UNIT-V

Nuclear Reactions : Types

BETHE'S NOTATION : A nuclear reaction, as the name implies, refers to a transformation of a target atomic nucleus, usually all by, by bombarding it with projectiles of light nuclei, (or) from neutrons (or) photons of adequate energy. A nuclear reaction is generally represented by an equation indicating the nuclear characteristics of the reactants and resultants, as

$$ {}^{A_1}_{Z_1}X + {}^{A_2}_{Z_2}a \longrightarrow {}^{A_3}_{Z_3}b + {}^{A_4}_{Z_4}Y $$

where X → stands for the target nucleus
a → for the projectile effecting the reaction
b → for the particle ejected (or) the ejectile
Y → for the product nucleus (or) recoil

Except when the nuclear charge conservation is to be emphasized $(Z_1+Z_2+Z_3+Z_4)$, the Zs are omitted in the equation, as these value are unique for each chemical element. Similarly A_2 and A_3 are omitted if the particles a and b are otherwise uniquely distinguishable. A shorter form of writing a nuclear reaction is due to Bethe, on which notation the above reaction is more elegantly represented by

$$ {}^{A_1}X\ (a,b)\ {}^{A_4}Y $$

Here, the target nuclide is written first and the product last, with the projectile and ejectile particles inside the parentheses, in the same order but separated by a comma, e.g.:

(i) ${}^{24}Mg\ (d,\alpha)\ {}^{22}Na$; (ii) ${}^{35}Cl\ (n,p)\ {}^{35}Si$;

(iii) ${}^{23}Na\ (n,\gamma)\ {}^{24}Na$: (iv) ${}^{63}Cu\ (p,p3n9\alpha)\ {}^{24}Na$.

The last example shows how, sometimes, many particles all shown to the right of the comma, may be

TYPES OF NUCLEAR REACTIONS :-

One way of designating a nuclear reaction is merely by naming (a, b) on the target. Thus, (n, γ) and (n, p) in the above examples are referred to as (n, p) reaction on ^{35}Cl and (n, γ) reaction on ^{23}Na respectively. Based on the nature of a and b following types are distinguished.

(i) **ELASTIC SCATTERING :-** Here a = b and X = Y, e.g., ^{9}Be (n, n) ^{9}Be ; the incoming particle strikes the target nucleus, loses a fraction of its kinetic energy in translating the latter. The projectile particle gets its direction deflected by an angle θ as in the scattering of a billiard ball. There is no change in total potential energy and the kinetic energy is conserved. Such a process is known as elastic scattering. The amount of energy transferred to the target in setting it in motion (translation) is given by the relation

$$E_M = \frac{4mM\cos^2\theta}{(m+M)^2} \cdot E_m.$$

Where E_m → is the initial kinetic energy of the incident particle of mass m,

E_M → the kinetic energy gained by the target nucleus of mass M,

θ → is the angle between the initial and final paths of the particle.

If E'_m is the residual kinetic energy of the incident particle, the conservation of energy leads to

$$E_m = E_M + E'_m.$$

The slowing down of fast neutrons by a moderator in a nuclear reactor is mainly by elastic scattering.

(ii) INELASTIC SCATTERING :-

A process of scattering is considered inelastic if some of the kinetic energy of the particle is used up in raising the potential energy of the target in some way (or other, as in exciting it to higher energy level. Here the kinetic energy of the system, as such, is not conserved,

e.g., $^{107}Ag\ (n, n')\ ^{107}Ag \xrightarrow[11.3\,s]{} ^{107}Ag$.

Here the incoming neutron of high energy, excites the target nucleus ^{107}Ag to an excited state which in this case has a long life of 11.3 s and in this process the scattered neutron has considerably less kinetic energy. This is indicated by priming the outgoing neutron as shown.

(iii) Photonuclear Reaction :

Nuclear reactions induced by X-ray (or) γ photons of high energy (> 10 MeV) are referred to as photonuclear reactions. Here $a = \gamma$ and b is more often n (or) p and, with some very high energy photons, b may be d, t (or) α (or) even a mixture of particles, e.g.,

(i) $^{9}Be\ (\gamma, n)\ ^{8}Be^{*} \longrightarrow 2\alpha$;

(ii) $^{2}H\ (\gamma, n)\ ^{1}H$.

It is by reaction (i) that neutrons are obtained from an Sb-Be Laboratory neutron source. The 2.5 MeV γ from ^{124}Sb brings about the (γ, n) reaction on beryllium as shown under (i) rexn.

(iv) RADIATIVE CAPTURE :-

Here the particle on capture leads to the emission of radiation in the form of one (or) more γ photons. (i.e) $b = \gamma$. The most common are (n, γ) reactions in which the product is an

isotope of the target element one mass unit higher as in ;

$^{23}Na\ (n,\gamma)\ ^{24}Na$; $^{31}P\ (n,\gamma)\ ^{32}P$; $^{197}Au\ (n,\gamma)\ ^{198}Au$

(n, γ) reactions have been realised with a very large number of target nuclides. There are also some (n, γ) reactions ; as

$^{19}F\ (p,\gamma)\ ^{20}Ne$;

$^{27}Al\ (\alpha,\gamma)\ ^{28}Si$;

(V) Other Types of Nuclear Reactions :-

A large variety of other types of nuclear reactions is known as (p, n), (n, p), (n, α), (α, n), (d, p), (d, n), (α, t). Some of these will be considered later.

Note: (Write the equations of above Reaction type, Give Example of it).

(VI) Special Nuclear Reactions :- In all the above nuclear reactions, the product nucleus differs from the target nucleus only by a few units of A (or) Z (or) N. There are on the other hand many reactions involving high energy projectiles in which the target nucleus is partly torn apart yielding products lighter by several units. Some of these are listed below in the order of violence of disruption.

1.) (a) Evaporation :-

When several nucleons, and/or these combinations as alphas, leave the nucleus, the process is referred to as evaporation, e.g.,

$^{133}Cs\ (\alpha, 4n)\ ^{133}La$;

$^{27}Al\ (d, p\alpha)\ ^{24}Na$;

(b) Spallation :-

This is more violent than evaporation, and a large number of nucleons are thrown out and the product nucleus is very much lighter than the parent,

e.g. : $^{63}Cu\,(p, p\,3n\,\gamma z) \rightarrow {}^{60}Na$; $(E_p \geq 70\ MeV)$,

$^{79}Br\,(p, p\,7n\,\gamma z) \rightarrow {}^{71}Se$; $(E_p \geq 40\ MeV)$

(c) Fission :- Fission is the process in which a nucleus excited by a neutron (or by other means breaks into two fragments of comparable sizes,

e.g. : $^{235}U + n \longrightarrow {}^{236}U^* \longrightarrow {}^{137}Te + {}^{97}Zr + 2n$

(d) Fusion :- A nuclear reaction that involves the combination of fusion of two lighter nuclei to form a behaviour one is called nuclear fusion.

Ex :- $H^1 + H^1 \rightarrow H^2 + {}_1e^0 + \gamma$

$H^1 + H^2 \rightarrow He^3 + \gamma$

$He^3 + He^3 \rightarrow He^4 + 2H^1 + \gamma$.

(e) Fragmentation :- When a nucleus on heavy excitation, around 0.5 GeV splits into a light and a heavy fragment having about the same N/Z ratio as in the parent, the process is referred to as fragmentation, or star process. The excitation energy not being equally distributed between the light and the heavy fragments, the former decays by β^- and the latter by evaporation.

(b) **Spallation** :- This is more violent than evaporation, and a large number of nucleons are thrown out and the product nucleus is very much lighter than the parent.

e.g. : $^{63}_{29}Cu\,(p, p\,3n\,7\alpha)\,^{41}_{11}Na$; $(E_p \geq 70\ MeV)$,

$^{79}_{35}Br\,(p, p\,7n\,7\alpha)\,^{44}_{14}Si$; $(E_p \geq 140\ MeV)$

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Q8. **Transfer Reactions (or Direct Reactions) Stripping and Pick up Reactions. The Buckshot hypothesis**

In some cases, the projectile does not react as a whole with the target nucleus, but one (or) more constituents of projectile (into which it splits in the joint Coulomb field of target and projectile), alone are captured by the target nucleus. (The buckshot hypothesis). In this way the products heavier than the target are produced.

With accelerated deuterons as projectiles they behave as if they are made up of a proton and a neutron, of which either alone is captured, more often the neutron,

e.g., $^{63}Cu + d\ (= n + p) \rightarrow {}^{64}Cu + p$.

These are referred to as Oppenheimer-Phillips' reactions.

With 125 MeV $^{14}N^{6+}$ ions as projectiles they behave as if they are stripped into $n + p + 3\alpha$ in the Coulomb field of the target of which some alone are captured by the target. Thus with ^{27}Al as the target, following reactions have been observed.

$$^{27}Al \xrightarrow{+p} {}^{28}Si$$

$$\xrightarrow{+n} {}^{28}Al$$

$$\xrightarrow{+\alpha} {}^{31}P$$

$$\xrightarrow{+2\alpha} {}^{35}Cl$$

$$\xrightarrow{+3\alpha} {}^{39}K.$$

Examples of a reverse transfer have also been reported, where in the projectile takes up a nucleon from the target as in $^{9}Be(d, {}^{3}He)\, {}^{8}Li$.

An interesting transfer reaction which has been studied much is

$$^{14}_{7}N(^{14}N, ^{15}N)\,^{15}_{7}N.$$

Where the target, the projectile, the ejectile and the recoil residue are all isotopes of the same element.

In general all transfer reactions, whether of stripping, or pick up, (or) knockout capture, appear to proceed without the formation of a compound nucleus.

(9) **Transmutation Reaction :** ✓

In this nuclear reaction the daughter element differs from the target only by a few units of mass number and atomic number. The reaction is accompanied by

(i) On Bombarding nitrogen by α-particles $_{8}O^{17}$ was produced.

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

Here projectile is α-particle, proton is emitted in this reaction, hence this is called (α, p) reaction.

(ii) Transmutation can also be produced by other particles as by neutrons.

$$_{8}O^{16} + {}_{0}n^{1} \longrightarrow {}_{6}C^{13} + {}_{2}He^{4}.$$

This is called (n, α) reaction.

(iii) $_{13}Al^{27} + {}_{1}H^{1} \longrightarrow {}_{12}Mg^{24} + 2\,{}_{2}He^{4}$, This is called (p, α) reaction.

(b) Disintegration :- Here the incident particle is absorbed by the target nucleus and the ejected particle is a different one. The composition of the resultant nucleus is also different from the parent nucleus.

(viii) (i) Photo disintegration :

When target materials are bombarded with radiations, the resulting compound nuclei are usually formed in excited state. These nuclei generally get rid of the excess excitation energy through neutron emission.

$$_1^2H + \gamma \rightarrow {}_1^1H + {}_0^1n$$ (requiring photon energy of the order of 2.2 MeV)

Nuclear Reaction Cross section

The Probability (or efficiency) of a nuclear reaction can be defined in terms of a quantity called the Nuclear Cross section. It represents the effective area of cross section of a single nucleus of a given species for a particular reaction.

Thus when probability of the process is high, the so called nuclear cross section reaction will be large. On the other hand, when the probability is low, the cross section will be small.

Let I be the number of incident particles striking in a given time a certain area of target material, containing N target nuclei per sq cm. Let A be the number of these nuclei that undergo interaction in the specified time. Then

The nuclear cross section σ represented as square cm per nucleus is denoted by,

$$\sigma = \frac{A}{NT} \text{ . Sq cm per nucleus}$$

The value of the nuclear cross section depends not only on the nature of the target element, but also on the particular reaction. Under consideration and the energy of the incident particle for given nucleus such as ^{7}Li.

For Ex; ^{7}Li will in general have different cross section for the reaction

$^{7}Li(P,n)$, ^{7}Be and $^{7}Li(P,\alpha)\,^{4}He$, which may occur simultaneously.

If it is sufficient to know the total nuclear cross section for all process in which the incident particles are removed, a simple procedure is possible to determine σ.

Let I_o be the number of incident particles in a narrow (or collimated) beam, a falling in a given time on the target material Sheet of thickness of x cm.

Let I be the corresponding number of these pasticle energing from the otherside of the sheet in the narrow beam.

The difference $I_o - I$ has been removed, in various nuclear reaction,

Then $$\frac{I}{I_o} = e^{-Nx\sigma}$$

Where N – is the no/. of target nuclei / cc.
e – is the base of natural logarithm
σ – is the total nuclear cross section

Here it is possible to determine the cross section from measurements of the intensity of the beam of incident particles before and after passage through the target material.

Experimental values for nuclear cross sections are usually in the vicinity of 10^{-25} to 10^{-23} sq. cm per nucleus. A unit called a barn equal to 10^{-24} sq. cm per nucleus has been adopted to explain nuclear reaction cross section. Thus nuclear cross sections are frequently the range of 0.1 to 10 barns. The variation of cross section for given reaction with the energy of the projectiles can be represented in the form of curve called excitation function.

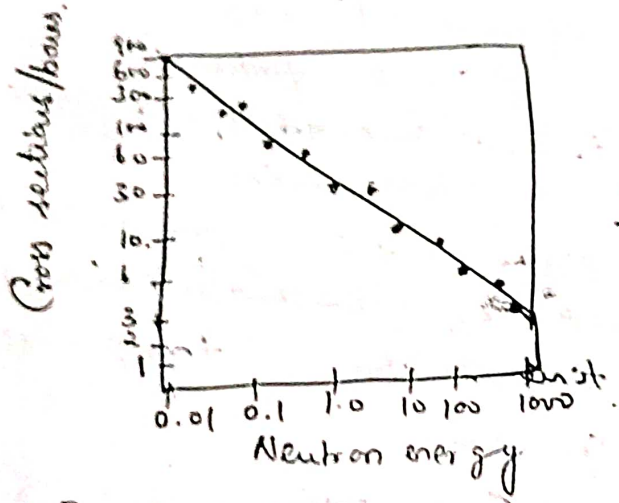
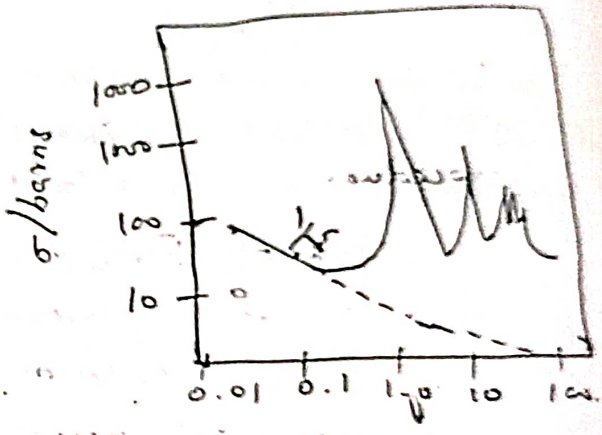


Fig (1a). $^{10}B(n,\alpha)^{7}$ Li reaction.



(fig 1b)

$^{109}Ag(n,\gamma)^{110}Ag$ reaction.

$\frac{1}{v}$ law upto 1 eV.

Fig: Variation of neutron cross section with energy. (1a & 1b).

Q- Value :-

The Q- value for "nuclear disintegration energy" is expressed in terms of mass in energy units, as the change in total kinetic energy of the system. As Q is also the change in total rest mass it has got same value in laboratory co-ordinates as well as in CM co-ordinates.

The laws of conservation of energy and momentum are the governing factors of Q-value equation. Let us now apply these laws to reaction started by an incident particle of mass M_i is emitted with kinetic energy T_i, leaving residual nucleus with mass M_r and energy, T_r. The situation is illustrated in the following figure.

p's refer to momenta of different particles.

The Conservation of energy underlines

$$E_r' + E_t' = E_e' + E_i' \quad \text{——— (1)}$$

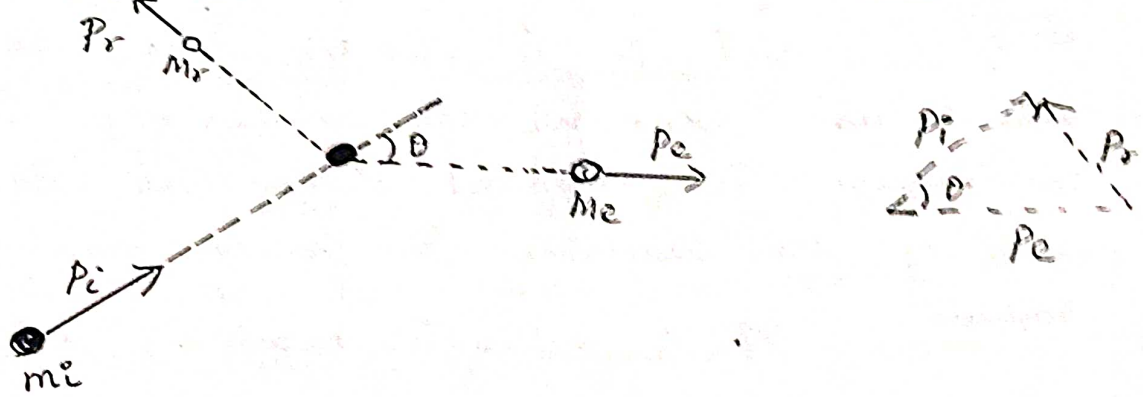


Fig: Schematic diagram of simple Nuclear Event.

In the above equation (1), where prime (') is used to mension the total energy including the rest mass energy. Splitting the total energy E' into kinetic energy T and the rest mass energy E^0, we have

$$(T_i + E_i^\circ) + (0 + E_i^\circ) = (T_e + E_e^\circ) + (T_r + E_r^\circ) \quad \text{--- (2)}$$

(T_i = 0)

In the above eqn, T_i is zero. It should be noted that we are discussing the problem in laboratory system well within the non-relativistic limit. According to the definition, the energy released in a nuclear reaction is called energy balance of the reaction (or) more commonly, the Q value.

$$Q = (T_e + T_r) - T_i = (E_t^\circ + E_t^\circ) - (E_e^\circ + E_r^\circ) \quad \text{--- (3)}$$

Separately we write the above eqn, we get

$$Q = T_e + T_r - T_i \quad \text{--- (4)}.$$

and

$$Q = [(M_i + M_t) - (M_e + M_r)c^2] \quad \text{--- (5)}$$

The equation (5) results by applying mass energy relation to the eqn (3).

Significance:

If Q is positive, the reaction is termed as exoergic (or) exothermic and implies that energy is released during the reaction; and mass of the reactants is greater than that of the products.

If Q value is negative, the reaction is endoergic (or) endothermic and reverse is true for this case. (i.e) energy is absorbed in the reaction and mass of the products is greater than the of reactants. Thus, Q value of the reaction furnishes information about the ~~mass~~ nuclear mass and particle energies.

Threshold energy :-

In endoergic reaction Q is negative and if T_t is taken zero then T_e comes out to be imaginary, inferring thereby that for a reaction to take place T_i should have some positive value.

Further in endoergic reaction $-Q$ is the energy which is needed to excite the reaction and this energy is supplied by kinetic energy of incoming particle. But all available kinetic energy is not used for excitation of the reactions for part of it is used to impart momentum to the compound nucleus. Hence, for a reaction in which $-Q$ energy is to be absorbed, the incident particle should supply some energy in addition to $-Q$. Thus, the minimum value of incident particle energy at which the reaction takes place is known as threshold energy. Assuming the formation of compound nucleus and applying conservation of momentum principle, we have

$$M_i V_i = M_c V_c \quad \text{—— (1).}$$

M_i & V_c are the mass and velocity of compound nucleus. The sharing of incident particle energy takes place as,

$$\left[\cancel{Q} = \cancel{\tfrac{1}{2} M_i V_i^2} - \cancel{\tfrac{1}{2} M_c V_c^2} = \cancel{\tfrac{1}{2} M_i V_i^2} \cancel{\tfrac{1}{2}} \right]$$

$$\boxed{\text{From} \quad V_c = \frac{M_i V_i}{M_c}} \quad \text{—— (2)}.$$

$$\text{K.E. of the Compound} = \tfrac{1}{2} M_c V_c^2 \quad \text{—— (3)}.$$

[illegible]

Substitute eqn ① in eqn ③.

$$= \frac{1}{2} M_c V_c^2 \qquad \left(V_c = \frac{M_i V_i}{M_c} \right)$$

$$= \frac{1}{2} M_c \left(\frac{M_i}{M_c} \right)^2 V_i^2$$

Energy available for the reaction $\} = \frac{1}{2} M_i V_i^2 - \frac{1}{2} M_c V_c^2$

$$= \frac{1}{2} M_i V_i^2 \left(1 - \frac{M_i}{M_c} \right) \quad \text{—— ④}$$

But $M_c = M_i + M_t$. (M_t = mass of target nucleus.)

$$\therefore \frac{1}{2} M_i V_i^2 - \frac{1}{2} M_c V_c^2 = \frac{1}{2} M_i V_i^2 \left(\frac{M_t}{M_i + M_t} \right)$$

$$-Q = \frac{1}{2} M_i V_i^2 \left(\frac{M_t}{M_i + M_t} \right)$$

$\therefore$ The threshold energy $= E_{th} = \frac{1}{2} M_i V_i^2 = -Q \left(\frac{M_i + \ldots}{M \ldots} \right.$

$$\therefore E_{th} = \frac{1}{2} M_i V_i^2 = -Q \left(\frac{M_t + M_i}{M_t} \right) \quad \text{—— ⑤}$$

The equation (5) determines threshold energ[y] for a reaction.

For a reaction induced by γ-rays / M_i [...] and $E_{th} = -Q$. In equation ⑤ all masses ar[e] nuclear masses, but in actual calculation ma[sses] of natural atoms may be used, for electrons [...] which are added to nuclei to form the result[ing] atoms cancel out in a nuclear reaction.

Example:

In a $N^{14}(\alpha, p)O^{17}$ reaction, the atomic masses are;

$M(N^{14}) = 14.007518$ amu

$M(He^4) = 4.003873$ amu

$M(O^{17}) = 17.004529$ amu

$M(H^1) = 1.008144$ amu.

Calculate the threshold energy.

The Q value is given by the equation,

$$Q = [(M_i + M_t) - (M_o + M_r)] \text{ amu}$$

$$= [(4.003873 + 14.007518) - (1.008144 + 17.004529)]$$

$$= [(18.011391) - 18.012673)$$

$$= -0.001282 \text{ amu}$$

$$\boxed{Q = -1.19 \text{ MeV} ; \text{ an endoergic reaction.}}$$

Hence

$$E_{th} = -Q\left(\frac{M_t + M_i}{M_t}\right)$$

$$= 1.19\left(\frac{14.007518 + 4.003873}{14.007518}\right) = 1.19\,(1.28)$$

$$\boxed{E_{th.} = 1.52 \text{ MeV}}$$

Shipping reactions

* High energy ($0.5 < E < 10$ MeV)

Ex: (d,P); (d,n); (d,pn)

(d,P) ⇒ ${}_{6}C^{13} + {}_{1}H^{2} \rightarrow ({}_{7}N^{15})^{*} \rightarrow {}_{6}^{14}C + {}_{1}H^{1}$

(d,n) ⇒ ${}_{3}Li^{7} + {}_{1}H^{2} \rightarrow ({}_{4}Be^{9})^{*} \rightarrow {}_{4}Be^{8} + {}_{0}n^{1}$

(d,2n) ⇒ ${}_{33}^{75}As + {}_{1}H^{2} \rightarrow {}_{34}^{75}Se + 2\,{}_{0}n^{1}$

(d,α) ⇒ ${}_{12}^{24}Mg + {}_{1}H^{2} \rightarrow {}_{11}^{22}Na + {}_{2}^{4}He$

* Very high energy ($E > 10$ MeV)

Ex: (d,P); (d,2n); (d,Pn); (d,2n); (d,t);

(d,t) reaction:

${}_{3}^{7}Li + {}_{1}H^{2} \rightarrow {}_{1}H^{3} + {}_{3}^{6}Li$

(d,t) reaction:

${}_{15}^{31}P + {}_{1}H^{2} \rightarrow {}_{15}^{30}P + {}_{1}H^{3}$

(d,m) reaction:

${}_{33}^{75}As + {}_{1}H^{2} \rightarrow {}_{33}^{76}As + {}_{1}H^{1} + {}_{0}n^{1}$

Reactions with Tritons:- Nuclear reactions effected by tritons are similar to those effected by deuterons The Oppenheimer – Phillips reactions take the form of (t,P) and (t,d) eg;

Ex: (t,P) reaction:

(i) ${}_{6}^{12}C + {}_{1}H^{3} \rightarrow {}_{6}^{14}C + {}_{1}H^{1}$

(ii) ${}_{27}^{59}Co + {}_{1}H^{3} \rightarrow {}_{27}^{61}Co + {}_{1}H^{1}$

Ex: (t,d) reaction.

(i) ${}_{29}^{63}Cu + {}_{1}H^{3} \rightarrow {}_{29}^{64}Cu + {}_{1}H^{2}$

Other Reactions are (t, n), (t, 2n) and (t, α)

Ex: (t, n) Reaction

(i) $^{16}_{8}O + {}_{1}H^{3} \longrightarrow {}_{0}n^{1} + {}^{18}_{9}F$

(ii) $^{32}_{16}S + {}_{1}H^{3} \longrightarrow {}_{0}n^{1} + {}^{34}_{17}Cl$

(t, 2n) ⟹ (iii) $^{76}_{32}Ge + {}_{1}H^{3} \longrightarrow 2_{0}n^{1} + {}^{77}_{33}As$

Ex: (t, α) Reaction.

(i) $^{7}_{3}Li + {}_{1}H^{3} \longrightarrow {}^{4}_{2}He + {}^{6}_{2}He$

Reactions with α (Alpha) Particles :-

Alpha particles from naturally occuring radioelement were the first projectiles used to be used in effecting nuclear reactions, the classic experiment of Rutherford in 1919 being the first one.

$$^{14}N + \alpha \longrightarrow P + {}^{17}O$$

Classification depending upon the energy of α particles are given below;

High energy (0.5 < E < 10 MeV)

[(α, n);]

Ex: $^{109}_{47}Ag + {}^{4}_{2}He \longrightarrow {}_{0}n^{1} + {}^{112}_{49}In$

[(α, P) ;]

Ex: $^{32}_{16}S + {}_{2}He^{4} \longrightarrow (A^{36})^{*}_{18} \longrightarrow {}^{35}_{17}Cl + {}_{1}H^{1}$.

Very high energy (E > 10 MeV)

[(α, 2n)] Rexn.

Ex: $^{109}_{47}Ag + {}^{9}_{2}He \longrightarrow 2_{0}n^{1} + {}^{111}_{49}In$

[(α, n) ; (α, P) ; (α, nP) ; (α, α).

[(α, n) :-] Rexn

$^{19}_{9}F + {}_{2}He^{4} \longrightarrow {}^{22}_{11}Na + {}_{0}n^{1}$

[(α, M)] Rexn

$^{239}_{94}Pu + {}_{2}He^{4} \longrightarrow 5_{0}n^{1} + {}^{235}_{96}Cm$

Nuclear fission and Nuclear fusion Reactions :

NUCLEAR FISSION REACTIONS :-

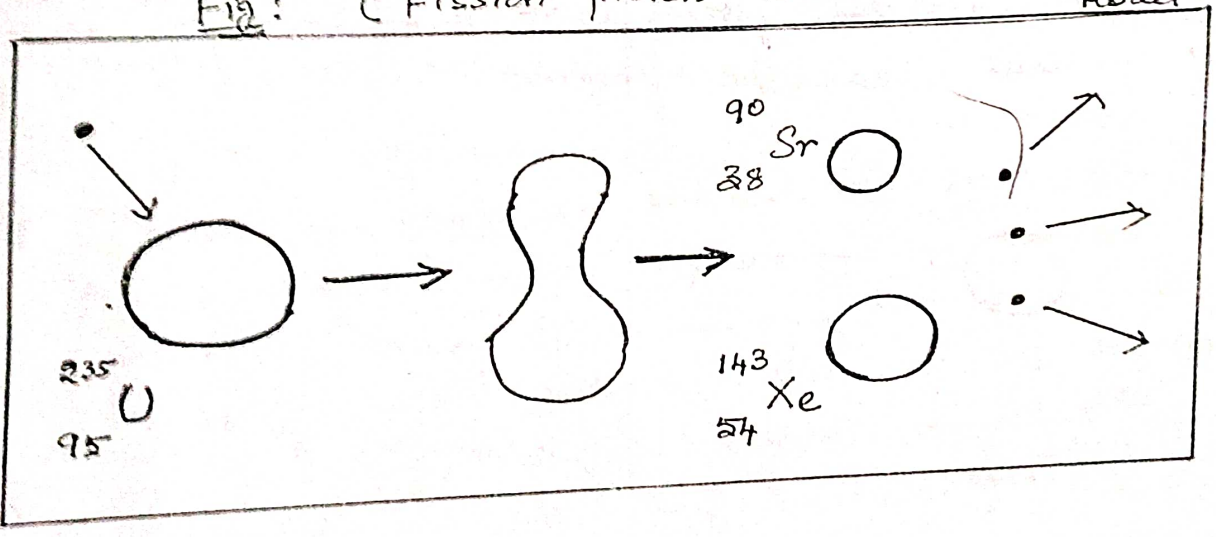
A nuclear fission is the splitting of a heavy nucleus (mass > 200) into smaller nuclei of intermediate mass. One (or more) neutrons are also formed in fission. The fission releases a large amount of energy.

A typical nuclear fission is the splitting of U-235

$$^{235}_{92}U + ^{1}_{0}n \longrightarrow ^{143}_{54}Xe + ^{90}_{38}Sr + 3\,^{1}_{0}n + 200\,MeV.$$

This fission is achieved by bombarding U-235 nuclei with thermal neutrons. (Thermal neutrons are slow neutrons, whose speed is comparable to that of gas molecules at room temperature. A nuclear fission is denoted in Figure given below; The following figure explains the fission process based on the liquid drop model of the nucleus.

Fig: (Fission process based on the liquid drop Model.



Theory of Nuclear fission :-

The theory of Nuclear fission can be explained by liquid drop model of nucleus proposed by Bohr and Wheeler. This model involves

the following steps :-

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

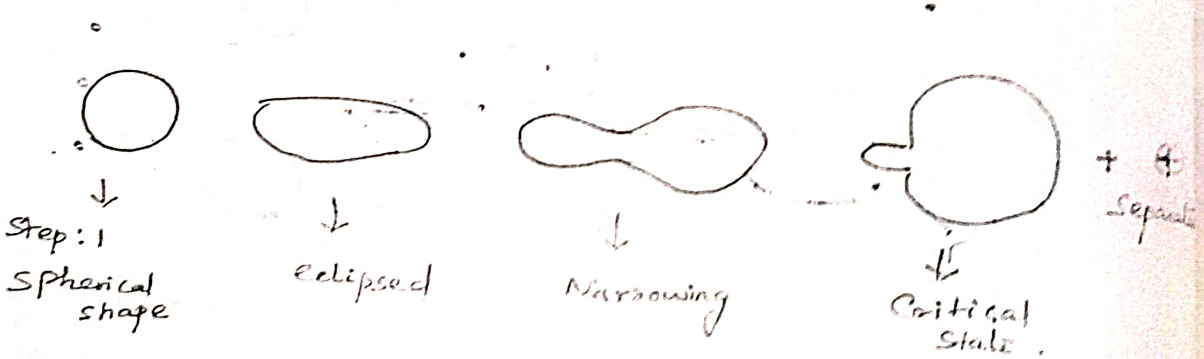
(Thermal neutron) 0.025 MeV

Compound Nucleus (higher energy)

Step: 1 When a nucleus undergoes fission by absorbing the nucleus combine with incident neutron to form a compound nucleus, which is highly energy, the compound nucleus regains its spherical shape by internal force.

Step: 2 Now the restoring force of nucleus, decreases due to short range inter nuclear forces. A constriction is related when oscillations becomes to violent the eclipsed narrows to dumb bell shape.

Step: 3 If the oscillations becomes more violent then the system finally breaks at the neck into the major portion due to coulombic repulsion. The above mechanism fission based on liquid drop model of nucleus can be represented as follows:



Characteristics of Nuclear fission :-

① Nuclear fission is excoergic, it release a large amount of energy - thermal, kinetic and

Hence, the binding energy per nucleon for the reactants is less than the sum of the binding energies for ^{95}Sr and ^{138}Xe. This implies a release of energy. The magnitude of the free energy released can be calculated from the binding energies.

Nucleus	Binding Energy ($\times 10^{-10}$ J)
^{235}U	2.68
^{95}Sr	1.22
^{138}Xe	1.93

The binding energies of the products $= 3.15 \times 10^{-10}$ J

The binding energies of the reactants $= 2.68 \times 10^{-10}$ J.

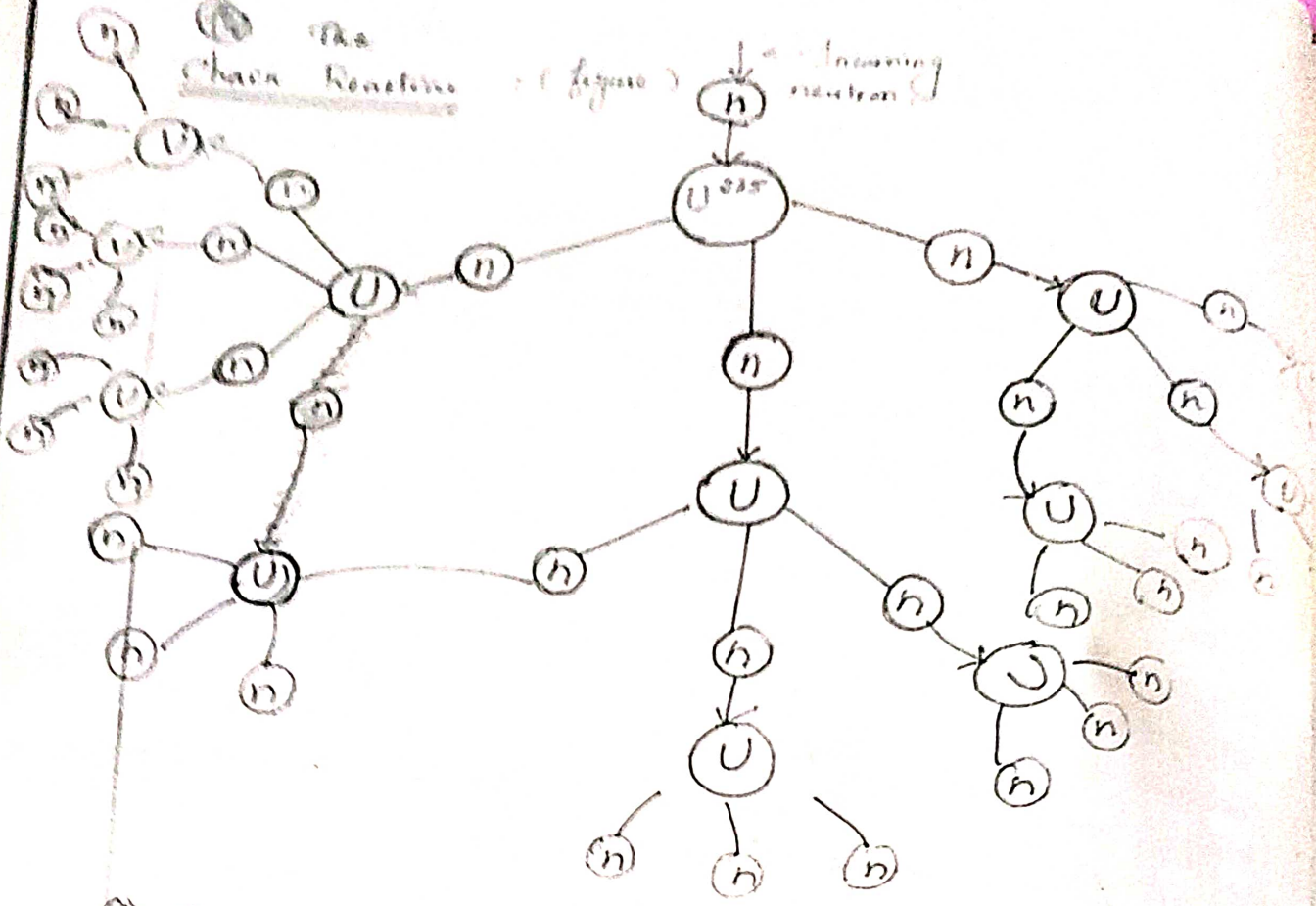
∴ Difference in binding energies $= 3.3 \times 10^{-11}$ J.

Thus, 3.3×10^{-11} J of energy is released when one uranium nucleus undergoes fission. For 1 mole of uranium, the energy released is $(3.3 \times 10^{-11}) \times$ Avagadro Constant $=$ $(3.3 \times 10^{-11}\text{ J})\ 6.02585 \times 10^{23} = 19.9 \times 10^{12}$ J.

This is an extremely exothermic process, infact, much larger than the energy released when one ton of coal undergoes combustion (8×10^7 J). Therefore, nuclear fission is a source of large energy.

(3) The fission of uranium-235 is a chain reaction. When one uranium nucleus is split by a neutron, three neutrons are formed. These three neutrons would in turn split three more uranium nuclei, producing nine neutrons, and so on. Therefore, once fission is excitated, it would continue by itself. The fission is thus self-sustaining. This chain reaction renders fission explosive, liberating a tremendous amount of kinetic and thermal energies to the surrounding. This chain reaction explained in the following figure:-

(4) The Chain Reaction : (figure)



(5) The products formed in the fission are a complex mixture. The equation given for fission indicates only the two products are formed in major proportion. In addition to these two nuclei, about 160 isotopes of about 40 elements have been identified in the fission product. Many of these products are radioactive and therefore, hazardous to handle. The products are formed in different quantities, some in large and others in small quantities. This fact is denoted by a graph called the fission yield curve. This is a plot of the relative yields of the products versus their mass number as shown in the following figure

Fig.: Fission yield curve.

(2) This fission would be shown in diagram only if sufficient uranium-235 is present in the sample to capture all the neutrons formed. Otherwise, the neutrons will escape from the sample and it does proceed with slow rates. The minimum mass of uranium-235 required for self-sustaining chain fission is called the critical mass. If the mass of uranium-235 is critical (as above mentioned, then most of the neutrons generated will be captured by uranium-235 maintaining a chain reaction.

(3) Different types of fission of the same nucleus (U-235) producing different products are possible. How exactly the nucleus splits depends on the energy acquired by the fissile nucleus. Other than the type already cited, three more common fission reactions of U-235 are,

$$^{235}_{92}U + {}^{1}_{0}n \longrightarrow {}^{144}_{56}Ba + {}^{90}_{36}Kr + 2\,{}^{1}_{0}n$$

$$^{235}_{92}U + {}^{1}_{0}n \longrightarrow {}^{138}_{53}I + {}^{95}_{39}Y + 3\,{}^{1}_{0}n$$

$$^{235}_{92}U + {}^{1}_{0}n \longrightarrow {}^{140}_{55}Cs + {}^{92}_{37}Rb + 4\,{}^{1}_{0}n.$$

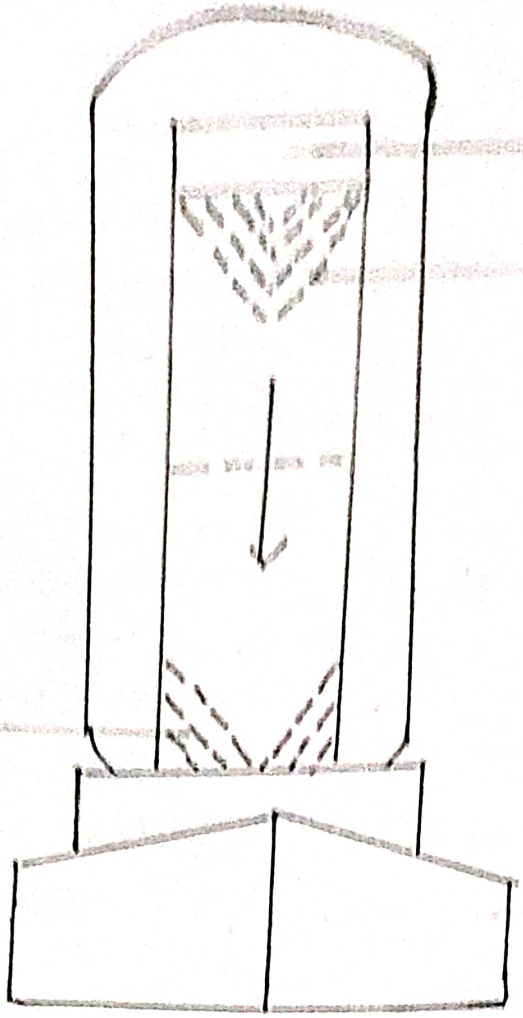
[illegible] the same reason, we have

Atomic bomb :

An atomic bomb is a device which releases an enormous amount of energy in a few seconds by nuclear fission. A neutron first [illegible] U-235 [illegible] subcritical segments in the bomb. These segments are forced into critical mass by using a conventional explosive such as trinitrotoluene. Then, neutrons released from a source of the bomb trigger chain fission leading to explosion. The large kinetic energy of fission fragments, [illegible] thermal energy burns the materials, and the nuclear radiation harm living beings.

On 6th August, 1945 an atomic bomb nicknamed "Little Boy" was dropped on Hiroshima, Japan; it contained U-235 fuel. On 9th August, 1945, a bomb containing Pu-239 nicknamed "Fat Man", was dropped on Nagasaki, another Japanese town. These bombs extensively damaged the two towns and killed several thousand persons. The world had not seen until then destruction of such speed and magnitude.

In a typical atomic bomb, two subcritical portions of a fissionable material are kept at the two sections of a tube, shown in the following figure. One portion is driven into the other to form a supercritical mass by an ordinary chemical explosive such as TNT (trinitrotoluene). This leads to an explosion. Enormous heat energy and also several deadly radionuclides are released in such an explosion. The radioactive dust and debris formed in a nuclear explosion are called the fallout.



*** Application
1) The nuclear fission can be utilised peacefully and constructive source of energy in nuclear reactors & power plants.
2) The nuclear fission can be utilised for destructive weapon atombomb.

Fig 1 Schematic representation of an atombomb.

Applications of Nuclear fission

NUCLEAR FUSION :-

The reaction of isotopes of two small nuclei to form a heavier, stable nucleus is called nuclear fusion. For example, a deuteron and a triton nuclei can be fused to produce a helium nucleus.

$$ {}_1^2H + {}_1^3H \longrightarrow {}_2^4He + {}_0^1n + 17.6\ MeV. $$

Problems Performing ~~Characteristics~~ of Nuclear fusion:-

① The production of the very high temperature required for fusion in the laboratory is extremely difficult and expensive.

② Even if such a temperature is produced, no reaction vessel can withstand the heat associated with the high temperature. "Holding" the plasma

(i.e. radius of the order 0.1 mm)

in space with magnetic fields to effect fusion is being experimented. Therefore, successful nuclear fusions have not yet been performed so far in any laboratory.

Characteristics of Nuclear fusion:-

① When the two nuclei to be fused are brought together, they experience a very large coulombic repulsion (potential barrier). This repulsion of barrier can be overcome only at a very high temperature, of the order of millions of degrees. Therefore, nuclear fusion reactions can be effected only at very high temperatures. Because of this, these reactions are called Thermo Nuclear reactions.

② A nuclear fusion is highly exoergic; it releases a tremendous amount of energy consequent to the conversion of mass into energy.

③ Nuclear fusions are possible only with light nuclei. With heavy nuclei, the high potential barrier for the reaction cannot be overcome. In addition, no stable product could be formed by fusing large nuclei

Some Nuclear Reactions along with their Energy released is given below;

$$_1H_1 + {}_1H^2 \longrightarrow 2\,He^3 + \gamma + 5.5\,MeV$$

$$_1H^2 + {}_1H^1 \longrightarrow 2\,He^3 + \gamma + 3.2\,MeV.$$

$$_1H^3 + {}_1H^1 \longrightarrow 2\,He^4 + \gamma + 19.7\,MeV.$$

$$_1H^3 + {}_1H^2 \longrightarrow 2\,He^4 + {}_0n^1 + 17.6\,MeV.$$

$_3Li^6 + {}_1H^2 \longrightarrow {}_2He^4 + {}_2He^4 + 22.4\ MeV.$

$_3Li^7 + {}_1H^1 \longrightarrow {}_2He^4 + {}_2He^4 + 17.3\ MeV$

The nuclear fusion reactions not only require very high temperatures but also suitable Striking device to start their initiation reaction.

Temperature Necessary for fusion :-

The fusion process require a temp of the order of 10^8, such high temperatures are developed during the explosion of atom bomb, and it is utilised initial energy to a nuclear fusion reaction. In this high the atoms are fully ionised and the ions and free electrons moving very rapidly and independent. (The mixture is electrically neutral and the whole state is called "plasma stable", which is a sort of second gaseous state.

Energy released in fusion :-

In Nuclear fusion, the mass of a product nucleus is less than the sum of masses of reacting nuclei. The difference between the masses of nuclei of reacting and the product is converted into energy.

According to Einstein equation

$$E = mc^2.$$

Ex: $_1H^2 + {}_1H^2 \longrightarrow 2\ He^4.$

The difference in mass 0.0255 amu is Converted into energy. The energy released in fusion is Nuclear bomb.

Nuclear fusion reactions in Stars (Sun) (i.e)

Source of a Stellar energy:

It is estimated that sun is releasing out energy equally in all possible directions at the rate of 3.7×10^{33} ergs / sec. The energy production in stars occur throughout overall hydrogen to helium nuclear fusion reaction

$$4\,{}_1H^1 \longrightarrow {}_2He^4.$$

This reaction occur in two different ways known as

(1) Carbon - Nitrogen cycle
(2) Proton - Proton chain Reaction.

Carbon Nitrogen - Cycle:

(Write the Notes which is given under Thermo Nuclear Reaction Page no:) (52)

Proton - Proton chain :-

(Write the Notes under given in Thermonuclear rexn (Page no: ___).

Applications of Nuclear fusion Reactions :-

* As it is very difficult to Control the Nuclear fusion

* The Nuclear fusion phenomenon give rise to the formation of hydrogen Bomb and Cobalt bomb :-

HYDROGEN BOMB :- (Note see the Notes which is given in last page no: 64).

Direct Reactions :-

A direct reaction is one which occurs without the formation of a compound nucleus. The time during which the incident particle interacts with the target nucleus is very much shorter than the life of a corresponding compound nucleus. Formation of compound nucleus is more likely at low energies whereas the direct reaction mechanism will prevail at higher energies.

The term direct reaction is used for a variety of nuclear processes including inelastic nuclear collisions, stripping and its inverse, the pick up reaction.

Stripping Reactions : The term stripping is used for a type of direct reaction in which the incoming compound particle splits into two fragments, one of which absorbed by the target nucleus and the other continues more (or) less undisturbed. In this type of reaction target nucleus captures one (or) two, sometimes three nucleons from the incident particle without the formation of a compound nucleus as an intermediate stage. The remaining portion of the projectile is usually proton, neutron (or) deuteron. Stripping reactions of several types

(e.g) (d, p), (d, n), (t, p), (t, d) and (α, p)

are known to occur at high particles energies with many different nuclei.

Ex :- (d, p) reaction.

Reactions of this type are quite common, and the product is always an isotope of the target element with mass number one unit higher.)

$$_{6}C^{13} + _{0}n^{1} \longrightarrow (_{6}C^{14})^{*} \longrightarrow _{6}C^{13} + _{0}n^{1}$$

$$_{83}Bi^{209} + _{0}n^{1} \longrightarrow (_{83}Bi^{210})^{*} \longrightarrow _{82}Pb^{206} + _{2}He^{4}$$

In pick up reaction the incident particles remains in the nucleus from the target nucleus. Reactions of this type are (P,α), (P,t), (P, He^3).

(Also add the Notes which is given in the Page no: 6 of the same unit).

Photo Nuclear Reactions :-

The excitation of a nucleus leading to its disintegration may be brought about not only by high energy particles, charged or otherwise, but also by the capture of high energy photons. Reactions of the latter type are known as photonuclear reactions which are briefly considered here.

Sources of High energy Photons :

(1) High energy photons are obtained by slowing down electrons accelerated to 10–100 MeV by tungsten or other targets.

(2) Certain radiative capture nuclear reactions lead to the emission of high energy photons.

e.g :-

^{7}Li (P, γ) ^{8}He ; $E_{\gamma} = 17.6$ MeV

^{3}H (P, γ) ^{4}He ; $E_{\gamma} = 19.8$ MeV.

(3) Annihilation gammas are obtainable from thick targets bombarded by high energy electrons which

lead to electron - positron pair formation and the pair on annihilation yield two γ photons each of 0.51 MeV energy

This is the first time the reaction studied by Cockroft and Walton in 1932 which provided that first experimental evidence of Einstein's equation $E = mc^2$. They were awarded the nobel prize in Physics in 1951

The mass loss in the reaction is 0.0186u as shown below,

$$^7Li + {}^1H \longrightarrow 2\ {}^4He$$

Mass $\quad 7.016004 + 1.007825 \rightarrow 2 \times 4.002603\,u.$

Mass loss $\quad \Delta m = -0.018623\,u.$

$\therefore$ Energy release $= \Delta m \cdot 931\,MeV = 17.34\,MeV$ (Theory)

$= 17.09\,MeV$ (observed)

The two helium atoms produced had each a kinetic energy of just 8.5 MeV, providing thus an excellant experimental verification of Einstein's mass energy formula of 1905.

TYPES OF PHOTONUCLEAR REACTIONS :-

Principal types of photonuclear reactions are (i) (γ, γ), i.e., excitation of the nucleus followed by its deexcitation by radiation emission. These are similar to (n, n') & (p, p') reactions

Ex: (γ, γ').

$^{115}In\ (\gamma, \gamma')\ ^{115}In$.

(2) (γ, p) (γ, n) and $(\gamma, 2n)$ reactions: In the excited nucleus, the energy is concentrated on a proton or a neutron and if the value exceeds the separation energy (~ 8 MeV) that nucleon is emitted. Though the Coulomb barrier may be expected to hinder (γ, p) reaction, in reality $\sigma(\gamma, p)$ is found to be greater than $\sigma(\gamma, n)$ (σ = Nuclear cross section). This may be due to a direct transfer of the photon energy to a proton, before being shared by other nucleons.

(3) (γ, α) reactions:

Ex:

(1) $^{51}V(\gamma, \alpha)^{47}Sc$; (2) $^{16}O(\gamma, \alpha)^{12}C$.

(4) (γ, n) reactions: (i-e) Photon capture followed by multiple evaporation of nucleons.

Forexample :-

(1) $^{12}C(\gamma, 3\alpha)$; (2) $^{16}O(\gamma, 4\alpha)$;

(3) $^{19}F(\gamma, 2n)^{17}F$; (4) $^{24}Mg(\gamma, \alpha pn)^{18}F$;

(5) $^{75}As(\gamma, \alpha p 2n)^{68}Zn$; (6) $^{107}Ag(\gamma, {}^{8}Li)^{99}Ru$.

(5) Fragmentation: Some nuclei on bombardment with high energy photons have led to their fragmentation into several nuclei of similar masses.

Some special Features of Photonuclear Reactions:-

Following are some special features.

(1) Photonuclear reactions of the (γ, n) type have been extensively studied on nearly all elements. A careful measurement of the photon threshold

gives the binding energy of the last neutron in a nucleus.

(2) The (γ, n) reactions yield monoenergetic neutrons

(3) The resonance widths, (i.e) the Γ at half-height in some cases are abnormally large; often the order of a few MeV. This is referred to as giant resonance. In other words, it means the cross section remains at the peak value over a wide range of energy of incident photons. The following figure shows the variation of σ for the emission of photoneutrons from ^{181}Ta by photons over the range (energy) 11–18 MeV.

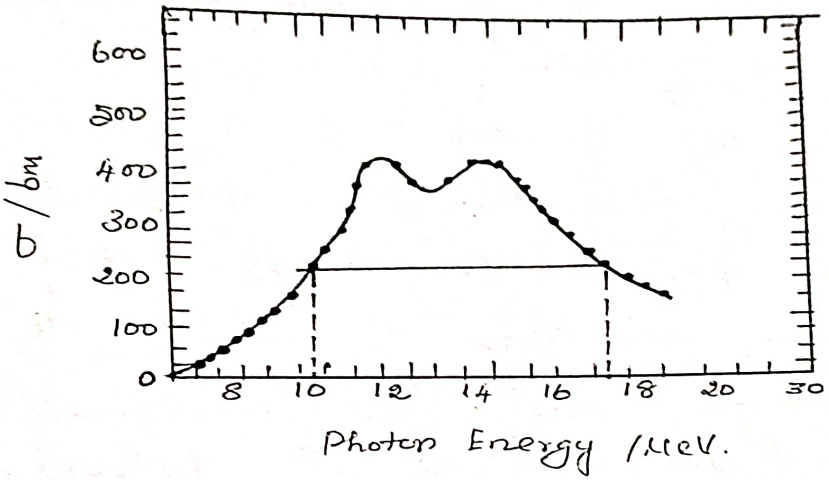


Fig: High energy (γ, n) photonuclear reaction on ^{181}Ta showing 'giant resonance'.

THERMONUCLEAR REACTIONS :-

It was pointed out earlier that the mass loss resulting in the fusion of four Protons into a helium nucleus, going on perpetually

In the sun and the star is 0.028 MeV, corresponding to 26.7 MeV per He nucleus formed. Our sun radiates around 3.8×10^{20} MJ of energy per second and this is indeed a very large amount of energy! In the process, the sun suffers a mass loss at the rate of 4.2×10^{6} tonnes per second. This staggering mass loss of the sun, however corresponds to just 10^{-5} per cent per million years of its present mass ($\sim 10^{27}$ tonnes). There are however formidable difficulties to be overcome before this process can be reproduced on the earth and the energy harnessed for practical purposes. (b)

Ex: The $4H \longrightarrow He$ Fusion Reaction in the Sun and Stars:

In the interior of the sun and stars due to enormous gravitational pressures such high temperatures prevail permitting several types of thermonuclear reactions of which the $4\,^1H \rightarrow {}^4He$, is the dominant one. The mechanism most likely for the fusion reaction is believed to be either the proton–proton chain (or) the carbon–nitrogen cycle, outlined below;

(a) The Proton - Proton Chain:-

$$[\,^1H + {}^1H \longrightarrow {}^2H + \beta^+ + \nu : \quad E = 1.42\,MeV] \times 2 \quad \text{—ⓐ}$$

$$[\,^1H + {}^2H \longrightarrow {}^3He + \gamma ; \quad E = 5.4\,MeV] \times 2 \quad \text{—ⓑ}$$

$$2\,{}^3He + {}^3He \longrightarrow {}^4He + 2\,{}^1H ; \quad E = 12.8\,MeV \quad \text{—ⓒ}$$

Reaction (a) is the slowest with a mean life of 7.15×10^9 years.

(b) The Carbon - Nitrogen Cycle*

$$^{12}C + {}^1H \longrightarrow {}^{13}N + \gamma \quad \text{—— (d)}$$

$$^{13}N \longrightarrow {}^{13}C + \beta^+ + \nu \quad \text{—— (e)}$$

$$^{13}C + {}^1H \longrightarrow {}^{14}N + \gamma \quad \text{—— (f)}$$

$$^{14}N + {}^1H \longrightarrow {}^{15}O + \gamma \quad \text{—— (g)}$$

$$^{15}O \longrightarrow {}^{15}N + \beta^+ + \nu \quad \text{—— (h).}$$

$$^{15}N + {}^1H \longrightarrow {}^{12}C + {}^4He \quad \text{—— (i).}$$

Here, reaction (g) is the slowest with a mean life of 3.2×10^8 years.

In addition, other mechanisms have also been suggested involving nuclei as Li, Be, B and F, but these reactions are all too fast, and incompatible with the age of the Sun which is around 5×10^9 y and having about much to go.

Ninetynine percent of the solar matter is known to consist of hydrogen and helium; other elements, mostly light constitute the rest of the matter. Hence the P-P chain is considered as the more likely mechanism of solar energy, while in the stars which are far more luminous and hotter than the Sun, the C-N cycle may be the probable mechanism.

The net reaction of any mechanism in the fusion of four protons into an alpha particle.

$$4\,{}^{1}H \longrightarrow {}^{4}He + 2\beta^{+} + 2\nu + \gamma \;;\; \Delta m = 0.0267 = 26.7\,MeV.$$

As the neutrinos carry away 0.5 MeV, the net energy released in 26.2 MeV per He nucleus formed The synthesis of other elements follows the formation of helium.

Thermonuclear Reactions on the Earth:

Other thermonuclear reactions are possible with the heavier isotopes of hydrogen (^{2}H and ^{3}H). Of these, deuterium (D) constituting one part in about 6666 parts of hydrogen, is plentifully available, while tritium (T) has to be generated by the $^{6}Li(n,\alpha)T$ reaction, requiring ^{6}Li in Large amounts to be obtained by isotopic separation from natural lithium which is 92.6 Per cent ^{7}Li and 7.4% ^{6}Li. The reaction involving the different hydrogen isotopes are as follows;

$$H + H \longrightarrow D + \beta^{+} + \nu \;;\; E = 1.42\,MeV \quad —(j)$$

$$H + D \longrightarrow {}^{3}He \;;\; E = 5.40\,MeV \quad —(k)$$

$$H + T \longrightarrow {}^{4}He \;;\; E = 19.83\,MeV \quad —(l)$$

$$D + D \longrightarrow H + T \;;\; E = 4.00\,MeV \quad —(m)$$

$$\longrightarrow {}^{3}He + n \;;\; E = 3.26\,MeV \quad —(n)$$

$$\longrightarrow {}^{4}He \;;\; E = 28.83\,MeV \quad —(o)$$

$$D + T \longrightarrow {}^{4}He + n \;;\; E = 17.59\,MeV \quad —(p)$$

$$T + T \longrightarrow {}^{4}He + 2n \;;\; E = 11.17\,MeV \quad —(q).$$

Stellar Energy :-

Stars produce enormous amounts of heat and light energies. Nuclear fusions are the source for such energies. The surface of the stars are extremely hot

For Example: the temperature on the sun; a star is about 15 million degrees kelvin. This temperature is sufficient for nuclear fusion. A cycle of fusion reactions is proposed to explain the production of energy in the sun. The net effect of this cycle is the fusion of four protons into one alpha particle. Two positrons are emitted in this cycle.

Theory :-

Bethe proposed a theory that is universally acceptable, this theory is based on two sets of reactions.

The first set of reaction is called Carbon-Carbon cycle in which carbon acts as a catalyst in facilitating the combination of 4-protons to form the He nucleus.

The second is referred as Proton-Proton Chain, since its first step involves the combination of 2 protons.

Also many other nuclear reactions accompanied by the release of energy by utilisation of heavier atoms that may be done probably cooler and hotter stars.

Carbon- Nitrogen Cycle :-

H Bethe suggested a sequence of reactions to explain the origin of sun's energy. This reaction sequence is called the Carbon-nitrogen cycle.

(i) $${}_6C^{12} + {}_1H^1 \longrightarrow {}_7N^{13} + \gamma \text{ (energy)}$$

In this cycle first the hydrogen interacts with carbon nucleus with a release of fusion energy.

(ii) The product ${}_7N^{13}$ is radioactive, it emit a positron ${}_1e^0$ with decay as

$${}_7N^{13} \longrightarrow {}_6C^{13} + (+1e^0) + \nu.$$

positron e^+

(iii) The stable ${}_6C^{13}$ is react with another proton more energy is liberated by this proton.

$${}_6C^{13} + {}_1H^1 \longrightarrow {}_7N^{14} + \gamma \rightarrow \text{energy}.$$

(iv) Also $${}_7N^{14} + {}_1H^1 \longrightarrow {}_8O^{15} + \gamma \rightarrow \text{energy}.$$

(v) ${}_8O^{15}$ is a positive β emitter with decay life time as 2.05 min which form the product as,

$${}_8O^{15} \longrightarrow {}_7N^{15} + e^+ + \nu.$$

(vi) Finally ${}_7N^{15}$ is interacts with fourth proton,

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

So the overall fusion reaction gives enough energy to power the solar system.

$$4\,{}_1^1H \longrightarrow {}_2^4He + 2\,e^+ + \text{Energy}.$$

years ago abruptly. The universe started expanding and within about 100 s of the event, most of the free neutrons decayed into protons; and hydrogen, the first element was thus created.

$$n_{free} \longrightarrow p(H) + \beta^- + \bar{\nu}, \quad \Delta E = 0.782\ MeV.$$

The neutron decay must have been completed in about an hour's time. The primordial matter was thus a mixture of n, p and e, known as the ylem. This was prior to the formation of the galaxies and the stars.

Though the remaining stages, gravitational contraction continued uninterruptedly, resulting in a very rapid rise in the density at each stage. The temperature, however, fell to a minimum in Stage II after which it rose rapidly, each stage being characterized by a constant temperature determined by the major reaction of the stage.

Stage : II Hydrogen Burning :-

(1) Major Reaction : The formation of helium.

$$4H \longrightarrow He + 2\beta^+ + 2\nu + \gamma, \quad \Delta E = 26.7\ MeV.$$

(2) Other Reactions : Successive p and n captures resulting in the formation of light nuclei as ^2H, ^7Li, ^9Be, ^{10}B and ^{11}B.

Stage : III Helium Burning :-

(1) Successive (α, γ) reactions resulting in the formation of poly α-nuclide as,

Even-Z : ^{12}C, ^{16}O, ^{20}Ne, ^{24}Mg, ^{28}Si, ^{32}S, ^{36}Ar and ^{40}Ca

Odd-Z : ^{10}B, ^{14}N (n, γ), ^{15}N, ^{19}F, ^{23}Na, ^{27}Al, ^{31}P, ^{35}Cl and ^{39}K.

(a) Either via $^{20}Ne - {}^{23}Na$ cycle (mainly on

$$^{20}Ne \xrightarrow{p} {}^{21}Na \xrightarrow{\beta^+} {}^{21}Ne \xrightarrow{p} {}^{22}Ne$$

$$\downarrow \beta^+$$

$$^{23}Na + {}^{4}He \xleftarrow{p} {}^{23}Na \xleftarrow{p} {}^{22}Ne$$

Catalyst reformed.

(b) (or) via $^{12}C - {}^{13}N$ cycle (mainly on red giant stars)

$$^{12}C \xrightarrow{p} {}^{13}N \xrightarrow{\beta^+} {}^{13}C \xrightarrow{p} {}^{14}N \xrightarrow{p}$$

$$^{4}He + {}^{13}C \xleftarrow{p} {}^{14}N \xleftarrow{\beta^+} {}^{15}O$$

Catalyst reformed.

Stage iv: Carbon Burning:

(1) Major Reaction:-

$$^{12}C + {}^{12}C \longrightarrow {}^{20}Ne + \alpha$$

$$\longrightarrow {}^{23}Na + p$$

$$\longrightarrow {}^{23}Mg + n$$

$$\longrightarrow {}^{24}Mg + \gamma.$$

The α, p, n and γ lead to numerous other reactions.

When T rose to 10^9k, Silicon was formed

$$^{12}C + {}^{16}O \longrightarrow {}^{28}Si + \gamma$$

The ^{28}Si accumulated being stable against all nuclear reactions at this temperature (2×10^9k).

Stage: V Silicon Burning:

As the temperature further rose to 3.4×10^9k, the black body emission Consisted of γ radiation and Si began to burn as a photonuclear reaction

$$^{28}Si(\gamma, \alpha)^{24}Mg$$

and

$$^{28}Si + {}^{28}Si \longrightarrow {}^{56}Ni \xrightarrow{\beta^+} {}^{56}Co \xrightarrow{\beta^+} {}^{56}Fe.$$

Thus were formed the iron group elements of Maximum stability close on 65% of Si was consumed in an extremely short period.

A Summary of the stagewise evolution of elements are given in the following table:

Stage	O	B	[illegible]	[illegible]	[illegible]	[illegible]
Density $g\,cm^{-3}$	10^{-7}	7×10^{-7}	10^{2}	10^{5}	10^{8}	10^{9}
Temperature K	10^{10}	1.3×10^{9}	$5-40\times10^{6}$	1.2×10^{8}	1.2×10^{9}	[illegible]
Main process	None	n-decays	H-burns	He-burns	C-burns	Si-burn
Heaviest elements formed	n	H	He, B	C, K, Ca	Si, Fe, Co, Ni	Bi, U

TOPIC UNDER NUCLEAR FUSION - APPLICATION - HYDROGEN BOMB

The operation of a hydrogen bomb involves the sudden release of enormous energy by nuclear fusion. The heat + kinetic energy is released in fusion destroy the place where such a bomb is exploded. The temperature required for fusion in this bomb is initially produced by a nuclear fission. The fission rxns function as a fuse to produce a temperature sufficient to start the fusion reaction. Because of the tremendous heat produced in a hydrogen bomb, it is called "thermonuclear bomb". The first thermonuclear bomb was tested in 1952 by the U.S.A.

The actual reaction used in a hydrogen bomb is secret. Some possible fusion reactions involved in such bomb are as follows;

$${}_{1}^{2}H + {}_{1}^{3}H \longrightarrow {}_{2}^{4}He + {}_{0}^{1}n$$

$${}_{1}^{2}H + {}_{1}^{3}H \longrightarrow {}_{2}^{4}He$$

$${}_{1}^{3}H + {}_{0}^{1}n \longrightarrow {}_{2}^{4}He + {}_{-1}^{0}\beta$$

$${}_{3}^{7}Li + {}_{1}^{1}H \longrightarrow {}_{2}^{4}He$$

present in H_2O. This is the reason why D_2O is used as

9.18 APPLICATION OF RADIOISOTOPES IN MEDICINE, INDUSTRY, AGRICULTURE, REACTION PATHWAYS, AGE OF MINERALS, RADIOCARBON DATING ETC.

In modern science radioisotopes have wide applicability in various discipline. Table 9.10 records several radioisotopes with their half lives.

9.18.1 Application of radioisotopes in the field of chemistry

I. **Isotopic dilution analysis :** This is a popular technique now-a-days in various analysis. This method is employed in those cases where the substance under consideration to be quantitatively estimated from a mixture of substances cannot be isolated.

The basic principle adopted here is that an inactive sample x is to be determined from a mixture. To this mixture an active tracer isotope x^* is mixed with the mixture. Initially the activity of the tracer is determined as per gram per minute. After the lapse of some time the tracer will form an uniform additive mixture, the activity of the additive mixture xx^* gram per minute is determined. Naturally this activity will be decreased compared to that first due to dilution effect. Here a condition is to be maintained that the half-life of the should be large so that during measurement the specific activity will not change appre

Let W_x is the amount of inactive sample (in gram) present in the sample and W_x^* amount (in gram) of the tracer isotope, then we can write :

$$\frac{\text{specific activity of additive i.e. } x^*}{\text{specific activity of additive mixture i.e. } xx^*} = \frac{W_x^*}{W_x + W_x^*}$$

Thus knowing the value of W_x^* and measuring the specific activities of x^* and xx^*, the a of W_x can be obtained.

Isotopic dilution analysis is one of the important tool in several biochemical aspects conventional routine analysis are not applicable. This method has been useful in,

(a) Biological studies such as estimation of a particular amino acid in a mixture of se

(b) Determination of blood volume in an animal or human body by using radioactive i.e. ^{59}Fe or radioactive sodium i.e. ^{24}Na. The procedure involves injecting a tracer or $^{24}(Na)$ compounds in a body of a donor subject and allowing sufficient time incorporation of the tracer to the circulating blood cells. A sample of blood withdrawn from the donor and its specific activity is determined per ml of blood. an aliquot of donor's blood are injected into the recipient subject whose blood vo is to be determined. After a suitable interval of time, a sample of blood from recipient is again collected and the specific activity is to be measured. From the e of dilution it is possible to calculate the total blood volume of the acceptor subj

One millilitre of a person's blood is collected and treated with tracer isotope ^{59}Fe. The activity of 0.1 ml of this blood sample is measured and the remaining is incorporated to a person's body whose blood volume is determined.

Let the activity of 0.1 ml of blood = a_i

then the activity of 0.9 ml of blood = $\frac{a_i \times 0.9}{0.1} = \alpha$(say)

After a certain interval of time whereby the injected tracer blood is homogeneo distributed throughout the blood volume and 1 ml of this blood is withdrawn an activity is measured.

Let the activity by 1 ml of the blood = a_f

and let the total blood volume = x ml

Thus final activity of the entire blood = xa_f

Then $\alpha = xa_f$

so that $x = \frac{\alpha}{a_f}$

Total blood volume can thus be determined and it is found that the total blood volume for an adult person is about 5-6 litres depending on the body weight. *Average blood volume is about 100 ml per kg of body weight of adult male and female.*

(c) Determination of the percentage of glycine in the products of protein hydrolysis by using ^{14}C isotope.

(d) This method is useful in the measurement of rare earth from the fission products. It is also used in the determination of geological ages.

8. Activation analysis : The determination of the quantity of an element by means of their induced radioactivity has been an established analytical method in recent years. The basic principle involves the determination of elemental constituents of a sample by measuring its radioactivity artificially produced through bombardment with high energy projectile. Then by comparing the radioactivity of a known amount of the elemental constituent subjected to the same irradiation of the same projectile,the unknown content of the elemental constituent is determined.

Neutron activation analysis is frequently used and this technique is highly efficient in those cases where the element concerned have high neutron capture cross-section. The sample to be analysed is irradiated with high thermal neutron flux from a reactor for a sufficiently long time to produce measurable amount of activity. The standard sample is then subjected to same procedure to produce the measurable activity. Then by comparing the radioactivity of the unknown and the standard sample, the amount of the unknown constituent can be determined from the following relation :

$$\frac{\text{Weight of the element say } X \text{ in the unknown sample}}{\text{Weight of the element } X \text{ in the standard sample}} = \frac{\text{Activity in the unknown sample}}{\text{Activity in the known standard sample}}$$

This method is suitable for analysis of microgram quantities of some elements (e.g. Na, P, Ca, Cr, Mn, Cu, Zn, As, Pt, Au etc.) with an accuracy of 10%. The feasibility of the process depends on the selective irradiation of a desired constituent in a mixture so that selective activity is produced for a particular constituent.

The method has been used :

(a) In the analysis of mixtures of rare-earth metals.

(b) Manganese content in tea leaves by $^{55}Mn(n,\gamma)^{56}Mn$ reaction.

(c) The determination of gallium in iron, copper in nickel and hafnium in zirconium.

(d) Chromium content in ruby laser by $^{50}Cr(n,\gamma)^{51}Cr$ reaction.

(e) For determination of trace amount of arsenic (0.1 to 1.0 ppm) in germanium, in biological sample like hair, nail etc. A non-radioactive ^{75}As converted to radioactive $^{76}As(t_{1/2} = 26.5h)$ by (n,γ) reaction. In the case of arsenic poisoning arsenic accumulates at the roots of hair and then distributes throughout the hair. In a particular case a strand of hair is collected from a suspected victim and activated with neutron, thereby ^{75}As is converted to ^{76}As which is beta active and the concentration of arsenic is much higher (e.g. 50-60 ppm) compared to that of normal hair which has 0.8 ppm. In this technique slow arsenic poisoning has been detected and this slow arsenic poisoning is related to the death of the great emperor Nepolean Bonaparte.

(f) In the estimation of trace amounts of Rb and Cs in rocks and meteorites.

(g) For analysis of jewels, stones, coins and in many archaeological specimens.

Merits of this method

(1) With the help of activation analysis accurate results are obtained in a ... concentrations which cannot be easily obtained by normal methods of analysis.

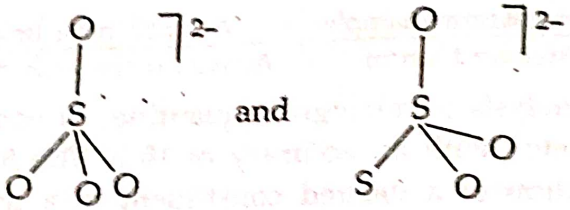
(2) The method enables impurities to be ascertained with an accuracy greater than ... per million.

Limitations of the process : For activation analysis to be useful, it is needless to ... that the radioisotopes formed due to neutron irradiation must have half life which ... too short or too long. Moreover the other element(s) present in the material under ... which may also be activated must not have similar half-life or similar type of ... activity as they will interfere with the actual measurement.

III. Radioactive Tracer Technique: Studies on Structure and Reaction Mechanism

Radioactive tracer techniques are valuable tools for investigations involving the ... of compounds, the nature of chemical linkage, the mechanism of chemical reactions and ... of chemical reactions etc.

Sulphate (SO_4^{2-}) and thiosulphate ($S_2O_3^{2-}$) ions are structurally similar both having ... geometry as depicted below :



Therefore $S_2O_3^{2-}$ is formed by the replacement of one oxygen atom of SO_4^{2-} by sulphur ... that the two sulphur atoms in thiosulphate is not identical—one sulphur is centrally linked ... three oxygen atoms and one sulphur atom. The nonequivalency of the two sulphur ... $S_2O_3^{2-}$ is verified in several ways.

If labelled sulphur[a] i.e. S^* is boiled with sulphite ion then active thiosulphate ion is ...

$$S^* + SO_3^{2-} \longrightarrow S^*SO_3^{2-}$$

The active thiosulphate ion on decomposition with acid in solution produces elemental ... and sulphite ion. If all the sulphur atoms in thiosulphate ion is identical then the activity ... be equally observed for elemental sulphur and sulphite ion. But actually the entire activity ... to elemental sulphur and no activity is observed in SO_3^{2-} ion. This proves the nonequ... nature of two sulphur atoms in $S_2O_3^{2-}$.

$$S^*SO_3^{2-} \xrightarrow{\text{acid}} S^* + SO_3^{2-}$$

---

a , the labelled S is ^{35}S and ordinary S is ^{32}S.

Active sodium thiosulphate $Na_2S^*SO_3$ is prepared by the action of iodine on a mixture of SO_3 and Na_2S^*.

$$Na_2S^* + I_2 + Na_2SO_3 \longrightarrow 2NaI + Na_2S^*SO_3$$

active thiosulphate is then used to form silver thiosulphate, $Ag_2S^*SO_3$ which is then mposed by boiling water to give silver sulphide and H_2SO_4.

$$Na_2S^*SO_3 + 2AgNO_3 \longrightarrow Ag_2S^*SO_3 + 2NaNO_3$$

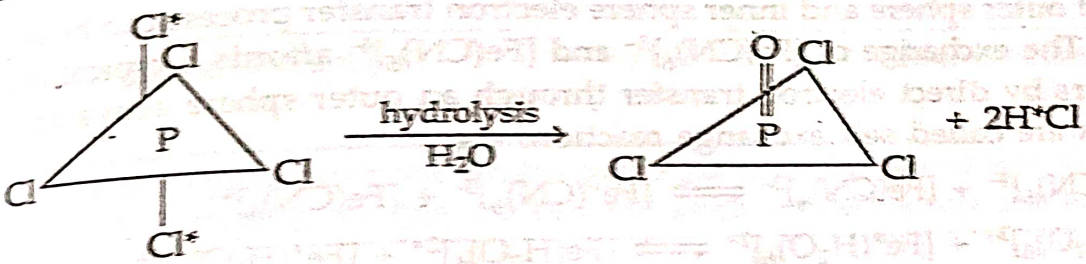
$$Ag_2S^*SO_3 + H_2O \longrightarrow Ag_2S^* + H_2SO_4$$

restingly all the activity goes to silver sulphide. If all the sulphur atoms were identical, then activity will be equally divided between silver sulphide and H_2SO_4.

We known that PCl_5 is an example of non-equivalent hybrid orbitals having TBP geometry . 3.2.6 and 3.2.8) with three equatorial i.e. relatively shorter bonds and two axial i.e. tively longer bonds. This indicates that all the chlonine atoms are not identical which is ported by the experimental facts that on hydrolysis of radioactive PCl_5, all the activity goes Cl and no activity was found to be in $POCl_3$.

$$PCl_3 + {}^*Cl_2 \longrightarrow PCl_3{}^*Cl_2 \xrightarrow{\text{hydrolysis}} POCl_3 + H^*Cl$$

is also supported from the structure of active PCl_5 as :



Radiocarbon i.e. ^{14}C has been widely used as a tracer in studying mechanisms involved in lation, polymerisation, catalytic cracking as well as many other ions of industrial importance.

Radioisotopes in reaction mechanism

The course of hydrolysis of ester can be established by using the r labelled with ^{18}O and the following two paths leading to the same product.

Path I $$R-C(=O)-OEt + H\overset{*}{O}H \longrightarrow R-C(=O)-\overset{*}{O}H + EtOH$$

Path II $$R-C(=O)-OEt + H\overset{*}{O}H \longrightarrow R-C(=O)-OH + Et\overset{*}{O}H$$

s been established that in majority of cases ^{18}O is associated with the acid and not with the hol suggesting that the hydrolytic behaviour of the ester will follow Path I.

When H_2O_2 reacts with strong oxidants i.e. PbO_2, $KMnO_4$, $K_2Cr_2O_7$ etc. and oxygen is duced.

$$PbO_2 + H_2O_2 \longrightarrow PbO + H_2O + O_2$$

It was a problem to establish whether O_2 comes from the oxidant or H_2O_2 or partly from both.

Path A.

Path B

Labelled ^{18}O is used to prepare $H_2O_2^*$. If the reaction followed path-A, then the activity will be distributed in water as well as in liberated oxygen. But mass spectrometric studies as well as activity measurement indicates that the sequence of the reaction will follow path-B i.e. all the oxygen comes from H_2O_2 leading to the establishment that O—O linkage is retained during the reaction.

Racemisation of tris-oxalato complexes of Co(III) and Cr(III) i.e. $M(C_2O_4)_3^{3-}$ complexes take place one ended dissociation process. It was established that all the twelve oxygen atoms in the complex undergo exchange with ^{18}O labelled H_2O but no detectable exchange noticed with $^*C_2O_4^{2-}$ in solution.

The mechanism of outer sphere and inner sphere electron transfer process can be established by isotopic labelling. The exchange of $[Fe(CN)_6]^{3-}$ and $[Fe(CN)_6]^{4-}$ affords a typical example of a process which occurs by direct electron transfer through an outer sphere activated complex. This type of reactions are called self exchange reactions e.g.

$$[Fe^*(CN)_6]^{4-} + [Fe(CN)_6]^{3-} \rightleftharpoons [Fe^*(CN)_6]^{3-} + [Fe(CN)_6]^{4-}$$

$$[Fe(H_2O)_6]^{3+} + [Fe^*(H_2O)_6]^{2+} \rightleftharpoons [Fe(H_2O)_6]^{2+} + [Fe^*(H_2O)_6]^{3+}$$

IV. Determination of solubility of a sparingly soluble salt : The determination of solubility of a sparingly soluble salt i.e. $PbSO_4$ was carried out by Hevesy and Paneth (1913). A known amount of radioactive ^{212}Pb as nitrate i.e. $^{212}Pb(NO_3)_2$ was mixed with known amount of ordinary $Pb(NO_3)_2$ to make a known volume of the mixed solution. After evaporating a certain volume of this known volume of the solution the activity of the residue was measured. This denoted the initial activity (a_i) of lead in the solution. The same volume of mixed solution is treated with H_2SO_4 whereby $^{212}PbSO_4$ and $PbSO_4$ were precipitated.

$$\underbrace{^{212}Pb(NO_3)_2 + Pb(NO_3)_2}_{\text{solution}} \xrightarrow{H_2SO_4} \underbrace{^{212}PbSO_4 + PbSO_4}_{\text{precipitate}}$$

After the precipitation the solution is filtered and the clear supernatant liquid was evaporated to dryness and the activity of the residue was determined in the same way as before. Let this activity = a_f

Suppose $a_i \propto x$ g Pb and $a_f \propto y$ g Pb

Let V = total volume of the solution and V_S = Volume of supernatant liquid.

Thus $y = \frac{xa_f}{a_i}$ g Pb in V_S volume of supernatant liquid. Therefore the total amount of lead dissolved in V volume of solution i.e.

$$W = \frac{V_{eq}}{V_{eq_1}} \times Pb$$

where knowing the value of W we can calculate the solubility of $PbCl_2$ as under

Radiometric Titrations : Radiometric titration is a quantitative analytical procedure using a reaction between an unknown and radioactive reagent or a radioactive substance and a stable reagent resulting in the formation of a radioactive compound easily separated from original radioactive substance by filtration or other standard analytical procedures. This type of titration developed by Langer in 1941. The principle of radiometric titration is based on the fact that the activity of the solution remains constant until the equivalent point is reached and the end point activity increases with the addition of the reagent. From the intercepts of the activity curves (Fig. 9.22) the end point will be determined.

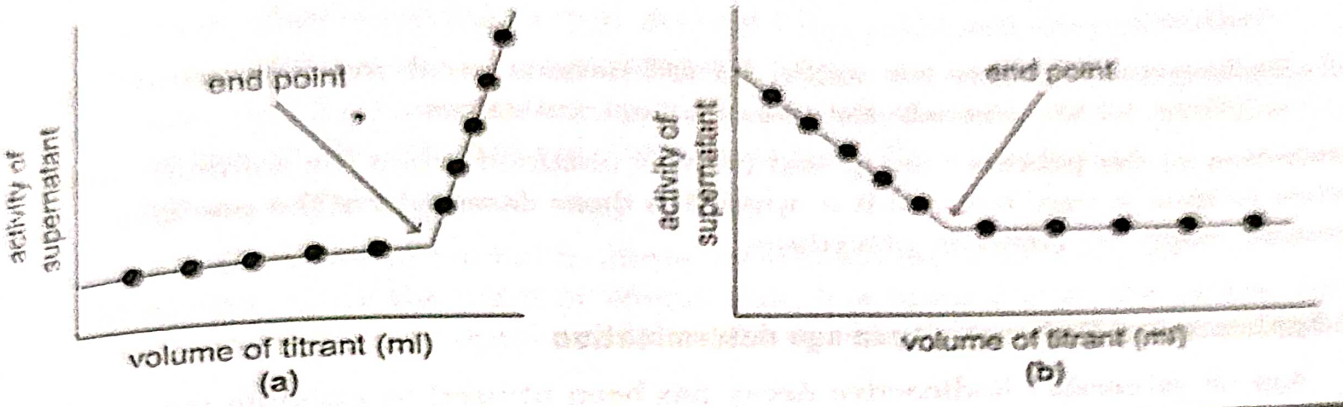


Figure 9.22 : Typical radiometric titration curves. (a) Rapid increase of activity at the end point. (b) Decreasing activity at the start with almost constant activity after end point.

The following examples of radiometric titrations justify the validity of the above curves.

(a) In the titration of Ag^+ with Cl^- ions labelled with ^{36}Cl, the solution remains inactive till the end point is reached as all the activity is removed as $Ag^{36}Cl$ precipitate. The end point is indicated by a sudden increase of activity (Fig. 9.22(a)) into the supernatant solution which contineously increasing thereafter. On the other hand if Ag^+ ions are labelled with ^{110}Ag, the solution remains active and the activity of the supernatant decreases gradually and at the end point corresponds to a constant minimum of activity (Fig. 9.22(b)). In both the cases the end point corresponds to a sharp inflection in the activity vs volume of titrant curve. It is necessary in every case, that the AgCl formed precipitates out without remaining colloidally suspended in solution.

(b) In another type of radiometric titration the indicator remains an insoluble solid till the end point is reached, the insoluble indicator gets soluble giving rise to a sharp increase in activity into the solution. As an example may be cited the complexometric titration of Ca^{2+} by EDTA using solid $^{110}AgIO_3$ as an indicator. The added EDTA removed all Ca^{2+} ions by complexation and end point is reached. It is only after the end point the EDTA reacts with $^{110}Ag^+$ to form the soluble Ag-EDTA complex, thereby giving a sharp hike in activity in solution phase shown in curve (a) of Fig. 9.22.

(c) In another variation of the titration radioactive ^{32}P is converted to soluble phosphate and added to Na_2HPO_4 solution whereby a standard $Na_2H^{*}PO_4$ solution is prepared. This solution is used to titrate Ba^{2+}, Pb^{2+}, Th^{4+}, Mg^{2+} and UO_2^{2+} solutions. After each addition of $Na_2H^{*}PO_4$ solution, a certain fraction of the clear supernatant or filtrate is sucked in the G.M. counter tube and the activity is measured. Before the end point the supernatant has no activity and the activity remains practically constant until the equivalence point is reached. But as soon as the equivalence point is reached, the activity of the supernatant gradually increases with increase in concentration of the titrant (Fig. 9.22(a)).

Utility of the titration

(a) These titrations are uneffected by changes in temperature, pH and other physical conditions.

(b) Radiometric titrations are useful for estimations involving coloured or highly turbid solutions which preclude the use of visual indicators.

Limitation of the process : Sharp end point is obtained when the solubility product of the precipitate formed is very low and it is applied is those cases where the precipitate formed can be separated easily by common procedure.

9.18.2 Application of Radioactivity in age determination

1. **Age of minerals :** Radioactive decay has been utilised to estimate the age of materi of geological and cosmological origin.

Let us consider a uranium containing rock formed many many years ago. The uranium present in the rock started to decay according to the natural radioactive disintegration series i.e. ^{238}U to ^{206}Pb. In this decay process the half lives of the intermediates are small compared to that of ^{238}U ($t_{1/2} = 4.5\times10^9$y) so that it is reasonable to assume that those uranium atoms that started decaying many many years ago must have been converted to the stable isotope of lead i.e. ^{206}Pb during this long period. The concentration of ^{238}U remaining after decay and ^{206}Pb formed during the decay process together made the original concentration of ^{238}U present at 'zero' time e. when the rock was solidified. Thus for equation (9.4) both N_0 and N are known and k can e obtained from the half-life of ^{238}U and so t i.e. age of the rock can be calculated.

Let us consider a sample of ^{238}U having $t_{1/2} = 4.5\times10^9$y was found to contain 11.9g of ^{238}U d 10.3g of ^{206}Pb. From these data we are able to calculate the age of the ore as :

$$k = \frac{0.693}{4.5\times10^9\text{y}} = 0.154\times10^{-9}\text{y}^{-1}$$

11.9g of ^{238}U = 0.05 mole of ^{238}U and 11.3g ^{206}Pb = 0.05 mole of ^{206}Pb.

Therefore the mole of ^{238}U originally present a zero time = 0.05 + 0.05 = 0.10 mole

so that t i.e. the age of the ore $= \frac{2.303 \log \frac{N_0}{N}}{k} = \frac{2.303 \log \frac{0.10}{0.05}}{0.154\times10^{-9}\text{y}^{-1}} = 4.5\times10^9$y

Age of the ore can also be obtained from the amount of helium gas trapped in the ore during ay process. Helium gas is formed from α-particles during radioactive decay process. It is dent that one gram of uranium in a state of equilibrium with its decay products produces ut 10^7 ml of helium per year. If we are able to know by analysis the amount of the uranium helium in the ore, then the age can be calculated as :

$$\text{Age} = \frac{\text{ml of helium per gram of the ore} \times 10^7}{\text{amount of uranium per gram of the ore}}$$

his proces it is assumed that no helium is lost to the atmosphere which is most unlikely. refore age determination in this process will give some lower value than the actual age of ore.

II. **Radiocarbon dating :** This is another isotopic method of age determination which is licable to antique objects having carbon derived from plant and animal bodies.

In nature the equilibrium mass ratio of $^{12}CO_2 : {}^{14}CO_2 = 1 : 10^{-12}$. During photosynthesis ction plants take up CO_2 from the atmosphere and thus the ratio of ^{14}C to ^{12}C will be the ne in plants as that of the atmosphere. We known that ^{14}C is β-active i.e.

$$^{14}_{6}C \longrightarrow {}^{14}_{7}N + {}^{0}_{-1}e + \bar{\nu} \quad t_{1/2} = 5700y$$

e carbon cycle in the plant to animal to atmosphere chain bears the same ratio of $^{14}C : {}^{12}C$ as t of the atmosphere. Once the plant or animal dies, it is isolated from the carbon cycle and a result there is no longer any uptake of ^{14}C and its concentration gradually falls because of ay of ^{14}C.

An examination of the specimens of 'fresh' wood i.e. in freshly cut plant would obtained m various sources of the world indicate a constant activity equal to 15.3 disintegration per nute per gram of carbon. On the other hand hardly any activity was noticed in very old mples of carbon such as wood, petroleum etc. which has been removed from the life cycle ny many years ago. Thus the accumulated ^{14}C in the living plant starts decaying with a long riod and the measurement of radioactivity due to ^{14}C of an old sample give us an idea about e age of sample. This method is applicable to those samples which are as old as between 1000 30000 years.

In order to test usefulness of this method a specimen of wood was collected from Egyptian nbs which was about 4600 years old. The age of the sample of wood was then calculated as :

$$Nt = N_0 e^{-kt}, \text{ i.e. } 2.303 \log \frac{N_t}{N_0} = -kt$$

We know that $t_{1/2} = \frac{0.693}{k}$, so that $t = \frac{\log \frac{N_0}{N_t}\, t_{1/2}}{0.4343 \times 0.693} = \frac{t_{1/2}}{0.30096} \log \frac{N_0}{N_t}$

ie activity was measured and found to be about 8.85 counts per minute per gram of carbon. herefore,

$$N_0 \propto 15.3 \text{ and } N_t \propto 8.85, \; t_{1/2} = 5700y$$

Hence $t = \frac{5700}{0.30096} \log \frac{15.3}{8.85} = 4503y$

This result is in good agreement with that obtained from archaeology. By this technique W.F. Libby et. al. were able to test numerous archaeological samples for which Libby awarded Nobel Prize in 1960 for his outstanding contribution in this field.

III. Tritium dating : There might be possibility of tritium dating. Due to cosmic ray radiation in the upper atmosphere fast neutrons interact with nitrogen to form tritium.

$$^{14}_{7}N + {}^{1}_{0}n \longrightarrow {}^{3}_{1}T + {}^{12}_{6}C$$

Tritium produced is then oxidised to form HTO (tritiated water). We know that tritium is also β-active.

$$^{3}_{1}T \longrightarrow {}^{3}_{2}He + {}^{0}_{-1}e + \bar{\nu} \qquad t_{1/2} \approx 12.4y$$

As carbon is the essential constituent of plant and animal body,similarly tritium may also enter into living body through tritiated water. Thus like carbon dating, tritium dating may have possibility by measuring the activity of the body which is isolated many many years ago from the living system. But tritium dating has some practical difficulty. As half life of tritium is much smaller compared to that of ^{14}C, so that tritium dating will not be feasible for a body having high age (beyond 60 years). Moreover this technique requires sophisticated instrument for activity measurement because β-particles from tritium has very low energy. Thus tritium dating is not a promising one like that of carbon dating.

9.18.3 Application of radioisotopes in biological field

Radioisotopes play important role in life science and mention may be made in the following selected applications :

(a) With the help of tracer technique it is established that the constituents of cell such as proteins, carbohydrates and fats are not in static condition but always in dynamic nature in cell boundries, being contineous replacement with extracellular components.

(b) By using labelled carbon metabolic fate of food such as sugar, faty acid or amino acid can be ascertained.

(c) The mechanism of the movement of ions through the cell membrane as well as their rate of transport may be ascertained by tracer technique.

(d) Tracer technique has important use in studying various types of **mineral metabolism.**

(e) **In photosynthesis reaction** of green plants in presence of sunlight, carbohydrates are produced and oxygen is evolved. It was a long standing problem that whether oxygen comes from water or CO_2 and it was established by Ruben and co-workers (1941-43) **that oxygen comes entirely from water.**

Path I $$6CO_2 + 12H_2O^* \longrightarrow C_6H_{12}O_6 + 6H_2O + 6^*O_2$$

Path II $$6CO_2^* + 12H_2O \longrightarrow C_6H_{12}O_6^* + 6H_2{}^*O + 6O_2$$

Using labelled ^{18}O it has been established that the entire activity goes to liberated oxygen. On the other hand if labelled ^{18}O in CO_2 is used, the activity is distributed between glucose and water and no activity is observed in liberated oxygen. Similarly labelled carbon i.e. ^{14}C in CO_2 will give us the same sequence of information. Thus the mechanism of photosynthesis reaction will follow Path I and not Path II.

(f) In modern biology the radioautography or autoradiography is an important tool regarding location, shape and mobility etc. of DNA molecules in cells by using tagged tritium (^3H). This is based on the principle that β and γ (photon) radiations emitted from the radioisotope can produce some images on a special photographic plate from which the information regarding the above properties of DNA molecules can be ascertained.

18.4 Radioactivity in Agriculture

1. The distribution of added fertilisers to the soil absorbed by roots and transferred to different sections of the plant, can be tracked by the technique of radioautography. For example SO_4^{2-} ions having tagged sulphur i.e. ^{35}S are added to the soil along with normal sulphates. Special photographic plates are held in front of different sections of the plant. The section of the plant which receives the radioactive sulphate emits radiation and effect the photographic plate and thus the movement of a particular fertiliser in the whole plant body may be trace out by the technique.

2. The micronutrients i.e. the elements B, Zn, Mn and Mo in trace quantities are required for proper plant growth. The amount of these elements cannot be determined by conventional analytical procedure. The use of radioactive micronutrients can give us information regarding the amount of absorbed nutrients as also the location of the micronutrients.

3. DDT is a good insecticide used to protect the plant from the various types of insects. Prolonged use of DDT causes immunity to the insects. Radiological technique using mild radiation which effect the reproductive system of the insects and may be very effective in controlling the problem.

4. ^{60}Co decays by γ-radiation and it is evident that application of mild dose γ-radiation substantially increased the yield and quality of crop.

18.5 Radioisotopes in the field of industry

1. The level of liquid in a storage tank can be measured from outside by means of a radiating isotope which is placed on the surface of the liquid within the tank. Generally ^{137}Cs and ^{60}Co isotopes are used. A GM counter is fitted outside the tank and γ-activity is measured from which the position of the float on the surface of the liquid is located and hence the level of the liquid is measured easily.

2. Movement of oil in pipelines and leakage in pipelines can also be located easily with the help of suitable radioisotopes.

3. The quality control department of Durgapur Steel Plant (DSP) uses radioisotopes such as ^{137}Cs (0.56 MeV) and ^{60}Co (1.33 MeV) for level measurements of finished products (The Statesman dated 17.1.2011). Actually the finished steel sheets are allowed to pass through a source and detector. If the uniformity of the thickness in the steel sheet is maintained then the activity signal in the detector will remain fixed but if there exist any non-uniform level then the detector signal will be changed and the rolling machine will be automatically adjusted.

4. The wear and tear of a piston due to friction and the effectiveness of a lubricant in internal combustion automobile engines can be easily judged by using radioisotopes which actually acting as a mediator to carry out (n, γ) transmutation reaction. For example the rate of wear in piston rings can be ascertained by irradiating the rings in a nuclear reactor (n, γ reaction) and then it is installed in test engine and the activity is measured with a particular lubricating oil collected in the oil pan.

5. **Gamma radiography or gammagraphy** has been widely used in metallurgy to study self-diffusion process in metals i.e. to establish uniformity of alloy system. This is also used to know the defects in metal structure if any during heat treatment operations such as annealing, quenching etc.

6. Radioisotopes are used to detect and to prevent corrosion in metals.

9.18.6 Application of radioisotopes in medical field

Probably the application of radioisotopes in medical science was earliest to solve various problems in medicine and biochemistry. Here we shall mention some important application of radioactivity.

(a) NaCl containing ^{24}Na is used to detect the location of obstruction in blood circulation. ^{24}Na is injected to the patient suffering from impaired blood circulation and the course of the tracer (^{24}Na) can be conveniently followed from outside the different parts of the body of the patient with the help of GM counter and thereby the exact position of impairment in blood circulation is detected.

(b) For diagnosis and treatment of thyroid ^{131}I or ^{126}I is used as NaI*. The functioning of the thyroid gland of a patient is compared with the efficiency of uptake of iodine with that of the normal person. The malignancy of thyroid glands which is known as **hyperthyroidism** or the cancer of the thyroid can be treated with the emission of radiation from ^{131}I or ^{126}I.

(c) ^{60}Co is produced by (n, p) reaction of ^{60}Ni and the isotope is effective for the treatment of malignancy of tumours.

$$^{60}_{28}Ni + {}^{1}_{0}n \longrightarrow {}^{60}_{27}Co + {}^{1}_{1}H$$

^{60}Co decays both with β and γ emission and this can destroy the cancer cell very quickly.

$$^{60}_{27}Co \longrightarrow {}^{60}_{28}Ni + {}^{0}_{-1}e + \gamma$$

(d) Detection and location of brain tumour can be made by using ^{131}I and ^{32}P. ^{32}P in the form of phosphate may be used for the treatment of **leukemia and polycythemia vera** which is a desease in which the bone marrow produces excess red blood cells. The phosphate containing ^{32}P preferentially absorbed in the bone and emits β-rays which destroy the red blood cells and inhibit the malignancy

(e) The radioimmunoassay (RIA) which is an extremely versatile technique developed by Miles and Hales (1968) for ascertaining the concentration levels of vitially important ingredients such as hormones, vitamins etc. in the body fluid. In this technique

labelled excess antigen is used. The RIA method has extreme utility in gynaecological field to estimate the human placental lactogen (HPL) in the early stages of pregnancy. This information is very important to distinguish normal or abnormal pregnancy of a mother.

Problem 9.42 A radioactive sample gives an average count of 9390±95 and the counting time for each count is 20±1 min. Calculate the average count rate (in cpm) and its standard deviation. [B.U. 2009]

Ans. : Count rate = $\frac{9390}{20}$ = 470 cpm

Standard deviation = $\frac{9390}{20}\sqrt{\left(\frac{95}{9390}\right)^2+\left(\frac{1}{20}\right)^2}$ = 470×0.0026 = 470×0.051 = 24

Therefore average count rate = 470±24 cmp.

Problem 9.43 An archaeological specimen containing ^{14}C gives 40 counts in 5 minutes per gram of carbon. A specimen of fresh wood gives 20.3 counts per gram of carbon per minute. The back-ground count recorded by a recorder is 5 counts per minute in absence of any ^{14}C sample. What is the age of the specimen? ($t_{1/2}$ of ^{14}C = 5668 year)

Ans. : The back-ground count of the recorder is to be subtracted from the actual count rate.

Therefore, count rate of specimen = $\frac{40}{5} - 5 = 3$ counts m^{-1}

Count rate of fresh wood = 20.3 – 5 = 15.3 counts m^{-1}

Decay constant (k) of ^{14}C = $\frac{0.693}{5668}$ y^{-1}

Let t is the age of the archaeological specimen, then

$$t = \frac{2.303}{k}\log\frac{N_0}{N} = \frac{2.303\times5668}{0.693}\log\frac{15.3}{3}\ y = 13328\ y.$$

Problem 9.44 An amount of 7.32g CO_2 was collected by burning a piece of wood. The total radioactivity in the produced CO_2 was 10.8 disintegration per minute (dpm). How old was the wood sample? [Given the current activity of ^{14}C = 15.3 dpm/g and $t_{1/2}$ for ^{14}C = 5730y] [B.U. 2008]

Ans. : 7.32g CO_2 contains 1.996g carbon.

Therefore the total activity for 1.996g carbon = 10.8 dpm = $\frac{10.8}{1.996}$ = 5.41 dpm/g

The radioactive decay constant (k) = $\frac{0.693}{t_{1/2}} = \frac{0.693}{5730}$ y^{-1}

Now, $t = \frac{2.303}{k}\log\frac{N_0}{N} = \frac{2.303\times5730}{0.693}\log\frac{15.3}{5.41}\ y = 8598y.$

So that the wood sample is 8598y old.

Problem 9.45 A small amount of solution containing ^{24}Na ($t_{1/2}$ = 15 hours) is injected into blood stream of a man. The initial activity of the injected sample is $2\times10^3 s^{-1}$. The activity of 1 cm^3 of blood sample taken after 5 hours is 16 min^{-1}. Find the total volume of blood of the man. [C.U. 2007]

UNIT : IV Applications belonging to Nuclear chemistry:

Neutron activation Analysis:-

In this technique, the element whose amount in a sample is to be determined is transformed by (n,γ) reaction into its radioactive isotope and from the activity of the product, the Amount of the target element is determined, since the Amount's of radioactive isotopes of half lives, between hours and years can be determined, within precession of the order of 10^{-12} gm, the technique is well suited and extremely efficient for a large number of elements specially those with large neutron capture cross section.

In this method activity is induced in one (or) more elements of the sample by irradiation with suitable particles such as neutrons (or) charged species, such as hydrogen Deuterium (or) He-3 ion. When neutrons from nuclear reactors are used for irradiation the method is known as neutron activation analysis.

In neutron activation analysis, the Sample is subjected to Thermal neutron and the resulting radioactivity is then measured. Neutron from reactors, radio nuclides

and neutrons are usually produced by the irradiation of nuclei by alpha particles, protons, neutrons and high energy (an MeV or more) gamma rays. These are termed as fast neutrons by passing through a moderator, which reduces their energies to a few hundreds of eV

Neutrons having energy around 0.025 eV are called as thermal neutrons and they are in thermal equilibrium with the surroundings. The process of moderating high energy neutrons to thermal neutrons is called thermalisation. The most efficient moderators are water, D_2O and paraffine. The most neutron activation method are based upon thermal neutrons, which react efficiently with most elements of analytical interest.

For some of the lighter element such as N, O, F, fast neutrons having energies about 14 MeV are more efficient for inducing radioactivity. Such neutrons are commonly produced by accelerator.

Nuclear reactors are a source of copious thermal neutrons and are therefore widely

used for activation analysis. A typical reactor will have a neutron flux of 10^{11} to 10^{14} neutrons / cm^2 / sec. These high neutron densities lead to detection limits from 10^{-3} to 10 µg for many elements.

Radioactive isotopes are convenient and relatively inexpensive sources of neutrons for activation analysis. The neutron flux densities range from 10^5 to 10^8 neutron / cm^2/sec. One common radioactive source is a transuranium element that undergo spontaneous fission to yield neutron. The most common example of this type of source consist of Californium - 252 which has a half-life of 2.6 years. Thermal flux density is about 3×10^7 neutrons / cm^2 / sec from this source.

Neutrons can also been produced by preparing an intimate mixture of an α - element such as Plutonium, Americium or curium such as Beryllium. This kind of source is based upon the reaction:

$$^{9}_{4}Be + ^{4}_{2}He \longrightarrow ^{12}_{6}C + ^{1}_{0}n + 4.7 \text{ meV}.$$

An accelerator consist of an ion sou
that delivers D ions to an area wher
they are accelerator through a potential of
about 150 kV to a target containing T
(Tritium) absorbed on Ti or Zr.

The reaction is,

$$^{2}_{1}H + ^{3}_{1}H \longrightarrow ^{4}_{2}He + ^{1}_{0}n$$

Neutrons from such accelerator have energies of about 14 MeV and are useful of activating the lighter elements.

Interaction of neutrons with matter :-

Free neutrons are non stable and decay with a half-life of about 12.5 minutes to give protons and electrons. Free neutrons donot generally exist long enough to disintegrate, however, because of their great tendency to react with ambient materials. The high reactivity of neutrons arises from their zero charge which permits them to approach charge nuclei without interference from coulombic forces.

Neutron capture is the most important reaction for activation methods. In this proces, a neutron is captured

by the analyte nucleus to give an isotope with the same atomic number, but with a different mass no that is greater by 1. The new nuclide is in a highly excited state because of the release of the binding energy of the neutrons.

$$_{11}Na^{23} + {}_{0}n^{1} \longrightarrow {}_{11}Na^{24} + \gamma$$

This excess energy is released by prompt γ-ray emission & emission of one or more nuclear particles such as neutron, proton or α particles.

The above equation is example of the reaction that produces γ-ray. Equation of the above type is usually written in abbreviated form as $^{23}Na(n,\gamma)^{24}Na$.

Principle:- Suppose the problem is to determine the amount of a given element 'x' in a particular sample.

Let 'x' gms of the sample containing 'N' atoms of the element be placed in a uniform flux of thermal neutrons for a sufficiently long period of seconds to produce measurable activity, say A_t. It is presumed that the activity A_t is

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and six 'β' particles

atom

$\times 10^3 = 69207$

$2 \times 10^3 = 51$

accumula

ake to be

Owing due to the isotope [illegible] [illegible] of any other nuclide present in the sample, the [illegible] [illegible], the activity of the gamma could be distinguished by the [illegible] by its characteristic radiation, half-life etc., The activity so produced is given by

$$A_t = n\phi\sigma(1 - e^{-\lambda t}) \longrightarrow (1)$$

ϕ – is the neutron flux (i.e.) n no. of neutrons/cm²/sec,

σ – the neutron cross section in cm² for the given target nuclide which is obtained from tables.

λ – The decay constant for one of the radioactive ~~decay~~ product.

A_t is the activity of the product measured immediately at the end of irradiation time t. Often this is not possible and a finite time 't', lapses between the end of irradiation and start of counting during which time some of the activity would have decay. The activity one actually measures after an interval 't' after irradiation is given

by,

$$A''t' = \lambda t \cdot e^{-\lambda t'}$$

$$= N\phi\sigma(1 - e^{-\lambda t}) \cdot e^{-\lambda t'} \longrightarrow (2)$$

From the above equation the weight in the 'x' gm of the sample is known from,

$$w = \frac{Nm}{L} = \frac{M}{L} \cdot \frac{At'}{\phi\sigma(1-e^{-\lambda t}) \cdot e^{-\lambda t''}} \quad \text{---} (3)$$

where M = is the atomic weight of the element.

L = Avagadro constant (6.023×10^{23}).

In the case of products of short half-life, the period of irradiation t can be prolonged to equal about 6 half-lifes. When the factor,

$$e^{-\lambda t} = e^{-0.693\, t/\tau} \rightarrow 0 \text{ as } t \gg \tau \text{ life period}$$

and the expression simplifies, The (n,γ) reaction in such a case goes to saturation. When τ is strong enough it would not be possible to irradiate to saturation. The above treatment needs only a small modification in case the target element is not monotopic, but consi-

two & 6s more stable isotopes. If the proportion of the particular isotope in the target element whose (n, α) radioactive product is being measured is parts per 100 of the element, the resulting N in equation (1), (2) & hence W in equation (3) must be multiplied by 100/f to obtain the total amount of the element x in x gm of the target sample

In actual practice; two samples, one std. containing a known amount of this element W° and the other containing unknown amount of element W are irradiated simultaneously and under identical Condition & the resulting activity At°(known), At (Unknown) are related, as,

$$\frac{W}{W^\circ} = \frac{At}{At^\circ}$$

Alternatively a series of unknown compound containing $W_1, W_2, W_3 \ldots W_n$ and the unknown are irradiated together and from the linear plot of W Vs At the Content of unknown is determined.

Application :-

(1) The analysis of trace element in mineral ores, in soils and special preparation as be possible by neutron activation.

(2) Neutron activation method offer several advantages including high sensitivity, minimal sample preparation and ease of calibration. As little as 10^{-9} µg of several elements can be detected by this method.

(3) Another greater advantage of this technique is that it is non-destructive (i.e) the sample remain unchanged at end of the analysis, except for the nuclear transformation of atoms in trace concentration and hence it is well applied to the analysis of rare and pressure sample as jewells, precious stones, ancient coins and other archaeological specimens as Forensic-samples etc.)

(4) The neutron activation method is potentially applicable to the determination of 60 elements of the periodic table like Na, P, La, Sc, Cr, Mn, Co, Cu, In, Ge, Ar, Se, Ag, W, Ir, Pt, Au etc.)

Some of the rare of the elements he

Sm, Gd, Hf, Yb, By having high neutron capture cross sections and well adapted for neutron activation analysis.

5. Four of the inert gases from an isotope with thermal neutrons and thus can be determined. Further oxygen, silicon, nitrogen, thorium can be activated with fast neutron from accelerators.

6. Chromium content of a Ruby:-

The ^{50}Cr in natural Cr becomes by (n,γ) reaction. The 27.7 day ^{51}Cr ($^{50}Cr + {}_0^1n \longrightarrow {}^{51}Cr + \gamma$). By irradiating with slow neutrons under identical conditions, a Cr-bearing ruby with a series of $Al_2O_3 + Cr_2O_3$ mixture of varying, but known Cr content, it was found that the ruby have 0.1 to 0.4 Cr. The precission and the fact that the pressures ruby remains undamaged at the end of the analysis highlight the value of this method of analysis.

7. Manganese content of Tea leaves:-

The mono isotope ^{55}Mn becomes by (n,γ) reaction 2.58 hr ^{56}Mn.

$$^{55}Mn + {}_0^1n \longrightarrow {}^{56}Mn + 2\gamma$$

Neutron irradiation of a known weight of dry tea leaves (as better its ash) along with a series of samples of known Mn content reveal that tea leaves contain 0.13 % Mn. About half of which passes in the Brew and the rest goes to waste.

8. Archaelogical specimens :-

Neutron activation analysis has helped in determining the precious composition of some ancient coins non-destructively and the results have thrown light on the historical and Geographic origin. Similarly the analysis of coloured pottery, ~~stra~~ of archaelogical discoveries go to establish the possible age, geography proximity to available minerals, besides throughing light on the development of ceramics in that region. All that is achieved without destroying the valuable specimens.

9. Radiometric titrations :-

Radiometric titrations employ radio isotopes to indicate the end point by a sudden release to (or) absorption from the solution of activity. For instance,

In the titration of silver by chloride ions labelled with ^{36}Cl, the solution remains inactive till the end point is reached, as all the activity is removed as AgCl ppt., the end point is indicated by the sudden release of activity into the solution which keeps increasing thereafter. On the other hand, if Ag ion have been used (^{110}Ag) the solution remains active, though slow and the end point corresponds to a constant minimum of activity. In either case the end point corresponds to a sharp inflexion in the activity Vs the titration curve.

There are two common types activation methods,

(i) destructive (ii) Non-destructive.

In both methods, both the samples and standards are irradiated simultaneously with neutron. The samples may be solids, liquids (or) gases. Although the first two are common

If the non-destructive method, the sample and standards are counted directly after cooling. The ability of a γ-ray spectrometer to descriminate among radiations of different energies provides

selectivity. The [illegible] of an [illegible] method requires that the spectrometer be able to isolate the γ-signal produced by analyte from signals arising from the other components.

The great advantage of the non-destructive approach is its simplicity in terms of sample handling and the minimal operation time required to complete an analysis.

On the other hand, a destructive method requires that the analyte separate from the other components of the sample prior to counting. In this case a known amount of the irradiated sample is dissolved and the analyte is separated by precipitation, extraction, ion-exchange (or) chromatography. The isolated material are fraction, is then counted for its γ-reactivity. As in the non-destructive method, standards are irradiated simultaneously and treated in an identical way as the sample.

Isotopic dilution Analysis:

This technique concerns the determination of an unknown amount of a given species of matter mixed up in a large sample, which cannot be otherwise analysed conveniently.

(i.e) For example, in assessing the amount of an active component as auromycin in a large fermentation broth (or) the volume of blood in a living being.

Also the technique has been very suitable where a compound can be isolated in a pure state but with only a very poor yield.

Principle: The technique consists in adding to the sample containing 'x' gm (unknown) of the species, 'y' gm of a radioisotopic form of this species of initial specific activity Si counts per millgm/min. After thoroughly mixing, a small amount of the species is isolated from the mixer and its final specific activity Sf is determined.

Obviously Sf would be less than Si. Just with these 2 measurements,

The unknown amount of 'x' is calculated on the principle of the conservation of total activity

(i.e)

$$(x+y)\,S_f = yS_i$$

Hence $x = \dfrac{y(S_i - S_f)}{S_f}$

S_i - Initial activation
S_f - Final "
y - "Amount of radioactive substance added.

Isotope dilution analysis can be of four type.

(1) Direct isotopic dilution :→ Determination of inactive material by diluting it with an active material.

(2) Inverse isotopic dilution :→ In this a radioactive material is determining by diluting it with an inactive material.

(3) Modified inverse isotopic dilution :
In this a radioactive material is determined by diluting it with a radioactive material.

(4) Double isotopic dilution : This method was developed Black & Anter, In this the radioactivity of the unknown may not be necessarily known.

Calculation of

Applications of Isotopic dilution Analysis :-

1. Estimation of a specific Aminoacid in a mixture of aminoacids
2. The Calculation of the % of glycine in a mixture obtained as a result of hydrolysis of proteins using ^{14}C.
3. The Determination of Rare earths in the fission products.
4. Determination of ^{13}C employing ^{140}Ce.
5. Determination of geological areas.
6. Applications of isotope dilution analysis in Antibiotics.

Determination for manufacture of Antibiotics : Isotope dilution analysis method has been used by the manufacture of Antibiotics. A given fermentation broth contains an unknown Amount of Aureomycin which is to be determined. Isotope dilution analysis consequles a simple way of Solving this.

Suppose to 1kgm of the broth containing xmg/m (unknown) of Aureomycin, one adds a mg of Aureomycin labelled with ^{14}C, whose initial specific Activity is Si = 150 counts / mg / min.

After a thorough mixing 1mg of Aureomycin is isolated and suppose the sample registers 400 counts in 20 minutes. This makes the final specific activity Sf = 20 Counts / mg / min, where the count rate is small, it is necessary to extend the counting over a sufficiently long period, to minimize counting errors.

By equation $\boxed{(x+y)\,Sf = y\,Si}$

We have $(x+1)\,20 = 150$

$x = 6.5$ Mg of Aureomycin / kg of broth.

(7) An instance where the technique was used was in computing the trace amount of potassium impurity in filaments of Tungsten [illegible] As supposed for the addition stage in mass spectroscopy, the [illegible] was interfering with [illegible] analysis of isotopically enriched samples of [illegible]

By diluting the impurity with potassium enriched in 40K (0.59%) the impurity of potassium was found to 3×10^{-6} % of Tungsten.

(8) **Assessing the Volume of Blood in a patient**

Sometimes it becomes necessary for a surgeon to know the amount of blood in a patient of Anemia (or) one to who has add severe haemorrhage in an accident. The simplest way of assessing the volume of blood in a person is by the technique of isotope dilution.

1 cm^3 of the patient's blood is withdrawn and it is labelled with a solution of ^{24}Na as [NaCl (or) less often with ^{125}I (or) ^{51}Cr (or) ^{32}P].

The initial specific activity of the labelled blood is measured in 0.1 cm^3 of it.

Let this be S_i min^{-1} cm^{-3}. The rest of the labelled sample containing 0.9 cm^3 of blood (equal to y) is reinjected intravenously. After about 15 minutes needed for the circulation and homogenization of the blood, once again 1 cm^3 of the blood is withdrawn and its specific activity S_f determined.

The Unknown volume of blood in the patient's body is calculated from,

$$\therefore Si = (x+y)\,Sf$$
$$= x \cdot Sf \quad [\because y \ll x]$$
$$x = y \cdot \frac{Si}{Sf} \cdot cm^3$$

In a normal adult human being may have between 5 to 6 litres of blood.

Auto Radiography (or) Radio Autography :-

This technique is frequently employed to study the detailed localisation of radioactive material in relatively small specimens of organic and inorganic material (i.e) not usually part of a living organism. This procedure makes use of the influence on a photographic emulsion of the radiation from radioactive body.

The effects observed By A.H. Becquerial where the first crude samples of Radioautography in which a radioactive substance is made in a sense to record its own photograph. The modern development in this technique come from the experiments of the French biologists. A. Lacassagne and J. Latter, Reported in 1924, on the distribution of the Radioelement Polonium (Po) injected into various organs.

Thin sections of the organ structures are used for histological study, Under the microscope, where placed in contact with a photographic plate which the plate was blackened represented the areas, where the (Po) had been concentrated. In recent years the radioautographic technique has been greatly improved so that it is now a highly valuable tool in biological results. High resolution definition is obtained