ELECTRONS

In metals each atom has a few loosely attached outer electrons which move randomly within the material. The atoms therefore exist as positive ions in a sea of free electrons. If one of these electrons near the surface of the metal tries to escape, it experiences an attractive inward force from the resultant positive charge left on the atoms. The electron cannot escape unless an external source does work against the attractive force and increases its kinetic energy until it becomes free.

Thermionic Emission

Thermionic emission is the release of electrons from a metal surface when heated.

When a metal is heated the kinetic energy of the free electrons inside the metal increases and the force of attraction between the positive atoms and electrons weakens. At a certain temperature usually near the melting point of the metal some electrons gain enough kinetic energy to escape from the surface of the metal and become free (a process similar to evaporation).

The temperature at which electrons are released varies from metal to metal. The minimum energy required to release electrons from a metal surface is called the *work function*.

The metal plate from which electrons are released is referred to as the *cathode (hot cathode).*

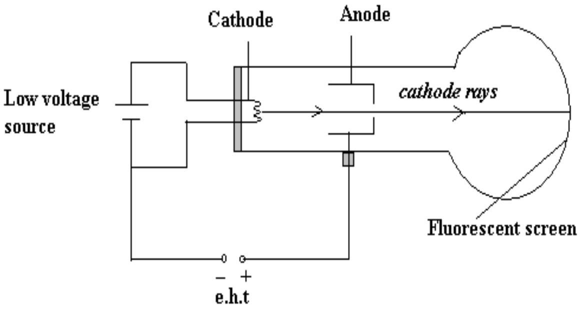
Thermionic devices have a plate called the *anode* at a high positive potential with respect to the heated cathode. The high positive potential is used to exert a large attractive force that accelerates the electrons.

Cathode Rays

Cathode rays are streams of electrons moving at high speed from the cathode.

Production of cathode Rays

A cathode ray tube (CRT) consists of an indirectly heated cathode and a hollow cylindrical anode enclosed in an evacuated glass envelope having a screen at one end that is coated with a fluorescent material.



The cathode is connected to a low voltage source enough to heat it to produce electrons. The anode is connected to the positive of a high voltage supply (extra high tension, e.h.t) of about 2 - 3 kV to accelerate the electrons across the tube.

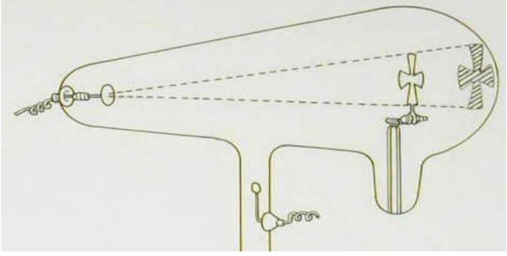
The anode and the cathode circuits are switched on and electrons produced thermionically from the cathode are accelerated by the anode potential to the fluorescent screen.

On falling on the fluorescent screen they lose their kinetic energy to the fluorescent substance which changes to internal energy and then light energy. Hence the fluorescent screen glows.

Properties of Cathode Rays

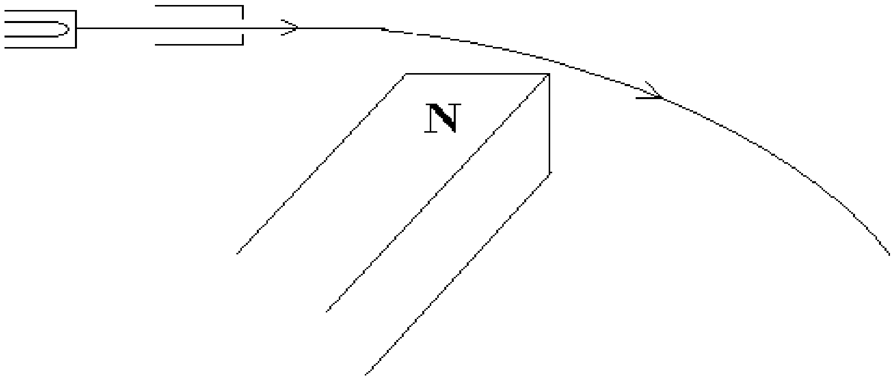
1. They travel from the cathode in straight lines.

When a Maltese cross is placed on their path a shadow is cast on the screen on a glowing background.



The Maltese cross stops some of the cathode rays and those which go past it fall on the screen and cause it to glow thus forming a shadow of the cross on a glowing background.

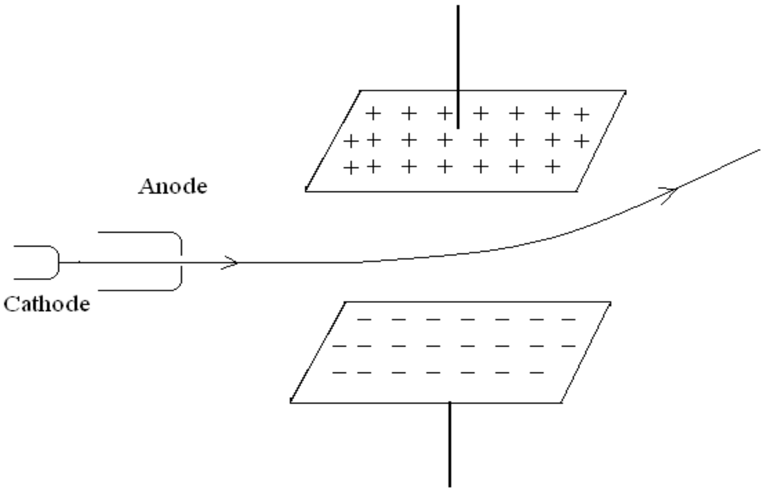
2. Cathodes rays are deflected by a magnetic field.



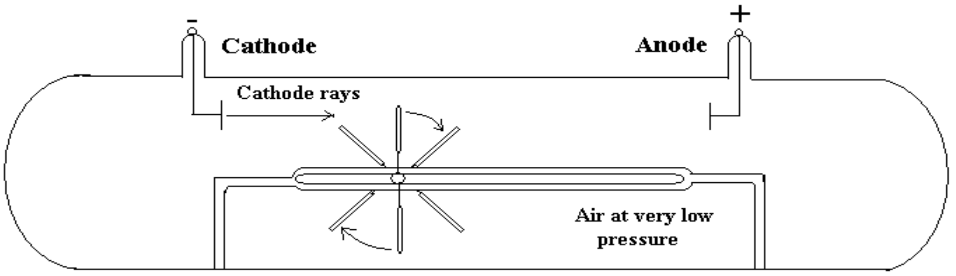
When a magnet is brought near a narrow beam of cathode rays in a CRT, the glowing spot on the screen shifts.

The deflection is at right angles to the direction of the rays and the direction of the magnetic field. Fleming's Left hand rule shows that the rays have a negative charge.

3. Cathode rays are deflected by an electric field towards the positive plate suggesting further that they are negatively charged.



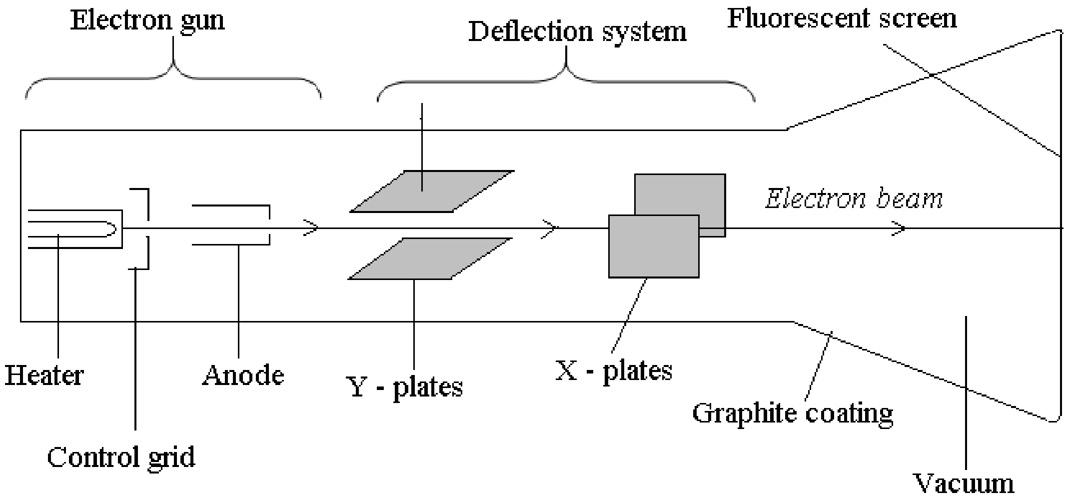
4. Cathode rays possess kinetic energy.



A small paddle wheel with mica vane rotates towards the anode when the vanes are struck by cathode rays.

5. When they strike matter they eject X –rays
6. They carry a negative charge.

THE CATHODE RAY OSCILLOSCOPE (CRO)



It is an instrument used to study the current and voltage waveforms in various electric circuits. It consists of three major components namely:

(a) The electron gun;

(b) The deflection system;

(c) A fluorescent screen.

The Electron Gun

- The cathode

  It is an indirectly heated electrode that produces electrons by thermionic emission.

- The Control Grid

  The control grid is an electrode to which a variable low negative voltage is applied to control the number of electrons passing through it. In effect it alters the brightness of the spot on the screen.

- The Anode

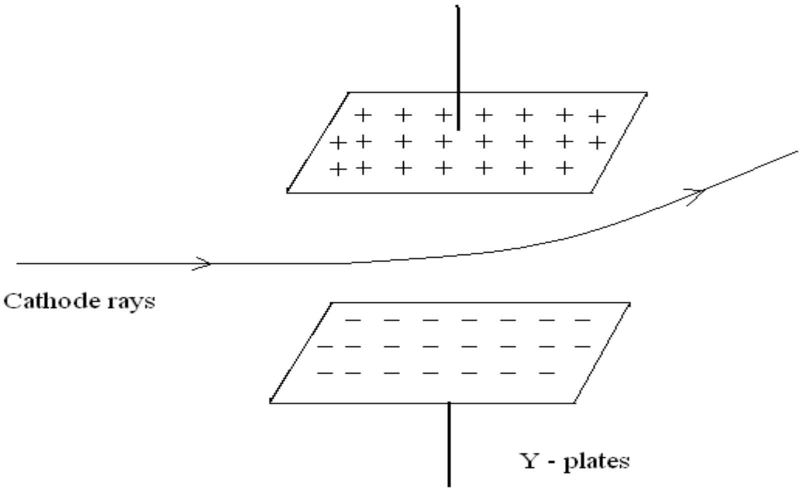
  A cylindrical anode or a series of cylindrical anodes at high positive potentials with respect to the cathode are used to accelerate the electrons produced from the cathode. In addition the anode also focuses the electrons to form a fine beam.

The Deflection System

It consists of two pairs of plates, a horizontal pair called the Y – plates and a vertical pair called the X – plates.

- The Y – plates

  The Y – plates are used to deflect the beam of electrons in a vertical direction or plane when a p.d is applied between them.



The electric field created between the plates accelerates the electrons vertically.

- The X – plates

When a potential difference is applied between the X – plates it creates an electric field that causes the beam to be deflected in a horizontal direction.

The fluorescent screen

At the end of the CRO is a screen coated with a fluorescent substance (phosphor or zinc sulphide) that glows to form a bright spot when the electron beam is focused on it.

The inside surface of the CRO is coated with graphite used to ground the electrons after bouncing from the screen.

NB: The CRO is evacuated to ensure that air molecules do not interfere with the motion of the electrons or cathode rays.

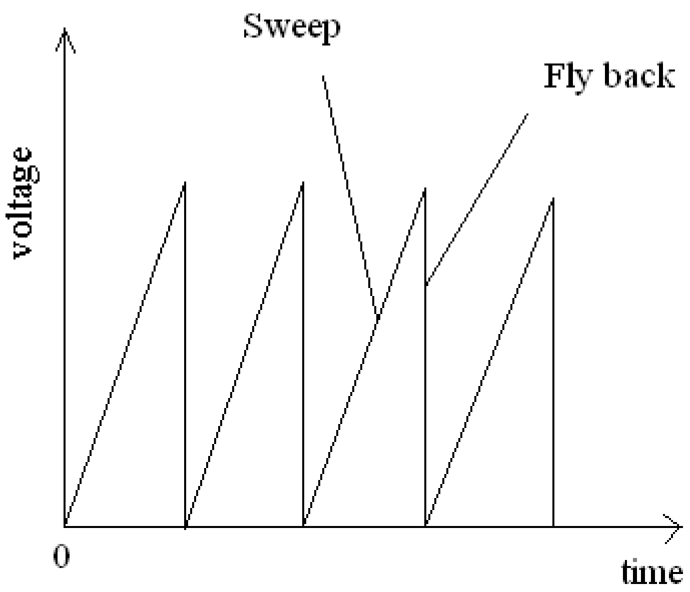
The Time – base Circuit

The CRO has a sweep generator or time – base circuit which generates a p.d between the X – plates. When the time – base is switched on it applies a p.d which builds up uniformly with time to a maximum and then falls rapidly to zero; this process repeats at regular intervals as long as the time – base in on.

This results in the spot moving horizontally across the screen steadily and the returning to zero instantaneously causing a fly back and the cycle repeats continuously.

At low frequency the trace appears as a moving spot but at high frequency it becomes a continuous line. This continuous line usually forms the time – axis.

Variation of p.d with time for the time – base circuit



Note that the graph applies when the applied p.d is a d.c voltage.

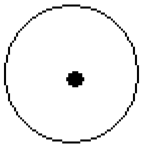
If a signal in the form of a simple a.c voltage is applied across the Y – plates, the spot will oscillate up and down in time with the voltage.

The resultant trace on the screen will be a combination of the Y – plate a.c signal and the X – plate sweep.

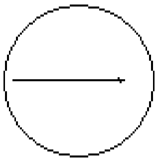
In effect the moving spot plots on the screen a luminous graph of a.c voltage variation with time.

<u>Traces obtained on the screen</u>

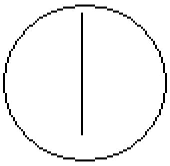
(i) Both plates switched off



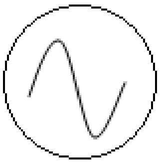
(ii) X – plate on and Y – plate off



(iii) Y – plate on with a.c and X – plate off

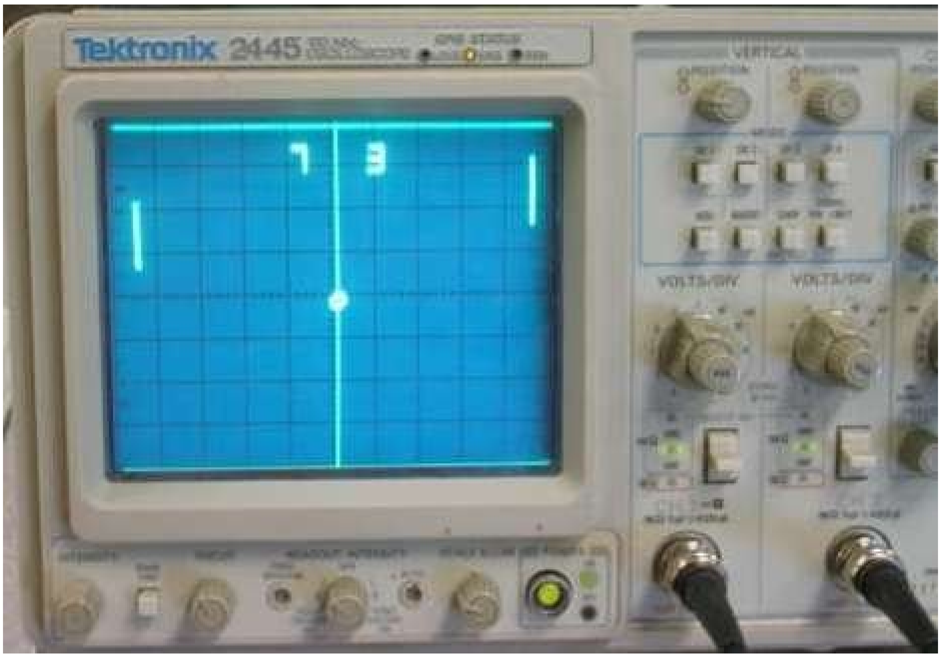


(iv) Both Y –plate and X-plate on with a.c applied to them



A single complete oscillation or wave is produced when the sweep frequency is equal to the a.c signal frequency.

Two or more complete waves will be seen when the signal is twice or some whole number multiple of the sweep frequency.



Uses of the C.R.O

(i) To measure frequency of waves

(ii) To measure voltages of both a.c and d.c type

(iii) To measure the phase difference between waves

(iv) To display and study different waveforms

(v) It is used in TV and computer monitors.

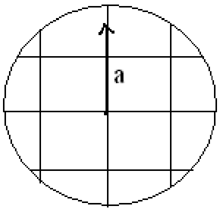
To measure Voltage

The voltage gain (voltage per unit cm) of the graph on the screen must be known.

To measure d.c voltage

The spot on the screen is centered when both Y- and X-plates are off

The unknown d.c voltage is applied to the Y-plates with the time-base switched off and trace is produced on the screen. If a steady d.c is applied the spot is displaced vertically.



The length (displacement)***, a***, of the trace is measured and is proportional to the applied voltage.

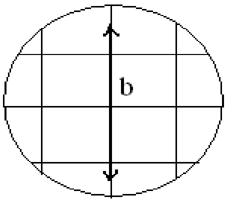
If the voltage gain (voltage per unit cm) is ***k***, then the applied p.d, $V = ka$.

To measure a.c

With both the X – and Y – plates switched off the spot is centered.

The alternating voltage is connected to the Y – plate with the time – base switched off.

A vertical line is obtained and then centered.



The length b, of the line is measured and is proportional to twice the amplitude or peak value V_o of the a.c

The peak value is given by:

$2 V_o = kb$

$$V_o = \frac{kb}{2}$$

Advantages of C.R.O as a voltmeter

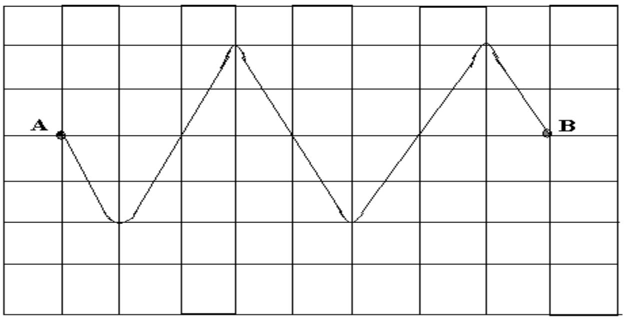
(i) it measures both a.c and d.c.

(ii) It is very accurate since it does not take any current from the circuit.

(iii) The electron beam has no mass and responds instantaneously.

Example

A C.R.O with time-base switched on is connected across a power supply. The wave form shown below is obtained. Distance between each line is 1 cm.



(a) Identify the type of voltage generated by the power supply.

(b) Find the amplitude of the voltage generated if the voltage gain is $5\ V\ cm^{-1}$.

(c) Calculate the frequency of the power source if the time – base setting on the C.R.O is $5.0 \times 10^{-3}\ s\ cm^{-1}$

Photoelectric Emission

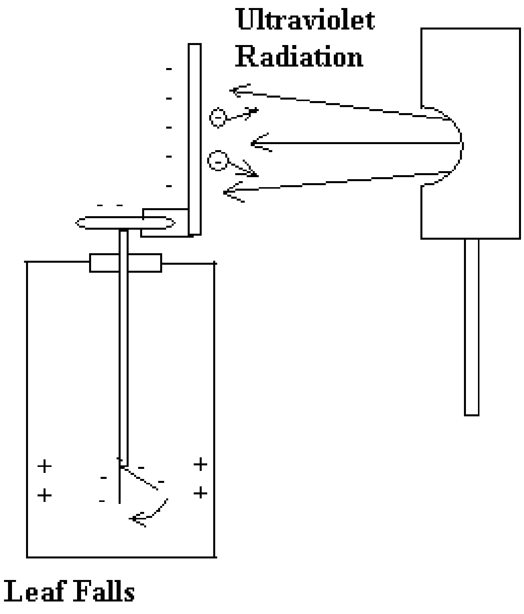
Photoelectric emission is the ejection of electrons from a metal surface when electromagnetic radiation of high enough frequency falls on it.

Free electrons in metals absorb energy from the incident radiation and if this energy is enough to overcome the attraction of the atoms the electrons become free and leave the metal surface.

The effect is given by zinc when exposed to X-rays or ultraviolet light. Sodium emits electrons with X-rays, ultraviolet radiation and all colours of visible light except orange and red. Caesium emits electrons with infrared radiation.

To demonstrate the photoelectric effect

A zinc plate is rubbed with emery paper to clean its surface and make it bright. The plate is insulated and then connected to the cap of a negatively charged gold leaf electroscope.

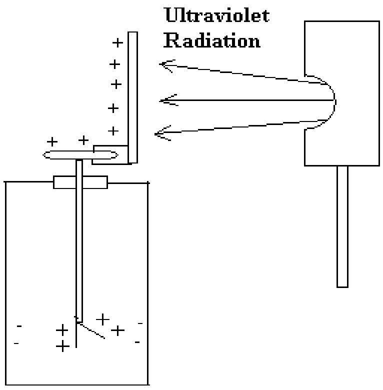


While in a darkroom, the zinc plate is exposed to ultraviolet light from a nearby lamp.

Observation:

The divergence of the leaf decreases.

When the experiment is repeated with a positively charged gold leaf electroscope, the leaf divergence remains unchanged.



Leaf divergence remains unchanged

Explanation of the observations

When the zinc plate and the gold leaf electroscope are negatively charged the electrons liberated from the zinc plate are repelled away and this leads to loss of negative charge from the electroscope, hence the decrease in the leaf divergence.

With both the zinc plate and the gold leaf electroscope positively charged electrons emitted from the plate are attracted back by the positive charge. The total positive charge therefore remains constant producing no change in the leaf divergence.

When a glass sheet is placed between the zinc plate and the lamp, it stops most of the ultraviolet light but transmits violet light from the lamp with which zinc does not produce electrons.

Conditions required to produce photoelectrons

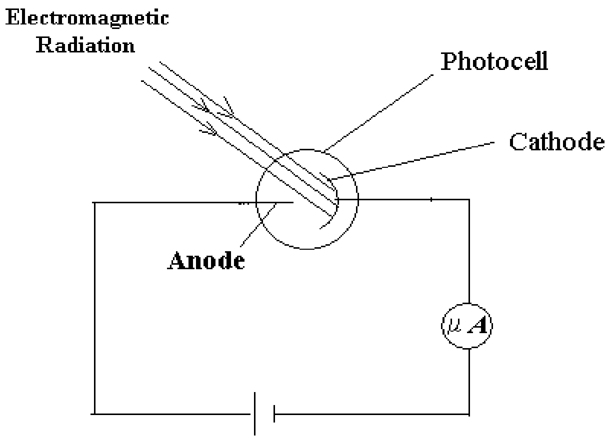
1. The metal surface must be clean
2. The frequency of the incident radiation must be high enough to liberate electrons from the metal surface.

Laws of Photoelectric emission

1. The number of photoelectrons emitted per second is proportional to the brightness or intensity of the incident radiation.
2. Photoelectrons are emitted with a range of kinetic energies from zero up to a maximum which increases as the frequency of the radiation increases and is independent of the intensity of the radiation.
3. For a given metal there is a minimum frequency below which no emission occurs.

Photocell

A photoelectric cell or a photocell changes electromagnetic radiation into an electric current.



It consists of electrodes enclosed in a glass bulb which may be evacuated or contain an inert gas at low pressure.

The cathode (photocathode) is a curved metal plate having an emissive surface facing the anode which is usually a cylindrical metal rod.

When electromagnetic radiation falls on the cathode photoelectrons are emitted and are attracted to the anode.

Charge circulates in the circuit and current is detected by the microammeter. The current produced increases with the intensity of the incident radiation.

There are three types of photocells:

(i) photo emissive cell
(ii) photoconductive cell
(iii) photovoltaic cell

Uses of Photocells

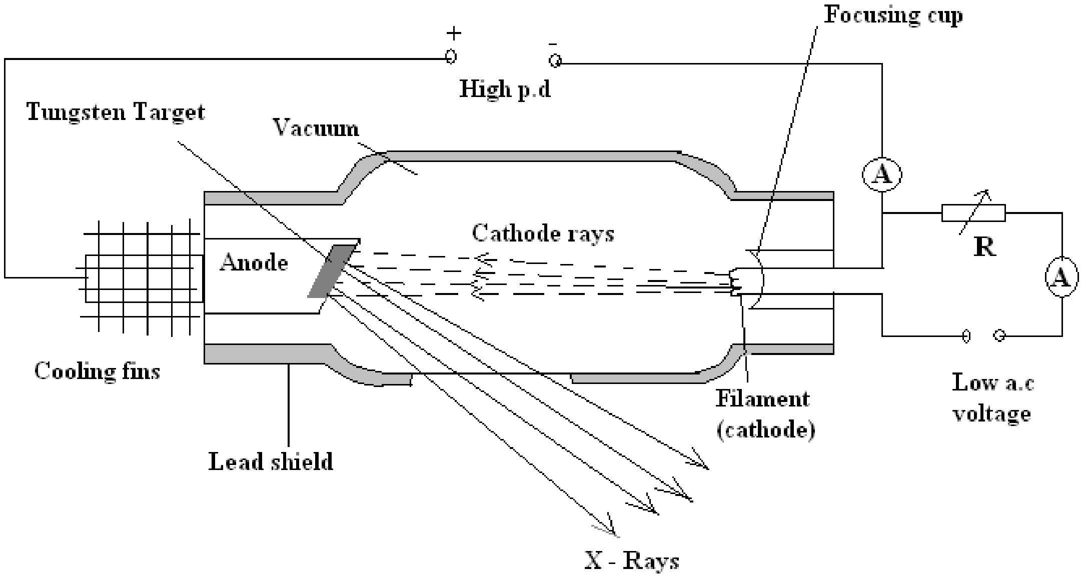
1. They are used in burglar alarms. Any one moving between the lamp and the cell reduces the intensity of the radiation and this starts the alarm to alert the concerned security.
2. In photography they are used as a light meter to determine the exposure time.

3. In factories photocells are used in counting systems. For example, as bottles or tins on a conveyor belt pass between the photocell and the lamp the radiation cut off momentarily is used to operate a counting system.
4. Photocells are used to automatically switch on artificial lights such as street lights at dusk
5. Photocells are used in sound track recording.

X-RAYS

X-rays are electromagnetic radiations that originate from energy changes within an atom when fast moving electrons strike matter.

The X-ray Tube



It consists of an evacuated glass envelope that has a cathode made of a spiral of tungsten wire surrounded by a concave metal cylinder used to focus the electron beam on the anode target.

The anode is a copper block having a target made of a very high melting point metal e.g. tungsten, platinum or molybdenum.

The anode is kept at a high positive accelerating potential with respect to the cathode.

The tube is surrounded by a lead shield with a small exit for X-rays.

Production of X-rays

The low voltage a.c source connected to the cathode and the high positive potential of the anode are switched on. The cathode heats up and emits electrons by thermionic emission.

The high positive potential of the anode accelerates the electrons towards the anode and the focusing cup focuses the electrons onto the tungsten target.

On reaching the target the cathode rays are stopped and lose their kinetic energy to the target.

About 0.5 % of the energy of the cathode rays changes to X-rays emitted through a small window in a lead shield. The rest of the energy converted to internal (heat) energy of the anode which therefore has to be cooled by the cooling fins attached to the anode.

Quality or Penetrating power of X-rays

The quality of X-rays depends on the velocity of the electrons reaching the target and the velocity depends on the p.d across the tube (anode potential)

Soft X-rays

These are X-rays produced when the accelerating p.d across the tube is low.

The have less penetrating power and long wavelengths.

The can only penetrate soft substances such as flesh, cloth, soft wood.

Hard X-rays

They are produced when the accelerating p.d across the tube is high.

The have short wavelengths and high penetration power.

The can penetrate more solid substances and are therefore more dangerous when exposed to.

> ***(Hard X-rays are routinely used to see if there are any faults deeper in any structure such as pipes, machine parts, aero plane bodies, etc. X-rays are used to see the characteristic qualities of gemstones, the genuineness and purity of precious metals such as gold, silver, etc. X-rays are also used to detect the percentage of certain elements in an ore before the ore is taken for commercial mining.)***

Intensity of X-rays

The intensity of X-rays is the quantity of X-rays emitted per second. It depends on the temperature of the filament which in turn depends on the current passing through the filament. The variable resistor R can be used to vary the intensity of the X-rays.

Properties of X-rays

(i) They travel in straight lines

(ii) They readily penetrate matter. Penetration is least in materials containing elements of high density and high atomic number. They can be absorbed by Lead.

(iii) They are not deflected by magnetic or electric fields suggesting that they do carry charge.

(iv) They cause certain substances to fluoresce e.g. barium platinocyanide.

(v) They affect a photographic film in a similar manner to light.

(vi) They eject electrons from matter by the photoelectric effect.

(vii) They ionize a gas, permitting it to conduct.

Uses of X-rays

(a) Medical Uses

In medicine X-ray photographs (radiographs) are used for a number of purposes;

(i) used to detect and investigate fractures

(ii) Used to detect lung tuberculosis. Healthy cells will allow the X-rays to pass through but diseased cells that are heavy will absorb the X-rays thus forming an image of the diseased cells on a photographic film.

(iii) Treatment of cancer. Very hard X-rays are used to destroy cancer cells which cause malignant growth.

(iv) To detect and locate foreign objects in the body e.g. bullets.

(b) Industrial Uses

(i) To detect faults (imperfections) in metal castings and welded joints.

(ii) To inspect a complete machine such as a car, oven, for faults without having to be dismantled.

(c) X-rays are used to study the structure of crystals of different compounds a technique known as X-ray crystallography.

(d) At air ports X-rays are used to detect fire arms e.g. guns and other dangerous metallic objects by irradiating the luggage of the passenger by X-rays.

Precautions

(i) Only the affected part of the body must be exposed to X-rays during medical examination.

(ii) Radiographers should protect themselves by putting on some protective gear.

(iii) The number of exposures to X-rays must be limited.

Difference between X-rays and Cathode Rays

(i) Cathode rays are –vely charged fast moving electrons while X-rays are electromagnetic radiations that originate from energy changes of atoms.

(ii) Cathode rays are deflected by magnetic and electric fields while X-rays are not affected by magnetic and electric fields.

ATOMIC STRUCTURE

An atom consists of a central nucleus that has tightly packed particles called neutrons and protons, with electrons moving around the nucleus at various energy levels or orbits.

The electrons are kept within the atom by strong electrostatic force exerted on them by the nucleus.

Protons

A proton is a hydrogen atom without an electron i.e. it is a positive hydrogen ion. Its charge is equal in size but opposite to that of an electron but its mass is about 2000 times greater.

Proton charge = +e

Symbol for a proton: ${}_{1}^{1}p$ or ${}_{1}^{1}H$

Neutrons

A neutron is an uncharged particle with almost the same mass as a proton i.e. it is neutral with a charge = 0.

Symbol for a neutron: ${}_{0}^{1}n$

The Nucleus

Protons and neutrons make up the nucleus and are referred to as ***nucleons.*** They account for the mass of the nucleus and most of that of the atom; protons account for its positive charge.

The Electron

An electron is a negatively charged particle in continuous circular motion around the positively charged nucleus. The mass of an electron is negligible compared with that of a proton or neutron.

Electron charge = -e

Symbol of an electron: ${}_{-1}^{0}e$

The simplest atom is a Hydrogen atom and consists of 1 proton and 1 electron.

Representation of an atom

An atom X is represented as: ${}_{Z}^{A}X$ where ***A*** is the mass number and ***Z*** the atomic number.

Atomic Number, Z

The atomic number of an atom is the number of protons in the nucleus. It is also called the proton number.

Mass Number, A

The mass number of an atom is the number of protons and neutrons in the nucleus. Mass number is also called nucleon number and is given by;

A = Z + N

Atomic nuclei are represented by symbols derived from their names. For example,

Hydrogen: $^{1}_{1}H$
Lithium: $^{7}_{3}Li$
Uranium: $^{235}_{92}U$

Helium: $^{4}_{2}He$
Carbon: $^{12}_{6}C$
Barium: $^{144}_{56}Ba$

Isotopes

Isotopes are atoms of an element which have the same number of protons but different numbers of neutrons or mass numbers.

Isotopes have the same chemical properties since they have the same number of electrons and occupy the same place in the periodic table.

Examples of elements with isotopes

Chlorine

- Chlorine – 35: $^{35}_{17}Cl$
- Chlorine – 37: $^{37}_{17}Cl$

Nitrogen

- Nitrogen -14: $^{14}_{7}N$
- Nitrogen -17: $^{17}_{7}N$

Oxygen

- Oxygen – 17: $^{17}_{8}O$
- Oxygen – 16: $^{16}_{8}O$

Carbon

- Carbon – 14: $^{14}_{6}C$
- Carbon – 12: $^{12}_{6}C$

Hydrogen

- Protium : $^{1}_{1}H$
- Deuterium: $^{2}_{1}H$

- Tritium: $^{3}_{1}H$

In low mass atoms or nuclei the number of protons is balanced by the number of neutrons making such nuclei stable.

As the mass number of atoms increases the number of neutrons becomes greater than the number of protons. This imbalance makes the atom unstable or radioactive.

An unstable nucleus can break up by emission of radioactive particles and radiations to become a stable or a fairly stable nucleus by a process known as radioactivity.

An Unstable nucleus or atom that disintegrates (decays) by emission of α-particles, β-particles and γ-radiation is called a radioactive substance or radioisotope or radioactive nuclide. The decay process leads to nuclear transformation.

Thus C -14, O – 17, N – 17 are radioisotopes of low mass, high mass radioactive nuclide include Uranium, Radon, Thoron, Polonium. The most abundant of these is Uranium.

RADIOACTIVITY

Radioactivity is the spontaneous disintegration of a radioactive nuclide accompanied by the emission of α – particles, β – particles and γ – radiation.

Radioactive decay is the process in which an unstable atomic nucleus loses energy by emitting ionizing particles and radiation.

This decay, or loss of energy, results in an atom of one type, called the *parent nuclide* transforming to an atom of a different type, called the *daughter nuclide*. For example: a carbon-14 atom (the "parent") emits radiation and transforms to a nitrogen-14 atom (the "daughter"). This is a random process on the atomic level, in that it is impossible to predict

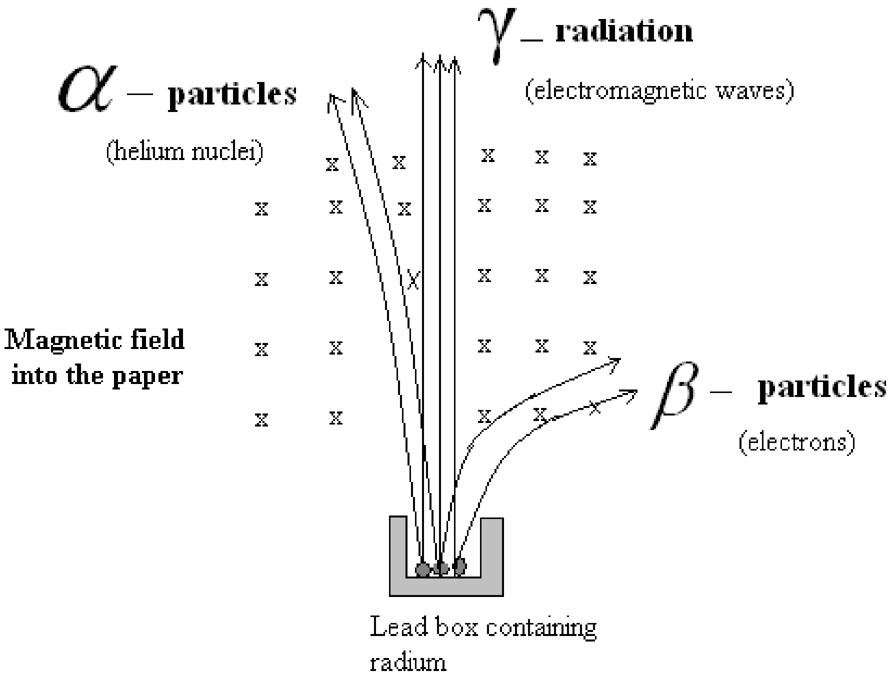
Radioactive decay is the process in which an unstable atomic nucleus loses energy by emitting ionizing particles and radiation. This decay, or loss of energy, results in an atom of one type, called the *parent nuclide* transforming to an atom of a different type, called the *daughter nuclide*. For example: a carbon-14 atom (the "parent") emits radiation and transforms to a nitrogen-14 atom (the "daughter"). This is a random process on the atomic level, in that it is impossible to predict when a given atom will decay.

when a given atom will decay.

Nature of the radiations produced from decay of radioactive substances

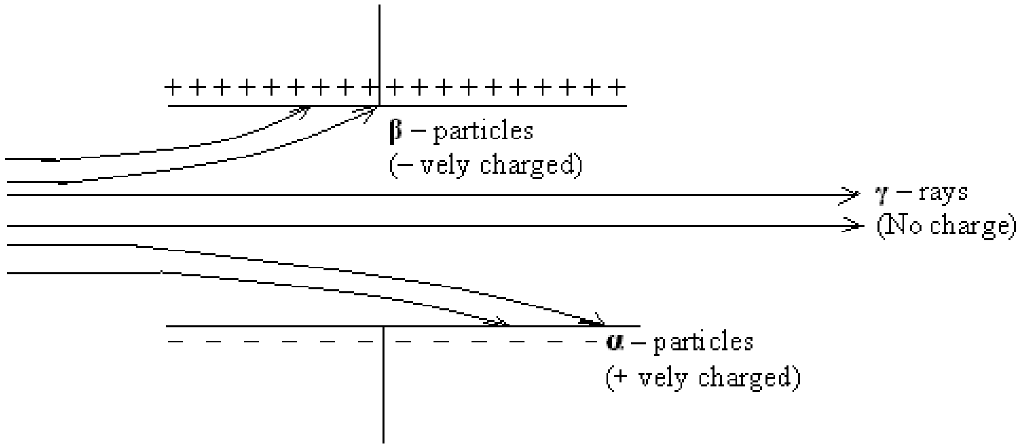
A small quantity of a radioactive substance is placed at the bottom of a small lead box and the radiations that emerge from it are subjected to the action of a very strong magnetic field at right angles to the direction.

Observation



- **α**-particles are deflected in a direction opposite to that of **β** – particles. Since β – particles have a negative charge; this therefore means that **α**-particles are positively charged.
- **α**-particles are least deflected by the field suggesting that they are heavier than **β** – particles.
- **γ** – radiation (rays) pass through the field straight (undeflected). This means that they don't carry any charge.

If these radiations are subjected to a strong electric field between two parallel plates at right angles to their directions, the **α** and **β –** particles are deflected towards the negative and positive plates respectively. This further suggests that **α**-particles are positively charged while **β** – particles are negatively charged.



α – particles

Alpha particles are helium atoms that have lost two of their orbital electrons i.e. they have a net charge of +2e.

They are represented as; ${}_{2}^{4}He$ or ${}_{2}^{4}\alpha$.

Properties of **α**-particles

a) They carry a positive charge;

b) They are deflected by a magnetic field;

c) They are deflected by an electric field;

d) They cause intense ionisation of a gas;

e) They are all ejected approximately with the same speed and are slower because of their large mass.

f) They have a range of a few centimetres in air at s.t.p and can be stopped by a thin sheet of aluminium foil and a sheet of paper i.e. they have the least penetration ability.

β – particles

Beta particles are streams of high - energy electrons similar to cathode rays. A **β** – particle is therefore an electron represented as ${}_{-1}^{0}e$ or ${}_{-1}^{0}\beta$.

Properties of **β** – particles

a) They carry a negative charge;

b) They are deflected by a magnetic field in a direction which shows that they are negatively charged;

c) They are deflected by an electric field towards the positively charged plate;

d) They cause less ionization of a gas compared to **α**-particles;

e) They have greater penetration ability than **α**-particles; they can penetrate several millimetres of aluminium;

f) They are emitted with variable velocities, approaching the velocity of light.

γ – radiation

γ – rays are electromagnetic waves of short wavelength or high energy photons produced by energy changes inside the nucleus of an atom. A γ – photon is usually emitted at the same time as a **β** – particles and an **α**-particles.

Properties of γ – rays

a) They carry no charge

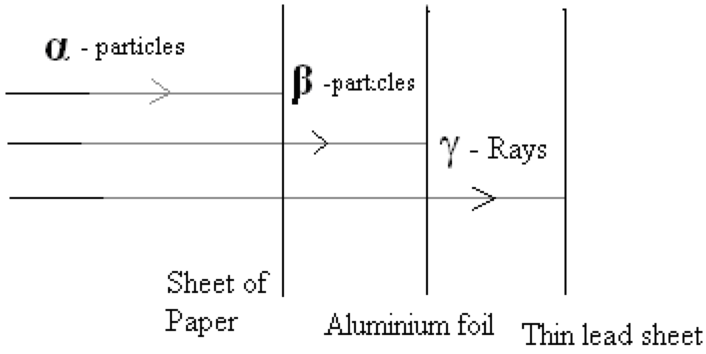
b) They ionize a gas weakly (They cause the least ionisation of a gas).

c) They are not deflected by both magnetic and electric fields.

d) They have the greatest penetration ability. They can penetrate several centimetres of lead. They are electromagnetic in nature similar to x – rays and have short wavelengths.

NB: The difference between γ – rays and X – rays is that γ – rays originate from energy changes in the nuclei of atoms while x – rays come from energy changes associated with the electron structure of atoms.

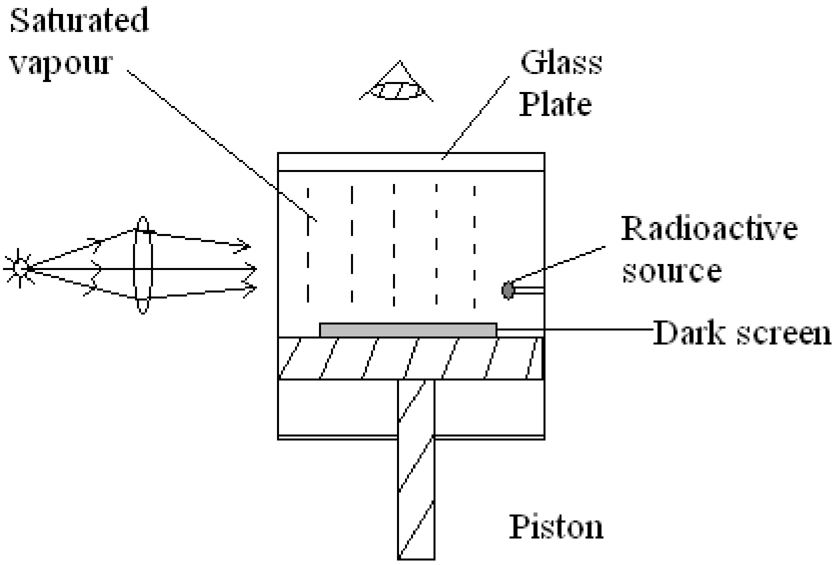
Absorption of radiation



Radiation Detectors of radioactivity products

(a) The Cloud Chamber

It consists of a chamber containing water or alcohol vapour.



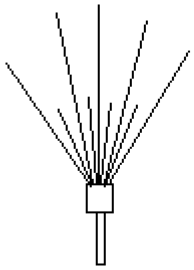
A radioactive source placed inside the chamber emits particles in the air space saturated with water or alcohol vapour.

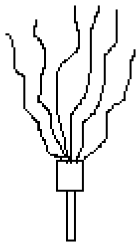
As the particles speed through air they collide with air molecules with such force that electrons are knocked off, leaving a trail of +ve and –ve ions.

When the air space is suddenly expanded by moving the piston, cooling occurs and vapour condenses out on the ions, thus revealing the paths (tracks) of the ionising particles.

Cloud chambers tracks

The appearance of the cloud tracks depends on the particles emitted by the source and can be used as a means of identifying the ionising particle.


α-tracks

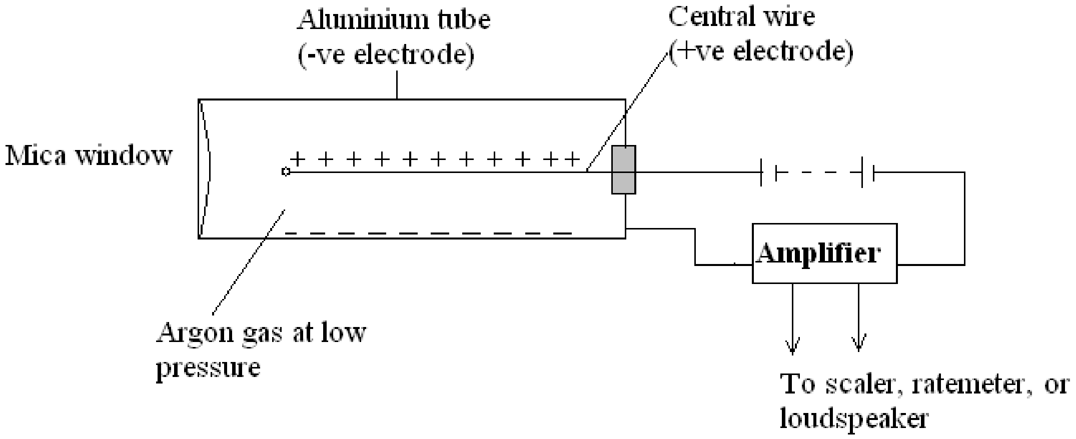

β – tracks


γ – tracks

- Each time an alpha particle is emitted from the source, it ionizes the air in its path and alcohol readily condenses around these ions. A narrow cloud made up of millions of tiny alcohol droplets forms along the track of the alpha – particle. The cloud track looks like the trail left by a high – flying aircraft. The resulting cloud chamber tracks are thick and straight.
- Beta – particle tracks are thin and crooked. The particles cause much less ionization and being light, suffer frequent repulsions from electrons of atoms near which they pass and make ionizing collisions less frequently. They make a few hundreds of ion – pairs per cm their paths display thin irregular cloud tracks.
- γ – rays do not produce cloud tracks along their own paths. A γ – photon may interact with an atom and give up part or the whole of its energy to the atom. The energy absorbed by the atom puts it in an excited state and electrons are ejected from it. The electrons behave like **β –** particles and produce irregular cloud tracks of their own which branch out from the direction of the γ – beam.

(b) <u>The Geiger – Muller tube</u>

It consists of a gas – filled aluminium tube which acts as the –ve electrode while a wire down the centre forms the +ve electrode.



The gas inside the tube consists of argon at low pressure with an added trace of bromine. A thin mica window at the end permits the entry of active particles or γ-photons.

When one of these enters the tube, the argon gas becomes ionized and triggers a whole avalanche of ions between the electrodes. The +ve ions will move towards the –ve electrode and the –ve ions move towards the +ve electrode. For a brief moment the gas conducts and a pulse of current flows in the circuit.

A scaler or ratemeter in the circuit counts the pulses and shows the total on a display. The ratemeter measures the rate of arrival of pulses on a micro ammeter calibrated in counts per second or per minute. A small loud speaker can also be used to indicate the audible pulses.

NB: *The wavering of the ratemeter pointer is a clear demonstration of the random nature of the disintegration or decay of radioactive substances.*

(c) The Gold leaf electroscope

The radiation source is placed near a charged gold leaf electroscope and the particles emitted from it ionise the surrounding air to produce –ve and +ve ions.

The ions of opposite sign to that on the gold leaf electroscope neutralise its charge and the leaf collapses. The more intense the radiation, the faster the leaf falls.

This method is not suitable for detecting β – particles and γ - radiations since they cause insufficient ionisation of air.

Laws of radioactive decay

Law – I (Alpha decay)

When an element disintegrates by the emission of an α – particle it turns into an element with chemical properties similar to those of an element two places earlier in the periodic table.

In α – decay the mass number of the radioactive nuclide decreases by 4 and the atomic number by decreases by 2.

If a parent nuclide X of mass number A and atomic number Z emits an α – particle to form a daughter nuclide Y, the decay is equation becomes;

$$\underset{\text{(Parent nuclide)}}{{}^{A}_{Z}X} \rightarrow \underset{\text{(Daughter nuclide)}}{{}^{A-4}_{Z-2}Y} + \underset{(\alpha-\text{particle})}{{}^{4}_{2}He}$$

<u>Examples of α - decay</u>

1. Decay of radium – 226 to radon

$$^{226}_{88}Ra \rightarrow {}^{222}_{86}Rn + {}^{4}_{2}He$$

2. Decay of uranium – 238 to thorium

$$^{238}_{92}U \rightarrow {}^{234}_{90}Th + {}^{4}_{2}He$$

Law – II (Beta – decay)

When an element disintegrates by the emission of a β – particle it turns into an element with properties similar to those of an element one place later in the periodic table.

A neutron changes to a proton and an electron, the proton remains in the nucleus and the electron is emitted as a β – particle. The new nucleus has the same mass number as the parent nucleus, but its atomic number increases by 1 since it has one more proton.

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

(Parent nuclide) (Daughter nuclide) (β - particle)

<u>Examples of β-decay</u>

1. Decay of Boron – 12 to Carbon – 12

$$ {}^{12}_{5}B \rightarrow {}^{12}_{6}C + {}^{0}_{-1}e $$

2. Decay of Carbon – 14 to Nitrogen – 14

$$ {}^{14}_{6}C \rightarrow {}^{14}_{7}N + {}^{0}_{-1}e $$

γ – decay

A γ – ray is a stream of electromagnetic radiation originating from the nucleus. After the emission of either an α – or β – particle some excess energy remains in the nucleus leaving the nucleus in an excited state. Stability is attained by emitting the excess energy in form of γ – radiation. No change occurs in the mass number and atomic number when a γ – photon is emitted.

Decay equation for γ – emission.

$$ {}^{A}_{Z}X \rightarrow {}^{A}_{Z}X + \gamma $$

(excited nucleus) (stable atom) (γ - radiation)

Half – life

- *The half – life period of a substance is the time taken for half the atoms in any given sample of the substance to decay.*
- *The half – life of a radioactive nuclide is the time taken for half the nuclei present in any given sample to decay.*

Half – lives vary from millionths of a second to thousands of millions of years. For example, Radium (Ra) has a half – life of 1620 years. This means if we start with 1 g of Ra, 0.5g will have disintegrated in 1620 years. After another 1620 years there will be 0.25 g e.t.c.

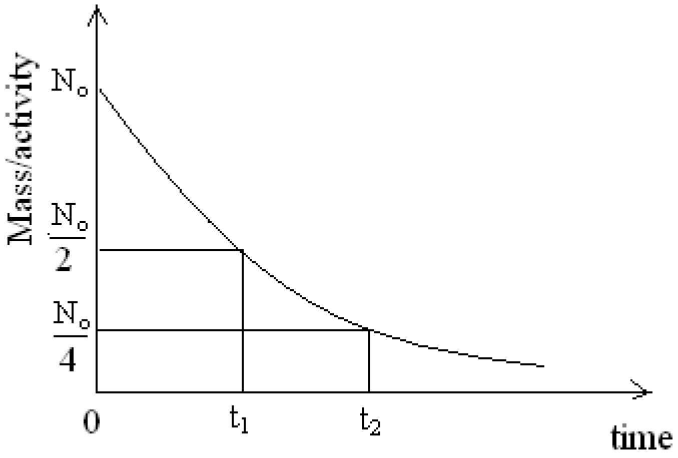
For Radon (Rn) the half – life is 4 days and for Uranium (U-238) it is 4.5 x 10^9 years.

In the measurement of half – life, the mass or activity of a sample of a radioactive source remaining is measured over a period of time and the values tabulated in a table as shown below.

Remaining Mass/Activity	Time

From the results a graph of remaining mass against time taken is plotted and then used to calculate the half – life of the radioactive substance.

Let the initial mass/activity at time t = 0 be N_o and the half – life be $t_{1/2}$.



From the graph the half - life is the time taken for the initial mass N_o to decay by half, i.e. $\frac{N_0}{2}$ and is given by

$t_{½} = t_1 - 0 = t_1$

Time take for the mass to reduce from $\frac{N_0}{2}$ to $\frac{N_0}{4}$ is also equal to the half – life.

$t_{½} = t_2 - t_1 = t_1$

Example 1

In 168 seconds, the activity of Thoron falls to one – eighth of its original value. What is its half - life?

Solution

Let the original activity be A_o and the half – life be $t_{½}$.

Method 1

Activity	Time/s
A_o	0

$\frac{A_0}{2}$	$t_{1/2}$
$\frac{A_0}{4}$	$2t_{1/2}$
$\frac{A_0}{8}$	$3t_{1/2}$

Time taken for the activity to fall to $\frac{A_0}{8}$ is equal to 3 half – lives.

Thus $3t_{1/2} = 168$

$$t_{1/2} = \frac{168}{3} = 56 \text{ s}$$

Method 2

$$A_o \xrightarrow{t_{1/2}} \frac{A_o}{2} \xrightarrow{t_{1/2}} \frac{A_o}{4} \xrightarrow{t_{1/2}} \frac{A_o}{8}$$

For the activity to reduce by one – eighth it takes 3 half – lives. Hence $3t_{1/2} = 168$

$$t_{1/2} = \frac{168}{3} = 56 \text{ s}$$

Example 2

(a) The half – life of uranium X of mass 0.64 g, is 24 days, using a table find the remaining mass of uranium after 120 days.

(b) Plot a graph of mass against time and use it to determine

(i) the mass remaining unchanged after 84 days

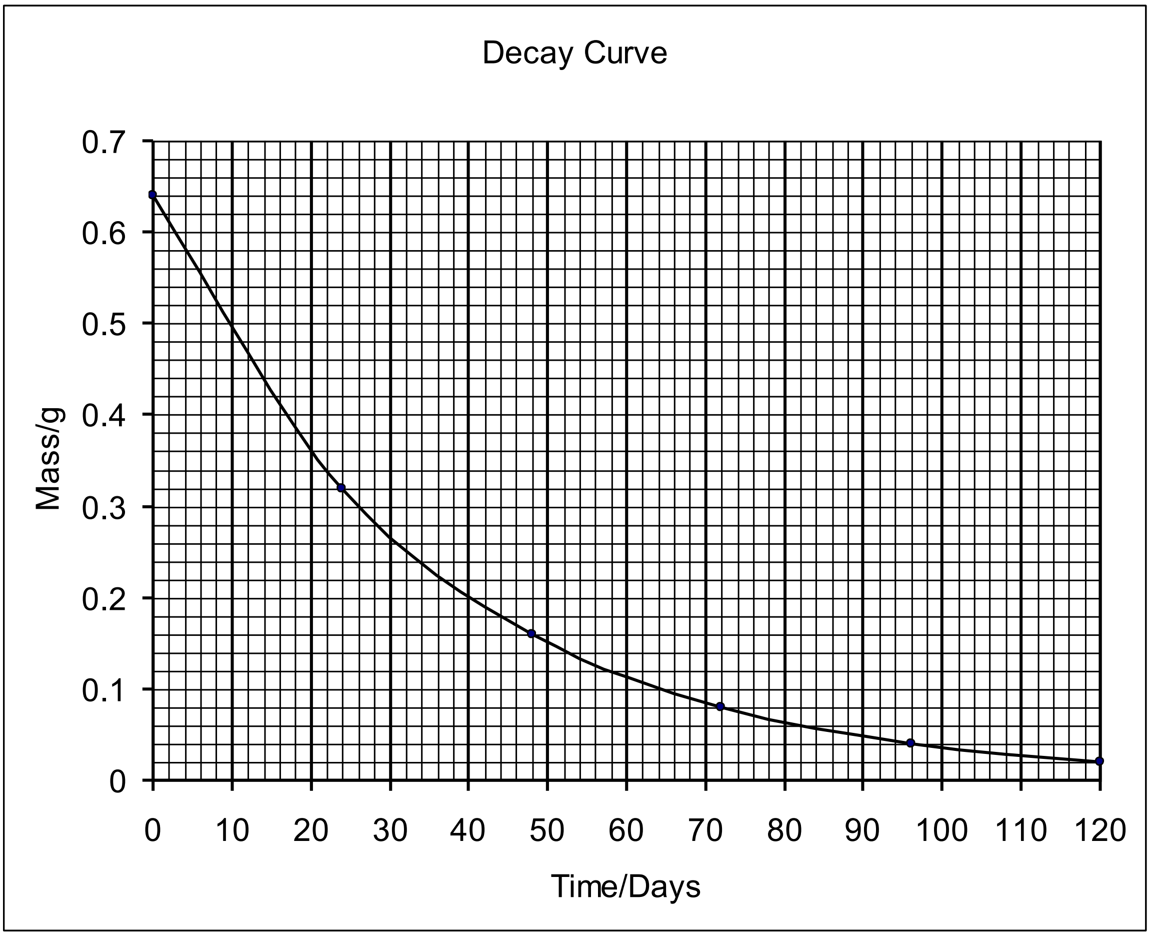
(ii) the time taken for the mass to reduce to 0.25 g.

Solution

(a)

Mass/g	Time/days
0.64	0
0.32	24
0.16	48
0.08	72
0.04	96
0.02	120

(b)



Background Radiation

This is the emission of radiations due to natural traces of radioactive substances. Sources of background radiation include:

- emissions from underground rocks and soils
- emissions from water bodies
- emissions from the atmosphere

When carrying out experiments to measure the activity or count rate of a radioactive source, the background reading should be determined and then subtracted from the final reading.

Example:

A rate meter records a background rate of 7 counts per second. When a radioactive source is held near, the count rate is 167 counts per second. If the half life of the source is 7 days, what will the rate meter record after 21 days?

Cosmic Rays

They are energetic particles originating from space that impinge on Earth's atmosphere. Almost 90% of all the incoming cosmic ray particles are protons, about 9% are helium nuclei (alpha particles) and about 1% are electrons (beta minus particles). The term "ray" is a misnomer, as cosmic particles arrive individually, not in the form of a ray or beam of particles.

The ozone layer limits or shields off the amount of cosmic radiation reaching the earth and therefore its depletion leads to disastrous effects.

NUCLEAR FUSION

This is a reaction where lighter nuclei combine to form a larger nucleus and give off large amounts of energy.

Fusion reactions are not spontaneous; they have to be induced by bringing the fusing nuclei close together by increasing the temperature of the reactants.

Nuclear fusion reactions take place inside the core of stars where temperatures are very high. Our nearest star is the sun which provides us with a lot of light and heat energy through the process of nuclear fusion.

Examples of Fusion Reaction

(i) Fusion of two deuterium nuclei to form a helium nucleus.

$$ {}^{2}_{1}H + {}^{2}_{1}H \rightarrow {}^{4}_{2}He + Energy $$

(Deuterium nuclei) Helium

(ii) Fusion of two He-3 nuclei to He-4 and 2 protons

$$ {}^{3}_{2}He + {}^{3}_{2}He \rightarrow {}^{4}_{2}He + 2\,{}^{1}_{1}H + Energy $$

High temperature conditions are required to give the fusing nuclei enough kinetic energy to overcome the repulsive force between the +ve charge of the nuclei.

Nuclear fusion in the sun takes place at very high temperatures of about 100,000,000 K. But above 6,000 K all matter is gas. At these exceedingly high temperatures plasma is formed. The electrons will have broken away from the nuclei and there is a swirling of electrons, ions, parts of ions and nuclei.

NUCLEAR FISSION

Nuclear fission is a reaction in which a heavy nucleus breaks (splits) up into lighter stable nuclei. The process is accompanied by release of large amounts of energy.

A fission reaction may be spontaneous or induced.

In a nuclear reactor the fission reaction is started by bombarding the nucleus of U-235 by a slow – moving neutron.

The neutron enters the nucleus and makes it highly unstable.

The nucleus breaks up into low mass nuclei and gives off some extra neutron (2 or 3). The extra neutrons produced are used to bombard other U-235 nuclei, thus forming a chain reaction.

$${}^{235}_{92}U+{}^{1}_{0}n\rightarrow{}^{236}_{92}U\rightarrow{}^{144}_{56}Ba+{}^{90}_{36}Kr+2{}^{1}_{0}+Energy$$

$${}^{235}_{92}U+{}^{1}_{0}n\rightarrow{}^{139}_{56}Ba+{}^{94}_{36}Kr+3{}^{1}_{0}+Energy$$

The mass of the resultant nuclei and neutrons is less than that of the parent nucleus. The mass defect appears as kinetic energy of the fragments, heat and light energy.

The chain reaction can be controlled by inserting control rods into the reactor. These rods are made from boron or cadmium which absorbs the neutrons without fissioning. They keep the reaction steady.

USES OF RADIOACTIVITY

1. They are used to detect leakages in pipes.
2. To detect lung cancer.
3. They are used in carbon dating to determine the age of rocks and any ancient fossils. All living things contain carbon and some of this is C-14 which is radioactive with half of 5,700yrs.

   By measuring the amount of C-14 atoms remaining in a given sample such as paper, wood, cloth, or bones, then comparing it with the amount in a sample of the material that leaves presently, the age of the material can be worked out.
4. γ - rays ere used as an alternative to x-rays to kill cancer cells.
5. They are used to sterilize medical equipment.
6. They are used to kill germs in tinned foods.
7. In industries they are used to check and control thickness of paper and aluminium during production or manufacturing.
8. They are used to check for faults and imperfections in welded joints.
9. They are used in smoke detectors to trigger off an alarm in case of fire. A smoke detector contains a radioactive source which emits α – particles. These particles ionize the air, freeing electrons to conduct electricity so that a small current can flow through it. If smoke particles enter the alarm they absorb the α -particles. The particles no longer ionize the air so less current flows. This sets off the alarm.
10. Production of genetically engineered agricultural products e.g. seeds.
11. Manufacturers of luminous paints from radium for the numbers in watches and other instruments.

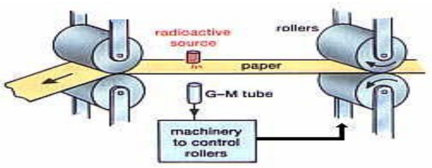
Smoke Detectors

Smoke alarms contain a weak source made of Americium-241.
Alpha particles are emitted from here, which ionize the air, so that the air

conducts electricity and small current flows.
If smoke enters the alarm, this absorbs the particles, the current reduces, and the alarm sounds.
Am-241 has a half-life of 460 years.

Thickness Control

In paper mills, the thickness of the paper can be controlled by measuring how much beta radiation passes through the paper to a Geiger counter. The counter controls the pressure of the rollers to give the correct thickness.
With paper, or plastic, or aluminium foil, α- particles are used, because α particles will not go through the paper.
We choose a source with a long half-life so that it does not need to be replaced often.



Sterilizing

Gamma rays can be used to kill bacteria, mould and insects in food.

This process prolongs the shelf-life of the food, but sometimes changes the taste.

Gamma rays are also used to sterilize hospital equipment, especially plastic syringes that would be damaged if heated.


Radioactive Dating

Animals and plants have a known proportion of Carbon-14 (a radioisotope of Carbon) in their tissues.

When they die they stop taking Carbon in, then the amount of Carbon-14 goes down at a known rate
(Carbon-14 has a half-life of 5700 years).

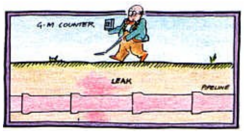
The age of the ancient organic materials can be found by measuring the amount of Carbon-14 that is left in a sample of the dead material with the amount of carbon in a sample that lives but the two should have the same mass.

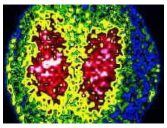
Radioactive Tracers

The most common tracer is called Technetium-99 and is very safe because it only emits gamma rays and doesn't cause much ionization.

Radioisotopes can be used for medical purposes, such as checking for a blocked kidney.
To do this a small amount of Iodine-123 is injected into the patient, after 5 minutes 2 Geiger counters are placed over the kidneys.

Also radioisotopes are used in industry, to detect leaking pipes. To do this, a small amount is injected into the pipe. It is then detected with a GM counter above ground.





Checking Welds

If a gamma source is placed on one side of the welded metal, and a photographic film on the other side, weak points or air bubbles will show up on the film, like an X-ray.

Cancer Treatment

Because Gamma rays can kill living cells, they are used to kill cancer cells without having to resort to difficult surgery. This is called

"**Radiotherapy**" and works because cancer cells can't repair themselves when damaged by gamma rays, as healthy cells can.

It's vital to get the dose correct - too much and you'll damage too many healthy cells, too little and you won't stop the cancer from spreading in time.

Some cancers are easier to treat with radiotherapy than others - it's not too difficult to aim gamma rays at a breast tumour, but for lung cancer it's much harder to avoid damaging healthy cells. Also, lungs are more easily damaged by gamma rays; therefore other treatments may be used.

Differences between X-rays and Cathode rays

- Cathode rays are charged particles. They are negatively charged electrons. X-rays on the other hand are electromagnetic radiations. X-rays have no charges.
- Cathode rays emanate from the cathode itself. X-rays are emitted when high-energy electrons are stopped.
- Cathode rays have low penetrating powers. X-rays have high penetrating powers, although X-rays are much more penetrating than the X-rays.
- Cathode rays travel at the speed given by the potential difference between the anode and the cathode. X-rays always travel at the speed of light.
- Cathode rays are deflected by electric and magnetic fields. X-rays are unaffected by both the electric as well as the magnetic fields.