13 NUCLEI

Composition of a Nucleus.

Protons and neutrons are the main building blocks of the nuclei of all atoms. A nucleus of mass number A and atomic number Z contains Z protons and A-Z neutrons. A protons give positive charge to the nucleus while protons and neutrons together give its mass

Nucleons

Protons and neutrones which are present in the nuclei of atoms are collectively known as nucleons The symbolic representation of an atom is $_{Z}X^{A}$ where

X = chemical symbol

Z = atomic number

A = mass numbers.

Isotopes.

The atoms of the same element having same atomic number but different mass number.

eg: $_{3}Li^{6}$, $_{3}Li^{7}$

and $_{1}H^{1}$, $_{1}H^{2}$

Isobars

The atoms having same mass number but different atomic number are called isobars

eg:. $_{1}H^{3}$, $_{2}He^{3}$. and $_{17}Cl^{37}$, $_{16}S^{37}$

Isotones

The nuclides having the same number of neutrons are called isotones

eg: $_{17}Cl^{37}$, $_{19}K^{39}$ and.

$_{80}Hg^{198}$, $_{79}Pu^{197}$

a.m.u (Atomic mass unit)

1 a.m.u is defined as $\frac{1}{12}^{th}$ of actual mass of C-12 atom.

$$1 \text{ a.m.u} = \frac{1}{12} \text{ of C-12 atom}$$

$$= \frac{1}{12} \times 1.99 \times 10^{-26} \text{ kg}$$

$$= 1.66 \times 10^{-27} \text{ kg.}$$

Relation between a.m.u and MeV (Energy equivalent of a.m.u)

The Einstein mass energy relation is

$$E = mc^2$$

To determine the energy equivalent of 1 a.m.u

$m = 1$ a.m.u

$= 1.66 \times 10^{-27}$ kg and $c = 3 \times 10^{8}$ m/s.

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

$$= \frac{1.66 \times 10^{-27} \times 9 \times 10^{16}}{1.6 \times 10^{-19}} \text{ eV}$$

$$= 931 \times 10^{6} \text{ eV} = \underline{931 \text{ MeV}}$$

Nuclear Size.

Experimental observation shows that the volume of a nucleus is directly proportional to its mass number

If R is the radius of the nucleus having mass number A

$$A \propto \text{volume}$$

$$A \propto \frac{4}{3}\pi R^3$$

$$A \propto R^3$$

or $R \propto A^{1/3}$

$$\boxed{R = R_0 A^{1/3}}$$

Thus the radius of a nucleus is proportional to the cube roots of its mass number.

R_0 is a constant which is of the order of the range of nuclear force. The value of R_0 depends on the nature of probe particles

for e^-'s $\quad R_0 = 1.2 \times 10^{-15}$ m

$= 1.2$ fm.

Nuclear density.

The density of nuclear matter is the ratio of mass of the nucleus to its volume.

Let A be the mass number and R be the radius of the nucleus. If 'm' is the average mass of the nucleon. The mass of the nucleus is mA

Volume of the nucleus $= \frac{4}{3}\pi R^3$

$$= \frac{4}{3}\pi (R_0 A^{1/3})^3$$

$$= \frac{4}{3}\pi R_0^3 A$$

$$\text{Density} = \frac{\text{mass}}{\text{Volume}}$$

$$= \frac{mA}{\frac{4}{3}\pi R_0^3 A}$$

$$\boxed{\rho = \frac{3m}{4\pi R_0^3}}$$

Clearly nuclear density is independent of mass number A.

Nuclear force.

The strongest attractive interaction acting between the nucleons is called nuclear force

ie it is the strongest force that binds the protons and neutrons together inside a tiny nucleus.

Properties of nuclear force.

* It is the strongest force in nature
* The relative strength of gravitational electrostatic and nuclear force is
  $f_g : f_e : f_n = 1 : 10^{36} : 10^{38}$.
* It is the short range force ie it operates only upto a very short distance of about 4 fm.
* It is charge independent
* It shows saturation effect ie nucleons interacts only with its neighbouring nucleons.
* They are non-central forces. They do not act along the line joining the centres of the two nucleons.

Variation of P.E of a pair of nucleons with distance.

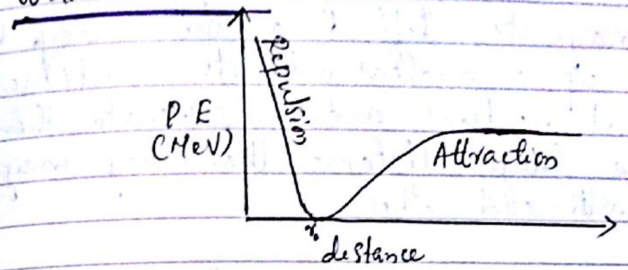


Figure shows a graph of the potential energy of a pair of nucleons as a function of distance.

The P.E is minimum at a distance $r_0 \simeq 0.8$ fm. The distance greater than r_0 the nuclear force is attractive. For a distance less than r_0 the nuclear force is strongly repulsive.

The negative potential energy signifies that the nuclear force is attractive.

Mass defect (Δm)

The difference between the rest mass of a nucleus and the sum of the rest masses of the constituent nucleons is called its mass defect.

Consider the nucleus X^A.

It has Z protons and (A-Z) neutrons.

Its mass defect

$$\boxed{\Delta m = [Zm_p + (A-Z)m_n] - m.}$$

where m_p, m_n and m are the rest masses of a proton, neutron and the nucleus $_Z X^A$ respectively.

Binding energy. (E_b) Binding energy of a nucleus may be defined as the energy required to break up a nucleus into its constituent protons and neutrons and to seperate them to such a large distance that they may not interact with each other.

$$\text{Binding energy } E_b = \Delta m\, c^2$$
$$= \left\{\left[Z m_p + (A-Z) m_n\right] - m\right\} c^2.$$

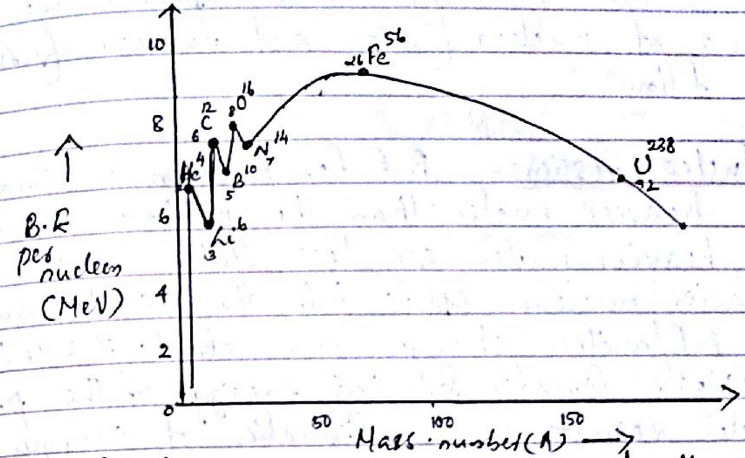
Binding energy per nucleon. (E_{bn})

It is obtained by dividing the binding energy of a nucleus by its mass number.

ie $$E_{bn} = \frac{E_b}{A}$$
$$= \frac{\left\{\left[Z m_p + (A-Z) m_n\right] - m\right\} c^2}{A}$$

The value of B.E per nucleon of a nucleus gives a measure of the stability of that nucleus. Greater the binding energy per nucleon of a nucleus, more stable is the nucleus.

Binding energy curve.



The binding energy curve reveals the following important features.

1. The B.E/nucleon is small for light nuclei $_1H^1$, $_1H^2$ and $_1H^3$.

2. In the mass numbers range 2-20, the B.E curve reveals maxima for nuclei He^4, $_6C^{12}$, $_8O^{16}$ indicating their higher stability and minima for $_3Li^6$, $_5B^{10}$, $_7N^{14}$ indicating their lower stability than the neighbouring nuclei

3. The curve has a broad maximum close to the value 8.5 MeV/nucleon in the mass number range from about 30 to 120. It has a peak value of 8.75 MeV/nucleon for $_{26}Fe^{56}$.

4. As the mass number increases further the B.E/nucleon shows a gradual decrease and drops to 7.6 MeV/nucleon for $_{92}U^{238}$.

Importance of binding energy curve. -

This curve explains the phenomena of nuclear fission and nuclear fusion as follows.

Nuclear fission:- B.E per nucleon is smaller for heavier nuclei than the middle ones. i.e, heavier nuclei are less stable. When a heavier nucleus splits into the lighter nuclei, the B.E/nucleon changes from about 7.6 MeV to 8.4 MeV. Greater binding energy of the product nuclei results in the liberation of energy. This is nuclear fission.

Nuclear fusion:- The B.E per nucleon is small for light nuclei, i.e they are less stable. So when two light nuclei combine to form a heavier nucleus, the higher binding energy per nucleon of the latter results in the release of energy. This is nuclear fusion.

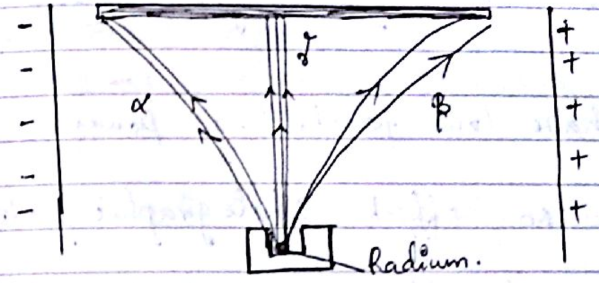
Radioactivity

It is the phenomenon of spontaneous disintegration of the nucleus of an atom with the emission of radiation to become stable.

The phenomenon of radioactivity was discovered by Henry Becquerel. The radiations emitted from the radioactive substance are α-rays, β-rays and γ-rays.

Electrical nature of the radioactive substance.

A small hole is drilled in lead block and a piece of radium is placed at its bottom. A photographic plate is placed at the top of the lead block. This set up is affected by means of a strong electric field.



It is observed that

1. Some radiations are moved towards the -ve electric field, which is a positively charged particle called α-rays.

2. Some radiation are moved towards the +ve electric field which is a negatively charged particle called β-rays.

3. Some radiations are undeflected which goes straight consists of neutral particles called γ-rays.

Properties of α-rays.

1. α-particles are equivalent to helium ($_2He^4$) nuclei

2. They are deflected by electric and magnetic fields. The deflection shows that α-particles are +vely charged particles.

3. Their velocity is of the order of $\frac{1}{10}$th of the velocity of light.

4. They ionise heavily the gases through which they pass.

5. They have low penetrating power.

6. They can affect photographic plate.

7. The excite fluorescence in certain substances.

Properties of β- rays.

1. β- particles are equivalent to electrons $\left({}_{-1}e^{0}\right)$

2. They are deflected by electric and magnetic fields. The deflection shows that β- particles are negatively charged particles

3. Their velocity is approximately 99% of the speed of light.

4. They ionise the gas through which they pass its ionising power is $\frac{1}{100}$th of α- rays.

5. They have penetrating power.

6. They can affect photographic plate.

7. They excite fluorescence in certain substances.

Properties of γ- rays.

1. They are electromagnetic waves

2. They are ~~do~~ not deflected by electric and magnetic fields, indicating that γ- particles do not carry any charge

3. They travel with the speed of light (3×10^{8} m/s)

4. They ionise gases very slightly.

5. They have high penetrating power.

6. They can affect photographic plate.

7. They excite fluorescence in certain substances.

Soddy - Fajan's displacement law.

1. When a radioactive nucleus emits α-particle, its atomic number decreases by 2 and mass number decreases by 4. ${}_{Z}X^{A} \longrightarrow {}_{Z-2}Y^{A-4} + {}_{2}He^{4}$

2. When a radioactive nucleus emits β- particle its atomic number increases by 1 and mass number remains the same ${}_{Z}X^{A} \longrightarrow {}_{Z+1}Y^{A} + {}_{-1}e^{0}$

3. The emission of a γ-particle does not change the mass number or the atomic number of the radioactive nucleus.

$$_{Z}X^{A} \longrightarrow {}_{Z}Y^{A} + \gamma\text{-radiation}$$

Radioactive decay law.

The law states the rate of disintegration of a nuclei is directly proportional to the total number of nuclei in the sample.

According to this law

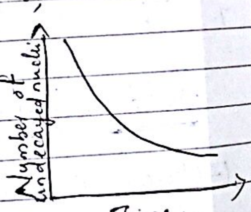
$$-\frac{dN}{dt} \propto N$$

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

where λ is a constant called decay or disintegration constant. Here the negative sign shows that the number of undecayed nuclei, N decrease with time.

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

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



Integrating we get

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

$$\log_e N = -\lambda t + C \quad \text{——} (1)$$

where C is a constant of integration.

At $t = 0$

$$N = N_0.$$

equ(1) becomes

$$\log_e N_0 = C$$

$\therefore$ equ(1) becomes

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

$$\log_e\left(\frac{N}{N_0}\right) = -\lambda t$$

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

$$\boxed{N = N_0 e^{-\lambda t}}$$

This equation represents the radioactive decay law.

Half-life ($T_{1/2}$).

The time interval in which one-half of the radioactive nuclei originally present in a radioactive sample disintegrate is called half-life of the radioactive substance.

When $N = \frac{N_0}{2}$ $t = T_{1/2}$.

$\therefore$ the radioactive decay law becomes

$$N = N_0 e^{-\lambda t}$$

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

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

$$e^{\lambda T_{1/2}} = 2$$

$\lambda T_{1/2} = \log_e 2$

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

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

$$\boxed{T_{1/2} = \frac{0.693}{\lambda}}$$

Mean life (τ)

The average life or mean life is the average time for which the nuclei of a radioactive sample exist. It is equal to the ratio of the combined age of all the nuclei to the total number of nuclei present in the given sample.

i.e. $\tau = \dfrac{\text{Sum of the lives of all the nuclei}}{\text{Total number of nuclei}}$

Relation between mean life and decay constant.

Suppose a radioactive sample contains N_0 nuclei at time $t=0$. After time t this number reduces to N. Furthermore, suppose dN nuclei disintegrate in time t to $t+dt$. As dt is very small, so life of each of dN nuclei can be approximately equal to t.

$\therefore$ Total life of dN nuclei $= t\,dN$.

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

Mean life $= \dfrac{\text{Total life of all the } N_0 \text{ nuclei}}{N_0}$

$$\tau = \frac{1}{N_0}\int_0^{N_0} t\,dN \quad \text{—(1)}$$

As $N = N_0 e^{-\lambda t}$

$\dfrac{dN}{dt} = N_0 e^{-\lambda t} \cdot -\lambda$

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

$\therefore dN = -\lambda N_0 e^{-\lambda t} dt.$

When $N = N_0$ $\quad t = 0$

$N = 0$ $\quad t = \infty$

$\therefore$ equ (1) changes to

$$\tau = \frac{1}{N_0}\int_\infty^0 t \cdot -\lambda N_0 e^{-\lambda t} dt$$

$$= \frac{1}{N_0}\int_\infty^0 -\lambda t N_0 e^{-\lambda t} dt$$

$$= \frac{-\lambda N_0}{N_0}\int_\infty^0 t e^{-\lambda t} dt.$$

$$= -\lambda \int_\infty^0 t e^{-\lambda t} dt$$

$$\tau = -\lambda \left[t \int_{\infty}^{0} e^{-\lambda t} dt - \int_{\infty}^{0} \frac{e^{-\lambda t}}{-\lambda} dt \right]$$

$$= -\lambda \left[\left[\frac{t e^{-\lambda t}}{-\lambda} \right]_{\infty}^{0} + \frac{1}{\lambda} \left(\frac{e^{-\lambda t}}{-\lambda} \right)_{\infty}^{0} \right]$$

$$= -\lambda \left[0 + \frac{1}{-\lambda^2} \left[e^{0} - e^{-\infty} \right] \right]$$

$$= \frac{-\lambda}{-\lambda^2} \left[1 - 0 \right]$$

$$\boxed{\tau = \frac{1}{\lambda}}$$

But $T_{1/2} = \frac{0.693}{\lambda}$

$\therefore \lambda = \frac{0.693}{T_{1/2}}$

$\therefore \tau = \frac{1}{\frac{0.693}{T_{1/2}}} = T_{1/2} \times \frac{1}{0.693}$

$\tau = T_{1/2} \times 1.44$

or $\boxed{\tau = 1.44\, T_{1/2}}$

Activity (R)

Activity or rate of decay is defined as number of radioactive disintegration per second.

ie $R = \frac{-dN}{dt}$ —— (1)

The negative sign shows that the activity of sample decreases with time.

According to radioactive decay law

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

ie $R = \lambda N$ —— (2)

As $N = N_0 e^{-\lambda t}$

$\therefore$ In equ (1)

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

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

$$= -N_0 \cdot e^{-\lambda t} \cdot -\lambda$$

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

$\boxed{R = R_0 e^{-\lambda t}}$ where $\lambda N_0 = R_0$ is the decay rate at time $t = 0$.

Units of radioactivity

1. The S.I. unit of activity is becquerel (Bq)

   1 Bq = 1 decay per second.

2. Older practical unit of activity is curie (Ci)

   1 Ci = 3.7×10^{10} decay per second

   1 Ci = 3.7×10^{10} Bq

3. Rutherford (rd) = 10^6 decays per second
$1 rd = 10^6 Bq$.
or $1 Ci = 3.7 \times 10^4 rd$.

Alpha decay.

It is a process in which an unstable nucleus transforms itself into a new nucleus by emitting an α-particle ($_2He^4$).
An α-decay can be expressed by the equation

$$_ZX^A = {}_{Z-2}Y^{A-4} + {}_2He^4 + Q.$$

Here Q is the energy released in the process and can be determined from Einstein's mass-energy relation which gives

$$Q = (m_X - m_Y - m_{He})c^2.$$

where m_x, m_y and m_{He} are the masses of the parent nucleus X daughter nucleus Y and the alpha particle respectively.

eg: $_{92}U^{238} \longrightarrow {}_{90}Th^{234} + {}_2He^4 + Q.$

Beta decay.

The process of spontaneous emission of an electron (e^{-1}) or a positron (e^{+}) from a nucleus is called β-decay.

β^- decay:- In β^- decay the mass number of the radioactive nucleus remains unchanged but its atomic number increases by 1. An $\bar{e}$ and a new particle antineutrino ($\bar{\nu}$) are emitted from the process. ie $_ZX^A \to {}_{Z+1}Y^A + {}_{-1}e^0 + \bar{\nu}$.

In a β^- decay an electron and an antineutrino are created and emitted from the nucleus via the reaction

$$n \longrightarrow p + \bar{e} + \bar{\nu}.$$

eg:. $_{15}P^{32} \longrightarrow {}_{16}S^{32} + \bar{e} + \bar{\nu}$.

β^+ decay:- In β^+ decay the mass number of the radioactive nucleus remains unchanged but its atomic number decreases by 1. A positron ($_{+1}e^0$) and a new particle - neutrino (ν) are emitted from the process

ie $_ZX^A \longrightarrow {}_{Z-1}Y^A + {}_{+1}e^0 + \nu$.

In a β^+ decay a positron and a neutrino are created and emitted from the nucleus via the process

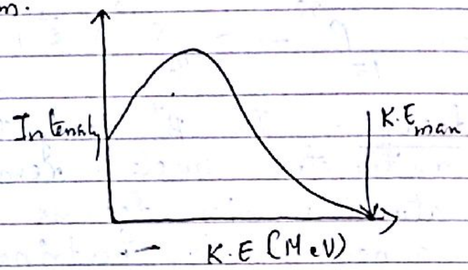
$$p \longrightarrow n + e^+ + \nu$$

eg:. $_{11}Na^{22} \longrightarrow {}_{10}Ne^{22} + e^+ + \nu$

Clearly in β-decay process involves the conversion of a neutron into a proton and vice versa. These nucleons have nearly equal masses that is why the mass number of the nuclide undergoing β-decay does not change.

Continuous energy spectrum for β-rays.

In a β-decay, the disintegration energy is shared in all proportions between the three particles: daughter nucleus, electron or positron and antineutrino or neutrino. As a result the K.E is not fixed. Their energy varies from 0 to maximum value K_{max}. Thus β-rays have a continuous energy spectrum.



γ-decay.

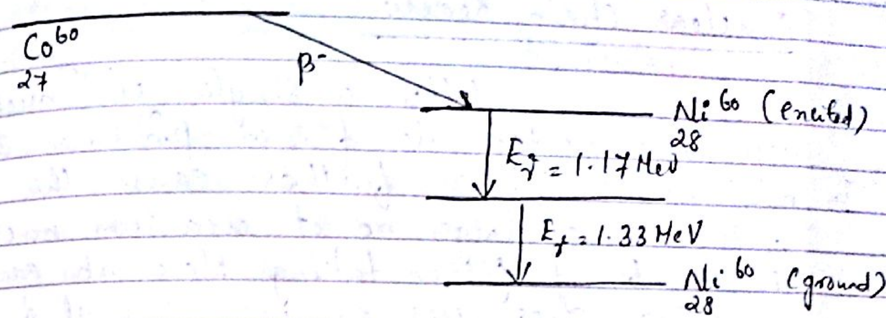
The process of emission of γ-ray during the radioactive disintegration of a nucleus is called gamma decay.
A γ-decay can be expressed as

$$X^{A}_{Z} \longrightarrow X^{A}_{Z} + \gamma.$$

(Excited State) (ground state)

A nucleus can exist in different energy states. After an α-decay or a β-decay the daughter nucleus is usually left in the excited state. It attains the ground state by single or successive emission of photons (γ-rays)

eg:- An example of γ-decay is shown through an energy level diagram.



Here an unstable Co^{60}_{27} nucleus is transformed via a β-decay into an excited Ni^{60}_{28} nucleus which in turn reaches the stable ground state by emitting photons of energies 1.17 MeV and 1.33 MeV in two successive γ-decay processes.

Nuclear energy

The energy released during a nuclear reaction called a nuclear energy. The production of nuclear energy are of two types Nuclear fission and nuclear fusion.

Nuclear fission:- The phenomenon in which a heavy nucleus splits up into two lighter nuclei liberating a large amount of energy. This is nuclear fission.

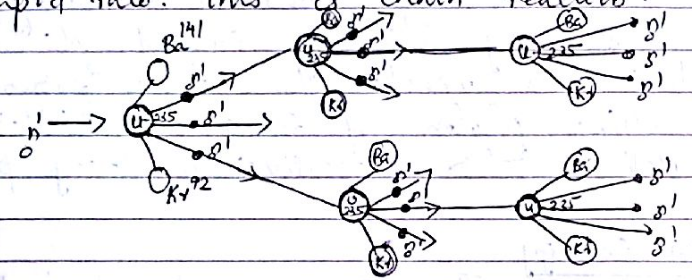
eg:- When Uranium is bombarded by fast moving neutrons, it splits up into Barium and Krypton along with the emission of 3 neutrons

$$U^{235}_{92} + n^{1}_{0} \longrightarrow Ba^{141}_{56} + Kr^{92}_{36} + 3\,n^{1}_{0} + Q$$

The disintegration energy Q is nearly about 200 MeV.

Nuclear Chain Reaction

When a single $_{92}U^{235}$ nucleus captures a neutron its fission produces 3 neutrons which can further cause the fission of a larger no: of uranium nuclei. The number of fission taking place at each successive steps goes on increasing at a rapid rate. This is chain reaction.



Uncontrolled chain reaction

If a chain reaction is started in a fissionable material having mass greater than certain critical mass, then the reaction will accelerate at such a rapid rate. The uncontrolled chain reaction results in tremendous explosion liberating a huge amount of energy. It forms the underlying principle of the atomic bombs.

Thermal neutrons.

These are slow moving neutrons of energy 0.0253 eV and having velocities of about 2200 m/s. These neutrons are more efficient in causing fission of $_{92}U^{235}$ nuclei than fast neutrons.

Multiplication factor (K)

The multiplication factor of a fissionable mass is defined as the ratio of the number of neutrons present at the beginning of a particular generation to the number of neutrons present at the beginning of the present generation.

$$\therefore K = \frac{\text{Number of neutrons present at the beginning of one generation}}{\text{Number of neutrons present at the beginning of previous generation}}$$

If $K > 1$, the chain reaction grows

If $K = 1$, the chain reaction remains steady.

If $K < 1$, the chain reaction gradually dies out.

Critical size and Critical mass.

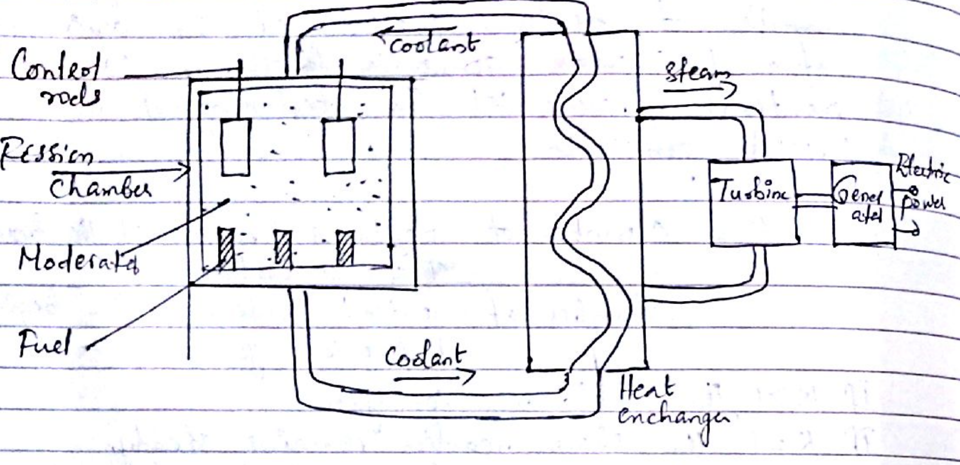
The size of the fissionable material for which the multiplication factor $K = 1$ is called critical size and the mass is called critical mass. The chain reaction in this case remains steady or sustained.

If $K > 1$ the neutron population increases exponentially with time and the size of the material is said to be super critical. The chain reaction builds up at a fast rate and results in an explosion.

If $K < 1$ the neutron population decreases exponentially with time and the size of the material is said to be subcritical. The chain reaction dies out gradually.

Nuclear Reactor

It is a device in which a nuclear chain reaction is initiated, maintained and controlled. It works on the principle of controlled chain reaction and provides energy at a constant rate.



Main parts of a nuclear reactor

1. Nuclear fuel:- Fissionable material used as fuel. U-235, Th-232, Pu-239 etc. Cylindrical rods of the fuel are arranged in a regular manner in the reactor core.

2. Moderator :- The moderators are the substances used to slow down the fast moving neutrons to thermal velocities. Heavy water, graphite or beryllium oxide is used as moderators in nuclear reactor.

3. Control rods:- To start, stop or control the chain reaction, rods of neutrons absorbing material like cadmium or boron are inserted in to the reactor core.

4. Coolant:- Coolant removes the heat produced during the chain reaction and is used to produce steam, which turn the turbine to produce electricity.

5. Shielding:- The reactor core is surrounded by thick concrete walls called protective shield to protect the workers from ~~neutrons~~ radioactive radiations.

Working:

Initially some neutrons are produced by the action of alpha particles on beryllium. These neutrons are slowed down and are used to initiate fission of U-235 nuclei. Fast neutrons so released are slowed down by the moderator to thermal velocities. The slow neutrons again cause fission of more U-235 nuclei and the chain reaction starts building up. Heat is produced during the chain reaction is removed from the reactor core by the use of coolant. This heat is used to produce steam which turns the turbine and rotates the generator to produce electricity.

Uses of nuclear reactor

1. In the generation of electric power.
2. In the preparation of radio-isotopes, which find extensive use in scientific research, medicine, agriculture and in industry.

Nuclear fusion:

The process in which two light nuclei combine at extremely high temperature and high density or pressure to form a single heavier nucleus is called nuclear fusion.

i.e nuclear fusion takes place in extremely high temperature and pressure so the nuclear fusion is also called thermonuclear reaction.

eg:- 1. $_1H^1 + {}_1H^1 \longrightarrow {}_1H^2 + {}_{+1}e^0 + \nu + 0.42\,MeV$

2. $_1H^2 + {}_1H^2 \longrightarrow {}_2He^3 + {}_0n^1 + 3.27\,MeV.$

Differentiate between nuclear fission and fusion.

	Nuclear fission	Nuclear fusion.
1.	Heavy nucleus splits up into two smaller nuclei	Two light nuclei fuse together to form a heavier nucleus
2.	It is a quick process	It occurs in several steps
3.	It produces very harmful radioactive wastes	The products of fusion are harmless.
4.	The stock of fissionable fusion is limited.	The fuel required for fusion is available in plenty.
5.	Nuclear fission produces energy in a nuclear reactor.	Nuclear fusion produces energy in sun and stars.

Important questions

1. Some scientists have predicted that a global nuclear war on earth would be followed by 'nuclear winter'. What would cause 'nuclear winter'?

Ans: The clouds produced by a global nuclear war would perhaps cover major parts of the sky preventing solar light from reaching many parts of the earth. This would cause a nuclear winter.

2. Write the nuclear reactions for the following
(i) α- decay of $_{84}Po^{204}$
(ii) β- decay of $_{15}P^{32}$
(iii) β^+ decay of $_6C^{11}$.

Ans:- (i) $_{84}Po^{204} \longrightarrow {}_{82}Pb^{200} + {}_2He^4 + Q.$

(ii) β- decay mean β^- decay

$$_{15}P^{32} \longrightarrow {}_{16}S^{32} + {}_{-1}e^0 + \bar{\nu}$$

(iii) β^+ decay of $_6C^{11}$

$$_6C^{11} \longrightarrow {}_5B^{11} + {}_{+1}e^0 + \bar{\nu}$$

3. What is packing fraction?

The packing fraction of a nucleus is defined as the ratio of mass defect to the mass number

$$P.F = \frac{\text{Mass defect}}{\text{Mass number}} = \frac{\Delta m}{A}$$

Packing fraction is +ve, then the nucleus is unstable and -ve if the nucleus is stable.

5. In β. decay why is it very difficult to detect the particle neutrino and antineutrino?

Ans. Neutrino and antineutrino are uncharged particle which interacts very weakly with matter and hence escapes undetected.

6. What is a breeder reactor?

Ans. A breeder reactor is one that produces more fissionable material than it consumes.

7. State the reason why heavy water is generally used as a moderator in a nuclear reactor.

Ans. Heavy water contains protons of mass nearly that of neutrons. Fast moving neutrons undergo elastic collision with these slow moving neutrons and thus get slowed down. Hence heavy water can be used as a moderator.
