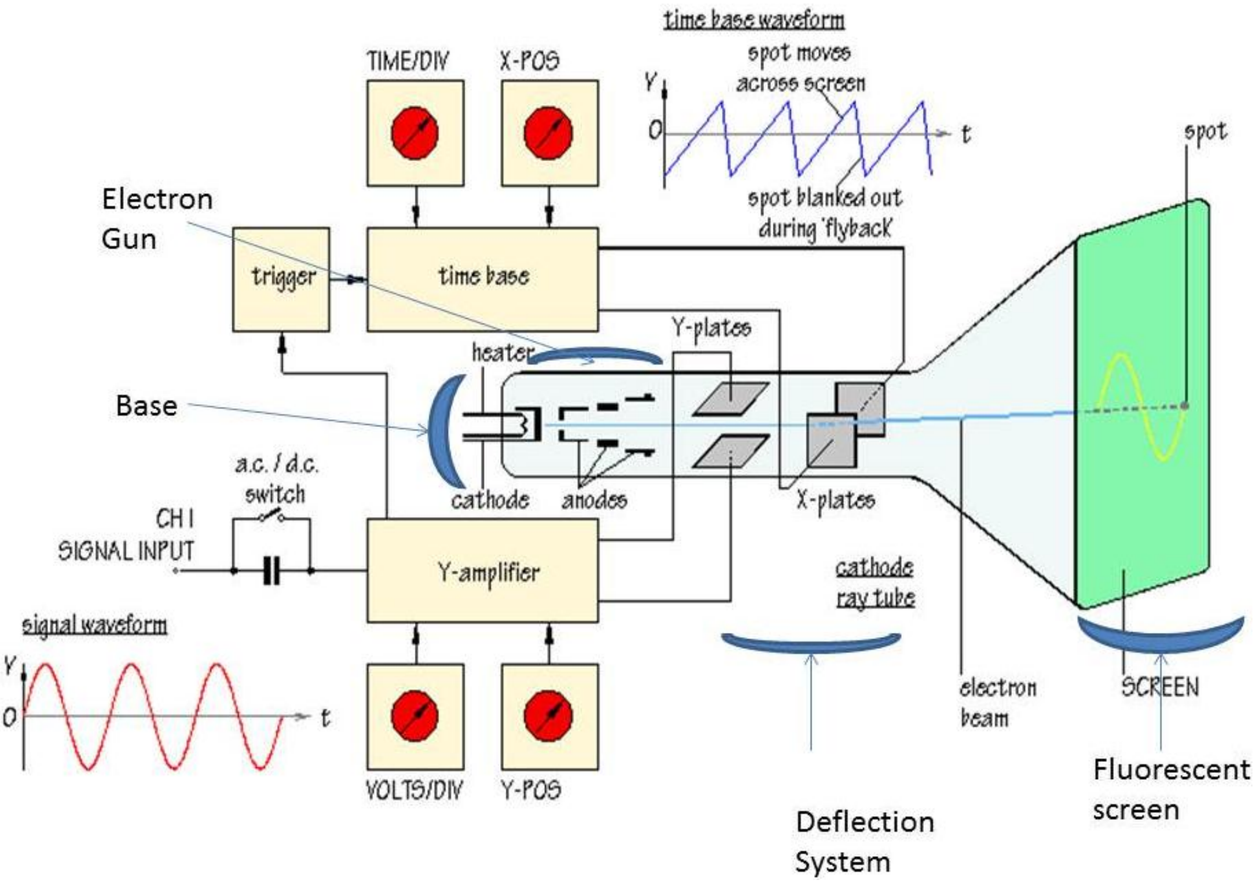
O' LEVEL PHYSICS

ATOMIC PHYSICS

ATOMIC MODEL

TIRAGANA GR



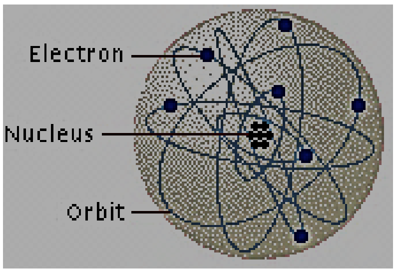
An atom is electrically neutral since the charge of electrons is equal and opposite to that of the protons

ATOMIC PHYSICS

Simple atomic model

An atom consists of

- Central nucleus which contains neutrons and protons. Theses are called nucleons. The protons are positively charged and the neutrons have no charge.
- Electrons revolving round the nucleus in certain allowed orbitals/shells
  The number of protons is always equal to the number of electrons and the atom is electrically neutral.



<u>Definitions</u>

1. Atomic number Z is the number of protons in the nucleus of an atom.
2. Mass number A is the number of nucleons in the nucleus of an atom $A = Z + N$
   N is the number of neutrons.

The nucleus of an atom is represented as $^{A}_{Z}$X where X is the chemical symbol of an element.

Example: $^{4}_{2}He, ^{23}_{11}Na$ and $^{24}_{12}Mg$. For each of these elements find the atomic mass, atomic number and the number of protons

Element	*Atomic number Z*	*Atomic mass A*	*Neutron number*
$^{4}_{2}He$	2	4	2
$^{23}_{11}Na$	11	23	12
$^{24}_{12}Mg$	12	24	12

In an atom of an element,

Particle	*Symbol*	*charge*	*Neutron number*
Proton	$^{1}_{1}H$	Positive	2
Electron	$^{0}_{-1}e$	Negative	12
Neutron	$^{1}_{0}n$	Nil	12

An atom is electrically neutral since the charge of electrons is equal and opposite to that of the protons.

3. Isotopes are atoms of elements with the same atomic number and different mass numbers.

Examples: $^{37}_{17}Cl,\ ^{35}_{17}Cl$ are isotopes of chlorine, $^{1}_{1}H,\ ^{2}_{1}H\ and\ ^{3}_{1}H$ are isotopes of hydrogen, and $^{24}_{12}Mg, ^{26}_{12}Mg$ are isotopes of magnesium

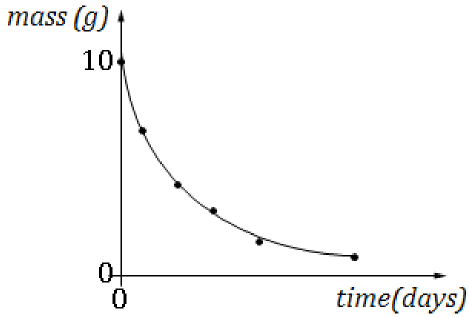
Radioactivity

Mass of unstable some elements (their atomic number is greater than 83) decrease with increase in time. Such materials are called radioactive materials and the whole process is called *disintegration/decay/breaking up*. This process occurs naturally without any foreign agent ie it occurs spontaneously.

During the decay process, some particles; alpha, α , beta, β and gamma, γ are emitted.

Radioactivity is a spontaneous disintegration of radioactive elements emitting alpha, beta and gamma rays.

Since the process involves decrease in mass with time, a decay graph is drawn



Properties of alpha particles

They are

- helium nuclide in nature
- positively charged (with charge of 2)
- more ionising than beta particles and gamma rays
- less penetrating than beta particles and gamma rays (are stopped by thin sheets of papers, cardboards)
- least deflected by both electric and magnetic fields since they are massive

Properties of beta particles

They are

- electrons in nature
- negatively charged
- less ionising than beta particles and gamma rays
- more penetrating than beta particles (are stopped by aluminium and lead sheets)
- more deflected by both electric and magnetic fields since they are less massive compare to alpha particles

Properties of gamma rays

They are

- electromagnetic radiations in nature
- carry no charge
- less ionising than alpha and beta particles
- more penetrating than alpha and beta particles (are stopped by lead sheets)
- pass through by both electric and magnetic fields undeflected

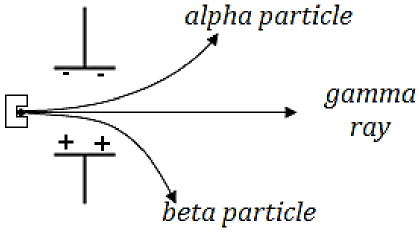
Similarity:

They

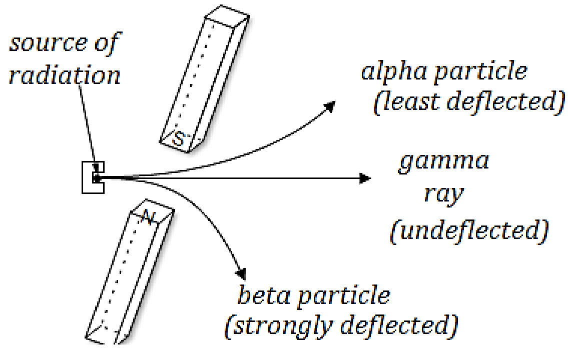
- all cause fluorescence with some metals.
- are produced when nucleus of un stable element decays

Effect of alpha, beta particles and gamma rays on

(i) Electric field

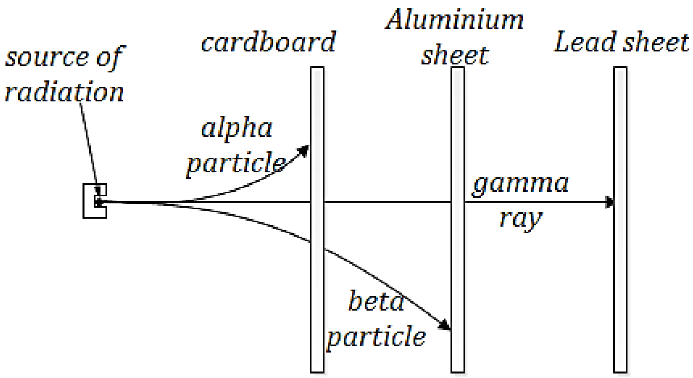


(ii) magnetic field



Note: conventionally, current flows in the direction opposite to the flow of electrons. According to Fleming's left hand rule – with **F**irst finger in the direction of the field, se**C**ond finger in the direction of current, the thu**M**b points in the direction of motion, the electrons (beta particles) pass downwards in the direction perpendicular to the magnetic field.

Absorption of alpha, beta particles and gamma rays by obstacles



Atomic disintegrations

(i) with emission of an alpha particle

When a nucleus of an element decays with emission of an alpha particle, its atomic number decreases by 2 and atomic mass decreases by 4. A new element called a *daughter nuclide* is formed.

$$\underbrace{{}^{A}_{Z}X}_{\text{parent nuclide}} \longrightarrow \underbrace{{}^{A-4}_{Z-2}Y}_{\text{daughter nuclide}} + \underbrace{{}^{4}_{2}He}_{\text{alpha particle}}$$

(ii) with emission of a beta particle

When a nucleus of an element decays with emission of a beta particle, its atomic number increases by 1 and atomic mass does not change.

$$\underbrace{{}^{A}_{Z}X}_{\text{parent nuclide}} \longrightarrow \underbrace{{}^{A}_{Z+1}Y}_{\text{daughter nuclide}} + \underbrace{{}^{0}_{-1}e}_{\text{beta particle}}$$

(iii) with emission of a gamma ray

When a nucleus of an element decays with emission of a gamma ray, its atomic mass and atomic number do not change.

<u>Exercise</u>

1.

$$^{232}_{90}X \xrightarrow{\ A\ } {}^{228}_{88}Y \xrightarrow{\ B\ } {}^{228}_{89}T \xrightarrow{\ C\ } {}^{228}_{89}Z$$

Identify the particles or radiations A, B and C emitted in the decay process above.

A is alpha particle, B is beta particle and C is the gamma ray

2. A radioactive nuclide $^{226}_{88}Ra$ decays by emission of two alpha particles and two beta particles to a nuclide Y. state the atomic number and mass number of Y

$$^{226}_{88}Ra \longrightarrow 2\,{}^{4}_{2}He + {}^{218}_{84}P \longrightarrow 2\,{}^{0}_{-1}e + {}^{218}_{84}Y$$

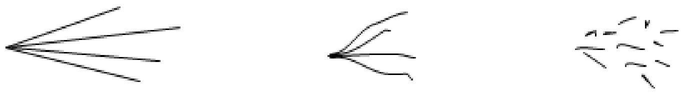
Atomic number of Y is 86 and its mass number is 218

<u>Detectors of the radiations</u>

Emitted radiations from the decaying radioactive materials can be detected by use of

- Geiger – Müller tube (G.M.T)
- a cloud chamber

As seen in a cloud chamber, their traces/paths of appear as below



alpha particle *beta particle* *gamma rays*

Half life

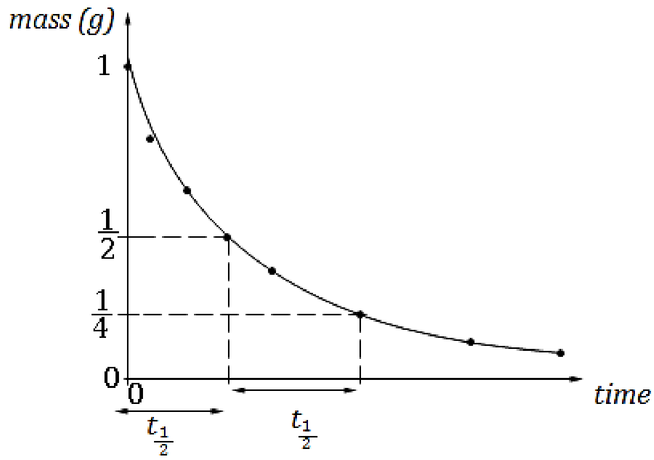
This is the time taken for half the number of a radioactive nuclide to decay

Example

$$1g \xrightarrow[t_{\frac{1}{2}}]{} \frac{1}{2}g \xrightarrow[t_{\frac{1}{2}}]{} \frac{1}{4}g \xrightarrow[t_{\frac{1}{2}}]{} \frac{1}{8}g$$

<u>Determination of half life from a graph</u>

Consider 1g of a radioactive element decaying.



The average time interval $t_{\frac{1}{2}}$ is half life of the radioactive nuclide.

Example: the table below shows the count rate with time of a radioactive element.

T(minutes)	0	1	2	3	4	5	6	7	8
Count rate(cs^{-1})	850	680	544	345	348	278	219	175	140

Plot a graph of count rate against time. From the graph, find the value of half life of the radioactive element.

<u>Calculations of half life</u>

1. A radioactive material of mass 8g has a half life of 20days. Find how much of the material will decay after 60 days.

   Solution: after 20days half of the mass of the material decays i.e

   <u>*Method 1*</u>

   $8g \xrightarrow[20\ days]{} 4g \xrightarrow[20\ days]{} 2g \xrightarrow[20\ days]{} 1g$

   Mass remained (un decayed) after 60 days decayed $= 1g$ *and*

   Mass decayed after 60 days decayed $= 8 - 1 = 7g$

   <u>*Method 2*</u>

   Number of half lives $n = \frac{t}{t_{\frac{1}{2}}}$ *where t is the time taken and* $t_{\frac{1}{2}}$ *is the half life.*

   $t = 60days,\ t_{\frac{1}{2}} = 20days \quad \Rightarrow n = \frac{60}{20} = 3$

   And mass remained $M = \frac{M_o}{2^n}$ *where* M_o *is the original mass of the element.*

   $\Rightarrow M = \frac{8}{2^3} = \frac{8}{8} = 1g$ *Thus mass decayed after 60 days decayed* $= 8 - 1 = 7g$

2. grams of a radioactive material of half life 3weeks decayed and 5.12g remained after 15weeks. What is the value of ?

   Solution: $M = 5.12g, t_{\frac{1}{2}} = 3\ weeks, t = 15weeks\ n = \frac{15}{3} = 5$

   $M = \frac{M_o}{2^n} \Rightarrow 5.12 = \frac{M_o}{2^5} = \frac{M_o}{32} \Rightarrow M_o = 32 \times 5.12 = 163.84g$

   $Mass\ decayed, x = M_o - M = 163.84 - 5.12 = 158.72g$

3. The mass of a radioactive substance decays to $\frac{1}{16}^{th}$ of its original mass after 16 days. What is

   (i) Its half life,

   (ii) The fraction of the original mass will have decayed after 20 days?

   Solution:

   (i) let M_o *be the original mass of the element, un decayed mass* $M = \frac{1}{16}M_o$

   $$from\ M = \frac{M_o}{2^n} \Rightarrow \frac{1}{16}M_o = \frac{M_o}{2^n} \quad \Rightarrow 2^n = 16 \ \Rightarrow n = 4.$$

   If $t = 16\ days,$ *number of half lives* $n = 4 = \frac{16}{t_{\frac{1}{2}}} \quad \Rightarrow t_{\frac{1}{2}} = \frac{16}{4} = 4\ days$

   (ii) $t = 20\ days,\ t_{\frac{1}{2}} = 4\ days \ \Rightarrow n = \frac{20}{4} = 5. \quad M = \frac{M_o}{2^n} = \frac{M_o}{2^5} = \frac{1}{32}M_o$

   Mass decayed$= M_o - M = M_o - \frac{1}{32}M_o = \frac{31}{32}M_o$

   Therefore $\frac{31}{32}$ *is the fraction of the original mass that decayed*

Questions

1. The half life of uranium is 24 days. Calculate the mass of uranium which remains after 120 days if its original mass is 64g. [2g]
2. A radioactive sample has a half life of 3.0×10^3years. How long does it take for three – quarters of the sample to decay? [6.0×10^3years]
3. The half life of a radioactive substance is 12 days. After 36 days, what fraction of the original activity
   (i) Will remain
   (ii) Will have decayed?

Health hazards of radioactive radiations

They

- Destroy living cells of a body
- Cause sterility (inability to produce children)
- Cause leukemia (cancer of blood)
- Serious abnormalities to unborn children.

Safety precautions

When dealing with radioactive materials,

- Use a pair of forceps not bare hands to hold the materials
- Keep a radioactive source in lead boxes
- Wear jackets with a layer of lead
- Avoid places where radioactive materials are kept
- Avoid eating when working with radioactive substances
- Keep a reasonable distance from the source of radiation.

Uses of radioactivity

1. Industrial use:

- Beta particles are used to estimate thickness of papers, plastics and metal sheets
- Beta particle when dissolved in flowing liquids, is used to detect leaks in underground pipes

2. Medical use:

- Radioactive iodine is used in the treatment and diagnosis of goiter
- Radioactive cobalt is used in the treatment of cancer
- Plastic syringes are sterilized by gamma radiation, after being manufactured.

3. Carbon dating:

   Every living thing contains a constant amount of carbon – 14, which decreases with time when they die. The age of fossils (remains of dead materials) can be obtained.

Nuclear fusion and fission

Nuclear fusion is the joining of two or more smaller nuclides to form a fairly heavy nuclide with release of energy.

Nuclear fusion occurs when there are

- two light and unstable nuclides
- extremely high temperature

Such reactions occur in the sun.

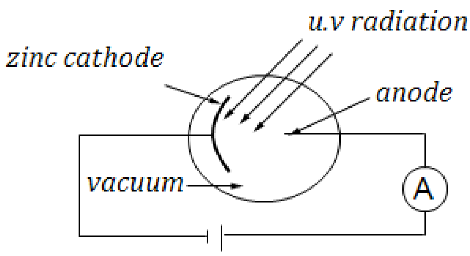
Nuclear fission is the splitting of a heavy nuclide to form slightly smaller nuclides with the release of energy.
Nuclear fission occurs when there is

- un stable nucleus
- a neutron directed to the nucleus of a radioactive substance such as uranium.

Such reactions occur in the nuclear reactors and nuclear bombs.

<u>PRODUCTION OF ELECTRONS</u>
Metals contain loosely attached electrons to their atoms. These electrons can easily escape/be emitted when they gain sufficient energy.
Methods of electron production include photo electric emission and thermionic emission.

1. <u>Photo electric emission</u>: this is the production of electrons when suitable radiation such as ultraviolet (u.v) falls on metal surfaces.



As electrons are produced when u.v falls on cathode, they are attracted to the anode and current flows through the circuit.
Note:

(a) A bright/intense /strong radiation produces more electrons and thus more current flows.
(b) Anode must be small in order to produce a stronger electric field around it.
(c) A beam of longer wavelength has less energy and if this energy is not sufficient, no electrons are emitted.
(d) A photocell is used in burglar alarms which are operated by infra red radiations

2. <u>Thermionic emission</u> is the production of electrons from metal surfaces when they are heated at higher temperatures.

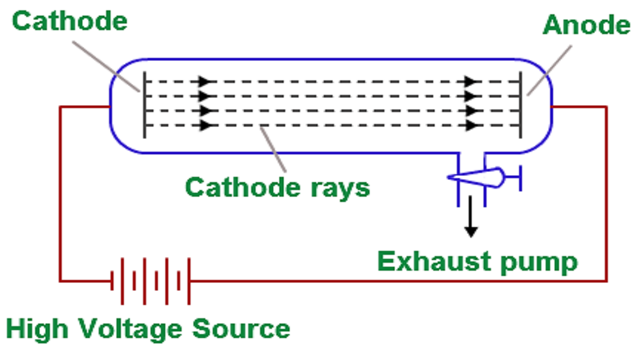
Cathode rays
These are fast moving electrons. They are produced when a metal is electrically heated at low voltage.

<u>Properties of cathode rays</u>
They

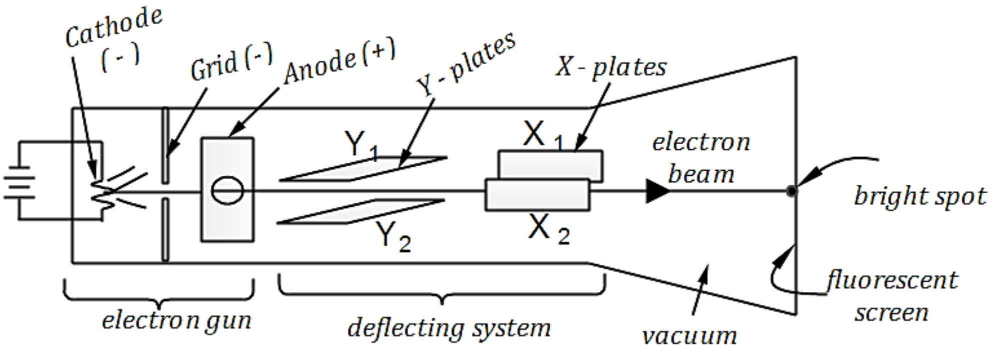
- are negatively charged
- are deflected by both electric and magnetic fields (like beta particle)
- travel in straight lines
- cause fluorescence with some metals
- have low penetrating power low ionising power

Cathode ray tube (CRT)

It consists of the anode and the cathode with a high voltage across them so that thermionically emitted electrons are attracted to the anode at high speed.



The cathode ray oscilloscope (CRO)



Thermionically emitted electrons from the cathode are accelerated to the anode by a high potential difference (p.d) between the cathode and the anode.

Functions of the parts

1. Grid: this controls brightness of the spot on the screen by controlling the number of electrons reaching the screen.
2. Anode: this accelerates and focuses the electrons on the screen
3. Y – Plates: these deflect the electron beam vertically on the screen. Any signal to be studied is connected to these plates
4. X – Plates: these deflect the electron beam horizontally on the screen. These plates provide a time – base for the wave form formed on the screen.
   The time – base circuit when connected to the x – plates automatically applies a p.d across x – plates so that the spot moves across and back on the screen.
5. Fluorescent screen: this provides a background where patterns to be studied are formed.

Note: the CRO is evacuated so that the electron beam moves freely without colliding with the gas atoms

Uses of CRO

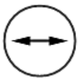
It is used

- as a voltmeter to measure voltage
- to determine the frequency of an alternating current (a.c)
- to study wave patterns
- as a timing device in radar system

<u>Wave pattern formed in a CRT</u>

1. 

a spot is formed when no p.d is applied to both x – plates and y – plates (i.e. when they are switched off)

2. 
a horizontal line is obtained when y – plates are off and the time – base is applied on x – plates are switched on.

3. 

A vertical line is obtained when a.c is applied to y – plates and time - base is switched off.

4. 

A vertical spot is obtained when a d.c is applied on y – plates with a positive terminal connected on plate Y_1.

5. 

A wave pattern is obtained when a.c is connected to y – plates and time – base is switched on.

The CRO is applied in
- T – V tubes
- Monitors of computers

X – rays

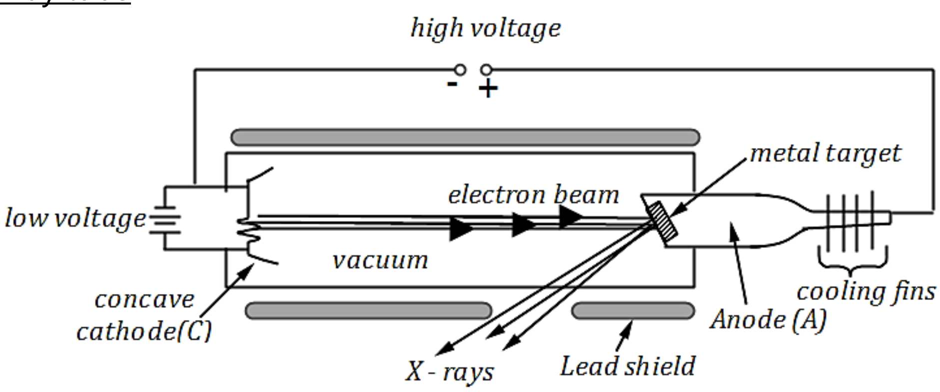
These are electromagnetic waves of short wavelength. They are produced when fast moving electrons – cathode rays collide with atoms of a metal target.

<u>Differences between x – rays and gamma rays</u>
- x – rays are produced when cathode rays hit a metal target while gamma rays are only produced when the nucleus of a radioactive element decays
- x – rays have longer wavelength than gamma rays
- production of x-rays is controlled by changing the temperature of the cathode while production of gamma rays is natural and can not be controlled.

<u>Properties of x – rays</u>

They
- carry no charge
- high penetrating power than gamma rays
- highly affect a photographic paper
- are not deflected by both magnetic and electric fields
- travel in straight lines
- cause fluorescence with some metals
- have low ionising power

The x –ray tube



Functions of the parts

1. High voltage: this accelerates cathode rays to the target due to high p.d between the cathode and the anode
2. Cooling fins: these conduct away the generated heat from the anode
3. Copper anode: this conducts heat quickly to the fins
4. Low voltage: this heats up the cathode to emit electrons
5. Cathode: this when heated, produces electrons.
6. Vacuum: reduces collisions and interference to flow of cathode rays and so there is no loss of their kinetic energy.
7. Metal target: it is here that there are atoms with in which transitions occur, leading to production of x – rays.

Note:

- The target is usually made of a metal such as tungsten with high melting point.
- The intensity of x – rays is increased by increasing temperature of the filament such more electrons are produced and reach the target.

Energy changes in x – ray tube

$$electrical\ energy\ \rightarrow heat\ energy\ \rightarrow kinetic\ energy\ \rightarrow x - ray\ heat$$

Question: describe briefly how x – rays are produced.
Cathode rays on collision with the metal target transfer their K.E to electrons in the atoms of the target.
The atoms become excited and electron transitions (electrons in higher energy levels fall to lower energy levels) occur leading to production of x – rays.

Types of x – rays

Hard x – rays	Soft x – rays
- Produced when a high p.d is applied between anode and cathode - Have short wavelength - Have high penetrating power	- Produced when a low p.d is applied between anode and cathode - Have longer wavelength - Have low penetrating power

Uses of x – rays

1. Medical:
   - soft x – rays are used in taking pictures of fractured bones
   - soft x – rays are used in destroying cancer cells
2. Industrial:
   - They are used in locating faults in welded joints
3. They are used in studying molecular arrangements in crystalline materials i.e x – ray crystallography

Health hazards of x – rays

They

- destroy living cells and stops them from multiplication
- lead to hereditary defects and even death in children

Safety precautions when in working with x – rays

- avoid unnecessary exposure to x – rays
- wear coats coated with lead
- expose x – rays to only the affected parts
- avoid exposure of x – rays to unborn babies and children
- shorten the exposure time
- x – ray machines be kept in buildings with concrete walls

Questions

1. (a) Describe a simple model of the atom.
   (b) Define the terms: atomic number and isotopes of an element.
   (c) State two differences between $\alpha -$ and $\beta -$ particles.

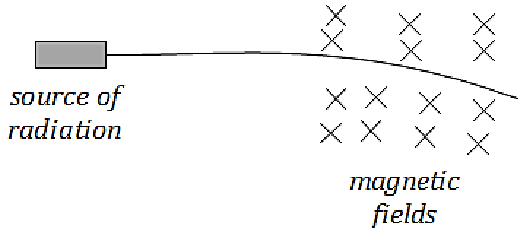
2. (a) Define the terms as applied to radioactivity: isotope and half – life
   (b) The mass of a radioactive substance falls to $\frac{1}{4}$ of its original after 10 days. What is its half life?
   (c) State one medical use and non medical use of radioactive tracers.

3. (a) What is radioactivity?
   (b) The nuclide $^{215}_{84}Po$ decays to a nuclide X by emission of an alpha particle. Write a balanced equation of the decay
   (c) What fraction of the original sample of the radioactive substance is left after 2 half lives?

4. (a) (i) what are cathode rays?
   (ii) Draw a well labeled diagram of a cathode ray oscilloscope (CRO). Explain one function of each of the parts you have labeled.
   (ii) Describe briefly how cathode rays are produced in the cathode ray tube
   (b) Give two uses of a CRO.

5. (a) Give two methods of producing electrons from metals.
   (b) State the effect of each of the following on a fine beam of electrons
   (i) electric field
   (ii) magnetic field
   (c)(i) Explain briefly how x – rays are produced.
   (ii) Distinguish between hard x – rays and soft x – rays.
   (iii) What precautions should be taken to minimise health hazards?

6. (a)(i) Name the particles emitted by a radioactive nuclides.
   (ii) Give one property common to the particles named in (i)



   (b) A stream of particles from a radioactive source passes through a magnetic field directed into a plane of paper as shown in the figure above.
   (i) Identify the particles in the stream.
   (ii) Sketch the path taken by the particles in an electric field.
   (c)(i) Define half life.
   (ii) A radioactive material has a half life of 30weeks. It decays and 20g remain after 150 days. What was the original mass before the decay?
   (d) Distinguish between nuclear fusion and nuclear fission.
   State two conditions necessary for each process to occur.

7. (a) List any two differences between X – rays and gamma rays.
   (b) With the aid of a labeled diagram describe how X – rays are produced.
   (c) What are the differences between hard and soft X – rays?
   (d) Define the following: radioactive nuclide and isotopes
   (e) Outline three uses of radioactivity.

8. (a) What is meant by thermionic emission?
   (b) (i) Name three main components of the cathode ray oscilloscope (CRO).
   (ii) Describe the functions of the components named in (b)(i) above.
   (iii) State two uses of a CRO
   (c) State the conditions under which electrons can be used to generate X – rays.
   (d) Give one use of X – rays.