KCSE PHYSICS PAPER 2: 2020 DISCUSSION

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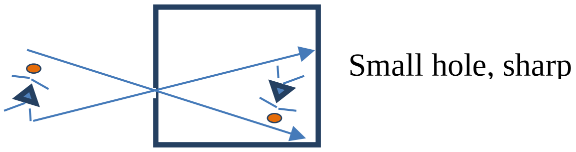
Section A (25 Marks)

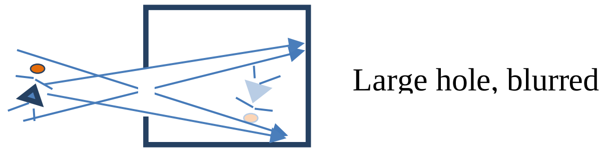
1. State the observation made on the image in a pin hole camera when the distance between the object and the pin hole is reduced. (2 marks)

A pinhole camera is a simple camera that operates without a lens. It is basically a light-proof box with a very small aperture. Light from an object enters the camera through the small aperture and forms an inverted image on the other end of the box.

NOTE 1:

The clarity (sharpness) of the image formed by a pinhole camera depends, among other factors, on the size of the aperture/hole. A small hole concentrates light entering the camera within a small region resulting in a sharp image. An extended hole on the other hand allows a lot of light to enter the camera. This light is spread over a large area making the image formed blurred.





NOTE 2:

If the aperture is too small, light entering the camera is diffracted (spreads out) leading to the formation of a blurred image.

NOTE 3:

If the distance between the aperture and the screen (length of the camera) is increased, the image size increases although it may become blurred.

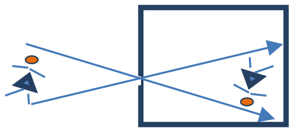


Image distance shorter, image relatively smaller

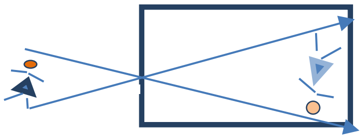
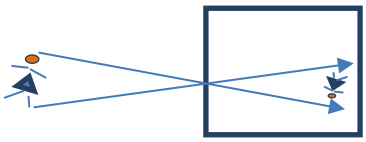


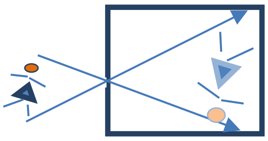
Image distance longer, image relatively larger

NOTE 4:

If the distance between the object and the pinhole is reduced, the size of the image becomes bigger.



Object distance long, image relatively smaller



Object distance short, image relatively larger

2. Figure 1 shows a gold leaf electroscope

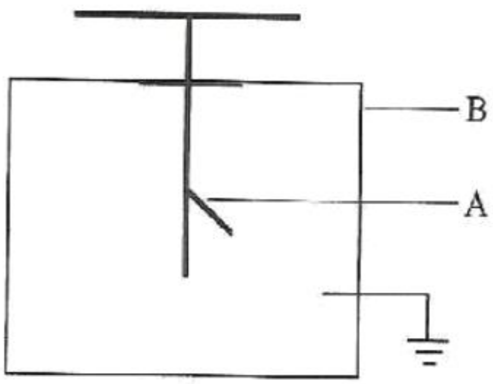


Figure 1

(a) Name the part labelled A. (1 mark)

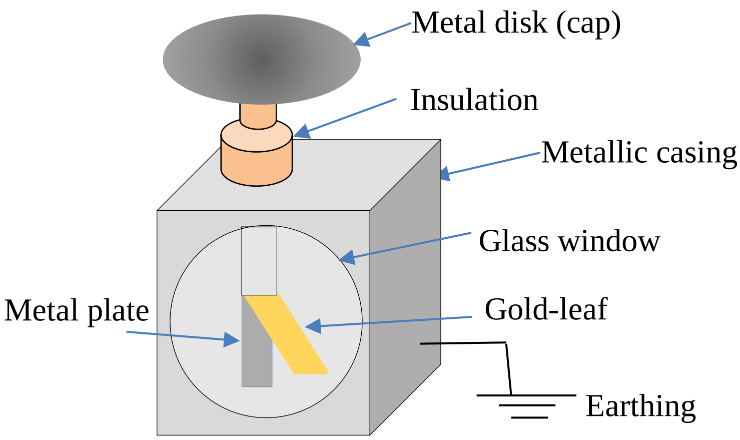
A gold-leaf electroscope is used for;

(i) Detecting the presence of electric charge on a body

(ii) Identifying the type of charge (positive or negative) on a body

(iii) Determining the relative magnitude of charge on a body

Parts of a gold-leaf electroscope:



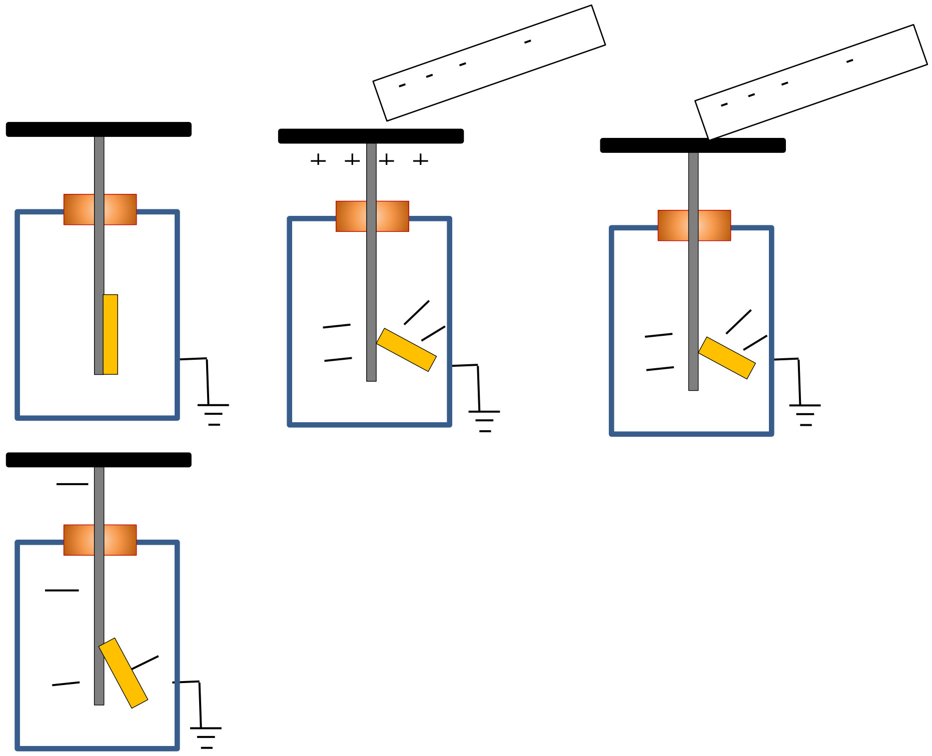
The wall (casing) of an electroscope is earthed. This is to ensure that any negative charge induced in the casing is conducted to the ground, or any positive charge induced is neutralised by charge from the ground. The casing therefore remains neutral at all times hence bearing no effect on the deflection of the gold-leaf. If an electroscope is not charged, the gold-leaf is not diverged. However, if the electroscope is charged, or a charged body is brought close to the electroscope, the leaf diverges. The degree of divergence is proportional to the magnitude of charge on the electroscope (or in the body).

There are two methods of charging an electroscope;

(i) Charging through contact

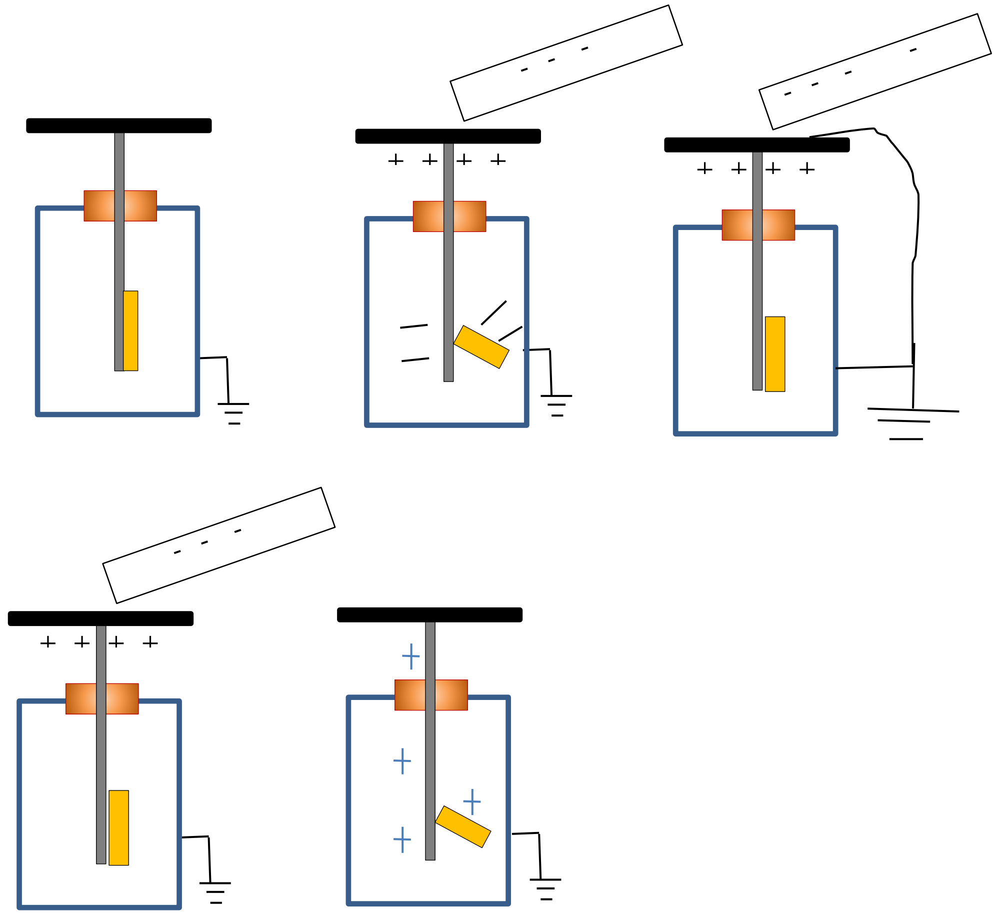
(ii) Charging through induction

Charging through contact: The charging process starts by bringing a charged body, say a negatively charged rod, near the cap of the electroscope. As a result of electrostatic force and bearing in mind that like charges repel and unlike charges attract, the negative charges on the electroscope are repelled to the leaf and the plate resulting in leaf divergence, while the positive charges move to the cap. The rod is then brought into contact with the cap. Consequently, some negative charges on the rod enter the electroscope and neutralise some of the positive charges, leaving the electroscope with a net negative charge. When the rod is withdrawn, the negative charges on the leaf and the plate are distributed throughout the electroscope. The leaf divergence reduces as the magnitude of charge reduces.



If a positively charged rod was used instead, the electroscope would have acquired a net positive charge.

Charging through induction: A charged rod, say negatively charged, is brought close to but not touching the cap of the electroscope. The negative charges on the electroscope are repelled to the leaf and the plate (leaf diverges) while the positive charges move to the cap. With the rod still in place, the cap is touched (earthed). Consequently, the negative charges on the electroscope are conducted to the ground leaving the plate and the leaf with no net charge, and the leaf therefore collapses. The earth connection is then removed while the rod is still in place (to prevent the electroscope from discharging). The rod is then withdrawn. The positive charges on the cap are distributed to the leaf and the plate. Consequently, the leaf diverges. The electroscope in this case has a net positive charge.



If a positively charged rod was used instead, the electroscope would have acquired a net negative charge.

NOTE 1:

An electroscope charged by contact acquires the same charge as the charging object, while one charged through induction acquires a charge opposite that of the charging object.

NOTE 2:

When a sharp pin is brought near the cap of a positively charged electroscope, the tip of the pin acquires a negative charge. Sharp points concentrate charge and consequently, the highly charged tip ionises the air around it, attracting the positively charged air molecules and repelling the negatively charged ones to the cap of the electroscope. The negative charges pair up with positive charges on the electroscope thereby discharging it. The leaf therefore collapses.

NOTE 3:

The magnitude of charge on a body is proportional to the divergence of the leaf. More charge results in greater divergence and vice versa.

NOTE 4:

Say a rounded object, for example a sphere, is brought near the cap of a negatively charged electroscope. The positive charges on the sphere will move to the side closest to the electroscope while the negative charges move to the other end. Some of the negative charges on the electroscope move to the cap leading to a reduction in charge on the leaf and the plate. The leaf divergence consequently reduces.

NOTE 5:

A charged electroscope is not devoid of one charge. It just has one charge in excess of the other. A positively charged electroscope has more positive charges than negative charges, while a negatively charged one has more negative charges than positive charges. If for example a positively charged body is brought close to a negatively charged electroscope, the negative charges on the electroscope will move to the cap, while the fewer positive charges move to the plate and the leaf. The leaf will therefore not collapse but the divergence will reduce. Also, if an uncharged body is brought close to a negatively charged electroscope, the negative charges on the electroscope will move to the cap, while the fewer positive charges move to the plate and the leaf. Consequently, the leaf divergence reduces. If on the other hand a negatively charged body is brought close to the cap of a negatively charged electroscope, the few positive charges will move to the cap of the electroscope while the majority negative charges move to the plate and leaf. The leaf divergence will therefore increase.

Now the question:

Gold-leaf

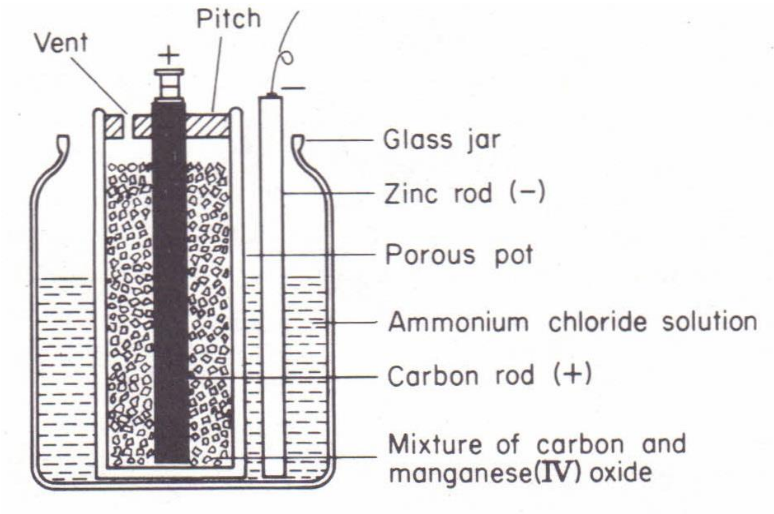
(b) State the function of the part labelled B. (1 mark)

Casing – to protect the gold-leaf from external influences

3. State two measurements that should be taken for one to decide whether a lead acid accumulator is due for charging. (2 marks)

A cell is a single source of electrical energy that employs chemical reaction to produce current. It converts chemical energy into electrical energy. A cell comprises two electrodes (terminals) and an electrolyte. Electrodes are conductors through which current flows while the electrolyte is a substance with free ions. Cells can either be un-chargeable or rechargeable (accumulators).

Broadly, cells are classified into two: Wet cells and dry cells. Like the names suggest, wet cells contain a liquid electrolyte while dry cells contain a moist solid electrolyte. Example of a wet cell is the lead-acid cell where the electrolyte is a mixture of sulphuric acid and water. Examples of dry cells are **zinc-carbon** cells (also known as **lechlanche cells**) and alkaline-cells. The zinc-carbon/lechlanche cells produce electricity from the electrochemical reaction between zinc and manganese four oxide (MnO_2) in the presence of an electrolyte which is either ammonium chloride or zinc chloride dissolved in water. Zinc acts as the anode and the manganese four oxide the cathode, although carbon is added to the cathode to increase conductivity and retain moisture.



Lechlanche cell

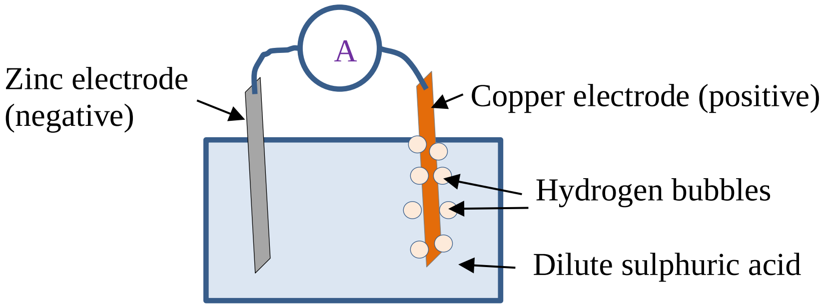
Zinc-Alkaline cells operate in a similar way as the lechlanche cell. However, they utilize manganese dioxide as the positive electrode as opposed to carbon though they have zinc as the negative electrodes. Also, zinc alkaline cells use potassium hydroxide as the electrolyte solution as opposed to ammonium chloride solution.

NOTE 1: Simple cell

A simple cell can be made by dipping two different metal electrodes of different reactivities in an electrolyte such as an alkaline or a dilute acid solution, or even a fruit such as an orange or a lemon. An example of a metal-pair commonly used as electrodes is zinc and copper since zinc is more reactive than copper. The greater the difference in reactivity the higher the voltage. The two electrodes are connected together by a conducting wire to complete the circuit. Common electrolytes used include dilute NaCl and H_2SO_4. The compounds are diluted with water so as to break them into ion-pairs. Example;

$dilute\ H_2SO_4\ spits\ into\ H^+\ and\ SO_4^{2-}$

When zinc and copper plates are dipped in the dilute sulphuric acid, the zinc plate starts dissolving into the electrolyte as Zn^{2+} ions (cations), with each zinc ion leaving two electrons behind, a process called oxidation. The zinc plate becomes the negative electrode (anode) and acts as a source of the electrons that flow through the connecting wire to the copper plate. The zinc ions Zn^{2+} react with the SO_4^{2-} in the electrolyte to form zinc sulphate.



As soon as the zinc ions enter the electrolyte, an equivalent number of hydrogen ions H^+ leave the solution for the copper plate, where they receive electrons e^- (anions) from the copper thereby becoming neutral hydrogen gas. The copper plate on losing electrons (a process called reduction) becomes the positive electrode (cathode) which enables it to attract the electrons from the zinc electrode. This movement of electrons constitute an electric current (hence an ammeter in the circuit is deflected). When current flows through a load in an external circuit, the cell **discharges. (NOTE:** The products of oxidation reaction at the anode (zinc plate) are positive ions or cations while the products of reduction reaction at the cathode (copper) are electrons or anions). The hydrogen gas formed collect as hydrogen bubbles on the surface of the copper plate, a process referred to as polarization. Some hydrogen bubbles escape into the air while some remain on the surface of the copper plate. As the bubbles pile up, they create a barrier between the copper plate and the electrolyte thereby reducing the rate of chemical reaction. The output current therefore decreases.

NOTE 2: Lead-acid accumulator

A lead-acid accumulator is a wet but rechargeable cell. Rechargeable cells are also referred to as secondary cells or accumulators. Lead-acid accumulators are constructed with ebonite, glass or hard rubber placed on the top to eliminate any kind of electrolyte discharge. It uses sponge lead (Pb) as the negative electrode and lead peroxide (PbO_2) as the positive electrode, with dilute sulphuric acid as the electrolyte where;

$dilute\ H_2SO_4\ splits\ to\ H^+\ and\ SO_4^{2-}$

During the discharging process (cell is connected to an external circuit), oxidation reaction takes place at the lead electrode. The lead electrode reacts with, and loses positive charges to, SO_4^{2-} ions, forming lead sulphate and leaving the electrode with a net negative charge. The lead electrode therefore acts as a source of electrons. Lead sulphate formed during the oxidation action collects as a white coating around the lead electrode.

As soon as SO_4^{2-} ions move to the sponge lead electrode, an equivalent number of H^+ ions leave for the PbO_2 (lead peroxide) electrode where they receive electrons leading to the production of lead sulphate. On losing the electrons, the lead peroxide electrode becomes positively charged, with the lead sulphate formed during the reduction action being deposited on the electrode as a thin white layer. The positive electrode attracts electrons from the negative electrode through the external circuit. This flow of electrons constitutes an electric current. The potential difference between the two electrodes reduces with time as current flows through the external circuit (discharges). NOTE: Both the anode and the cathode are covered by a white layer of lead sulphate during discharge. The coating is responsible for the voltage drop during usage of the cell as it increases the resistance of the electrodes.

To charge a lead-acid accumulator, an external DC source is applied to the accumulator. The negative terminal of the DC source is connected to the negative terminal (Pb) and the positive terminal of the DC source connected to the positive terminal (PbO_2). At the negative terminal (anode), the electrons injected by the negative terminal of the DC source repel the sulphate ions SO_4^2 back into the electrolyte. Reduction action therefore occurs as opposed to oxidation action that occurred when the cell was discharging. The reduction action converts the negative electrode into pure lead, returning it to the state it was before the cell was discharged. At the positive electrode (cathode), the applied positive potential attracts electrons from the electrolyte back to the electrode (oxidation occurs as opposed to reduction) turning it back to the state it was before the cell discharged.

NOTE 1: There are three ways of determining when an accumulator is fully charged:

(1) the final current level

(2) the peak charging voltage while this current flows

(3) the colour on the positive plate. It is dark brown when the accumulator is fully charged (only visible if the cell has transparent cover).

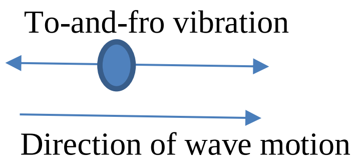
NOTE 2: The caps of the cell are usually left open when charging a lead acid accumulator to allow for the escape of hydrogen and oxygen gases formed during the charging process.

NOTE 3: The ratio of density of a liquid to that of water at the same temperature is called **relative density**. The relative density of a fully charged accumulator is 1.26. When a lead-acid accumulator is discharging, the relative density of the electrolyte reduces as the sulphur (in sulphuric acid) move to the plates. The accumulator is usually topped up with distilled water to maintain the relative density of the electrolyte. Relative density is measured using a hydrometer.

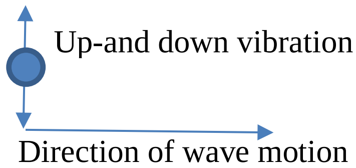
NOTE 5 (answer to question): The state of charge of an accumulator can be determined based on the **relative density of the electrolyte** and **the voltage output**, both of which reduce with accumulator usage.

4. Explain what happens to the speed of a water wave as it moves from the shallow to the deep end in a ripple tank. (2 marks)

Waves fall under two broad categories: electromagnetic (EM) waves and mechanical (elastic) waves. The main difference between the two types of waves is that EM waves do not require a medium for propagation while mechanical waves require a medium for propagation. Examples of EM waves include radio waves, light and X-rays. Examples of mechanical waves include sound waves and water waves. Mechanical waves are further divided into two types: longitudinal waves and transverse waves. Longitudinal waves occur when the direction of vibration of particles is parallel to the direction of motion of the waves, example sound waves.



Transverse waves on the other hand occur when particles vibrate in a direction perpendicular to the direction of wave travel, for example water waves.



(NOTE: all EM waves are considered to be transverse).

Nonetheless, all waves be it EM or mechanical waves have several characteristics in common:

(i) Obey the wave equation

$v = \lambda f$ (i)

Where v is the velocity of the wave, λ is the wavelength and f is the frequency. Now, **velocity** is the distance travelled by a wave in unit time while w**avelength** is the distance between two consecutive particles that are in phase. Particles are said to be **in phase** when they occupy identical positions and are travelling in the same direction. **Frequency** refers to the number of complete wavelengths passing a particular point in unit time;

$Frequency\ (f) = \frac{number\ of\ complete\ wavelengths\ (N)}{time\ (t)}$ (ii)

$f = \frac{N}{t}$ (iii)

Period ($\boldsymbol{T}$) is the time taken by a complete wavelength to pass a particular point (time for one complete oscillation). In other words, if $N = 1$, then $t = T$. Applying this condition in equation (iii) gives;

$f = \frac{1}{T}$ (iii)

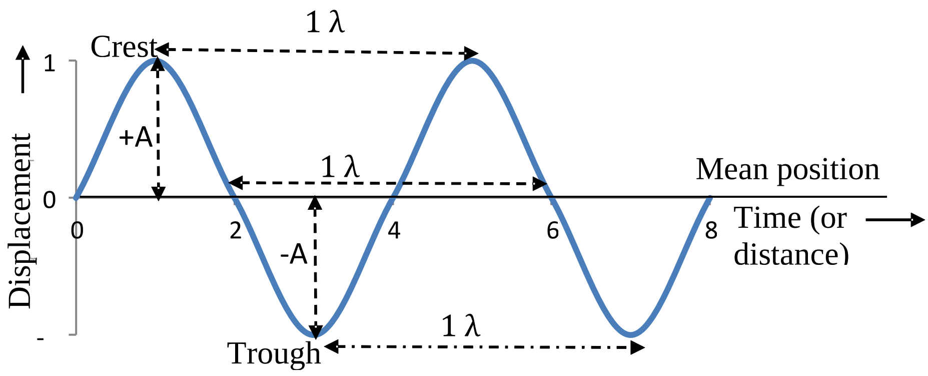
$\Longrightarrow T = \frac{1}{f}$ (iv)

Thus, period (T) is the reciprocal of frequency (f).

Amplitude (A) of a wave is defined as the maximum displacement of a particle from its mean position. **Mean position** refers to the position of a particle when not vibrating. For example, the surface of water before waves are formed.

(ii) **Are graphically represented by a sinusoidal waveform**

The sinusoidal waveform comprises of crests (maximum displacement in the positive direction) and troughs (maximum displacement in the negative direction).



Particles at the apex of crests are in phase with each other. Particles at the base of troughs are also in phase with each other. Thus, wavelength can also be defined as the distance between two adjacent crests, or distance between two ajacent troughs.

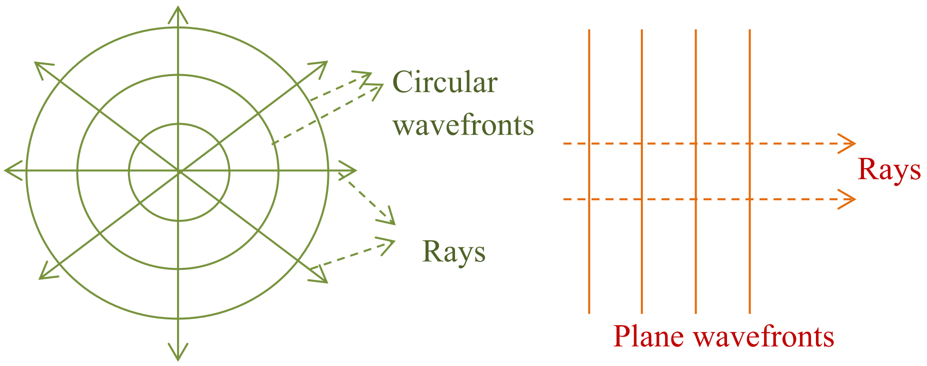
NOTE 1:

The locus of all points in a wave having the same phase of oscillation, e.g. apexes of crests, is called a **wavefront.** Wavefronts can be;

(i) curved (spherical wavefronts) – e.g. those from a point source. They originate from a point and spread outwards

(ii) Straight (plane wavefront) e.g. from a far off source or straight source.

Wavefronts are represented by equally spaced lines with the distance between two consecutive wavefronts being equal to the wavelenth λ of the wave.



A **ray** is a line drawn perpendicular to the wavefront that indicates the direction of travel of the wave.

NOTE 2: Refraction of water waves

When water waves move from a deep region to a shallow region, their velocity reduces (similar to reduction of velocity when EM waves e.g. light move from a less dense (say air) to a denser region (say water). And by the way the fact that colurs of light move with different velocities in water is what causes the rainbow).

If we let the velocity of water waves in the deep and shallow regions be v_d and v_s respectively, and λ_d and λ_s the wavelengths in deep and shallow regions respectively, then;

$v_d = \lambda_d f$ (vi)

$v_s = \lambda_s f$ (vii)

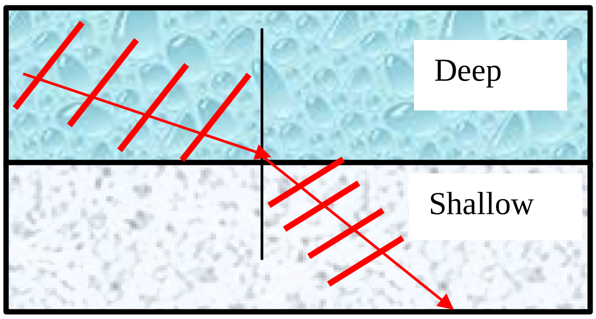
The frequency f of the wave is independent of the medium of propagation (it depends on the source).

Comparing equations (vi) and (vii), it follows that;

$\frac{v_d}{\lambda_d} = \frac{v_s}{\lambda_s}$ (viii)

Equation (viii) implies that since the velocity of a wave reduces (frequency constant), then the wavelength has to reduce proportionately.

Thus, when waves move from a deep region to a shallow region, both the velocity and wavelength reduce proportionately while the frequency remains constant. If the waves enter a shallow region from a deep region obliquely, they change direction with the refracted wave (wave in the shallow region) bending towards the normal.



If waves moves from a shallow to a deeper region, both the velocity and wavelength increase proportionately while the frequency remains constant, and if they enter obliquely, the wave in the deeper region is refracted away from the normal.

To the question:

From shallow to deep region - speed increases (wavelength increases as well but frequency remains constant),

5. The critical angle for a ray travelling from glass to air is 42°. Determine the refractive index of the glass. (3 marks)

When a ray of light moves from one medium to another of different optical density, its velocity changes. Light is a form of electromagnetic wave and has its highest velocity ($3 \times 10^8\ m/s$) in space (vacuum, air). When light enters another medium for example a liquid such as water or a solid such as glass, its velocity reduces since these materials are denser relative to space. The change in velocity leads to refraction of light (refraction of light refers to the change in direction of travel (bending) of light when it non-normally enters a medium of different density). The ratio of velocity of light in one medium to that of velocity of light in a second medium of different optical density is referred to as the refractive index of the second medium with respect to the first. Example, say light enters water from air. If c be the velocity of light in air and v_{water} the velocity in water, then the refractive index of water with respect to air η_{water} is given by;

$$\eta_{water} = \frac{c}{v_{water}} \qquad \text{(i)}$$

The frequency of light f is independent of the medium of propagation but the wavelength is not. If λ be the wavelength of light in air and λ_{water} in water, then by the wave equation ($v = \lambda f$) equation (i) may be expressed as:

$$\eta_{water} = \frac{\lambda f}{\lambda_{water} f} \qquad \text{(ii)}$$

$$\Longrightarrow \eta_{water} = \frac{\lambda}{\lambda_{water}} \qquad \text{(iii)}$$

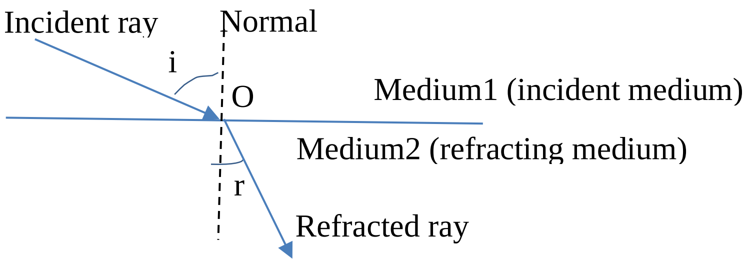
Comparing equations (i) and (iii) leads to;

$$\frac{c}{v_{water}} = \frac{\lambda}{\lambda_{water}} \qquad \text{(iv)}$$

Since c and λ are constant, a reduction in v_{water} leads to a proportionate reduction in λ_{water}. This means that when light moves from a less dense to a denser medium, its wavelength reduces.

Suppose a ray of light in air enters water at some point on the air - water interface. The ray that strikes the interface is referred to as the **incident ray** while the ray that progresses into the water is called the **refracted ray**. An imaginary line perpendicular to the interface at the

point the incident ray enters water is called the **normal**. The point of intersection of the incident ray, the normal and the refracted ray is called the **point of incidence** (O). The angle between the incident ray and the normal is called the **angle of incidence** (i) while that between the refracted ray and the normal is the **angle of refraction** (r).
When a ray of light enters a denser medium at an angle of incident greater than zero (obliquely), the ray in the denser medium bends towards the normal (refraction is often defined as the change in direction of light when it moves from one medium to another of different optical density). In this case $i > r$.



There are two laws that are associated with refraction:
1st law: This states that the incident ray, refracted ray and the normal all lie on the same plane at the point of incidence
2nd law: The second law is also referred to as Snell's law: It states that the ratio of sine of angle of incidence to sine of angle of refraction for a pair of media is constant. This constant is referred to as the refractive index ($1\eta_2$) of the second medium (refracting medium) with respect to the first medium (incident medium);

$$1\eta_2 = \frac{\sin i}{\sin r} \qquad \text{(v)}$$

If medium (1) is air and (2) is water, then by equations (i), (iii) and (v);

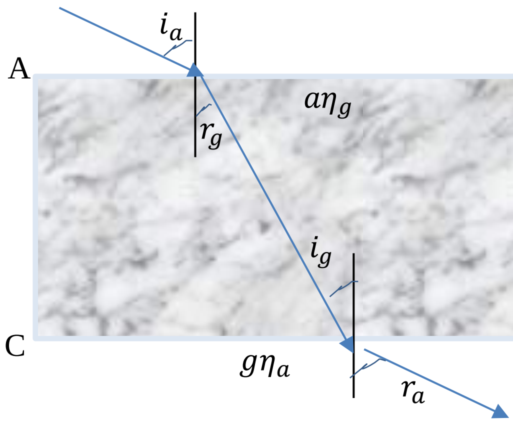
$$\eta_{water} = \frac{\sin i}{\sin r} = \frac{c}{v_{water}} = \frac{\lambda}{\lambda_{water}} \qquad \text{(vi)}$$

NOTE 1:

(i) A ray that enters a second medium normally (parallel to normal) passes through un-deviated.

(ii) When a ray moves from a denser to a less dense medium, it bends away from the normal.

(iii) Say a ray of light moves from air to glass then back to air as shown. Suppose that $a\eta_g$ is the refractive index of glass with respect to air and $g\eta_a$ the refractive index of air with respect to glass.



It follows that for the ray incident on face AB:

$$a\eta_g = \frac{\sin i_a}{\sin r_g} \qquad \text{(vii)}$$

For the ray incident on face CD;

$$g\eta_a = \frac{\sin i_g}{\sin r_a} \qquad \text{(viii)}$$

From trigonometry; $i_a = r_a$ and $r_g = i_g$. With this in mind, equation (viii) may be written as;

$$g\eta_a = \frac{\sin r_g}{\sin i_a} \qquad \text{(ix)}$$

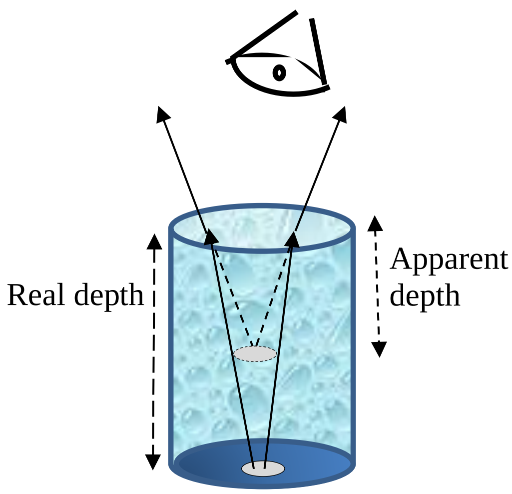
Comparing equation (vii) and (ix) leads to;

$$a\eta_g = \frac{1}{g\eta_a} \qquad \text{(x)}$$

Equation (x) represents the law of reversibility of light travel.

NOTE 2:

If for example a coin is placed at the bottom of a long cylinder filled with water, it appears closer to the surface than it really is when viewed from the surface (top). This is attributed to the refraction of light. As the light moves from water to air, it bends away from the normal.

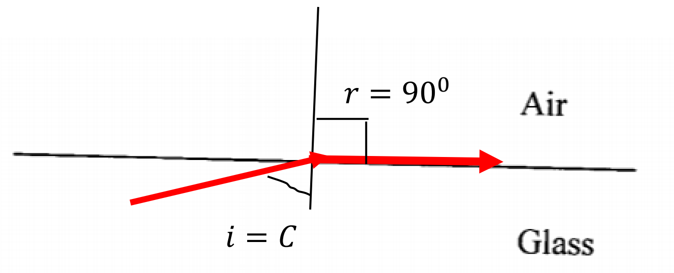


For us to see an object, light must bounce off, or appear to bounce off, the object straight to our eyes. When we view an object in a denser medium, rays bouncing off the object appear to come from a point closer to the surface as opposed to where the object is actually situated. The object appears closer to the surface than it really is. The actual distance between the surface of the denser medium and the object is referred to as **real depth,** while the distance between the surface of the denser medium and where the object appears to be is called **apparent depth**. It can be shown that the refractive index of the denser medium with respect to air, η_{denser} is;

$$\eta_{denser} = \frac{Real\ depth}{Apparent\ depth} \qquad \text{(xi)}$$

NOTE 3:

When a ray of light moves from a denser medium (say glass) to a less dense medium (say air) it bends away from the normal. This means that the angle of incidence is always smaller than the angle of refraction. **Critical angle** (C) refers to the angle of incidence when the angle of refraction is 90^0.



Now, for a ray of light moving from air to glass, the refractive index of glass with respect to air, $a\eta_g$ is given by;

$$\frac{\sin i_{air}}{\sin r_{glass}} = a\eta_g \qquad \text{(xii)}$$

If the ray moves from the same glass to air, and if $g\eta_a$ is the refractive index of air with respect to glass, then;

$$\frac{\sin i_{glass}}{\sin r_{air}} = g\eta_a \qquad \text{(xiii)}$$

Comparing equation (xii) and (xiii), it follows that;

$$\frac{\sin i_{glass}}{\sin r_{air}} = \frac{1}{a\eta_g} \qquad \text{(xiv)}$$

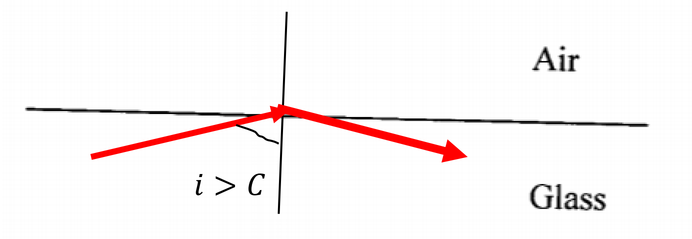
Now $i_{glass} = critical\ angle\ (C)$ when $r_{air} = 90^0$ hence;

$$\frac{\sin c}{\sin 90^0} = \frac{1}{a\eta_g} \qquad \text{(xiv)}$$

But $\sin 90^0 = 1$ hence;

$$Sin\ C = \frac{1}{a\eta_g} \qquad \text{(xv)}$$

When the angle of incidence increases beyond the critical angle, **total internal reflection** takes place.



Conditions for total internal reflection to occur:

i. Ray of light must move from a denser to a less dense medium

ii. Angle of incidence must exceed the critical angle

To the question:

$$Sin\ C = \frac{1}{a\eta_g}$$

$$a\eta_g = \frac{1}{\sin C} = \frac{1}{\sin 42^0} = \frac{1}{0.67} = 1.49$$

6. Figures 2(a) and 2(b) show two circuit diagrams with identical lamps and identical cells.

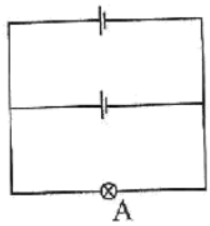


Figure 2(a)

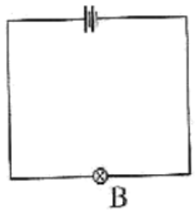
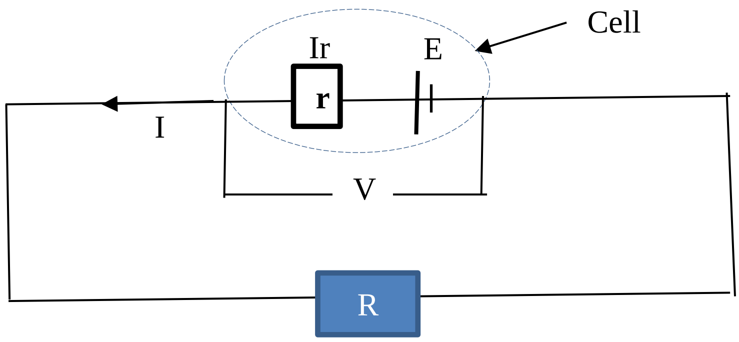


Figure 2(b)

State with a reason which of the bulbs will be brighter (2 marks)

EMF *E* (electromotive force) is the voltage across a cell when it is not connected to an external circuit (cell is not operating), while potential difference *V* (pd) is the voltage across a cell when connected to an external circuit (cell is in operation). EMF is usually greater than the pd. This is because when the cell is in operation, some of the EMF is used to overcome internal resistance (r) of the cell.

Suppose that an operating cell drives a current *I* through an external circuit containing a resistor *R*.



The potential drop due to the internal resistance *r* is equal to *Ir*. The potential difference *V* across the cell is therefore given by:

$V = E - Ir$ (i)

The potential difference given in equation (i) drives the current (*I*) through the resistor *R* hence;

$E - Ir = IR$ (ii)

NOTE 1: When cells are connected in series, the current that passes through the load also passes through all the cells. The total (equivalent) EMF in the circuit is equal to the sum of the EMFs of individual cells. The total internal resistance is equal to the sum of internal resistances of individual cells (similar to resistors in series)

NOTE 2: For cells in parallel, the current through the load is divided amongst the different cells. The total (equivalent, resultant) EMF is equal to EMF of each cell. The total internal resistance is however computed in a manner similar to that of resistors in parallel.

NOTE 3: The main advantage of cells in parallel is that if one fails, others will continue operating since the circuit will remain closed. Household appliances are usually connected in parallel so that if one of the appliances breaks down, other circuits will not be affected. One disadvantage of a parallel arrangement is that the voltage cannot be increased by increasing the number of cells.

NOTE 4: The advantage of cells connected in series is that they give a greater resultant voltage than individual cells, with the voltage increasing if the number of cells increases. One disadvantage is that a failure in one of the cells breaks the circuit. This may however be viewed as an advantage in some instances since it becomes easy to detect and replace faulty cells.

NOTE 5: By the way: Increasing the number of bulbs in a series circuit decreases the brightness of the bulbs. In a series circuit, the voltage is equally distributed among all the bulbs. Bulbs in parallel are brighter than bulbs in series. In a parallel circuit, the voltage across each bulb is the same as the voltage in the circuit.

To the question
The total (equivalent, resultant) EMF in parallel circuit is equal to EMF of each cell while the total (equivalent) EMF in the series circuit is equal to the sum of the EMFs of individual cells.
Effective EMF in B is higher than in A hence B will be brighter.

7. Figure 3 shows an annular ring

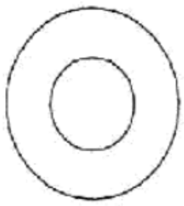
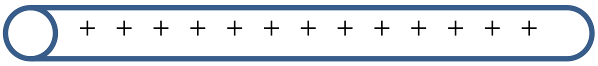


Figure 3

On the diagram, sketch the distribution of charge on the ring when the ring is negatively charged.

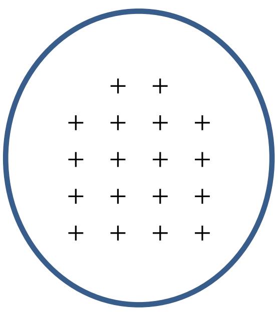
There are three types of charge distribution:
Linear charge distribution: Charge, say Q, is uniformly spread in a line on a straight line say length l (for example a wire), or circumference of a circle.



In this case, charge is quantified in terms of linear charge density, λ, defined as charge Q per unit length l, i.e.

$\lambda = \frac{Q}{l}$ (i)

Surface charge distribution. Charge, say Q, is distributed continuously and uniformly over some surface area, say A (for example a circular sheet of metal).



The charge is quantified in terms of surface charged density σ, defined as charge per unit surface area;

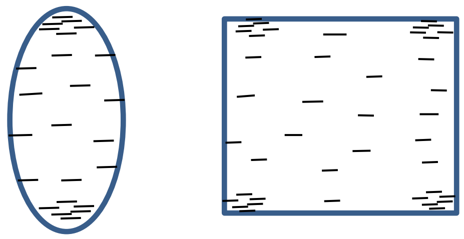
$\sigma = \frac{Q}{A}$ (ii)

Volume charge distribution: charge is continuously and uniformly distributed over a volume, for example a sphere. It is quantified in terms of volume density ρ defined as charge Q per unit volume V;

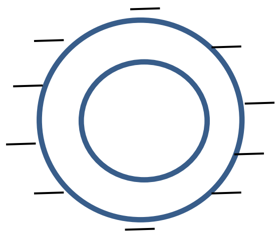
$\rho = \frac{Q}{V}$ (iii)

NOTE:

When charge is placed on a pointed object, the magnitude of charge (say negative charge) is greatest at the pointed ends.



To the question: An annular ring is associated with surface charge density hence the charge will be uniformly distributed on the surface of the ring.



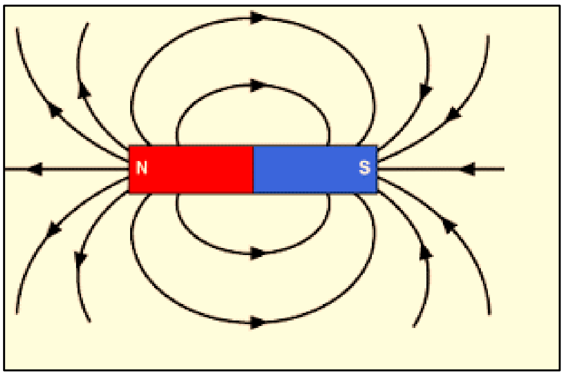
8. When iron filings are sprinkled onto a bar magnet, it is observed that there are more iron filings at the ends than in the middle. Explain this observation. (2 marks)

Magnetic field is the region around a magnet where its effects can be felt. Magnetic field is a vector quantity, represented by lines called magnetic field lines or lines of force.

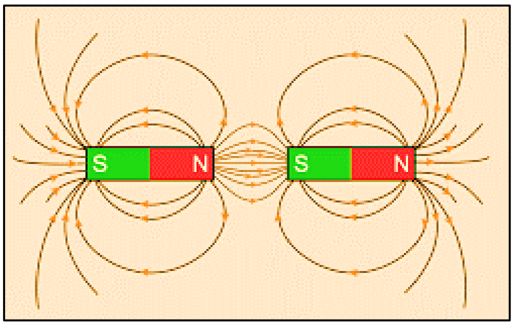
Properties of magnetic field lines;

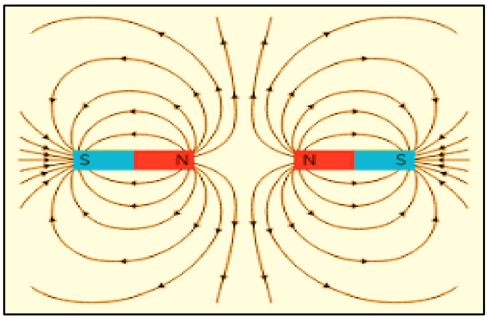
- point from north to south
- leave north pole and enter south pole at right angles

- do not cross each other



According to the law of magnetism, like poles repel and unlike poles attract. The field between two attracting and repelling magnets is as shown, respectively.



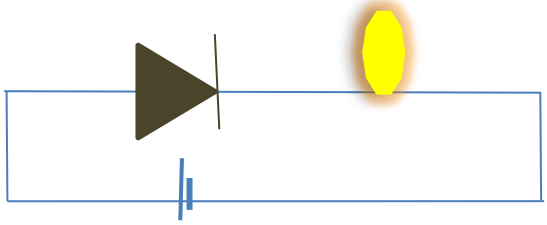


NOTE (answer to question)

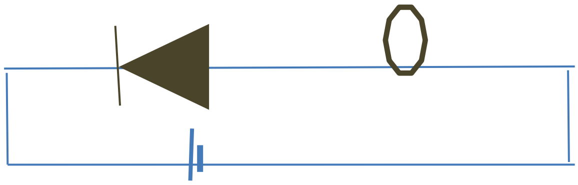
A magnet is strongest at the poles as opposed to the middle. The stronger the magnet, the higher the magnetic field. Since magnetic field refers to the number of magnetic field lines passing perpendicularly in a unit area, the magnetic field lines will be closer together at the poles where the magnet is strongest than at the center. Iron fillings follow the magnetic field lines hence the filings will be more concentrated at the ends where the magnet is strongest as opposed to the middle.

9. Draw a diagram to show a p-n junction connected in the reverse bias mode. (2 marks)

A diode is a 2-terminal device that conducts electricity in one direction only. This means that it has minimum resistance when connected one-way and maximum resistance when connected the other way. When conducting, the diode is said to be forward biased and when not conducting it is said to be reverse biased.

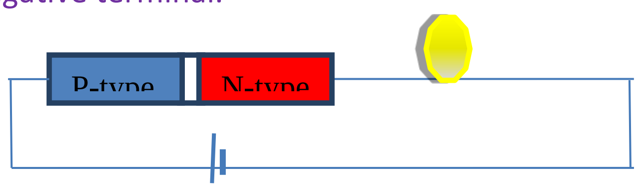


Forward biased; Current flows in the circuit. The bulb lights up.

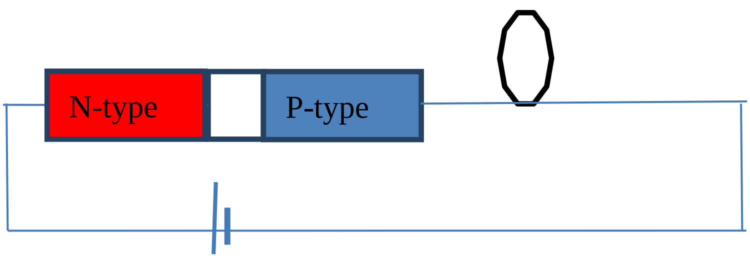


Reverse biased; No current flows in the circuit. The bulb does not light up

A PN junction diode is made up of two layers of semiconductor materials. A semiconductor is a solid whose conductivity lies between that of a conductor and an insulator. It can be a conductor under certain conditions and an insulator under other conditions. One layer is doped with a P-type material and the other N-type material. A P-type material has an excess of positively charged carriers. It’s an extrinsic semiconductor formed when a trivalent element (impurity) is added to an intrinsic (pure) semiconductor. An N-type material on the other hand has an excess of negatively charged carriers. It is an extrinsic semiconductor formed when an intrinsic semiconductor is doped with a pentavalent element. A PN junction diode is said to be forward biased when the P-type region is connected to the positive terminal of a power source and N-type region to the negative terminal. It is reverse biased when the N-type region is connected to the positive terminal of a power source and P-type region to the negative terminal.

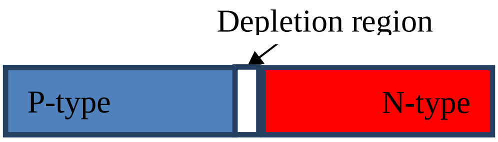


Forward biased, bulb lights up



Reverse biased, bulb off

Soon after fabrication of a PN junction diode, a thin depletion region is formed between the P-type and N-type materials (without the aid of external power source).

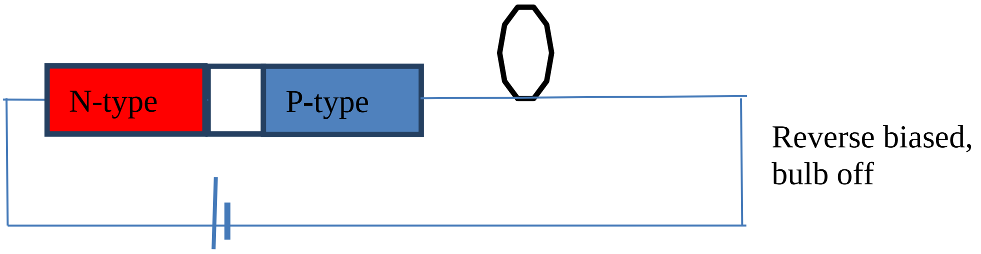


The depletion region is formed due to diffusion of negative charge carries in to the P-region and holes into the N-region on account of concentration gradient. The holes and electrons diffusing towards each other merge, forming a region devoid of free charge carriers. This region, called depletion region, acts as an insulator. The thickness of the depletion region is reduced when the diode is forward biased as more electrons are pushed across the junction. An increase in forward voltage leads to a further decrease in the thickness of the depletion region leading to an increase in the diode conductivity. If the voltage is increased beyond a certain threshold value, the thickness of depletion layer is reduced so much so that the diode becomes a super conductor and the current increases sharply. Thickness of the depletion region is increased by reverse biasing the diode as holes (positive charge carriers) move to one end of the diode due to attraction by the negative terminal (well, holes appear to move but in reality, it is the few electrons in the P-region that are repelled by the negative voltage leaving holes behind) while the negative charge carriers move to the other extreme end under the action of the positive terminal. If the reverse voltage is increased beyond a certain threshold value, the diode breaks up and starts conducting. This threshold voltage is called breakdown voltage.

NOTE:

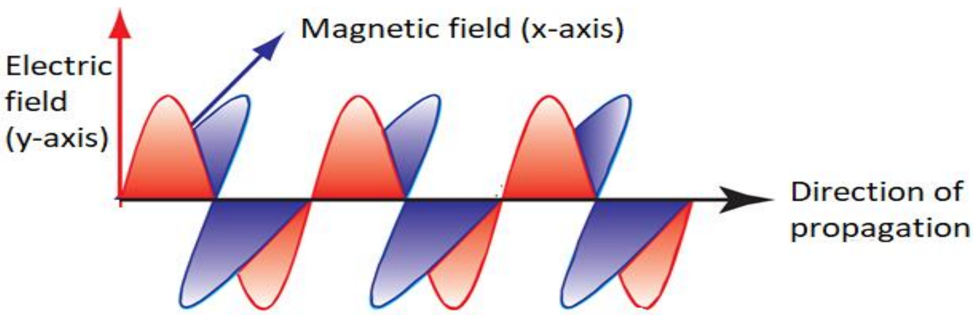
- The conductivity of a pure semiconductor can be increased by doping (adding an impurity).
- Heating a semiconductor (increasing the temperature) increases its conductivity as electrons gain more kinetic energy hence become more mobile. if temperature is reduced, the KE of the electrons reduces thus reducing their mobility. The diode conductivity reduces.
- For a conductor such as metal, conductivity reduces with temperature but for a semiconductor, conductivity increases with temperature.

To the question: Reverse biased diode



10. A broadcasting station produces radio waves of wavelength 800 m. Determine their frequency (speed of air is 3 x 10^8ms^{-1}). (2 marks)

Electromagnetic (EM) waves are formed by varying electric and magnetic fields at right angles with each other. They are transverse in nature in that the direction of propagation is at right angles with the direction of variation of the electric and magnetic waves.



EM waves have a dual nature which means that they behave as waves as well as particles. The wave nature is used to explain characteristics such as reflection, refraction and interference. EM waves obey the wave equation;

$c = \lambda f$ (i)

Where c is the velocity of the EM waves in space, λ is the wavelength and f is the frequency. All EM waves travel at the same velocity (c) in space (vacuum, air) with $c = 3 \times 10^8\ m/s$.

According to the particle theory, EM waves are particles called photons, and each photon carries a discrete amount of energy E which is directly proportional to frequency f, i.e.

$E \infty f$ (ii)

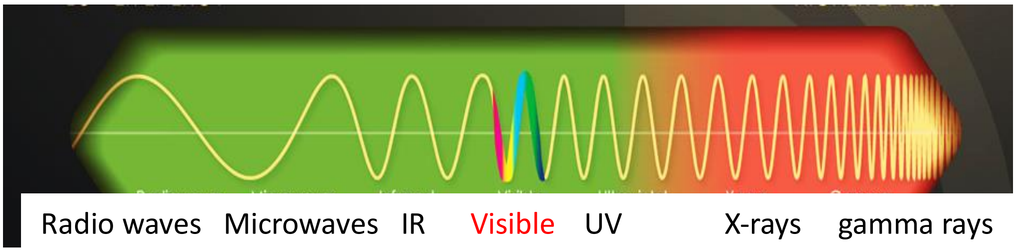
$\Rightarrow E = hf$ (iii)

Where h is the constant of proportionality called Planck's constant.

Using equation (i) in equation (iii) leads to:

$$E = \frac{hc}{\lambda} \qquad \text{(iv)}$$

EM waves are classified in terms of energy and represented in the electromagnetic spectrum. Radio waves and microwaves have the lowest energy while X-rays and gamma rays (γ-rays) have the highest energy.



Radio waves	Microwaves	Infrared		Ultra violet (UV)	X-rays	Gamma rays

Visible region: red, orange, yellow, green, blue, Indigo, violet

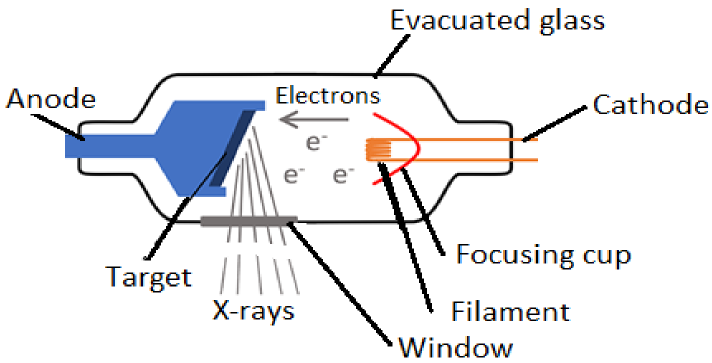
To the question

$c = \lambda f$

$$f = \frac{c}{\lambda} = \frac{3 \times 10^8}{800} = 3.75 \times 10^5\ Hz$$

11. Explain how x-rays are produced in the x-ray tube. (2 marks)

X-ray production in X-ray tube:



The negative cathode is heated to very high temperatures leading to the emission of electrons through thermionic emission. The higher the temperature, the more the electrons emitted. The emitted electrons are accelerated towards the tungsten anode (positive) by a potential difference between the anode and the cathode. The higher the potential difference, the greater the speed of the electrons. When the electrons hit the target, their speed and hence their KE reduces. The difference between the initial and final KE is converted to X-rays.

NOTE 1: increasing the cathode temperature leads to the emission of more electrons. More electrons reach the anode leading to increase in intensity (think brightness) of the X-rays produced.

NOTE 2: Increasing the accelerating voltage increases the kinetic energy of the electrons. The difference in KE after collision with the anode will therefore be higher. The higher the change in KE the higher the energy of the X-rays produced (more penetrating X-rays are produced).

12. State the purpose of a fuse in an electrical circuit. (1 mark)

Electric energy is the work W done when a charge Q moves between two points with a potential difference V and is given by;

$W = VQ$ (i)

We know that current is charge passing a particular point per unit time, that is;

$I = \frac{Q}{t}$ (ii)

$\Longrightarrow Q = It$ (iii)

Using equation (iii) in equation (i) leads to;

$W = VIt$ (iv)

From definition of power;

$Electric\ power\ (P) = \frac{work}{time} = \frac{VIt}{t}$ (v)

$\Longrightarrow P = VI$ (vi)

Now, fuses determine the amount of current that can flow through a load (say an appliance) before some safety mechanism is triggered. If more current than configured flows through an appliance, the appliance may be damaged (blow). A fuse is a weak link in an electrical circuit that blows up and breaks the circuit in the event of excess current (overload, current beyond a given threshold) thereby protecting the appliance from potential damage. For an individual circuit, fuse rating should have a value closest to the full load current.

To the question:

A fuse is a weak link in an electrical circuit that blows up and breaks the circuit in the event of excess current (overload, current beyond a given threshold) thereby protecting the appliance from potential damage.

13. Figure 4 shows circular water waves incident on a plane reflector placed at an angle to the path of the waves. Complete the diagram to show the reflected waves. (2 marks)

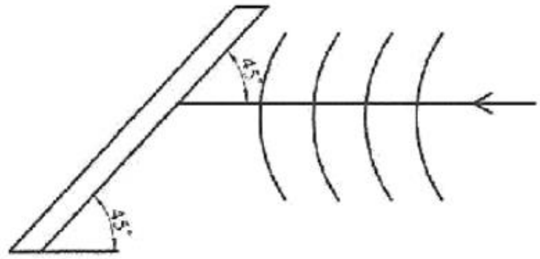


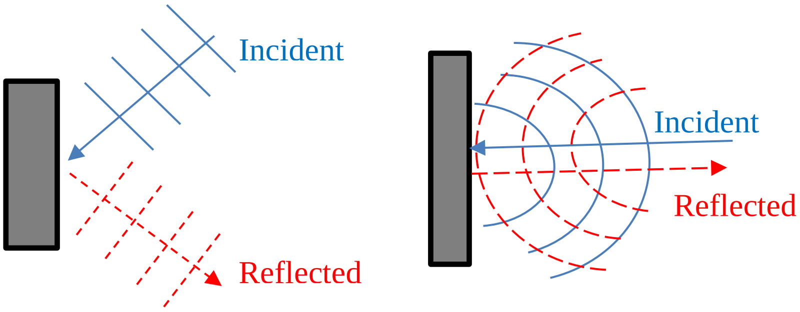
Figure 4

Like any other waves, water waves obey the laws of reflection;

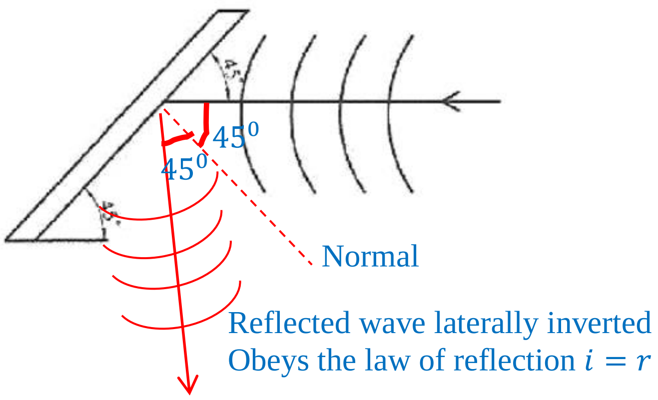
(i) Angle of incidence equals angle of reflection.

(ii) At the point of incidence, the incident ray, the reflected ray and the normal all lie on the ssame plane.

Also, if water waves hit a plane reflector, the reflected waves are laterally inverted (left becomes right).



To the question:



SECTION B (55 MARKS)

14.(a) State two ways of minimising power losses during the transmission of electric power. (1 mark)

When current passes through a wire, heating (Joule's heating) occurs due to power loss. For a wire of resistance R carrying current I, power loss P_{loss} is given by;

$$P_{loss} = I^2R \qquad \text{(i)}$$

From equation (i) it is clear that if the resistance of the wire, and/or the current passing through the wire are high, power loss will be equally high. This is because a higher amount of work is required to move current through a wire of high resistance as well as in cases where a high current is involved. Power meant for transmission does this work hence the power loss. For power loss to be minimised therefore, current should be as low as possible and wires/cables of low resistance used.

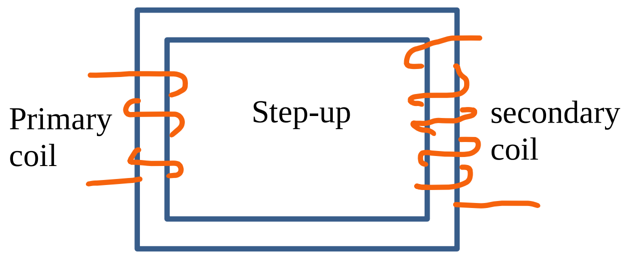
Now, electric power generated P is given by;

$$P = VI \qquad \text{(ii)}$$

Equation (ii) implies that if the current is reduced to a minimum before transmission so as to reduce power loss, the voltage has to be increased proportionately. The process of increasing voltage is referred to as stepping up. Many appliances for example in homes operate at relatively low voltages. The stepped-up power must therefore be stepped down to appropriate voltages before being distributed for consumption. The devise used for stepping up or down voltage is called a transformer. The stepping up/down is usually through induction and as such the voltage involved has to be alternating voltage.

There are two types of transformers:

(i) Step-up transformers which have more turns in the secondary coil relative to primary coil:

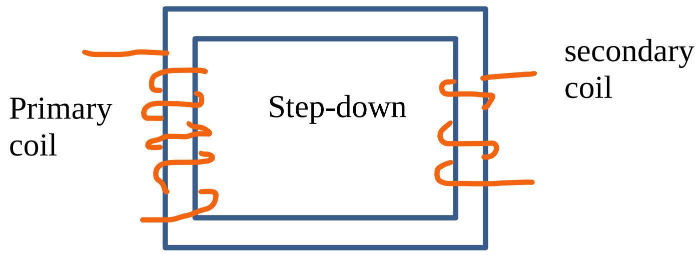


The primary coil is connected to an alternating voltage/current. Current flowing through a wire has an associated magnetic field whose direction depends on the direction in which the current is flowing. When current in the primary coil changes direction, the magnetic field changes direction too. According to Faradays laws, a changing magnetic flux ϕ (magnetic field B passing normally through a given area A, hence $\phi = BA$) induces EMF (voltage) in a coil (secondary coil) linked to the changing magnetic field of the primary coil. The magnitude of the induced EMF depends on the number of turns (in the secondary coil) and the rate of change of magnetic flux, summarized mathematically as;

$$EMF = N\frac{d\phi}{dt} \qquad \text{(iii)}$$

A higher number of turns in the secondary coil means that a higher voltage (EMF) is induced.

(ii) the step-down transformers – have more turns in the primary coil;



NOTE 1

Assuming the transformers are 100% efficient (no power loss during stepping up and down voltage) input power (power in primary coil) is equal to output power (power in secondary coil). If V_p *and* I_p be voltage and current in the primary coil and V_s *and* I_s the voltage and current in the secondary coil, then;

$$V_pI_p = V_sI_s \qquad \text{(iv)}$$

$$\Longrightarrow \frac{V_p}{V_s} = \frac{I_s}{I_p} \qquad \text{(v)}$$

Also;

$$\frac{V_p}{V_s} = \frac{N_p}{N_s} \qquad \text{(vi)}$$

From equations (iv) and (v), it follows that;

$$\frac{V_p}{V_s} = \frac{N_p}{N_s} = \frac{I_s}{I_p} \qquad \text{(vii)}$$

NOTE 2:

The resistance R of a wire is:

i. inversely proportional to cross-section area A, ie.

$$R \infty \frac{1}{A} \qquad \text{(viii)}$$

ii. directly proportional to length l, ie.

$$R \infty l \qquad \text{(ix)}$$

iii. Combing equations (viii) and (ix) leads to;

$R \propto \frac{l}{A}$ (xi)

$\Rightarrow R = \frac{\gamma l}{A}$ (xii)

where γ is a constant of proportionality called resistivity. Different materials naturally have different magnitudes of resistivity. For example, aluminium wire has a higher resistivity than a copper wire of equal dimensions. This means that the best way to reduce the resistance of aluminium power lines (and hence the power loss) is by using thick cables (cables with a large cross-sectional area).

Answer to the question:

Minimising power losses during the transmission of electric power

- To reduce Joule's heating on account of power loss given by $P = I^2R$, the power is **stepped up to vey hight voltages** so as to reduce the current (power remains constant since $P = VI$)
- To reduce the resistance of the transmitting cables, **thick cables are used** since from $R = \frac{\gamma l}{A}$ the thicker the wire the higher the cross-sectional area (A) of the cable the lower the resistance.

(b) An electric cooker is rated 2.5 kW, 250 V. State the meaning of these values. (1 mark)

Power =2.5 kW

Voltage = 250 V

(c) A consumer has the following appliances in the house:

An electric iron rated 1500 W

A water heater rated 500 W

An electric cooker rated 2500 W

Three bulbs each rated 60 W.

The house is fitted with a 12 A fuse. Determine:

(i) whether the consumer can connect all the appliances to the 240 V power supply at the same time;(4 marks)

Electric appliances are usually connected in parallel. In a parallel circuit, the voltage across each appliance is equal to the supply voltage (240 V) while the total current equals the sum of currents through each appliance. If the house is fitted with a 12 A fuse, then the total current should not exceed this amount by much. From the equation;

$P = VI$

Current I through each appliance is given by

$I_{appliance} = \frac{P_{appliance}}{V}$

$I_{iron} = \frac{1500}{240} = 6.25\ A$

$I_{heater} = \frac{500}{240} = 2.08\ A$

$I_{cooker} = \frac{2500}{240} = 10.42\ A$

$I_{bulb} = \frac{60}{240} \times 3 = 0.75\ A$

$Total\ current\ = 6.25 + 2.08 + 10.42 + 0.75$

$Total\ current = 19.5\ A \gg 12\ A$

Hence cannot connect all the appliances at the same time.

NOTE: Total power (power in the circuit) for a parallel arrangement equals the sum of power in individual circuits. The total voltage is however equal to the voltage across each circuit. Thus;

$P_{total} = VI_{total}$

$I_{total} = \frac{P_{total}}{V} = \frac{1500 + 500 + 2500 + (60 \times 3)}{240}$

$Total\ current = 19.5\ A$

(ii) the resistance of the heating element used in the electric cooker. (3 marks)

$I_{heater} = \frac{2500}{240} = 10.417\ A$

From Ohm's law,

$V = IR$

$R = \frac{V}{I} = \frac{240}{10.417} = 23.04\ \Omega$

15.(a) Describe how the focal length of a concave mirror can be determined using a screen and a metre rule. (1 mark)

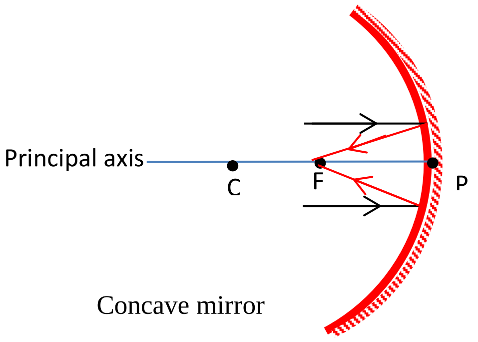
There are two types of curved mirrors:

(i) Concave mirrors which are silvered on the outside

(ii) Convex mirrors which are silvered on the inside.

(i) Concave Mirrors

A concave mirror is also referred to as converging mirror since it reflects parallel rays to a point. If this point lies on the principal axis, it is called principal focus F. Principal focus is real and is located in front of the mirror.



A concave mirror forms both virtual (cannot be formed on a screen, formed opposite the object relative to the mirror) and real images (can be formed on a screen, formed on the same side as the object) depending on the position of the object relative to the mirror.

Characteristics of images formed by Concave (converging) mirror

Object at infinity

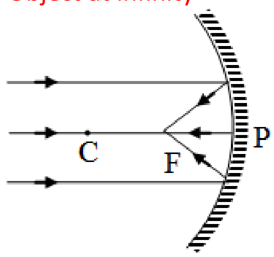


Image characteristics
Real, at F

Object beyond C

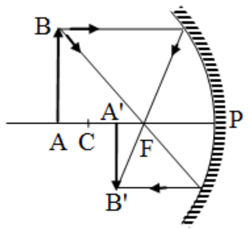


Image characteristics:
real, inverted,
between F and C,
smaller than object

Object at C

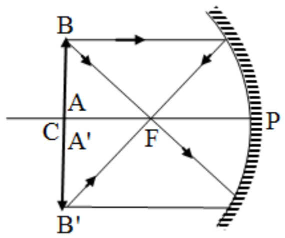


Image characteristics
Real, at C, inverted,
same size as object

Object between
C and F

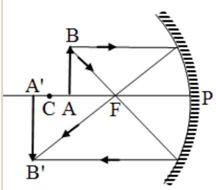


Image characteristics:
Real, inverted, larger,
beyond C

Object at F

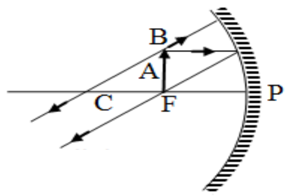


Image characteristics:
Image at infinity (very
far

Object between F and mirror

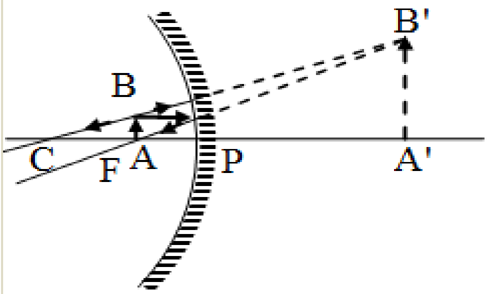
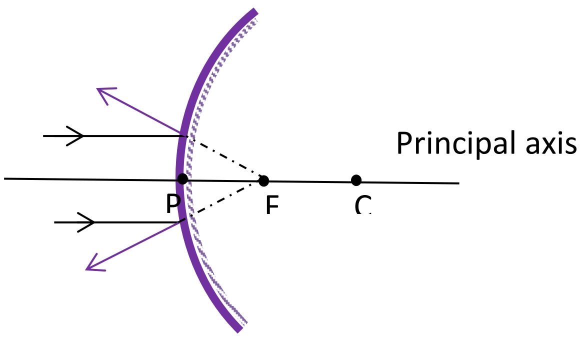


Image characteristics:
Behind the mirror, virtual, upright, bigger than object. Mirror acts as a magnifying glass

Convex mirror

A convex mirror on the other hand reflects parallel rays such that they appear like they are form a principal focus behind the mirror. Principal focus is virtual and is located behind the mirror.



Convex mirror

A convex mirror forms a virtual image irrespective of the position of the object relative to the mirror.

Object at infinity

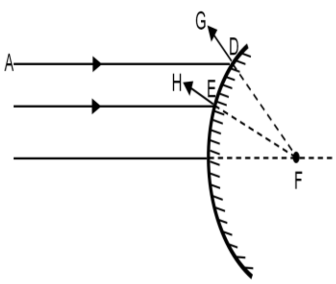


Image at the focus F, behind the mirror,

Object between infinity and pole P

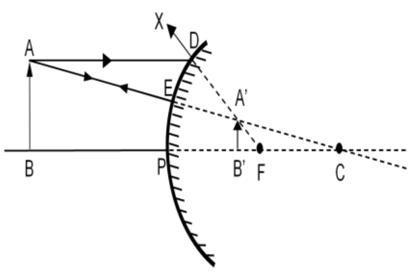


Image is between P and F, behind the mirror, diminished, virtual, erect

NOTE 1: All curved mirrors obey the mirror formula:

$$\frac{1}{f} = \frac{1}{u} + \frac{1}{v} \qquad \text{(i)}$$

Where f is the focal length (distance between center of the mirror (pole) and the principal focus; u is the distance between the object and the mirror (object distance); v is the distance between the image and the mirror (mirror distance). Now, the distance between the center of curvature, C (center of the sphere of which the mirror is part of) and the pole is called the radius of curvature R. It can be shown that:

$$f = \frac{R}{2} \qquad \text{(ii)}$$

NOTE 2: All virtual distances are assigned a negative value while all real distances are assigned a positive value (real is positive). For all virtual images, the image distance is therefore negated. Also, since the principal focus of a convex mirror is virtual, then the focal length is negated.

NOTE 3: Formation of images by curved mirrors is represented graphically by ray diagrams. Any two of the following three rays may be used;

Concave mirror:

(i) Rays parallel to the principal axis are reflected through the principal focus

(ii) Rays through the principal focus are reflected parallel to the principal axis

(iii) Rays through the center of curvature are reflected along the same path.

Convex mirror:

(i) Rays parallel to the principal axis are reflected as if they are from the principal focus behind the mirror

(ii) Rays directed towards the principal focus are reflected parallel to the principal axis

(iii) Rays directed towards the center of curvature are reflected along the same path.

NOTE 4: Focal length of a concave mirror is the point on the principal axis where rays parallel to the principal axis converge after reflection. It is real and in front of the mirror. Focal length of a convex mirror on the other hand is the point on the principal axis where rays parallel to the axis appear to diverge from after reflection. It is virtual and behind the mirror.

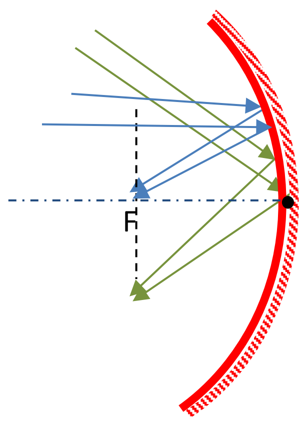
NOTE 5: There are various experimental methods of determining the focal length of a concave mirror:

(i) Using the mirror formula

- Place an object between a concave mirror and a screen.
- Vary the distance between the object and the concave mirror until a sharp image is formed on the screen.
- Measure the distance between the object and the mirror (u)
- Measure the distance between the image (screen) and the mirror (v).
- Use the mirror formula $\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$ to determine the focal length f.

(ii) Focussing a far-off object (Answer to the question):

- Parallel rays (rays from far-off objects are more or less parallel) always converge at a point on the focal plane (plane passing through the principal focus):



- Use the concave mirror to focus a far-off object on a screen.
- Adjust the distance between the mirror and the screen until a sharp image is formed.
- Measure the distance between the mirror and the screen.
- This distance corresponds to the focal length of the mirror.

(b) An object is placed 8cm from a concave mirror whose radius of curvature is 20cm. Determine the position of the image. (3marks)

$R = 2f$

$\Longrightarrow f = \frac{R}{2} = \frac{20}{2} = 10\ cm$

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

$$\Rightarrow \frac{1}{10} = \frac{1}{8} - \frac{1}{v}$$

$$\frac{1}{v} = \frac{1}{8} - \frac{1}{10} = \frac{1}{40}$$

$$v = 40\ cm$$

(c) An object of height 10 cm is placed 30 cm from a converging lens of focal length 18 cm.

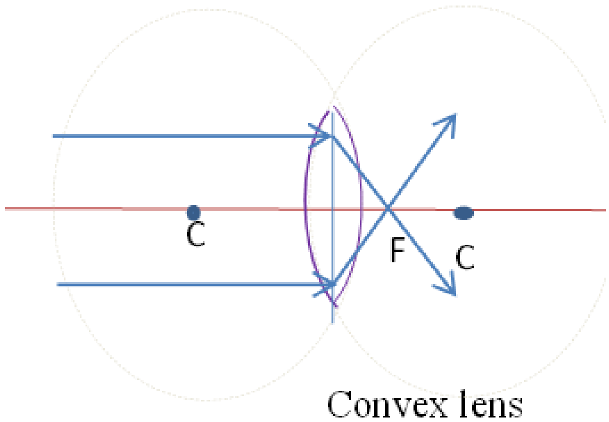
There are two types of curved lenses:

(i) convex lens (bulges at the center) and

(ii) concave lens (thin at the center).

Convex lens

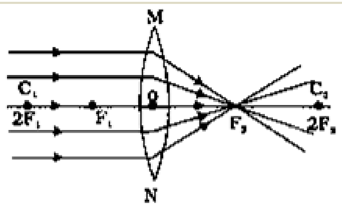
A convex lens is a converging lens in that all parallel rays incident on it are refracted so as to converge at a point called a focal point. If the focal point lies on the principal axis, it is referred to as the principal focus F.



Convex lens

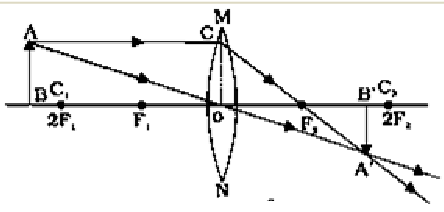
A convex lens can form either virtual or real images depending on the position of the object relative to the lens.

Characteristics of images formed by a convex (converging) lens



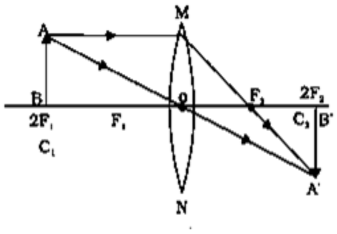
Case (i) Object at infinity

Image characteristics;
Real, at F



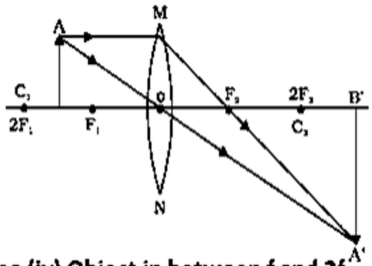
Case (ii) Object at beyond 2f

Image characteristics; real, inverted, diminished (smaller), between F and 2F



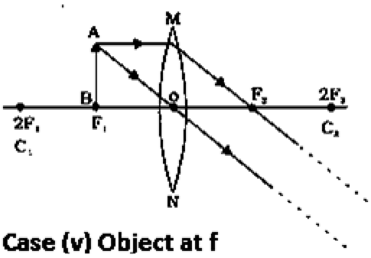
Case (iii) Object at 2f

Image characteristics; real, inverted, same size as object, at C (2F)



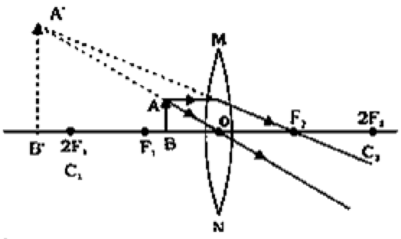
Case (iv) Object in between f and 2f

Image characteristics; real, inverted, bigger than object, beyond C (2F)



Case (v) Object at f

Image at infinity



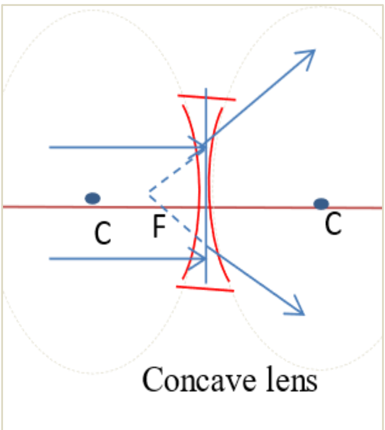
Case (vi) Object distance < f

Image characteristics; Virtual, upright, bigger than object, same side as object

For a convex lens to form a virtual image, the object must be placed between F (principal focus) and the lens. The virtual image is always bigger than the object.

Concave lenses

A concave lens on the other hand diverges all parallel rays falling on it in such a way that they appear as if they are coming from a point on the opposite side (principal focus if point is on the principal axis). It only forms virtual images irrespective of the position of the object.



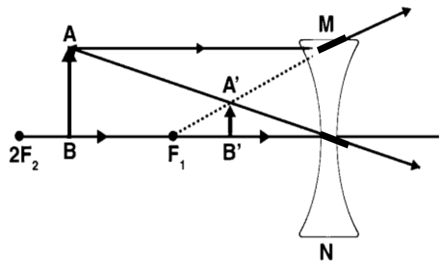


Image Characteristics, Virtual, Smaller than object, Same side as object, upright

All images formed by a concave lens bear these characteristics.

NOTE 1:

Curved mirrors form images through reflection of light while lenses form images through refraction of light. Also, concave mirror is converging while concave lens is diverging. Similarly, convex mirror is diverging while convex lens is converging).

NOTE 2

All lenses obey the lens formula (similar to the mirror formula);

$$\frac{1}{f} = \frac{1}{u} + \frac{1}{v} \qquad \text{(i)}$$

Where f is the focal length, u is the distance of the object from the lens and v is the distance of image from the lens. Real distances are taken to be positive (object distances, distances of real images, focal length of convex lens,) while virtual distances are taken to be negative (distances of virtual images and focal length of concave lens).

NOTE 3:

Image magnification M refers to the ratio of size (e.g. height) of the image to that of the object (or how much an image is bigger than the object). If for example h_o be the height of the object and h_i the height of the image formed, then the magnification M is given by:

$$M = \frac{h_i}{h_0} \qquad \text{(ii)}$$

It can be shown that if u be the distance of the object from the lens and v the distance of image from the lens, then;

$$M = \frac{v}{u} \qquad \text{(iii)}$$

Comparing equations (ii) and (iii) shows that;

$$M = \frac{h_i}{h_0} = \frac{v}{u} \qquad \text{(iv)}$$

Now, if the $M > 1$, the image is larger than the object; $M = 1$, the image is of the same size as the object and if $M < 1$, the image is smaller than the object.

NOTE 4:

Formation of images by lenses is represented graphically by ray diagrams. To obtain the ray diagram, any two of the following three rays may be used;

Convex lens:

- Rays through the center of the lens pass through un-deviated
- Rays parallel to the principal axis are refracted through the principal focus
- Rays through the principal focus are refracted parallel to the principal axis

Concave lens:

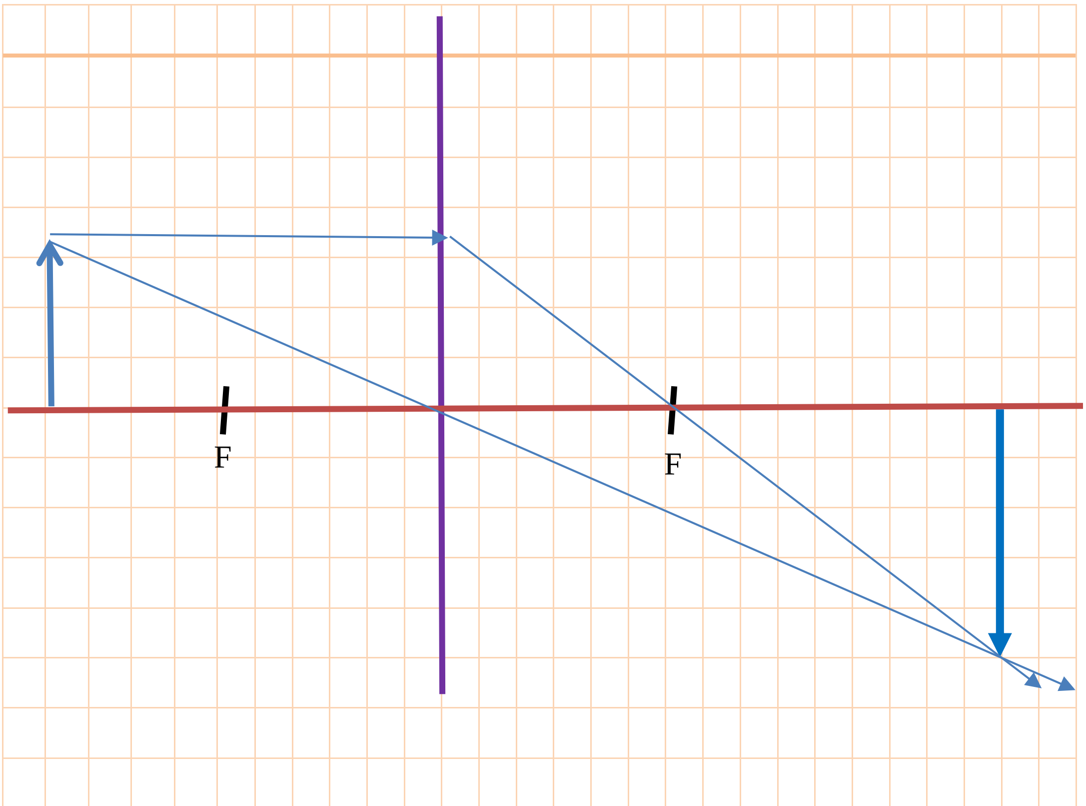
- Rays through the center of the lens pass through un-deviated

- Rays parallel to the principal axis are refracted as if they are coming from the principal focus on the same side as the rays
- Rays directed towards the principal focus on the other side of the lens are refracted parallel to the principal axis

(i) On the grid provided. draw a ray diagram to locate the position of the image formed. (3 marks)

Object height 10 cm is placed 30 cm from a converging lens of focal length 18 cm.

Scale 1 box rep 3 cm



(ii) From the diagram in part (i), determine the:

(I) image height; (2 marks)

$5 \times 3 = 15\ cm$

(II) image distance. (2 marks)

$15 \times 3 = 45\ cm$

16.(a) State two uses of radioactivity in medicine. (1 mark)

Radioactivity or radioactive decay is the disintegration of unstable atomic nuclei with the release of energy/radiation. Atoms or elements with unstable nuclei are said to be radioactive. Radioactive element/atoms are called radionuclides. Atoms are composed of electrons which are negatively charged, revolving in orbits (shells) around a core called a nucleus. A nucleus contains protons which are positively charged and neutrons which carry no charge. The protons and neutrons are collectively referred to as nucleons. The nucleus carries nearly all the mass of the atom.

Instability of the nucleus occurs either because nucleus:

(i) is too heavy

(ii) has too many neutrons

(iii) has too many protons

(iv) is excited (has excess energy).

The nucleus therefore decays to try and achieve stability by transforming to a new element and releasing particulate energy in the process, or by shedding off the excess energy in the form of electromagnetic radiation without transforming into a new element. Where transformation occurs, the transforming element is called the parent while the new element is the daughter. If the daughter is radioactive, it also disintegrates to a daughter. The process continues until a stable (non-radioactive) element is produced. The radionuclides formed before a stable element is produced makes up the decay series, also called decay chain.

Radioactive decay generally falls under three categories based on the type of radiation emitted; (i) alpha decay (ii) beta decay (iii) gamma decay. Alpha and Beta decays produce particulate radiation hence the parent is transformed to a new element. Gamma decay produce energy in the form of electromagnetic radiation and does not transform the parent into a new radionuclide. Further;

i. Alpha decay – occurs in heavy atoms. In alpha decay, the parent (X) transforms into a daughter (Y) and an alpha particle is released. An alpha particle is a helium nucleus ($^{4}_{2}He$). During the decay process, the atomic number Z (mass of protons) of the parent reduces by 2 and the atomic mass A (mass of protons and neutrons) reduces by 4;

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

Alpha particles are heavy, slow, less penetrating (can be stopped by a thin paper), highly ionizing (form thick tracks) and are deflected by both electric and magnetic field. Alpha particles are extremely damaging when they interact with soft tissue such as lungs and can lead to cancer.

ii. Beta decay (beta minus) – occurs in elements with an excess of neutrons. During beta decay, a neutron is converted to a proton and an electron. The electron is emitted as a beta (beta minus) particle (${}_{-1}^{0}e$) while the proton adds the atomic number by one. The atomic mass does not change since $atomic\ mass\ = protons + neutrons$

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

Beta particles are very light, much faster and more penetrating than alpha particles (stopped by aluminium foil), less ionising (tracks not as thick) and are deflected by both electric and magnetic field but in opposite direction to the alpha particles

iii. Gamma decay does not transform the parent to a new element. When beta and alpha decays occur, the daughter is often left in an excited (excess energy) state. The daughter de-excites (goes to ground state) by shedding off the excess energy in the form of gamma rays.

Gamma rays are massless electromagnetic waves unlike alpha and beta particles. They are extremely penetrating (stopped by lead metal), mainly ionize indirectly, and are not deflected by either electric or magnetic field

Gamma rays, like X-rays have many applications:

In hospitals:

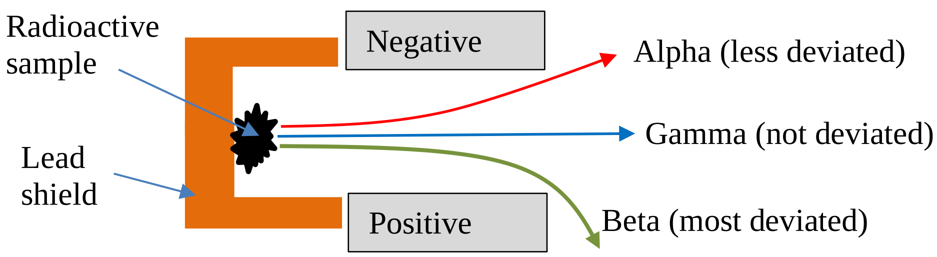
- Used in the treatment of cancer whereby the radiation kills the cancer cells by damaging their DNA.
- Sterilize medical equipment by killing germs.
- Used in imaging body organs.

In industry:

- Used to check for defects for example in metal pipes. When gamma rays are directed towards a metal pipe, the solid parts of the pipe will block most of the rays while most of the rays will pass through the cracked parts.
- Used to determine the thickness of metal since thicker metal will block more gamma rays than thinner metal.
- Used in the food industry for example to sterilize food products (irradiated food) such as potatoes by killing germs (instead of using pesticides) hence prolonging the shelf-life.

Alpha, beta and gamma radiation are forms of ionizing radiation which means that they are capable of removing electrons from atoms. Ionizing radiation can damage cells and should therefore be handled by trained personnel only. Alpha radiation is the most ionizing (hence most dangerous if produced inside the human body), followed by beta and lastly gamma.

Alpha and beta particles are deflected by an electric field while gamma radiation is not. Alpha particles are attracted by the negative plate since they are positively charged while beta particles are attracted by the positive plate since they are negatively charged. Gamma radiation is not deflected since it has no charge.



The decay process is not a one-off affair where all radioactive atoms decay at once. Rather, it is a random spontaneous process where atoms decay at different times. Consequently, the number of atoms of parent radionuclide reduce with time. To put it into perspective, imagine a *kiondo* full of fresh tomatoes. As time goes by, the tomatoes decay gradually thereby reducing the number of fresh tomatoes. Eventually all the tomatoes in the *kiondo* decay. Now, according to the **decay law**, the rate of decay (disintegration) of radioactive elements is directly proportional to the number of radioactive elements present at the time. If for example there are N radioactive elements present at time $t = 0$, then;

$$\frac{dN}{dt} \infty N \quad \text{(i)}$$

$$\frac{dN}{dt} = -\lambda N \quad \text{(ii)}$$

where λ is a constant of proportionality called decay constant. The negative sign is used to show that the number of radioactive elements reduces with time. The rate of decay is referred to as activity.

$$-\frac{dN}{dt} = \lambda N = Activity \quad \text{(iii)}$$

Decay constants are unique to each element. Some elements have a large decay constant while others have a small decay constant. Those with large decay constant disintegrate very fast hence have a higher activity (for example radon) while those with a small decay constant disintegrates very slowly hence have a lower activity (for example uranium).

Equation (ii) may be expressed as:

$$\frac{dN}{N} = -\lambda dt \qquad \text{(iv)}$$

If at $t = 0, N = N_0$ and at a later time $t = t\ N = N$, then;

$$\int_{N_0}^{N} \frac{dN}{N} = -\lambda \int_0^t dt \qquad \text{(v)}$$

$$\ln N - \ln N_0 = -\lambda t \qquad \text{(vi)}$$

$$\ln\left(\frac{N}{N_0}\right) = -\lambda t \qquad \text{(vii)}$$

$$\frac{N}{N_0} = e^{-\lambda t} \qquad \text{(viii)}$$

$$N = N_0 e^{-\lambda t} \qquad \text{(ix)}$$

Equation (ix) is often used to represent the decay law.

The activity of radionuclides is usually related to the half-life (T) of the radionuclide. **Half-life** refers to the time required for half the radionuclides initially present to decay. If for example at some time $t = 0$ the number of radionuclides present is N_0, then at time $t = T(halflife)$, the number of radioactive atoms present N will be $\frac{N_0}{2}$, i.e., when;

$$t = T,\ N = \frac{N_0}{2} \qquad \text{(x)}$$

Using relation (x) in equation (ix) leads to;

$$\frac{N_0}{2} = N_0 e^{-\lambda T} \qquad \text{(xi)}$$

$$\frac{1}{2} = e^{-\lambda T} \qquad \text{(xii)}$$

$$\frac{1}{2} = \frac{1}{e^{\lambda T}} \qquad \text{(xiii)}$$

$$e^{\lambda T} = 2 \qquad \text{(xiv)}$$

Obtain natural logarithms on both sides of equation (xiv) to get rid of the exponential part;

$$\lambda T = Ln\ 2 \qquad \text{(xv)}$$

$$T = \frac{\ln 2}{\lambda} \qquad \text{(xvi)}$$

$$T = \frac{0.693}{\lambda} \qquad \text{(xvii)}$$

Equation (xvii) shows that radionuclides with a short half-life decay faster (have a high activity) than those with a long half-life (have a low activity). The half-life of radioactive elements ranges from billions of years to a fraction of a second.

NOTE 1: Decay law in terms of half-line

Consider a radioactive element of half-life T and decay constant λ. If N_0 be the number of radioactive atoms initially present and N the elements present at time $t = t$, then by decay law;

$\frac{N}{N_0} = e^{-\lambda t}$ (i)

$\text{Ln}\left(\frac{N}{N_0}\right) = -\lambda t$ (ii)

But;

$\lambda = \frac{\ln 2}{T}$ (iii)

Using equation (iii) in equation (ii) leads to;

$\ln\left(\frac{N}{N_0}\right) = {}^{-t}/_{T} \ln 2$ (iv)

$\ln\left(\frac{N}{N_0}\right) = \ln 2^{-({}^{t}/_{T})}$ (v)

Obtain natural log on both sides;

$\frac{N}{N_0} = 2^{-({}^{t}/_{T})} = \frac{1}{2^{t/T}}$ (vi)

Hence

$N = \frac{1}{2^{{}^{t}/_{T}}} N_0$ (vii)

It follows that if:

$t = 1T$(fist half-life), then $N = \frac{1}{2} N_0$

$t = 2T$(second half-life), then $N = \frac{1}{2^2} N_0$

$t = 3T$(third half-life), then $N = \frac{1}{2^3} N_0$

In general, if $t = nT$(n[th] half-life), then;

$N = \frac{1}{2^n} N_0$ (viii)

NOTE 2: Activity

Activity is defined as rate of decay, i.e., $A = -\frac{dN}{dt} = \lambda N$. Since $N = N_0 e^{-\lambda t}$ it follows that;

$A = -\frac{d}{dt}\left(N_0 e^{-\lambda t}\right) = -N_0 \frac{de^{-\lambda t}}{dt}$ (i)

$A = N_0 \lambda e^{-\lambda t}$ (ii)

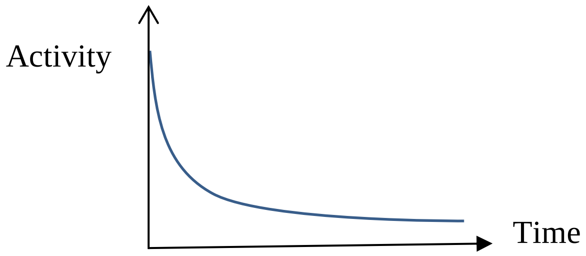
But

$A_0 = N_0 \lambda = \ initial\ activity$ (iii)

Hence

$A = A_0 e^{-\lambda t}$ (iv)

Equation (iv) shows that the activity of a radioactive element reduces exponentially with time:



NOTE 3: Nuclear fission

Radioactivity is the spontaneous disintegration of unstable nuclei with the release of alpha, beta and gamma radiation. During radioactive particle (alpha, beta) decay, the parent radionuclide transforms into one daughter element. Radioactivity occurs naturally without human influence.

Nuclear fission refers to the situation whereby an element disintegrates into more than one daughter elements, emitting radiation (alpha, beta, gamma and neutrons) in the process. Nuclear fission for the most part is artificially induced inside nuclear reactors by bombarding atoms with fast moving neutrons. There are many applications of nuclear fission. For example;

- Nuclear fission is used to produce radio-isotopes (mainly short-lived) for use in medicine and industry.
    - In medicine, the radioisotopes are used for example in cancer treatment as well as in imaging. During cancer treatment, the radioisotopes are introduced to or near the area being treated for instance through injection. The radiation released when the radioisotopes decay destroys the cancer cells.
    - In industry, the radioisotopes are used for instance to trace pollution transfer e.g. liquid sewage. The radioisotopes are mixed with waste and the radiation emitted monitored.
    - Radioisotopes are also used in the oil industry to monitor leaks in pipes. Fuel is spiked with the radioisotopes and the intensity of gamma radiation along the path of the pipeline monitored. In regions where oil is leaking, the intensity of gamma radiation will be higher than in regions where there is no leakage as the gamma penetration will be higher (not blocked by the pipe)
- During nuclear fission, a great amount of heat is generated. The heat is used in nuclear power plants to convert water to vapour which is then used to turn turbines in magnetic fields leading to generation of electricity. Electricity generated using heat from nuclear reactions is called nuclear power. Advantages of nuclear power i(over fossil fuels like petrol and paraffin) are:

- It is a low carbon source hence clean
- It helps in reducing the precursors of climate change
- It is reliable and cost-effective in the long run

Disadvantages of nuclear power are:

- Expensive to build a nuclear power plant
- Security threats (e.g. terrorism related)
- Adverse environmental impact of improperly disposed nuclear waste
- Adverse effects in the event of nuclear accidents

NOTE 4: Nuclear radiation

Alpha, beta, gamma and neutrons radiation emitted during radioactive decay or fission is collectively referred to as nuclear radiation. (Nuclear radiation is radiation that originates from the nucleus of an atom).

To the question now;

Uses of radioactivity in medicine

- Used in the treatment of cancer whereby the radiation kills the cancer cells by damaging their DNA.
- Sterilize medical equipment by killing germs.
- Used in imaging body organs.

(b) The following is a nuclear reaction equation:

$$^{6}_{3}Li + ^{1}_{0}n \rightarrow ^{3}_{1}H + ^{x}_{y}P$$

Determine the values of x and y. (2 marks)

This is an example of nuclear fission whereby an element combines with a neutron leading to the formation of two fragments. Atomic mass (neutrons + protons) and atomic number (protons) before fission must be equal to that after fission, hence;

$6 + 1 = 3 + x$

$x = 7 - 3$

$x = 4$

$3 + 0 = 1 + y$

$y = 3 - 1$

$y = 2$

(c) Figure 5 shows a radioactive element placed in an evacuated glass chamber. The element produces alpha, beta and gamma emissions.

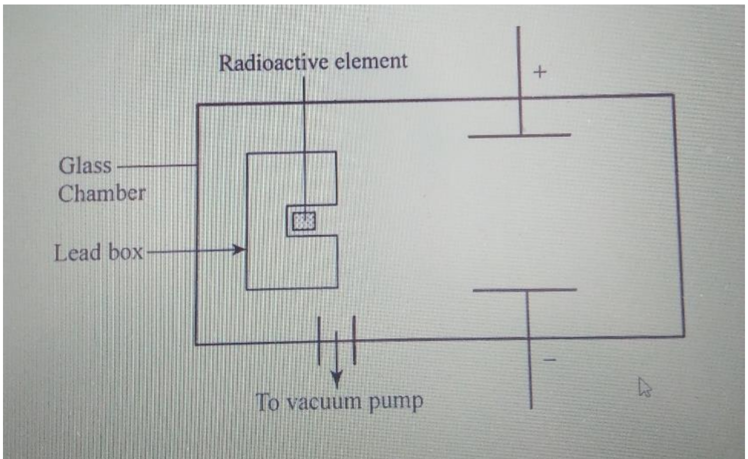
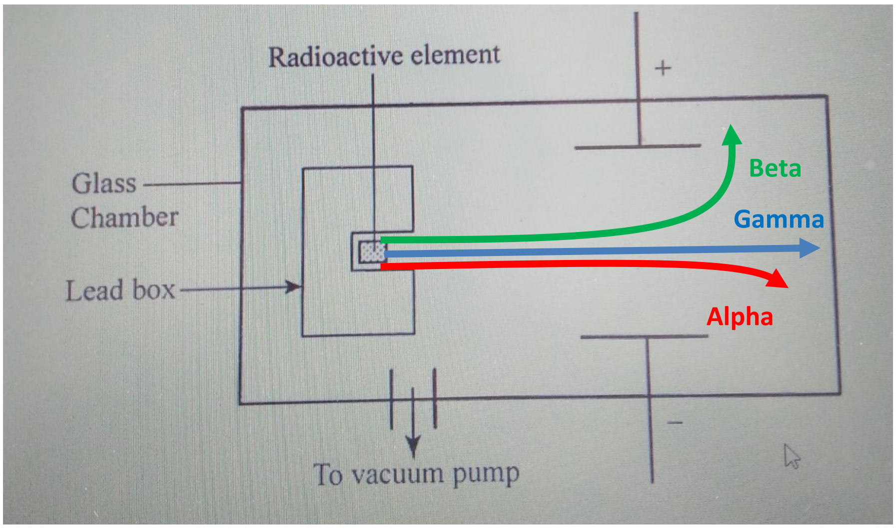


Figure 5

The three emissions that pass through an electric field.

(i) Complete the diagram to show the path of each of the emissions. (3 marks)



(ii) State the reason why:

- Beta particles are negatively charged so they are attracted towards the positive terminal. They are also light hence the deviation is relatively more.
- Gamma radiation is uncharged. It is a form of electromagnetic radiation hence is not deflected by the electric field.
- Alpha particles are positively charged and for that reason they are attracted towards the negative terminal. They are relatively heavy

hence deviation is relatively larger than that of the lighter beta particles.

(I) the radioactive element is kept inside a lead box: (1mark)

Gamma radiation is extremely penetrating and requires lead shielding to stop it from escaping. (Radiation sources must be shielded to stop radiation formed during radioactive decay from escaping). Nuclear radiation is ionizing and capable of destroying cells (can cause harm). Radiation sources must therefore be stored n such a way that they do not contaminate the environment.

(II) the chamber is evacuated. (1 mark)

Ionization is the process through which atoms gain or lose electrons. If an atom gains an electron, it becomes negatively charged (an anion), and if it loses an electron, it becomes positively charged (a cation). Ionization process therefore converts a neutral atom into an ion-pair.

Beta (electrons, negatively charged) and alpha (helium nuclei, positively charged) particles carry energy in the form of kinetic energy. When these charged particles collide with air molecules, some of their kinetic energy is used to dislodge electrons from atoms. Each alpha and beta particle has sufficient kinetic energy to remove electrons from multiple atoms (though alpha particles are more ionizing than beta particles). Alpha and beta particles therefore cause direct ionization. As the charged particles knock off electrons, their KE energy reduces. Gamma radiation is not a particle but an electromagnetic wave with energy E dependent on the frequency f ($E = hf$). Unlike the charged particles where a single particle can cause multiple direct ionization, a single photon causes only one direct ionization (photoelectric effect). The entire photon is absorbed and a single electron ejected. If the photon is energetic enough, the emitted photoelectron is emitted with sufficient kinetic energy ($KE = hf - hf_0$) and goes on to cause ionization just like a beta particle would. Gamma radiation is therefore said to cause indirect ionization.

To the question:

Chamber is evacuated so as to limit ionization (d(ii) The half-life of a certain radioactive substance is 24 days. Given that the initial (i) sample of the substance has a mass of 64 g, determine the mass which is left after 72 days. (2 marks)

Number of half-lives $n = \frac{72}{24} = 3$

$N = \frac{1}{2^n} N_0$

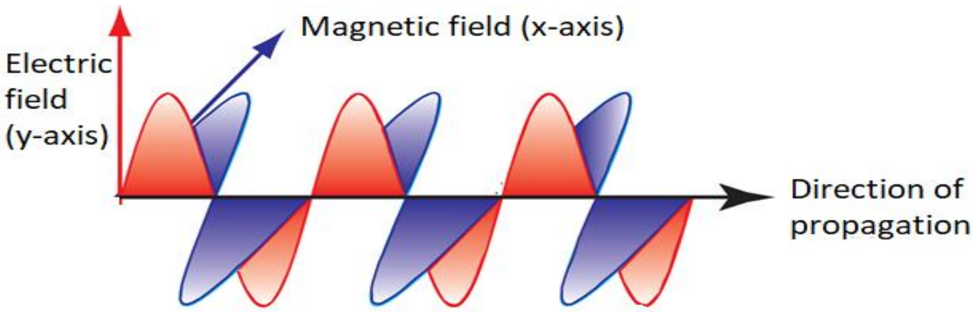
Number of atoms correspond to the mass hence

$Final\ mass = \frac{1}{2^n} \times intial\ mass$

$Final\ mass = \frac{1}{2^3} \times 64 = 8\ g$

)(i) Arrange the following electromagnetic waves in the order of decreasing frequency: Microwaves; Gamma rays; Radio waves; X-rays. (1 mark)

Electromagnetic (EM) waves do not require a medium for propagation. EM are formed by varying electric and magnetic fields at right angles with each other. They are transverse in nature in that the direction of propagation is at right angles with the direction of variation of the electric and magnetic waves.



EM waves have a dual nature which means that they behave as waves as well as particles. The wave nature is used to explain characteristics such as reflection, refraction and interference. EM waves obey the wave equation;

$c = \lambda f$ (i)

Where c is the velocity of the EM waves in space, λ is the wavelength and f is the frequency. All EM waves travel at the same velocity (c) in space (vacuum, air) with $c = 3 \times 10^8\ m/s$.

According to the particle theory, EM waves are particles called photons, and each photon carries a discrete amount of energy E which is directly proportional to frequency f, i.e.

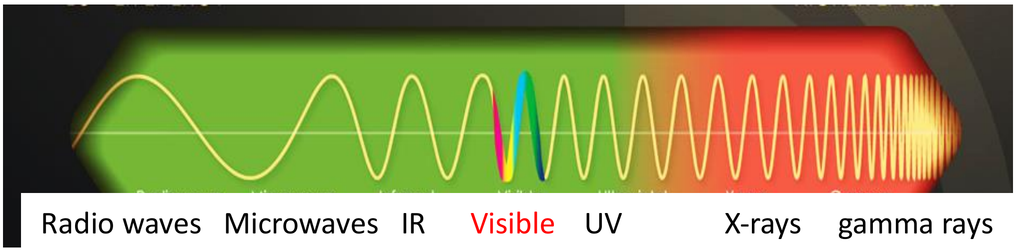
$E\infty f$ (ii)

$\Rightarrow E = hf$ (iii)

Combining equations (i) and (iii) leads to;

$E = \frac{hc}{\lambda}$ (iv)

Where h is the constant of proportionality called Planck's constant. EM waves are classified in terms of energy and represented in the electromagnetic spectrum.



Radio waves	Microwaves	Infrared		Ultra violet (UV)	X-rays	Gamma rays

Visible region: red, orange, yellow, green, blue, Indigo, violet

NOTE: High energy UV, X-rays and gamma rays are forms of ionizing radiation hence capable of damaging cells. This damaging effect is positively employed in treatment of cancer by killing cancerous cells as well as killing germs (UV being less dangerous is used in salons to sterilize equipment). X-rays and gamma rays are very penetrating. Their penetrating power is used in imaging (in hospitals and industry). The distance in air covered by ionizing radiation is much less that that of the non-ionizing radiation (radio waves, microwaves, IR, visible and lower energy UV). Radio waves and microwaves are not only non-ionising, they are also less scattered by air particles hence can cover very long distances in air (on account of their long wavelengths). It is for this reason that they (especially radio waves) that they are used for communications (in TV, radio, mobile phones).

To the question now;

The most energetic waves have the highest frequency (but least wavelength) hence in order of decreasing frequency, we have:

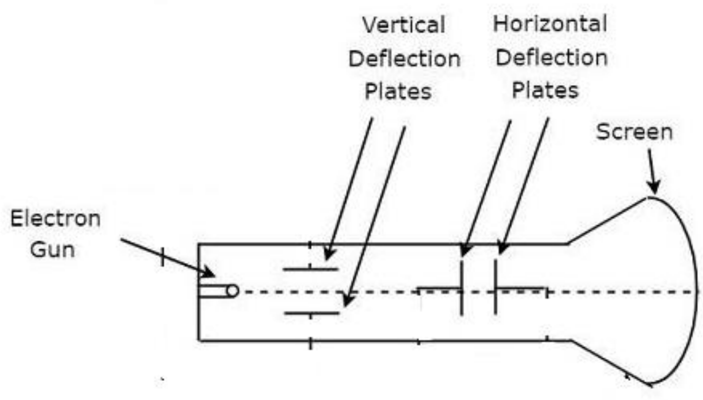
Gamma rays; X-rays; Microwaves; Radio waves

17.(a)(i) Name the three components of the electron gun in a cathode ray tube (CRT). (3 marks)

A cathode ray oscilloscope (CRO) is an instrument used for the observation, measurement, and analysis of waveforms. A CRT (cathode ray tube) of a CRO has four main components:

a) Electron gun
b) Vertical deflection plates (Y-plates)
c) Horizontal deflection plates (X-plates)
d) fluorescent screen

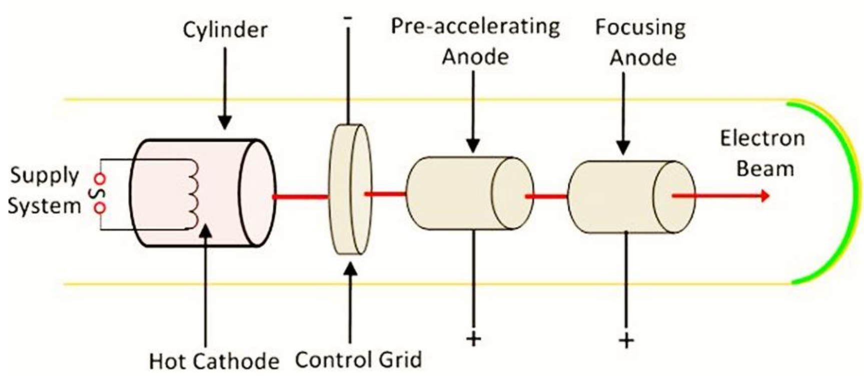
The components are housed in a highly evacuated structure. The evacuation minimises ionisation that may lead to loss of kinetic energy of the electrons as they move from the electron gun to the screen which may affect clarity of the waveform generated on the screen.



a) The electron gun:

This is the source of a focused and accelerated electron beam. It is made up of three components:

(i) Heating coil (cathode)
(ii) Control grid
(iii) Anodes



The cathode produces electrons by thermionic emission (heated). After emission, the electrons pass through the control grid. The control grid has a negative biasing. Its function is to control the intensity (number) of the transmitted electrons. The electron beam is accelerated by a highly positive pre-accelerating or accelerating anode (at about 1500 V) and directed by the focussing anode (at about 500 V). There are two ways focussing of the electron beam can be achieved;

(i) Electrostatic focussing which uses an electric field

(ii) Electromagnetic focussing which employs a magnetic field.

A CRT employs an electric field for focussing electrons. A television tube however employs a magnetic field for focussing.

b) Vertical deflection plates – moves the beam vertically

c) Horizontal deflection plates – moves the plate horizontally.

NOTE: The vertical and horizontal deflection plates enable the electron beam to reach any part of the fluorescent screen.

d) Fluorescent screen/monitor - the screen is made of phosphor. When the electron beam hits the screen, the phosphor atoms are excited and light is emitted at that point. The screen therefore turns electric energy (beam of fast-moving electrons) into light energy. The bright spot on the phosphor monitor moves due to the effect of the electrostatic forces on the mutually perpendicular Y and X-plates and outlines a waveform based on the input signal.

To the question:

Components of **electron gun**

- Heating coil (cathode)
- Control grid
- Anodes

(ii) State one difference between the deflection systems of a cathode ray tube and the television tube. (1 mark)

In cathode ray tube, focussing is achieved through the application of an electric field while in a TV tube it is through application of a magnetic field.

(b) Figure 6 shows a graph of stopping potential against the frequency for a certain photo emissive surface, drawn by a student from the data collected when carrying out an experiment on photoelectric effect.

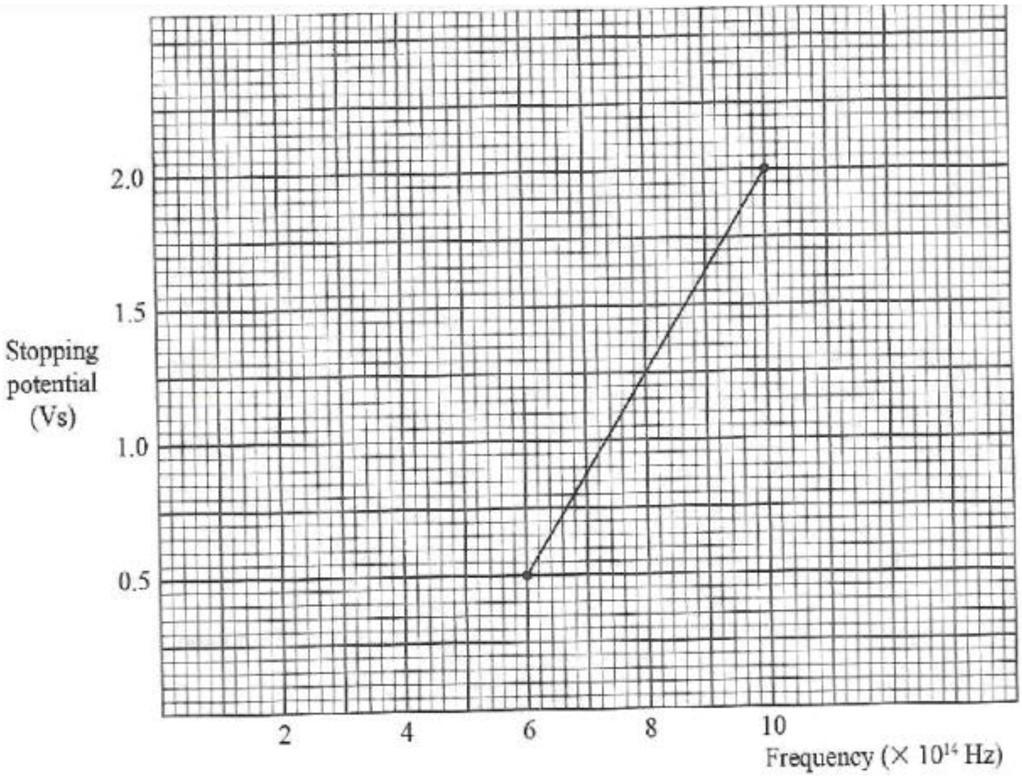


Figure 6

From the graph, determine the:

(i) threshold frequency of the surface:(3 marks)

Light is an electromagnetic wave and like all EM waves, it has a dual nature in that it exists both as a wave and a particle. As a wave, it obeys the wave equation;

$c = \lambda f$ (i)

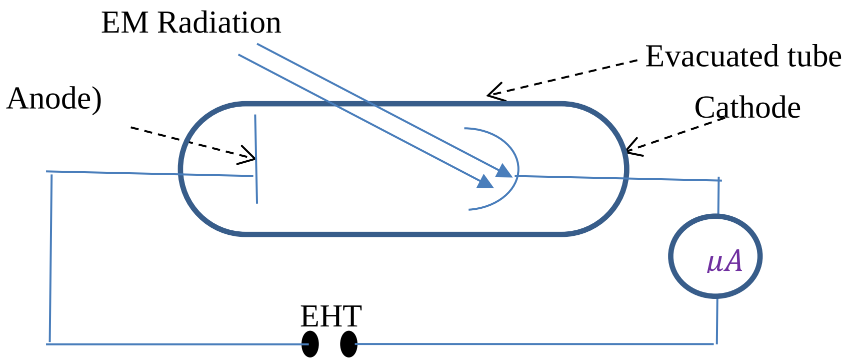
where c is the velocity, λ the wavelength and f the frequency. The wave nature of light is used to explain properties such as reflection, refraction, interference and dispersion.

The particle nature postulates that light is made up of discrete particles called photons, and each photon carries a discrete amount of energy E given by;

$E = hf$ (ii)

where h is a constant of proportionality called Planck's constant. Particle nature of light explains properties such as **photo-electric effect** and black body radiation.

Photoelectic effect refers to the emission of electrons from a metal surface when light (or any other electromagnetic radiation) falls on it.



Electrons are naturally bound to the atom by electrostatic force (binding energy). When light falls on an atom, an entire photon of energy equal to or greater than the binding energy must be absorbed for the electron to be free (an atom cannot be freed by a photon of energy less than the binding energy). Part of the photon energy is used to overcome the force binding the electron to the atom (this energy is referred to as the work function, w_o, and is equal to the binding energy) while the rest is converted to kinetic energy of the emitted electron (photo-electron). Hence;

$hf = w_0 + KE$ (iii)

Once emitted, the photoelectrons are attracted by the positively biased anode. The circuit is completed and the microampere records a current. (If the positive bias is increased, more electrons reach the anode hence higher current flows in the circuit).

Because the energy of a photon is dependent on the frequency, photo-electric effect cannot occur below a certain frequency. This frequency is called threshold frequency f_0, (threshold frequency is the frequency below which photoelectric effect cannot occur). If for a given radiation $f = f_0$, then the photon energy is only sufficient for removing the electron from the metal surface (no photon energy is converted to KE). Equation (iii) therefore becomes;

$hf_0 = w_0$ (work function) (iv)

Combining equations (iii)and (iv) gives photo-electric equation:

$hf = hf_0 + KE$ (v)

Now, the wave equation; $c = \lambda f \Longrightarrow f = \frac{c}{\lambda}$ (vi)

When frequency equals threshold frequency $f = f_0$, wavelength equals threshold wavelength $\lambda = \lambda_0$. Hence;

$f_0 = \frac{c}{\lambda_0}$ (viii)

Using equations (vi) and (vii) in equation (v) leads to;

$\frac{hc}{\lambda} = \frac{hc}{\lambda_0} + KE$ (ix)

NOTE 1:

Since one photon is required to dislodge one electron, an increase in the number of photons leads to more electrons being dislodged. Increasing the intensity of radiation increases the number of photons and consequently the number of electrons dislodged hence the current in the circuit increases

NOTE 2:

From the equation $hf = w_0 + KE$ it follows that;

$KE = hf - w_0$ (x)

Equation (x) shows that the **kinetic energy of the photoelectrons depends on two factors;**

(i) Energy of the incident photon

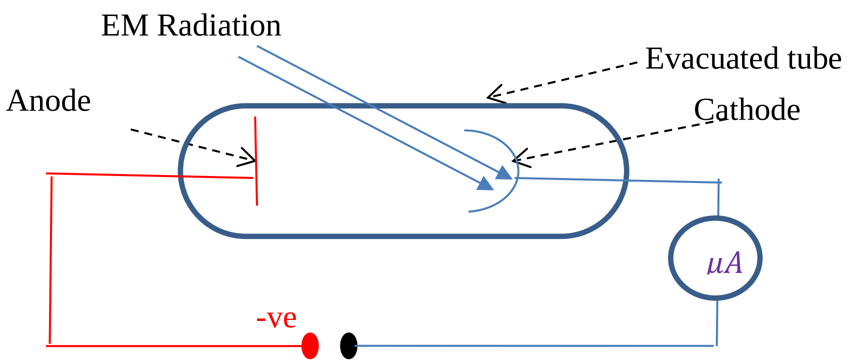
(ii) Work function.

The energy needed to remove an electron from the metal surface (work function) is equal to the binding energy, no more and no less. Any excess photon energy is converted to kinetic energy. A photon of higher energy (or higher frequency since $E = hf$) will therefore produce photoelectrons with higher kinetic energy.

Also, for some metals, electrons are more tightly bound to the atom than in other metals. Since work function is equal to the binding energy, the lower the work function, the more the KE of the photoelectrons.

NOTE 3: Stopping potential and maximum kinetic energy

To determine the maximum kinetic energy of the photoelectrons produced during photoelectric effect, the anode is given a negative voltage.



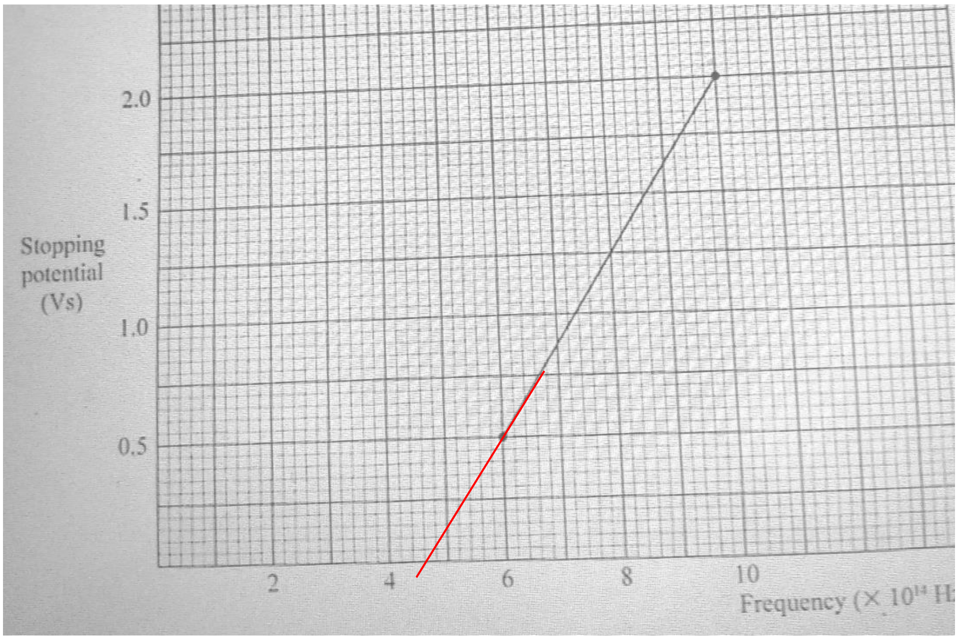
As the negative voltage is increased, the number of photoelectrons reaching the anode decreases as more electrostatic force of repulsion opposes the driving KE of the photoelectrons. Eventually, even the most energetic photoelectrons do not reach the anode. The minimum negative voltage applied to the anode that stops photoelectrons from reaching the anode is called **stopping potential, V_s**. The stopping potential, expressed in electron-volt, eV, is thus equal to the maximum kinetic energy of the photoelectrons, i.e

$V_s\,(eV) = KE_{Max}$ (xi)

Where;

$1eV = 1.6 \times 10^{-19} J$ (xii)

To the question: to determine the threshold frequency of the surface, xtrapolate the graph to the point where it cuts the x-axis.



Since

$KE = hf - hf_0$

$\Longrightarrow V_s = hf - hf_0$

At $V_s = 0$ (where the graph cuts the x-axis), $hf = hf_0$

Hence

$f = f_0$

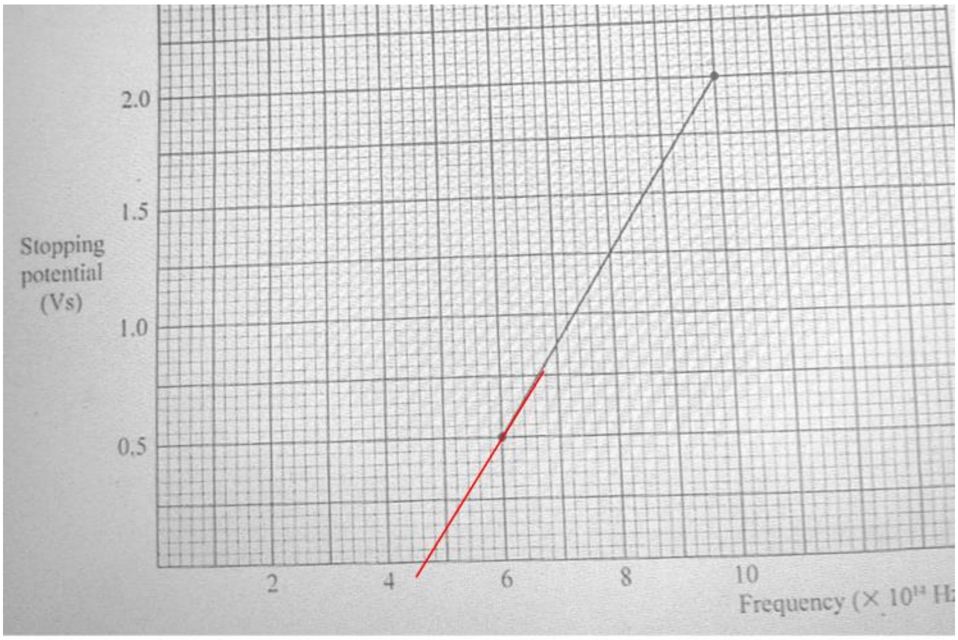
$\Longrightarrow f_0 = 4.6 \times 10^{14}\ Hz$

(ii) plank's constant h, given that the energy of the incident photon is 1.6X 10^{-19} J; (3 marks)

$V_s = hf - hf_0$

$V_s = h(f - f_0)$

$$\frac{V_s}{f - f_0} = h\ (= gradient\ in\ eV/HZ)$$



Using the points ($6x10^{15}$, 0.5) and ($8x10^{5}$, 1.25)

$$h = \frac{1.25 - 0.5}{(8 - 6) \times 10 \times 10^{14}} = 3.75 \times 10^{-14}\ eV/Hz$$

Now $Hz = s^{-1}$ hence

$h = 3.75 \times 10^{-14}\ eV/s$

Since $1eV = 1.6 \times 10^{-19}J$, it follows that

$h = 3.75 \times 10^{-14}\ \times 1.6 \times 10^{-19}$

$h = 6 \times 10^{-34}\ J/s$

(iii) work function of the surface. (3 marks)

$w_0 = hf_0$

$w_0 = 6 \times 10^{-34} \times 4.6 \times 10^{14} = 27.6 \times 10^{-20}\ J$

$w_0 = 6.276 \times 10^{-19}\ J$

18.(a) Figure 7 shows a soft iron ring placed between the poles of two bar magnets.

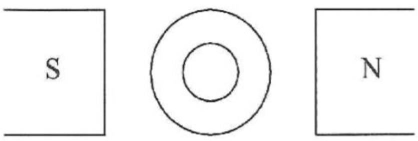
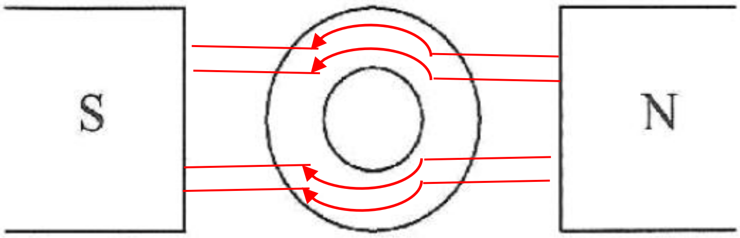


Figure 7

On the figure, draw the magnetic field lines between the poles. (2 marks)

Soft iron concentrates magnetic field. The field will travel through the soft iron.



(b) Figure 8 shows two straight conductors P and Q connected to a battery and a variable resistor.

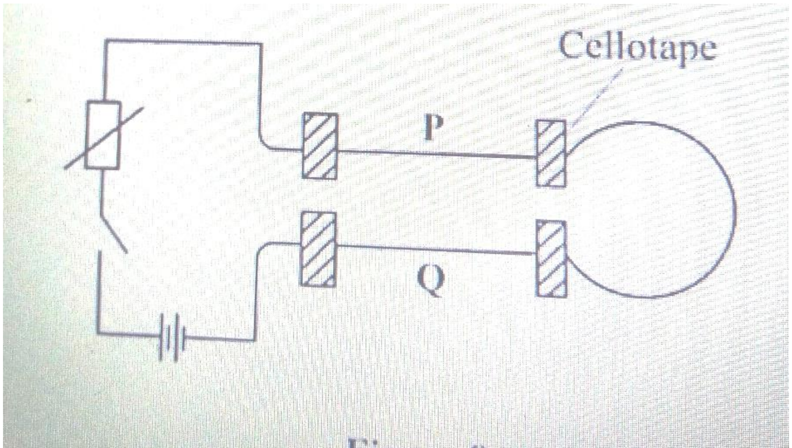
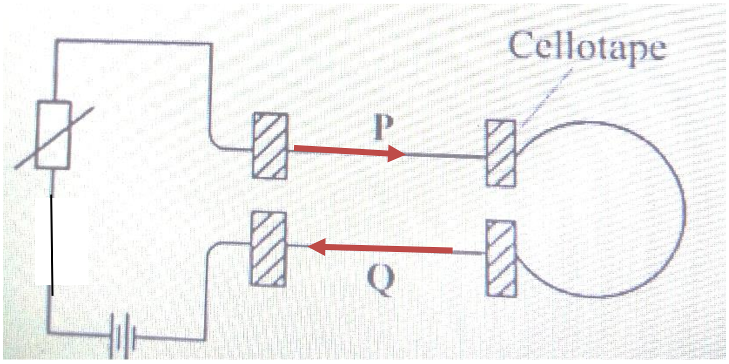


Figure 8

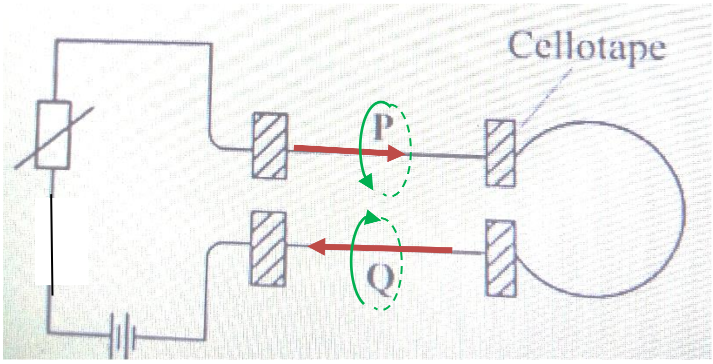
(i) Using arrows, indicate on the diagram the direction of current that flows through P and Q when the switch is closed. (1 mark)

Current flows from the positive to the negative terminal hence;



(ii) State what is observed as the current flows through the conductors. (1 mark)

A current has an associated magnetic field whose direction depends on the direction of flow of current. Imagine gripping the current-carrying wire with the right hand with the thumb pointing in the direction of the current. The curled fingers will indicate the direction of the magnetic field. The direction of the magnetic field around P is in the anticlockwise direction while that around Q is in the clockwise direction.



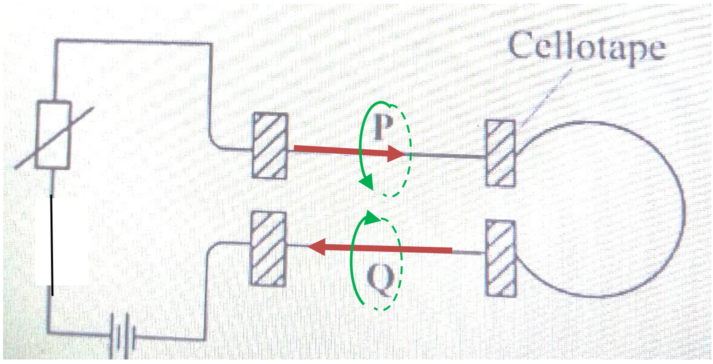
The field cannot cross from one wire to the next. A current carrying conductor in a magnetic field experiences a force called Lorentz force.

To the question:

The wires therefore move away from each other (repel)

(iii) Explain the observation in (ii). (3 marks)

A current has an associated magnetic field whose direction depends on the direction of flow of current. Imagine gripping the wire with the right hand with the thumb pointing in the direction of the current. The curled fingers will indicate the direction of the magnetic field. The direction of the magnetic field around P is in the anticlockwise direction while that around Q is in the clockwise direction.

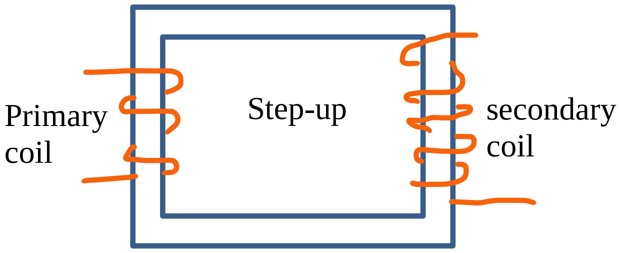


The field cannot cross from one wire to the next. The wires therefore move away from each other (repel)

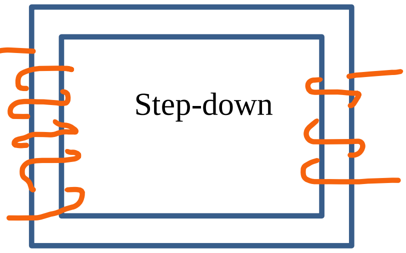
NOTE: A current carrying conductor in a magnetic field experiences a force called Lorentz force.

(c)i. State how eddy currents are minimised in a transformer. (1 mark)

Once electricity is generated in a.c. (alternating current meaning that the direction of current reverses periodically), it is transmitted at very high voltages (very low current) so as to reduce power loss. This means that it has to be stepped up for transmission. Most electrical appliances use low voltage power. Before being distributed to consumers, the transmitted voltage must therefore be stepped down to the desired voltage. The device used for stepping up and down voltage is called a transformer which steps up (and down) of voltage through induction. There are thus two types of transformers: (i) Step up transformer which has more turns in the secondary coil relative to primary coil:



(ii) the step-down transformer with more turns in the primary coil;



Either way, input power (power in primary coil) is equal to output power (power in secondary coil) **assuming no power loss takes place**. That is;

$V_p I_p = V_s I_s$ (i)

Hence

$\frac{V_p}{V_s} = \frac{I_s}{I_p}$ (ii)

$Also$;

$\frac{V_p}{V_s} = \frac{N_p}{N_s}$ (iii)

From equations (ii)and (iii)it follows that;

$\frac{N_p}{N_s} = \frac{I_s}{I_p}$ (iv)

NOTE: Power loss in transformers and correction

In reality, transformers are not 100% efficient. This means that power input is not equal to power output, $V_p I_p \neq V_s I_s$. The power in the primary circuit is always higher than the power in the secondary circuit. The ratio of the output power to the input power is referred to as the efficiency of the transformer, often expressed as a percentage, i.e.,

$Eefficiency = \frac{power\ output}{power\ input} \times 100\%$ (v)

$Efficiency = \frac{V_s I_s}{V_p I_p} \times 100\%$ (vi)

A transformer loses power due to;

- Current flowing in the coils (load/copper losses)
- Magnetic field in the core (no load/iron losses)

(1) Copper losses: Copper losses are mainly due to Joule heating (heat losses) that occurs as current flows through the wires. Power lost due to this heating in the coils is given by;

$P = I^2 R$ (vii)

This power loss can only be addressed by using coils of low resistance. Resistance (R) of the coil depends on the resistivity (γ) of the coil material, the cross-sectional area (A) of the coil and its length (l) according to the formula;

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

Some materials such as copper are naturally good conductors hence have low resistivity. Additionally, wires of larger cross-sectional area offer lower resistance to the flow of current. Using copper coils of a large cross-sectional area can therefore help in addressing power loss through heating.

NOTE: copper losses are load (current) dependent. The higher the current, the higher the losses.

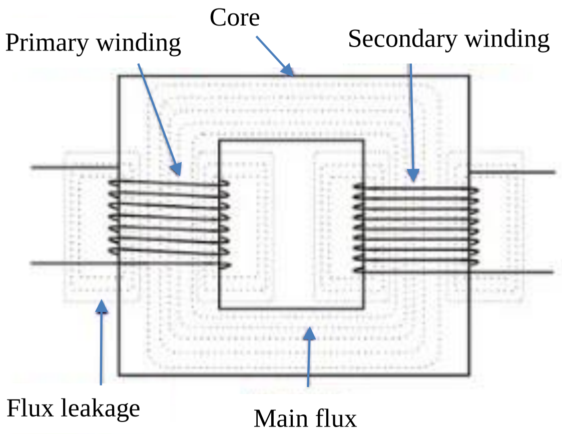
(2) Iron (no-load) losses: These occur in the core as a result of the magnetization of the core caused by the alternating current. They are independent of the load. Iron losses fall under two main categories;

- Hysteresis losses
- Eddy current losses

Hysteresis losses occur due to the periodic reversal of the magnetic field in the core of the transformer as a result of the alternating current. Power is required to reverse the direction of this magnetic field. This power, dissipated in the form of heat, is referred to as hysteresis loss. The losses increase with the area of the hysteresis loop. Magnetic materials with small hysteresis loop area, for example silicon steel, are therefore used for the construction of transformer cores to minimize these losses.

Eddy current losses on the other hand arise when the change in the direction of the electromagnetic field in the transformer core induces EMF in the core. The induced EMF produces currents within the core called eddy currents. Since the core has some internal resistance, the eddy currents lead to power loss ($P = I^2R$) through heating. To minimise power (P) loss through eddy currents, the magnitude of the eddy currents (I) should be as low as possible. This is achieved by creating transformer core which has a very high resistance (R). A high resistance core is attained by laminating the core (creating a core composed of multiple layers as opposed to one solid layer), with each lamination insulated from the next by means of a thin varnish coating. Each lamination therefore acts as a separate core of a small cross-sectional area thus offering a high resistance to the flow of eddy currents (resistance varies inversely with the cross-sectional area. The smaller the cross-sectional area, the higher the resistance).

NOTE: Flux leakage losses: These occur in both the primary and secondary coils when a small portion of the magnetic flux links one coil but not both.



Flux leakage in a transformer can be minimized by winding the primary and secondary coils over each other.

To the question
Eddy currents are minimised by laminating the core of the transformer

ii. A step down transformer has 600 turns in the primary coil. The input voltage is 120 V while the output voltage is 24 V. Determine the number of turns in the secondary coil. (3 marks)

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

$$\frac{120}{24} = \frac{600}{N_s}$$

$$N_s = \frac{24}{120} \times 600 = 120\ turns$$

END