NUCLEAR CHEMISTRY

[INORGANIC CHEMISTRY – B.sc – III (HONS)]

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NUCLEAR CHEMISTRY :-

Definition:- "It is that branch of chemistry in which we study about the nucleus of atom".

Isotopes :- Iso = Same, Topes = Position

First definition:- "When two or more atoms have same atomic number but different mass number they are called as isotopes".

Example:-

(i) $_{1}H^{1}$ → P = 1, n = 0

$_{1}H^{2}$ or $_{1}D^{2}$ → P = 1, n = 1

$_{1}T^{3}$ or $_{1}H^{3}$ → P = 1, n = 2

(ii) $_{6}C^{12}$ → P = 6, n = 6

$_{6}C^{13}$ → P = 6, n = 7

$_{6}C^{14}$ → P = 6, n = 8

Second definition:- When two or more than two atoms have same number of protons but having different number of neutrons, they are called as isotopes.

Properties:- Isotopes have same chemical properties because they have same number of electrons. But isotopes have different physical properties.

Isobars:- Iso = Same, Bar = Mass

First definition:- When two or more than two atoms have same mass number but having different atomic number they are called as isobar.

Example:-

(i) $_{6}C^{14}$ → P = 6, n = 8

$_{7}N^{14}$ → P = 7, n = 7

(ii) $_{18}Ar^{40}$ → P = 18, n = 22

$_{19}K^{40}$ → P = 19, n = 21

$_{20}Ca^{40}$ → P = 20, n = 20

Second definition:- When two or more than two atoms have different both number, they are called as isobars.

Properties:- Isobar have different physical and chemical properties.

Isotopes:- Iso = Same, tones = Neutrons

Definition:- When two or more than two atoms have same number of neutrons but having different atomic number and mass number they are called as isotones.

Examples:-

(i) $_{15}P^{31}$ → P = 15, n = 16

$_{16}S^{32}$ → P = 16, n = 16

(ii) $_{23}V^{51}$ → P = 23, n = 28

$_{24}Cr^{52}$ → P = 24, n = 28

Properties:- Isotones have both physical and chemical properties different.

Natural Radioactivity:-

Natural Radioactivity was discovered by hennery Becquerel in 1896.

Definition:- When a substance emits naturally special types of rays which can penetrate substances, which can effect photographic plate and which has get ionization power the phenomenon is called as "Natural Radioactivity".

The special types of rays are called as "radioactivity rays or Becquerel rays" and the substances are called as, "Radioactive Substance".

Note:- Radioactivity doesn't depend upon physical state, chemical environment and temperature.

Contribution of Madame Curie in Radioactivity:-

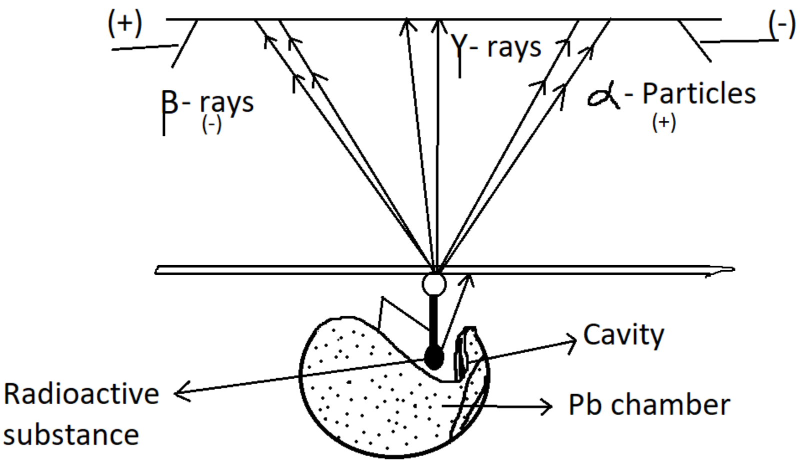
In 1898 Marie in her Ph.D thesis told that rate of radioactivity depend upon the amount of radioactive element but not upon the chemical environment.

After that Marie Curie and her has husband pierre curie discovered Radium and Polonium from pitchblende ore.

*For which he has awarded with Nobel prize of 1908 in chemistry.

Nature of Radioactive rays :-

The nature of radioactive rays was discovered by Ernest Rutherford in 1904 with the help of an experiment which is as follows.



Natural radioactive rays are homogeneous.

Modern definition of Natural radioactivity:-

"When a substance emits spontaneously $\alpha,\ \beta\ and\ \gamma$ rays the phenomenon is called as natural Radioactivity".

Properties of α, β and γ – rays :-		
α – Particles or α – rays.	β – Particles or β – rays.	γ – rays.
(1). That particles is called as α – Particles on which 2^+ unit charge and 4 unit mass are present. Thus, α – Particles are just like $_2H^{4\ 2+}$.	(1). That particles is called as β – Particles on which -1 unit charge and 1/1837 unit mass are present. The β – particles is just like on electron.	(1). γ – rays have not any charge and mass. It is a form of electromagnetic radiation.
(2). Penetrating power. α – particles have 10000 times less penetrating power than γ – rays (1).	(2). β – Particles have 100 times greater penetrating power than α – rays particles but 100 times less penetrating power than γ – rays (100).	(2). γ – rays have 10000 times greater penetrating power than γ – particles. (100
(3). Ionization power. α – Particles have 10000 ti more ionization power than γ – rays. (10000).	(3). β – rays particles have 100 times more ionization power than γ – rays and 100 times less ionization power than α – particles. (100).	(3). γ – rays have 10000 times less ionization power than α – particles. (1).
(4). Velocity. Velocity of α – particles is about 2×10^7m/sec.	(4). The velocity of β – particles is 236 to $2{\cdot}83\times10^8$m/sec.	(4). The velocity of γ – is 3×10^8m/sec.
(5). Effect on photographic plate. The effect of α – particles on photographic plate is maximum.	(5). β – Particles have less effect on photographic plate then α – particles.	(5). γ – rays have very small effect on photographic plate.
(6). Toxic effect. α – Particles have toxic effe more than β – *rays* but less than γ – rays.	(6). β – Particles are less toxic than α *or* α – rays.	(6). γ – rays are very high toxic effect.
(7). ZnS plate. α – particles have maximum luminescence effect on ZnS plate.	(7). β – Particles have less luminescence effect on ZnS plate than α – particles.	(7). γ – rays have very l effect on ZnS plate.

(8). Formation of new elements. When an atom emits one $\alpha -$ particles a new atom is formed whose atomic number is less by two and mass number is less by 4 than parent atom. $_{92}U^{238} \rightarrow {}_{90}Th^{234} + {}_{2}He^{4}$ Parent atom Daughter atom	(8). When an atom emits one $\beta -$ particles a new atom is formed whose atomic number is greater than one but mass number remains the same as parent atom. $_{90}Th^{234}$ $_{91}Pa^{234} + \beta^{-}$ P = 90 → P = 91 $+ \beta^{-}$ n = 144 n = 143 $n^{0} \rightleftharpoons P^{+} + e^{-}$	(8). $\gamma -$ rays emission does not produce any new atom.

Law of Radioactivity:-

There are following three laws of natural radioactivity.

(1) In natural radioactivity only three types of rays I,e $\alpha,\ \beta,\ \gamma$ are emitted.

(2) Emission of $\alpha,\ \beta\ and\ \gamma -$ rays always takes place, one by one. They will never emitted simultaneously. Also, at a time more than one $\alpha,\ \beta\ or\ \gamma -$ rays cannot be emitted.

(3) Group displacement law :-

This law was given by soddy and Fajans. So, it is also called as soddy and Fajans law which is as follows.

"When a radioactive atom emits one $\alpha -$ particle the position of new atom in the periodic table shifts two position left and when a radioactive atom emitted one $\beta -$ particle the position of new atom shifts one position right side in the periodic table".

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

$_{90}Th^{234}$ $_{91}Pa^{234} + \beta$

Rate of Radioactive disintegration:-

"The number of $\alpha -\ and\ \beta -$ particles emitted in one hour or sec or one minute is called as rate of radioactive disintegration".

The number or emitted $\alpha\ or\ \beta$ both particles is the number of times by which a radioactive nucleus disintegrates.

Rate of radioactivity is measured by the following instruments:-

(1) Scintillation counter.

(2) Wilson cloud chamber.

(3) Geiger miller counter.

Law of Radioactive disintegration :-

According to this law :-

"The rate of radioactive disintegration is directly proportional to the number of Atom of radioactive substance".

Let us suppose No is the number of a radioactive substance before disintegration, and N is the number of radioactive atoms after 't' time of disintegration.

Then according to above law –

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

Here, $\frac{-dN}{dt}$ = Rate of disintegration and -Ve sing indicates that rate decreases with time.

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

Here, λ = Decay constant.

Or, $\frac{-dN}{dtN} = \lambda$

Or, $\frac{-dN}{N} = \lambda dt$ ⟶ (1)

Now, after integration equation (1) we have –

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

Formula : $\int \frac{dN}{N} = lnN$

ln = loge

$\int dx = x$

Or, -loge N = $\lambda t + I$ ⟶ (2)

Here, I = integration constant.

Now, if t = 0, N = No

Putting these values in equation (2) we have.

-lnNo = I ⟶ (3)

Now, after putting the value of 'I' from equation (3) to (2) we have –

-lnN = λt -lnNo

Or, lnNo -lnN = λt

Or, $\frac{-lnNo}{N}$ = -λt

Or, $\frac{-lnN}{N}$ = -λt

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

Or, N = $No.e^{-\lambda t}$ ⟶ (4)

Or, N = $\frac{No}{e\lambda t}$

From equation (4) it is clear that N = 0 only when t = ∞

Hence, complete disintegration of a radioactive substance is not possible.

Half – life period (t ½):-

"Half – life period of a radioactive substance is defined as the time required to become half the amount or activity or number of radioactive atoms of a radioactive substance".

Example :-

(i) $t\frac{1}{2}$ of ${}_{92}U^{238}$ is $4\cdot 5 \times 10^9$ years.

(ii) $t\frac{1}{2}$ of ${}_{84}Po^{209} = 0\cdot 00015\ sec.$

Thus, larger will be the value of $t\frac{1}{2}$ of a radioactive substance greater will be its stability and vice versa.

Explanation :- The time required to become 100gm of Ra, 50gm is the same (1890 years) as the time required by 50gm of Ra to become 25gm is the same. The reason of this behavior is that the rate of disintegration decreases in such a way that the time to become half the radioactive substance remains always the same.

Value :- From law of radioactive disintegration we know that.

$$\lambda t = ln\frac{No}{N} \longrightarrow (1)$$

Here, No = Number of atoms before disintegrative.

N = Number of atoms after disintegration.

λ = Decay constant.

t = Time

Now, if $t = t\frac{1}{2}$

Then, $N = \frac{No}{2}$

Again, putting these values in equation (1)

$$\lambda t\frac{1}{2} = \ln \frac{No}{\frac{No}{2}}$$

Or, $t\frac{1}{2} = \frac{ln2}{\lambda}$

Or, $t\frac{1}{2} = \frac{2\cdot303\times log2}{\lambda} = \frac{2\cdot303\times0\cdot3010}{\lambda}$

$$\boxed{t\frac{1}{2} = \frac{0\cdot693}{\lambda}} \longrightarrow (2)$$

It is clear from equation (2) that $t\frac{1}{2}$ of a radioactive substance is independent of the number of atoms present in radioactive substance.

Importance formula:-

(i) $N = No\,(t\frac{1}{2})^n$ Here, Number of $t\frac{1}{2}$

(ii) $T = n \times t\frac{1}{2}$ Here, $T = \text{Total time}$

Average life period :-

Definition:- "The reciprocal of decay constant (λ) of a radioactive substance is called as average life period of the radioactive substance".

Thus, $\boxed{Tav = \frac{1}{\lambda}} \longrightarrow (1)$

Relation between Tav and t ½ :-

From the definition of $t\frac{1}{2}$ we know.

That, $t\frac{1}{2} = \frac{0\cdot693}{\lambda}$

Or, $\lambda = \frac{0\cdot693}{t\ 1/2}$ ⟶ (2)

Now, putting the value of λ from equation (2) to (1) we have :-

Tav = $\frac{1\times t\ 1/2}{0\cdot693} = 1\cdot443 \times t\frac{1}{2}$

Tav = $1\cdot443 \times t\frac{1}{2}$

Thus, Average life period.

= $1\cdot443 \times Half\ life\ period.$

Unit of Radioactivity :-

(1) Curie :- One curie is that amount of a radioactive substance gives $3\cdot7 \times 10^{10}$ disintegration per sec. (dps).

1 curie = $3\cdot7 \times 10^{10}$ dps.

(2) Ruther ford (rd) :- One Rutherford is that amount of a radioactive substance which gives 10^6 dps.

Thus, 1 rd = 10^6 dps.

(3) Becquerel (Bq):- This is the SI system for the unit of radioactive.

"One Becquerel is that amount of radioactive substance which gives one disintegration per second".

Thus, 1Bq = 1dps

Nuclear Force :-

Since protons are found at the nucleus of an atom whose radius is very small (in the order of 10^{-13} cm), these should be a very strong type of coulombic force of repulsion. According to scientists, this repulsive force should be about 27 tones. Hence nuclear force can be defined as:

"There is imaginary and special type of attractive force acting between proton, neutron, neutron and also between proton – proton, this force is called as nuclear force".

Thus, essentially nuclear force is much greater than coulombic force of repulsion acting between two protons. Whenever there is increase in the number of protons, the coulombic forces between protons become greater than nuclear force and hence the nuclear becomes unstable and shows radioactivity.

Stability of nucleus :-

Very high stability of nucleus of an atom is explained by following fives theories:

(1) Mass defect and nuclear binding energy.

(2) Packing fraction.

(3) n/p ratio.

(4) Meson theory.

(5) Nuclear shell model.

(1) Mass defect and nuclear binding energy mass defect :-

"Mass defect of an atom is the difference between expected mass and actual mass of an atom".

Thus, mass defect = Expected mass – Actual mass.

Example:- $_2He^4$

Calculated of expected mass of $_2He^4$:-

Mass of 2 protons = $2 \times 1 \cdot 00758 = 2 \cdot 01516\ amu$.

Mass of 2 electrons = $2 \times 0 \cdot 000548 = 0 \cdot 001096\ amu$.

Mass of 2 neutrons = $2 \times 1 \cdot 00893 = 2 \cdot 01786\ amu$.

Total expected mass = $4 \cdot 0341\ amu$.

And Real mass of $_2He^4$ = $4 \cdot 0039\ amu$.

So, mass defect = Expected mass – Real mass

= $4 \cdot 0341 - 4 \cdot 0039 = 0 \cdot 0302\ amu$.

Nuclear Binding Energy :-

"The energy released in the formation of a nucleus or the energy required to break a nucleus in to its constituent is called as nuclear binding energy of a nucleus".

Calculation of nuclear binding energy :-

Actually, at the time of the energy formation of a nucleus the mass defect is converted in to energy by the Einstein equation of theory of relativity, $E = mc^2$. Here, m = mass defect and c = velocity of light. And the energy is the value of nuclear binding energy.

Example :- Calculation of nuclear binding energy of $_2He^4$:

Mass defect of $_2He^4$ = $0 \cdot 0302\ amu$.

So, nuclear binding energy of $_2He^4$:

E = $0 \cdot 0302 \times (3 \times 10^8$ m/sec$)^2$

= $0 \cdot 0302 \times 931\ mev\ [1\ amu = 931\ mev]$

= $28 \cdot 14\ mev$.

Application :- Larger the value of nuclear binding energy of a nucleus grater will be the stability of nucleus and vice – versa.

(2) Packing fraction :-

This theory was given by Aston which is as follows:

Definition:- "The packing fraction is the ratio of difference of (atomic – weight and mass number) and mass number".

For convenience packing fraction is multiplied by 10^4.

Thus, packing fraction = $\frac{Atomic\ weight - mass\ number}{mass\ number} \times 10^4$

Example :-

(i) $_2He^4$:- $f = \frac{4\cdot0039-4}{4} \times 10^4 = 9\cdot75$

(ii) $_{17}Cl^{35}$:- $f = \frac{34\cdot98-35}{35} \times 10^4 = -5\cdot7$

Properties :- The value of packing fraction may be positive or negative or zero.

Significance :- Smaller the value of packing fraction greater will be the stability of the nucleus and vice – versa.

(3) n/p ratio :-

cause of radioactivity :-

(i) n/p = 1 :- When n/p ratio of a nucleus is one it is very stable nucleus and will never show radioactivity. Such type of nuclei are found at the straight line of the graph.

(ii) n/p>1 :- When n/p ratio of a nucleus is greater than one, it is unstable nucleus and this nucleus show radioactivity.

These nuclei are neutron rich and would decay by β^- emission to produce a daughter nucleus with a lower n/p ratio of $\frac{n-1}{p+i}$.

Example :- $_6C^{14}$:- $_7N^{14} + \beta^- + \gamma$

$$n/p = \frac{8}{6} = 1\cdot33 \qquad \frac{7}{7} = 1$$

These types of nuclei are found above the zone of stability belt.

(iii) n/p<1 :- When n/p ratio of a nucleus is less than one this nucleus will also show radioactivity and it lies below the zone of stability belt.

These types of nuclei can decay with β^- or e^+ or K – capture.

Example :- $_7N^{13}$:- $_6C^{13} + e^+ (\beta^+)$ position.

$$n/p = \frac{6}{7} = 0\cdot85\,, \; n/p = \frac{7}{6} = 1\cdot16$$

The daughter nuclei of these emissions have.

$\frac{n+1}{z-1}$ = ratio of n/p

Positron emission :- Charge is equal to proton and mass is equal to electron.

At the nucleus following types of reaction is going on.

$$P^+ \rightleftharpoons n + \beta^- \text{ or } e^+$$

An example of β^+ emission is positron.

$$_{11}Na^{22} \longrightarrow {}_{10}Ne^{22} + 1^e (\beta^+)$$

"K – capture" :- In some nuclides the nucleus may capture an electron from the K – shell. The vacancy created is filled by electrons from higher levels giving rise to characteristic X – rays. This process is known as K – electron capture or simply K – capture.

Example :- $_{56}Ba^{133} + e^- \longrightarrow {}_{55}Cs^{133}$ + X – rays.

In the nucleus following reaction takes place.

$$P^+ + e^- \longrightarrow n$$

Here, the neutron produced remains in the nucleus and the atomic number decreases by one unit as a result of K – capture.

Nucleus having $\frac{n}{p} > 1$, also disintegrate through $\alpha - emissiom$.

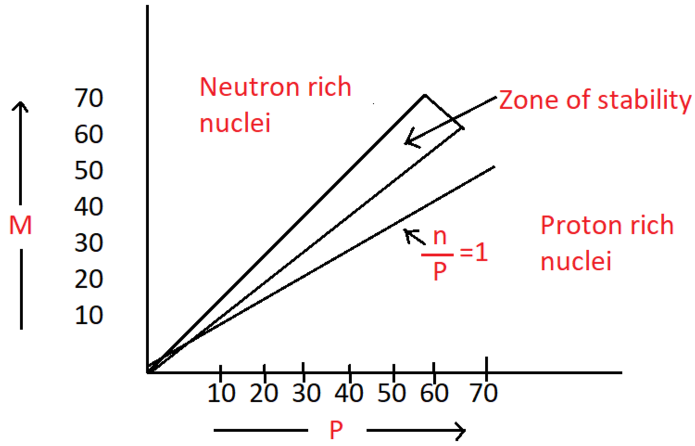
$\alpha - emissiom$:- When the value of Z becomes greater than 82, same nuclides attain greater stability by $\alpha - emissiom$ which reduces the initial $\frac{n}{p}$ value to $\frac{n-q}{p+2}$. The more important consequence being the reduction of Z or P leading to the reduction of P – P repulsions.

(4) Mass of a radioactive atom is always greater then the sum of the mass of products.

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

Here, M $_{92}U^{238}$ > M $_{90}Th^{234}$ + M $_{2}^{4}He^{2+}$

Graph :- Neutrons vs Protons.



From above grape following observations are noted :-

(i) Element having atomic number 84 and more than 84 have got all isotopes radioactive.

(ii) About 2000 radioactive isotopes are found.

(iii) Transuranic elements :- The transuranic elements. All transuranic elements are artificial.

(iv) Zone of stability belt :- All elements found in zone of stability belt are non – radioactive elements.

(v) Those nuclei which are found above and below the zone of stability belt are radioactive.

Nuclear Fission :-

Nuclear fission reaction was discovered by Autohan and Strassman in 1939 which is defined as follows:

"When a heavy nucleus after bombardment of neutron gives two nuclei having approximately same mass same neutrons and large amount of energy is evolved this reaction is called as nuclear fission reaction".

Example :- $_{92}U^{235} + {}_{0}N^{1} \longrightarrow {}_{92}U^{236} \longrightarrow {}_{56}Ba^{141} + {}_{36}Kr^{92} + 3n^{1}$ + 200 mev/nuclei.

Energy :- Here, mass of $_{92}U^{236}$ is greater than sum of the masses of $_{56}Ba^{141}$, $_{36}Kr^{92}$, 3n.

$$M\ U^{236} > M\ Ba^{141} + M\ Kr^{92} + M\ 3n.$$

Hence, there is some loss of mass here. This loss of mass is converted in to energy according to equation.

$$E = \Delta mc^2$$

Here, Δm = 1055 of mass.

That is why tremendous amount of energy is released when all nuclei of one pound of uranium show nuclear fission reaction we get such large amount of energy. Which can be obtained from thirty million tone of coal.

- Only following nuclides can show nuclear fission reaction.

$_{92}U^{235}$, $_{92}U^{233}$, $_{94}U^{239}$ and $_{94}U^{241}$ (only for)

It has been seen that U^{236} shows nuclear fission reaction in 40 different ways some of them are.

$$_{92}U^{235} + {}_{0}n^{1} \longrightarrow {}_{92}U^{236} \longrightarrow$$

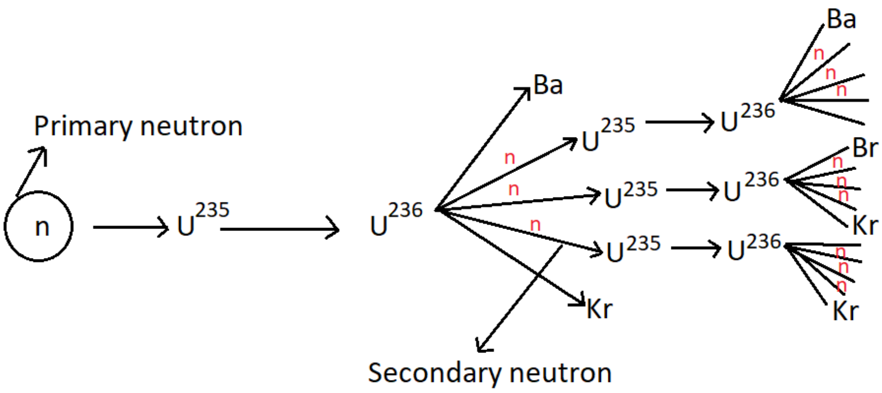
(i) $_{56}Ba^{141} + {}_{36}Kr^{92} + 3n^{1}$ + 200 Mev.

(ii) $_{56}Ba^{140} + {}_{36}Kr^{94} + {}_{2}n^{1}$ + E.

(iii) $_{57}La^{154} + {}_{35}Br^{80} + {}_{2}n^{1}$ + E and so on.

Chain reaction :-

It is characteristic of fission that every nucleus first absorbs one neutron and ejects two or more of them called secondary neutrons. These neutrons may bring about fission of more uranium nuclei there by propagating and repeating fission reactions time and again. Such a self, sustaining reaction is called as chain reaction or Autocatalytic reaction which may be represented as below.



Critical mass :-

Some of the secondary neutrons will escape from the surface and would not be involved in the chain reaction. In order to sustain the chain reaction a sufficient or minimum amount of fissionable material is required. This minimum amount of fissionable material which is required to continue the chain reaction is called as critical mass. The critical mass of U^{235} is 1 kg to 100 kg.

Some neutrons may be absorbed by U^{238} present as impurity.

If the mass of fissionable material is more than the critical mass, it is called as super critical mass on the other hand if the mass of the fissionable material is less than the critical mass it is called sub – critical mass. It may be noted the mass greater or lesser than the critical mass will hinder the propagation of chain reaction.

Application of Nuclear Fission reaction :-

(1) For constructive work :-

Nuclear Reactor :-

If the nuclear fission reaction is made to occur at a controlled rate, the energy released can be harnessed for constructure purposes. The equipment used to carry out the fission reaction in a controlled manner is called a "Nuclear Reactor".

The first nuclear reactor was made by army (in 1942). A reactor consists of –

(a) A fissionable material U^{235} (2 – 3 %).

(b) A moderator (graphite or heavy water D_2O) to slow down the neutrons there by increasing the efficiency of their capture to bring about fission reaction.

(c) Control rods made up to boron or steal or cadmium which will capture some of the neutrons so that the chain reaction does not become violent by having too many neutrons. The control rods are inserted between the fuel elements and they can be raised or lowered to control the chain reaction.

$${}_{48}Cd^{113} + n^1 \longrightarrow {}_{48}Cd^{114} + \gamma - ray.$$

$${}_{5}B^{10} + n^0 \longrightarrow {}_{5}B^{11} + \gamma - ray.$$

The large amount of energy released in the from of heat is converted in to electrical energy. Four such nuclear power plants have been set up in India at Tarapur, Narora, Kota and Kalpakkam.

Breeder Reactions :-

Naturally occurring uranium consists of only 0.7% of the fissionable isotope U^{239} and need to be enriched in the latter to be used as a fuel in a nuclear reactor. A breeder reaction is that which produces more fissionable nuclei than is consumes. For ex when ${}_{92}U^{238}$ is bombarded with fast neutrons it produces Pu^{239} nuclei by the following sequence of reactions –

$${}_{92}U^{238} + n^1 \longrightarrow {}_{92}U^{239} \longrightarrow {}_{93}Np^{239} + {}_{-1}e^0$$

$${}_{93}Np^{239} \longrightarrow \boxed{{}_{94}Pu^{239}} + {}_{-1}e^0$$

$${}_{94}Pu^{239} + {}_{0}n^1 \longrightarrow \text{products} + 3n^1 + E.$$

Similarly, the naturally more abundant Th^{232} can be used to breed the fissionable isotope ${}_{92}U^{233}$.

$_{90}Th^{232} + _{0}n^{1} \longrightarrow _{90}Th^{233} \xrightarrow{-\beta^-} _{91}Pa^{233} \xrightarrow{-\beta^-} _{92}U^{233}$

Nuclear fusion Reaction :-

Definition :- "A nuclear reaction that involves the combination or fusion of two or more lighter nuclei to form a heavier one with evolution of huge amount of energy is called Nuclear fusion".

Example :-

(i) Reaction on sun :-

$4\ _{1}H^{1} \longrightarrow _{2}He^{4} + 2e^{+} + E\ (26.7\ Mev)\ \gamma - ray.$

Posi from

(ii) Reaction in Hydrogen bomb :-

$_{1}H^{3} + _{1}H^{2} \longrightarrow _{2}He^{4} + n^{1} \pm 25 \cdot 8\ Mev$

(Tritium Deuterium)

The energy released in the fusion reaction is much larger than in fission reaction. This is due to much greater number of H – atoms per gram of Hydrogen than in per gram of $_{92}U^{235}$.

Coulomb Barrier :-

As the nucleus contains positively charged protons, if two or more of them are brought together they would naturally repel each other. So, if we want the two nucleus to touch each other and fuse we will have to overcome this repulsive force between the protons. The energy required to over come the repulsive force is called coulomb barrier one way to overcome the barrier is to heat up the nuclei to such a level that their kinetic energy becomes larger. That is why nuclear fusion reaction is also called as thermonuclear reaction.

Also, in course of hydrogen bomb first atom bomb is exploded to generate such high temperature (10 millions). So, it is also called as thermonuclear bomb.

Once the two nuclei come closer to each other nuclear attractive forces which are much stronger than the coulomb repulsion for smaller nuclei, come to action and they may fuse to liberate energy.

For nuclear fusion temperature is of the order of several millions degrees ($>10^{6}$k) are required to over come the coulomb barrier in hydrogen. The temperature of the sum is 100 million ^{0}c.

Energy :- Energy produced in nuclear fusion reaction is again due to mass defect. The mass of the reactants is greater than the mass of product. The last mass is converted in to energy according to equation.

$$E = mc^2$$

It may be noted that the conversion of Hydrogen in to Helium, which is the source of solar energy, is so, slow even at such a high temperature that it takes several million years for the conversion of one gram of hydrogen in to Helium. The reason why the sun is capable of producing energy at such a high rate lies in its enormous size.

Application :-

(i) The fusion reaction is the basis of so, called Hydrogen or thermonuclear bomb.

(ii) The reaction occurring in sum is nuclear fusion reaction.

(iii) Up till now the constructive application of nuclear fusion reaction is not possible by mankind because the energy released in the reaction can't be controlled. This is still a challenge among scientists. If it would be possible there will be no problem of energy on the earth because in oceans enormous amount of deuterium ($_1H^2$) isotope is found.

Artificial Nuclear Transmutation or Transformation :-

This process was discovered by ernest Rutherford and Blackeff in 1919 which is as followed.

Definition :- "The process of conversion of one element in to another element by artificial means is called artificial transmutation of elements".

The sub atomic particles used for bombarding the nuclei (Target) are called bombarding particles or projectiles.

Examples :-

(i) The transformation performed by Rutherford first of all was.

$$_7N^{14} + {_2He^4} \longrightarrow {_8O^{17}} + {_1H^1}$$

(Target Projectile) (Ejected partial)

(ii) In 1932 Chadwick discovered neutron by following transformation.

$$_4Be^9 + {_2He^4} \longrightarrow {_6C^{12}} + n^1$$

Projectiles :- In the above transmutation $\alpha - particles$ act as projectiles. However, the scientists faced a problem by using $\alpha - particles$ as projectiles. Since $\alpha - particles$ are positively charged species they had a difficulty in approaching the positively charged atomic nuclei of target because of repulsion between the two consequently the transmutation reaction was quite slow.

To overcome the repulsion attempts were made to accelerate the speed of projectiles several types of accelerators such as linear accelerator, cyclotron, Synchrotron or bevatron etc. are used. The following projectiles are used. The following projectiles are used for transmutation.

(i) $_2H^4$

(ii) $_1H^1$

(iii) $_1H^2$

(iv) n^1

The projectiles finally leave the instrument with a velocity of about 25000 miles per second. The neutrons need not to be accelerated as they are neutral projectiles. The above two transformation can also be represented as.

(i) $_7N^{14}\ (\alpha, p)\ _8O^{17}$

(ii) $_4Be^9\ (\alpha, n)\ _6C^{12}$

The most effective apparatus, cyclotron was developed by E.O Lawrence at the university of California (USA).

It may be noted that the total positive charge (atomic number) and mass before and after the bombardment remains the same.

Some nuclear transmutation reaction :-

(i) (p, α) type :-

$_{19}K^{39} + {_1H^1} \longrightarrow {_{18}Ar^{36}} + {_2He^4}$

(ii) (α, n) type :-

$_4Be^9 + {_2He^4} \longrightarrow {_6C^{12}} + n$

(iii) (d, α) type :-

$_{13}Al^{27} + {_1H^2} \longrightarrow {_{12}Mg^{25}} + {_2He^4}$

(iv) (n, α) type :-

$_8O^{16} + n \longrightarrow {_6C^{13}} + {_2He^4}$

(v) (γ, n) type :-

$_4Be^9 + v \longrightarrow {_4Be^8} + n^1$

Induced Radioactivity or Artificial Radioactivity :-

In 1934 Frederic Joliot and Irene curie (son – in - law and daughter of marie curie) discovered the phenomenon of induced radioactivity. Which is as follows –

"The phenomenon of conversion of a stable non – radioactive nuclei in to a radioactive nuclei is called artificial radioactivity of induced radioactivity".

The first man – made radioisotopes $_{15}P^{30}$, $_{14}Si^{27}$ and $_7N^{13}$ were prepared by Irene curie and her husband F. Joliot in 1934.

Examples :-

(i) $_{13}A^{27} + {_2He^4} \longrightarrow {_{15}P^{30}} + n^1$

(Nonradioactive) Radioactive ($t_{\frac{1}{2}} = 3\ min$)

$_{15}P^{30} \longrightarrow {_{14}Si^{30}} + e^+$ (positron)

Nonradioactive

Note :- Emission of $\gamma - rays$ is observed virtually in all nuclear reactions from nuclei which are left in an excited state by an earlier emission of an α or $\beta - particles$.

(ii) $_{13}Al^{27} + {_2He^4} \longrightarrow {_{15}P^{31}} \xrightarrow{-n} {_{15}P^{30}} \xrightarrow{t\,½ = 3\ min} {_{14}Si^{30}} + e^+$ (stable)

(iii) $_{12}Mg^{24} + {_2}He^4 \longrightarrow {_{14}}Si^{27} + n^1$

Nonradioactive — Radioactive

$_{14}Si^{27} \xrightarrow{t\ ½ = 7\ min} {_{13}}Al^{27} + e^+$ (stable)

(iv) $_5B^{13} + {_2}He^4 \longrightarrow {_7}N^{13} + n^1$

Radioactive

$_7N^{13} \xrightarrow{t\ ½ = 9.9\ min} {_6}C^{13} + e^+$ (stable)

Induced radioactive nuclei may be produced by $_2He^4$, $_1D^2$, n^1, γ etc. projectiles.

Characteristics of Induced Radioactivity :-

(1) There is one or two step process in the case of artificial radioactivity.

(2) Generally, e^+ or e^- or n^1 are produced during disintegration.

(3) The artificial radioactivity follows the same laws of decay as natural radioactivity.

(4) Artificial radioactive elements have very low half – life period as compared to natural radioactive elements.

Preparation of transuranic elements :-

"All the elements often uranium have been synthesized and are called transuranic elements".

It was found by Seaborg at the university of California that when uranium is bombarded with neutrons it gives the atom of higher mass number.

$_{92}U^{238} + n \quad {_{92}}U^{239} + \gamma - rays.$

This new isotope of $_{92}U^{239}$ gives rise to $_{93}U^{239}$ by

$\beta - emission \quad {_{92}}U^{239} \quad {_{93}}Np^{239} + e^-$

Now, Np gives rise to $_{94}Pu^{239}$

$_{93}Np^{239} \quad {_{94}}Pu^{239} + \beta - rays.$

In the way by successive emission of $\beta - rays$ other transuranic elements such as $_{95}Am$, $_{96}Cm$, $_{97}Bk$ etc. are prepared

Transuranic elements can also be prepared by the bombardment of H^2, $_2He^4$, $_6C^{12}$ projectiles on $_{92}U^{238}$, $_{94}Pu^{239}$ etc. isotopes

Examples :-

(i) $_{94}Pu^{239} + {_1}H^2 \longrightarrow {_{95}}Am^{241}$

(ii) $_{94}Pu^{239} + {_2}H^4 \longrightarrow {_{96}}Cm^{242} + n^1$

(iii) $_{92}U^{238} + {_6}C^{12} \longrightarrow {_{98}}Cf^{246} + 4n^1$

Radioactive disintegration series :-

This was discovered by Rutherford and Soddy. "The series of radioactive changes that takes place starting from radioactive element till the formation of stable nonradioactive element is called as radioactive disintegration series". There are four radioactive series. These four series are 4n series (4n + 1) series, (4n + 2) series, (4n + 3) series,

Series	Name of series	Initial element	Last stable element	Value of n for initial element	Value of n for stable element
4n	Thorium series	$_{90}Th^{232}$	$_{82}Pb^{208}$	58	52
(4n + 1)	Neptunium series	$_{93}Np^{237}$	$_{83}Bi^{209}$	59	52
(4n + 2)	Uranium series	$_{92}U^{238}$	$_{82}Pb^{206}$	59	51
(4n + 3)	Actinium series	$_{89}Ac^{231}$	$_{82}Pb^{207}$	57	51

Thorium series :-

$_{90}Th^{232} \xrightarrow{-\alpha} {}_{88}Ra^{228} \xrightarrow{-\beta} {}_{89}Ac^{228} \xrightarrow{-\beta} {}_{90}Th^{228} \xrightarrow{-\alpha} {}_{88}Ra^{224} \xrightarrow{-\alpha}$
$_{86}Rn^{220} \xrightarrow{-\alpha} {}_{84}Po^{216} \xrightarrow{-\alpha} {}_{82}Pb^{212} \xrightarrow{-\beta} {}_{83}Bi^{212} \xrightarrow{-\alpha} {}_{81}Tl^{208} \xrightarrow{-\beta} {}_{82}Pb^{208}$

(Q) Half – life of $_{84}Po^{210}$ is 140 days. Calculate the time in which one gram Po becomes ¼ gm.

Ans :- We know that N = $No.e^{-\lambda t}$

For t ½ No/2 = $No.e^{-\lambda(140)}$

Or, $e^{(\lambda\times 140)} = 2$

$\therefore \lambda \times 140 = ln2$

$\therefore \lambda = \frac{ln2}{140} = \frac{0{\cdot}693}{140}$