from the surface, if the refractive index of water is $^4/_3$? ***(Answer: 7.5 cm)***

- A graph of **real depth** against **apparent depth** is a straight line through the origin whose gradient gives the refractive index, **n**.



REFRACTIVE INDEX IN TERMS OF VELOCITY OF LIGHT

- *For a ray of light travelling from medium **1** to medium **2**, refractive index is the ratio of velocity of light in medium **1** to velocity of light in medium **2***

$$\text{Refractive index, } {}_1n_2 = \frac{\text{velocity of light in medium } \mathbf{1}}{\text{velocity of light in medium } \mathbf{2}}$$

For example, for a ray of light travelling from air to water

$${}_an_w = \frac{\text{velocity of light in air}}{\text{velocity of light in water}}$$

Refractive index can therefore be defined as being ***the ratio of the speed of light in a vacuum to the speed of light in a medium under consideration.***

Worked Example 63

The speed of light in air is 3.0 x 10^8 m/s. What is the speed of light in glass? Take refractive index of glass = 1.5

Answer

$${}_an_g = \frac{\text{velocity of light in air}}{\text{velocity of light in glass}}$$

$$1.5 = \frac{3.0 \times 10^8}{v \text{ in glass}}$$

$$v \text{ in glass} = \frac{3.0 \times 10^8}{1.5}$$

$$v \text{ in glass} = 2 \times 10^8 \text{ m/s}$$

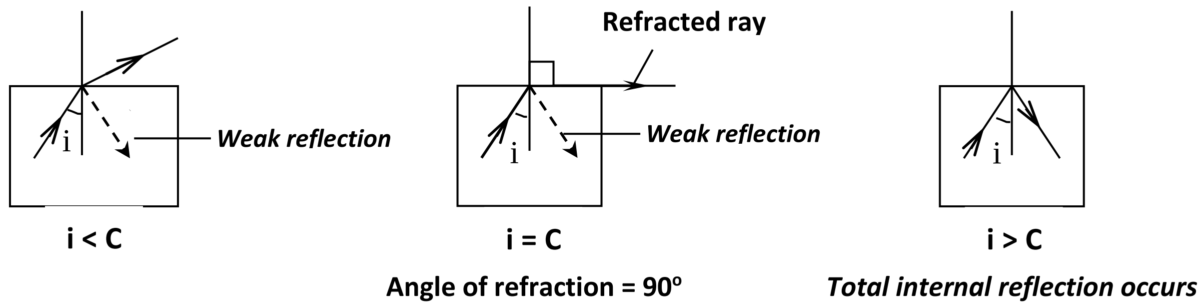
Practice Question

The refractive index of water is $^4/_3$. Find the speed of light in water given that the speed of light in air is 3.0×10^8 m/s ***(Answer: 2.25×10^8 m/s)***

CRITICAL ANGLE – C

Critical angle is the angle of incidence in the optically dense medium when the angle of refraction in the optically less dense medium is 90°

***NOTE**: If the angle of incidence is greater than the critical angle, **total internal reflection occurs**.*



Conditions necessary for the occurrence of total internal reflection of light

a) *A ray must move **from the denser medium to the less dense medium***

b) *The angle of incidence must be greater than the critical angle*

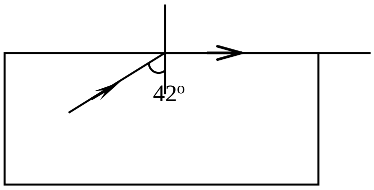
Critical Angle and Refractive Index

$$n = \frac{1}{\text{Sine } C}$$

***C** – the critical angle;* ***n** – refractive index*

Worked Example 64

The figure below shows the path of a ray of light passing through a rectangular glass block placed in air.



Answer

$$n = \frac{1}{\sin C}$$

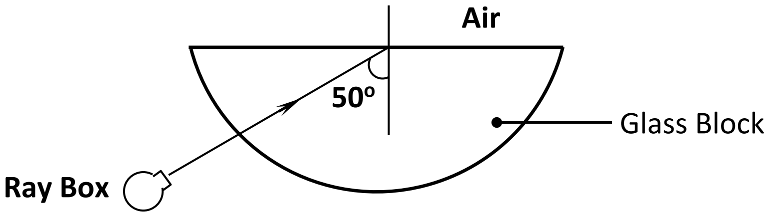
$$= \frac{1}{\sin 42}$$

$$= \frac{1}{0.6691}$$

n = 1.5

Practice Question

1. *A certain glass material has a refractive index of 2.5. What is its critical angle?* ***(Answer: 23.57°)***
2. *The critical angle of paraffin is 45°. What is the refractive index of paraffin?* ***(Answer: 1. 414)***
3. *The critical angle for crown glass is 42° using this information complete the figure below to show the passage of the ray shown through the glass block.*



SOME EFFECTS OF TOTAL INTERNAL REFLECTION OF LIGHT

(a) Mirage

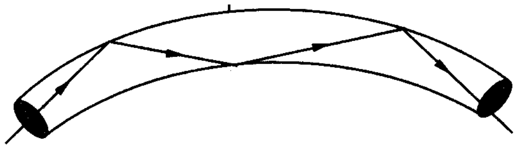
- This is an impression of the presence of imaginary water some distance away
- Mirages are often seen during hot sunny days

(b) Twinkling of stars

APPLICATIONS OF TOTAL INTERNAL REFLECTION

1. Optical fibres

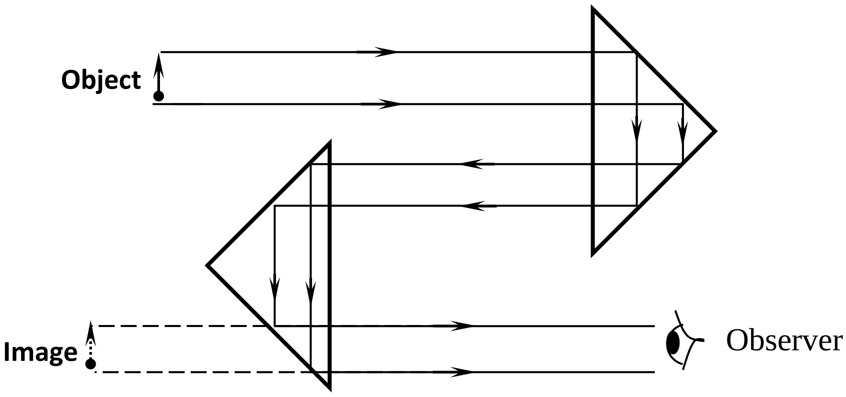
- An optical fibre is a flexible glass rod whose inside is made of a material of high refractive index than the outside.



- Optical fibre is used in:
  - ***(i)*** *Medicine to view inner body organs*
  - ***(ii)*** *Telecommunication to send message signal*

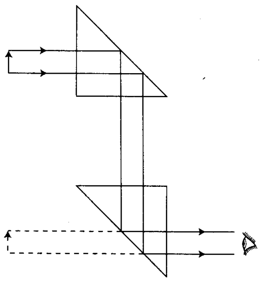
2. Prism binoculars

- These are used to view distant objects
- Prism binoculars make use of two prisms arranged as shown below



3. Prism periscope

- This is used to observe objects over obstacles



Advantage of prism periscope over plane mirror periscope

- *Prism periscope does not form multiple images*
- *Prism periscope is not painted unlike mirror whose paint can pill off after some time*

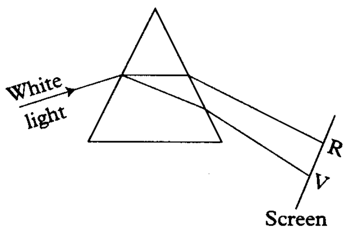
DISPERSION OF WHITE LIGHT

- *Dispersion is the separation of white light into its component colours when it passes through a prism*

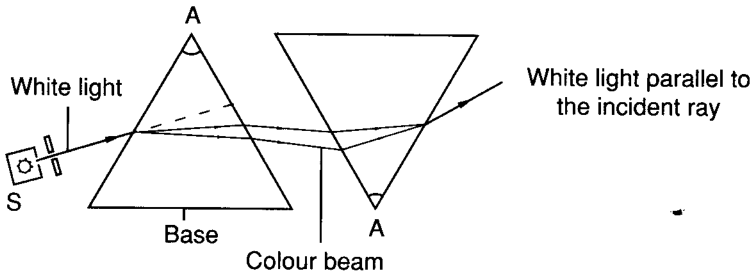
- *Dispersion occurs because lights of different colours have different velocities in glass therefore they are refracted to different extents.*

  Red light is refracted the least while violet light is refracted most

  Reason: *In glass, velocity of red light is higher than velocity of violet light.*



- The colours of the spectrum can be recombined by using a second inverted prism.



NOTE: Formation of rainbows is due to dispersion of light by drops of water / rain drops.

10. HEATING EFFECT OF ELECTRIC CURRENT

FACTORS AFFECTING HEATING EFFECT OF ELECTRIC CURRENT

- *Heating effect of electric current depends on* ***three main*** *factors*:

1. THE RESISTANCE OF THE CONDUCTOR **(R)**
   - *The heat developed is directly proportional to the resistance,* ***R*** *of the conductor. The higher the resistance, the more the heat produced*

2. TIME FOR PASSING THE CURRENT **(t)**
   - *The longer the time the greater the heat developed*

3. THE CURRENT FLOWING **(I)**
   - *Heat produced is directly proportional to the square of the current. The higher the current, the more the heat produced.*

ELECTRIC ENERGY AND POWER

- Electric energy is calculated as:

1. $E = VIt$
2. $E = I^2Rt$
3. $E = \frac{V^2t}{R}$

E *– Electric energy in joules (J)* ***V*** *– operating voltage in volts (V)*

I *– current in amperes (A)* ***t*** *– time in seconds (s)* ***R*** *– Resistance in ohms (Ω)*

Worked Example 65

An electric iron box has resistance of 30Ω and it takes a current of 10A. Calculate the heat in kJ developed in 1 minute

Answer

R = 30 Ω; I = 10 A; t = 60 seconds

Therefore,

$$E = I^2Rt$$
$$= 10^2 \times 30 \times 60$$
$$= 180000\ J$$
$$\underline{E = 180\ kJ}$$

Practice Question

An electric cooker has a coil of resistance 5000Ω. If it is operated on a 250V mains supply for 1 hour, hour much heat energy does it produce. ***(Answer: E = 45 kJ)***

- Electric power is calculated as:

1. **P = VI**
2. **$P = I^2R$**
3. **$P = \frac{V^2}{R}$**

V *– operating voltage in volts (V)* ***I*** *– current in amperes (A)*

R *– Resistance in ohms (Ω)* ***P*** *– electric power in watts (W)*

Worked Example 66

An electric bulb is rated 60W, 240V. Determine:

a) **The resistance of the filament**

b) **The current flowing through the bulb when it is connected to the mains supply**

Answer

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

P = 60W ***V = 240V*** ***R =?***

$$60 = \frac{240 \times 240}{R}$$

$$R = \frac{240 \times 240}{60}$$

$$\underline{R = 960\Omega}$$

(b) Method 1

From ohms law:

$$V = IR$$

$$240 = I \times 960$$

$$I = \frac{240}{960}$$

$$\underline{I = 0.25A}$$

(b) Method 2

Using the formula: ***P = VI***

P = 60W *V = 240V* *I =?*

Substituting these in the equation:

$$60 = 240 \times I$$

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

$$\underline{I = 0.25A}$$

Practice Question

An electric motor powered by a 240V mains supply requires a current of 30A to lift a load of mass 3 tonnes at the rate of 5 m per minute. Calculate:

a) *The power input* **(Answer: 7 200W)**

b) *The power output* **(Answer:2500 W)**

c) *The overall efficiency of the machine* **(Answer: 34.72%)**

Worked Example 67

What is the maximum number of 100 W bulbs which can be safely connected from a 240V source supplying a current of 5A?

Answers

Total power supply is given by: $P = VI$

$= 240 \times 5$

$P = 1200\ W$

Let the total number of bulbs which can be connected be **n**

Therefore, total power consumed by the bulbs $= 100 \times n$

$= 100n$

Therefore, $100n = 1200$

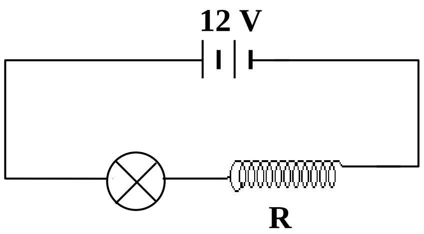
$$n = \frac{(1200)}{10}$$

$\underline{n = 12 \text{ bulbs}}$

Practice question

1. *How many 100 W bulbs can be safely connected from a 240V source supplying a current of 4A?* **(Answer: 9 bulbs)**

2. *The circuit diagram below was used to light 3V 0.5A bulb from 12.0V* **D.C** *supply. Determine the rate at which electrical energy is converted into heat energy in appliance* **R**. **(Answer: 4.5 joules/ second or 4.5 watts)**



APPLICATIONS OF HEATING EFFECT OF ELECTRIC CURRENT

1. Electric cooker

2. Electric kettle

3. Filament lamp

4. Electric iron box

NOTE: GO OVER THE WORKING OF EACH OF THESE DEVICES

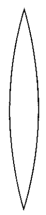
11. THIN LENSES

CLASSES OF THIN LENSES

- *There are two main types of thin lenses*:

i) CONVERGING (CONVEX) LENSES

- *These are thicker at the centre than at the edges*



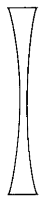
Bi-convex

Plano convex

Converging meniscus

(ii) DIVERGING (CONCAVE) LENSES

- *These are thicker at the edges than at the centre*

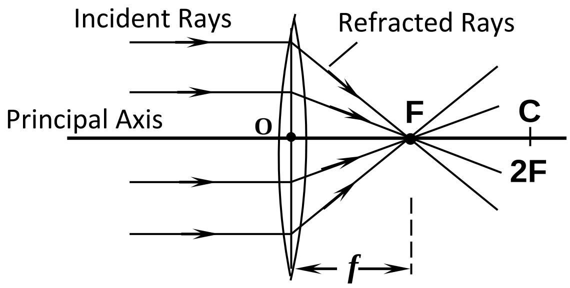


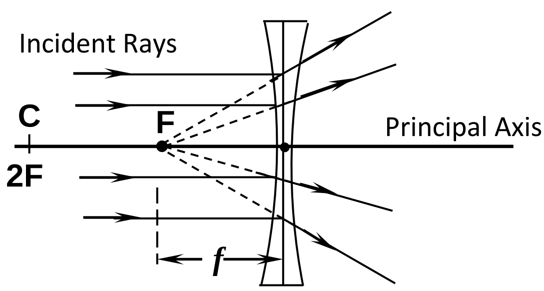
Bi-concave

Plano-concave

Diverging meniscus

DEFINITION OF SOME TERMS





1. **Centre of curvature (C):**

   - *This is the centre of the sphere from which the lens forms a part*

2. **Principal axis**

   - *This is the line which passes through the middle of the lens, joining the respective centres of curvature*

3. **Optical centre (O):**

   - *This is the point on the principal axis, midway between the lens surfaces*

4. **Radius of curvature (R):**

   - *This is the radius of the sphere of which the lens is a part*

5. **Principal focus (focal point) (F):**

   (a) *For a converging lens*:

   - *This is the point on the principal axis at which rays of light which are parallel to the principal axis meet / converge after refraction.*

   (b) *For a diverging lens*:

   - *This is the point on the principal axis from which incident parallel rays of light diverge or appear to diverge from after refraction.*

6. **Focal length (*f*)**

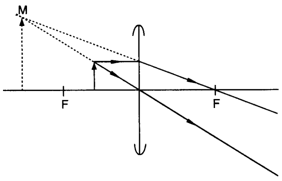
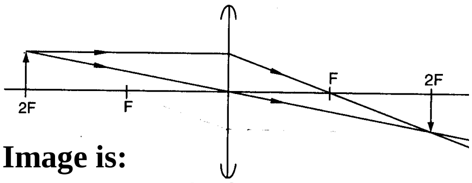
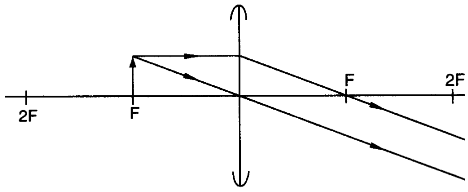
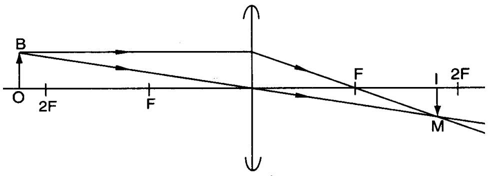
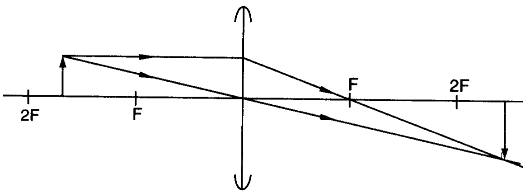
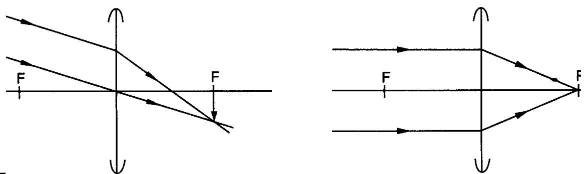
   - *This is the length between the principal focus (**F**) and the optical centre (**O**)*
   - ***Note**: Focal length of a lens (f) is half the radius of curvature (R), i.e.*

$$f = \frac{R}{2}$$

Or

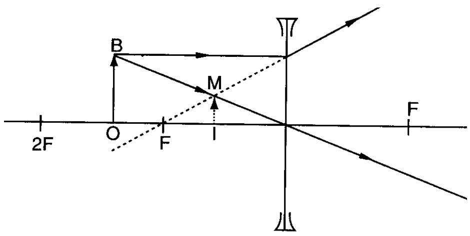
$$R = 2f$$

IMAGES FORMED BY CONVEX LENSES

1. Object between principal focus, F, and pole, P.  **Image is:** – *Behind the mirror* – *Virtual* – *Upright* – *Magnified i.e. larger than the object*	**4. Object at C**  **Image is:** – *At C* – *Real* – *Inverted* – *Same size as the object*
2. Object at principal focus, F.  **Image is at infinity**	**5. Object beyond C**  – *Between C and F* – *Real* – *Inverted* – *Smaller than the object*
3. Object between F and C  **Image is:** – *Beyond C* – *Real* – *Inverted* – *Magnified i.e. larger than the object*	**6. Object at infinity**  **Image is:** – *At F* – *Real* – *Inverted* – *Smaller than the object*

IMAGES FORMED BY CONCAVE (DIVERGING) LENSES

i) When Object is between principal of focus (F) and centre of curvature (C)



The image is:

– *Smaller than the object (diminished)*

– *Upright*

– *Virtual (not real)*

In <u>all</u> cases of images formed by concave lenses, the images will always be:

(a) Smaller than the object (diminished)

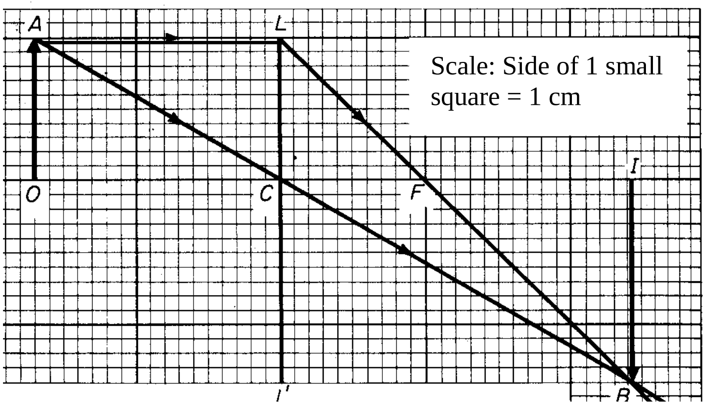
(b) Upright

(c) Virtual (not real)

<u>Worked Example 68</u>

An object 10 cm tall stands vertically on the principal axis of a convex lens of focal length 10 cm and at a distance of 17 cm from the lens. By means of accurate graphical construction find the position, size and nature of the image formed

<u>Answer</u>



(a) *Position of the image = 24 x 1*

= <u>24 cm from the lens</u>

(b) *Size of the image = (14 x 1)*

= 14 cm tall

(c) *Nature of the image: The image is (i) Real and (ii) inverted*

<u>Practice Question</u>

An object 8 cm tall is placed 20 cm in front of a convex lens of focal length 16 cm. By means of accurate graphical construction, determine the position, size and nature of the image formed. ***(Position = 60 cm, Size: = 24 cm, Nature: Real image)***

THE LENS EQUATION

$$\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$$

Where:

f *– focal length* ***u*** *– distance from the object to the lens* ***v*** *– distance from the image to the lens*

Important conditions when using this formula:

i) Distances of real objects, real images and focal lengths are positive values

ii) Distances of virtual images and objects are negative values

iii) The focal length of a diverging (concave) lens is a negative value.

Worked Example 69

An object is placed 20 cm in front of a convex lens of focal length 12 cm. Find the position and the nature of the image formed

Answer $u = 20$ cm $f = 12$ cm $v = v$

$$\frac{1}{f} = \frac{1}{v} + \frac{1}{u}$$

$$\frac{1}{12} = \frac{1}{v} + \frac{1}{20}$$

$$\frac{1}{v} = \frac{1}{12} - \frac{1}{20}$$

$$\frac{1}{v} = \frac{5-3}{60}$$

$$\frac{1}{v} = \frac{2}{60}$$

$$\frac{1}{v} = \frac{1}{30}$$

$$v = 30 \text{ cm}$$

- *A positive value of **v** means a real image is formed. Hence a real image is formed 30 cm away from the lens.*

Practice Question

An object is placed 10 cm from a diverging lens of focal length 15 cm. Find the position of the image formed. State the nature of the image formed.

*(**Answer: 6 cm. The image is virtual**)*

MAGNIFICATION

- This is the ratio of image height to object height

$$\text{Magnification} = \frac{\text{Height of image}}{\text{Height of object}}$$

Also,

$$\text{Magnification} = \frac{\text{Image distance (v)}}{\text{Object distance (u)}}$$

And

$$\text{Magnification, } m = \frac{v}{f} - 1$$

Worked Example 70

A four times magnified virtual image is formed of an object placed 12 cm from a converging lens. Calculate the position of the image and the focal length of the lens.

Answer ***Magnification = 4,*** ***u = 12 cm*** ***v = v*** ***f = f***

$$\text{Magnification} = \frac{v}{u}$$

$$4 = \frac{v}{12}$$

$$v = (12 \times 4)$$

$$v = 48 \text{ cm}$$

Note: *Since the image formed is virtual, the image distance,* ***v*** *is a negative value. i.e.* ***v = –48 cm***

$$\frac{1}{f} = \frac{1}{v} + \frac{1}{u}$$

$$\frac{1}{f} = \frac{1}{-48} + \frac{1}{12}$$

$$\frac{1}{f} = \frac{-1+4}{48}$$

$$\frac{1}{f} = \frac{3}{48}$$

$$\frac{1}{f} = \frac{1}{16}$$

$$f = 16 \text{ cm}$$

Practice Question

An object is placed, (a) 20 cm (b) 5 cm, from a converging lens of focal length 15 cm. Find the nature, position and magnification of the image formed in each case

Answer

(a) *A real image is formed 60 cm from the lens on the side opposite to the object, of magnification 3*

(b) *A virtual image is formed 7.5 cm from lens on the same side as the object of magnification 1.5*

APPLICATIONS OF THIN LENSES

CORRECTION OF VISION DEFECTS

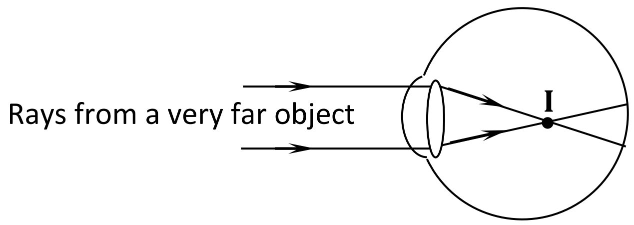
There are two main defects of the eye. These are:

i) ***Short sightedness***

ii) ***Long sightedness***

1. SHORT SIGHTEDNESS

- *This is a vision defect in which the eyeball is too long. The image formed by distant objects is focussed in front of the retina, and not on the retina.*

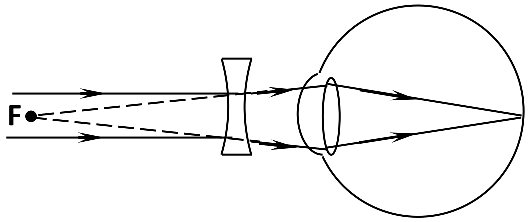


SHORT SIGHTEDNESS
- *Eyeball too long*
- *Lens has a short focal length*

- *A short sighted person can see objects which are near more clearly, but not objects which are far.*

Correction of short sightedness

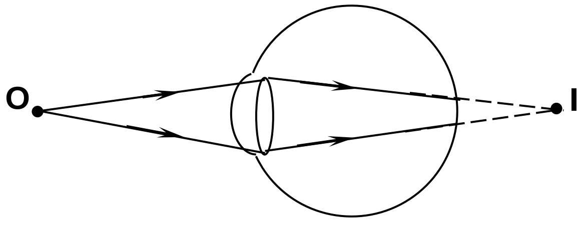
- *Concave (diverging) lens is used. This diverges the light rays before they reach the retina.*



CORRECTION
- *Diverging lens causes rays to diverge as though coming from **F***

2. **LONG SIGHTEDNESS**

- *This is a vision defect in which the eyeball is short. The image of near objects is focussed behind the retina, and not on the retina.*

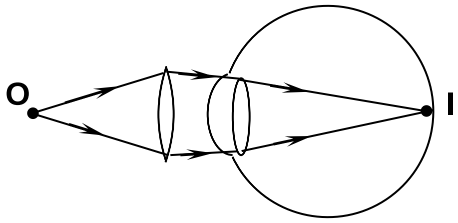


LONG SIGHTEDNESS
- *Eyeball too short*
- *Lens has a long focal length*

- *A long sighted person can only see objects which are far more clearly, but not objects which are near.*

Correction of long sightedness:

- *A converging lens is used. This lens converges the light before it enters the eye*



CORRECTION
Converging lens reduces divergence of the rays

2. THE LENS CAMERA

Similarities between the camera and the eye

	CAMERA	EYE
1.	*– Uses a convex lens*	*– Uses a convex lens*
2.	*– Diaphragm controls light*	*– Iris control light*
3.	*– Shutter keeps out light*	*– Eye lid keeps out light*
4.	*– Image formed on the film*	*– Image formed on the retina*
5.	*– Black paint stops internal reflection of light*	*– Black layer (choroids) stops internal reflection of light*
6.	*– Air (transparent) between the lens and the film*	*– Jelly (transparent) between the lens and the retina*
7.	*– Image formed is small and inverted*	*– Image formed is small and inverted*

DIFFERENCES BETWEEN THE CAMERA AND THE EYE

	CAMERA	EYE
1.	*– Lens is hard glass*	*– Lens is soft and elastic*
2.	*– Thickness of lens does not change*	*– Thickness of lens changes*
3.	*– Image is focussed by moving the lens*	*– Image is focussed by changing the thickness of the lens*
4.	*– Only the lens refracts the light*	*– Aqueous and vitreous humour refract the light*
5.	*– Diaphragm can be altered*	*– Iris alters itself*

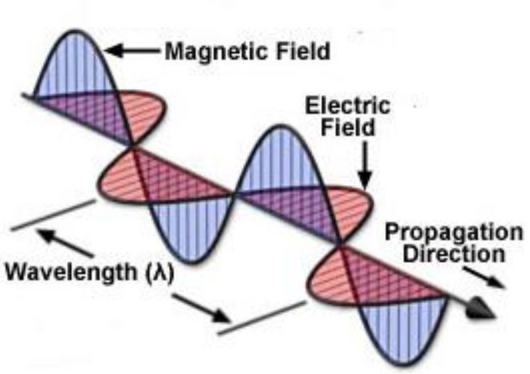
3. THE SIMPLE MICROSCOPE (MAGNIFYING GLASS)

4. THE COMPOUND MICROSCOPE

N/B: *Go Over These*

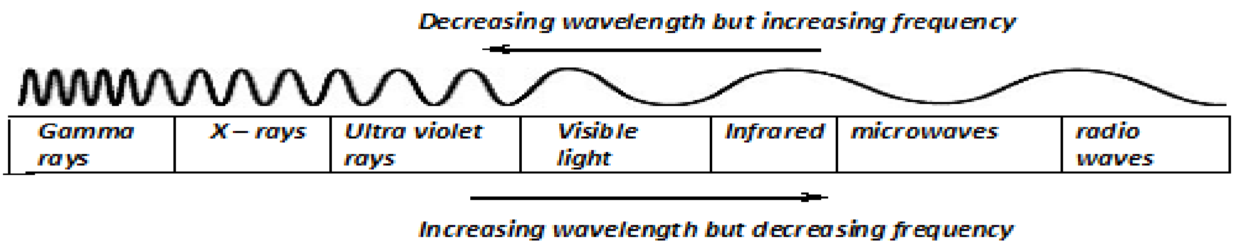
12. ELECTROMAGNETIC SPECTRUM

***Electromagnetic waves are transverse waves formed as a result of interaction between electric and magnetic fields*.**



- The waves have different frequencies and wavelengths, ***but the same velocity (i.e. 3.0 x 10^8 m/s)***
- When the waves are arranged in order of their frequencies they form the ***electromagnetic spectrum***
- Electromagnetic waves are:

Gamma rays; X – Rays; ultra violet rays; visible light; infra red; microwaves and radio waves



PROPERTIES OF ELECTROMAGNETIC WAVES

1. *They are not charged therefore are not deflected by either electric or magnetic fields*
2. *They travel in straight lines at the speed of light (3.0 x 10^8 m/s)*
3. *They travel through a vacuum*

Worked Example 71

State two differences between sound waves and electromagnetic waves

Answer

- *Sound waves requires materials medium while electromagnetic waves don't*
- *Sound waves are longitudinal while electromagnetic waves are transverse*

4. *They undergone interference, refraction and diffraction*

5. *They obey the equation*

$$c = f\lambda$$

Where:

c – speed of light; f – frequency in Hz λ – wavelength in meters

Worked Example 72

What is the wavelength of radio waves of frequency 95.6 MHz? (c = 3.0 x 10^8 m/s)

Answer

$$v = f\lambda$$

$$v = 3.0 \times 10^8 m/s$$

$$f = 95.6\ MHz$$

$$= 95.6 \times 10^6\ Hz$$

$$3.0 \times 10^8\ m/s = 95.6 \times 10^6 \times \lambda$$

$$\lambda = \frac{3.0 \times 10^8\ m/s}{95.6 \times 10^6\ Hz}$$

$$\lambda = 3.14\ m$$

Practice Question

The wavelength of red light in air is 6.98 x 10^{-7} m. Calculate the frequency of the red light. c = 3.0 x 10^8 m/s

(Answer: 4.3 x 10^{14}Hz)

6. *They carry energy. The energy of electromagnetic waves is calculated as:*

$$E = hf$$

Where:

E** – Energy of the E.M waves in **J** **h** – Plank's constant in **Js** **f** – frequency in **Hz

Worked Example 73

The energy of X-ray is 1.989 x 10 $^{-14}$ joules. Given that the speed of light is 3.0 x 10^{8}m/s and plank's constant is 6.6 x 10 $^{-34}$Js, find the wavelength of the x-rays

Answer

$$E = hf$$

$$1.989 \times 10^{-14} = 6.6 \times 10^{-34} \times f$$

$$f = \frac{1.989 \times 10^{-14}}{6.6 \times 10^{-34}}$$

$$f = 3.01 \times 10^{19}\ Hz$$

$$\text{But } c = f\lambda$$

$$3.0 \times 10^{8} = 3.01 \times 10^{19}\ Hz \times \lambda$$

$$\lambda = \frac{3.0 \times 10^{8}}{3.01 \times 10^{19}}$$

$$\underline{\lambda = 9.967 \times 10^{-12} m}$$

Practice Question

1. *The following form part of the electromagnetic spectrum. Visible light, gamma rays, radio waves, X-rays and microwaves. Arrange them in the order of increasing wavelength*
2. *A radioactive element emits gamma rays of energy 3.6 x 10^{-12} joules. Given that the speed of light is 3.0 x 10^{8}m/s and plank's constant is 6.6 x 10 $^{-34}$Js, find:*
   a) the frequency of the gamma rays ***(Answer: 5.454 x 10^{21} Hz)***
   b) *the wavelength of the gamma rays* ***(Answer: 5.501 x 10 $^{-14}$ m)***

SOURCES, DETECTORS AND USES OF E.M. WAVES

RADIATION	SOURCE	DETECTOR	USES
Gamma rays	○ Radioactive substances	○ Photographic plate ○ Geiger Muller tube	**1.** *In medicine to locate internal body organs* **2.** *Sterilize surgical instruments* **3.** *To detect flaws in metals*
X – rays	○ X – ray tubes	○ Florescent screens ○ Photographic film	**1.** *Detect fractured bones and dislocations* **2.** *Treatment of cancer* **3.** *Study of crystal structures*
Ultra violet	○ The sun ○ Mercury vapour lamps ○ Sparks	○ Photographic films ○ Photocells ○ Paper smeared with Vaseline	**1.** *Detect forgeries e.g. of bank notes* **2.** *Source of vitamin D* **3.** *To kill bacteria in water*
Visible light	○ The sun ○ Luminous objects	○ The eye ○ Photocells ○ Photographic films	**1.** *Ordinary photography* **2.** *Enables the eye to see* **3.** *Photosynthesis*
Infra red	○ The sun ○ Fires ○ Hot bodies	○ Thermometer with blackened bulbs ○ Thermopile ○ Bolometer	**1.** *Infra red photography* **2.** *Drying substances* **3.** *Source of warmth*
Microwaves	○ Magnetrons in microwave ovens	○ Solid state diodes	**1.** *For cooking in microwave ovens* **2.** *Satellite communication* **3.** *Radar communication*
Radio waves	Oscillating electric circuits	○ Aerials ○ Diodes ○ Earphones in electric circuits	**1.** *Radio and ground communication*

13. ELECTROMAGNETIC INDUCTION

Electromagnetic induction is the production of electricity / voltage in a conductor situated in a changing magnetic field or a conductor moving through a stationary magnetic field.

- An E.M.F is only induced in a conductor when there is relative motion between the conductor and the magnetic field.

FACTORS AFFECTING THE MAGNITUDE OF THE INDUCED E.M.F

1. STRENGTH OF THE MAGNET

- *The stronger the magnet, the bigger the induced E.M.F*

2. NUMBER OF TURNS IN THE COIL

- *The more the number of turns in the coil, the bigger the induced E.M.F*

3. THE SPEED AT WHICH THE WIRE OR THE MAGNET IS MOVED (*rate of change in magnetic flux linkage*)

- *Induced E.M.F. increases with the speed of relative motion of the conductor in the field*

LAWS OF ELECTROMAGNETIC INDUCTION

- There are two laws:
  - ***(i)*** *Faraday's law*
  - ***(ii)*** *Lenz's law*

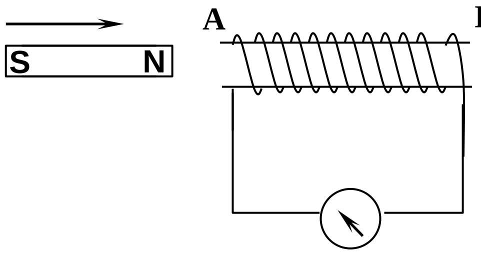
FARADAYS LAW OF ELECTROMAGNETIC INDUCTION

Faraday's law of electromagnetic induction states that the magnitude of induced E.M.F is directly proportional to the rate of change in the magnetic flux linkage

LENZ'S LAW

Lenz's law states that the direction of induced current is such that it tends to oppose the change producing it

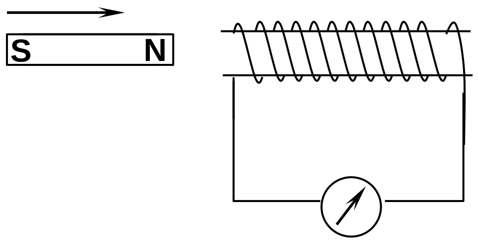
Illustration of the Lenz's law



- *When the magnet is pushed towards the coil, a **N – pole** is developed at end **A** which will oppose the motion of the magnet by repelling it.*
- *When the magnet is pulled away from the coil, a **S – pole** is developed at end A which will oppose the motion of the magnet by attracting it.*

Worked Example 74

When a magnet is pushed into the solenoid in the figure below, the ammeter record a brief current



(a) **Explain why current is produced in the circuit**

Answer: *Because there is relative motion between the coil and the magnet // magnetic field lines are cut by the coil*

(b) **State the magnetic pole produced at the left-hand end of the solenoid**

Answer: *North pole*

(c) **State the rule you have used to determine the polarity above**

Answer: *Lenz's law*

(d) **State three ways by which the magnitude of the induced current can be increased**

Answer:

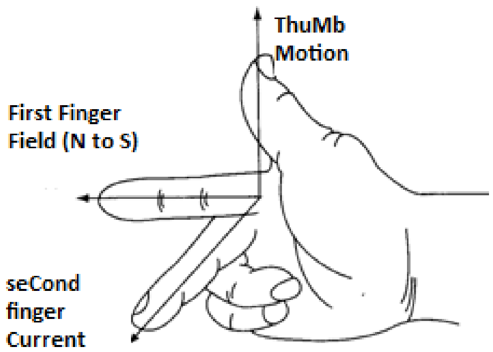
1) *By using a more powerful magnet*

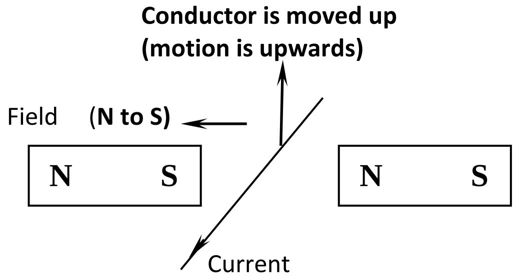
2) *By increasing the number of turns in the solenoid*

3) *By increasing the speed at which the magnet is pushed into the solenoid*

THE FLEMINGS RIGHT HAND RULE (THE DYNAMO RULE)

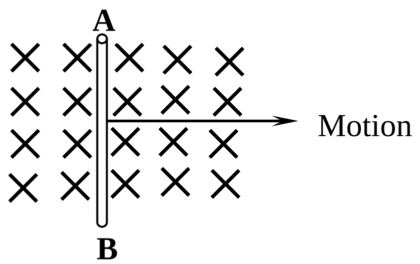
If the right hand is held with the thumb, the first finger and the second fingers mutually at right angles so that the first finger points in the direction of the magnetic field and the thumb in the direction of the motion of the conductor, then the second finger will point in the direction of the induced current





Worked Example 75

The figure below shows a conductor AB moving in a region of uniform magnetic field.



Take Note: *Any time the symbol: × is used, it means that the direction of the magnetic field is into the paper, and if the symbol ⊙ is used it means that the direction of the magnetic field is from the paper outward.*

a) In the figure above, state the direction of the flow of the induced current

Answer:

- *The induced current flows in the conductor from the end* ***B to A*** *i.e. upwards*

b) State three ways in which the magnitude of the induced current can be increased

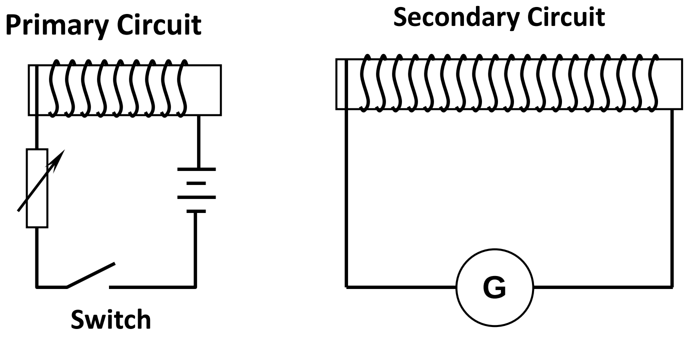
Answer:

- *By increasing the strength of the magnetic field*
- *By increasing the speed at which the rod is moved*
- *By increasing the length of the conductor*

MUTUAL INDUCTION

- Mutual induction occurs when a changing electric current in one coil induces a current in another coil placed close to it.

Example



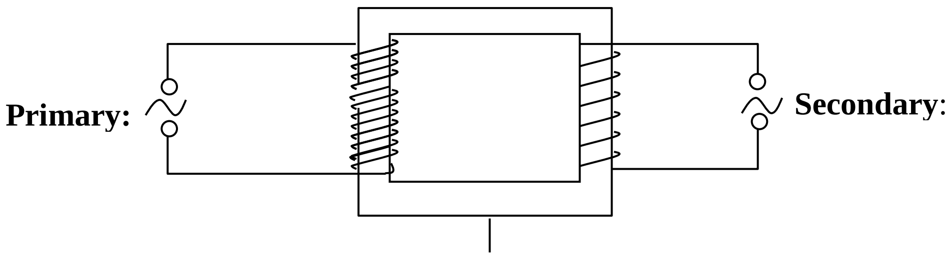
- *When the switch in the primary coil is closed and opened rapidly, the galvanometer in the secondary coil shows some deflection. This is because current is induced in the secondary coil.*

- ***The induced current in the secondary coil can be increased by:***

  1. *Winding the coils on a soft iron rod or coil*
  2. *Winding the secondary coils over the primary coil*
  3. *Increasing the number of turns in the secondary coil*

TRANSFORMER

- *A transformer is a device which transfers electric energy from one circuit to another by electromagnetic induction.*



- Transformers work on ***alternating current, A.C.*** and ***not direct current, D.C.***

Reason*: Alternating current changes both in magnitude and direction* ***<u>therefore produces a changing magnetic field,</u>*** *unlike the direct current which* ***<u>does not produce a changing magnetic field</u>***

- There are ***two*** types of transformers:
  - ***(i)*** *Step down transformers*
  - ***(ii)*** *Step up transformers*

THE STEP DOWN TRANSFORMER

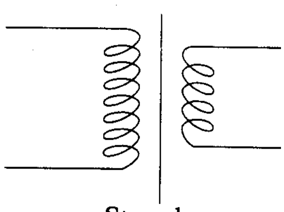
- ***In this transformer***:

  (i) *The primary turns are more than the secondary turns* ***($N_p > N_s$)***

  (ii) *The primary voltage is greater than the secondary voltage* ***($V_p > V_s$)***

  (iii) *The current in the primary coils is* ***lower*** *than the current in the secondary coils.* ***($I_P < I_S$)***

Symbol for step down transformer



THE STEP UP TRANSFORMER

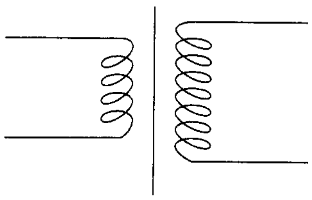
- ***In this transformer:***

  (i) *The primary turns are less than the secondary turns* ***($N_P < N_s$)***

  (ii) *The secondary voltage is greater than the primary voltage* ***($V_S > V_P$)***

  (iii) *The current in the primary coils is* ***higher*** *than the current in the secondary coils.* ***($I_P > I_S$)***

Symbol for step up transformer



TURNS RATIO

This is the ratio of the number of turns in the secondary coil to the number of turns in the primary coil

$$\text{Turns Ratio} = \frac{\text{Number of turns in secondary } (N_S)}{\text{Number of turns in primary } (N_p)}$$

- For a transformer:

$$\frac{V_S}{V_p} = \frac{N_S}{N_p} = \text{turns ratio}$$

- For an ideal transformer, that is, a transformer ***which is 100% efficient***:

Power input = power output

Power in primary coils = power in secondary coils

$$V_p \times I_p = V_s \times I_s$$

EFFICIENCY OF A TRANSFORMER

The efficiency of a transformer in the ratio of power output to power input expressed as a percentage.

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

$$\text{Efficiency} = \frac{\text{Power in secondary coils}}{\text{Power in primary coils}} \times 100$$

OR

$$\text{Efficiency} = \frac{V_s \times I_s}{V_p \times I_p} \times 100$$

Worked Example 76

A transformer with primary coil of 400 turns and secondary coil 200 turns is connected to 240 V ac mains. Calculate the secondary voltage.

$$\frac{V_P}{V_s} = \frac{N_P}{N_s}$$

$$\frac{240}{V_s} = \frac{400}{200}$$

$$\underline{\underline{V_s = 120\ \text{V}}}$$

Worked Example 77

A transformer with primary coil of 1200 turns and secondary coil 600 turns is connected to 240 V ac mains. *If the primary current is 3.0A and secondary is 5.0A. What is its efficiency?*

$$\frac{V_P}{V_s} = \frac{N_P}{N_s}$$

$$\frac{240}{V_s} = \frac{1200}{600}$$

$$Vs = 120\ V$$

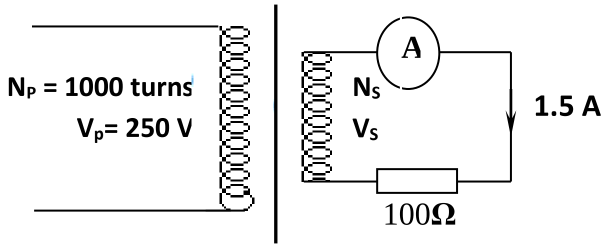
$$\text{But, Efficiency} = \frac{P_{out\ put}}{P_{in\ put}} \times 100$$

$$= \left[\frac{V_s \times I_s}{V_p \times I_p}\right] \times 100$$

$$= \left[\frac{120 \times 5}{240 \times 3}\right] \times 100$$

Efficiency = 83%

(a) **A transformer has 1000 turns in its primary coil, which is connected to a 250V a.c supply. The secondary coil is connected to an ammeter via a 100 Ohm resistor. Determine the number of turns in the secondary coil if the ammeter reads 1.5A**



p.d across 100 Ω resistor, $V = IR$

$= 1.5 \times 100$

$= 150\ V$

This is the secondary voltage, V_s

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

$$\frac{150}{250} = \frac{N_s}{1000}$$

$$250\ N_s = 150 \times 1000$$

$$N_s = 600$$

(b) A student designed a transformer to supply a current of 10 A at a potential difference of 60 V to a motor from an a.c mains supply of 240V. If the efficiency of the transformer is 80% Calculate

(i) The power supplied to the transformer

$$\frac{P_{out}}{P_{in}} \times 100 = E$$

$$P_{out} = V_s I_s$$

$$= 60 \times 10$$

$$= 600\ W$$

$$\frac{600}{P_{in}} \times 100 = E$$

$$\frac{600}{P_{in}} \times 100 = 80$$

$$P_{in} = \frac{600 \times 100}{80}$$

$$\underline{P_{in} = 750\ W}$$

(ii) the current in the primary coil

$$P_{in} = V_p I_p$$

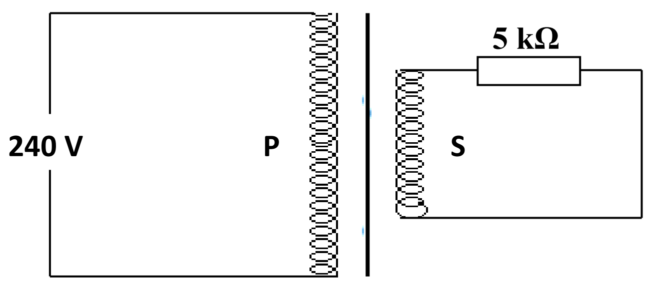
$$750W = I_p \times 240$$

$$I_p = \frac{750}{240}$$

$$\underline{I_p = 3.125A}$$

Practice Question

*The figure below shows a step – down transformer connected to a 240 V mains socket. The primary coil, **P**, has 4000 turns while the secondary coil, **S**, has 200 turns. The efficiency of the transformer is 60% and a current of 50A flows through **P**. Calculate the current through **S**.* ***(Answer: 600A)***



SOURCES OF ENERGY / POWER LOSES IN A TRANSFORMER

- *There are **four main** causes of energy / power loss in a transformer. These are:*

1. RESISTANCE OF COILS (COPPER LOSSES)

- *This is caused by high resistance of copper wire, which leads to energy loss in form of heat*

  ***Remedy:** This is minimised by use of thick copper wires*

2. FLUX LEAKAGE

- *This leads to energy loss as a result of magnetic flux produced by the primary coils failing to link up with the secondary coils*

  ***Remedy**: Flux leakage minimised by winding the secondary coils over the primary coil*

3. HYSTERESIS LOSSES

- *This is energy lost due to continuous magnetisation and demagnetisation of the core*

  ***Remedy**: Hysteresis loss is minimised by use of soft iron core which is easily magnetised and demagnetised*

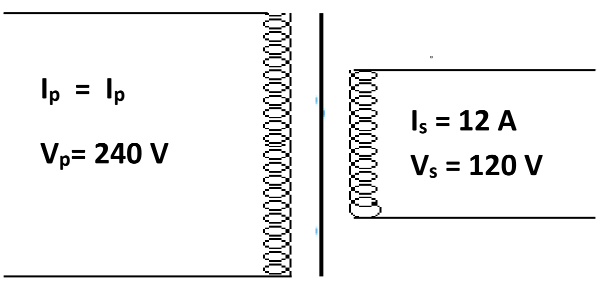
4. EDDY CURRENTS

- *Eddy currents circulating through the core produces a lot of heat*

  ***Remedy**: Eddy currents are minimised by laminating the core*

Practice Question

A transformer is used on a 240 V a.c supply to deliver 12A at 120 V to a heating coil. If 20% of energy taken from the supply is dissipated in the transformer

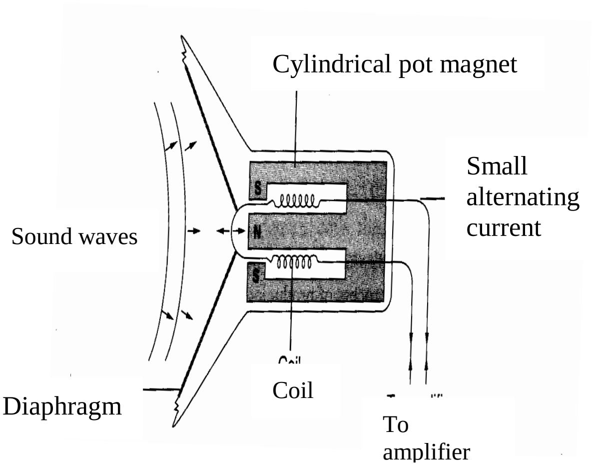


(a) *What is the current in the primary coil?* ***(Answer: 7.5A)***

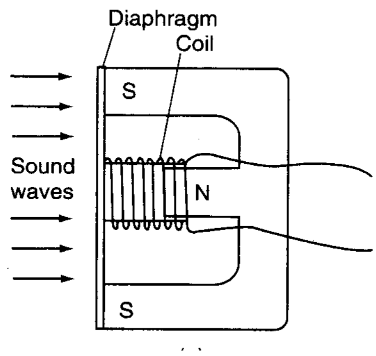
(b) *Give three causes of 20% energy dissipation in the transformation above.*

APPLICATIONS OF ELECTROMAGNETIC INDUCTION

1. MOVING COIL MICROPHONE

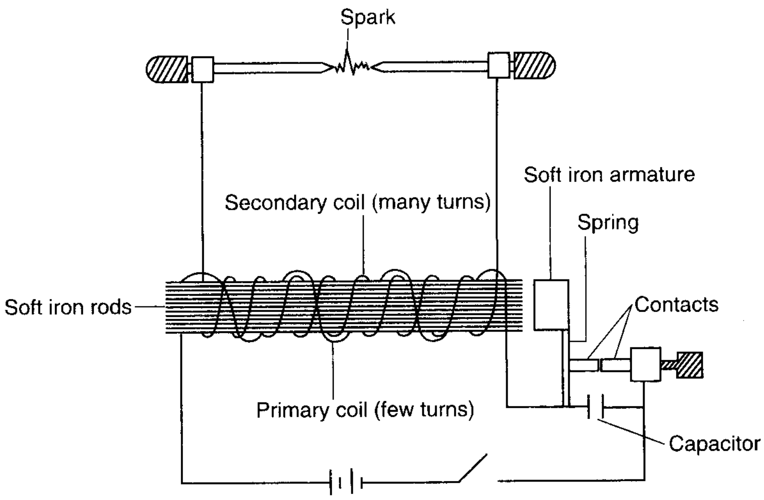


OR



- *When a person speaks on the microphone, sound waves cause the diaphragm to vibrate*
- *This causes the coil to move to and fro between the poles of the magnet.*
- *A small electric current is induced in the coils. This flows to the loudspeaker where it is converted to sound.*

2. INDUCTION COIL



- *When the switch is closed, current flows through the primary coil and the soft iron core becomes magnetized.*
- *The magnetised soft iron rods then attract the soft iron a mature.*
- *As the armature moves towards the soft iron rods, the contacts open and the primary current cut off. This rapidly reduces the magnetic field to Zero.*
- *This in turn induces a large e.m.f in the secondary coil by mutual induction. Meanwhile the spring pulls the armature back to make the contacts once again. Then the process repeats itself.*

Function of the capacitor

- The capacitor is used to Minimize the sparking between the contacts

Worked Example 75

(a) Distinguish between self induction and mutual induction.

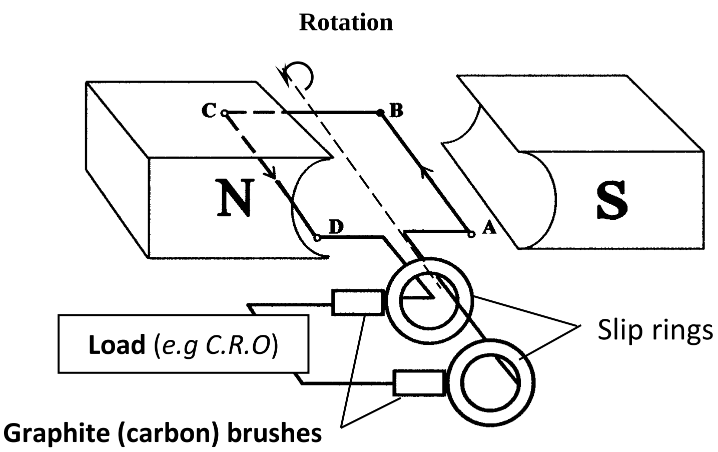
- *Self induction is where a changing magnetic field around a conductor induces current / e.m.f in the same conductor*
- *Mutual induction – where a changing magnetic field in one coil or circuit induces an e.m.f /current in another circuit or cell near it*

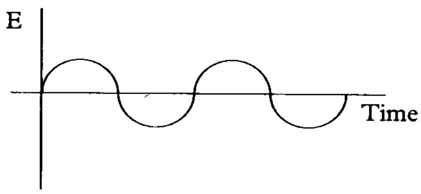
(b) State one difference between a step-up transformer and an induction coil.

- *Step up transformer uses A.C only while induction coil uses D.C*

3. **THE A.C GENERATOR**

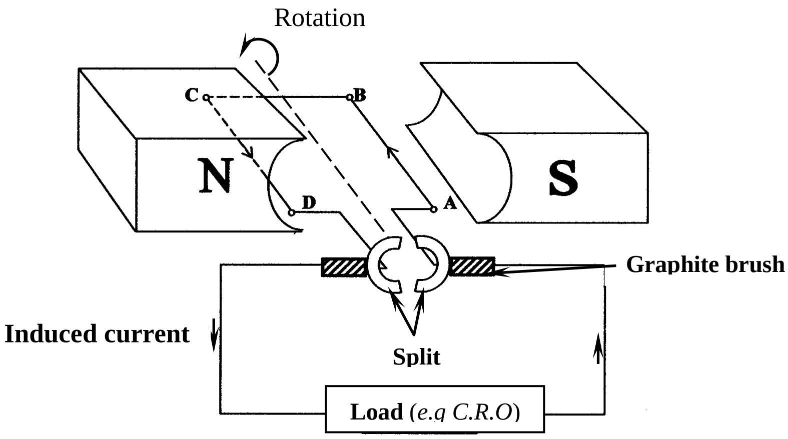
- *The coil is rotated between the poles of the magnet*

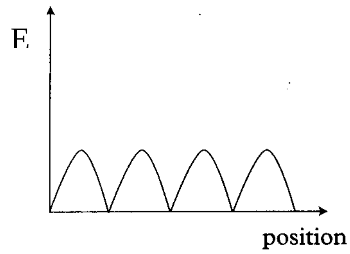




- *Starting with the coil in the horizontal position, sides **AB** and **CD** are cutting the magnetic lines of force. An E.M.F is therefore induced in the coil. Current flows from **A** to **B** and from **C** to **D**.*
- *When the coil is in the vertical position, sides **AB** and **CD** are moving **along** the magnetic lines of force. The induced E.M.F drops to zero and current stops flowing*
- *During the second quarter rotation, the coils start cutting the lines of force and induced E.M.F increases from zero to a maximum value when the coil is in a horizontal position again. Current flows from **B** to **A** and from **D** to **C**, i.e. is reversed.*
- ***The direction and magnitude of the induced e.m.f changes with time depending on the position of the coil***

4. **<u>THE D.C GENERATOR</u>**





- *The D.C. generator has the same features as an AC generator except that* ***instead of the slip ring, a split ring (known as a commutator) is used.***

- *Starting with the coil in the horizontal position, sides* ***AB*** *and* ***CD*** *are cutting the magnetic lines of force. An E.M.F is therefore induced in the coil. Current flows from* ***A*** *to* ***B*** *and from* ***C*** *to* ***D****.*

- *When the coil is in the vertical position, sides* ***AB*** *and* ***CD*** *are moving along the magnetic lines of force. The induced E.M.F drops to zero and current stops flowing*

- *During the second quarter rotation,* ***<u>the commutator exchanges contacts at the brushes</u>****. The coils start cutting the lines of force and induced E.M.F increases from zero to a maximum value when the coil is horizontal again. Current* ***in the coil*** *flows from* ***B*** *to* ***A*** *and from* ***D*** *to* ***C****, i.e. is reversed. However, because the commutator exchanges contacts at the brushes, current in the external circuit flows in the same direction*

- The commutator exchanges the brushes after every half cycle. ***This ensures that the direction of induced E.M.F does not change.***

NOTE

In both AC and DC generators, the induced current can be increased by:

1. Using stronger magnet
2. Increasing the number of turns of the coil
3. Increasing the speed of rotation of the coil
4. Winding the coil on a soft iron core so as to increase the magnetic flux through the coil

Worked Example 80

(a) **A student designed an a.c generator which produces a current of 10A at a p.d of 340V. State three ways by which he can improve his generator to increase its output.**

1. *Using stronger magnet*
2. *Increasing the number of turns of the coil*
3. *Increasing the speed of rotation of the coil*
4. *Winding the coil on a soft iron core*

(b) **What is the difference in energy transformation between a D.C motor and a D.C generator**?

- *In a D.C motor Electrical energy is converted to Mechanical energy while*
- *In a D.C generator mechanical energy is converted to electrical energy*

(c) **What is the main structural difference between the D.C. generator and the A.C. generator**?

- *In the D.C. generator a **split ring (commutator)** is used, while in an A.C. generator, a set of **slip rings** are used.*

14. MAINS ELECTRICITY

SOURCES OF MAINS ELECTRICITY

1. **HYDROELECTRIC POWER STATIONS:** *In these water falling from great heights is used to turn the turbines*
2. **GEOTHERMAL POWER STATIONS:** *These use steam from underground to turn the turbine*
3. **NUCLEAR POWER STATIONS:** *These use steam produced when water is heated by the energy given out as a result of nuclear reactions to turn the turbines*
4. **FOSSIL FUEL:** *These use steam produced when water is heated by the energy given out as a result of burning of fossil fuels e.g. diesel, coal e.t.c to turn the turbines*
5. **WIND POWER:** *These use wind energy to turn the turbines*

TRANSMISSION OF ELECTRICITY

- Electricity generated at the power stations is usually at low voltage and high current.
- Before transmission, the voltage is first stepped up to very high voltages then transmitted over a network of transmission cables ***known as the national grid system***.

***QUESTION**: What is meant by the national grid system?*

***ANSWER**: The national grid system is a network of transmission cables connecting all power stations in a country to each other and to the consumers*

Advantage of the national grid system of transmission

- This ensures that the power is available to consumers even when one of the stations fails.

- Transmission of power over long distance is usually done at ***very high voltage and low current as opposed to low voltage and high current.***

Reason: *High voltage transmission of electricity minimises power loss during the transmission*

Worked Example 81

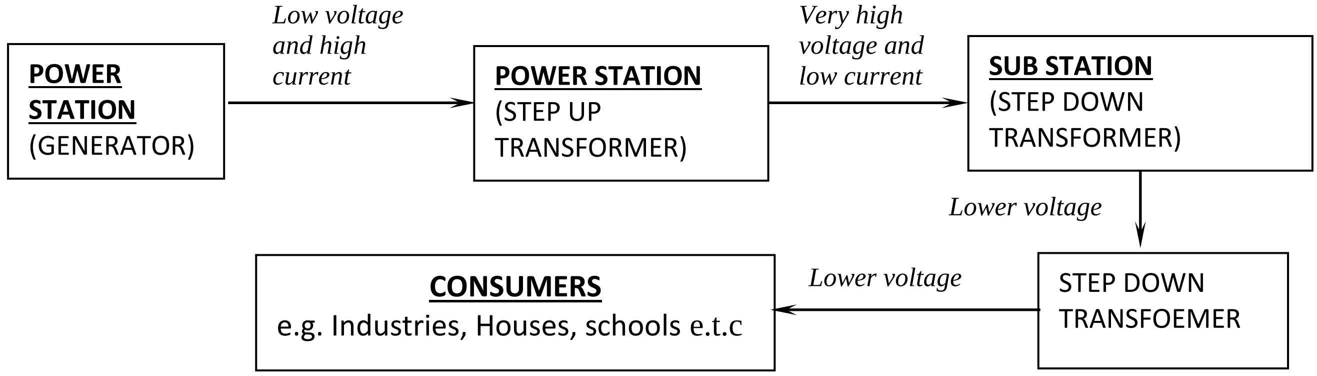
(a) What is the advantage of having a national grid in power transmission?

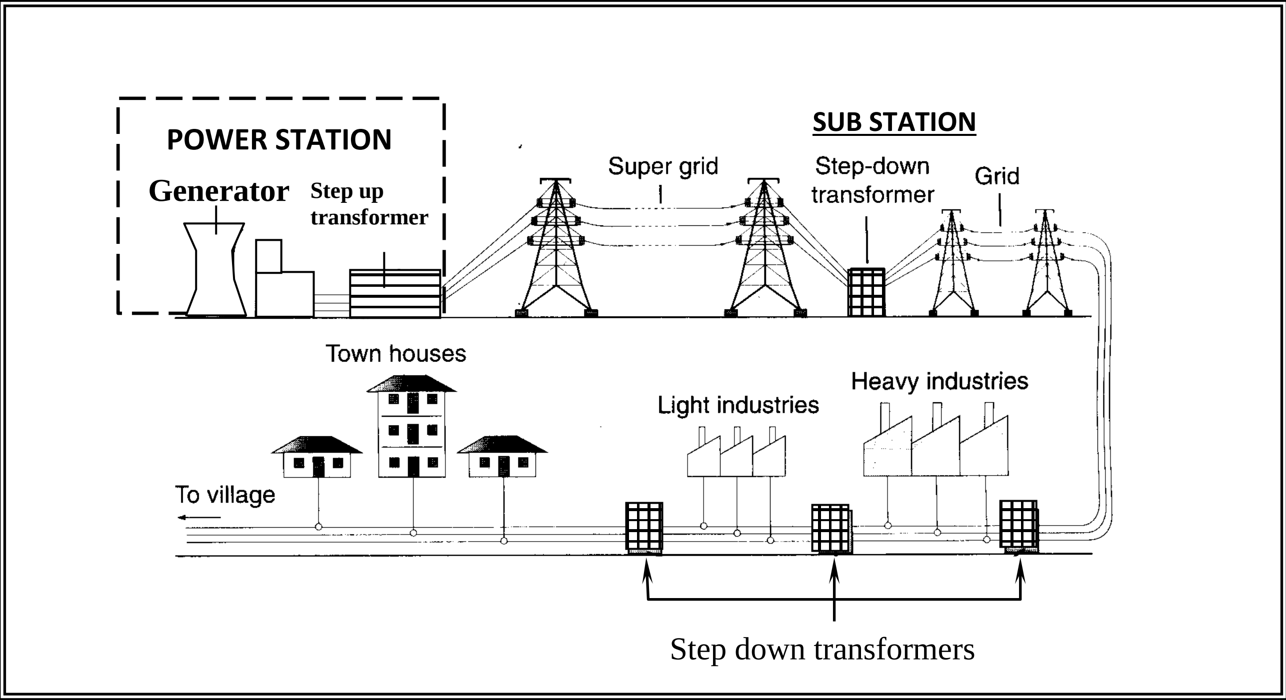
- *The national grid helps to ensure if one power station breaks down there would still be power everywhere (no black out)*

(b) Why is the electricity transmitted at very high voltage and low current?

- *Transmission of electricity at high voltage and low current ensures that there is low power / energy loss during the transmission*

SUMMARY OF STEPS INVOLVED DURING THE TRANSMISSION OF ELECTRICITY





POWER LOSS DURING TRANSMISSION

- Power loss during transmission, **P**, is given by:

$$P = I^2R$$

Where:

***P** – Power lost during transmission;* ***I** – current in the cables;* ***R**- resistance of the cables*

Worked Example 82

(a) Explain why long distance power transmission is done at a very high voltage.

- *This reduces the heating effect in the cables and reduces energy losses in the form of heat*

(b) A power line from a power substation to a town some distance away, has a resistance of 0.10 ohms per kilometre. Determine the rate of energy loss in the transmission of power over 50km at a current of 60 Amperes

*Total resistance over the 50 km distance, **R*** $= 0.1 \times 50$

$= 5\ \Omega$

Power loss $= I^2R$

$= 60^2 \times 5$

$= 3600 \times 5$

Power loss = 18000 watts

Practice Question

(a) *The resistance of a length of power transmitting cables is 10 Ω and is used to transmit 11 kV at a current of 1.0A. Determine the power loss.* ***(Answer: 10W)***

(b) *If this voltage is stepped up to 160 kV by a transformer, determine the power loss (assume the transformer is 100 % efficient)* ***(Answer: 0.048 W)***

(c) *By what factor is the power loss reduced when the power is transmitted at 16 kV as opposed to 11 kV.* ***(Answer: 208.33 times)***

DANGERS OF HIGH VOLTAGE TRANSMISSION

(i) *Risk of electric shock due to the high voltage*

(ii) *Risks of fire when the cables touch each other*

(iii) *Strong electric fields set up by high voltages are harmful to animals and human beings*

Precautions

- To minimise the dangers of high voltage transmission, the cables are supported ***high above the ground***

Practice Question

A power line from a power substation to a town some distance away, has a resistance of 0.40 Ω per kilometre. Determine current flowing through the power lines if the rate of energy loss in the transmission of power over 100 km is 100 000 watts

(Answer: 50 amperes)

Worked Example 83

During the transmission of electricity over long distances, an alternating current is passed over aluminium cables at high voltages and low current.

(a) Why is alternating current (a.c) used in preference to direct current (d.c)?

Answer

- *Alternating current can be easily stepped up and down since transformers work only on alternating current a.c. and not direct current.*
- *Direct current requires thick overhead cables which will be expensive to buy and support*

(b) Why are aluminium cables preferred to copper for long distance transmission of electricity

Answer

(i) Aluminium is lighter than copper, therefore easy to support. Use of copper wires will require very strong poles to support since copper wires are fairly heavy

(ii) Aluminium is a better conductor of electricity than copper

(iii) Aluminium does not corrode easily, unlike copper

DOMESTIC WIRING

PARTS OF DOMESTICS WIRING

1. Live wire (L): *This is usually coloured either red or brown*

The live wire is at full potential and it can give electric shock if touched

2. Neutral wire (N): *This is usually coloured either black or blue*

The neutral wire this is earthed at the local substation and it is at zero potential

3. Earth wire (E): *This is usually coloured either yellow or yellow and green*

The earth wire is usually connected to the metal casing of the appliance and it prevents risks of electric shocks in case of short circuiting.

4. Switches: ***Switches are fitted to the live wire*** *so that when the switches are off, no appliance is at full potential / voltage.*

5. **<u>Circuit breakers</u>:** *Circuit breaker is a magnetic devices that breaks the circuit through an electromagnet when a certain amount of current is exceeded*

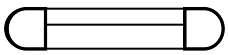
6. **<u>Bulbs</u>:** *In the lighting circuit bulbs **<u>are placed in parallel and not in series</u>***

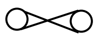
***<u>Reasons</u>*:** **(1)** *This is done so that if one of the bulbs fails, the rest will continue working*

(2) *This ensures that all the bulbs operate at the same mains voltage*

7. **<u>Fuses</u>:** *These are **<u>fitted to the live wire</u>**. They protect appliances from excess current.*

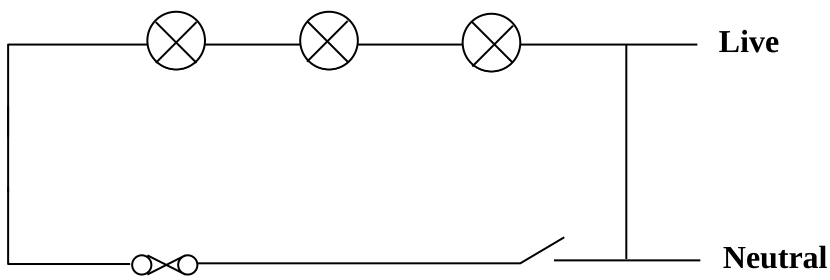
When the current flowing exceeds the required value, the fuse wire melts and breaks the circuit



Fuse Symbol: 

<u>Worked Example 84</u>

The following circuit connection was made from a.c mains.



Identify the faults in the wiring and suggest away of connecting them

(i) *The switch is connected in the neutral instead of live wire*

(ii) *The fuse is connected in the neutral wire instead of live wire*

(iii) *The bulbs are connected in series. Should be in parallel*

<u>FUSE RATING</u>

- Fuse rating means the maximum current that can flow through a fuse before the fuse wire blows off. This is usually calculated by dividing the power of the appliance with the mains voltage / operating voltage

$$\text{Fuse current} = \frac{\text{Total Power of appliances in watts}}{\text{Mains voltage}}$$

Worked Example 85

(a) Briefly explain how the fuse works and state the importance of a fuse in a circuit.

Answer

- *A fuse has a wire which melts and cuts off the current in case of an excess current.*
- *It safeguards the circuit and the appliances against being burnt off*

(b) An electric kettle is rated 3 KW 240V mains. What size of fuse should be used in the plug?

Answer :

$$P = VI$$

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

$$I = \frac{3000}{240}$$

$$I = 12.5\ A$$

A 13 A fuse is adequate

(c) State two advantages of circuit breakers over a fuse in a circuit.

- *The circuit breaker breaks the circuit instantly while a fuse takes time to melt.*
- *The circuit breaker can be reset for use again once the fault has been rectified.*

Practice Questions

1. *A room has a lighting circuit operated from the 240 V. mains. Seven bulbs rated at 150 w, 240 V are switched on at the same time. What is the most suitable fuse for this circuit?* ***(Answer 5 A)***

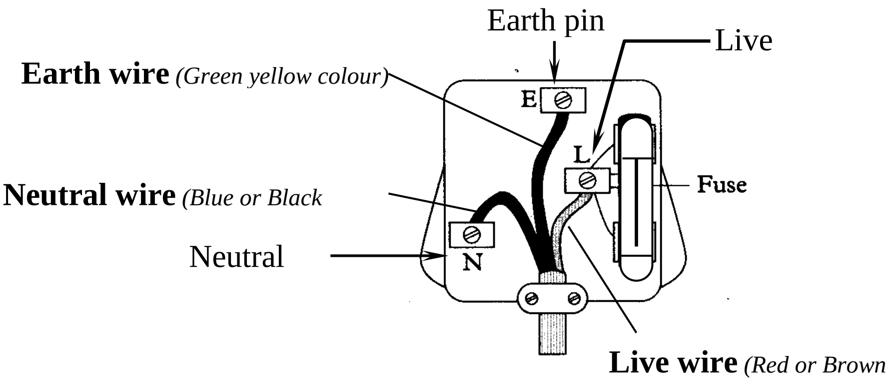
2. *A three pin mains plug is fitted to the lead for a 1kW electric iron box to be used on a 250 V AC supply. What value of the fuse can be safely used in the plug?* ***(Answer: 4A)***

3. *Select the most appropriate value of the fuse to be used from the available fuses of 5A, 10A, 13A, and 15A for an electric heater rated 240V, 3 000W when connected to a 240V mains supply.* ***(Answer: 13A fuse)***

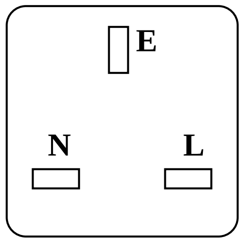
8. The three pin plug: *This has three pins (***E***arth,* **N***eutral, and* **L***ive) which fit into the socket*

The Earth pin is longer than the Live and the Neutral

Reason: The Earth pin is the first to enter and open the socket.



9. Socket : *Has three holes for* **E***arth,* **N***eutral and* **L***ive pins of the plug*



10. The lighting circuit

- *In the lighting circuit, the lamps are connected in parallel and not in series*

  Reasons: **(1)** *This ensures that if one of the bulbs fails, the rest will continue working*

  (2) *This ensures that all the bulbs operate at the same mains voltage*

- *The switches are on the live wire and not the neutral wire*

  Reason: *This is so that when the switches are off, no appliance is at full potential / voltage.*

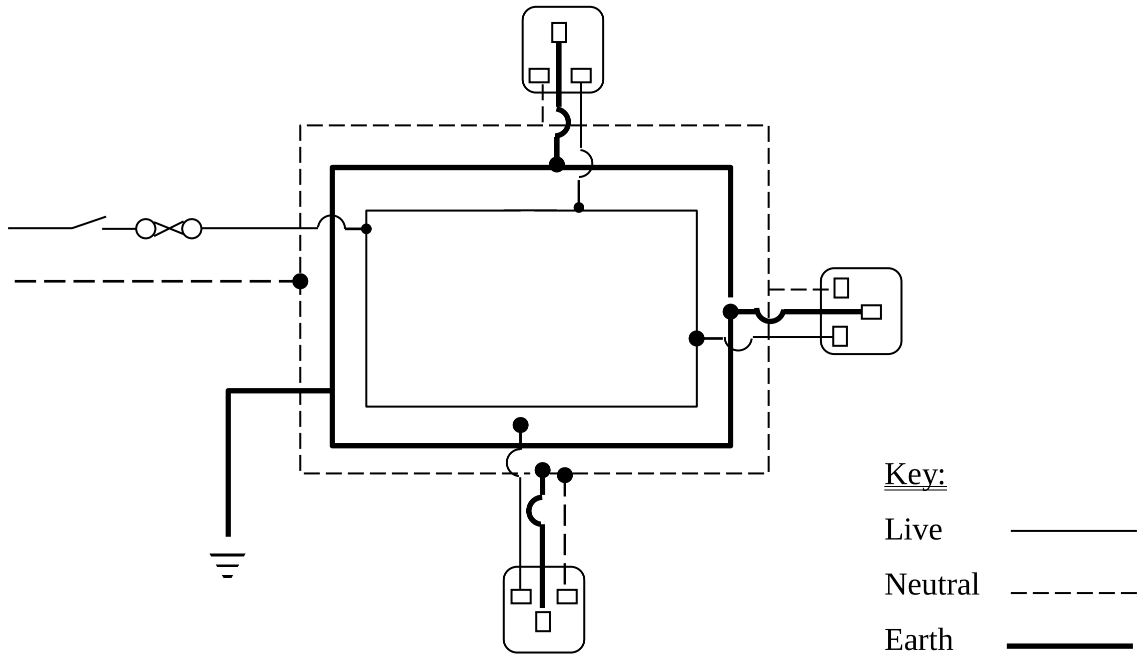
- *The lighting circuit does not require the earth connection* ***unless florescent tubes are used for lighting purposes***

- *The wires used in the lighting circuit are relatively thinner than for other circuits*

  Reason: *The lighting circuit carries smaller current*

11. *The ring mains circuit*

- *In this circuit, a cable containing three wires (**L**ive, **E**arth and **N**eutral) form a loop*
- *Power sockets in the various rooms are connected at convenient points*



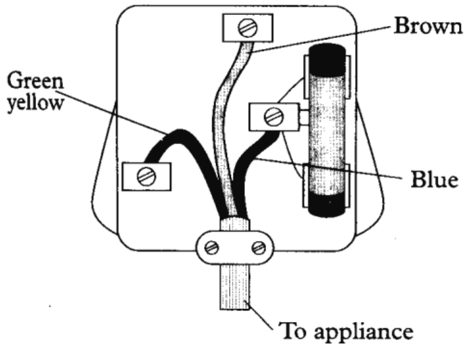
12. *The cooker circuit*

- *Cooker and water heater circuits are earthed and their wires are relatively thicker than those for lighting circuits.*

  ***Reason**: Cooker and water heater circuits carry large currents*

Worked Example 86

The figure below shows a flex to the 13 A – 3 pin plug which has been incorrectly fitted.



(a) List the mistakes and suggest corresponding remedies

- *Brown (live wire) is connected to the earth pin. **Should be connected to the fuse pin***
- *Blue (neutral) is connected to the live pin / fuse. **Should be connected to the neutral pin***
- *Green / yellow (earth) is connected to the neutral pin. **Should be connected to the earth pin***

(b) What would happen if the plug was connected to the mains socket?

- *The fuse would blow out*

(c) In a three pin plug, why is the earth pin normally longer than the other two pins?

- *The longer earth pin opens the blinder which covers the live and the neutral holes of sockets*

(d) Distinguish between a fuse and a circuit breaker

- *Fuse is a wire of low melting point which melts when a certain amount of current is exceeded*
- *A circuit breaker is a magnetic device that breaks the circuit through an electromagnet when a certain amount of current is exceeded*

COST OF ELECTRICITY

- Cost of electricity is calculated as:

Cost = number of units x cost per unit

- A unit of electricity is known as the kilowatt – hour, and is calculated as:

Number of units in kWh = Power in kW x time in hours

- 1 kilowatt hour is the energy supplied by the rate of working of 1000W for 1 hour (3 600 seconds)

1 kWh = 1 kW x 1 hr

= (1000 W x 3600) J

1 kWh = 3 6000 000 J

Worked Example 87

(a) Express 2.5 kWh in joules

Answer:

2.5 kWh = 2500 watts x 3600 seconds

= 9 000 000 joules

(b) Find the cost of using a 3 kW immersion heater and five 75 W electric bulbs for a day if the price per unit (kWh) is 80 cts

Answer

Total power consumed = 3 kW + (75 W x 5)

= 3000 + 375

= 3375 W

= 3.375 kW

1 day = 24 hrs

Power used in 1 day = 3.375 x 24

= 81 kWh

1 kWh = 80 cts

81 kWh = (81 x 80)

= 6480 cents

Cost = 64.80 shillings

Worked Example 88

Mrs Rono has an electric iron rated 2.5 kW an electric fan rated 500 W and a 1.5 kW electric stove. She bought a T.V rated 250 W and a radio cassette with 500 W speakers. Her power supply has a voltage of 240 V.

(a) Determine the current drawn from the mains if she connected all the appliances at the same time.

Total power consumed = 2500 W + 500 W + 1500W + 250W + 500W

= 5250 W

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

$$= \frac{5250}{240}$$

$$I = 21.88\ A$$

(b) Give a reason why she may not use all the appliances at the same time if her power supply has main fuse rated 15A.

- *The fuse will blow off*
- ***Reason***: *Current drawn is higher than fuse current OR power required (5250 W) is higher than power supplied*

(c) Determine:

(i) The resistance of the heating element in the electric stove

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

-

$$\text{Therefore, } R = \frac{V^2}{P}$$

$$= \frac{240 \times 240}{1500}$$

$$R = 38.4\ \Omega$$

(ii) The cost of using the electric iron and stove for 17 hours a week at the cost of sh. 2.50 per unit

Total power = 2.5 + 1.5

= 4.0 kW

No. of units = power (kW) x time (hours)

= 4 x 17

= 68 kWh

Total Cost = number of units x cost per unit

= 68 x 2.5

Total cost = 170 shillings

Practice Question

A house has five rooms, each with a 240V 60W bulb. If the bulbs are switched on from 7:00p.m to 10.30p.m, calculate the cost per week for lighting these rooms at Ksh. 6.70 per unit.

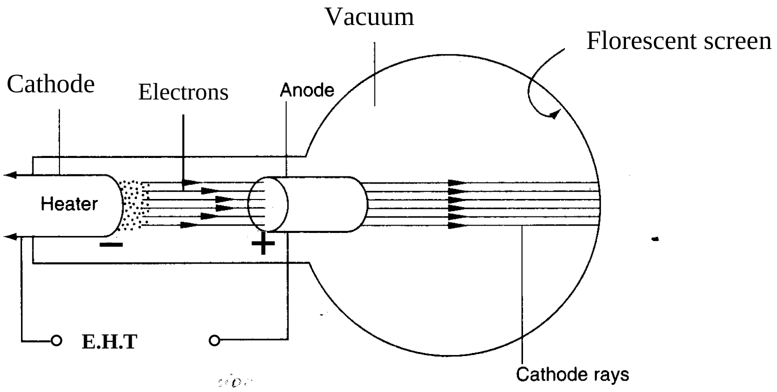
(Answer: 49.245 shillings)

15. CATHODE RAYS

Cathode Rays are fast moving electrons emitted from the cathode moving to the anode in a cathode ray tube

PRODUCTION OF CATHODE RAYS

- Cathode rays are produced in a cathode ray tube.



Cathode Rays

- *Current flows through the cathode which is then heated up and electrons are produced by the process of* ***thermionic emission****.*
- *These electrons are then accelerated towards the fluorescent screen by the anode.*
- *When the electrons hit the screen, the screen glows.*

Question: Why is the tube evacuated?

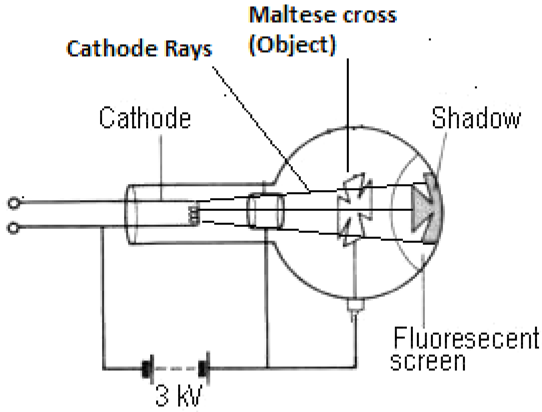
Answer: The tube is evacuated so as to prevent the electrons from losing their energy as a result of interacting with air particles before reaching the screen.

PROPERTIES OF CATHODE RAYS

1. Cathode rays travel in a straight line.

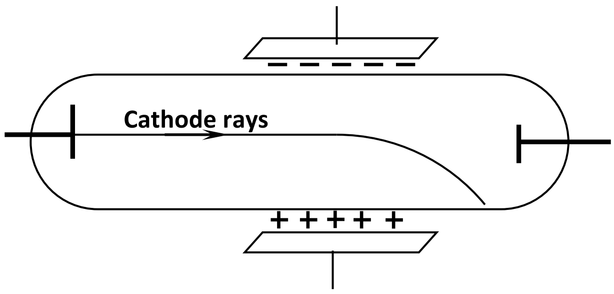
***Evidence**: Cathode rays cast shadow of any solid object placed in their path.*

***Example**:*

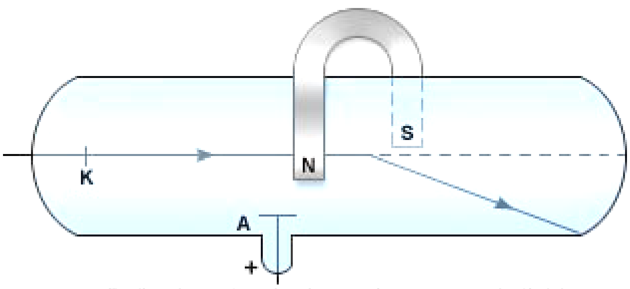


2. *Cathode rays are negatively charged therefore are deflected by both electric and magnetic fields.*

(i) *In the electric field, cathode rays are deflected **towards the positive plate***



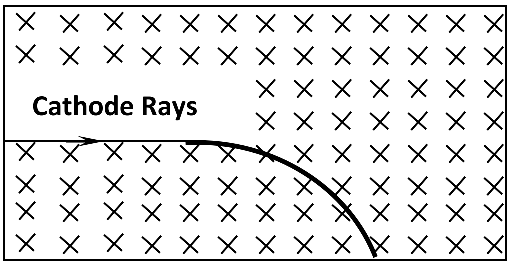
(ii) *The direction of deflection in the magnetic field can be determined using the Flemings left hand rule, but with **the second finger pointing in the opposite direction to the one the cathode rays are moving***



Deflection of cathode rays by a magnetic field

Worked Example 89

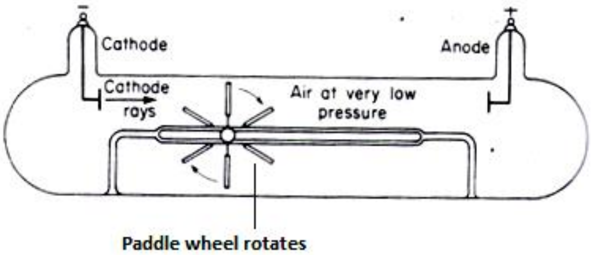
The figure below shows a stream of cathode rays entering a magnetic field. Complete the diagram to show the path of the cathode rays in the magnetic field. (NOTE: **done using the bold curve**)



Take Note:

- × – *Means the direction of the field is towards / into the paper. And If* ⊙ *is used, it would mean the direction of the field is from the paper outward*
- *The direction of the current is in the opposite direction to that of the cathode rays*

3. *Cathode rays possess kinetic energy. A paddle wheel placed on their path is therefore rotated.*



4. *When cathode rays are stopped by metallic targets, X – rays are produced*

5. *Cathode rays affect photographic papers*

6. *Cathode rays can ionise gas molecules through which they travel*

Worked Example 90

(a) Give similarities between cathode rays and light.

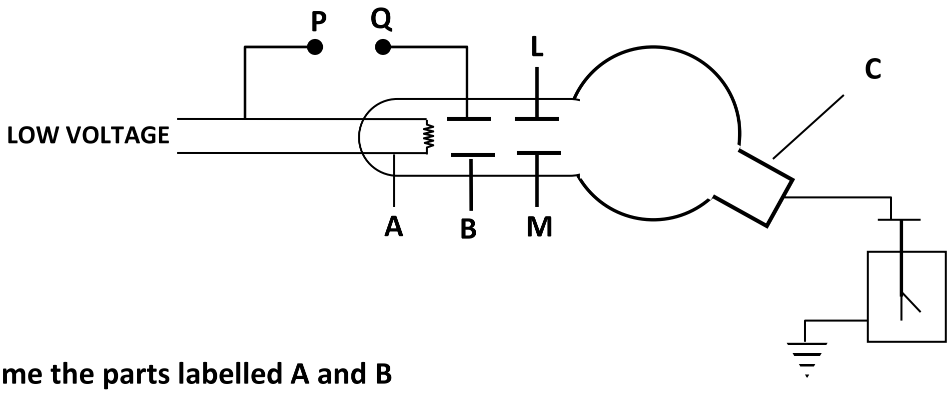
- *Both travel in a straight line*
- *Both affect photographic paper*

(b) State the differences between cathode rays and light

- *Cathode rays are charged whereas light is not*
- *Cathode ray passes kinetic energy whereas light is does not*

Worked example 91

The figure below shows a circuit of a special type of a cathode ray tube



(a) Name the parts labelled A and B

- *__A__: Cathode* *__B__: Grid*

(b) C is a metal can mounted inside the side tube and is connected externally to a negatively charged electroscope with its casing earthed. The p.d. across the metal L and M was then adjusted so that the cathode rays were deflected into the can and it was observed that the electroscope leaf rose steadily

(i) Why did the leaf rise steadily?

- *The leaf rose steadily due to the extra accumulation of negative charges. Like charges repel*

(ii) What does the result in (ii) above tell you about the charge on the cathode rays

- *Cathode rays are negatively charged*

(iii) State <u>one</u> other property of cathode rays not mentioned above.

- *They travel in straight lines*
- *They have momentum and energy*
- *They are deflected by both electric and magnetic fields*

<u>THE CATHODE RAY OSCILLOSCOPE (C.R.O)</u>

- This uses cathode rays to display waveforms on a fluorescent screen.

<u>MAIN PARTS OF THE CATHODE RAY OSCILLOSCOPE</u>

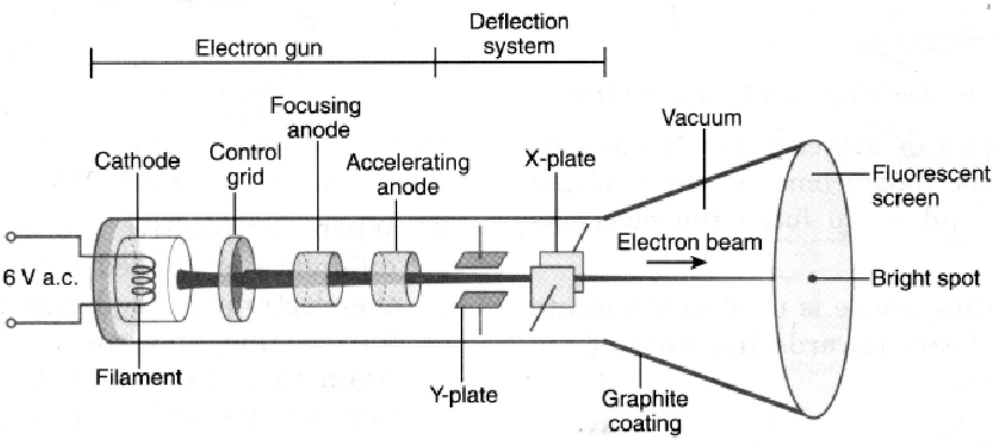
- *The cathode ray oscilloscope consists of* ***four*** *main parts. These are*:

1. The electron gun

2. The deflection system

3. A fluorescent screen

4. An evacuated strong glass envelope



1. **THE ELECTRON GUN**

- This *supplies electrons*, *accelerates them towards the screen* **and** *focuses the beam to a point on the screen*

- The electron gun consists of three main parts:

  a) **A Heated Cathode**, *which readily releases electrons when heated*

  b) **A Grid**, *which controls the rate of flow of electrons*

  c) **Cylindrical Anodes**, *which are maintained at a high positive potential relative to the cathode. These therefore attract the emitted electrons and cause them to accelerate towards the screen.*

a) The heated cathode

The cathode is made of a material which when heated, readily emits electrons. ***This process of electron emission is known as thermionic emission.***

b) The grid

- This controls the brightness (intensity) of the beam by controlling the number of electrons screen.

c) Cylindrical anodes

- These are used to accelerate and focus the electrons so that the beam converges into a fine spot on the screen.

2. **THE DEFLECTION SYSTEM**

- This is used to deflect the electron beam either vertically or horizontally.
- It consists of two plate:

  1. ***X*** *– Plates and*

  2. ***Y*** *– Plates*

(i) Y–plates:

- *The* **Y** *plates are used to deflect the electron beam in the vertical direction*

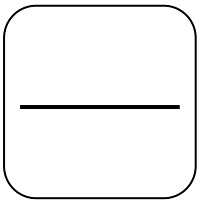
(ii) X–plates:

- *The* **X** *plates are used to deflect the electron beam in the horizontal direction*

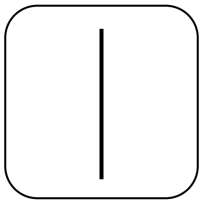
1. *When an input voltage is applied at the* **X** *– plates, the spot moves along the* **X** *– axis*

2. *When an input voltage is applied at the* **Y** *– plates, the spot moves along the Y – axis*

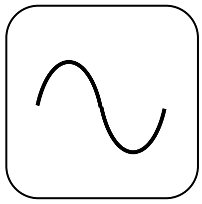
3. *Simultaneous application of the input voltage at the* **X** *– plates and the* **Y** *– plates leads to the movement of the spot on the screen in two dimensions, producing a waveform on the screen.*



X – Plate sweep only (**Time Base**)



Y – Plate a.c. signal only



X – Plate sweep and Y – plate signal combined

3. **THE FLUORESCENT SCREEN**

- The screen consists of a glass material coated with a fluorescent substance. When the accelerated electrons hit the screen, it glows

4. **THE EVACUATED STRONG GLASS ENVELOPE**

- The inside of the glass tube is coated with graphite. This graphite has three main functions:

(i) It allows the electrons to be conducted to the earth

(ii) It shields the electron beam from external magnetic fields

(iii) It accelerates the electrons towards the screen since it is at the same potential as the anode.

USES OF THE CATHODE RAY OSCILLOSCOPE

- The cathode ray oscilloscope can be used:

1. **As a voltmeter**
2. **To determine the frequency of alternating current (A.C.) signal**

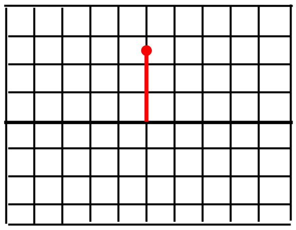
a) AS A VOLTMETER

Voltage = vertical displacement x sensitivity

Note: Sensitivity means volts per division and is sometimes known as the Y – gain

Worked Example 92

A D.C voltage of 50V when applied to the Y-plates of a C.R.O causes a deflection of the spot on the screen as shown below.



Determine the sensitivity of the Y-gain

Answer

Spot deflection on the screen = 2.5 divisions

Voltage = 50V

$$\text{Sensitivity} = \frac{\text{voltage}}{\text{Number of divisions}}$$

$$= \frac{50}{2.5}$$

Sensitivity = 20V/div

ADVANTAGES OF THE C.R.O FOR USE AS A VOLTMETER

1. *It can measure both direct and alternating current*
2. *It can measure very large voltages without getting damaged*
3. *It responds instantaneously, unlike ordinary meters whose pointers swing momentarily about the correct position*
4. *It does not take any current due to its high resistance and therefore does not interfere with the circuit.*

b) TO DETERMINE THE FREQUENCY OF AN ALTERNATING CURRENT SIGNAL

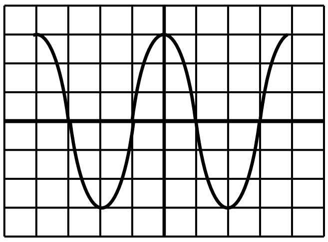
$$f = \frac{1}{T}$$

*Where **T** is time for one signal / Periodic time in seconds*

- *A signal applied on the X – plates is known as the **time base** and it displaces the electron spot along the X – axis (i.e. along the horizontal direction)*

Worked Example 93

The figure below shows the trace on the screen of an a.c. signal connected to the Y plates of a C.R.O with the time base on.



Given that the time base control is 5 ms/div. and the Y gain is at 100 V/div, determine:

a) The frequency of the a.c. signal

Answer

Time base control = *5 ms/div*

Number of divisions covered = *8*

Therefore total time = *(5 x 8)*

= *40 ms*

= $(40 \times 10^{-3} s)$ *seconds*

Total number of complete cycles = *2*

Therefore, periodic time (time for one cycle) = $\frac{40 \times 10^{-3} s}{2}$

T = 20×10^{-3} *seconds*

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

Frequency, f, = $\frac{1}{20 \times 10^{-3}}$

f = 50 Hz

b) The peak voltage of the input signal

Answer

Y-gain = 100V/div

Deflection = 3 div. from zero level

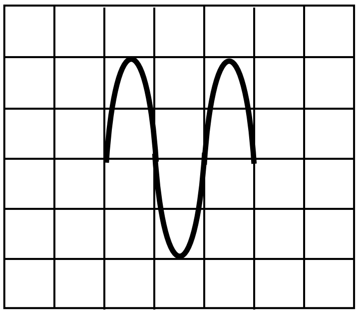
Peak voltage = Y-gain **x** *number of divisions*

= *100* **x** *3*

Peak voltage = 300volts

Practice Questions

1. *The figure below shows the trace on the screen of an A.C signal connected to the y-plates of a C.R.O with time base on. Given that the time base control is 100 ms/div and the y-gain is at 120 V/div*



(a) *Determine:*

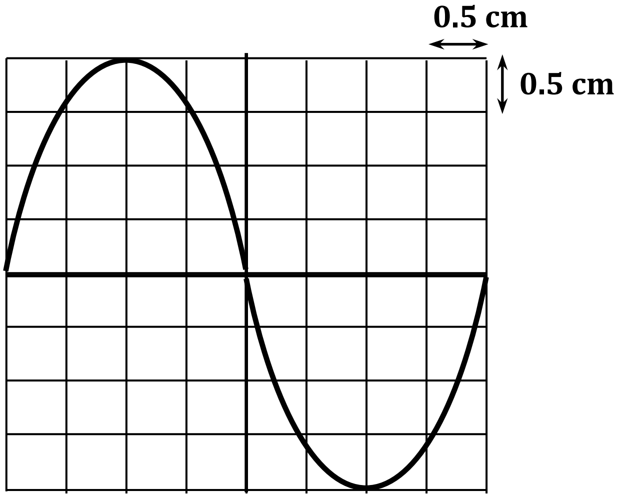
(i) The frequency of the A.C signal ***(Answer: 5Hz)***

(ii) The peak voltage of the input signal ***(Answer: 240V)***

(b) *State the purpose of the grid in the cathode ray oscilloscope*

Answer: *The grid controls the intensity of the beam and Hence the brightens of the spot on the screen*

2. *In a CRO, a waveform given below was displayed on the screen when the Y-shift of the CRO was set at 85 V/cm*



Determine:

(a) *The peak voltage* ***(Answer: 170 V)***

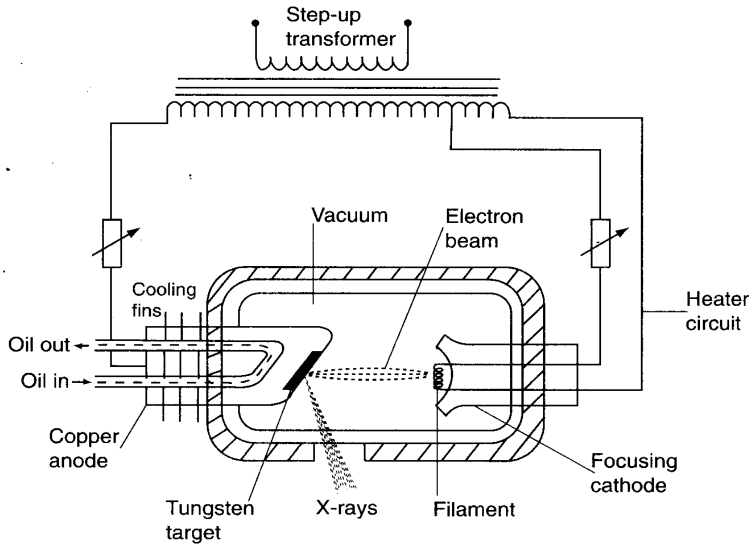
(b) *The peak to peak voltage* ***(Answer: 340 V)***

16. X – RAYS

- X – Rays are electromagnetic waves with very high frequencies and short wavelengths

- X – Rays are produced whenever fast moving electrons are stopped suddenly by metallic targets

THE X – RAY TUBE



HOW IT WORKS

- Current flows through the filament, which then becomes hot and electrons are then emitted by the process of thermionic emission.
- The emitted electrons are then accelerated towards the target (anode) by the high potential difference between the anode and the cathode.
- When the electrons hit the tungsten target, they are stopped and X – Rays are produced
- Only 0.5% of the kinetic energy of the electrons is converted to X – Rays. The rest is converted to heat.

Energy changes occurring in the X- ray tube during the production of x - rays:

Electric Energy ⟶ Heat Energy ⟶ Kinetic Energy ⟶ Heat Energy + X–Rays

IN THE X – RAY TUBE:

1. *The cathode is concave shaped so that it can focus the electrons onto the target*

2. *The anode is made of a good conductor of heat such as copper This is used to ensure that the heat generated when electron hits the target is quickly conducted away from the target*

3. *The target is made of tungsten because tungsten has a high melting point therefore can withstand the heat generated without melting*

4. *Cooling in X – Ray tube cooling is enhanced by:*
   - *(i) The cooling fins outside the tube*
   - *(ii) The oil circulating through the channels in the copper anode*
   - *(iii) The anode made of a good conductor of heat (copper)*

5. *The tube is highly evacuated so that electrons don't collide with air particles on their way to the target. The air particles can cause the electrons to lose some of their kinetic energy*

6. *The X – Ray tube is surrounded by lead shield. This is used to absorb any stray X – Rays*

PROPERTIES OF X – RAYS

1. *X – Rays are not charged therefore are not deflected by either magnetic or electric fields*
2. *X – Rays travel at the speed of light (3.0×10^8 m/s)*
3. *X – Rays can penetrate matter*
4. *X – Rays can cause florescence in certain substances e.g zinc sulphide*
5. *X – Rays can cause photoelectric emission*
6. *X – Rays can ionize air particles*
7. *X – Rays affect photographic film*

Worked Example 94

State two differences between x-rays and cathode rays

- ***X – Rays*** *are not deflected by either magnetic or electric fields since they are not charged while cathode rays are deflected by electric and magnetic fields since they are negatively charged*
- ***X – Rays*** *are highly penetrative while cathode rays are not highly penetrative*
- ***X- Rays*** *have no momentum while cathode rays have momentum*

KINETIC ENERGY OF ELECTRONS AND ENERGY OF X – RAYS

- Kinetic energy of ***electrons in an electric field*** is given by:

$$K.E = eV \quad \text{Or} \quad \frac{1}{2}mv^2 = eV$$

Where:

m *– mass of the electron in* ***kg***

e *– charge on the electron (1.6×10^{-19}C)*

v *– Velocity of the electron in* ***m/s***

V – accelerating voltage

Worked Example 95

(a) **A potential difference of 50kV is applied across an X-ray tube. Given that the charge of an electron e = 1.6×10^{-19}coulombs and the mass of an electron, m_e = 9.1×10^{-31} kg. Calculate the kinetic energy of the electrons.**

Answer:

Kinetic energy = Electron energy

$= eV$

$e = 1.6 \times 10^{-19} C$

$V = 50 \text{ kV}$

$= 50\,000 V$

Therefore, Kinetic energy $= 1.6 \times 10^{-19} \times 5 \times 10^4$

Kinetic Energy = 8×10^{-15} J

(b) **An accelerating potential of 25 kV is applied to an X-ray tube. Given that take the charge on an electron to be 1.6×10^{-19}C and the mass of an electron to be 9.0×10^{-31} kg, Calculate the velocity of these electrons**

Answer

Kinetic energy = Electron energy

$$\frac{1}{2}mv^2 = eV$$

$e = 1.6 \times 10^{-19} C$

$V = 25 \text{ kV}$

$= 25\,000 V$

$$\tfrac{1}{2} \times 9.0 \times 10^{-31} \times v^2 = 1.6 \times 10^{-19} \times 25\,000$$

$$4.5 \times 10^{-31} v^2 = 1.6 \times 10^{-19} \times 25\,000$$

$$v^2 = \frac{1.6 \times 10^{-19} \times 25\,000}{4.5 \times 10^{-31}}$$

$$v^2 = \frac{1.6 \times 10^{12} \times 25\,000}{4.5}$$

$$v^2 = 3.556 \times 10^{11} \times 25\,000$$

$$v^2 = 8.89 \times 10^{15}$$

$$v = \sqrt{(8.89 \times 10^{15})}$$

$$v = 9.43 \times 10^7 \text{ m/s}$$

Practice Question

An accelerating voltage of 100 kV is applied in an X-ray tube. Calculate the Kinetic energy of the electrons arriving at the target (e = 1.6×10^{-19} C) ***(Answer: 1.6×10^{-14} J)***

ENERGY OF X – RAYS

- The energy possessed by X – Rays of frequency f is given by:

$$E = hf \quad \text{OR} \quad E = \frac{hc}{\lambda}$$

Where
E *– Energy of the X – Rays in joules;* ***h*** *– Plank's constant in Js* ***c*** *– speed of light in m/s*
λ *– Wavelength of the X – Ray's in m* ***f*** *– frequency of the X – Rays in Hz*

Worked Example 96

1. **The energy of x-ray is 1.989 x 10^{-14} joules. Given that the speed of light is 3.0 x 10^{8}m/s and plank's constant is 6.6 x 10^{-34}Js, find the wavelength of the X-rays**

Answer

$$E = hf$$

But for an electromagnetic wave, $c = f\lambda$

Therefore, $f = \frac{c}{\lambda}$

Consequently, $E = \frac{hc}{\lambda}$

$$1.989 \times 10^{-14} = \frac{6.6 \times 10^{-34} \times 3.0 \times 10^{8}}{\lambda}$$

$$\lambda = \frac{6.6 \times 10^{-34} \times 3.0 \times 10^{8}}{1.989 \times 10^{-14}}$$

$$\lambda = 9.955 \times 10^{-12} m$$

Question 2

2. (a) **In the X-ray tube, an accelerating voltage of 100 kV is used. Calculate Kinetic energy of the electrons arriving at the target (e = 1.6 x 10^{-19} C)**

Answer

$$V = 100{,}000V \qquad e = 1.6 X10^{-19}\ C$$

$$K.E = eV$$

$$= 1.6 \times 10^{-19} \times 100\ 000$$

$$K.E = 1.6 \times 10^{-14} J$$

Continued.....

......Continuation

(b) **If 0.5 % of the electron energy in 2(a) above is converted into X – rays determine the frequency of the emitted X- rays ($h = 6.63 \times 10^{-34}$ JS, and $C = 3.0 \times 10^{8}$ ms $^{-1}$)**

Answer

$$X - Rays = 0.5\% \text{ of the kinetic energy}$$

$$= \frac{0.5}{100} \times 1.6 \times 10^{-14}$$

$$= 8.0 \times 10^{-17} J$$

$$\mathbf{E = hf}$$

$$8.0 \times 10^{-17} = 6.63 \times 10^{-34} \times f$$

$$f = \frac{8.0 \times 10^{-17}}{6.63 \times 10^{-34}}$$

$$= \left(\frac{8}{6.63}\right) \times 10^{17} Hz$$

$$\underline{\mathbf{f = 1.206 \times 10^{17} Hz}}$$

Question 3

The potential difference between the electron gun and the target of x-ray tube is 30 kV. 15% of the energy of electrons is converted to X-rays. Given that charge of an electron is 1.6×10^{-19}C; Plank's constant is 6.6×10^{-34}Js and velocity of light, $c = 3.0 \times 10^{8}$ m/s,

(a) **Calculate the frequency of X-rays produced.**

Answer

$$\mathbf{E = eV}$$

$$e = 1.6 \times 10^{-19} C$$

$$V = 30 \text{ kV}$$

$$= 30\,000 \text{ V}$$

$$\text{Therefore, } \mathbf{E} = 1.6 \times 10^{-19} \times 30\,000$$

$$= 48 \times 10^{-16}$$

$$X - Rays = 15\% \text{ of } \mathbf{E}$$

$$= \frac{15}{100} \times 48 \times 10^{-16}$$

$$\text{Energy of X-rays, } \mathbf{E} = 7.2 \times 10^{-17} J$$

$$\text{But, } \mathbf{E = hf}$$

$$7.2 \times 10^{-17} = 6.6 \times 10^{-34} \times \mathbf{f}$$

$$f = \frac{7.2 \times 10^{-17}}{6.6 \times 10^{-34}}$$

$$\underline{\mathbf{f = 1.091 \times 10^{17} Hz}}$$

continued................

.........continuation

(b) What is the wavelength of the waves produced?

Answer: $c = f\lambda$

$$3.0 \times 10^8 = 1.091 \times 10^{17} \times \lambda$$

$$\lambda = \frac{3.0 \times 10^8}{1.091 \times 10^{17}}$$

$$\underline{\lambda = 2.75 \times 10^{-9}\ m}$$

Practice Questions

1. *Calculate the maximum velocity of electrons that would produce X-rays of frequency 8.0×10^{16} Hz if only 20% of their kinetic energy is converted to X-rays.*
   (Answer: 1.21×10^7 m/s)

2. *The energy of x-ray is 1.989×10^{-14} joules. Given that the speed of light is 3.0×10^8m/s and plank's constant is 6.6×10^{-34}Js, find the wavelength of the x-rays.*
   (Answer: 9.955×10^{-12} m)

TYPES OF X – RAYS

- There are two types of X – Rays

   1. ***Hard X – Rays***
   2. ***Soft X – Rays***

(a) Hard X – Rays

- *These are X – Rays which have very short wavelengths, high frequency and high penetrating powers*

- *Hard X – Rays are produced by a high accelerating voltage which produces fast moving electrons*

(b) Soft X – Rays

- *These are X – Rays which have relatively longer wavelengths' lower frequencies and low penetrating powers*

- *Soft X – Rays are produced by low accelerating voltage which produces electrons moving at lower speed*

NOTE:

1. **The quality** (*hardness or softness*) of X – Rays ***is controlled by the potential difference between the filament and the target***. *The higher the potential difference, the harder the X – Rays produced*

2. **The intensity** (*amount*) of X – Rays produced ***is controlled by the heating current***. *The higher the heating current, the more the electrons emitted and hence the higher the intensity of the X – Rays*

USES OF X – RAYS

A. IN MEDICINE

1. *To detect fractured bones and dislocations*
2. *To locate foreign objects in the body*
3. *To detect growths inside the body*
4. *To treat cancer*

B. IN INDUSTRIES

1. To detect flaws in metal castings and welding. *Hard X-rays are used because they have high penetrating powers*
2. To sterilize surgical equipment before packing
3. In crystallography to study crystal structures
4. X – Rays are used to inspect baggage at airports for any dangerous weapons.

DANGERS OF X – RAYS

- Excessive exposure to X – Rays can lead to:
    1. Cancer
    2. Cell mutation
    3. Skin burns

Precautions

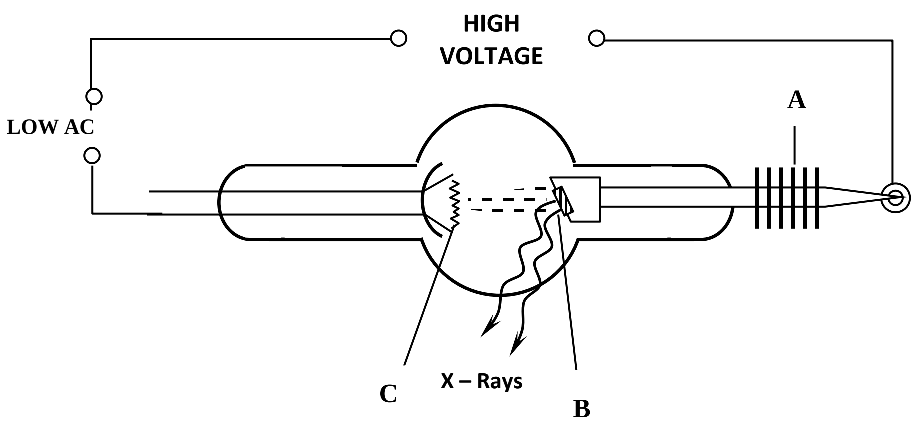
(i) Exposure to X – Rays should be limited to short time intervals

(ii) X – Rays tubes should be surrounded by lead shield to protect operators from stray X – Rays

(iii) Concrete walls should be used for rooms that store X – Ray tubes

Worked Example 97

The figure below shows an X – ray tube



(a) Name the parts labelled **A**, **B** and **C**

- **A**: *cooling fins* **B**: *Metal target* **C**: *Filament cathode*

(b) Explain how X-rays are produced in the tube

- *Electrons emitted by heated cathode are accelerated by positive anode where they hit the metal target producing X-rays*

(c) Why is it necessary to use an evacuated tube

- *To minimise the chances of electrons colliding with air molecules*

(d) What are the purposes of the high and low voltages in the tube

- *Low voltage heats up the cathode filament to emit electrons*
- *High voltage accelerates electrons towards the metal target*

(e) With a reason, state the most appropriate metal to be used to make part B

- *Tungsten or molybdenum*
- *It has a high melting point*

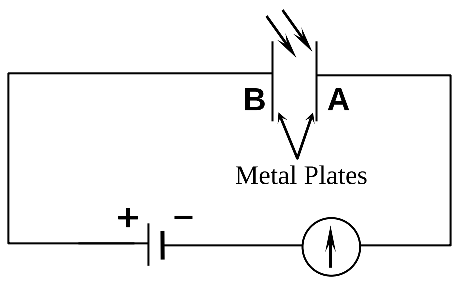
Practice Questions

1. *State* ***one*** *property of X-rays which makes it possible to detect fractured bones*
2. *The penetrating power of x-rays is normally varied depending on the intended use. Explain briefly how this is done.*
3. *X-rays are passed through the air surrounding a charged electroscope. State what is observed.*
4. *How can the intensity of X-rays in an X-ray tube be increased.*

17. PHOTOELECTRIC EFFECT

Photoelectric effect is the process of removing electrons from the surface of a metal by using electromagnetic radiation of sufficient energy.

Demonstration



- *Ultra violet radiations are directed towards plate **A** and the galvanometer observed*
- *A barrier is then placed between the source and plate **A***

Observation

- *When ultra violet radiations are allowed to fall on metal plate **A**, the galvanometer gave a deflection*
- *When a barrier is introduced so that the radiation is cut off, the galvanometer shows no deflection*

Explanation

- *When ultraviolet radiation energy falls on a metal surface, some electrons absorb this energy and are removed / dislodged from the surface.*
- *The electrons emitted at plate **A** are then attracted to plate **B**, causing a current to flow, hence causing the galvanometer to deflect.*

Worked Example 98

Distinguish between photoelectric and thermionic emission of electrons

Answer

- *Thermionic emission is a process by which the surface of a metal emits electrons when it is heated*
- *Photo electric effect is the emission of photo electrons when light of suitable wavelength falls on the surface of a metal*

THRESHOLD FREQUENCY (f_o)

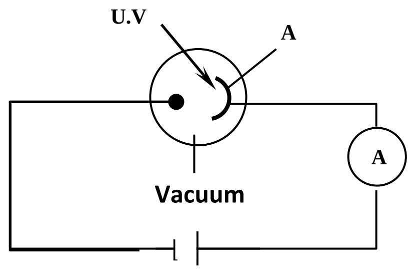
Threshold frequency (f_o) is the minimum frequency of the radiation that would cause emission of electron from a metal surface

NOTE: *(i) If the frequency of the radiation falling on a metal surface is lower than the threshold frequency, electrons will **not** be emitted from the metal surface.*

(ii) The wavelength corresponding to the threshold frequency is known as the threshold wavelength (λ_o)

Worked Example 99

The Figure below shows a set up used to demonstrate photoelectric effect using a photo cell



(a) Explain why current flows when U.V light is shone on the part labelled A

- *The electrons on the surface of the cathode absorb the U.V light and are dislodges from the metal surface. The emitted electrons are then attracted to the Anode, causing a flow of current*

(b) Explain why U.V and not infra red radiation is used

- *Infra-red has lower frequency (longer wavelength) than U.V- radiation*

(c) Give one reason why the photocell is evacuated

- *To minimize the chance of emitted electrons colliding with air which will reduce their kinetic energy*

WORK FUNCTION (W_o)

This is the minimum energy needed to completely remove an electron from the surface of a metal

- Work function is measured in electron volts (eV)
- **1 eV = 1.6 x 10^{-19} joules**
- Work function is calculated as

$$W_o = hf_o$$

W– *Work function* ***f***

f_o – *threshold frequency* ***h*** – *Planks constant*

NOTE: *If the energy of the radiation falling on a metal surface* <u>*is lower than the work function of the metal , electrons will **not** be emitted from the metal surface*</u>*.*

Worked Example 100

(a) **An electron is ejected from the surface of a metal with a kinetic energy of 2.24 x 10^{-19}J. What is the energy of the electron in electron volts?**

Answer:

$$\text{K.E. of the electron} = 2.24 \times 10^{-19} J$$

$$\text{But, } 1.6 \times 10^{-19} J = 1 \text{ eV}$$

$$\text{Therefore, } 2.24 \times 10^{-19} J = \frac{(2.24 \times 10^{-19})}{1.6 \times 10^{-19}} \text{ eV}$$

$$= \underline{\mathbf{1.4 \text{ eV}}}$$

(b) **Light of frequency 5.7 x 10^{14} Hz is irradiated on a surface of a metal whose work function is 2.6 eV. Explain whether photoelectric emission will take place or not.**

Answer:

$$W_o = hf_o$$

$$\text{Therefore, } f_o = \frac{W_o}{h}$$

$$= \frac{2.6 \times 1.6 \times 10^{-19}}{6.63 \times 10^{-34}}$$

$$\underline{\mathbf{f_o = 6.3 \times 10^{14} Hz}}$$

CONCLUSION: *Photoelectric emission will **not** take place because the frequency of the light used **(5.7 x 10^{14} Hz)** is lower than the threshold frequency **(6.3 x 10^{14}Hz)**.*

Practice Question

*The work function of caesium is 1.93 eV. Given that **1eV** = 1.6 x 10^{-19}J, **c** = 3.0 x 10^{8} m/s and Planks constant **h** = 6.63 x 10 ^{34}Js, determine:*

(i) *The threshold frequency of caesium* ***(Answer: f_o = 4.66 x 10^{14}Hz)***

(ii) *The threshold wavelength of caesium* ***(Answer: λ_o = 6.44 x 10^{-7}m)***

EINSTEIN'S PHOTOELECTRIC EQUATION

- When a photon strikes an electron, the energy of the photon (***hf***) will be used in two ways:

  (a) *Some of the energy will be used to remove the electron from the metal surface* (W_o)

  (b) *The rest of the energy will provide the ejected electron with kinetic energy,* ($\frac{1}{2} mv^2_{max}$) That is:

Energy of a photon = energy needed to remove an electron from metal surface + maximum kinetic energy gained by the electron

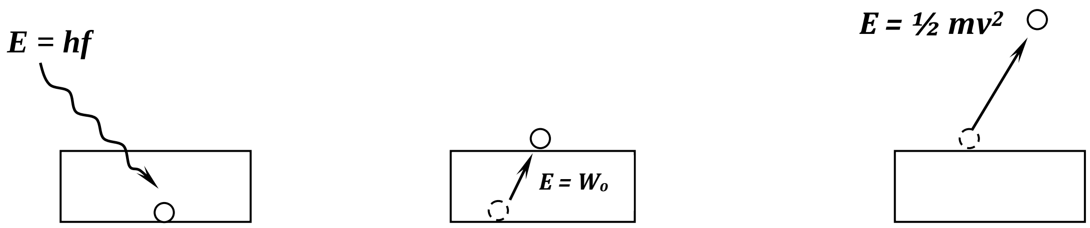
$$hf = W_o + \tfrac{1}{2} mv^2_{max}$$

OR

$$hf = hf_o + \tfrac{1}{2} mv^2_{max}$$

h *– Planks constant* f_o *– threshold frequency* ***m*** *– mass of an electron* W_o *– work function*

f *– frequency of the incident radiation* v_{max} *– maximum velocity of the emitted electrons*



Photon with energy = ***hf***, falls on the surface of a metal

Electron absorbs part of that energy and moves to the surface. This energy is the work function of the metal W_o

The "excess" energy gives the electron enough kinetic energy to move away from the metal surface

NOTE: A photon is a discrete packet of light energy

- *The kinetic energy (hence the velocity) of the electron emitted depends on three factors:*

  1. The Work Function of the Metal, W_o

  - *The bigger the work function, the lower the velocity of the electrons emitted*

  2. Frequency of the Incident Radiation, ***f***

  - *The higher the frequency of the Incident radiation, the higher the kinetic energy (hence velocity) of the emitted electrons*

  3. The potential difference between the anode and the cathode (applied voltage), V

  - *The higher the potential difference, the higher the kinetic energy / velocity of emitted electrons*

Worked Example 101

Light of wavelength 2.0 x 10^{-7}m is incident on a metal surface of work function 4.0 eV. Find the velocity of the photoelectrons emitted.

(Take: c = 3.0 x 10^{8} m/s, h = 6.6 x 10^{-34}Js, mass of electron m_e = 9.1 x 10^{-31}kg)

Answer:

$$c = f\lambda$$

$$3.0 \times 10^{8} = f \times 2.0 \times 10^{-7}$$

$$f = \frac{3.0 \times 10^{8}}{2.0 \times 10^{-7}}$$

$$\text{Therefore, frequency, } f = \mathbf{1.5 \times 10^{15} Hz}$$

$$1 \text{ eV} = 1.6 \times 10^{-19} J$$

$$4.0 \text{ eV} = 4 \times 1.6 \times 10^{-19}$$

$$\text{Therefore, } W_o = \mathbf{6.4 \times 10^{-19} J}$$

$$\text{But, } hf = W_o + \tfrac{1}{2} mv^2_{max}$$

$$6.6 \times 10^{-34} \times 1.5 \times 10^{15} = 6.4 \times 10^{-19} + \tfrac{1}{2} mv^2$$

$$9.9 \times 10^{-19} = 6.4 \times 10^{-19} + \tfrac{1}{2} \times 9.1 \times 10^{-31} \times v^2$$

$$(9.9 - 6.4) \times 10^{-19} = 4.05 \times 10^{-31} \times v^2$$

$$3.5 \times 10^{-19} = 4.05 \times 10^{-31} \times v^2$$

$$v^2 = \frac{3.5 \times 10^{-19}}{4.05 \times 10^{-31}}$$

$$v^2 = 0.8642 \times 10^{12}$$

$$v = \sqrt{(8.642 \times 10^{11})}$$

$$\underline{v_{max} = 9.296 \times 10^{5} \text{ m/s}}$$

Practice Question

A metal has a work function of 2.0 eV. Calculate:

a) *The threshold frequency e = 1.6 x 10^{-19}C and h = 6.6 x 10^{-34}Js*

(Answer: 4.85 x 10^{14} Hz)

b) *The threshold wavelength of the metal given that (c = 3.0 x 10^{8} m/s)*

(Answer: 6.1875 x 10^{-7}m)

c) *The maximum velocity of the emitted electron if light of frequency 9.0 x 10^{15} Hz falls on the metal (mass of electron m_e = 9.1 x 10^{-31} kg)* ***(Answer: 3.51 x 10^{6} m/s)***

Worked Example 102

The threshold wavelength of a metal surface is 0.45µm. Calculate:

a) The threshold frequency

Answer:

$$c = f_o \lambda_o$$

$$\lambda_o = 0.45\mu m$$

$$= 0.45 \times 10^{-6}$$

$$3.0 \times 10^8 = f_o \times 0.45 \times 10^{-6}$$

$$f_o = \left(\frac{3.0 \times 10^8}{0.45 \times 10^{-6}}\right)$$

$$\underline{f_o = 6.67 \times 10^{14}\ Hz}$$

b) The work function in electron volts

Answer:

$$W_o = hf_o$$

$$= (6.63 \times 10^{-34} \times 6.67 \times 10^{14})$$

$$= 4.42 \times 10^{-19}\ J$$

But, $1.6 \times 10^{-19} J = 1\ eV$

Therefore, $4.42 \times 10^{-19} = \left(\frac{4.42 \times 10^{-19}}{1.6 \times 10^{-19}}\right)\ eV$

$$\underline{W_o = 2.76\ eV}$$

c) The maximum velocity with which a photoelectron is emitted if the frequency of the radiation falling on the surface is 7.5 x 10^{14}**Hz**
(Take: Planks constant h = 6.63 x 10^{-34}**Js; m**$_e$ **= 9.11 x 10**$^{-31}$**kg; c = 3.0 x 10**^{8} **m/s)**

Answer:

$$hf = W_o + \tfrac{1}{2} mv^2_{max}$$

$$\tfrac{1}{2} mv^2_{max} = hf - W_o$$

$$\tfrac{1}{2} mv^2_{max} = [hf - W_o]$$

$$= [(6.63 \times 10^{-34} \times 7.5 \times 10^{14}) - 4.42 \times 10^{-19}]$$

$$\tfrac{1}{2} mv^2 = (4.97 \times 10^{-19} - 4.42 \times 10^{-19})$$

$$\tfrac{1}{2} mv^2_{max} = 5.53 \times 10^{-20}$$

Therefore, $v^2_{max} = \frac{2 \times 5.53 \times 10^{-20}}{m}$

$$v_{max} = \sqrt{\frac{2 \times 5.53 \times 10^{-20}}{9.11 \times 10^{-31}}}$$

$$\underline{v_{max} = 3.48 \times 10^5\ m/s}$$

Practice Question

Electrons emitted from a metal when light of a certain frequency is shone on the metal are found to have a maximum kinetic energy of 8.0 x 10^{-19} J. If the work function of the metal is 2.0 eV, determine the wavelength of the light used.
(c = 3.0 x 10^{8} m/s; e = 1.6 x 10^{-19}C, h = 6.6 3x 10^{-34}) ***(Answer: 1.776 x 10^{-7}m)***

FACTORS AFFECTING PHOTOELECTRIC EFFECT

- There are ***three main*** factors which affect photoelectric emissions. These are:

  1. The intensity (brightness) of the radiation used

  2. The frequency of the radiation used, ***f***

  3. Work function of the metal used , $\mathbf{W_o}$

(a) THE INTENSITY (BRIGHTNESS) OF THE RADIATION USED

- *The higher the intensity of the radiation used the higher number of electrons emitted and hence the current produced.*

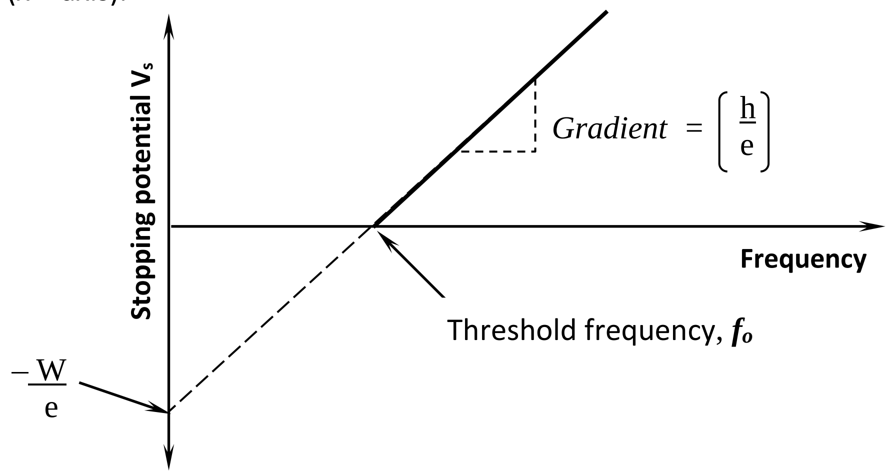
Reason: *When radiation of high intensity is used, more electrons are ejected, leading to increased current.*

(b) THE FREQUENCY OF THE RADIATION USED

- *The frequency of the radiation used affects the maximum kinetic energy of the electrons emitted but does not affect the number of the electrons emitted.*

- *Radiations of high frequency emit electrons with higher kinetic energy while radiations of low frequency emit electrons with low kinetic energy*

- A graph of stopping potential $\mathbf{V_s}$, against frequency ***f***, is a straight line cutting through the frequency axis (x – axis).



- For this graph:

  (i) *The point at which the line cuts the frequency axis (x – axis) is the threshold frequency* f_o.

  (ii) *The slope of the graph represents the quantity* $\frac{h}{e}$

  (iii) *The point at which the line cuts the y – axis represents the quantity* $\frac{-W_o}{e}$

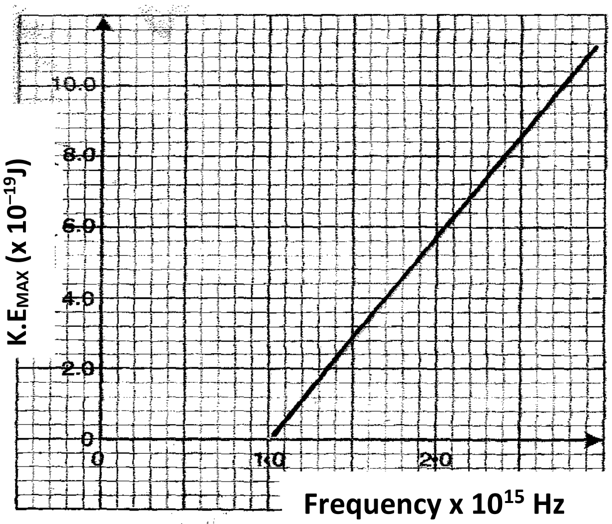
- ***N/B:*** If the graph plotted is of Kinetic Energy of electrons against frequency, ***f***, then *the* ***gradient of the graph will represents planks constant h****, while the* ***Y - intercept value will represent the work function***

Worked Example

(a) Give a condition necessary for electrons to be emitted from the cathode of a photocell

- *The energy of the incident radiation should be equal to or greater than the work function of the cathode*

(b) The graph below shows how the maximum kinetic energy varies with the frequency, f. Use the graph to determine Planck's constant, h



From K.E = hf - w$_o$

Planck's constant = Gradient of the graph

$$h = \frac{(8.2-0)x10^{-19}}{(2.5-1.0)x10^{15}}$$

$$h = \frac{8.2}{1.5}x10^{-34}\ JS$$

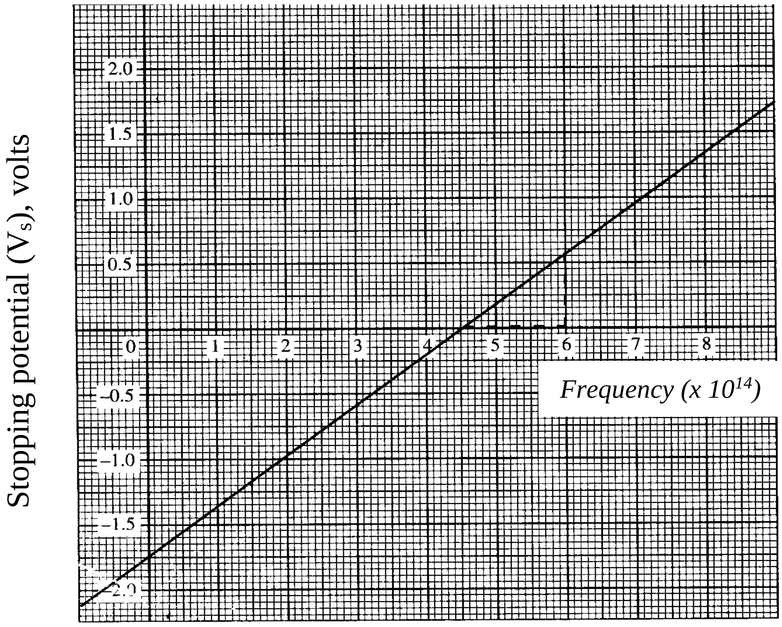
$$h = 5.5x10^{-34}\ JS$$

(c) *W*ORK FUNCTION OF THE METAL USED

- *Different metals have different values of threshold frequency values, below which no photoemission takes place, no matter how intense the radiation is.*

Worked Example 103

The below shows a plot of the stopping potential against frequency for metal Q



Given that the charge on the electron e = 1.6 x 10^{-19}, use the graph to determine:

(a) The threshold frequency of the metal

Answer: *Threshold frequency* f_o = *the frequency reading at the x – intercept*

$$f_o = 4.5 \times 10^{14} Hz$$

(b) the plank constant

Answer: *Gradient* $= \dfrac{\Delta V_s}{\Delta f}$

$$= \frac{(0.6 - 0)}{(6.0 - 4.5) \times 10^{14}}$$

$$= 4.0 \times 10^{-15}$$

But $\dfrac{h}{e}$ = *gradient*

Therefore, **h = gradient x e**

$$= 4.0 \times 10^{-15} \times 1.6 \times 10^{-19}$$

$$h = 6.4 \times 10^{-34} Js$$

(c) Work function of the metal:

Answer: $W_o = hf_o$

$$= 6.4 \times 10^{-34} \times 4.5 \times 10^{14}$$

Work function W_o in joules = 2.88 x 10^{-19}J

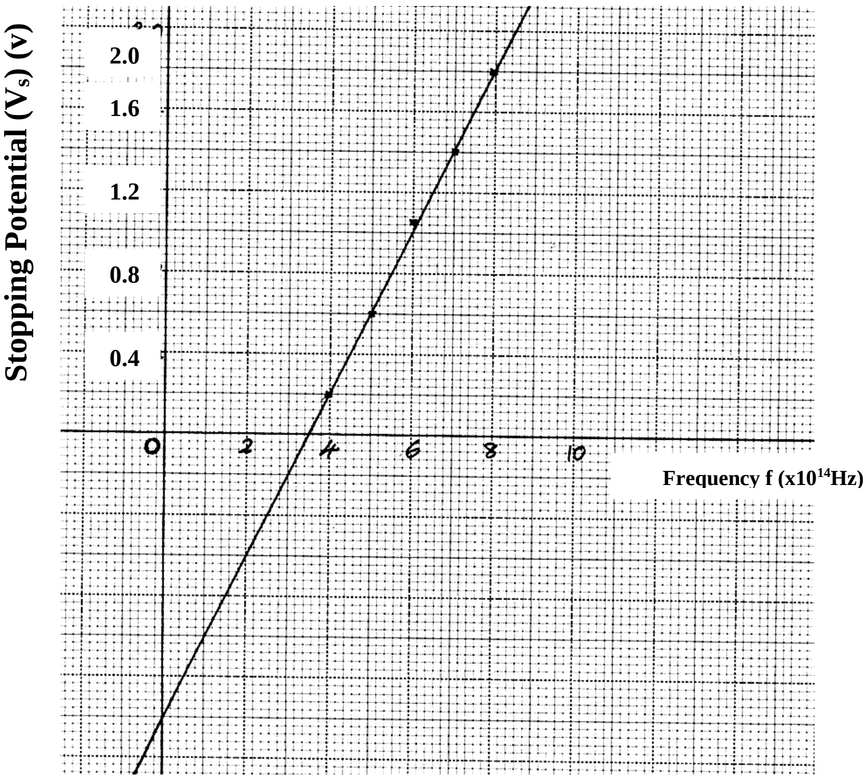
But $1.6 \times 10^{-19} J = 1 eV$

Therefore, $2.88 \times 10^{-19} J = \dfrac{2.88 \times 10^{-19} J}{1.6 \times 10^{-19} J}$

Work function W_o in eV = 1.8 eV

Practice Question

A light was radiated onto a metal surface and the results obtained were used to plot a graph of stopping potential (Vs) against the frequency (f) of radiation. Shown below



From the graph determine:

(a) *The threshold frequency* **(Answer: 3.6×10^{14} Hz)**

(b) *The threshold wavelength. ($c = 3.0 \times 10^{8}$ m/s)* **(Answer: 8.33×10^{-7} m)**

(c) *Planck's constant (h) ($e = 1.6 \times 10^{-19}$)* **(Answer: 6.4×10^{-34} Js)**

(1) *In an experiment to observe photo-electric emission from a clean caesium surface the following readings were obtained*

Stopping potential (V)	0.6	1.0	1.4	1.8	2.2
Frequency ($\times 10^{14}$) Hz	6	7	8	9	10

(a) *Plot a graph of stopping potential Vs (y-axis) against frequency.*

(b) *From the graph determine*

(i) *The threshold frequency of the surface* **(Answer: 4.5×10^{14}Hz)**

(ii) *The threshold wavelength of the surface. Take $c = 3.0 \times 10^{8}$ m/s*

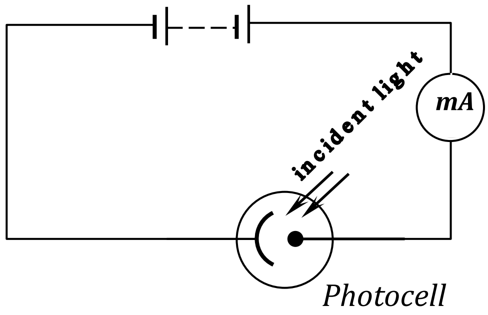
(Answer: 6.667×10^{-7} m)

(iii) *Planks constant* **(Answer: 6.56×10^{-34} Js)**

(iv) *The work function of the surface* **(Answer: 2.952×10^{-19}J OR 1.845 eV)**

Worked Example 104

The diagram below shows a circuit for a photocell



(a) **Explain why the milliameter shows a reading when light is shone on the photocell as in the diagram**

- *When light falls on the negative plate, electrons are emitted. The electrons are attracted by the positive plate hence current flows causing the milliameter to deflect*

(b) **What will be the effect of increasing the light intensity on the milliameter reading?**

- *More electrons will be emitted, causing the current to increase and the milliameter reading increases*

(c) **State two factors which determine the speed of the photo electrons emitted by the metal surface C**

- *Frequency of the ultra violet rays*
- *Work function of the metal*

(d) **When the experiment was carried out using violet light, the milliameter gave a reading, but when the experiment was repeated using red light, the milliameter gave no deflection. Explain this observation.**

- *Ultra violet light has high frequency (higher than the threshold frequency of the metal) therefore enough energy to dislodge the electrons from the metal. Red light on the other hand has lower frequency and therefore does not have enough energy to remove the electrons from the metal, hence no current flows in the circuit*

APPLICATIONS OF PHOTOELECTRIC EFFECT

- Photoelectric effect is applied mainly in photocells.
- ***A photocell is a device which converts electromagnetic radiation directly to electrical energy.***
- There are ***three*** main types of photocells. These are:

1. *Photoemissive cells*
2. *Photovoltaic cells*
3. *Photoconductive cells (also known as light dependent resistors)*

18. ELECTRONICS

1. SEMICONDUCTORS

Semiconductors are materials whose electrical conductivity is midway between metals and non metals.

- *The electrical conductivity of semi conductors increases as the temperature of the semiconductor increases, while the electrical conductivity of good conductors (e.g. metals)decreases as the temperature of the metal increases*

- Semi conductors are classified into two categories:
  - i) **Intrinsic semi conductors** (*These are pure semi conductors*)
  - ii) **Extrinsic semi conductors** (*These are impure semiconductors*)

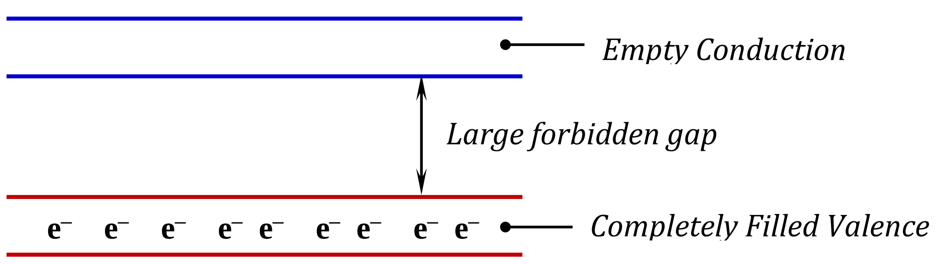
NOTE: Extrinsic (impure) semiconductors are made by a process known as doping

THE ENERGY BAND THEORY

- This theory assumes that when two or more atoms are brought closer to each other, the energy levels split into smaller energy levels known as ***bands***
- There are ***two*** important types of bands in electronics. These are:
  - a) **Valence band**: This contains the valence electrons
  - b) **Conduction band**: This contains conduction electrons
- A gap exists between these two bands. This gap is known as ***forbidden energy gap*** or simply, the ***forbidden gap***

1. INSULATORS

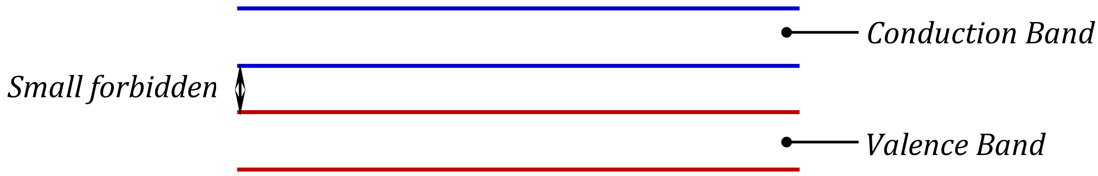
- **These are materials which are generally poor conductors of electricity and heat**
- Insulators have a very large forbidden gap between an empty conduction band and a completely filled valence band



2. SEMICONDUCTORS

- **These are materials whose electrical conductivity is midway between metals (conductors) and insulators**

- In semiconductors, the forbidden energy gap is small compared to that of insulators such that electrons can easily jump from the valence band to the conduction band.



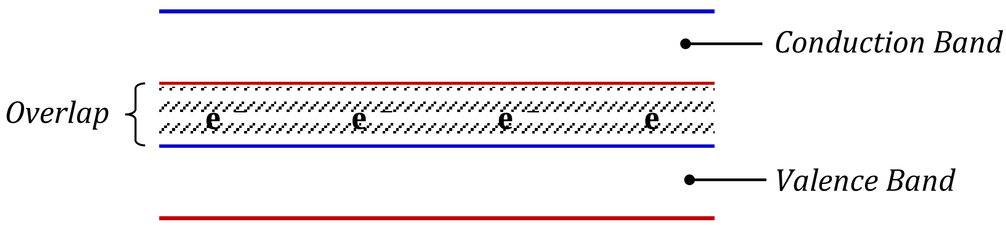
NOTE: *Electrical conductivity of semiconductors increases as temperature increases (resistance decreases as temperature increases)*

Reason: *When the temperature of a semiconductor is increased, more electrons in the valence band gain enough energy to enable them jump over the forbidden gap into the conduction band*

3. CONDUCTORS

- **These are materials which conduct electricity and heat at all times**

- In conductors, the valence band and the conduction band overlapp such that electrons move freely from partially filled valence band to the conduction band



NOTE: *Electrical conductivity of conductors decreases as temperature increases (resistance increases as temperature increases)*

Reason: *When the temperature of a conductor is increased, the vibration of its atoms increases and this interferes with the flow of electrons*

2. DOPING

> **Doping is the process of introducing an "impurity" to a pure semi conductor so as to improve its electrical conductivity.**

- Doping of pure semi conductors can result into two types of semi conductors, namely:
  - a) **N – type semiconductor** and
  - **b) P – type semi conductor**

a) The N – type semiconductor

N – Type semiconductor is one in which majority charge carries are electrons

- *An N – type semiconductor is produced when an intrinsic (pure) semiconductor is doped with a pentavalent atom such as Antimony, Phosphorous* Or *Arsenic*

b) P – Type semiconductor

P – Type semiconductor is one in which the majority charge carriers are holes

- *A P – type semiconductor is produced when an intrinsic (pure) semiconductor is doped with a trivalent (group 3) atom such as* ***Boron*** *,* ***Gallium*** or ***Indium***

Worked Example 105

(a) State two differences between conductors and semi conductors in terms of their electrical conductivities

Answer

- *In conductors conduction is by electrons only while in semi conductors, conduction is by holes and electrons*
- *Electrical conductivity of metals decreases as temperature increases while the electrical conductivity of semi-conductors increases as temperature increases*

(b) Explain how you can obtain an N-type extrinsic semi – conductor

Answer

- *By doping pure semi conductor (group 4 elements) by pentavalent (group five) elements*

Practice Question

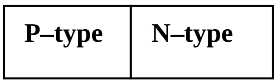
(a) *Define the term doping*

(b) *Explain briefly how a P-type semiconductor may be made from a pure semiconductor material*

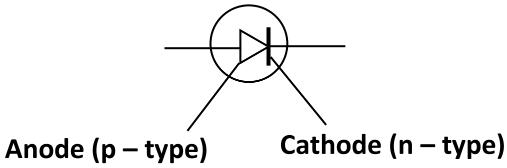
P – N JUNCTION DIODE

- P–N junction diodes are formed when a P– type semiconductor and an N– type semiconductor of the same material are joined together

Example



symbol



- A P–N junction diode *conducts electricity in only one direction*.

BIASING (CONNECTION) OF P – N JUNCTION DIODES

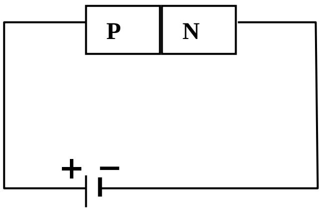
- There are two ways of biasing the P –N junction diodes. These are:

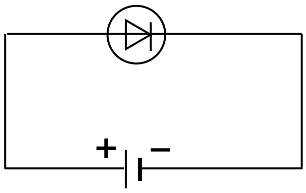
  (i) Forward biasing

  (ii) Reverse biasing

(i) FORWARD BIASING

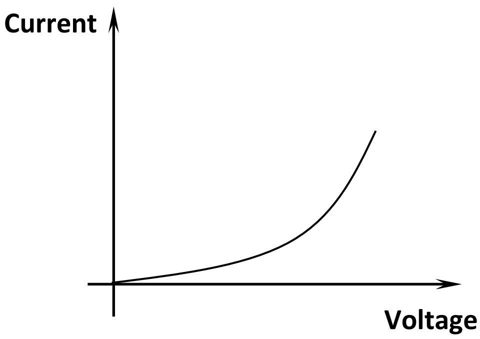
- P–N junction diode is ***forward biased*** *when the* <u>*P-type region is connected to the positive*</u> *terminal of a cell and the* <u>*N-type region is connected to the negative*</u> *terminal of the cell*





- When a P–N junction diode is <u>***forward biased it allows current to flow***</u>, i.e. it conducts electricity.

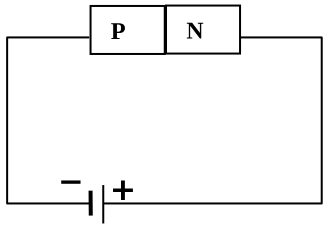
- The <u>***characteristic***</u> for a diode *in the forward bias mode* is as shown below

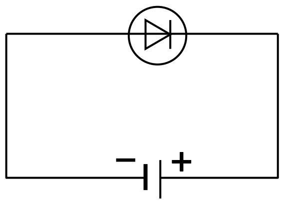


NOTE: ***A diode characteristic is a graph showing how current varies as voltage is increased across the diode***

(ii) REVERSE BIASING

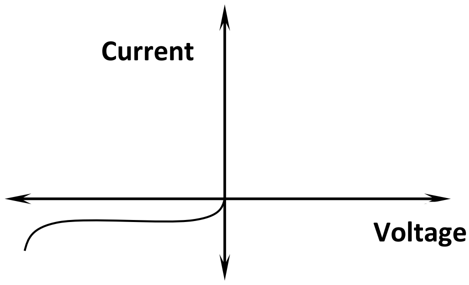
- P–N junction diode is ***reverse biased*** *when the P-type region is connected to the negative* terminal of a cell and the *N-type region is connected to the positive* terminal of a cell





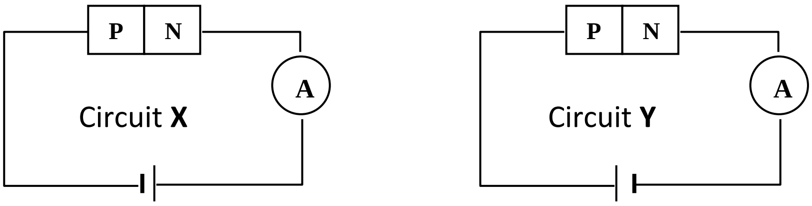
- When a P– N junction diode is ***reverse biased it does NOT allow current*** to flow, i.e. it does NOT conducts electricity

- The ***characteristic*** for a diode *in the reverse bias mode* is as shown below



Worked Example 106

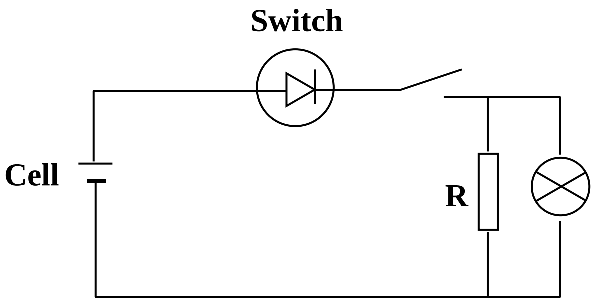
(a) **The figure below shows two ways of biasing a p-n junction. Explain why Current may flow in circuit Y and not in circuit X.**



Answer

- ***Y** is forward biased and therefore the resistance at the P-N junction is greatly reduced and current therefore flows through the circuit*
- ***X** is reverse based and so resistance at the P-N junction is increased. Current therefore does not flow through the circuit*

(b) **In the circuit below, when the switch is closed, the bulb lights. However, when the cell terminals are reversed and the switch is closed the bulb does not light. Explain this observation**

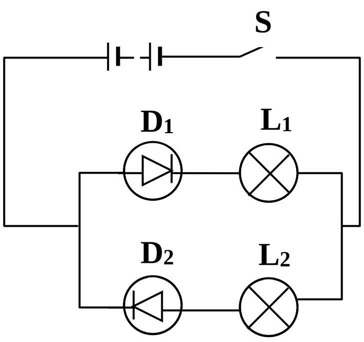


Answer

- *The bulb lights in the first case because the diode is forward biased therefore current flows through the circuit. When the cell terminals are however reversed, the diode is reversed biased therefore current does not flow through the circuit and the bulb does not light.*

Practice Question

*The diagram below shows a circuit with two diodes **D_1** and **D_2**, two lamps, **L_1** and **L_2**, and a battery. State and explain the observation that would be made when switch **S** is closed*



USE OF P–N JUNCTION DIODES IN A.C. RECTIFICATION

Rectification is the process of converting an alternating current into a direct current.

- Rectification of alternating current is done by using ***rectifier circuits***, in which P-N junction diodes are connected.

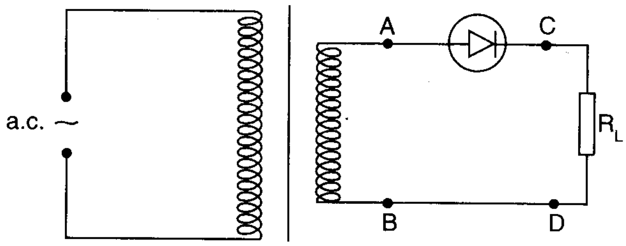
- There are ***two*** types of rectification, namely:

  (i) *Half wave rectification*

  (ii) *Full wave rectification*

1. HALF WAVE RECTIFICATION

- *A single diode is connected in series with the loads as shown below.*



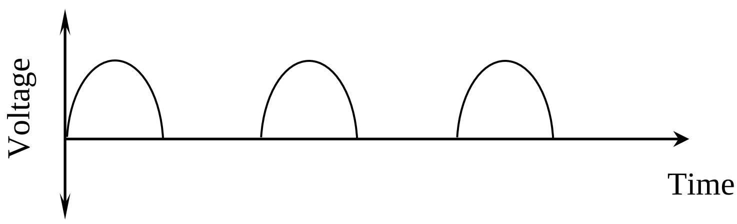
How it works

- *The transformer is used to step down the input voltage.*

- *During the first half cycle (positive) the diode is forward biased, therefore it conducts electricity. The current flows through* $\boldsymbol{R_L}$*, building a voltage across it which then decreases to zero.*

- *During the second half cycle (negative) the diode is reverse biased and so it does not conduct electricity. Current does not flow then.*

The voltage output for this rectification



Worked Example 107

(a) What makes a P – N junction diode suitable for use as a rectifier?

Answer

- *It allows current to move in one direction only*

(b) State **two** disadvantage of half – wave rectification using a junction diode

Answer

1. *The output in this rectification is not smooth*
2. *There is much power loss as one of the half-cycles is eliminated*

2. FULL WAVE RECTIFICATION

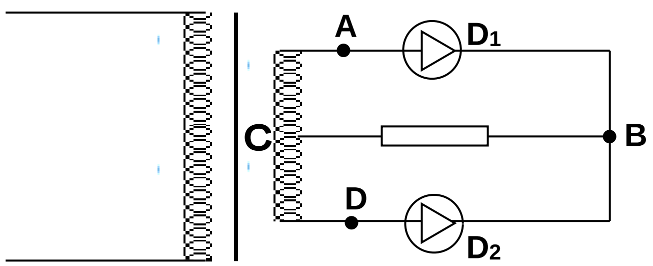
This can be achieved in two ways:

(i) Using two diodes

(ii) Using four diodes

(a) Full wave rectification using two diode

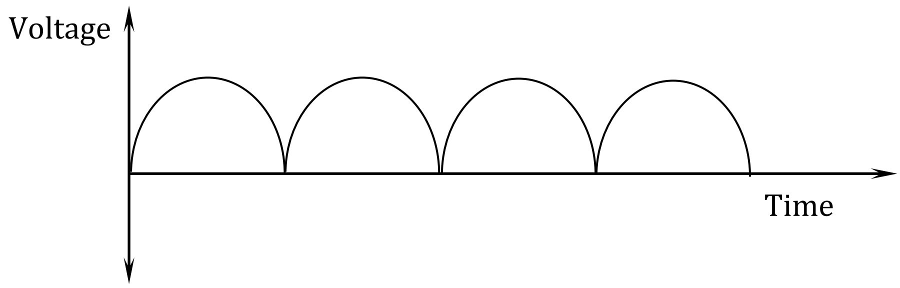
- The two diodes are connected in such a way that each conducts a current through the resistor during a particular half- cycle as shown below



- *During the first half- cycle* $\boldsymbol{D_1}$ *is forward bias while* $\boldsymbol{D_2}$ *is reversed biased hence current flows through* ***AD***$\boldsymbol{_1}$ ***BCA****.*

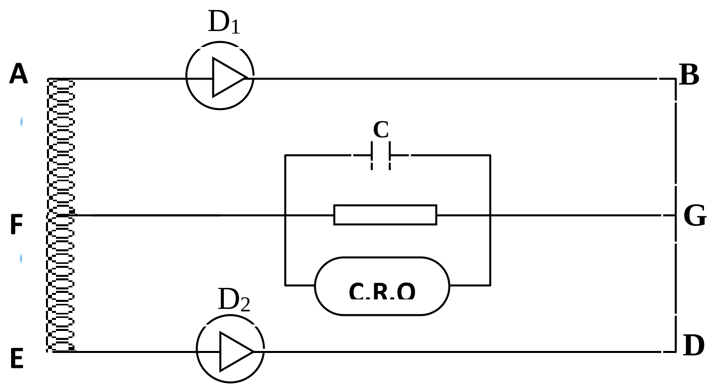
- *During the next half –cycle,* $\boldsymbol{D_2}$ *is forward biased while* $\boldsymbol{D_1}$ *is reversed biased and the path of the current in* ***DD***$\boldsymbol{_2}$ ***BCD****. Current flows through the resistor in the same direction in both cycles.*

<u>The voltage output signal is of the form</u>:



<u>Worked Example 108</u>

Figure below shows a full wave rectification circuit.



(a) What do you understand by full wave rectification of A.C

- *When **all** the cycles of A.C are converted to D.C*

(b) Identify the diode that is reverse biased when point E is positive with respect to point A.

- *D1*

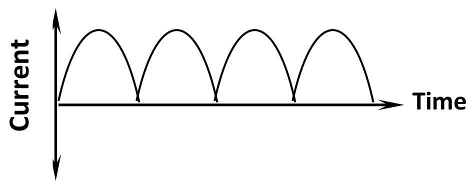
(c) **State the direction of electric current when part A is positive with respect to point E.**

- *A ⟶ B ⟶ G ⟶ F*

(d) What is the purpose of the capacitor C?

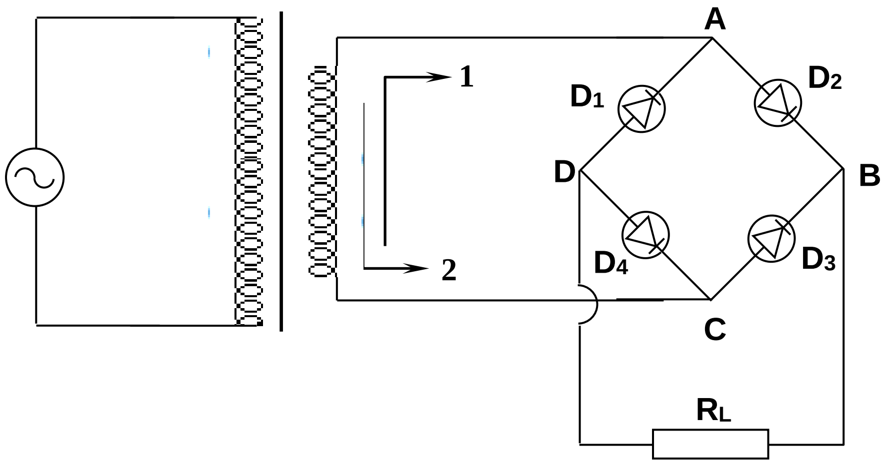
- *The capacitor is used to produce a **smooth** rectified wave*

(e) Sketch the waveform of the output current as seen in the C.R.O.



(b) Full wave rectification using four diode

- Four diodes are connected as shown below



How it works

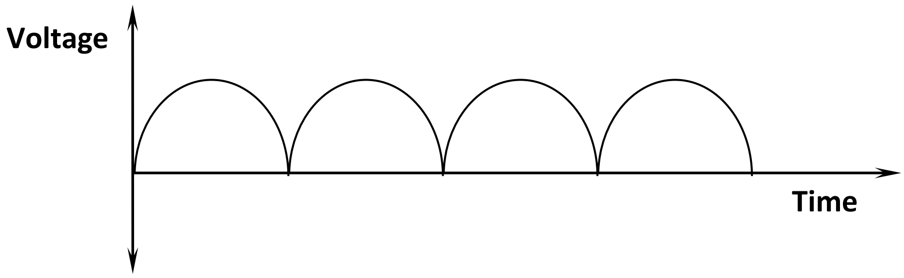
- *During the first half cycle, point **A** is positive with respect to point **C**. the diodes **D_1** and **D_3** are forward biased, while **D_2** and **D_4** are reversed biased. Current therefore flows along the path **ABR_LDCA***

- *During the second half cycle, point **A** becomes negative with respect to **C** and diodes **D_2** and D_4 become forward biased while **D_1** and **D_3** are reversed biased. Current therefore flows along the path **CBR_LDC***

1. *During both half cycles, current flows through the load resistor R_L in the same direction.*

2. *The transformer is used to **step down** the input voltage.*

3. The voltage output signal is of the form:



Worked Example 109

State two advantage of the four diode rectifier over a two diode one

- *A small transformer can be used since no need of centre –tapping.*
- *It is suitable for high voltage regulations*

19. RADIOACTIVITY

Radioactivity is the spontaneous disintegration of the nucleus of unstable elements with the emission of radiations

- There are three main type of radiations:

  1. *Alpha particles* ***(α – particle)***
  2. *Beta particles* ***(β – particle)***
  3. *Gamma rays* ***(γ – rays)***

ALPHA PARTICLES (α – PARTICLE)

- *An alpha particle is the nucleus of helium, and is represented as:*

$$^{4}_{2}\mathrm{He}$$

- Alpha particles are positively charged therefore they are deflected by both electric and magnetic fields.
  - **(i)** *In the electric field, they are deflected towards the negative plate.*
  - **(ii)** *In a magnetic field the direction of their deflection can be predicted by using the Fleming's left hand rule. The direction of the current (second finger) is the same as the direction that the alpha particles are moving*

- Alpha particles ionize air particles more strongly than beta particles and gamma rays. ***This is because alpha particles have bigger mass than beta particles and gamma rays***.

- Alpha particles have low penetrating powers and can be stopped by a thin piece of paper
- Alpha particles are heavy and move at low speeds.

When an element decays by emitting an alpha particle, its **mass number decreases by 4** and its **atomic number decreases by 2**

- In general

$$^{A}_{Z}\mathrm{X} \longrightarrow {}^{A-4}_{Z-2}\mathrm{X} + {}^{4}_{2}\mathrm{He}$$

Worked Example 110

The element polonium (Po) has atomic number 84 and mass number 210. The element decays by emitting an alpha particle to form lead (Pb). Write a nuclear equation for this decay

Answer:

$$^{210}_{84}\mathrm{Po} \longrightarrow {}^{206}_{82}\mathrm{Pb} + {}^{4}_{2}\mathrm{He}$$

Practice Question

*Uranium $^{238}_{92}U$ emits an alpha particle to become another element **X**, as shown in the equation below.*

$$^{238}_{92}U \longrightarrow\ ^{A}_{Z}X + \text{Alpha particle}$$

Determine the values of A and Z ***(Answer: A = 234; Z = 90)***

BETA PARTICLES (β – PARTICLE)

- *A beta particle is an electron emitted from the nucleus of an atom and is represented as* :

$$^{0}_{-1}e$$

- Beta particles are negatively charged therefore they are deflected by both electric and magnetic fields.

  (i) *In the electric field, they are deflected towards the positive plate.*

  (ii) *In a magnetic field the direction of their deflection can be predicted by using the Fleming's left hand rule. The direction of the current (second finger) is opposite to the direction that the beta particles are moving*

- Beta particles have less ionizing powers compared to alpha particles. ***This is because beta particles have smaller mass than alpha particles***.

- Beta particles have fairly high penetrating powers. They can penetrate through paper but can be stopped by a thin aluminium

- Beta particles are lighter compared to alpha particles, and they move at fairly high speed

When an element decays by emitting a beta particle, its mass number remains the same, but its atomic number increases by 1.

- In general

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

Worked Example 111

The element Thorium (Th) has atomic number 90 and mass number 234. The element decays by emitting a beta particle to form Protactinium (Pa). Write a nuclear equation for this decay

Answer:

$$^{234}_{90}Th \longrightarrow {}^{234}_{91}Pa + {}^{0}_{-1}e$$

Practice Question

*The following reaction is part of a radioactive series. Identify the radiation **x** and determine the values **b** and **c***

$$^{210}_{83}A \xrightarrow{x} {}^{210}_{84}B \xrightarrow{\alpha} {}^{c}_{z}Q$$

(Answer: x is beta particle, c = 206, z = 82)

GAMMA RAYS (γ – RAYS)

(i) *Gamma rays are electromagnetic waves with very short wavelengths and high frequencies*

(ii) *Gamma rays have no mass*

(iii) *They are not charged therefore are not deflected by either magnetic or electric fields*

(iv) *Gamma rays cause little ionization*

(v) *Gamma rays have very high penetrating powers and the can pass through paper and aluminium but can be stopped by thick block of lead metal.*

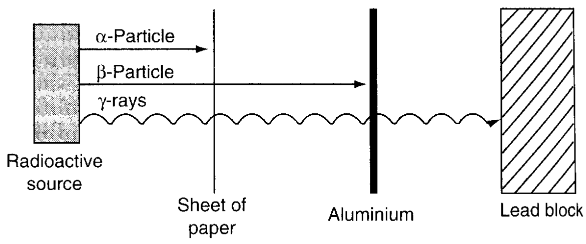
When an element decays by emitting gamma rays its mass number and atomic number remain the same.

Example

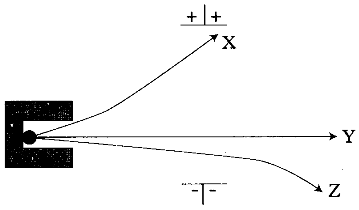
$$^{60}_{27}Co \xrightarrow{\gamma} {}^{60}_{27}Co + \gamma$$

SUMMARY

A) PENETRATING POWERS



B) DEFLECTION IN AN ELECTRIC FIELD



X – Beta particle; **Y** – Gamma rays **Z** – Alpha particles

HALF LIFE ($t_{1/2}$)

Half life is the time taken for half the number of nuclide initially present in a radioactive sample to decay

- The half life of a radioactive element can be calculated by using:
  1. Linear method
  2. Formula method
  3. Graphical method

LINEAR METHOD

- *This involves dividing the initial mass / percentage / fraction by two after each half life.*
- *In general, if N_0 is the initial mass, and $t_{1/2}$ the half life, then:*

$$N_0 \xrightarrow{t_{1/2}} \frac{N_0}{2} \xrightarrow{t_{1/2}} \frac{N_0}{4} \xrightarrow{t_{1/2}} \frac{N_0}{8} \xrightarrow{t_{1/2}} \frac{N_0}{16}$$

Worked Example 112

The count rate of a radioactive indium falls from 3200 counts per minute to 200 counts per minutes in 220 minutes. Determine the half-life of the radioactive isotope

Answer

$$3200 \xrightarrow{t_{1/2}} 1600 \xrightarrow{t_{1/2}} 800 \xrightarrow{t_{1/2}} 400 \xrightarrow{t_{1/2}} 200$$

Total number of half lives = 4

Total time taken = 220

Therefore, $4\, t_{1/2} = 220$ *minutes*

$$t_{1/2} = \frac{220}{4}$$

$$t_{1/2} = \mathbf{55\ minutes}$$

Practice Question

What is the half-life of a radioactive material if its activity falls to $^{1}/_{8}$ *of its initial value in 3360 seconds?* ***(Answer: 1120 seconds)***

USING FORMULA

- The formula used is:

$$\frac{N}{N_0} = \left(\frac{1}{2}\right)^{\frac{t}{t_{1/2}}}$$

Where:

N_0 – initial mass / fraction / activity / percentage

t – total time taken

N – Final mass / fraction / activity / percentage

$t_{1/2}$ – half life

Worked Example 113

If a radioactive isotope has a half-life of 2.5 hours how long will it take for 256 grams of the isotope to decay to 32 grams?

Answer

$$\frac{N}{N_0} = \left(\frac{1}{2}\right)^{\frac{t}{t_{1/2}}}$$

$N = 32$ grams $\quad N_0 = 256$ grams

$t = t \quad t_{1/2} = 2.5$hours

$$\frac{32}{256} = \left(\frac{1}{2}\right)^{\frac{t}{2.5}}$$

$$\frac{1}{8} = \left(\frac{1}{2}\right)^{\frac{t}{2.5}}$$

$$\left(\frac{1}{2}\right)^{3} = \left(\frac{1}{2}\right)^{\frac{t}{2.5}}$$

$$\frac{t}{2.5} = 3$$

$$t = (2.5 \times 3)$$

$$t = 7.5 \text{ hours}$$

Practice Question

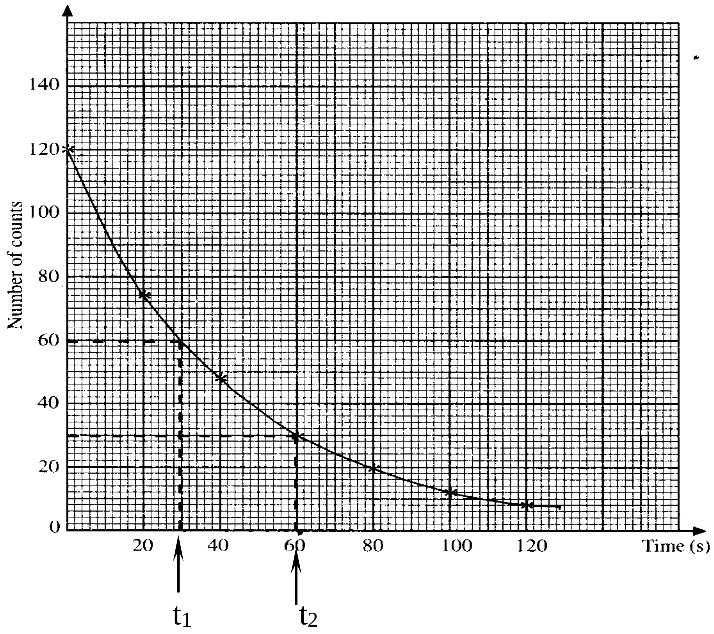
*A radioactive isotope **M** decays by emitting two alpha and beta particles to form $^{214}_{83}Y$. What is the atomic number of **M**. After 224 days, $^{1}/_{16}$ of mass of **M** remained. Determine the half life of **M**.*

(Answer: Atomic number of m = 87, half life = 56 days)

GRAPHICAL METHOD OF DETERMINING HALF LIFE

- This method involves plotting a decay curve, then using the curve to work out the half life
- A decay curve is a graph of either mass, count rate, activity, percentage e.t.c against time.

Example



Half life, $t_{1/2} = (t_2 - t_1)$

$= 60 - 30$

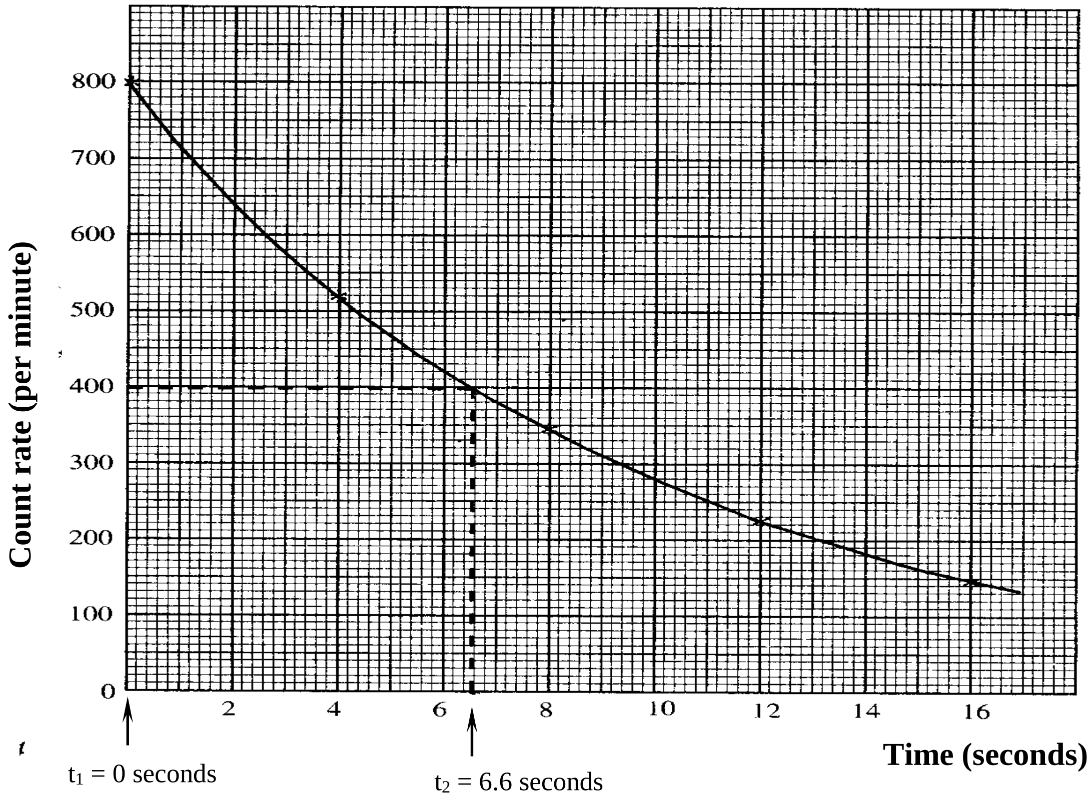
$t_{1/2}$ = 30 seconds

ARTIFICIAL AND NATURAL RADIOACTIVITY

- In Natural radioactivity the nucleus of the elements disintegrate on their own accord
- In artificial radioactivity, the nucleus must be excited by injection of a neutron for radioactivity to start

Worked Example 114

The graph below is a decay curve for element X. Use the graph to determine the half life of element X

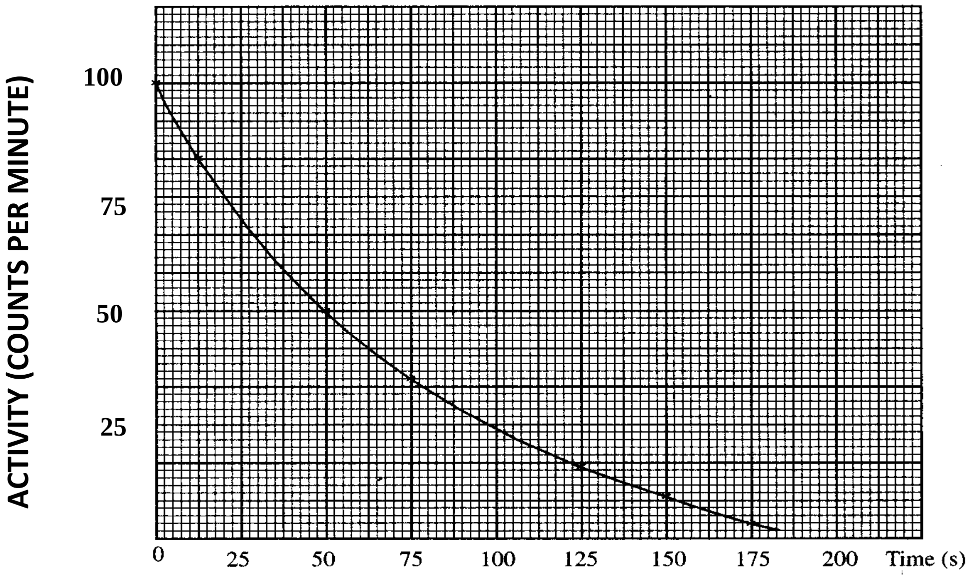


Answer: *half life = 6.6 – 0*

Half life = 6.6 hours

Practice Questions

*The figure below shows the decay of a certain element **M**. From the graph find the half life of element **M*** ***(Answer: 50 seconds)***



DETECTORS OF RADIATIONS

1. PHOTOGRAPHIC EMULSION

   - *All radiations blacken photographic plate*

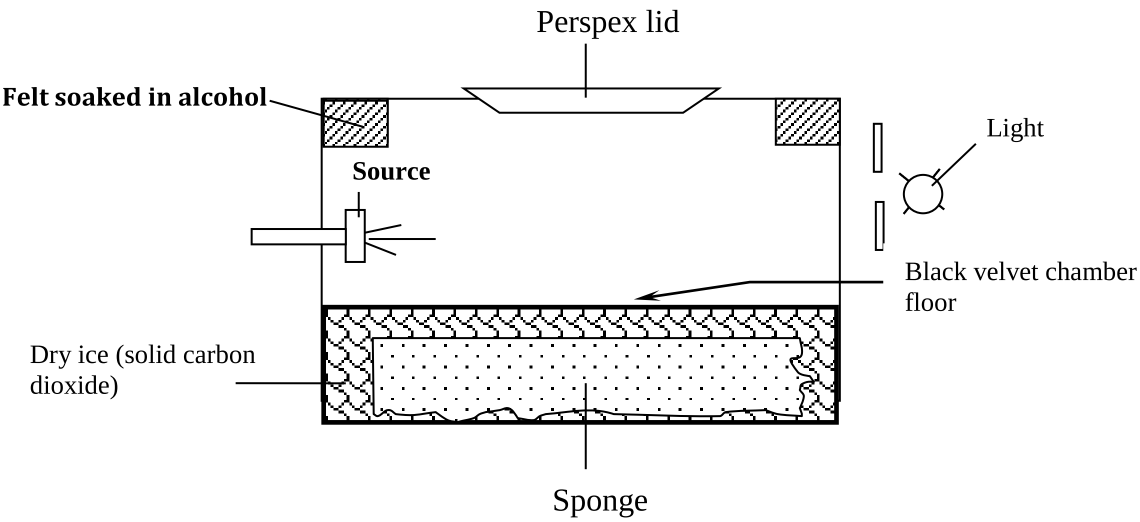
2. LEAF ELECTROSCOPE

   - *Radiations emitted by radioactive material cause ionization in air*
   - *When placed close to a charged electroscope, the electroscope is discharged due to neutralization and the leaf falls*

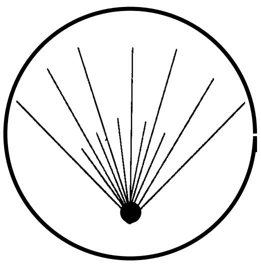
Disadvantage of the electroscope

This method is not suitable for beta and gamma radiations *because they have low ionizing powers*

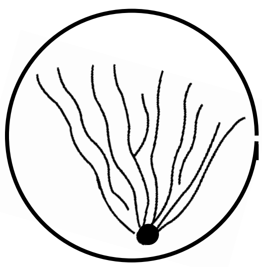
3. DIFFUSION CLOUD CHAMBER



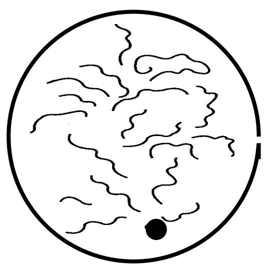
- *The air inside chamber is ionized by the radiation in its path. This leads to the formation of* ***air ions***
- *Alcohol vapour condenses on these* ***air ions*** *forming droplets along the path i.e. forms some tracks*
- *These droplets / tracks are visible and so radiation is detected*
- *Each radiation forms a definite pattern. The radiation is identified by analyzing the nature of the patterns formed.*



Tracks formed by alpha particles



Tracks formed by beta particles



Tracks formed by gamma rays

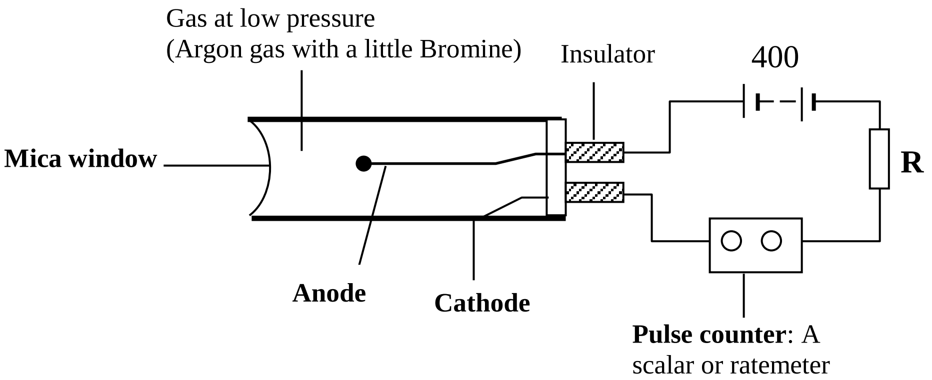
Note:

1. *The Alcohol produces alcohol vapour which condenses on* ***air ions*** *to show trails of radiation path*
2. *Dry ice (Solid carbon dioxide) cools the alcohol vapour below condensation temperature*

Advantage of diffusion cloud chamber detector over charged electroscope

- *It can detect alpha, beta and gamma radiations unlike a charged electroscope which can only detect alpha particles*

4. GEIGER MULLER TUBE



- The mica window allows radiations to enter the tube
- Radiations entering the tube collide with argon gas causing ionization
- More electrons are produced (Avalanche/electrons). Positive ions are attracted to the cathode while negative ions are attracted to the anode
- A pulse of current is produced which is passed through the counter as clicks;

Note:

1. *The bromine in the tube acts as a quenching agent by absorbing kinetic energy of the positive ions*
2. *The argon gas in the tube should be at low pressure so that it can be easily ionized by the radiations.*
3. *The sensitivity of the tube can be increased by the use of amplifier*
4. *The mica window is made thin so that it can allow penetration of radiation*

APPLICATIONS OF RADIOACTIVITY

(a) IN MEDICINE:

1. *Radioactive iodine 131 is used to monitor the function of thyroid gland*
2. *Radioactive sodium is used to monitor blood circulation*
3. *Gamma rays from cobalt 60 are used to sterilize surgical equipment*

OTHER USES

1. *Detecting pipe leakage*
2. *To determine thickness of material*
3. *Carbon dating to determine the age of ancient remains*

Worked Example 115

Archaeologists can determine the age of organic matter by measuring the proportion of carbon-14 present in a sample. Assuming that carbon -14 has a half- life of 5600 years, calculate the age of a piece of wood found to contain $^1/_8$ as much carbon -14 as in a living material.

$$1 \xrightarrow{t_{1/2}} \frac{1}{2} \xrightarrow{t_{1/2}} \frac{1}{4} \xrightarrow{t_{1/2}} \frac{1}{8}$$

Answer

Total number of half lives = 3 $t_{1/2}$

Therefore total time = 3x5600 years

= 16 800 years

Therefore age of wood = 16 800 years

HAZARDS OF RADIOACTIVITY

- *Excessive exposure to radioactive materials can lead to:*
  1. *Cancer*
  2. *Cell mutation*
  3. *Skin burns*

Precautions

(i) *Radioactive elements should not be handled with bare hands. Forceps should be used instead*

(ii) *Radioactive materials should be stored in thick lead containers*

(iii) *Concrete walls should be used for rooms that store radioactive elements*

Worked Example 116

Explain why long half life of nuclear waste products presents a health hazard

Answer

- *If the half – life is long /large, the activity remains at a very high level for a very long time resulting in a health hazard;*

NUCLEAR FISSION AND NUCLEAR FUSION

Nuclear fission is the splitting of a heavy nucleus to give smaller lighter nuclei

- Nuclear fission happens when a nuclei absorbs a neutron, and is usually accompanied by the evolution of energy

Examples

$$^{235}_{92}\mathrm{U} + {}^{1}_{0}\mathrm{n} \longrightarrow {}^{147}_{57}\mathrm{La} + {}^{87}_{35}\mathrm{Br} + 2\,{}^{1}_{0}\mathrm{n} + \text{Energy}$$

$$^{235}_{92}\mathrm{U} + {}^{1}_{0}\mathrm{n} \longrightarrow {}^{141}_{56}\mathrm{Ba} + {}^{92}_{36}\mathrm{Kr} + 3\,{}^{1}_{0}\mathrm{n} + \text{Energy}$$

Nuclear fusion is the process in which light nuclei combine to form a heavier nucleus

- Nuclear fusion occurs when nuclei are made to collide at very high velocity, and is also accompanied by the evolution of energy

Example

$$^{2}_{1}\mathrm{H} + {}^{2}_{1}\mathrm{H} \longrightarrow {}^{3}_{2}\mathrm{He} + {}^{1}_{0}\mathrm{n} + \text{Energy}$$

BACKGROUND RADIATION

This is radiation due to a source other than that of a radioactive material under consideration

Sources of background radiation

- Cosmic rays from outer space
- Radiations from the sun
- Some rocks which contain traces of a radioactive material e.g. granite
- Natural and artificial radioisotopes

NOTE: ***Background radiation count must be subtracted from the total count registered by a detector to obtain the actual / correct count of the source***

Worked Example 117

The activity of a radioactive element when measured using the Geiger Muller tube was found to be 63 counts per minute. Given that the background radiation was 8 counts per minute, determine:

(a) The actual activity of the radioactive element

Answer

Actual activity = (recorded activity – background radiation)

= (63 – 8)

Actual activity = 55 counts per minute

(b) The half life of the element If the activity dropped from 128 counts/minute to 23 counts per minute in 6 hours

Answer

Actual Initial activity = (128 – 8)

= 120 counts per minute

Actual final activity = (23 – 8)

= 15 counts per minute

Using the linear method:

$$120 \xrightarrow{t_{1/2}} 60 \xrightarrow{t_{1/2}} 30 \xrightarrow{t_{1/2}} 15$$

$$3\,t_{1/2} = 6 \text{ hour}$$

$$t_{1/2} = \frac{6}{3}$$

$$\mathbf{t_{1/2} = 2 \text{ hour}}$$

Practice Question

In an experiment to determine the half – life of the radioactive element, the following data was obtained.

Activity (counts) per minute	*52*	*44*	*34*	*28.5*	*24*	*19.0*	*17.5*	*15*
Time (minutes)	*0*	*0.5*	*1.0*	*1.5*	*2.0*	*2.5*	*3.0*	*3.5*

(a) *Given that the background radiation is 10 counts per minute, Plot a decay curve for the element.*

(b) *Estimate from your graph, the half-life of the element*

(Answer: 1.15 minutes)

Additional Practice Question