Unit-8 (B) Nucleus

14 Composition of a Nucleus:

After the Rutherford α-ray scatterings experiment two theories of composition of nucleus were proposed which are as follow.

Proton electron hypothesis:-

According to this hypothesis a nucleus is consist of all protons and some of electrons. Some electrons lie inside the nucleus and some revolve around the nucleus. This theory failed due to:

- *By this theory we cannot predict the position of electron in an atom.*
- *The stability of atom con not is explained by this theory.*

Proton–Neutron Hypothesis:

After the discovering of neutron by Chadwick, Heisenberg proposed proton-neutron hypothesis in 1932. According to this theory a nucleus is consist of Z number of protons and (A-Z) number of neutrons. Electrons equal to protons revolve around the nucleus in circular orbits.

Symbol of an atom $_{Z}X^{A}$

Here an atom may be represented by X, the atomic number is represented by Z and atomic mass is represented by A. As Mass of Nucleus=mass of proton+mass of neutron.

i.e. A=p+n

15 Some Terms Related to Composition of A Nucleus:

- **Nucleus:**

The sum of protons and neutrons present in a nucleus collectively known as nucleus.

- **Atomic Number:**

The number of protons present in nucleus of a atom is known as atomic number. It is denoted by Z.

- **Mass Number:**

The total number of protons and Neutrons present in a nucleus is called mass number. It is denoted by A.

- **Nucleus Mass:**

The total mass of and nucleus present in a nucleus is called nuclear mass.

16 Isotopes, Isobars and Isotones:

(i) Isotopes:

The atom having same atomic numbers but different mass numbers are called isotopes e.g:- Hydrogen have three isotopes $_1H^1$, $_1H^2$, $_1H^3$ named hydrogen, Deuterium and Tritium respectively, other isotopes are $_{17}C^{35}$ *and* $_{17}C^{37}$, $_6C^{12}$ and $_6C^{14}$.

- Gold have 32 isotopes ranging from $A = 173 \ to \ 204$.
- Isotopes of an element exhibit similar chemical properties.
- Zinc contains five isotopes $_{30}Zn^{64}$, $_{30}Zn^{66}$, $_{30}Zn^{67}$, $_{30}Zn^{68}$, $_{30}Zn^{70}$
- Nickel also contains five isotopes $_{28}Ni^{58}$, $_{28}Ni^{60}$, $_{28}Ni^{61}$, $_{28}Ni^{62}$, $_{28}Ni^{64}$
- Oxygen contains three isotopes $_8O^{16}$, $_8O^{17}$, $_8O^{18}$

(ii) Isobars:

The atoms having different atomic numbers but same mass numbers are called isobars e.g.: (i) $_1H^3$ and $_1He^3$ (ii) $_{17}CI^{37}$ and $_{16}S^{37}$ (iii) $_{18}Ar^{40}$ and $_{20}Ca^{40}$

(iii) Isotones:

The atoms having different atomic numbers but same number of neutrons are called isotones

e.g: (i) $_{17}C^{37}$ and $_{19}K^{39}$ contains 20 neutrons in each.

(ii) $_4Be^9$ And $_5B^{10}$ contains 5 neutrons each.

(iii) $_{11}Na^{23}$ And $_{12}Mg^{24}$ contains 12 neutrons in each.

(iv) Isomers:

The atoms having same atomic numbers and same mass number but different energy states are called isomers.

17 Atomic Masses:

One atomics mass unit (1amu) is defined as $\frac{1}{12}$*th of the actual mass of* $C - 12$ *atom.*

It is denoted by $1amu$ or just by u.

i.e $1amu = \frac{1}{12} \times mass \ of \ C - 12 \ atom = \frac{1}{12} \times 1.992678 \times 10^{-26} = \mathbf{1.66 \times 10^{-27}}Kg$

Now mass of electron $= m_e = 0.00055 amu = 9.1 \times 10^{-31} Kg$

Mass of proton $= m_p = 1.0073 amu = 1.6726 \times 10^{-27} Kg$

Mass of neutron $= m_n = 1.0086 amu = 1.67 \times 10^{-27} Kg$

Mass of H-atom $= m_H = m_e + m_p = 1.0078 amu$

The amu can be measured accurately by using mass spectrometer.

Electron Volt:

The amount of energy required to acceleration an electron through a potential difference of one volt is called one electron volt. $\mathbf{1eV = 1.602 \times 10^{-19} J}$

The other unit of electron volt is MeV.

As $1\,MeV = 10^6 eV = 1.6 \times 10^{-13} J$

Relation between amu and MeV:

As we know $1 amu = 1.66 \times 10^{-27} Kg$

Now from Einstein's mass energy equivalence $E = mc^2 = 1.66 \times 10^{-27} \times (3 \times 10^8)^2 J$

$$E = \frac{1.66 \times 10^{-27} \times 9 \times 10^{16}}{1.6 \times 10^{-19}} eV \simeq 931 MeV$$

$\Rightarrow$ $\mathbf{1 Amu = 931 MeV}$

18 Nucleus Size:

Experiment observations shows that the volume of a nucleus is directly proportional to its mass number.

Suppose R is the radius of nucleus and A is mass number then $\frac{4}{3}\pi R^3 \ \alpha\ A$

Or $R \ \alpha\ A^{\frac{1}{3}}$

Thus radius of the nucleus is proportional to the cube acts of its mass number, we may also write

$$R = R_0 A^{\frac{1}{3}} \text{ Where } R_0 \text{ is a constant}$$

For electron $\mathbf{R_0 = 1.2 \times 10^{-15} m = 1.2 Fm.}$

19 Nucleus Density:

The mass per unit volume of a nucleus is called nuclear density.

i.e $\quad Nuclear\ Density\ \rho = \frac{mass\ of\ Nucleus}{volume\ of\ the\ Nucleus}$

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

And volume of nucleus $= \frac{4}{3}\pi R^3 \implies \quad \rho = \frac{mA}{\frac{4}{3}\pi R^3} = \frac{mA}{\frac{4}{3}\pi\left(R_0 A^{\frac{1}{3}}\right)^3} = \frac{mA}{\frac{4}{3}\pi R_0^3 A} = \frac{3m}{4\pi R_0^3}$

Clearly ρ does not depend upon mass number A or size of the nucleus.

It is found of the order of $2.30 \times 10^{17} Kg/m^3$

20 Nucleus Force:

After the discovery of neutron, it was proposed that all the protons and neutrons lies inside the very small sized $(10^{-15} m)$ nucleus. Then question arises that what holds the nucleons inside a nucleus. Then it was suggested that gravitational force must be responsible for this but gravitation force is 10^{36} times weaker then Colombian force of repulsion between proton and proton.

Latterly the Japanese physicist Yukawa gave the concept of nuclear force on the bases of exchange of π-mesons between nucleons. This nuclear force was assumed to be so strong then Colombian force of repulsion between nucleons of a nucleus. Here π-mesons act as a *piece of bone between two dogs*.

☞ *Thus a strong attractive force which binds the nucleons inside a nucleus is called nuclear force.*

Properties of Nuclear Force:

I. **Nuclear force is short range force:** This force is applicable only up to distance equal to size of the nucleus i.e. $10^{-15} m$.

II. **Nuclear force is charge independent**: The nuclear force between $p-p,\ n-n, n-p$ is same so we can say that it is charge independent.

III. **Nuclear force is strongest in Nature**: Nuclear force is 100 time stronger then Colombian force of repulsion and 10^{38} time stronger then gravitational force.

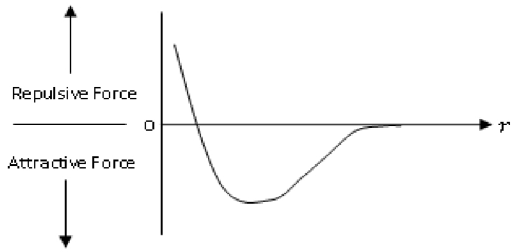
IV. **Nuclear force is Spin Dependent**: Nuclear force between nuclear having parallel spin is greater than nucleons' having anti parallel spins thus it is spinning dependent.

V. Nucleon attracts only neighbor nucleon so nuclear force is saturated force.

VI. Nuclear force does not act along the line joining their centre so it is non central force.

VII. It is due to exchange of π-mesons between nucleons so it may be called exchange force.

VIII. Nuclear force has a small component of repulsive force. Suppose one nucleon at O. when the distance between nucleons is largely the nuclear force is attractive and small. Now with decreases and becomes maximum then starts decreases and becomes repulsive to avoid collisions between nucleons.



21 Mass Defect and Packing Fraction [imp]:

Mass Defect:

It is found that the rest mass of a stable nucleus is slightly less than the sum of masses of the nucleus lying into the nucleus. Thus mass defect is the difference between the rest mass of a nucleus and the sum of rest masses of nucleons. It is denoted by Δm.

For a nucleus suppose ${}_ZX^A$ the mass of nucleus is m, mass of protons is Zm_p and mass of neutrons is $(A-Z)m_n$. Then mass defect $\Delta m = Zm_p + (A-Z)m_n - m_N$

Packing Fraction:

The mass defect per unit mass number is called packing fraction.

i.e P.F of a nucleus$= \frac{mass\ defect}{mass\ number} = \frac{\Delta m}{A}$

- If P.F is $+ve$ $(in\ case\ of\ A < 20\ to\ A > 200)$ the nucleus is unstable.
- If PF is $-ve$ $(in\ case\ of\ A = 20\ to\ A = 200)$ means some mass is conversed into energy hence nucleus is stable.

22 Binding Energy and Binding Energy per Nucleus [imp]:

Binding Energy:

Total energy required to separate all the nucleons of a nucleus is called binding energy or the energy which hold the nucleons inside a nucleus is called binding energy.

Expression for Binding Energy:

Suppose an atom ${}_ZX^A$ having Z numbers of protons, Z number of electrons and (A-Z) number of neutrons. Now if m_p is mass of protons, m_n is mass of neutrons and m_e is the mass of electrons

Then total masses of proton $= Zm_p$

Total masses of neutrons $= (A - Z)m_n$

Total masses of electron $= Zm_e$

And mass of nucleus$= m_N$, mass of atom $= m(\,_ZX^A)$

Now the mass defect may be given as $\Delta m = Zm_p + (A - Z)m_n - m_N$

According to Einstein's mass energy equivalence, the binding energy due to mass defect Δm is

$$\Delta E = \Delta mc^2 = [Z(m_p) + (A - Z)m_n - m_N]C^2$$

Or $$\Delta E = [Zm_p + Zm_e + (A - Z)m_n - m_N - Zm_e]C^2$$

$$\Delta E = [Z(m_p + m_e) + (A - Z)m_n - (m_N + zm_e)]C^2$$

Where $m_e + m_p = m_H = mass\ of\ H - atom$

And $m_N + Zm_e = m(\,_ZX^A) = mass\ of\ the\ atom$

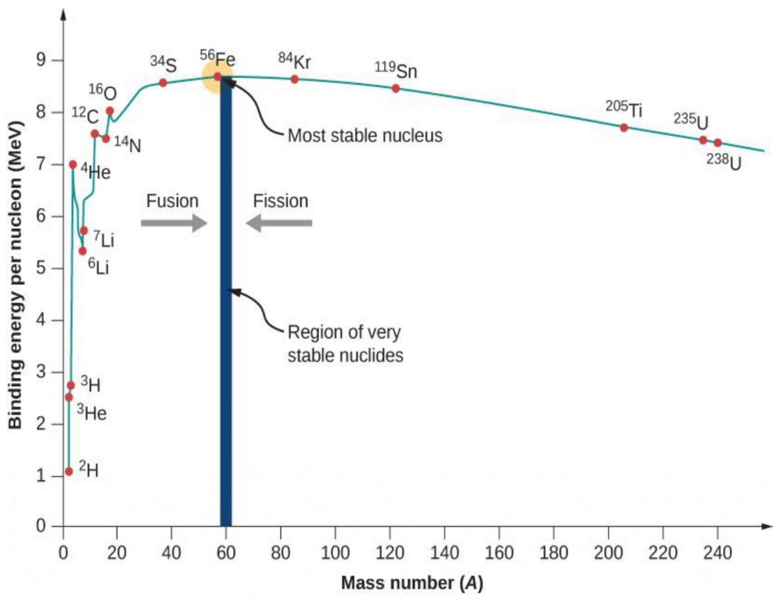
$$\Rightarrow \quad \boldsymbol{\Delta E = [Zm_H + (A - Z)m_n - m(\,_ZX^A)]C^2}$$

Binding Energy per Nucleons:

The average energy required to remove a nucleon from nucleus is called bonding energy per nucleon. B. E per nucleon $= \frac{\text{Binding Energy}}{\text{Total Number of Nucleons in the Nucleus}}$

Or $$\frac{B.E.}{Nucleon} = \frac{\Delta E}{A} = \frac{[Zm_H + (A - Z)m_n - m(\,_ZX^A)]C^2}{A}$$

23 Binding Energy Curve imp:



This curve explains the stability of a nucleus. The stability of a nucleus is directly proportional to the B.E/nucleons. The variation of B.E per nucleon with mass number is as shown in fig. from the graph it is clear that

(1) The B.E/nucleon is small for lighter nuclei like $_1H^1$, $_1H^2$, $_1H^3$.

(2) In the mass number range 2 to 20 there are some maximums and minimum. The maxima

occurs for ${}_2He^4$, ${}_4Be^8$, ${}_6C^{12}$ and ${}_8O^{16}$ indicate their extra stability from neighbor elements ${}_3Li^6$, ${}_5B^{10}$ and ${}_7N^{14}$.

(3) The curve have broad maximum close to value $8.5 MeV/nucleon$ from$A = 40$ to $A = 120$. It has a peak value of $8.8 MeV/nucleon$ for ${}_{26}Fe^{56}$.

(4) As mass number increase further then B.E/nucleon decreases and becomes $7.6\ MeV/nucleon$ for ${}_{92}U^{238}$.

Importance of B.E Curve:

(i) *The lower nuclei having small mass number are less stable, to acquire stability they combine to form a nuclei of more stability, which is responsible for nuclear fusion* rx^n.

(ii) *The heavier nuclei also have low B.E/nucleon so less stable, to accrue stability the breaks into lighter nuclei, this is responsible for fission* rx^n.

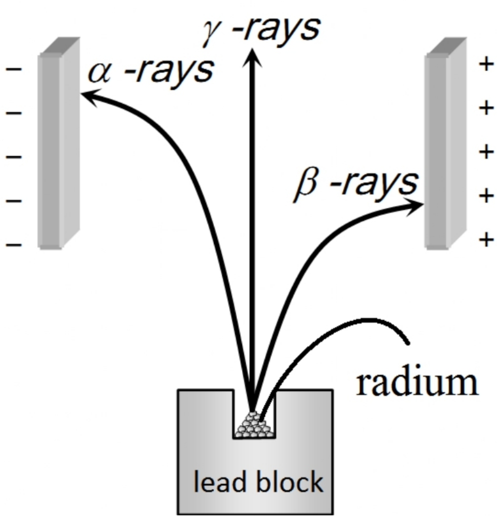
24 Radioactivity:

The phenomenon of spontaneous emission of radiation by a heavy element is called radioactivity. The element which shows this phenomenon is called radioactive element.

In 1896 Antoine Henri Becquerel noted that an element U-235 gave some invisible rays that can penetrate thick black paper and affect a photographic plate on the other side. After several months later Pierre Curie and Marie Curie showed that polonium and radium (${}_{84}Po^{210}$ and ${}_{88}Ra^{226}$) are much more radioactive then uranium. They called Becquerel says to more emitted by radioactive elements.

24 Nature of Radioactive (Becquerel Rays) Rays [imp]:

Rutherford and Billiard performed a experiment to analyze the radiations emitted by radium. The experiment consists of a lead cavity having small hole. A small piece of radium is placed in hole from which radioactive radiations are emitted. A electric field is applied by two plates and seen that



1. Some rays went at small angle toward $+ve$ plate; it means it is consist of $-vely$ charged. Small particle called β-particle or β-rays.
2. Some rays went at comparatively large angle toward $-ve$ plate; it means these rays (particle) have $+vely$ charged called α-rays or α-particle.

3. Some rays went straight without any deflection by electric plates, which show that they does not have any charge and called γ rays.

Properties of α, β, γ Rays:

(i) Properties of α Rays:

- These are double ionized $+vely$ charged He nuclei.
- The velocity of α particle is of order of $\frac{1}{10}th$ of velocity of light.
- They can affect a photo graphic plate.
- They ionize the gas through which they pass.
- They can penetrate a aluminum foil of thickness 0.1 cm.
- They are scattered while passed through thin metal sheets.
- They can cause artificial disintegration of an atom.
- They produce heating effect when stopped and cause fatal burn on human body.

(ii) Properties of β Rays:

- They consist of fast moving electrons of nuclear origin and have $-ve$ charge.
- They may travel up to 99% of velocity of light.
- They affect a photo graphic plate more strongly than α-particle.
- They can ionize a gas but their ionizing power is $\frac{1}{100}$ time to that of α rays.
- They perpetrating power of β rays are about 100 times to that of α ray.
- They can penetrate the aluminum foil up to 5mm.
- They range of B particle in air is much more α rays.
- They can be easily scattered by atomic nuclei due to their small mass.
- They β particle emits with a elementary particle called neutrino.

(iii) **Properties of γ Rays:**

- They are electromagnetic waves having wavelength less then x rays.
- γ ray do not carry any charge so are not deflected by electronic or magnetic field.
- They travel with speed of light.
- They affect photographic plate even more strongly than β rays.
- They ionize gas slightly their ionizing power is $\frac{1}{10000}$ times to that of α rays.
- Their penetration on power is 10000 times to α ray and can penetrate iron block up to 30cm.
- They defect like $X-$ rays by a crystal.
- They eject β particle from substance on which they fall.
- They show pair production i.e. $\gamma = {}_0e^- + {}_0e^+$

25 Comparison between the Properties of α, β, γ:

Properties	**α-ray**	**β-ray**	**γ-ray**
1. Nature	Helium Nuclei	Electron of Nuclear Origin	High energy em radiation
2. Mass	$6.67 \times 10^{-27} Kg.$	$9.11 \times 10^{-31} Kg.$	Rest mass is zero
3. Charge	$+2e$	$-e$	0
4. Deflection by $\vec{E}$	Deflection toward $-ve$ pole	Deflection toward $+ve$ pole	Nil
5. Speed	$\simeq 10^7 ms^{-1}$	$\simeq 10^8 ms^{-1}$ but variable	$3 \times 10^8 m/sec$
6. Ionizing Power	10^4 times that of γ ray	10^2 times that of γ ray	Minimum
7. Penetrating Power	Minimum	10^2 times that of γ ray	10^2 times that of α ray
8. Effect on photo graphic plate	Strong effect	Less effect	Least effect

26 B. Soddy- Fajan's displacement laws **or law of Radioactive disintegration** m.imp:-

According to Rutherford-Soddy theory when a radioactive disintegration occurs, then α or a β particle emits. The original nuclei called parent nuclei and the nuclei after disintegration is called daughter nuclei. They gave two rules to explain nature of radioactive reaction.

1. The algebraic sum of charge before the disintegration must be equal to total electric charge after disintegration.
2. The sum of mass numbers before disintegration must be equal to total mass numbers after disintegration.

On the basis of these rule Soddy and Fajan gave displacement law for radioactive disintegration which are as below:

I. *When a α-particle emit during disintegration then atomic number of daughter nuclei decrease by 2 and mass number decrease by 4. e.g* ${}_{z}X^{A} \longrightarrow {}_{z-2}Y^{A-4} + {}_{2}He^{4}$

II. *When a β particle emit during disintegration then atomic number increases by one and mass number remains same e.g:-* ${}_{z}X^{A} \longrightarrow {}_{z+1}Y^{A} + {}_{-1}\beta^{0}$

III. *The emission of a γ particle does not change the mass number or atomic number of the radioactive nuclei. e.g:* ${}_{z}X^{*A} \longrightarrow {}_{z}Y^{A} + \gamma$

IV. *No individual atom can simultaneously emit both α- particle and β-particle.*

V. *A γ particle emit after emission of β - particle or a α-particle*

Radioactive Decay law [m.imp]:- (this topic is a part of law of radioactive disintegration)

According to radioactive decay law, *the rate of disintegration of a radioactive substance is directly proportional to the number of atoms remained un-decayed in the substance.*

Suppose initially at $t = 0$, the number of radioactive nuclei are no and at time t the number of radioactive nuclei remained un-decayed are N.

Then according to decay law $-\frac{dN}{dt} \;\alpha\; N$

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

Or $\frac{dN}{N} = -\lambda dt \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (i)$

Where λ is constant of proportionality called *disintegration constant* and $-ve$ sign indicate that the atoms are disintegrating. Integrating both sides

we get $\log_e N = -\lambda t + C \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (ii)$

Here c is a constant of integration $At\ t = 0\ ,\ N = No$

So from eq. (ii) $\log_e No = C$

Then the eq. (ii) becomes

$$\text{Log}_e N = -\lambda t + \log_e No$$

$$= \log_e N - \log No = -\lambda t$$

Or $\log_e \frac{N}{No} = -\lambda t$

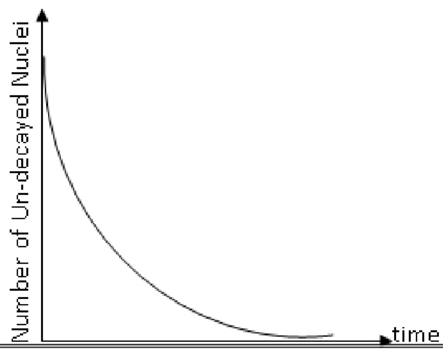
Taking exponential both sides we get $_e\log_e \frac{N}{No} = e^{-\lambda t}$

Or $\frac{N}{No} = e^{-\lambda t} = N_o e^{-\lambda t}$

This eq. represents the radioactive decay law. It gives the number of active nuclei after time t.

The graphical relation between un-decayed nuclei and time is as shown in fig.

- The disintegration is fast in the beginning but becomes slower and slower on the passes of time.
- Radioactive substance decay completely at infinite time.



Radioactive Decay Constant or Disintegration constant imp:

If $t = \frac{1}{\lambda}$ then $N = N_0 e^{-\lambda \cdot \frac{1}{\lambda}}$

Or $N = N_0 e^{-1} = \frac{N_0}{e} = \frac{N_0}{2.718} = 0.368 N_0$

Hence decay constant or disintegration constant may be defined as the reciprocal of time during which the number of active nuclei in a sample reduces to $\frac{1}{e}$ times of initial value.

Unit: the unit of decay constant is S^{-1} or min^{-1} or day^{-1} or $year^{-1}$.

27 Half Life m.imp:

The time duration in which half of radioactive substance remains un-decayed is called half life a radioactive substance.

Expression for Half Life:

Suppose at $t = 0$, the number of radioactive nuclei present in a radioactive sample is N_0 and after t time the number of radioactive nuclei remained un-decayed are N.

Now at time $t = T_{1/2}$ the amount of substance $N = \frac{N_0}{2}$

Now from $N = N_0 e^{-\lambda T}$ we get $\frac{N_0}{2} = N_0 e^{-\lambda T_{1/2}}$

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

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

Taking log both sides we get $\lambda . T_{1/2} \log_e e = \log_e 2$

Or $T_{1/2} = \frac{\log_e 2}{\lambda} = \frac{2.303 \times log\, 2}{\lambda} = \frac{2.303 \times .3010}{\lambda}$

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

- *Thus half life does not depend upon the quantity of substance present initially and depend only on disintegration constant.*
- Half life of a radioactive substance tells about the stability of a radioactive substance.

- Larger the value of half life, larger will be the stability of radioactive substance.
- There is no effect of temp and pressure on $T_{1/2}$.
- $T_{1/2}$ Of $U^{238} = 4.5 \times 10^9 year$.
- $T_{1/2}$ Of $U^{235} = 7.1 \times 10^8 year$
- $T_{1/2}$ Of thorium $Th^{234} = 24.1\ days$.

28 Number of un-decayed atoms in the radioactive substance after n half Lives:

As we know after one half lives, the numbers of un-decayed atoms are $N = \frac{N_0}{2} = N_0\left(\frac{1}{2}\right)^1$

After two half life $N = \frac{N_0}{4} = N_0\left(\frac{1}{2}\right)^2$

Again after three half life $N = \frac{N_0}{8} = N_0\left(\frac{1}{2}\right)^3$

So after n half life $N = \frac{N_0}{n} = N_0\left(\frac{1}{2}\right)^n \Rightarrow \left(\frac{N}{N_0}\right) = \left(\frac{1}{2}\right)^n$

But $t = n \times \frac{T}{2}$ $\Rightarrow n = \frac{t}{\frac{T}{2}}$ so $\frac{N}{N_0} = \left(\frac{1}{2}\right)^{\frac{t}{T/2}}$

29 Mean life or average life of a radioactive substance:

The average time for which the nuclei of an atom exist is called mean life or average life of radioactive substance and is equal to the ratio of combined age of all the nuclei to the total number of nuclei present in the given sample.

It is denoted by t. i.e mean life $\tau = \frac{Total\ Life\ of\ All\ the\ N_0\ Nuclei}{N_0}$

or $\tau = \frac{1}{N_0}\int_0^{N_0} t \cdot dN$ $(\because Total\ Life\ of\ dN\ Nuclei = tdN)$

as $N = N_0 e^{-\lambda t} \Rightarrow dN = -\lambda N_0 e^{-\lambda t} dt$

Also when $N = N_0$ at $t = 0$ and $N = 0$ at $t = \infty$ So $\tau = \frac{1}{N_0}\int_0^{\infty} t\lambda N_0 e^{-\lambda t} dt$

Here we have ignored $-ve$ sign as it just shows that disintegration occurs.

Now $\tau = \lambda \int_0^\infty te^{-\lambda t}dt = \lambda\left[\left\{\frac{te^{-\lambda t}dt}{-\lambda}\right\}_0^\infty - \int_0^\infty \frac{e^{-\lambda t}}{-\lambda}dt\right]$

$$= 0 + \frac{\lambda}{\lambda}\int_0^\infty e^{-\lambda t}dt = \int_0^\infty e^{-\lambda t}dt = \left[\frac{e^{-\lambda t}}{-\lambda}\right]_0^\infty$$

$$= -\frac{1}{\lambda}[e^{-\infty} - e^0] = -\frac{1}{\lambda}[0-1]$$

Or $\tau = \frac{1}{\lambda}$ Also $T_{1/2} = \frac{0.693}{\lambda}$ So $\boldsymbol{T_{1/2} = 0.693\,\tau}$

30 Activity of a Radioactive Substance:

The rate or activity of a radioactive decay is defined as the number of radioactive disintegration taking place per second in the sample. i.e. $R = -\frac{dN}{dt}$

Now according to radioactive decay law $-\frac{dN}{dt} = \lambda N \implies R = N\lambda$

As $N = N_0e^{-\lambda t}$ so we can write $R = \lambda N_0 e^{-\lambda t}$ Or $R = R_0 e^{-\lambda t}$

This is another form of radioactive decay law.

31 Unit of radioactivity imp:

There are various units to explain radioactive decay. Some of them are:

- **Becquerel(Bq):**

It is defined as the decay rate of one disintegration per second

i.e. $\underline{1\,Becquerel = 1Bq = 1\,decay\,per\,second.}$

- **Curie(Ci):**

One curie is defined as the decay rate of 3.7×10^{10} *disintegration per second.*

$$\underline{1\,curie = 1\,Ci = 3.7\times10^{10} decay\,per\,second = 3.7\times10^{10}Bq.}$$

$1mCi = 3.7\times10^{7}Bq$ $\quad 1\mu Ci = 3.7\times10^{4}Bq.$

- **Rutherford (rd):**

One Rutherford is the decay rate of 10^6 *disintegration per second*

$$\underline{1rd(rutherford) = 10^6 decay\,per\,second = 10^6 Bq}$$

Or $1Ci = 3.7\times10^{4}rd$

32 Alpha Decay imp:

The process of emission of a α-particle by unstable nucleus to become stable is called alpha decay.

As α-particle have two protons and two neutrons. So by emission of α-particle the atomic numbers of daughter nucleus reduce by 2 and mass number reduce by 4.

A α-decay can be expression as $_{Z}X^{A} \longrightarrow {}_{Z-2}Y^{A-4} + {}_{2}He^{4} + Q$

e.g: (i) $_{92}U^{238} \longrightarrow {}_{90}Th^{234} + {}_{2}He^{4} + Q$

(ii) $_{84}Po^{208} \longrightarrow {}_{82}Pb^{204} + {}_{2}He^{4} + Q$

(iii) By emitting α-particle the nuclei becomes stable, because α-particle have larger value of binding energy$\simeq 28MeV$.

Explanation of α-decay (Tunneling Theory of α-decay):

A α-particle can escape from the nuclei of atom if its K.E is of order of potential barrier of the nucleus about 26MeV. But according to classical mechanics α-particle having actual energy 5.4MeV cannot cross the height of the potential barrier. The problem of escaping of α-particle from nucleus was solved by Gamow and Condor and Gurney in 1928 by using Quantum mechanics.

According to this theory, the motion of α-particle may be considered as a wave. It is small but definite probability that α-particle may tunnel through (leak) the potential barrier even if K.E of α-particle is less than the height of the potential barrier. This effect is known as the *tunneling of nucleus*.

33 Beta Decay imp:

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

There are of two types of β-decay:

I. β^{-} Decay:

This decay occurs by converting of a neutron into a proton due to which an (e^{-}) and an antineutrino particle $(\bar{\nu})$ emits. As $n \longrightarrow P + e^{-} + \bar{\nu}$

☞ By β^{-} decay, the mass number of the doctor nucleus remains unchanged and atomic number increases by one.

The general eq. of β^{-} decay is $_{Z}X^{A} \longrightarrow {}_{Z+1}Y^{A} + \beta^{-} + \bar{\nu}$

The Q value of β^{-} decay is +ve and for β^{+} is –ve. So β^{-} results into stability of the nucleus.

e.g: (i) ${}^{32}_{15}P \longrightarrow {}^{32}_{16}S + {}_{-1}e^{0} + \bar{\nu}$ (ii) $_{90}Th^{234} \longrightarrow {}_{91}Pa^{234} + {}_{-1}e^{0} + \bar{\nu}$

II. **β^+ Decay:** *This decay occurs due to conversion of a proton into a neutron by which a position (e^+) and neutron emits.* As $P \longrightarrow n + e^+ + v$

☞ In β^+ decay the mass number of daughter nucleus remains unchanged but atomic number decreases by 1.

e.g.: ${}_{11}Na^{22} \longrightarrow {}_{10}Ne^{22} + {}_{+1}e^{0} + v$

Explanations of β decay (Paul's Neutrino Hypothesis):

The violation of law of conservation of energy and angular momentum were resolved by Pauli. He suggested that another particle called antineutrino emits along with a β-particle. It is anti particle of neutrino.

Neutrino is like a photon. It has zero charge and zero rest mass on the basis of neutrino theory the conservation of angular momentum and energy may be well defined as if a β-particle have low energy then antineutrino will have high energy and vice versa, total energy remains constant.

34 Gamma Decay imp:

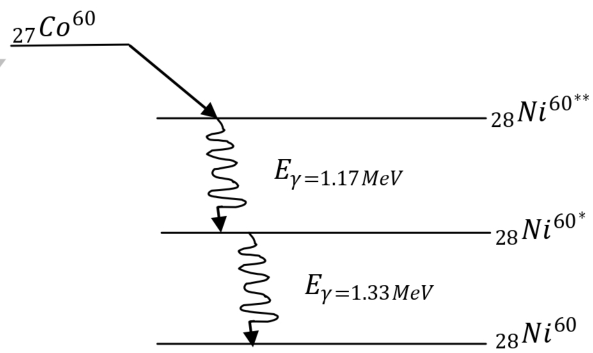
The process of emission of a gamma ray photon from a radioactive nucleus is called γ-ray.

This occurs when an excited nucleus makes a transition to a state of lower energy. As γ-ray does not have any charge and mass so by γ decay, the charge and mass of daughter nucleus remains same as that of parent nucleus.i.e. ${}_{Z}X^{*A} \longrightarrow {}_{Z}X^{A} + \gamma$

e.g.: During conversion of ${}_{27}Co^{60}$ into ${}_{28}Ni^{60}$ the various stages are ${}_{27}Co^{60} \longrightarrow {}_{28}Ni^{60**} + {}_{-1}e^{0} + \bar{v}$

$${}_{28}Ni^{60**} \longrightarrow {}_{28}Ni^{60*} + \gamma \left(E_\gamma = 1.17MeV\right)$$

$${}_{28}Ni^{60*} \longrightarrow {}_{28}Ni^{60} + \gamma \quad \left(E_\gamma = 1.33MeV\right)$$



35 Natural and Artificial Radioactivity:

Natural Radioactivity: *The phenomenon of spontaneous emission of α, β and γ radiations from the nuclei of natural occurring elements or isotopes is called radioactivity.*

Artificial or Induced Radioactivity: *The phenomenon of emission of α, β and γ radiations from a nuclei by bombarding them by a sufficient high energetic particle is called artificial radioactivity.*

Examples: When **B**oron is bombarded by α-particle then it forms a radioactive isotopes of nitrogen which decay into carbon in half life of 10.1 minutes as

$${}_{5}B^{10} + {}_{2}He^{4} \longrightarrow {}_{7}N^{13} + {}_{0}n^{1},\ {}_{6}C^{13} \longrightarrow {}_{6}C^{13} + {}_{1}e^{0} + v$$

36 Nuclear Reaction m.imp:

A reaction representing the transformation of a stable nucleus into other nuclei by bombarding the former with suitable high energy particle is called nuclear reaction.

Symbolically we can represent a nuclear reaction as ${}_{z}X^{A} + {}_{2}He^{4} \longrightarrow {}_{z+2}C^{A+4} \longrightarrow {}_{z+1}Y^{A+3} + {}_{1}H^{1} + Q$

Where X is target nucleus, He is bombarded particle and Y is daughter nuclei with emitted particle ${}_{1}H^{1}$ and Q is the amount of energy absorbed or gained in the rx^{n}.

Some examples of nucleus rx^{n} are

(i) ${}_{7}N^{14} + {}_{2}He^{4} \longrightarrow {}_{9}F^{18*} \longrightarrow {}_{8}O^{17} + {}_{1}H^{1}$ $(\alpha_1 P\ rx^{n})$

(ii) ${}_{3}Li^{7} + {}_{1}H^{1} \longrightarrow {}_{4}Be^{8*} \longrightarrow {}_{2}He^{4} + {}_{2}He^{4}$ $(P_1\ \alpha\ Rx^{n})$

(iii) ${}_{5}B^{11} + {}_{1}H^{1} \longrightarrow {}_{6}C^{12*} \longrightarrow {}_{6}C^{11} + {}_{0}n^{1}$ $(P_1\ n\ Rx^{n})$

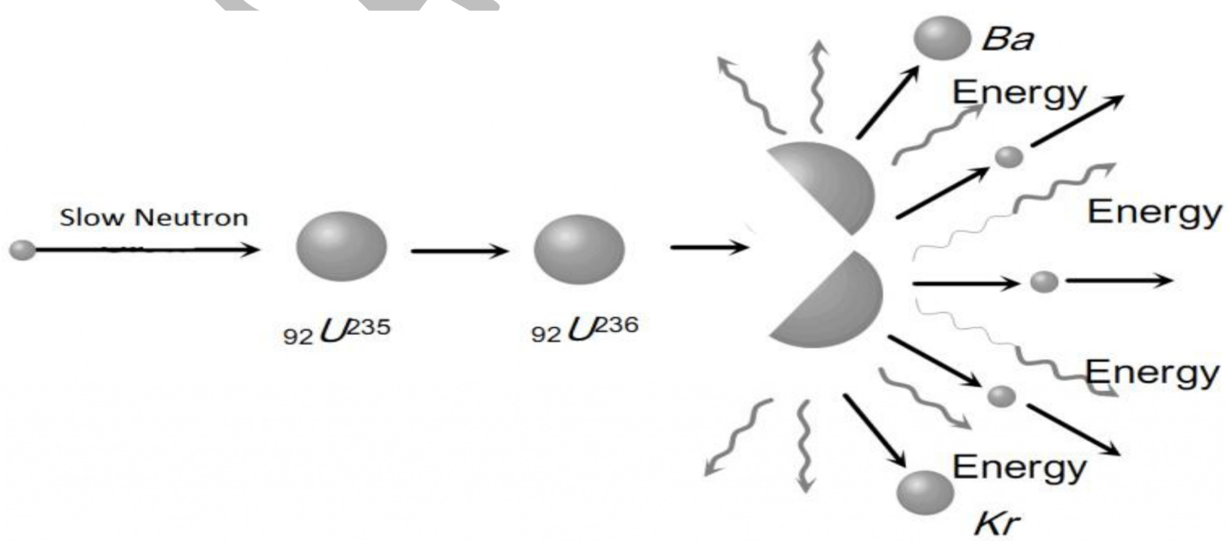
(iv) ${}_{6}C^{12} + {}_{1}H^{1} \longrightarrow {}_{7}N^{13*} \longrightarrow {}_{7}N^{13} + \gamma$ $(P_1\ \gamma\ Rx^{n})$

(v) ${}_{7}N^{14} + {}_{0}n^{1} \longrightarrow {}_{7}N^{15*} \longrightarrow {}_{6}C^{14} + {}_{1}H^{1}$ $(n_1\ P\ Rx^{n})$

(vi) ${}_{1}H^{2} + \gamma \longrightarrow {}_{1}H^{1} + {}_{0}n^{1}$ (Photo Disintegration)

- In a nuclear rx^{n} the laws only electron are transferred from one atom to another atom but in nuclear rx^{n} proton and neutron (nucleons) a nucleus takes part.

37 Nuclear Fission imp:



It is the phenomenon of splitting of a heavy nucleus into two lighter nuclei of comparable masses along with the emission of large amount of energy.

It was discovered by Otto Hahn and Stresemann in 1939. They bombarded slowly moving thermal neutron on $({}_{92}U^{235})$ uranium-235 and found that products were Barium and Krypton along with three neutron and 200MeV energy per fission.

This energy arises due to mass $deflect\ = 0.2153$

So energy= $0.2153 \times 931 = 200.4MeV$

The rx^n is represented as ${}_{92}U^{235} + {}_0n^1 \longrightarrow {}_{56}Ba^{141} + {}_{36}Kr^{92} + 3\,{}_0n^1 + Q$

There may other elements be in decay of U-235 as

☞ ${}_{92}U^{235} + {}_0n^1 \longrightarrow {}_{54}Xe^{140} + {}_{38}Sr^{94} + 2\,{}_0n^1$

38 Nuclear Chain Reaction m.imp:

The fission reaction of ${}_{92}U^{235}$ by thermal neutron may be represented as

$${}_{92}U^{235} + {}_0n^1 \longrightarrow {}_{56}Ba^{141} + {}_{36}Kr^{92} + 3_0n^1 + Q$$

Here we can see that the slowly moving neutron (thermal neutron) when hit the U-235 then Ba and Kr are produces along with three more neutron. These three neutrons may strike to three U-235 atoms and produces 9 neutrons and so on.

Thus a continuous reaction is called nuclear chain reaction. In a few microsecond a huge amount of energy release in chain reaction. The Enrico Fermi was the first who explained the nuclear chain reaction.

The chain reaction may be of two types:

1. **Uncontrolled chain reaction:**

If a chain reaction has mass greater than critical mass, then the reaction will accelerate at such a rapid rate that the whole materials explode within a microsecond, librating a huge amount of energy. Such a chain reaction is called uncontrolled chain reaction. This becomes atomic bomb.

2. Controlled Chain Reaction:

If the neutrons originating in each step are controlled by absorbing some neutrons in such a way that average one neutron remains available for exciting further fission then the reaction becomes controlled nuclear reaction. A nuclear reactor works on the principle of controlled chain reaction.

39 Multiplication Factor and Critical Size imp:

Multiplication Factor:

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 previous generation is called multiplication factor.

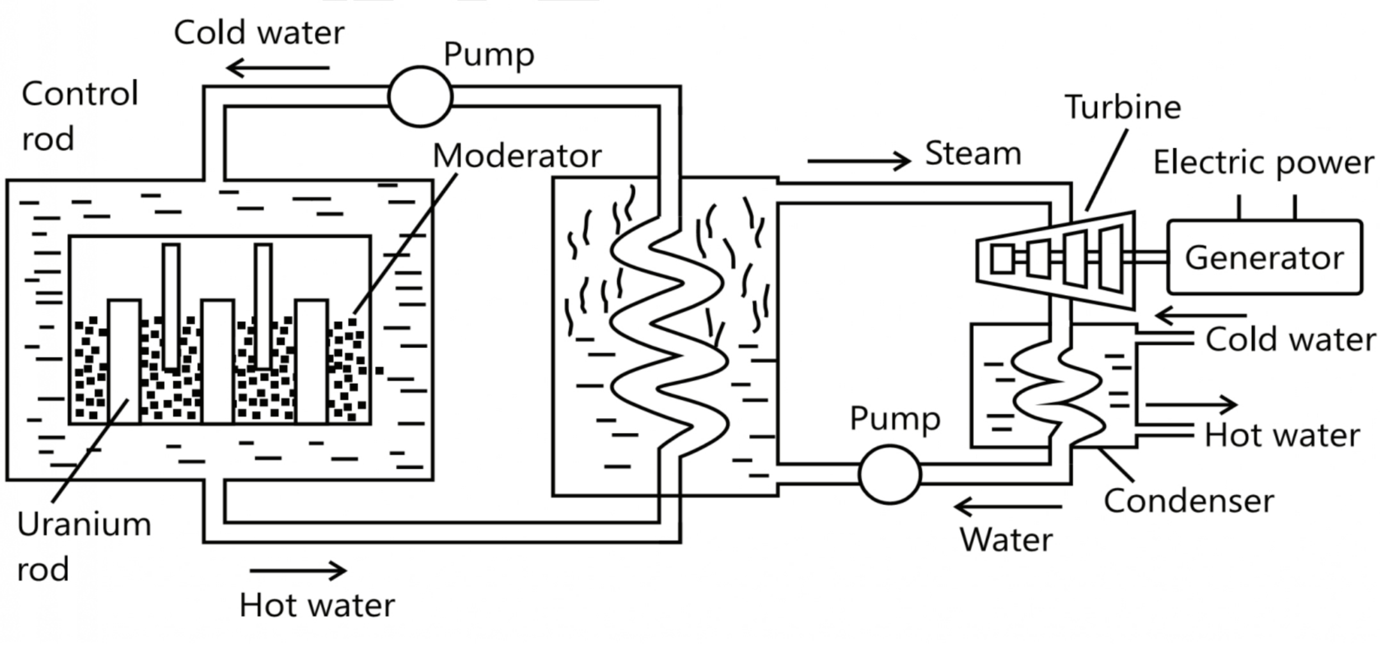
i.e $K = \frac{\text{Number of Neutron Pres ent in Bigining of One Generation}}{\text{Number of Neutron Present in Bigining of Previous Generation}}$

The multiplication factor K gives a measure of the growth rate of the neutrons in a fissionable mass.

- *If $K > 1$ the chain reaction grows at fast rate and size of the material is called super critical.*
- *If $K = 1$ the chain reaction remains steady, the size is called critical size and mass is called critical mass.*
- *If $K < 1$ the chain reaction gradually dies out and the size of material is said to be subcritical.*

40 Nuclear Reactor imp:

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



Main parts of Nuclear Reactor:

(i) **Nuclear Fuel:** The material that can be fissioned by neutrons like, U-235, Th-232 and Pu-239 can be used as the reactor fuel. The fuel in the form of rods, tightly sealed in aluminum container, separated by moderator is placed in the core of the reactor.

(ii) **Moderator:** The heavy water, graphic and beryllium oxide used to slow down the velocity of fast moving neutrons are called moderators.

(iii) **Controlled Rod:** To start, stop or control the nuclear chain reaction cadmium or boron rods are inserted between uranium rods are called control rods.

(iv) **Coolant:** The material used to cool the fuel rods and the moderator and is of capable of caring large amount of heat produced in the fission process is called coolant. The coolant must have high boiling point and high specific heat. Heavy water and sodium are good coolant.

(v) **Shielding:** A concrete wall used to protect the worker from the harmful radiations emitted by radioactive element is called shielding.

(vi) **Working:** Initially some neutrons are produced by the action of α-particles on polonium or beryllium. Which are slowed to thermal velocities by passing through the moderator? These slow neutrons cause fission of more ${}_{92}U^{235}$ nuclei and thus the chain reaction builds up. By raising or lowering the controlled rods, the chain reaction is suitably controlled.

Uses of Nuclear Reactor:

(i) In preparation of radio isotopes which are used in scientific research, medicine and agriculture.

(ii) In generation of electric power.

(iii) In preparation of fast neutrons which are used in nuclear bombardment.

(iv) In producing fissile materials like plutonium which is used in atomic bomb.

41 Breeder Reactor:

A reactor which produces more fissionable nuclei than it consumes is called breeder reactor.

Natural uranium contains 0.7% U^{235} and 99.3% non fissile U^{238}. When U^{238} is bombarded with moving neutrons then following reaction occurs.

$${}_{92}U^{238} + {}_{0}n^{1} \longrightarrow {}_{92}U^{239} \xrightarrow{-\beta^-} {}_{93}Np^{239} \xrightarrow{-\beta^-} {}_{94}Pu^{239} \xrightarrow{-\alpha} {}_{92}U^{235}$$

Here Pu is fissionable and undergoes α-decay (with T=24000 years) to produce $_{92}U^{235}$. Thus using an un-fissionable nucleus we produce a fissible nuclei Pu. There is no moderator is used in this reactor.

42 Nuclear Fusion [imp]:

The phenomenon of combining of two or more than two lighter nuclei to form single heavier nuclei is called nuclear fusion.

e.g: $_1H^1 + {}_1H^1 \longrightarrow {}_1H^2 + {}_+e^0 + \text{v} + 0.42\text{MeV}$

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

$$_1H^2 + {}_1H^2 \longrightarrow {}_1H^3 + {}_1H^1 + 4.03MeV$$

In the above reactions we can see that two nuclei combine to from heavy nuclei. The fusing nuclei have to overcome very high electrostatic repulsion. *To carry nuclear fusion reaction the temperature of the material should be* 10^6K*. So that the colliding nuclei have enough high energy to penetrate coulomb's barrier. This process is called thermonuclear fusion.*

Necessary Conditions for Nuclear Fusion:

- The temperature should be high about 10^6K so that can penetrate coulomb's repulsive barrier between nuclei.
- There should be high density and pressure so that frequency of collision of light nuclei can be increased.

These conditions cannot be produced in a laboratory.

43 Fusion as a source of energy in sun and stars:

As the sun is radiating energy at a rate of $3.8 \times 10^{26} Js^{-1}$ from several billion years without showing any sign of cooling off. A satisfactory explanation was given in 1939 by H. Bethe. As according to H. Bethe , there is high temperature in the interior of sun and starts so four protons fuse together to from helium nuclei, librating a huge amount of energy. This fusion takes places via two different cycles.

(i) Proton-Proton Cycle:

The rx^n in proton-proton cycle are $_1H^1 + {}_1H^1 \longrightarrow {}_1H^2 + e^+ + v + 0.42MeV$

$$e^- + e^+ \longrightarrow \gamma + \gamma + 1.02MeV$$

$$_1H^2 + {}_1H^1 \longrightarrow {}_2He^3 + \gamma + 5.49MeV$$

$$_2He^3 + {}_2He^3 \longrightarrow {}_2^4He + {}_1H^1 + 12.86MeV$$

The net rx^n may be given as $4\,{}_1H^1 + 2e^- \longrightarrow {}_2He^4 + 2v + 6\gamma + 26.7MeV$. *Thus for protons combine to produce one Helium nuclei with 26.7 MeV energy*

(ii) Carbon-Nitrogen Cycle:

In this cycle, carbon absorbs protons and emits a α-particle. The carbon-nitrogen cycle takes places in following sequence ${}_6C^{12} + {}_1H^1 \longrightarrow {}_7N^{13} + \gamma + 1.93\,MeV$

$${}_7N^{13} \longrightarrow {}_6C^{13} + e^+ + v + 1.20\,MeV$$

$${}_6C^{13} + {}_1H^1 \longrightarrow {}_7N^{14} + \gamma + 7.6\,MeV$$

$${}_7N^{14} + {}_1H^1 \longrightarrow {}_8O^{15} + \gamma + 7.39\,MeV$$

$${}_7O^{15} \longrightarrow {}_7N^{15} + e^+ + v + 1.71MeV$$

$${}_7N^{15} + {}_1H^1 \longrightarrow {}_6C^{12} + {}_2He^4 + 4.99MeV$$

The overall rx^n may be represented as ${}_1H^1 + {}_6C^{12} \longrightarrow {}_2He^4 + {}_6C^{12} + 2e^+ + 2v + 3\gamma + 24.8MeV$

Here again four protons combine to form a helium nucleus, γ-ray and neutrons along with about 25 MeV energy. Here carbon acts as a catalyst.

As the temperature of sun is about $2 \times 10^6 K$ both proton-proton cycle and carbon-nitrogen cycle participate equally in generation of energy in the sun. Star hotter than sun get their energy in carbon-nitrogen cycle while those collar than sun get their energy from proton-proton cycle.

44 Controlled Thermonuclear Fusion Reactions:

Controlled thermonuclear fusion reaction is the basis of fusion reactor, which is the future source of unlimited and unpolluted energy.

The most attractive reactions for terrestrial uses are

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

$${}_1H^2 + {}_1H^2 \longrightarrow {}_1H^3 + {}_1H^1 + 4.03MeV$$

$${}_1H^2 + {}_1H^3 \longrightarrow {}_2He^4 + {}_0n^1 + 17.59MeV$$

Deuterium, the source of deuterons for these reactions is available in unlimited quantity in sea water.

Other requirements for a fusion reactor are

- *High particle density, a high plasma temperature, along confinement time.*

45 Nuclear Holocausts:

It is a name given to large scale destruction and devastation that would cause by the use of nuclear weapon.

In fission of single U^{235} 200MeV energy releases in $10^{-9} sec$ If 50 Kg U^{235} undergo fission reach then total energy released would be 4×10^{15} Joule.

Which is equivalent to energy obtained from 200 tons of TNT Such an uncontrolled energy causes atomic explosion.

First such explosion occurred in 6 August 1945 in Hiroshima in Japan where 6600 person killed and 69000 peoples injured. It is estimated that nuclear arsenal sufficient to destroy every form of life on earth. Such a holocaust will not only destroy life that exists but make the earth unfit for life for all time.

The radioactive waste will hang like a cloud in the earth atmospheric which will absorb the sun radiations and there may be a long nuclear winter. Let us hope that man uses nuclear technology for improving the quality of life rather than for destroying the planet.

46 Distinction between Nuclear Fission and Fusion [m.imp]:

Nuclear Fission	***Nuclear Fusion***
1. *In fission, a heavy nucleus split into two lighter nuclei.*	1. *In fusion, two or more than two lighter nuclei fuse together to from heavy nuclei.*
2. *In fission reaction, a bombard particle is needed.*	2. *In fusion reaction the lighter nuclei should bring close to each other.*
3. *The energy released in fission reaction is smaller as compared to fusion.*	3. *The energy released in fusion reaction is much larger then fission reaction.*
4. *The products of nuclear fission are radioactive and harmful for environment.*	4. *The products of nuclear fusion are not radioactive and harmful for environment.*
5. *We can easily control nuclear fission reaction.*	5. *We cannot control nuclear fusion reaction.*
6. *The external conditions can be maintained.*	6. *The temperature required for fusion rx^n in $10^6 K$ which cannot be easily maintained.*

SOME IMPORTANT MCQ:-

1. The Lyman series of hydrogen spectrum lies in the region

(a) Infrared (b) Visible **(c) Ultraviolet•** (d) Of x rays

2. Which one of the series of hydrogen spectrum is in the visible region

(a) Lyman series **(b) Balmer series•** (c) Paschen series (d) Bracket series

3. When a hydrogen atom is raised from the ground state to an excited state

(a) P.E. increases and K.E. decreases• (b) P.E. decreases and K.E. increases

(c) Both kinetic energy and potential energy increase (d) Both K.E. and P.E. decrease

4. in Bohr model of the hydrogen atom, the lowest orbit corresponds to

(a) Infinite energy (b) The maximum energy **(c) The minimum energy•** (d) Zero energy

5. The minimum energy required to excite a hydrogen atom from its ground state is

(a) 13.6 eV (b) 6 . 13 eV (c) 3.4 eV **(d) 10.2 eV•**

6. Which one of these is non-divisible?

(a) Nucleus **(b) Photon•** (c) Proton (d) Atom

7. to explain his theory, Bohr used

(a) Conservation of linear momentum **(b) Conservation of angular momentum•**

(c) Conservation of quantum frequency (d) Conservation of energy

8. in Rutherford scattering experiment, what will be the correct angle for α scattering for an impact parameter b = 0

(a) 90^0 (b) 270^0 (c) 0^0 $\boldsymbol{(d)}$ $\mathbf{180^0}$**•**

9. The splitting of line into groups under the effect of electric or magnetic field is called

(a) Zeeman's effect• (b) Bohr's effect (c) Heisenberg's effect (d) Magnetic effect

10. Minimum excitation potential of Bohr's first orbit in hydrogen atom is

(a) 13.6 V (b) 3.4 V **(c) 10.2 V•** (d) 3.6 V

11. Energy of electron in a orbit of H-atom is

(a) Positive **(b) Negative•** (c) Zero (d) nothing can be said

12. The concept of stationary orbits was proposed by

(a) Neil Bohr• (b) J.J. Thomson (c) Ruther ford (d) I. Newton

13. Who discovered spin quantum number?

(a) Unlenbeck and Goudsmit • (b) Nell's Bohr (c) Zeeman (d) Sommerfield

14. In hydrogen atom which quantity is integral multiple of $\frac{h}{2\pi}$

(a) Angular momentum• (b) Angular velocity (c) Angular acceleration (d) Momentum

15. The order of the size of nucleus and Bohr radius of an atom respectively are

(a) $10^{-14}m$, $10^{-10}m$ • (b) $10^{-10}m$, $10^{-8}m$ (c) $10^{-20}m$, $10^{-16}m$ (d) $10^{-8}m$, $10^{-6}m$

16. Which of the following is quantized according to Bohr's theory of hydrogen atom?

(a) Linear momentum of electron **(b) Angular momentum of electron•**

(c) Linear velocity of electron (d) Angular velocity of electron

17. The kinetic energy of an electron revolving around a nucleus will be

(a) Four times of P.E. (b) Double of P.E. (c) Equal to P.E. **(d) Half of its P.E•**

18. Which of the following particles are constituents of the nucleus?

(a) Protons and electrons **(b) Protons and neutrons•**

(c) Neutrons and electrons (d) Neutrons and positrons

19. The neutron was discovered by

(a) Marie Curie (b) Pierre Curie **(c) James Chadwick•** (d) Rutherford

20. Nuclear binding energy is equivalent to

(a) Mass of proton (b) Mass of neutron (c) Mass of nucleus **(d) Mass defect of nucleus•**

21. Size of nucleus is of the order of

(a) 10^{-10}m **(b) 10^{-15}m•** (c) 10^{-12}m (d) 10^{-13}m

22 From a newly formed radioactive substance (Half-life 2 hours), the intensity of radiation is 64 times the permissible safe level. The minimum time after which work can be done safely from this source is

(a) 6 hours **(b) 12 hours** (c) 24 hours (d) 128 hours

Solution: (b) By using $A = A_0\left(\frac{1}{2}\right)^n \Rightarrow \frac{A}{A_0} = \frac{1}{64} \Rightarrow \left(\frac{1}{2}\right)^6 = \left(\frac{1}{2}\right)^n \Rightarrow n = 6$ so time $t = 6 \times 2 = 12hour$