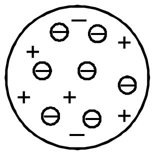
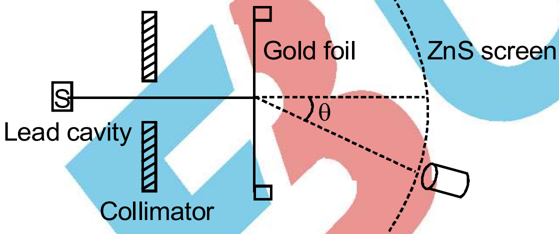
ATOMS

Thomson's Atomic Model : According to this model, an atom consists of a positively charged sphere in which entire mass & positive charge of the atom is uniformly distributed. Inside this sphere, the electrons are embedded like seeds in a waternelon or like plums in a pudding. The number of electrons is such that their negative charge is equal to positive charge. Thus, atoms is electrically neutral.



Limitations of Thomson's Model : (i) Could not explain the origin of spectral series of hydrogen & other atoms. (ii) Could not explain large angle scattering of α - particles observed by Rutherford.

Rutherford's α-scattering experiment : An α - particle is He nucleus containing 2 protons & 2 neutrons. It has 4 units of mass & 2 units of positive charge. Many radioactive elements emit α - particles.



S is a radioactive source contained in a lead cavity. The α - particle emitted by the source are collimated into narrow beam with the help of collimator. The collimated beam is allowed to fall on a thin gold fail of thickness $\approx 10^{-5}$ m. α - particles are scattered in different directions are observed though a rotatable detector consisting of ZnS screen & a microscope. The α - particles produce bright flashes on ZnS screen. These are observed by the microscope &counted at different scattering angle θ.

Observations : (i) Most of the α- particle pass straight through the gold foil or suffered very small angle of deflections.

(ii) A few α- particles scatter through large ogles (> 90°).

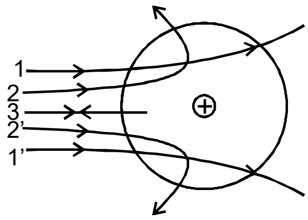
(iii) Rarely, an α - particle rebounces i.e., scattered through an angle of 180°

Explanation :

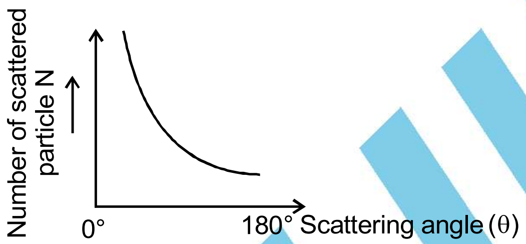
(i) Since most of the α- particles passed undeviated, the atom has a lot of empty space in it.

(ii) To explain large scattering of α - particles, Rutherfored suggested that all the positive charge & entire mass of the atom is confined to an extremely small central core called as nucleus.

(iii) The scattering of α - particles through different angles was explained as : The α-particles I, I′. Which pass through the atom at a large distance from from the nucleus experience a small electrostatic force of repulsion & undergo a small defection. The α - particles 2. 2′ which pass through the atom at a close distance from the nucleus suffer a larger defection. The α - particle 3, which travels directly towards the nucleus shows down, comes to rest & is deflected through 180° and hence retraces its path.

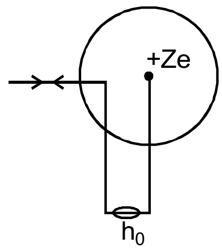


The graph between scattering angle θ & the number of α - particles directly scatted N is as shown :



Distance of closet Approach : An α - particle travelling towards the center of the nucleus slows down as it apparoaches the nucleus. At a certain distance, say r_0 from the nucleus, the α-particle comes to rest for a moment and then retraces it path. It initial kinetic energy is completely converted into electrostatic potential energy. This distance r_0 is called the distance of closest approach. This distance gives an

estimate fo the size of the nucleus. Mathematically.

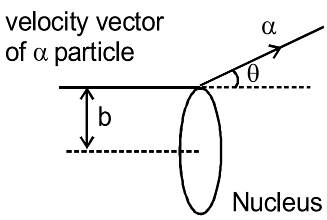


$$\frac{1}{2}mv^2 = \frac{1}{4\pi\varepsilon_0}\frac{(2e)(Ze)}{r_0}$$

where 2 e is the charge on α- particle and Ze is the charge on nucleus.

$$r_0 = \frac{Ze(2e)}{4\pi\in_0\left(\frac{1}{2}mv^2\right)}$$

Impact Parameter : Impact parameter is defined as the perpendicular distance of the velocity vector fo the α - particle from the center of the nucleus, when it is far away from the nucleus of the atom. Rutherford derived the relation between impact parameter and scattering angle, which is given by.



$$b = \frac{1}{4\pi\varepsilon_0}\frac{Ze^2\cot\theta/2}{\frac{1}{2}mv^2}$$

Rutherford's Model : On the basis of α - scattering experiment, Rutherford proposed the model of an atom as :

1. An atom consists of a small and massive central core in which the entire positive charge and almost the whole mass are concentrated. This core is called a smucleus.

2. The size of the nucleus is very small as compared to the size of atom.

3. The nucleus is surrounded by a number of electrons so that their total negative charge is equal to the total positive charge and the atom is electrically neutral.

4. The electrons revolve around the nucleus in various orbits. The centripetal force required for their revolution is provided by the electrostatic attraction between the electrons and the nucellus.

Drawbacks of Rutherford's model of Atom :

1. It failed to explain the stability of the atom. The electrons revolving around the nucleus are accelerated towards the nucelus of the atom. Any charged particle while accelerating ore retarding loses energy through electromagnetic radiations. As a result, the radius of the path of the electron should go on decreasing and ultimately it should fall into the nucleus by following spiral path. But, in fact, it never happens. It contradicts the stability of matter.

2. It failed to explain the spectrum of an atom. As electron can revolve around a nucleus in circular orbits of all possible radii, so atom should emit continuous energy spectrum. But even the simplest atom i.e. hydrogen atom has line spectrum instead of continuous spectrum, which Rutherford's model could not explain.

Bohr's Model of Hydrogen Atom :

1. An atom consists of a central core called nucleus, in which entire positive charge and almost entire mass of the atom is concentrated. Electron revolve around the nucleus in circular orbits. The centripetal force required for revolution is provided by the electrostatic force of attraction between he electron and the nucleus. If m is the mass of electron moving with a velocity v in a circular orbit of radius r, then the necessary centripetal force if F = $\frac{mv^2}{r}$

Also, the electrostatic force of attraction between the nucleus of charge (+Ze) and electron of charge (−e) is

$$F = \frac{1}{4\pi\varepsilon_0}\frac{(Ze)(e)}{r^2} = \frac{KZe^2}{r^2} \qquad \text{where } K = \frac{1}{4\pi\varepsilon_0}$$

$$\frac{mv^2}{r} = \frac{KZe^2}{r^2}$$

2. According to Bohr, electrons can revolve only is those certain discrete non radiating orbits, called sateionary orbits, for which total angular momentum of the revolving electron is an integral multiple of $h/2\pi$, where h is Plank's constant. Thus the angular momentum of the orbiting electron is quantized. While revolving in these stationary orbits, an electron does not radiate energy. For any permitted stationary orbit.

$$mvr = \frac{nh}{2\pi}$$

where n is any positive integer, 1, 2, 3 .... It is called principal quantum number.

3. The emission/absorption of energy occurs only when an electron jumps from one stationary non-radiating orbit to another. The difference in the total energy of electron in the two permitted orbits is absorbed when the electron jumps from inner to the outer orbit i.e., absorbs photons, and emitted when electron jumps from outer to the inner orbit i.e., emits photons. If E_1 is total energy of electron in an inner stationary orbit and E_2 is its total energy in an outer stationary orbit, then $h\nu = E_2 - E_1$

Some quantities related to Bohr's orbit :

(a) Radii of Bohr's statioanry orbits : We know, $mvr = \frac{nh}{2\pi}$ or $v = \frac{nh}{2\pi mr}$

Substituting v in the equation $\frac{mv^2}{r} = \frac{KZe^2}{r^2}$

$$\frac{m}{r}\frac{n^2h^2}{4\pi^2m^2r^2} = \frac{KZe^2}{r^2}$$

$$r = \frac{n^2h^2}{4\pi^2mKZe^2}$$ for hydrogen atom Z = 1

$$r = \frac{n^2h^2}{4\pi^2mKe^2}$$ This shows that $r \propto n^2$ i.e. radii of stationary orbits are in the ratio $1^2 : 2^2 : 3^3$ and so on i.e. 1 : 4 :9 .... Clearly the stationary orbits are not equally spaced.

(b) Velocity of electron in Bohr's sationary orbit : We have,

$$r = \frac{KZe^2}{mv^2}$$ Also, $r = \frac{nh}{2\pi mv}$

Therefore, $\frac{KZe^2}{mv^2} = \frac{nh}{2\pi mv}$ or $v = \frac{2\pi KZe^2}{nh}$

For hydrogen atom Z = 1 Therefore, $v = \frac{2\pi Ke^2}{nh}$

(c) **Total energy of electron :** The energy of electron revolving in a stationary orbit is of two types :

Kinetic energy is due to motion and potential energy is due to position of electron. We have.

$$\frac{mv^2}{r} = \frac{KZe^2}{r^2}$$

i.e., K.E. of electron = $\frac{1}{2}mv^2 = \frac{KZe^2}{2r}$

Potential energy of electron = $\frac{KZe(-e)}{r} = -\frac{KZe^2}{r}$

Total energy of electron in the orbit E = K.E. + P.E. = $\frac{1}{2}\frac{KZe^2}{r} - \frac{KZe^2}{r} = -\frac{KZe^2}{2r}$

Substituting $r = \frac{n^2h^2}{4\pi^2mKZe^2}$ we get, $E = -\frac{2\pi^2 mK^2Z^2e^4}{n^2h^2}$

For hydrogen atom Z = 1, $\therefore$ $E = -\frac{2\pi^2mK^2e^4}{n^2h^2}$

Substituting the standard values, we get $E = -\frac{13.6}{n^2}eV$

Total energy of electron in a stationary orbit is negative, which means the electron is bound to the nucleus by means of electrostatic attraction.

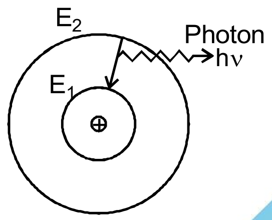
Origin of spectral lines :

Suppose E_1 = total energy of electron in the inner (n_1 th) orbit and e_2 = total energy of electron in the outer (n_2th) orbit. When an electron jumps from an outer to an inner orbit, the frequency of radiation emitted, according to Bohr's third postulate is $hv = E_2 - E_1$

$$h\nu = -\frac{2\pi^2 mK^2e^4}{n_2^2h^2} + \frac{2\pi^2 mK^2e^4}{n_1^2h^2}$$

$$\frac{hc}{\lambda} = \frac{2\pi^2 mK^2e^4}{h^2}\left[\frac{1}{n_1^2} - \frac{1}{n_2^2}\right]$$

$$\frac{1}{\lambda} = \frac{2\pi^2 mK^2e^4}{h^2}\left[\frac{1}{n_1^2} - \frac{1}{n_2^2}\right]$$



Now, $\frac{1}{\lambda} = \bar{\nu}$, the wave number of radiation emitted i.e., number of complete wave in unit length.

and $\frac{2\pi^2 mK^2e^4}{ch^3} = R$ is a constant called Rydberg constant. R= 1.097×10^7 m^{-1}

$\therefore$ From above equation $\bar{\nu} = R\left[\frac{1}{n_1^2} - \frac{1}{n_2^2}\right]$

This equation is called the Rydberg formula for the spectrum of hydrogen atom.

Bohr's explanation of Spectral of Hydrogen Atom :

1. **Lyman Series :** Bohr postulated that Lyman series of obtained when an electron jumps to the first orbit (n_1 = 1) from any outer orbit (n_2 =2, 3, 4 ....)

$\bar{\nu} = R\left[\frac{1}{1^2} - \frac{1}{n_2^2}\right]$ where n_2 : 2, 3, 4............ This series lies in the ultra violet region of the spectrum and agree well with the values of $\bar{\nu}$ observed experimentally by Lyman.

2. **Balmer Series :** According to Bohr, Balmer series is obtained when an electron jumps to the second orbit (n_1 = 2) from any outer orbit (n_2 = 3, 4, 5 ....) Wave number of these spectral lines is

$\bar{\nu} = R\left[\frac{1}{2^2} - \frac{1}{n_2^2}\right]$ where n_2 = 3, 4, 5......... This series lie in the visisble part of the spectrum.

3. Paschen Series : According to Bohr Paschen series is obtained when an electron jumps to the 3rd orbit (n_1 = 3) from any out of orbit (n_2 = 4, 5, 6......) Bohr calculated the wave number of spectral lines of Paschen series from the relation.

$$\bar{\nu} = R\left[\frac{1}{3^2} - \frac{1}{n_2^2}\right]$$

where n_2 = 4, 5, 6 .... This series lies in the infrared region of the spectrum.

4. **Brackett Series :** According to Bohr, Brackett series is obtained when an electron jumps to the 4th orbit (n_1 = 4) from any out orbit (n_2 = 5, 6, 7 ....). This series lie in far infrared region.

$\bar{\nu} = R\left[\frac{1}{4^2} - \frac{1}{n_2^2}\right]$ where n_2 = 5, 6, 7. ....

5. **Pfund Series :** According to Bohr, Pfund series is obtained when an electron jumps to the 5^{th} orbit (n_1 = 5) from any outer orbit (n_2 = 6, 7, 8........). This series lies in far infrared region.

$$\bar{\nu} = R\left[\frac{1}{5^2} - \frac{1}{n_2^2}\right] \qquad \text{where } n_2 = 6, 7, 8 \ldots\ldots\ldots\ldots\ldots$$

Energy Level Diagram :

A diagram which represents the total energies of electron in different sationary orbits of an atom are called the energy level diagram and are represented by parallel horizonal lines. Total energy in the nth orbit of hydrogen atom is given by $E = \frac{-2\pi^2 mK^2e^4}{n^2h^2}$

On substituting the values, we get $E = \frac{13.6}{n^2}\text{eV}$

Substituting n = 1, 2, 3........... we get the energies of electrons in various stationary orbits as :

$$E_1 = \frac{-13.6}{1^2} = -13.6\,\text{eV} \qquad E_2 = \frac{-13.6}{2^2} = -3.4\,\text{eV}$$

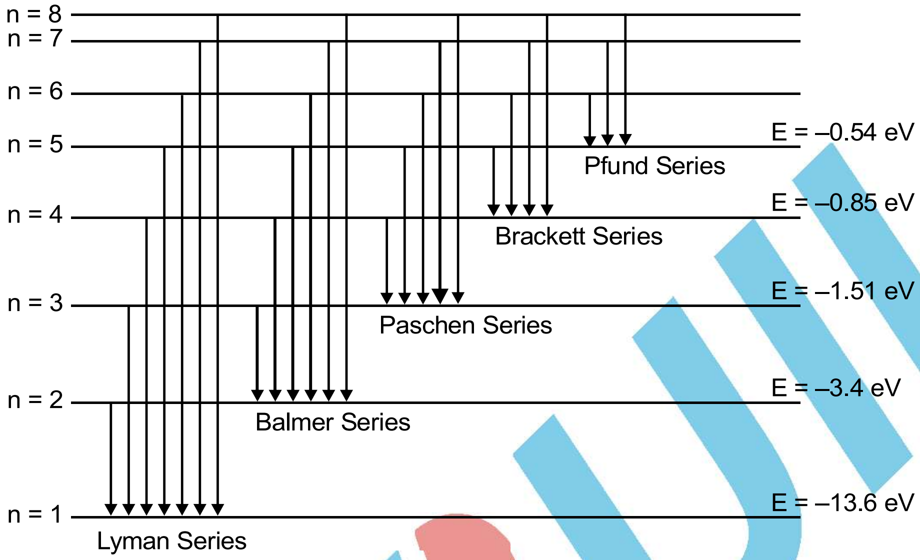
$$E_3 = \frac{13.6}{3^2} = 1.51\text{eV} \qquad E_4 = \frac{-13.6}{4^2} = -0.85\,\text{eV}$$

$$E_5 = \frac{-13.6}{5^2} = -0.54\,\text{eV} \qquad E_6 = \frac{-13.6}{6^2} = -0.37\,\text{eV}$$

$$E_7 = \frac{-13.6}{7^2} = -0.28\,\text{eV}$$

Clearly, as n increases, E_n becomes less negative until at n = ∞, E_n = 0

NUCLEI



Limitations of Bohr's Theory :

1. This theory is applicable only to simplest atom like hydrogen, with Z = 1. The theory fails in case atoms of other elements for which Z > 1

2. The theory does not explain why orbits of electrons are taken as circular, while elliptical orbits are also possible.

3. Bohr's theory does not explain the fine structure of spectral lines even in hydrogen atom.

4. Bohr's theory does not say anything about the relative intensities of spectral lines.

5. Bohr's theory does not take into account the wave properties of electrons.

Excitation : It is the process of absorption of energy by an electron of an atom when it jumps from lower energy state to higher energy state.

Excitation energy : It is defined as the energy required by an electron to jump from the ground satte to any on of the excited states, First excitation energy of hydrogen is

$$= E_2 - E_1 = -3.4 - (-13.6) = 10.2 \text{ eV}$$

Excitation potential : It is defined as the potential difference through which an electron in an atom must be accelerated so that it may go from the ground state to the excited state. First excitation potential of hydrogen

$$= -3.4 - (-13.6) = 10.2 \text{ V}$$

Second excitation potential of hydrogen

$$= -1.51 - (-13.6) = 12.09 \text{ V}$$

Ionisation : The process of knocking out an electron from the atom is called ionization.

Ionisation energy : It is defined as the energy required to knock an electron completely out of the atom i.e.

energy required to take an electron from its ground state to the outermost orbit ($n = \infty$). Ionisation energy of hydrogen

$$= E_\infty - E_1 = 0 - (-13.6) = 13.6 \text{ eV}$$

Ionisation potential : The potential difference through which an electron of the atom is accelerated so that it is knocked out of the atom. The ionization potential of hydrogen atom $= 0 - (-13.6) = 13.6$ V

Atomic Nucleus : Rutherford established that atomic nucleus is the central core of every atom, in which the entire positive charge & almost entire mass of the atom are concentrated. The atomic nucleus is regarded as a tiny sphere of diameter ranging from 10^{15} m to 10^{-14} m. Most of the space around the nucleus in an atom is empty space. Thus, a nucleus of an atom consists of positively charged particles called protons and neutral particles called neutrons.

Atomic Number : The number of protons present inside the nucleus of an atom is called atomic number. It is equal to the number of electrons present in that atom. It is represented by Z.

Mass Number : Mass number of an element is the total number of protons & neutrons present inside the nucleus of the element. It is represented by A.

Number of protons = Number of electrons = 2

Number of nucleons = A Number of neutrons = A – Z

An element is represented as $_zX^A$, where Z is the atomic number, A is the mass number & X is the chemical symbol of that element, Example $_nNa^{23}$

Nuclear Size : It is experimentally found that volume of a nucleus is proprotional to its mass number A.

$$\frac{4}{3}\pi R^3 \propto A$$ where R is the radius of the nucleus.

$R \propto A^{1/3}$ $\Rightarrow$ $R = R_0A^{1/3}$ where R_0 is called as empirical constant.

Nuclear Density : Nuclear Density is the ratio of mass of nucleus to its volume.

If m is the average mass of a nucleon then mass of nucleus = mA

$$\text{Volum of nucleus} = \frac{4}{3}\pi R^3 = \frac{4}{3}\pi(R_0A^{1/3})^3 = \frac{4}{3}\pi R_0^3 A$$

$$\text{Nuclear density } \rho = \frac{mA}{\frac{4}{3}\pi R_0^3 A}$$

$$\rho = \frac{3m}{4\pi R_0^3}$$ It is of the order of 10^{17} kg/m^3

Atomic Mass Unit (amu or u) : One atomic mass unit is defined as 1/12 th of the mass of an atom of $_6C^{12}$ isotope.

1 amu = 166×10^{-27} kg

Energy Equivalent of Atomic Mass Unit : According to Einstein's mass energy equivalent : $E = mc^2$

$m = 1 \text{ amu} = 1.66 \times 10^{-27}$ kg

$E = 1.66 \times 10^{-27} \times (3 \times 10^8)^2 \Rightarrow E = 1.49 \times 10^{10}$

$$E = \frac{1.49 \times 10^{-10}}{1.6 \times 10^{-10}} \text{MeV}$$

E = 931.25 MeV

Hence 1 amu = 931 MeV

Isotopes : Isotpes of an element are the atoms of the element which have the same atomic number but mass number. For e.g.

$_1H^1$, $_1H^2$, $_1H^3$ are the isotopes of hydrogen.

$_2He^3$, $_2He^4$, $_2He^6$ are the isotopes of helium.

$_6C^{10}$, $_6C^{11}$, $_6C^{12}$, $_6C^{14}$ are the isotopes of carbon.

Isobars : Isobars are the atom of different elements which have the same mass number, but different atomic number. The total number of nucleons is same. For e.g. $_{11}Na^{22}$ and $_{10}Ne^{22}$ are isobars.

Isotones : $_1H^3$ & $_2He^4$ are isotones $_8O^{16}$ & $_6C^{14}$ are isotones.

Isomers : These are the nuclei with same atomic number and same mass number but existing in different energy states.

Nuclear Forces : Nuclear forces are the strong attractive forces which hold together the nucleons (protons & neutrons) in the nucleus. Important characteristic of these force are :

1. Nuclear forces act between a pair of neutrons, a pair of protons & also between a neutron & a proton with the same strength. This shows that these forces are independent of charge.

2. Nuclear forces are the strongest forces in nature.

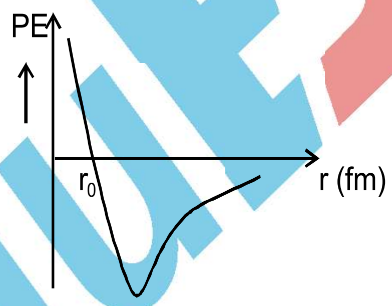
3. Nuclear forces are the very short-range forces.

4. Each nucleon interacts with its immediate neighbors only.

5. Nuclear forces are non-central forces. The force between two nucleons does not act along the line joining their centres.

6. Nuclear forces are exchange forces. These forces are due to exchange of π mesons between the nucleons.

Various of PE of a pair of nucleons with distance : Nuclear binding force dominates over the Coulomb repulsive force between protons inside the nucleus. So nuclear force is stronger than the Coulomb force or gravitational force between two charges.



(a) The PE is minimum at a distance r_0 = 0.8 fm. For a distance greater than r_0, the PE is negative which signifies that the nuclear force is attractive. It rapidly decreases with distance and becomes negligible small at a distance of about 4 fm.

(b) For a distance less than r_0, the nuclear force is strongly repulsive, so the PE is positive.

Mass Defect : The different between the sun of the masses of the nucleons in a nucleus & the rest mass of the nucleus is known as mass defect. It is denoted by Δm. The nucleus of an atom $_zX^A$, contains Z protons & (A – Z) neutrons. Mass of the nucleons in the nucleus = $Zm_p + (A - Z)m_n$ where m_p is the mass of a proton and m_n is the mass of a neutron. If m is mass of the nucleus of $_ZX_A$ then mass defect is given by :

$$\Delta m = [Zm_p + (A - Z)m_n] - m$$

When a nucleus is formed from its nucleons, some of their mass is converted into energy which binds the nucleons together inside the nucleus. This energy is called binding energy and is equivalent to mass defect. Mass defect is measured in a.m.u if atomic masses are in a.m.u and if atomic masses are in kg, then mass defect is measured in kg.

Binding energy : Binding energy of a nucleus is the energy required to break up a nucleus into its constituent protons and neutrons and to separate the nucleons at infinite distance apart from the nucleus, so that they may not interact with each other. If Δm is the mass defect of the nucleus. then according to Einstien's mass energy relation :

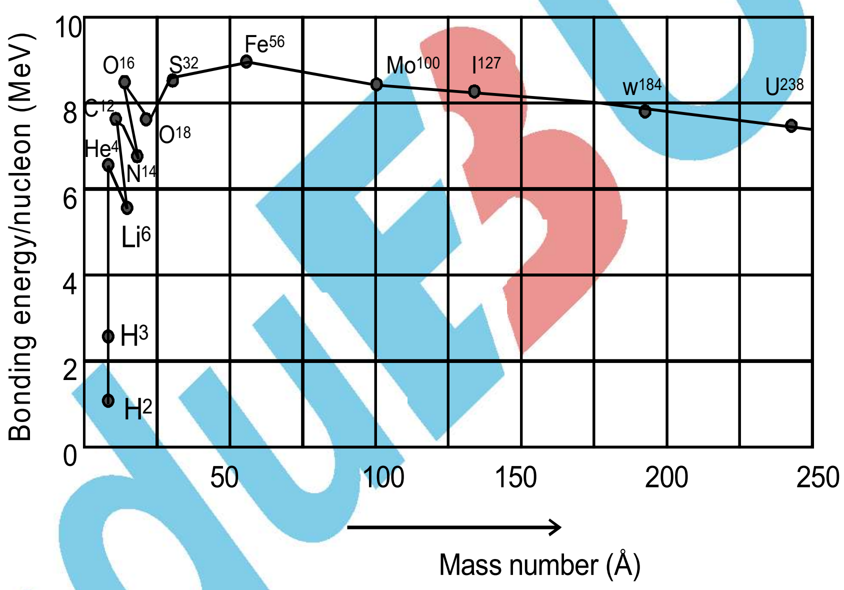
Bonding energy = $\Delta mc^2 = [Zm_P + (A - Z)m_n - m]c^2$

If Δm is in a.m.u. then Binding energy = $|Zm_P + (A - Z)m_n - m| \times 931.5$ MeV

Binding energy per nucleon : The binding energy per nucleon is the average energy required to extract one nucleon from the nucleus. It gives the measure of the stability of that nucleus. Greater the binding energy per nucleon, more stable is the nucleus.

$$\text{B.E. per nucleon} = \frac{B.E}{A} = \frac{[Zm_p + (A - Z)m_n - m]c^2}{A}$$

Binding energy curve : The variation of average B.E. per nucleon with mass number A is shown as :



(i) Average B.E./nucleon for light nucei like ${}_1H^4$, ${}_1H^2$, ${}_1H^3$ is small

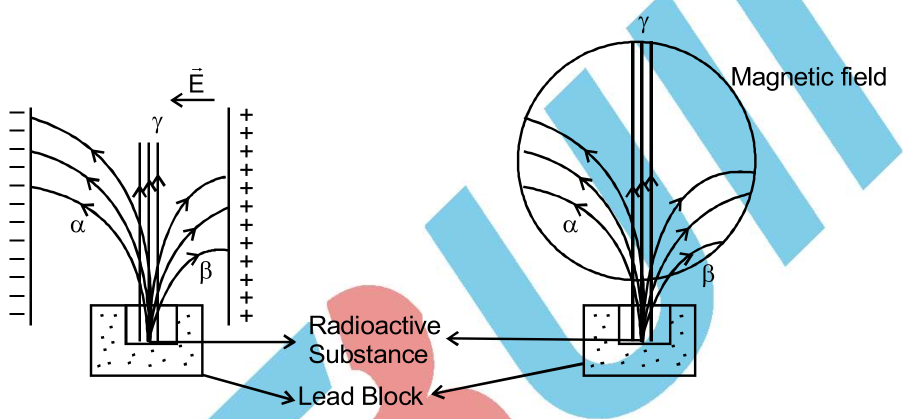
(ii) For mass numbers ranging from 2 to 20, there are sharply defined maxima peaks corresponding to ${}_2He^4$, ${}_6C^{12}$, ${}_8O^{16}$. The peaks indicate that these nuclei are relatively more table the nuclei in their neighborhood like ${}_3Li^6$, ${}_5B^{10}$, ${}_7N^{14}$

(iii) After mass number 20, binding energy per nucleon increases & for mass numbers between 40 & 120, the curve become more or less flat. For ${}_{26}Fe^{56}$, the B.E./nucleon is maximum & it is equal to 8.75 MeV. The average value of B.E. / nucleon is this region is about 8.5 MeV

(iv) As the mass number increases, the B.E./nucleon decreases gradually to abut 7.6 MeV for ${}_{92}U^{238}$. The decrease is due to Coulomb repulsion between the protons. The heavy nuclei are therefore, relatively less stable.

(v) The B.E./nucleon has low value for both very light & very heavy nuclei. If order to attain higher value of B.E. / nucleon, the lighter nuclei may unit together (nuclear fusion) or a heavy nucleus may split into higher nuclei (nuclear fission).

Radioactivity : The spontaneous transformation of an element into another with the emission of some particles or radiations (α-particles, β - particles, γ-rays) is called natural radioactivity. The substances capable of emitting radiations are called radioactivity was discovered by Becquerel, who noted that Uranium element gave out some invisible rays or radiations that can penetrate through several thick black papers and affect a photographic plate on the other side. Pierre Curie and Marie Curie then confirmed the same phenomenon. They named these rays as Becqurerel rays. Rutherford and this associates investigated the nature of Becquerel rays. These are of three types : α - rays, β - rays & γ - rays. A sample of radiactive element (Radius) is placed in small cavity drilled in a lead block. The radiations coming out of the cavity are subjected to an electric field provided by two plates as shown in the figure.



The α-rays are defected through smaller angles towards the negative plate. The β - rays are deflected through larger angles towards the positive plate. The γ-rays or photons remains undeflected. So it was concluded that α-rays consist a stream of positively charged particles, where as β - rays consists a stream of negatively charged particles. Since γ - rays were undeflected they could be waves or uncharged particles. Same results were obtained when these radians were subjected to magnetic field applied are to plane of paper.

Properties of α-rays :

1. An α - particle is equivalent to a helium nucleus ($_2He^4$) consisting of two protons and two neutrons.
2. It has a positive charge equal to +2e. where e = 1.6×10^{-19}C
3. Mass of α - particle is of the order of $\frac{1}{10}$th of the velocity of light.
4. Because of large mass, pentrating power of α -particles is very small, α - particles can be easily stopped by an AI sheet, 0.02 mm thick.
5. Because of large mass, penetrating power of α-particles is very small. α-particles can be easily stopped by an Al sheet, 0.02 mm thick.
6. Because of large mass and large velocity, α - particles have large ionizing power.
7. α-particles produce fluorescene in certain substances like sinc sulphide.
8. They affect photographic plate.
9. They are deflected by electric & magnetic fields.
10. While passing through thin metal foils, they get scatted.
11. They cause burns on human body.

Properties of β-rays :

1. A β -particles is a fast moving electron ($_{-1}e^0$)
2. A β-particle carries the charge of an electron i.e. 1.6×10^{-19} C of negative charge.
3. The rest mass of β-particle is 9.1×10^{-31} kg. same as that of electron.
4. The velocity of β-particle range from 33% to 99% of velocity of light. So β-particles are fast moving electrons.
5. Because of small mass, the penetrating power of β-particles is very large. They can easily pass through a few millimeter of Ai sheet. Their penetrating power is 100 times that of α-particles.
6. The β-particles ionize the gas through which they pass, but their ionizing power is 1/100th that of α-particles.
7. They can also produce fluorescence in certain substances like Zinc Sulphide.
8. They affect photographic plate.
9. They are deflected by electric & magnetic fields.

Properties of γ-rays :

1. They are electromagnetic waves which have wavelength less than of X-rays.
2. γ-rays are not deflected by electric & magnetic field showing that they do not have any charge.
3. γ-rays travel with the speed of light. The rest mass of a γ-photon is zero.
4. γ-rays have very large penetrating power. Their penetration power is 100 greater than that of β-particles. They can pass through several cm. of iron & lead sheet.
5. They have small ionising power. Their ionizing power is about 1/100 times the ionizing power of β-particles.
6. They can produce fluorescence in certain substances.
7. They can knock out electrons from the surface on which they fall.
8. They affect a photographic plate more than β-particles.
9. They can produce nuclear reactions.

Radioactive transformation :

1. Radioactivity is a spontaneous phenomenon i.e. it does not depend upon external factors like temperature pressure etc.

2. When a radioactive atom disintegrates, either an α-particle or a β-particle is emitted. Both are never emitted simultaneously. Also at a time, a radioactive atom can never emit more than one α-particle or β-particle.
3. The emission of α-particle by a radioactive atom results in a new atom whose atomic number is 2 units less & mass number is 4 units less than the original atom

$$_zX^A \xrightarrow{\alpha-\text{decay}} {}_{z-2}Y^{A-4}$$

4. The emission of β-particle by a radioactive atom results in a new atom, whose atomic number is one unit more but mass number is same that of original atom.

$$_zX^A \xrightarrow{\beta-\text{decay}} {}_{z+1}Y^{A}$$

Radioactive decay law : This law states that the number of nuclei disintegrated per second of a radioactive sample at any instant is directly proportional to the number of undecayed nueli present in the sample at that insant.

Mathematical form of decay law : Let N_0 be the total no. of nuclei present originally in a sample at t = 0. Let N be the total no. of nuclei left in the sample at time t and dN be the total no. of nuclei that disintegrate in time dt. Rate of disintegration R = $-\dfrac{dN}{dt}$ Here(–) ve sign indicates that no. of nuclei left undecayed decrease with time. According to radioactive decay law :

$$-\frac{dN}{dt} \propto N \Rightarrow R = -\frac{dN}{dt} = \lambda N \qquad ...(1)$$

where λ is called as disintegration constant or decay constant. Eq. (1) can be written as :

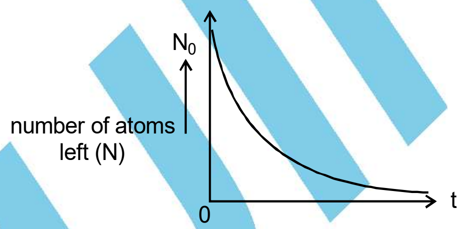
$$\frac{dN}{N} = -\lambda dt$$

Integrating both sides : $\displaystyle\int_{N_0}^{N} \frac{dN}{N} = -\lambda \int_0^1 dt$

$$\log_e N - \log_e N_0 = -\lambda t$$

$$\log_e \frac{N}{N_0} = -\lambda t \quad \Rightarrow \quad \frac{N}{N_0} = e^{-\lambda t}$$

$$N = N_e e^{-\lambda t}$$



Graph of radioactive decay shows that the number of active nuclei in the sample decreases exponentially with time.

Decay or Disintegration Constant : We have $N = N_e e^{-\lambda t}$

Substituting t = $\dfrac{l}{\lambda}$ we get, $N = N_0 e^{-1} = \dfrac{N_0}{e} = 0.368 N_0$

Thus disintegration constant of a radioactive element is the reciprocal of time at the end of which, the number of active nuclei left undecayed in a radioactive substance reduces to $\left(\dfrac{1}{e}\right)$ times or 36.8% of its initial value. Its SI unit is s^{-1}.

Half Life of Radioactive Element : Half life of radioactive element is defined as the time during which half the number of radioactive nuceli present initially in the sample of the element decay. It is represented by $T_{1/2}$.

When t = $T_{1/2}$, N = $N_0/2$

Substituting in N = $N_0 e^{-\lambda t}$, we get

$$\frac{N_0}{2} = N_0 e^{-\lambda T_{1/2}} \quad \Rightarrow \quad \frac{1}{2} = e^{-\lambda T_{1/2}} \quad \Rightarrow \quad 2 = e^{\lambda T_{1/2}}$$

Taking log of both sides : $\lambda T_{1/2} \log_e e = \log_e 2 = 2.303 \log_{10} 2$

$$\lambda T_{1/2} \times 1 = \log_e 2 = 2.303 \times 0.3010$$

$T_{1/2} = \dfrac{0.693}{\lambda}$ Thus half life is inversely proportional to decay constant and independent of N_0.

When t = $T_{1/2}$, N = $\dfrac{N_0}{2}$ After 2 half lives, $N = \dfrac{1}{2}\left(\dfrac{N_0}{2}\right) = N_0\left(\dfrac{1}{2}\right)^2$

After 3 half lives, $N = \dfrac{1}{2}\left(\dfrac{N_0}{4}\right) = N_0\left(\dfrac{1}{2}\right)^3$ ....

After n half lives, $N = N_0\left(\dfrac{1}{2}\right)^n = N_0\left(\dfrac{1}{2}\right)^{T_{1/2}}$ where t = n × $T_{1/2}$ is the total time of n half-lives.

Average life or Mean life of Radio effective Element :

The average time for which the nuceli of radioactive sample exist is called mean life or average life of that sample. Average life of radioactive element can be determined by calculating the total life time of all the nuclei & dividing it by the total number of nuclei present initially in the sample. Total life of dN nuclei = t dN

Total life time of all the N_0 nuclei = $\int_0^{N_0} t\,dN$

Average life $\quad T_{av} = \frac{\int_0^{N_0} t\,dN}{N_0} = \frac{1}{N_0}\int_0^{N_0} t\,dN$

We know $\quad dN = -\lambda N dt = -\lambda(N_0 e^{-\lambda t})dt$

Therefore, $\quad T_{av} = \frac{1}{N_0}\int_\infty^0 -\lambda N_0 e^{-\lambda t} dt \times t \qquad$ when N = 0, t = ∞ & when N = N_0, t = 0

$$T_{av} = \lambda \int_0^\infty t e^{-\lambda t} dt$$

Integrating by parts, we get $T_{av} = \frac{1}{\lambda}$

Thus average life is the reciprocal of decay constant. As $\lambda = \frac{0.693}{T_{1/2}}$

Therefore, $T_{av} = \frac{T_{1/2}}{0.693} = 1.44\,T_{1/2}$

Decay rate or activity of a radioactive sample : The activity of a radioactive sample is defined as the number of radioactive disintegration taking place per second in the sample. If a radioactive sample contains N radionucleir at any time t, then activity R is given by

$R = -\frac{dN}{dt}$ Here (–) sign indicates that activity of the sample decreases with the passage of time

We know $N = N_0 e^{-\lambda t}$ so, $R = -\frac{dN}{dt} = -\frac{d}{dt}(N_0 e^{-\lambda t}) = \lambda N_0 e^{-\lambda t}$

$R = \lambda N = \frac{0.693 N}{T_{1/2}}$ More is the half life, less is the activity of the substance.

Units of Activity :

1. **Becquered (Bq) :** The activity of a radioactive substance is said to be 1bequerel if it has 1 disintegration per second. 1 Becquerel = 1 disintegration/second.

2. **Curie (Ci) :** The activity of a radioactive substance is said to be 1 Curie if it has 3.7×10^{10} disintegrations per second.

   1 Curie = 3.7×10^{10} disintegration/second = 3.7×10^{10} Bq

3. **Rutherford (rd) :** The activity of a radioactive substance is said to be 1 Rutheford if it has 10^6 disintegrations per second. 1 Rutherford = 10^6 disintegration/second.

Alpha Decay : Alpha decay is a process in which an unstable nucleus transforms into a new nucleus by emitting an α - particle. When a nucelus emits an α - particle its mass number decreases by 4 & atomic number decreases by 2.

$$_zX^A \longrightarrow {}_{z-2}Y^{A-4} + {}_2He^4 + Q$$

where Q is the energy released in the decay. Q is calculated by Einstein mass energy relation $E = mc^2$

$$Q = (m_x - m_y - m_{He})c^2$$

e.g. : $_{92}U^{238} \rightarrow {}_{90}Th^{234} + {}_2He^4 + Q$

Beta Decay : It is the penomenon of spontaneous emission of an electron (e^-) or a position (e^4) from a radioactive nucleus.

Beta minus decay : In β^- decay, the mass number remains unchanged but its atomic number increases by one. An electron and a new particle antineutrino ($\bar{\nu}$) are emitted from the nucleus.

$$_zX^A \rightarrow {}_{z+1}Y^A + {}_{-1}e^0 + \bar{\nu} \text{ or } {}_zX^A \rightarrow {}_{z+1}Y^A + \beta^- + \bar{\nu}$$

e.g. : $_{15}P^{32} \rightarrow {}_{16}S^{32} + e^- + \bar{\nu}$

Beta plus decay : In β^+ decay, the mass number remains unchanged but its atomic number decreases by one A position and a new particle neutrino (ν) are emitted from the nucleus.

$$_zX^A \rightarrow {}_{Z-1}Y^A + {}_{+1}e^0 + \nu \text{ or } {}_zX^A \rightarrow {}_{Z-1}Y^A + \beta^+ + \nu$$

e.g. $_{11}Na^{22} \rightarrow {}_{10}N_e^{22} + e' + \nu$

Note : A nucleus does not contain any electron, positron neutrino and antineutrino, yet it can eject these particles. In beta-minus decay, a neutron transforms into a proton inside the nucleus via the reaction.

$$n \rightarrow p + e^- + \bar{\nu}$$

In beta-plus decay, a proton transforms into a neutron inside the nucleus via the reaction.

$$p \rightarrow n + e^- + \bar{\nu}$$

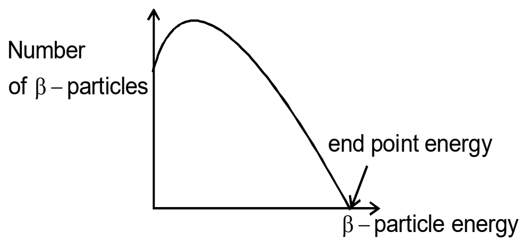
It shows that a beta decay process involves the conversion of a neutron into a proton or vice-versa. These nucleons have nearly equal mass. That is why the mass number A under-going beta decay does not change.

The graph between energy of β-particles & their number is as shown :

(i) Most of the β-particles emitted carry small energies

(ii) Only very few β-particles carry maximum energy called end point energy.

(iii) The energy spectrum of emitted β - particles is continuous i.e. β- particles can carry all possible energies from zero to maximum.



Gamma Decay : It is phenomenon of emission of gamma ray photon from a radioactive nucleus. It occurs when an excited nucleus makes a transition to a state of lower energy.

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

After an α-or β-dacay, the nucleus is usually in an excited state & it attains ground state by emitting one or more γ-rays photons. e.g. : The β-decay of $_{27}Co^{60}$ transforms it into an excited $_{28}Ni^{60}$ nucleus. This reaches the ground sate by emission of γ-rays of energies 1.17 MeV & 1.33 MeV. The energy level diagram is as shown.

$$_{27}CO^{60} \rightarrow _{28}Ni^{60**} + _{-1}e^{0}$$

$$_{28}Ni^{60++} \rightarrow _{28}Ni^{60*} + E_{\gamma}(1.17\,MeV)$$

$$_{28}Ni^{60++} \rightarrow _{28}Ni^{60*} + E_{\gamma}(1.33\,MeV)$$

Nuclear Reaction : it represents the transformation of stable nucleus of one element into stable nucleus of another element. Rutherford bombarded nitrogen with α-particle given by

$$_{7}N^{14} + _{2}He^{4} \rightarrow _{8}O^{17} + _{1}H^{1}$$

In any nuclear reaction the quantities conserved are : Momentum, Nucleon, Charge and Energy.

Nuclear Fission : The phenomenon of splitting of a heavy nucleus into two or more lighter nuclei.

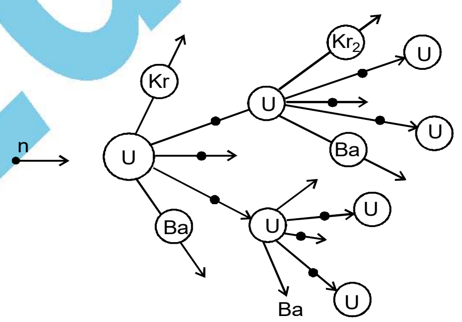
e.g. : $_{92}U^{235} + _{0}n^{1} \rightarrow _{56}Ba^{141} + _{36}Kr^{92} + 3\,_{0}n^{1} + Q$

Mass defect in this reaction is 0.2153 amu.

Energy released per fission of $_{92}U^{235} = 0.2153 \times 931\,MeV = 200.4$

Chain Reaction : In the above reaction three neutrons produced may bring about the fission of three more $_{92}U^{235}$ nuceli & produce 9 neutrons, which in turn bring fission of nine $_{92}U^{235}$ nuclei & so on. Thus a continuous reaction called chain reaction would start & a huge amount of energy is released in a short time. It is of two types :

(i) Uncontrolled chain reaction : If the fissionable material has a mass greater than the critical mass, then the reaction will accelerate at such a rapid rate that the whole material will explode within a microsecond, liberating a hage amount of energy. Such a chain reaction is called uncontrolled chain reaction. It forms the underlying principle of atom bombs.



(ii) Controlled chain reaction : If the chain reaction is controlled and maintained at steady state by absorbing a suitable number of neutrons at each stage, then the reaction is called as controlled chain reaction. Here the energy released does not get out of control. A nuclear reactor works on this principle.

Multiplication Factor : It is defined as the ratio of rate of production of neutrons to the rate of loss of neutrons.

$$k = \frac{\text{rate of production of neutrons}}{\text{rate of loss of neutrons}}$$

(i) If k = 1, the chain reaction will be steady. The size of the fissionable mateial is said to be the critical size and its mass, the critical mass.

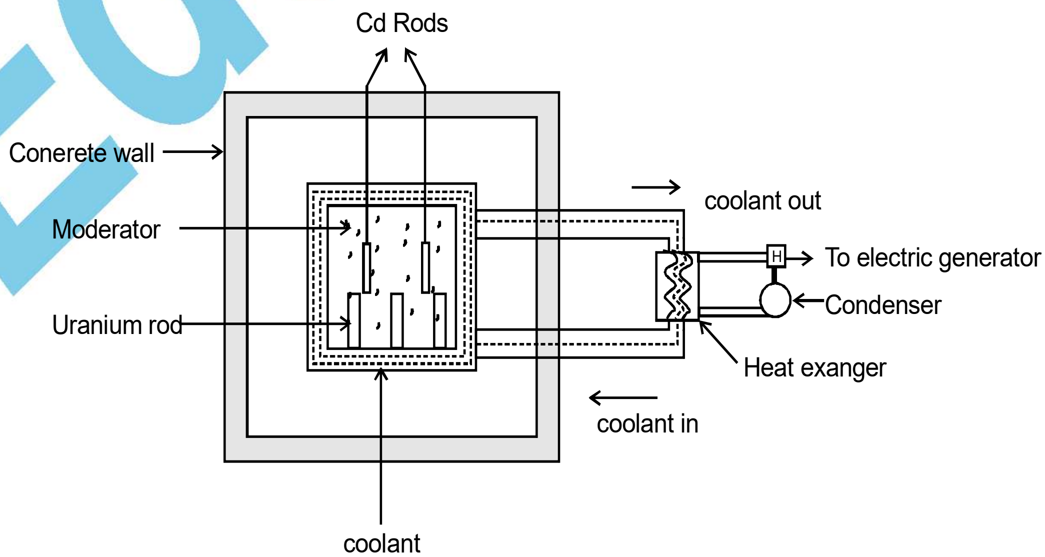
(ii) If k > 1, the neutron population increases exponentially with time and the chain reaction accelerates resulting in an explosion. The size of the material in this case is said to besupercritical.

(iii) If k < 1, the neutron population decreases exponentially with time and the chain reaction gradually dies out. The size of the material in this case is said to be subcritical.

Nuclear Reactor : The controlled nuclear Fission chain reactions for peaceful purposes can be carried out in nuclear reactors. It works on the principle of controlled chain reaction and provides energy at a constant rate.

Construction : Its essential parts are :

1. **Nuclear fuel :** Uranium isotope (U^{235}), Thorium isotope (Th^{232}), etc are the most commonly used fuels in the reactor.
2. **Moderator :** Moderator is used to slow down the fast moving neutrons. Most commonly used moderator are graphite, heavy water etc. When heavy water is used as moderator, then non-enriched U can be used as fuel because heavy water has more neutrons to produce fission.
3. **Control Rods :** They are used to control the chain reaction and to maintain a stable rate of reaction. It controls the number of neutrons available for the fission. Cadmium rods are inserted into the core of the reaction because they can absorb the neutrons. The neutrons available for fission are controlled by moving the cadmium rods in or out of the core of the reactor.
4. **Coolant :** It is a cooling material that removes the heat generated due to fission in the reactor, Commonly used coolants are water, liquid sodium etc.
5. **Protective Shields :** A protective shields in the form of aconcrete thick wall surrounds the core of the reactor to save the person working around the reactor from the hazardous radiations.



Working : A few $_{92}U^{235}$ nuclei undergo fission liberating fast neutrons. These fast neutrons are slowed down by surrounding moderator. The cadmium rods are used to control the chain reaction. The fission produces heat in the nuclear core. The coolant transfers this heat from the core to the heat exchanger, where steam is formed. This steadm produced at very high-pressure runs a turbine and the electricity is obtained at the generator. The dead steam from the turbine condenses into water and is returned to the heat exchange. The process repeats and combinuous supply of electrical energy is obtained. In addion to the production of electricity, nuclear reactor is used to produce radioactive isotopes.

Nuclear Fusion : The phenomenon of fusing two or more lighter nuclei to form a single heavy nucleus. The mass of product nuclear is slightly less than the sun of the mass of the higher nuclei fusing together. This difference in masses results in the release of tremendous amount of energy.

e.g. (i) $_1H^1 +_1 H^1 \rightarrow_1 H^2 + e^+ + \nu + 0.42\text{ MeV}$

(ii) $_1H^2 +_1 H^2 \rightarrow_2 H^3 + n + 3.27\text{ MeV}$

(iii) $_1H^2 +_1 H^2 \rightarrow_1 H^3 +_1 H^1 + 4.03\text{ MeV}$

In (i) two protons combine to form a deutron & a positorn with release of 0.42 MeV

In (ii) two deutrons combine to form a light isotope of He & a neutron with release of 3.27 MeV

In (iii) two deutrons combine to form triton & a proton with release of 4.03 MeV

The essential conditions for carrying out nuclear fusion are :

(i) High temperature is necessary for the light nuclei to have sufficient kinetic energy so that they can ovecome nutual Coulombic repulsions and come closer than the range of nuclear force. This process is called thermonuclear fusion.

(ii) High density or pressure increases the rate of fusion.

Energy source of start : Protons are most abundant in the body of sun and stars. At extremely high temperatures protons fuse together to form helium nuclei, liberating a huge amount of energy. This fusion takes place via two different cycles :

(i) Proton-proton cycle (P-P cycle) (ii) Carbon - Nitrogen cycle (C-N cycle)

(i) P-P cycle $_1H^1 +_1 H^1 \rightarrow_1 H^2 + e^+ + 0.42\text{ MeV}$

$e^+ + e^- \rightarrow \gamma + \gamma + 1.02\text{ev}$

$_1H^2 +_1 H^1 \rightarrow_2 He^3 + \gamma + 5.49\text{ MeV}$

$_2He^3 +_2 He^3 \rightarrow_2 He^4 +_1 H^1 + 12.86\text{ MeV}$

For the fourth reaction to occur, the first three reactions must occur twice. Thus the net reaction will be :

$$4\,{}_1H^1 + 2e^- \rightarrow {}_2He^4 + 2\nu + 6\gamma + 26.7\text{MeV}$$

Thus four protons combine to form one helium nucelus with the liberation of 26.7 MeV of energy.

(ii) C-N cycle : $\quad {}_6C^{12} + {}_1H^1 \rightarrow {}_7H^{13} + \gamma + 1.93\text{MeV}$

$${}_7H^{13} \rightarrow {}_6C^{13} + e^+ + \nu + 1.20\text{MeV}$$

$${}_6C^{13} + {}_1H^2 \rightarrow {}_7H^{14} + \gamma + 7.6\text{MeV}$$

$${}_7C^{14} + {}_1H^1 \rightarrow {}_8H^{15} + \gamma + 7.39\text{MeV}$$

$${}_8O^{15} \rightarrow {}_7N^{15} + e^+ + v + 1.71\text{MeV}$$

$${}_7O^{15} + {}_1N^1 \rightarrow {}_6C^{12} + {}_2He^4 + 4.99\text{MeV}$$

The overall reaction is :

$${}_1H^1 + {}_6C^{12} \rightarrow {}_2He^4 + {}_6C^{12} + 2e^+ + 2\nu + 3\gamma + 24.8\text{MeV}$$

Thus four protons combine to form a helium nucleus, gamma rays and neutrons to liberate about 25 MeV of energy. Both P - P and C - NB cycles participate almost equally in the generation of energy in the sun. Starts hotter than the sun get their energy from the C - N cycle, while those cooler than sun get their energy from P - P cycle. continuously and can be used for generation of electrical power. The energy produced by fusion is clean and is not polluted by any radioactive waste. Moreover, the fuel is available in plenty in sea water.

But it is very difficult to set up a sustained and controllable source of energy because fusion requires a very high temperature to $10^6 - 10^7$ K. This temperature is attained by causing explosing through a fission process. Moreover, no solid container can withstand such a high temperature.

SOLVED PROBLEMS

1. ***In a radioactive decay as follows***

$$A \xrightarrow{{}_{+1}e^0} A_1 \xrightarrow{\alpha} A_2$$

The mass number and atomic number of A_2 are 176 and 71 respectively, what are the mass numbers and atomic numbers of A_1 and A. Which of these elements are isobars.

Sol. The reaction may be expressed as

$$\underset{(A)}{{}_zX^A} \longrightarrow \underset{(A_1)}{{}_{z-1}Y^A} + {}_1e^0 \longrightarrow \underset{(A_2)}{{}_{z-3}Y_1^{A-4}} + {}_2He^4$$

Give Z – 3 = 71 ⇒ Z = 74 and Z – 1 = 73

Also A – 4 = 176 ⇒ A = 180

Thus mass number of A_1 and A are 180 each

The atomic numbers of A_1 and A are 73 and 74 respectively.

The elements A and A_1 are isobars.

2. ***A radioactive nucleus A undergoes a series of decay according to following scheme :***

$$A \xrightarrow{\alpha} A_1 \xrightarrow{\beta^-} A_2 \xrightarrow{\alpha} A_3 \xrightarrow{\gamma} A_4$$

The mass number and atomic number of A are 180 and 72 respectively. What are these numbers for A_4.

Sol. The decay scheme may completely be represented as

$${}_{72}A^{180} \xrightarrow{\alpha} {}_{70}A_1^{176} \xrightarrow{\beta^-} {}_{71}A^{176} \xrightarrow{\alpha} {}_{69}A_3^{172} \xrightarrow{\gamma} {}_{69}A_4^{172}$$

Clearly, mass number of A_4 is 172 and atomic number is 69.

3. ***A radioactive isotope D decays according to sequence***

$$D \xrightarrow{{}_0n^1} D_1 \xrightarrow{\alpha} D_2$$

If the mass number of atomic number of D_2 are 176 and 71 respectively, find the mass number and atomic number of D. Amongst D, D_1 and D_2 do we have any isobars or isotopes ?

Sol. The decay scheme may be represented as

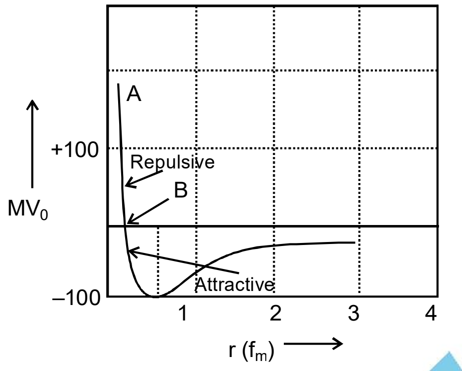
$${}_zD^A \xrightarrow{{}_0n^1} {}_zD_1^{A-1} \xrightarrow{\alpha} {}_{Z-2}D_2^{A-5}$$

Given Z – 2 = 71 and A – 5 = 176 ⇒ Z = 73 and A = 181

The mass number of D is 181 and atomic number 73. Clearly D and D_1 are isotopes.

4. **Draw a graph showing the variation of potential energy between a pair of nucleons as a function of their separation. Indicate the regions in which the mnucleus force is (i) attractive, (ii) repulsive.**

Sol. Part AB represents repulsive force and Part BCD represents attractive force.



5. Define the term : Half-life period and decay constant of a radioactive sample. Derive the relation between these terms.

Sol. **Half-life Period :** The half-life period of an element is defined as the time in which the number of radioactive nuclei decay to half of its initial value.

Decay Constant : The decay constant of a radioactive element is defined as the reciprocal of time in which the number of undecayed nuclei of that radioactive element falls to $\frac{1}{e}$ times of its initial value.

Relation between Half-life and Decay Constant : The radioactive decay equation is

$$N = N_0\, e^{-\lambda t} \qquad \ldots(1)$$

when $t = T,\ N = \frac{N_0}{2}$

$$\frac{N_0}{2} = N_0 e^{-\lambda t}$$

or $$e^{-\lambda t} = \frac{1}{2} \qquad \ldots(2)$$

Taking log of both sides

$$-\lambda T \log_e e = \log_e 1 - \log_e 2$$

or $$\lambda T = \log_e 2$$

$$T = \frac{\log_e 2}{\lambda} \qquad \ldots(3)$$

$$= \frac{2.3026 \log_{10} 2}{\lambda} = \frac{2.3026 \times 0.3010}{\lambda} \qquad \text{or} \qquad T = \frac{0.6931}{\lambda}$$

EXERCISE - I UNSOLVED PROBLEMS

1. What is the shortest wavelength present in the Paschen series of spectral lines ?

2. The ground sate energy of hydrogen atom is – 13.6 eV. What are the KE and PE of the electron in this state ?

3. A hydrogen atom initially in the ground lvel absorbs a photon, which exictes it to the n= 4 level. Determine the frequency and wavelength of photon.

4. The radius of the innermost electron orbit of a hydrogen atom is 5.3×10^{-11} m. What are the radii of n = 2 and n = 3 orbits ?

5. The total energy of an electron in the first excited state of the hydrogen atom is about – 3.4 eV

(a) What is the KE of the electron in this state ?

(b) What is the PE of the electron in this state ?

(c) Which of the answers would change if the zero of PE is change ?

6. Half life of a certain radioactive mateial is 100 days. After how much time the undecayed fraction will be 6.25 %

7. A radioactive material is reduced to 1/16 of its original amount in 4 days. How much material should one begin with so that 4×10^{-3} kg of the material is left after 6 days ?

8. Write the equation for (i) α- decay of $_{88}Ra^{226}$

(ii) β^+ decay of $_6C^{11}$ (iii) β^- decay of $_{15}P^{32}$

9. Two different radioactive elements with half lives T_1 and T_2 have N_1 and N_2 undecayed atoms respectively present at a given instant. Determine the ratio of their activities at this instant.

10. The radioactive isotope D decays according to the sequence $D \xrightarrow{\beta} D_1 \xrightarrow{\alpha} D_2$. If the mass number and atomic number of D_2 aer 176 and 71 respectively, what is (i) the mass number (ii) atomic number of D ?

11. With the help of an example, explain how the neutron to proton ratio changes during a decay of a nucleus ?

12. Calculate the energy required by an electron to jump from the ground state to the second excited state ?

13. A radioactive sample decays to 1/32 of its initial activity in 25 days. Calcualte the half life of the substance.

14. The half life of ^{14}C is 5700 years. What does it mean ? Two radioactive nuclei X and Y initially contain an equal number of atom. Their half life is 1 hour and 2 hours respectively. Calculate the ratio of their rates of disintegration after 2 hours.

[one half of the present number of radioactive nucei will remain undecayed after 5700 years]

15. Calculate the BE per nucleon of ${}_{20}Ca^{40}$ nucleus. Given m(${}_{20}Ca^{40}$) = 39.962589 u, mass of neutron = 1.008665 u, mass of proton = 1.007825 u

16. If the nucleons of a nucleus are separated for apart from each other, the sum of masses of all the nucleons is larger than the mass of the nucleus. Where does this mass difference come from ? Calculate the energy released if ${}^{238}U$ nucleus emits an α-particle. Given atomic mass of ${}^{238}U$ = 238.0508 u, atomic mass of ${}^{234}Th$ = 234.04363 u, atomic mass of alpha-particle = 4.00260 u and 1u = 931 MeV/e^2.

17. What is the effect on neutron to proton ratio in a nucleus when (i) an electron (ii) a positron is emitted ? [In emission of an electron, a neutron is converted into a proton. Therefore, number of neutrons decreases and the number of proton increases. The neutron to proton ratio decrease. In the emission of a positron, a proton is converted into a neutron. Hence the ratio increases.

18. Which one of ${}_{3}X^{7}$ and ${}_{3}Y^{4}$ is likely to be more stable ? Give reason.

[${}_{3}X^{7}$ is likely to be more stable as it contains larger number of neutrons (4) as compared to ${}_{3}Y^{4}$, which contains only one neutron.

19. The half life of ${}_{38}Sr^{90}$ is 28 years. What is the disintegration rate of 15 mg of this isotope ?

EXERCISE - II BOARD PROBLEMS

1. Express relationship of the mass of nucleus, M(A, Z) in terms of its binding energy and the masses of free protons and neutrons

2. State any two postulate of Bohr's theory of hydrogen atom

3. What is the maximum possible number of spectral lines observed when the hydrogen atom is in its second excited state ? justify your answer calculate the ratio of the maximum and minimum wavelength of radiation emitted in this process

4. Distinguish between
(1) Isotopes and Isobar
(2) mass defect and binding energy of nuclear

5. (a) The mass of a nucleus in its ground state is always less than the total mass of its constituent-neutrons and protons. Explain
(b) Plot a graph showing the variation of potential energy of a pair of nucleons as a function of their separation.

6. Draw a plot showing the variation of Binding energy per nucleon versus mass number A. Explain with the help of this plot the release of energy in the processes of nuclear fission and fusion.

7. Write a typical nuclear reaction in which a large amount of energy is released in the process of nuclear fission.

8. Name the absorbing material used to control the reaction rate of neutron in a nuclear reactor.

9. Define the term activity of a radio nuclide. Write the S.I. unit

10. If the nucleons of a nucleus are separated far apart from each other, the sum of mases of all these nucleons is larger than the mass of the nucleus. Where does this mass difference come from ?

11. Write two charactristic feature of nuclear force which distinguish it from coulomb's force.

12. Anucleus of mass number A, has a mass defect Δm, Give the formula, for the biding energy per nucleon, of this nucelus.

13. Give the mass number and atomic number of elements on the right hand side of the decay process.

14. State the condition for controlled chain reaction to occur in a nuclear reactor.

15. Write the nuclear decay process for β-decay of ${}^{32}_{12}P$.

16. Draw a plot of potential energy of a pair of nucleons as a function of their separations. Mark the regios where the nuclear force is (i) attractive and (ii) repulsive. Write any two characteristic features of nuclear forces.

17. In a Geiger – Marsden experiment calculate the distance of closest approach to the nucleus of Z = 80, when an α- particle of 8 MeV energy impinges on it before it comes momentarily to rest and reverses its direction.

18. Define the activity of a given radioactive substance. Write its S.I. unit.

ANSWER KEY

EXERCISE - I UNSOLVED PROBLEMS

1. [R/9 = 8199 Å] **2.** [KE = 13.6 eV, PE = –27.2 eV]

3. [3.078×10^{15} Hz, 974.4 Å] **4.** [2.12×10^{-10} m, 4.77×10^{-10} m]

5. (a) [3.4 eV], (b) [–6.8 eV], (c) [PE]

6. [400 days] **7.** [0.256 kg]

8. (i) $[{}_{88}Ra^{226} \rightarrow {}_{86}Rn^{232} + {}_{2}He^{4}]$, (ii) $[{}_{6}C^{11} \rightarrow {}_{5}B^{11} + e^{+} + \nu]$,

(iii) $[{}_{15}P^{32} \rightarrow {}_{16}S^{32} + e^{-} + \bar{\nu}]$

9. $\left[\frac{N_1T_2}{N_2T_1}\right]$ **10.** [180, 72] **11.** [More]

12. [12.09 eV] **13.** [5 days]

14. [one half of the present number of radioactive nucei will remain undecayed after 5700 years]

15. [8.55 MeV] **19.** [7.87×10^{10} Bq]