RADIOACTIVITY

1. NUCLEAR CHEMISTRY

Nuclear chemistry deals with the phenomenon related with nucleus, like Radioactivity, Nuclear fission and fusion reactions, etc.

2. NUCLEAR STABILITY

The number of discovered elements till date is 118. All have some isotopes. The total number of isotopes is about 2000. Among these isotopes, the number of non-radioactive isotopes is even less than 300. Most of the isotopic forms have unstable nucleus due to very strong protonic repulsion. These unstable nuclei undergo spontaneous disintegration, causing radioactivity.

The stability of few nuclei against very strong protonic repulsion may be explained by the following theories :

2.1 NUCLEAR FORCE THEORY :

Nuclear force is an imaginary force which holds the nucleons together.

i. The exact nature of force is not known because it does not obey inverse square law.

ii. It is a very short range force & it drops to 0 at 10^{-14}m. The nuclear force becomes repulsive at very small distance (8×10^{-16}m).

iii. Nuclear force acts equally between all the nucleons. p–p = n – n = n – p

iv. In the stable nucleus, the nuclear force is stronger than protonic repulsion.

v. On increasing atomic number, protonic repulsion increases. As the nuclear force can't hold the particles, nucleus becomes unstable.

2.2 YUKAWA'S MESON THEORY :

Yukawa suggested that inside the nucleus, interconversion between proton & neutron occur with the help of mesons by which nucleons hold each other.

p-meson or pions π° π^+ π^-

μ-meson or muons μ° μ^+ μ^-

mass of meson = (200 to 300) × m_e

(i) Role of positive meson :

$$p \rightleftharpoons n + \pi^+$$

$$p_1 + n_2 \rightleftharpoons n_1 + \pi^+ + n_2 \rightleftharpoons n_1 + p_2$$

(ii) Role of negative meson :

$$n \rightleftharpoons p + \pi^-$$

$$n_1 + p_2 \rightleftharpoons p_1 + \pi^- + p_2 \rightleftharpoons p_1 + n_2$$

(iii) Role of neutral meson :

$$n_1 \rightleftharpoons n_2 + \pi^0$$

$$p_1 \rightleftharpoons p_2 + \pi^0$$

2.3 MASS DEFECT AND BINDING ENERGY :

For all the isotopes (radioactive/non-radioactive), the theoretical mass (sum of masses of protons, neutrons and electrons) is greater than its isotopic (actual) mass. This difference in mass is called **mass defect** (Δm). For example,

For $_2He^4$, isotopic mass = 4.0026 u

Now, Mass due to e^- = 2 × 0.00054 = 0.00108u

Mass due to p = 2 × 1.00727 = 2.01454u

Mass due to n = 2 × 1.00867 = 2.01734u

Total	4.03296u

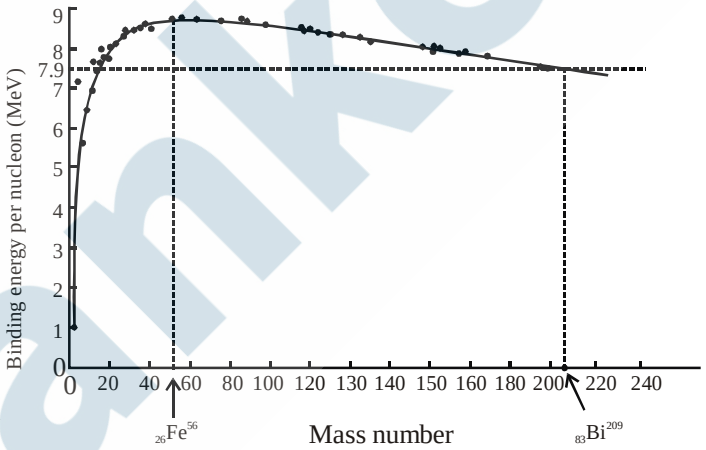
The decrease in mass is due to its conversion into energy at the time of atom formation, by Einstein equation :

$E = \Delta m.c^2$

As this energy is released in binding the particles together, it is called **binding energy**.

If Δm = 1 a.m.u,

then B.E., $E \simeq 1.5 \times 10^{-10}$ J $\simeq$ 931.5 MeV



* Binding energy per nucleon gives a quantitiative measure of nuclear stability. B.E. per nucleon = $\frac{\text{B.E.}}{\text{No. of nucleons}}$

Greater the value of B.E. per nucleon, more is the stability of nucleus.

(i) Nuclear binding energy is maximum for mass number 50 – 60.

(ii) Fe, Co, Ni have very high binding energy per nucleon.

(iii) A very heavy nucleus, say A = 240, has lower binding energy per nucleon compared to that of a nucleus with A = 120. Thus if a nucleus A = 240 breakes into two A = 120 nuclei, energy would be released in the process. This implies nucleons get more tightly bound. It has very important applications for energy production through fission.

(iv) Consider two very light nuclei ($A \leq 10$) joining to form a heavier nucleus. The binding energy per nucleon of the heavier nuclei is more than the binding energy per nucleon of the lighter nuclei, again energy would be released in such a process of fusion.

(v) All the nuclei having BE/nucleon greater than 7.9 MeV are stable. The value 7.9 is not applicable for lighter nuclei because they may be stable even at lower value.

Ex.1. Calculate BE/nucleon for $_{17}Cl^{35}$

$m_e = 0.00054$ u, $m_p = 1.00727$ u, $m_n = 1.00867$u

Sol. $\Delta m = (17 \times 0.00054 + 17 \times 1.00727 + 18 \times 1.00867) - 35 = 0.28883$ u

B.E. $= 0.28883 \times 931.5 = 269.045$ MeV

$\therefore$ B.E. nucleon $= \dfrac{269.045}{35} = 7.687$MeV .

Ex.2. Calculate BE for an additional neutron in $_3Li^6$ nucleus. Nuclear mass of $Li^6 = 6.0025$, $Li^7 = 7.0081$, $m_n = 1.0087$u

Sol. $_3Li^6 + {}_0H^1 \rightarrow {}_3Li^7$

$\Delta m = (6.0025 + 1.00087) - 7.0081 = 0.0031$ u

$\therefore$ Energy released $= 0.0031 \times 931.5 = 2.888$ MeV

Ex.3. A nucleus A^{240} (BE/nucleon = 7.3 MeV) dissociate into two identical nuclei B^{120}, (BE/nucleon = 8.2 MeV). Calculate the amount of energy absorbed or released.

Sol. Energy released $= 2 \times 120 \times 8.2 - 240 \times 7.3 = 216$ MeV

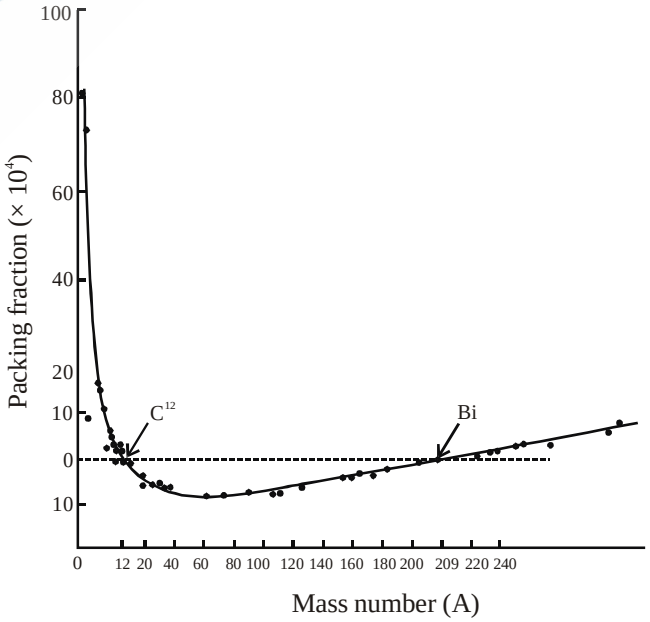
2.4 PACKING FRACTION :

'Aston' expressed relation between isotopic mass & mass number in terms of packing fraction.

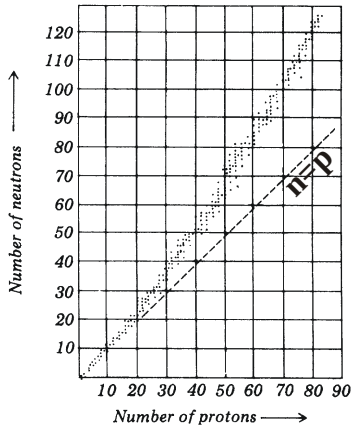
◆ **Packing Fraction**

$$= \frac{\text{Atomic mass} - \text{Mass number}}{\text{Mass number}} \times 10^4$$

* packing fraction of C–12 is exactly zero.
* packing fraction may be positive or negative
* negative packing fraction implies that nuclei is stable
* positive packing fraction implies that nuclei is unstable
* Some lighter nuclei have positive packing fraction although nucleus is stable



2.5. NEUTRON / PROTON RATIO AND STABILITY BELT :



- All the stable nuclei lie in a zone or belt of stability, as shown in the figure.
- None of the stable nucleus have $\frac{n}{p}$ ratio less than 1 (except ${}_1H^1$) and greater than 1.52 ($\frac{n}{p}$ ratio of heaviest stable nucleus ${}_{83}Bi^{209}$).
- In lighter nuclei (Z < 20), $\frac{n}{p}$ ratio of stable nuclei is very close to 1.

2.6 EVEN ODD THEORY :

The number of stable nuclides is maximum when both protons and neutrons are even numbers.

p	n	No. of stable nucleus	Examples
even	even	~ 165	${}_2He^4$, ${}_6C^{12}$, ${}_8O^{16}$, etc
even	odd	~ 55	${}_4Be^9$, ${}_6C^{13}$, ${}_8O^{17}$, etc
odd	even	~ 50	${}_3Li^7$, ${}_5B^{11}$, ${}_9F^{19}$, etc
odd	odd	5	${}_1H^2$, ${}_3Li^6$, ${}_5B^{10}$, ${}_7N^{14}$, ${}_{73}T^{180}$

- Nearly 60% of stable nuclei have even number of protons and neutrons.

2.7 MAGIC NUMBERS :

Nuclei with 2, 8, 20, 50, 82 or 126 protons or neutrons are exceptionally stable and have a larger number of stable isotopes than neighboring nuclei in the periodic table. These numbers are called magic numbers. They are supposed to represent completely filled nuclear shells or energy levels.

e.g. ${}_{50}Sn$ having 10 stable isotopes while ${}_{51}Sb$ has only two stable isotopes.

- Nuclei with magic number of protons as well as neutrons have notably high stabilities. [eg. ${}^4_2He$, ${}^{16}_8O$, ${}^{40}_{20}Ca$ and ${}^{208}_{82}Pb$].

3. RADIO ACTIVITY

The spontaneous emission of particles, electromagnetic radiation or both by unstable nuclei, is known as radioactivity. Only unstable nuclei exhibit this property.

This phenomenon (radioactivity) was discovered by Henry Becquerel. On working with uranium salt, he observed that some radiations having the following properties come out from these salts:

(i) They blacken the photographic plates.

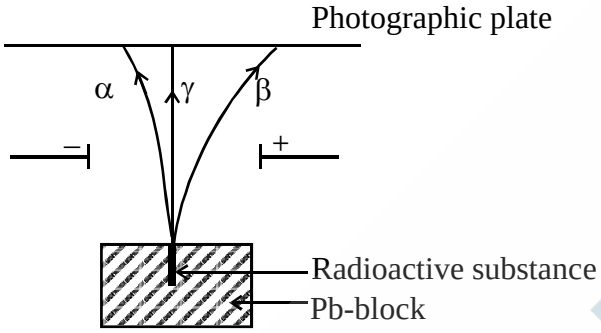
(ii) They cause fluorescence on ZnS screen.

(iii) They ionise the gas through which they pass.

He gave the name **becquerel rays** to these radiations.

Later on, **Madam Curie** discovered two elements Radium (Ra) and Polonium (Po). She found that these elements as well as their salts emit similar radiations. She generalised the name of Becquerel rays as **radioactive rays** and the phenomenon, as **radioactivity**.

4. NATURE OF RADIOACTIVE RAYS



4.1 PROPERTIES OF α, β-PARTICLES AND γ-RAYS :

	Properties	Alpha	Beta	Gamma
1.	Nature	Fast moving He nuclei	Fast moving electrons	Electromagnetic radiation of very high energy.
2.	Representation	${}_2He^4$ or α	${}_{-1}e^0$ or ${}_{-1}\beta^0$ or β^-	γ or ${}^0_0\gamma$
3.	Charge	2 unit (+ve)	1 unit (–ve)	no charge
4.	Velocity	10-20% of speed of light	33% to 90% of speed of light	Same as light waves
5.	Relative penetrating power	1 (0.01 mm of Al foil)	100 (0.1 cm Al foil)	10000 (8 cm lead or 25 cm steel)
6.	Travel distance in air (Range)	2 – 4 cm	200 – 300 cm	–
7.	Kinetic energy	high	low	–
8.	Effect on ZnS plate	Luminosity	Little effect	–
9.	Mass g/particle	6.64×10^{-27} kg	9.109×10^{-31}kg	–
10.	Relative ionising power	10000	100	1

4.2. α-DECAY :

If any α-emitter is taken in a closed vessel, after sufficient time, presence of He gas is observed in the vessel. It is experimental fact considering α-particle as He^{2+} ion or He nucleus.

It is assumed that inside the nuclieds, some p & n exists as a α-particle due to the following facts :

(a) Initially all the lighter nucliedes ($Z \leq 19$) were transmuted by α-particles except ${}_2He^4$, ${}_4Be^8$, ${}_6C^{12}$. These nucliedes were supposed to have 1, 2 and 3 α-particles respectively.

(b) Among the lighter nucleides, BE/nucleon for He is exceptionally high ($\simeq$7MeV). Hence the combination of 2p & 2n as α-particles is considered stable combination.

(c) Among p, n, deutron (d) & α-decay, Q value is positive only for α-decay (energy is released). Hence among these decay, α-decay is only spontaneous decay.

(i) Effects of α-decay :

(a) The atomic number decreases by two units and mass number by 4 units per decay.

$${}_zX^A \xrightarrow{-\alpha} {}_{Z-2}Y^{A-4}$$

(b) n/p ratio increases on α-decay.

(c) Isodiaphers are formed. Isodiaphers are the atoms of different elements having the same number of excess neutron over proton. [Same [N – P] difference.]

(ii) Q-value for α-emission :

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

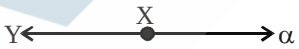
Δm = (nucleidic mass ${}_ZX^A$) – (nucleidic mass ${}_{Z-2}Y^{A-4} + {}_2He^4$)

= Atomic mass of ${}_ZX^A$ – At mass of $({}_{Z-2}Y^{A-4} + {}_2He^4)$

Now, $Q = \Delta mC^2 = \Delta m \times 931.5$ MeV.

(iii) KE of emitted α-particle :

Q value = $(KE)_\alpha + (KE)_Y$



& $(mV)_\alpha = (mV)_Y$

$$(KE)_\alpha = \frac{m_Y}{m_Y + m_\alpha} \times Q = \frac{A-4}{A} Q$$

All the α-particle emitted out from a particular radio-nucleide must have same KE, if the contribution of γ-photon is neglected.

4.3 β-DECAY :

On β-decay, the atomic species get changed and hence β decay is always due to some nuclear change.

(i) A neutron breaks into proton, electron & anti-neutrino. As e and anti-neutrino can never exist in the nucleus, they come out.

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

(ii) Effect of β-decay :

(a) The atomic number increases by one unit but the mass number remains unchanged.

(b) n/p ratio decreases.

(c) Isobars are formed. (Atom of different elements having same mass number)

(d) Isotopes are formed by the sequential decay of 1α & 2β particles. (Atoms of same element having different mass numbers.)

(e) Normally a radio nucleide either undergoes α or β decay. There are very few radio nucleides which undergo simultaneous α & β decay.

(iii) Q-value

$$_{Z}X^{A} \longrightarrow {}_{Z+1}Y^{A} + e^{-} + \bar{\nu}$$

Δm = nucleidic mass $[{}_{z}X^{A} - ({}_{Z+1}Y^{A} + m_e + m_{\bar{\nu}})]$

= At mass $({}_{Z}X^{A} - {}_{Z+1}Y^{A})$

$Q = \Delta mc^2$

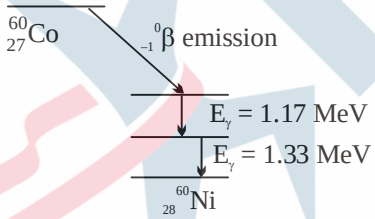
(iv) K.E. of β-particle : The Q value will be shared between emitted β-particles & antineutrino. Hence KE of β-particles may have any value from 0 to Q value. The β-particle emitted out from a particular radionucleide may have different KE.

4.4. γ-DECAY :

This is a secondary phenomenon. When an α or β decay takes place, the daughter nucleus generally formed is in excited state & comes to ground state by a single or successive transitions by emitting electromagnetic radiations i.e. γ rays.

$${}^{60}_{27}Co \longrightarrow {}^{60}_{28}Ni + {}^{\circ}_{-1}\beta$$

$${}^{60m}_{28}Ni \longrightarrow {}^{60}_{28}Ni + {}^{0}_{0}\gamma$$



i. The atomic number & mass number remain unchanged.

ii. Nuclear isomers are formed. They have same nuclear composition but different energy.

Ex 4. $A \xrightarrow{-\alpha} B \xrightarrow{-\alpha} C \xrightarrow{-\beta} {}_{89}D \xrightarrow{-\beta} E \xrightarrow{-\alpha} F \xrightarrow{-\beta} G^{212}$

(i) Identify isotopic pairs

Sol. (B, E) ; (C, F) ; (D, G)

(ii) What is the atomic & mass number of A

Sol. 92, 224

Ex 5. Which of the following may be the disintegration product of $_{92}U^{238}$

I. (a) $_{90}Th^{234}$ (b) $_{88}Ra^{232}$ (c) $_{85}Ra^{235}$ (d) $_{87}Fr^{227}$

(a)

II. (a) $_{88}Ra^{230}$ (b) $_{89}Ac^{230}$ (c) $_{87}Fr^{230}$ (d) $_{87}Fr^{226}$

(e) $_{86}Rn^{226}$

Sol. **(a, b, d, e)**

Ex 6. Russian and American scientist have artifically prepared elements with atomic number greater than 100. The number of alpha and beta particles produced when one atom of $^{257}_{103}Lr$ decay after being produced by artificial means to its stable product is -

(A) 4 α and 5 β (B) 4 α and 12 β (C) 12 α and 4 β (D) 12 α and 5 β

Sol. 6. Ans. (C)

$$^{257}_{103}Lr \longrightarrow {}^{209}_{83}Bi$$

4.5 POSITRON DECAY :

Given by Irene Curie and F.Juliot.

When Mg^{24}, Al^{27} or B^{10} were bombarded by α-particle, emission of p, n & β^+ (positron) occur. On stopping the bombardment, p & n emission stop but β^+ emission continues obeying 1st order kinetics. The isotope responsible for such β^+ emission is called artificial **radio isotope** and the phenomenon as artificial radioactivity.

$$_{13}Al^{27} + {}_2He^4 \longrightarrow {}_{14}Si^{30} + {}_1H^1$$

$$_{13}Al^{27} + {}_2He^4 \longrightarrow {}_{15}P^{30} + {}_0n^1$$

$$\downarrow$$

$$_{14}Si^{30} + {}_{+1}e^0$$

In positron decay, a proton (inside the nucleus) breaks into neutron, positron and neutrino.

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

As β^+ and ν can never exist in the nucleus, they come out, resulting positron decay.

Note: *A free neutron may break into proton (mass decreases) but a free proton can never break into neutron (mass increases). Inside the nucleus, both conversions are possible because of involvement of nucleus.*

(i) Effect of β^+-decay :

(a) The atomic number decreases by one unit but the mass number remain unchanged.

$$_ZX^A \xrightarrow{-\beta^+} {}_{Z-1}Y^A$$

e.g. $_{11}Na^{20} \longrightarrow {}_{10}Ne^{20}$

(b) Isobars are formed.

(c) n/p ratio increase.

(ii) Q-value :

$${}_{Z}X^{A} \longrightarrow {}_{Z-1}Y^{A} + e^{+} + \nu$$

Δm = (nucleidic mass of ${}_{2}X^{A}$) – (nucleidic mass of ${}_{z-1}Y^{A}$ + mass of β^{+} + mass of ν)

= At mass (${}_{Z}X^{A} - {}_{Z-1}Y^{A}$) – $2m_e$

(iii) K.E. of β^{+} : The KE of emitted e^{+} may have any value from 0 to Q-value.

4.6. K-CAPTURE OR ELECTRON CAPTURE :

In electron capture, nucleus captures an electron of K-shell. Proton converts into neutron inside the nucleus.

$$p + e^{-} \longrightarrow n + \nu$$

As neutrino can not exist in the nucleus, it comes out.

(i) Effects of electron capture :

(a) Atomic number decreases by one unit but mass number remains unchanged.

$${}_{Z}X^{A} \xrightarrow{EC} {}_{Z-1}Y^{A}$$

$${}_{47}Ag^{106} \xrightarrow{EC} {}_{46}Pd^{106}$$

(b) $\frac{n}{p}$ ratio increases

(c) Isobar is formed.

(d) As one electron from K-shell is captured by nucleus, electron from higher shell de-excite to K-shell, emitting X-rays.

(ii) Q-value :

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

Δm = (nuclear mass of ${}_{Z}X^{A}$ + mass of electron) – (nuclear mass of ${}_{Z-1}Y^{A}$ + mass of neutrino)

= Atomic mass of ${}_{Z}X^{A}$ – Atomic mass of ${}_{Z-1}Y^{A}$

and Q–value = $\Delta m.C^2$

(iii) K.E. of emitted neutrino = Q-value

5. PREDICTION OF KIND OF RADIOACTIVE DECAY:

(i) $\frac{n}{p}$ ratio increases in α-decay, β^{+}-decay and electron capture but $\frac{n}{p}$ ratio decreases in β^{-} - decay.

If the $\frac{n}{p}$ ratio of any radioisotope is greater than that of non-radioactive (stable) isotope of the same element, the possible mode of decay is β^{-}-decay. For example, ${}_{6}C^{12}$ is non-radioactive and ${}_{6}C^{14}$ is β^{-} emitter.

$${}_{6}C^{14} \xrightarrow{-\beta^{-}} {}_{7}N^{14}$$

$\frac{n}{p} = \frac{8}{6} > \frac{6}{6}$ of ${}_{6}C^{12}$ $\quad \frac{n}{p} = \frac{7}{7}$

If the $\frac{n}{p}$ ratio is smaller, the possible mode of decay may be α-decay or β^+ - decay or electron capture. For example, $_{11}Na^{23}$ is non-radioactive and $_{11}Na^{20}$ is β^+ - emitter.

$$_{11}Na^{20} \xrightarrow{-\beta^+} {}_{10}Ne^{20}$$

$$\frac{n}{p} = \frac{9}{11} < \frac{12}{11} \text{ of } {}_{11}Na^{23} \qquad \frac{n}{p} = \frac{10}{10}$$

(ii) Normally, α-decay occurs only in heavier nucleus

(iii) If (atomic mass of $_{Z}X^{A}$ - Atomic mass of $_{Z-1}Y^{A}$) is less than mass of two electrons, β^+-decay is not possible (Q-value will become negative)

Ex.7. Predict the possible mode of radioactive decay by (i) $_1H^3$ (ii) $_8O^{18}$ (iii) $_2He^3$ (iv) $_2He^6$

Sol. (i) $\left(\frac{n}{p}\right)$ of $_1H^3 = \frac{2}{1} > \left(\frac{n}{p}\right)$ of $_1H^1$ or $_1H^2$

hence, $_1H^3$ is β^- - emitter.

(ii) $\left(\frac{n}{p}\right)$ of $_8O^{18} = \frac{10}{8} > \left(\frac{n}{p}\right)$ of $_8O^{16}$

hence, $_8O^{18}$ is β^- - emitter

(iii) $\left(\frac{n}{p}\right)$ of $_2He^3 < \left(\frac{n}{p}\right)$ of $_2He^4$

hence, $_2He^3$ may be β^+ - emitter

(iv) $\left(\frac{n}{p}\right)$ of $_2He^6 > \left(\frac{n}{p}\right)$ of $_2He^4$

hence, $_2He^6$ is β^- -emitter

Ex.8. The isotope $_{71}Lu^{173}$ is neutron deficient for stability. The isotopic masses of $_{71}Lu^{173}$ and stable isotope $_{70}Yb^{173}$ are 172.9390 and172.9383 amu, respectively. Predict whether $_{71}Lu^{173}$ decays by β^+ - emission or electron capture or both.

Sol. Δ m = 172.9390 – 172.9383 = 0.0007 amu < 2 × mass of electron

Hence, $_{71}Lu^{173}$ can not undergo β^+-decay. The decay mode must be electron capture.

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6. RADIOACTIVE DISINTEGRATION SERIES

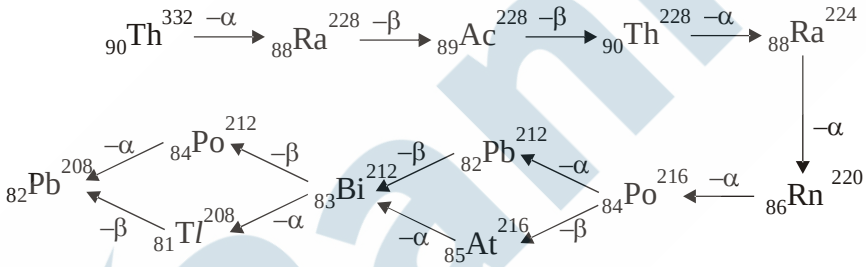
Many radioacitve nucleus (Z > 82) are obtained as a member of decay series.

The series of nuclei is known as radioactive disintegration series.

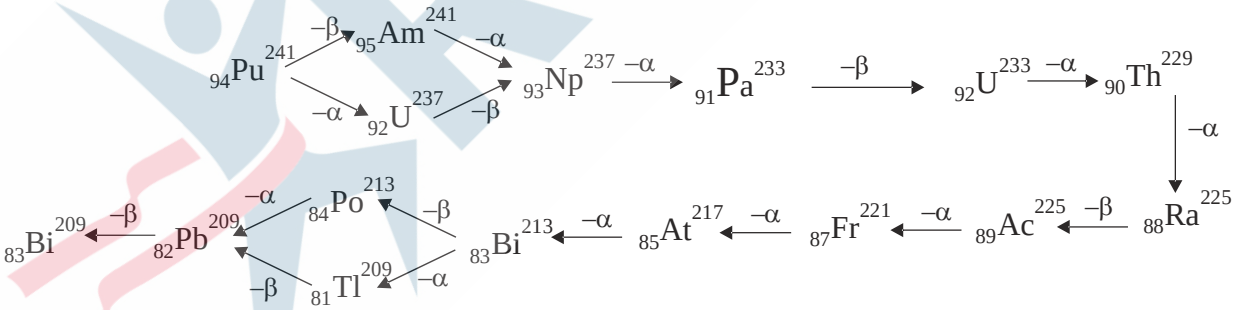
Series	Parent Nucleus	Last Nucleus	No. of α-particles	No. of β-particles
4n or Thorium series	$_{90}Th^{232}$	$_{82}Pb^{208}$	6	4
(4n+1) or Neptutinum series	$_{94}Pu^{241}$	$_{83}Bi^{209}$	8	5
4n+2 or Uranium series	$_{92}U^{238}$	$_{82}Pb^{206}$	8	6
4n + 3 or Actinium series	$_{92}U^{235}$	$_{82}Pb^{207}$	7	4

4n, 4n + 2 and 4n + 3 series are natural while (4n +1) is artifical.

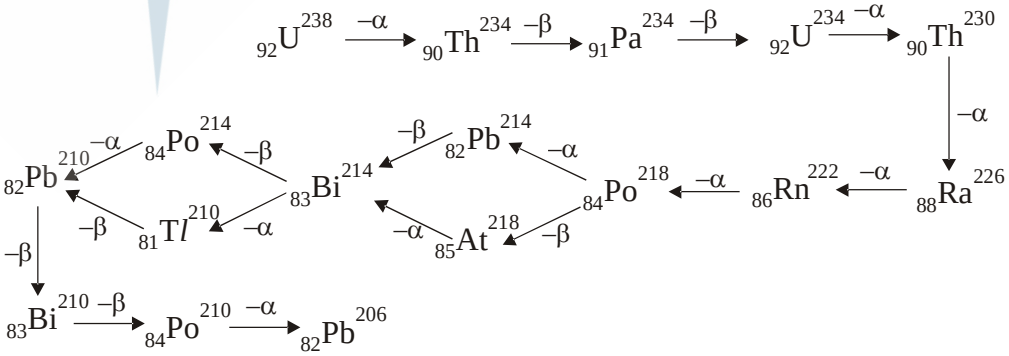
(A) The thorium series :



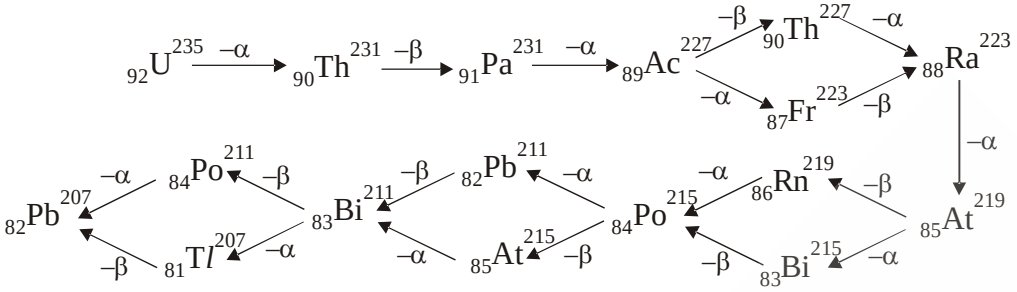
(B) The neptunium series :



(C) The uranium series :



(D) The actinium series :



7. RATE LAW

- **Rutherford and Soddy's law :**

  At an instant, rate of decay or disintegration of active nuclei is directly proportional to the number of active nuclei at that instant.

  $-\frac{dN}{dt}$ = rate of decay or activity (A) at time t and N = active nuclei at time t

  $$-\frac{dN}{dt} \propto N \text{ or } -\frac{dN}{dt} = \lambda N \qquad ...(i)$$

  Here λ is the decay constant or disintegration constant, which is characteristic of that radioisotope, independent from any chemical or physical condition.

  Integral rate law : $N = N_0 e^{-\lambda t}$

7.1 UNITS OF RATE OF DECAY OR ACTIVITY :

1 Becquerel (1 Bq)= 1 dps (SI unit)

1 Curie (Ci) = 3.70×10^{10} dps

1 Rutherford (1 Rd) = 10^6 dps

- **Specific activity :** Activity of 1 gm sample of radioactive substance. Its unit is (dps per gram)

  Specific activity of radium (226) is 1 Ci/gm.

- **Geiger – Muller counter** is used for detecting and counting the α and β–particles.

7.2 HALF LIFE ($T_{1/2}$) :

It is the time in which half of the active nuclei decay

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

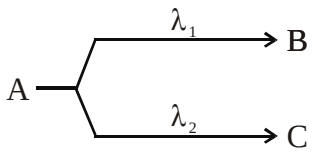
After 'n' half lives, the activity as well as the number of active nuclei reduced to $\frac{1}{2^n}$ times of initial value.

7.3 MEAN OR AVERAGE LIFE (T_{av}) :

It is the average age of all active nuclei i.e.

$$T_{av} = \frac{\text{sum of times of existance of all nuclei in a sample}}{\text{initial number of active nuclei in that sample}} = \frac{1}{\lambda}$$

7.4 PARALLEL DECAY:



(a) The overall decay constant of A, $\lambda = \lambda_1 + \lambda_2$

(b) $\frac{N_B}{N_C} = \frac{\lambda_1}{\lambda_2}$

(c) λ_1 = fractional yield of B × λ

(d) λ_2 = fractional yield of C × λ

7.5 SEQUENTIAL DECAY :

$A \xrightarrow{\lambda_1} B \xrightarrow{\lambda_2} C$ and $\lambda_1 \neq \lambda_2$

(a) At any time, t:

$$N_A = N_A^o . e^{-\lambda, t}$$

$$N_B = \frac{\lambda_1 . N_A^o}{\lambda_2 - \lambda_1} \cdot (e^{-\lambda_1 t} - e^{-\lambda_2 t})$$

$$N_C = N_A^o - (N_A + N_B)$$

(b) Time for maximum nuclei fo B,

$$T_{max} = \frac{1}{\lambda_2 - \lambda_1} \cdot ln \frac{\lambda_2}{\lambda_1}$$

(c) Maximum nuclei of B,

$$N_{Bmax} = N_A^o \cdot \left(\frac{\lambda_2}{\lambda_1}\right)^{\frac{-\lambda_2}{\lambda_2 - \lambda_1}}$$

(d) For steady state of B (radioactive equilibrium $\lambda_1 \cdot N_A = \lambda_2 \cdot N_B$

Ex.9 A free neutron is unstable against β–decay with a half life of about 600 seconds.–

(i) Write the expression of this decay process.

(ii) If there are 600 free neutrons initially, calculate the time by which 450 of them have decayed. Also determine the initial decay rate of the sample.

Sol. (i) $n \rightarrow p + e^- + \bar{\nu}$

(ii) The number of undecayed neutron would be 150 by using $N = N_0 e^{-\lambda t}$

$150 = 600e^{-\lambda t} \Rightarrow t = 2T_{1/2} = 1200$ sec

Decay rate (initial) $R = \lambda N_0 = \frac{0.693}{600} \times 600 = 0.693 \text{ dps}$

Ex.10. Obtain the amount of polonium necessary to provide a radioactivity source of 5.0 mili curie strength. The half life of polonium is 138 days.

Given : 1 curie = 3.7×10^{10} disintregration/sec., Avogadro number = 6.02×10^{26} per k-mole

Sol. Given : $r = 5 \times 10^{-3} \times 3.7 \times 10^{10}$ disint./sec. & $t_{1/2} = 138 \times 24 \times 3600$ sec and $r = \lambda N$

$= \frac{0.693}{t_{1/2}} N$

$\Rightarrow N = \frac{138 \times 24 \times 3600 \times 5 \times 3.7 \times 10^7}{0.693} = 3.18 \times 10^{15}$ atoms

$\therefore$ Amount of ${}_{84}Po^{210}$ in grams required $= \frac{210 \times 3.18 \times 10^{15}}{6.02 \times 10^{23}} = 1.11 \times 10^{-6}$

Ex.11. Calculate the radioactive disintegration constant if 3.7×10^{10} alpha particles are emitted by 1 gram of radium per second. Avogadro's number is 6.03×10^{23} and the mass number of radium is 226.

Sol. Activity $= N\lambda = \left(\frac{N_A}{M_w} \times m\right)\lambda$

$\Rightarrow 3.7 \times 10^{10} = \left(\frac{6.03 \times 10^{23}}{226} \times 1\right)\lambda$

$\lambda = \frac{3.7 \times 10^{10} \times 226}{6.03 \times 10^{23}} = 1.38 \times 10^{-11}$ per second

Ex.12. The half lives of X and Y are 3 minutes and 27 minutes respectively. At some instant activity of both are same, then the ratio of active nuclei of X and Y at that instant is ?

Sol. $A_1 = \lambda_1 N_1$ and $A_2 = \lambda_2 N_2$

$A_1 = A_2 \Rightarrow \frac{0.693}{T_1} N_1 = \frac{0.693}{T_2} N_2$

$\Rightarrow \frac{N_1}{T_1} = \frac{N_2}{T_2} \Rightarrow \frac{N_1}{N_2} = \frac{3}{27} = \frac{1}{9}$

$\Rightarrow N_1 : N_2 = 1 : 9$

Ex.13. Decay constant of two radioactive samples is λ and 3λ respectively. At t = 0, they have equal number of active nuclei. Calculate when will be the ratio of active nuclei becomes e : 1.

Sol. Number of active nuclei of two radioactive sample is

$N_1 = N_{01}e^{-\lambda t}$ and $N_2 = N_{02}e^{-3\lambda t}$

$$\therefore \frac{N_1}{N_2} = \frac{e}{1} = \frac{N_{01}e^{-\lambda t}}{N_{02}e^{-3\lambda t}} = e^{2\lambda t} \quad [\because N_{01} = N_{02}]$$

$$\therefore 1 = 2\lambda t \quad \Rightarrow \quad t = \frac{1}{2\lambda}$$

Ex.14. The fraction of a radioactive sample which remains active after time t is $\frac{9}{16}$. What fraction remains active after $\frac{t}{2}$ time ?

Sol. Active fraction $= \frac{N}{N_0} = e^{-\lambda t}$ At time t, $\frac{9}{16} = e^{-\lambda t}$

At time t/2 active fraction = $x = e^{-\lambda t/2} = \left(e^{-\lambda t}\right)^{\frac{1}{2}}$

So $x = \left(\frac{9}{16}\right)^{\frac{1}{2}} = \frac{3}{4}$

Ex.15. Two radioactive nuclides A and B have half life 150 min and 15 mins respectively. A fresh sample contains nuclides of B to be 32 times that of A. How much time should elapse so that number of nuclides of A becomes twice that of B ?

Sol. **(100 sec)**

N_0 = initial nuclides of A

After t mins, $N_0 e^{-\left(\frac{\ln 2}{150}\right)t} = 2\left[32N_0 e^{-\left(\frac{\ln 2}{15}\right)t}\right] \Rightarrow t = 100$ sec.

Ex.16. ${}^{M}_{Z}X(g) \longrightarrow {}^{M-8}_{Z-4}Y(g) + \alpha - \text{particles}$

The radioactive disintergration follows first order kinetics starting with one mole of X in a 12-litre closed flask at 27°C. Find the total pressure (in atm) after two half lives.

[R = 0.08L atm $mol^{-1}K^{-1}$]

Ans. 5

${}^{M}_{Z}X(g) \longrightarrow {}^{M-8}_{Z-4}Y(g) + 2{}^{4}_{2}He$

t = 0	1 mol	0	0
$t = 2t_{½}$	0.25 mol	0.75 mol	1.5 mol

total gaseous moles = 0.25 + 0.75 + 1.5

= 2.5 mol

$$p = \frac{nRT}{V} = \frac{2.5 \times 0.08 \times 300}{12} = 5 \text{ atm}$$

Ex.17. In the parallel radioactive decay,

$A \xrightarrow{\lambda_1} B$

$A \xrightarrow{\lambda_2} C$

the time when number of radioactive nuclei of A, B & C becomes equal is

[Given $\lambda_1 = \ell n3\ hr^{-1}$, $\lambda_2 = \ell n3\ hr^{-1}$]

(1) 0.5 min (2) 30 min (3) 60 min (4) 90 min

Ex.17. Ans.(2)

Sol. $C_A = C_{A_0} - C_B - C_C$

$x = C_{A_0} - x - x$

or $3x = C_{A_0} \Rightarrow x = \frac{C_{A_0}}{3}$

$\because C_A = C_{A_0} e^{-(\lambda_1+\lambda_2)t}$

or $\frac{C_{A_0}}{3} = C_{A_0} e^{-(\lambda_1+\lambda_2)t}$

or $3 = e^{(\lambda_1+\lambda_2)t}$

or $t = \frac{\ln 3}{2 \ln 3} = \frac{1}{2}\ hr = 30\ min$

8. APPLICATION OF RADIOACTIVITY AND RADIO ISOTOPES

8.1 IN MEDICINE :

(i) Testing of blood circulation – Cr^{57}

(ii) Brain tumour detecting – Hg^{203}

(iii) Thyroid testing (cancer) – I^{131}

(iv) Cancer cure – Co^{60}

(v) Blood cancer cure – Au^{189}, Na^{24}, P^{32}

8.2 IN AGRICULTURE :

(i) For protecting potato from earthworm – Co^{60}

(ii) Fertilizers – P^{32}

8.3 IN ARCHAEOLOGY :

8.3.1 Carbon dating (age of fossils) :

Radiocarbon $({}_6C^{14})$ dating of historical wooden derived objects is based on the knowledge that the cosmic ray intensity (responsible for C^{14} production) has been practically constant for thousands of years. C^{14} is formed in the upper atmosphere by the action of cosmic radiation of N^{14}.

${}_7N^{14} + n_0^1 \longrightarrow {}_6C^{14} + {}_1H^1$

The C^{14} so produced is eventually converted into CO_2, which in term is incorporated into plants and trees by the process of photosynthesis and then finds way into animals, which eat plants, Because of the natural plant-animal cycle, an equilibrium is set up and all living matter contains the same proportion of C^{14} as it occurs in the atmosphere. Once the plant or animal dies, the uptake of the CO_2 by it ceases and the level of C^{14} in the dead begins to fall due to β^-- decay.

$$_6C^{14} \longrightarrow {}_7N^{14} + \beta^-$$

A comparision of the β^--activity of the dead matter with that of the carbon still in circulation enables measurement of the period of isolation of the material from the living cycle (age of fossil).

Ex.18. The beta activity of 1 g of carbon made from green wood is 15.3 counts per minute. If the activity of 1 g of carbon derived from the wood of an Egyptian mummy case is 9.4 counts per minute under the same conditions, how old is the wood of the mummy case? $t_{1/2}$ of C^{14} = 5770 yrs.

Sol.. $t = \dfrac{t_{1/2}}{\log 2} \cdot \log \dfrac{r_0}{r} = \dfrac{5770}{\log 2} \cdot \log \dfrac{15.3}{9.4} \simeq$ 3920 yrs.

8.3.2 Rock dating (Age of minerals, rocks, earth, etc) :

The age of the rocks and minerals may be determined by analysing the sample for a radionucleide (say U^{238}) and its decay product (Pb^{206}). Assuming that no decay product was present initially and all the intermediate products (if any) have achieved steady state, we can determine the age.

	$\underset{\text{radio nuclide}}{A} \longrightarrow \underset{\text{decay product}}{B}$	
t = 0	a mole	0
t = present	(a–x) mole	x mole

$\therefore$ age of rock, $t = \dfrac{1}{\lambda}, \quad l\,n \dfrac{a}{a-x}$

In the determination of age of earth, moon, etc, it is assumed that the rock was present from the time of evolution of earth, moon, etc.

Ex.19. A rock was found to contain U^{238} and Pb^{206} in 1.19: 1.03 mass ratio. What is the age of rock? $t_{1/2}$ of $U^{238} = 4.5 \times 10^9$ yrs.

Sol.

	$U^{283} \longrightarrow$	Pb^{206}
t = 0	a mole	0
t = t	(a–x) mole	x mole
	$= \dfrac{1.19}{238}$	$= \dfrac{1.03}{206}$

$\therefore \quad x = 5 \times 10^{-3}$ and $a = 10 \times 10^{-3}$

$$\text{Now, } t = \frac{t_{1/2}}{\log 2} \cdot \log \frac{a}{a-x} = 4.5 \times 10^9 \text{ yrs}$$

Ex.20. To determine age of a stone it was analysed and 10^{20} nuclei of A & 7×10^{20} nuclei of B were obtained. If nuclei B are assumed to be obtained only due to radioactive decay of A and no B was present initially. Find age of stone in days. [Half life of A = 1000 days]

Sol. A $\longrightarrow$ B

$a - x = 10^{20}$ $\quad x = 7 \times 10^{20}$

$a = 10^{20} + 7 \times 10^{20} = 8 \times 10^{20}$

$$\frac{a}{a-x} = \frac{8}{1}$$

$t = 3 \times t_{1/2} = 3 \times 1000 = 3000$ days

9. NUCLEAR REACTIONS

The reactions in which nuclei of atoms interact with other nuclei or elementary particles such as α-particle, proton, neutron, deutron, etc, resulting in the formation of new nuclei with or without liberation of one or more elementary particles, are called nuclear reactions. The particles causing nuclear reactions are also called projectiles. In all the nuclear reactions, the sum of number of protons and neutrons and the total charge are conserved. Nuclear reactions may be expressed as similar as chemical reactions, like

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

Here, the nucleus of nitrogen atom is converted in to the nucleus of oxygen atom by α-particle and proton is also produced as a by-product. These reactions may be expressed by short hand notation, in which the projectile and the liberating particle are expressed by their symbols, in a small bracket in between the parent and the product nucleus. For example, the above reaction may also be expressed as :

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

9.1 SOME DIFFERENCES BETWEEN NUCLEAR AND CHEMICAL REACTIONS :

No.	Chemical reaction	Nuclear reaction
1.	No new element is formed	New element is formed
2.	Valence electrons of atoms participates	Only the nucleus of atoms participates
3.	Balanced by the conservation of atoms	Balanced by the conservation of nuclear charge and mass number (total number of neutrons and protons)
4.	Mass conservation is obeyed	Disobey mass conservation
5.	May be exothermic or endothermic, liberating or absorbing relatively small amount of energy	May be exothermic or endothermic, liberating or absorbing relatively very high amount of energy
6.	May be reversible	Irreversible
7.	May obey kinetics of any order	Obeys only first order kinetics
8.	Rate depends on external factors like temperature and the catalytic conditions	Rate is independent of any external condition

Ex.21. Select the incorrect nuclear reaction -

(A) ${}_7N^{14}(\alpha, p){}_8O^{17}$ (B) ${}_{21}Sc^{45}(n, \alpha){}_{20}Ca^{42}$

(C) ${}_{11}Na^{22} \xrightarrow{\beta^+ \text{ decay}} {}_{12}Mg^{24}$ (D) ${}_6C^{11} \xrightarrow{K-e^- \text{ Capture}} {}_5B^{11}$

Ans (B, C)

(A) ${}_7N^{14}(\alpha, P){}_8O^{17}$

${}_7N^{14} + {}_2^4He \rightarrow {}_8O^{17} + {}_1^1H$

(A) is correct

(B) ${}_{21}Sc^{45}(n, \alpha){}_{20}Ca^{42}$

${}_{21}Sc^{45} + {}_0^1n \rightarrow {}_{20}Ca^{42} + {}_2^4He$

(B) is incorrect

(C) ${}_{11}Na^{22} \xrightarrow{\beta^+ \text{decay}} {}_{12}Mg^{24}$

${}_{11}Na^{22} \rightarrow {}_{12}Mg^{24} + {}_1^0e$

(C) is incorrect

(D) ${}_6C^{11} \xrightarrow{Ke^- \text{cap}} {}_5B^{11}$

${}_6C^{11} + {}_{-1}^0e \rightarrow {}_5B^{11}$

(D) is correct

hence Ans is (B) & (C)

9.2 ARTIFICAL TRANSMUTATION :

It is the method of conversion of atom of one element in to the atom of other element with the help of some particles like alpha particle, proton, deutron, neutron, etc (called projectiles). The first such transmutation was performed by Rutherford. When N^{14} atoms were bombarded by very fast moving α-particles, the nitrogen atom has changed in to oxygen atom and proton is produced simultaneously

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

Later on, Rutherford and Chadwick showed that most of the nuclei may be transmuted by the suitable projectile. After the discovery of cyclotron, a particle accelerating machine, such transmutations became easier.

9.3 TYPES OF NUCLEAR REACTIONS :

(A) Projectile Capture Reactions :

$$_{92}U^{238} + {}_{0}n^{1} \rightarrow {}_{92}U^{239} + \gamma$$
$$_{13}Al^{27} + {}_{0}n^{1} \rightarrow {}_{13}Al^{28} + \gamma$$

(B) Particle - particle reactions :

$$_{11}Na^{23} + {}_{1}H^{1} \rightarrow {}_{12}Mg^{23} + {}_{1}n^{1}$$
$$_{11}Na^{23} + {}_{1}H^{2} \rightarrow {}_{11}Na^{24} + {}_{1}H^{1}$$

(C) Spallation reactions : High speed projectiles with 400MeV bombarded on high nucleus giving smaller nucleus.

$$_{29}Cu^{63} + {}_{2}He^{4} \rightarrow {}_{17}Cl^{37} + 14\,{}_{1}H^{1} + 16\,{}_{0}n^{1}$$

(D) Fission reactions : It is the nuclear reaction in which a heavy nucleus is broken down by a slow or thermal neutron (energy about 0.04 eV) into two relatively smaller nuclei with the emission of two or more neutrons and large amount of energy. For example,

the **reaction of atom bomb :** $_{92}U^{235} + {}_{0}n^{1} \rightarrow {}_{56}Ba^{141} + {}_{36}Kr^{92} + 3\,{}_{0}n^{1} + 200$ MeV

It is also found that the products of nuclear fission reactions are not unique. Some more products are formed. The most probable mass numbers of the two nuclides formed are around 95 and 140 and an average of 2.5 neutrons is emitted out per fission.

$$_{92}U^{235} + {}_{0}n^{1} \rightarrow {}_{54}Xe^{139} + {}_{38}Sr^{95} + 2\,{}_{0}n^{1}$$
$$\rightarrow {}_{53}I^{137} + {}_{39}Y^{97} + 2\,{}_{0}n^{1}, \text{ etc}$$

The destructive action of atom bomb is due to the following reasons:

(i) As some neutrons are produced in each fission, they may collide efficiently with the other U^{235} nuclei to produce more neutrons and thus the reaction occurs in chain like fashion. It results the emission of a large amount of energy in very small time.

(ii) Each product of fission is radioactive and hence increases the intensity of radiation in that region, causing the problems due to radiations.

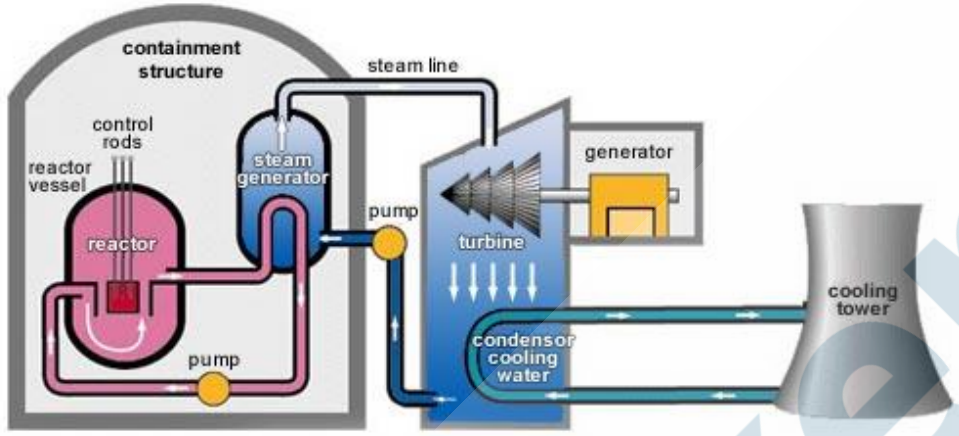
(E) Fusion reactions: It is the nuclear reaction in which two or more light nuclei fused together to form heavier nuclei, with the evolution of tremendous amount of energy. In such reactions, relatively more stable nucleus having higher binding energy per nucleon is formed. Such reaction is difficult to occur because when the nuclei of different atoms come closer, they repel each other strongly. This is why, very high temperature of the order 10^{6}K is needed for the occurrence of such reactions. However, the overall reaction is highly exothermic due to large mass defect. Some examples of nuclear fusion reactions are :

Probable reaction of hydrogen bomb: $_{1}H^{2} + {}_{1}H^{2} \rightarrow {}_{2}He^{4} + 24.9$ MeV

Probable reaction occurring at the surface of sun: $4\,{}_{1}H^{1} \rightarrow {}_{2}He^{4} + 2_{+1}e^{0} + 24.7$ MeV

10. NUCLEAR REACTOR

A nuclear reactor is the furnace, place where nuclear fission reaction is performed to get energy. The essentials of a nuclear reactor are:



(A) Fuel : Nuclear fuels are of two types:

(i) Fissile materials : These are the nuclides which directly results chain reaction on bombardment with slow neutrons. Such nuclides are U^{235}, Pu^{239}, $U^{233,}$ etc.

(ii) Fertile material : These are the nuclides which are non-fissile, but they may be converted in to a fissile material by the action of neutrons. Such nuclides are U^{238} and Th^{232}.

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

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

Such conversions are performed in a special type of nuclear reactor called **Breeder Reactor**.

(B) Moderator: It is used to slow down the fast neutrons without absorbing them. Example: water, graphite, helium, D_2O etc.

(C) Control rods: These are the rods of material which can absorb neutrons and hence control the fission reaction. Example: Cadmium, boron, etc.

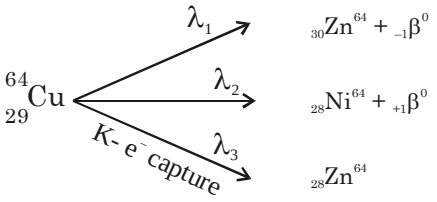
(D) Coolant : These are the material which transforms the energy produced in the fission reaction in to heat energy. Example: Liquid alloy of sodium and potassium, heavy water, polyphenyls, etc

PREVIOUS MISCELLANEOUS QUESITON

Q.1 ^{64}Cu (half-life = 12.8 hr) decays by β^- emission (38%), β^+ emission (19%) and electron capture (43%). Write the decay product and calculate partial half-lives for each of the decay processes. **[JEE 2002]**

Ans. $^{64}_{30}Zn$, $^{64}_{28}Ni$, $(t_{1/2})_1 = 33.68$ hr, $(t_{1/2})_2 = 67.36$ hr, $(t_{1/2})_3 = 29.76$ hr

Sol.



$$\frac{\lambda_1}{\lambda_1+\lambda_2+\lambda_3}\times 100 = 38 \quad \text{.....(i)}$$

$$\frac{\lambda_2}{\lambda_1+\lambda_2+\lambda_3}\times 100 = 18 \quad \text{.....(ii)}$$

$$\frac{\ln 2}{\lambda_1+\lambda_2+\lambda_3} = 12.8 \quad \text{.....(iii)}$$

On solving equations :

$\lambda_1 = 0.38$ $(t_{1/2})_I = 33.68$ hr ; $(t_{1/2})_{II} = 67.36$; $(t_{1/2})_{III} = 29.7$ hr

Q.2 A radioactive sample emits n β-particles in 2 sec. In next 2 sec it emits 0.75 n β-particles, what is the mean life of the sample? **[JEE 2003]**

Ans. $1.75n = N_0(1 - e^{-4\lambda})$, 6.95 sec, $\dfrac{2}{ln\left(\dfrac{4}{3}\right)}$

Sol. $n = N_0[1 - e^{-2\lambda}]$ .....(i)

$1.75\ n = N_0\ [1 - e^{-4\lambda}]$ .....(ii)

$\Rightarrow 1.75 = 1 + e^{-2\delta}$

$$\frac{3}{4} = e^{-2\lambda}$$

$$\lambda = \frac{1}{2}\ln\left(\frac{4}{3}\right)$$

Q.3 Fill in the blanks **[JEE 2005]**

(a) $^{235}_{92}U + ^{1}_{0}n \longrightarrow ^{137}_{52}A + ^{97}_{40}B +$ _____.

(b) $^{82}_{34}Se \longrightarrow 2\,^{0}_{-1}e +$ _____.

Ans. (a) $2\,^{1}_{0}n$, (b) $^{82}_{36}Kr$

Question No. 4 to 6 (3 questions)

Carbon 14 is used to determine the age of orgainc material. The procedure is based on the formation of ^{14}C by neutron capture in the upper atmosphere.

$$_7N^{14} + _0n^1 \longrightarrow _6C^{14} + _1H^1$$

^{14}C is absorbed by living organisms during photosynthesis. The ^{14}C content is constant in living organism once the plant or animal dies, the uptake of carbon dioxide by it ceases and the level of ^{14}C in the dead being falls due to the decay which C^{14} undergoes.

$$_6C^{14} \longrightarrow _7N^{14} + _{-1}e^{\circ}$$

The half life period of ^{14}C is 5770 years. The decay constant (λ) can be calculated by using the following formula $\lambda = \dfrac{0.693}{t_{1/2}}$

The comparison of the β^- activity of the dead matter with that of carbon still in circulation enables measurement of the period of the isolation of the material from the living cycle. The method however, ceases to be accurate over periods longer than 30,000 years. The proportion of ^{14}C to ^{12}C in living matter is $1 : 10^{12}$ **[JEE 2006]**

Q.4 Which of the following option is correct ?

(A) In living organisms, circulation of ^{14}C from atmosphere is high so the carbon content is constant in organism

(B) Carbon dating can be used to find out the age of earth crust and rocks

(C) Radioactive absorption due to cosmic radiation is equal to the rate of radioactive decay, hence the carbon content remains constant in living organism

(D) Carbon dating cannot be used to determine concentration of ^{14}C in dead beings.

Ans. (C)

Q.5 What should be the age of fossil for meaningful determination of its age?

(A) 6 years (B) 6000 years

(C) 60000 years (D) it can be used to calculate any age

Ans. (B)

Q.6 A nuclear explosion has taken place leading to increase in concentration of C^{14} in nearby areas. C^{14} concentration is C_1 in nearby areas and C_2 in areas far away. If the age of the fossil is determined to be t_1 and t_2 at the places respectively, then

(A) The age of the fossil will increase at the place where explosion has taken place and $t_1 - t_2 = \dfrac{1}{\lambda} \ln \dfrac{C_1}{C_2}$

(B) The age of the fossil will decrease at the place where explosion has taken place and $t_1 - t_2 = \dfrac{1}{\lambda} \ln \dfrac{C_1}{C_2}$

(C) The age of fossil will be determined to be the same

(D) $\dfrac{t_1}{t_2} = \dfrac{C_1}{C_2}$

Ans. (A)

Sol. Age in nearby areas :

$$\lambda t_1 = \ln \frac{C_1}{C_t} \quad .....(i)$$

age in for away area

$$\lambda t_2 = \ln \frac{C_2}{C_t} \quad .....(ii)$$

as $C_1 > C_2$ so age of fossil increase is nearby areas by value.

$$(t_1 - t_2) = \frac{1}{\lambda} \ln \left(\frac{C_1}{C_2} \right)$$

Q.7 A positron is emitted from $^{23}_{11}Na$. The ratio of the atomic mass and atomic number of the resulting nuclide is **[JEE 2006]**

(A) 22/10 (B) 22/11 (C) 23/10 (D) 23/12

Ans. (C)

$$_{11}Na^{23} \longrightarrow {}_{10}Ne^{23} + {}_{1}\beta^{0}$$

$$\frac{n}{p} = \frac{23}{10}$$

Q.8 **STATEMENT-1 :** The plot of atomic number (y-axis) versus number of neutrons (x-axis) for stable nuclei shows a curvature towards x-axis from the line of 45° slope as the atomic number is increased.

and

STATEMENT-2 : Proton-proton electrostatic repulsions begin to overcome attractive forces involving protons and neutrons in heavier nuclides. **[JEE 2008]**

(A) STATEMENT-1 is True, STATEMENT-2 is True ; STATEMENT-2 is a correct explanation for STATEMENT-1

(B) STATEMENT-1 is True, STATEMENT-2 is True ; STATEMENT-2 is NOT a correct explanation for STATEMENT-1

(C) STATEMENT-1 is True, STATEMENT-2 is False

(D) STATEMENT-1 is False, STATEMENT-2 is True

Ans. (A)

Q.9 The total number of α and β particles emitted in the nuclear reaction $^{238}_{92}U \rightarrow ^{214}_{82}Pb$ is. **[JEE 2009]**

Ans. (8)

Sol. $_{92}U^{238} \longrightarrow {}_{82}Pb^{214} + 6\ {}_{2}He^{4} + 2\ {}_{-1}\beta^{0}$

Q.10 The number of neutrons emitted when $^{235}_{92}U$ undergoes controlled nuclear fission to $^{142}_{54}Xe$ and $^{90}_{38}Sr$ is - **[JEE 2010]**

Ans. (4)

Sol. $_{92}U^{235} + {}_{0}n^{1} \longrightarrow {}_{54}Xe^{142} + {}_{38}Sr^{90} + 3\ {}_{0}n^{1}$

EXERCISE (S-1)

Q.1 Of the three isobars $^{114}_{48}Cd$, $^{114}_{49}In$ and $^{114}_{50}Sn$, which is likely to be radioactive? Explain your choice.

Q.2 Classify each of the following nuclides as "beta $\left(^{0}_{-1}\beta\right)$ emitter", or "positron $\left(^{0}_{+1}\beta\right)$ emitter":

$^{49}_{20}Ca$, $^{195}_{80}Hg$, $^{8}_{5}B$, $^{150}_{67}Ho$, $^{30}_{13}Al$, $^{94}_{36}Kr$. Note: $^{84}_{36}Kr$, $^{200}_{80}Hg$ and $^{165}_{67}Ho$ are stable

Q.3. (a) Calculate number of α and β-particles emitted when $_{92}U^{238}$ changes into radioactive $_{82}Pb^{206}$.

(b) $_{92}U^{235}$ disintegrates and emits 4β- and 7α-particles to form a stable element. Find the atomic number and mass number of the stable product. Also identify the element.

Q.4 A radioactive isotope disintegrates and emits 6 β and 7 α particles to form a stable product. Find the difference between atomic number of parent radioactive isotope and the stable product.

Q.5 Find the α-activity of 1 gm ^{200}Ra. ($\lambda = 4.8 \times 10^{-7} min^{-1}$) in dpm. ($N_A = 6 \times 10^{23}$)

Q.6 The half life of the nuclide Rn^{220} is 54.5 sec. Find mass (in kg) of radon is equivalent to 1 millicurie.

Q.7 At any given time a piece of radioactive material ($t_{1/2}$ = 30 days) contains 10^{12} atoms. Calculate the activity of the sample in dps.

Q.8 The activity of the radioactive sample drops to 1/64 of its original value in 2 hr. Find the decay constant (λ).

Q.9 A radioactive substance decays 20% in 10 min. If at start there are 5×10^{20} atoms present, find time after which the number of atoms will be reduced to 10^{18}. (log2 = 0.3)

Q.10 The half life period of $_{53}I^{125}$ is 60 days. What % of radioactivity would be present after 240 days.

Q.11 The activity of a radioactive sample decreases to 1/3 of the original activity (A_0) in a period of 9 years. After 9 years more, its activity is A_0/x. Find the value of x.

Q.12 5 moles of a radio-active isotope $^{A}_{Z}X$ (s) were taken in a 24.6 litre vessel at 600K and the following decay started : $^{A}_{Z}X(s) \longrightarrow {}^{A-8}_{Z-4}Y(s)$

If pressure developed after 16 hours was 15 atm, calculate half life of sample 'X' in hours.
Use : R = 0.082 L-atm/mol-K.

Q.13 Calculate the age of a vegetarian beverage whose tritium content is only 15% of the level in living plants. Given $t_{1/2}$ for $_1H^3$ = 12.3 years. (log2 = 0.3, log3 = 0.48)

Q.14 The volume of the blood in a patient is estimated by recording the activity of Na^{24} administered into the patient's blood. Find the volume (in ℓ) of the blood if the activity after 25 hrs is 8 dpm $m\ell^{-1}$. Given the initial activity of Na^{24} sample is 2×10^3 Bq when administered & the $t_{1/2}$ for Na^{24} = 15 hrs. (use $32^{1/3} \simeq 3$)

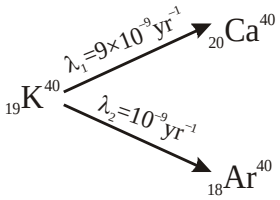
Q.15 A sample of U^{238} (half life = 4.5×10^9 yr) ore is found to contain 23.8 g of U^{238} and 20.6 g of Pb^{206}. Calculate the age of the ore.

Q.16 An isotopes of Potassium $^{40}_{19}K$ has a half life of 1.4×10^9 year and decays to Argon $^{40}_{18}Ar$ which is stable.

(i) Write down the nuclear reaction representing this decay.

(ii) A sample of rock taken from the moon contains both potassium and argon in the ratio 1/3. Find age of rock.

Q.17 K^{40} decays into Ca^{40} & Ar^{40} simultaneously as follows



Ratio of atoms of 'Ar' to 'K' in a rock sample is 3 :10. Calculate age of rock sample assuming that source of 'Ar' is radioactive decay of 'K^{40}' only and no 'Ar' was present at the time of formation of rock.

If your answer is ($\ln$ x) × 10^8 years, then the value of 'x' is.

Q.18 Complete the following nuclear equations:

(a) ${}^{14}_{7}N + {}^{4}_{2}He \rightarrow {}^{17}_{8}O + ...$

(b) ${}^{9}_{4}Be + {}^{4}_{2}He \rightarrow {}^{12}_{6}C + ...$

(c) ${}^{9}_{4}Be\ (p, \alpha) .....$

(d) ${}^{30}_{15}P \rightarrow {}^{30}_{14}Si + ...$

(e) ${}^{3}_{1}H \rightarrow {}^{3}_{2}He + ...$

(f) ${}^{43}_{20}Ca(\alpha,....) \rightarrow {}^{46}_{21}Sc$

(g) ${}^{23}_{11}Na + {}^{4}_{2}He \rightarrow {}^{26}_{12}Mg + ...$

(h) ${}^{64}_{29}Cu \rightarrow \beta^{+} + ...$

(i) ${}^{106}_{47}Ag \rightarrow {}^{106}_{48}Cd + ...$

(j) ${}^{10}_{5}B + {}^{4}_{2}He \rightarrow {}^{13}_{7}N + ...$

Q.19 Consider the following reaction; ${}^{2}H_1 + {}^{2}H_1 \rightarrow {}^{4}_{2}He + Q$: Mass of the deuterium atom = 2.0141 u ; Mass of the helium atom = 4.0024 u. Find approximate value of 'Q' (in MeV)

Q.20 Calculate the energy released in MeV in the following nuclear reaction:

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

Assume that the masses of ${}^{2}_{1}H$, ${}^{3}_{2}He$ and neutron (n) respectively are 2.020, 3.016 and 1.008 in amu.

EXERCISE (S-2)

Q.1 In the nuclear reaction $X^{200} \longrightarrow A^{110} + B^{90}$. If the binding energy per nucleon for X, A and B is 7.4 MeV, 8.2. MeV and 8.2 MeV respectively, Find the energy released.

Q.2 The binding energies per nucleon for $_1H^2$ and $_2He^4$ are 1.1 MeV and 7.0 MeV respectively. Find the energy released when two deuterons fuse to form a helium nucleus.

Q.3 When ^a_cX changes to ^b_dY . Find number of α and β particle.

Q.4 At a given instant there are 25 % undecayed radioactive nuclei in a sample. After 10 sec, the number of undecayed nuclei remains 12.5 % . Calculate :

(i) mean – life of the nuclei and

(ii) The time in which the number of undecayed nuclear will further reduce to 6.25 % of the reduced number.

Q.5 One of the hazards of nuclear explosion is the generation of Sr^{90} and its subsequent incorporation in bones. This nuclide has a half life of 40 year. Suppose one microgram was absorbed by a new-born child, how much Sr^{90} will remain in his bones after 20 years?

Q.6 During the decay of 928 gm $_{90}Th^{232}$ to $_{82}Pb^{208}$, total 9.3×10^{24} β-particle are emitted upto 't' time. Then calculate t/T.

[λ of "Th" = $\frac{l\,n\,2}{T}$; $N_A = 6 \times 10^{23}$].

Q.7 The β count given by carbon obtained from an ancient fossil was 12 counts per second, while the β-count given by carbon sample from freshly cut tree was found to be 15 count per second. What is the age of fossil in years. Given : ($t_{1/2}$ of C^{14} = 5770 yrs, ln5 = 1.6, ln2 = 0.7)

Q.8 The nuclidic ratio ^3_1H to ^1_1H in a sample of water is 8.0×10^{-18} : 1 Tritium undergoes decay with a half-life period of 12 years. How many tritium atoms would 10.0 g of such a sample contain 36 years after the original sample is collected.

Q.9 Ac^{227} has a half life of 22 year w.r.t radioactive decay. The decay follows two parallel paths, one leading the Th^{227} and the other leading to Fr^{223}. the percentage yields of these two daughters nucleides are 2% and 98% respectively. What is the rate constant in yr^{-1}, for each of the separate paths?

Q.10. Consider the following process of decay,

$_{92}U^{234} \rightarrow _{90}Th^{230} + _2He^4$; $t_{1\backslash 2}$ = 250000 yr

$_{90}Th^{230} \rightarrow _{88}Ra^{226} + _2He^4$; $t_{1\backslash 2}$ = 80000 yr

$_{88}Ra^{226} \rightarrow _{86}Rn^{222} + _2He^4$; $t_{1\backslash 2}$ = 1600 yr

After the above process has occurred for a long time, a state is reached where for every two thorium atoms formed from $_{92}U^{234}$, one decomposes to form $_{88}Ra^{226}$ and for every two $_{88}Ra^{226}$ formed, one decomposes. Calculate the ratio of number of atoms of $_{90}Th^{230}$ to $_{88}Ra^{226}$ at this state.

EXERCISE (O-1)

Q.1 $^{14}_{6}C$ decays by emission of

(A) β^- (B) β^+ (C) n (D) α

Q.2 When $^{30}_{15}P$ emits a positron, the daughter nuclide formed is

(A) $_{15}P^{29}$ (B) $_{16}Si^{30}$ (C) $_{14}Si^{30}$ (D) $_{16}P^{30}$

Q.3 $^{27}_{13}Al$ is a stable isotope. $^{29}_{13}Al$ is expected to disintegrated by

(A) α emission (B) $^{0}_{-1}\beta$ emission (C) Positron emission (D) Proton emission

Q.4 Loss of a β – particle is equivalent to

(A) Increase of one proton only

(B) Decrease of one neutron only

(C) Increase of one proton and decrease of one neutron

(D) None of these.

Q.5 Which of the following nuclear reactions will generate an isotope?

(A) neutron emission (B) positron emission

(C) α-emission (D) β-emission

Q.6 The S^{35} is neutron-rich, therefore, it is likely to undergo radioactive decay by

(A) electron capture (B) beta emission (C) positron emission (D) alpha emission

Q.7 The number of α and β-particles emitted, when the following nuclear transformation takes place are _____ and _____ respectively.

$^{238}_{92}X \longrightarrow ^{206}_{82}Y$

(A) 6, 2 (B) 5, 6 (C) 8, 4 (D) 8, 6

Q.8 $_{35}X^{88}$ an unstable isotope, decays in two successive steps to produce stable isotope $_{32}Z^{84}$ as

$_{35}X^{88} \xrightarrow{I} Y \xrightarrow{II} {}_{32}Z^{84}$

The correct statement is (possible emission are α, β,positron, neutron, and K-capture)

(A) I may involve a β-emission. (B) II may involve a neutron emission

(C) Y and Z may be isodiaphers (D) X and Z may be isodiaphers

Q.9 Which of the following can not be natural decay product (only α, β & γ decay) of $_{90}Th^{232}$

(A) $_{89}Ac^{228}$ (B) $_{86}Rn^{220}$ (C) $_{88}Ra^{226}$ (D) $_{84}Po^{216}$

Q.10 The half-life of a radioactive isotope is three hours. If the initial mass of the isotope were 256 g, the mass of it remaining undecayed after 18 hours would be

(A) 16.0 g (B) 4.0 g (C) 8.0 g (D) 12.0 g

Q.11 The half-life of a radioisotope is four hours. If the initial rate of the isotope was 200 dpm, the rate after 24 hours is

(A) 6.25 dpm (B) 2.084 dpm (C) 3.125 dpm (D) 4.167 dpm

Q.12 The half life of Tc^{99} is 6.0 hr. The delivery of a sample of Tc^{99} from the reactor to the nuclear medicine lab of a certain hospital takes 3.0 hr. What is the minimum amount of Tc^{99} that must be shipped in order for the lab to receive 10.0 mg? ($\sqrt{2} = 1.41$)

(A) 20.0 mg (B) 15.0 mg (C) 14.1 mg (D) 12.5 mg

Q.13 Two radioactive nuclides A and B have half lives of 50 min and 10 min respectively. A fresh sample contains the nuclides of B to be eight time that of A. How much time should elapse so that the number of nuclides of A becomes double of B

(A) 30 min. (B) 40 min. (C) 50 min. (D) 100 min.

Q.14 A radioactive sample had an initial activity of 56 dpm (disintegration per min). After 69.3 min it was found to have an activity of 28 dpm. Find the number of atoms in a sample having an activity of 10 dpm.

(A) 693 (B) 1000 (C) 100 (D) 10,000

Q.15. The radioactivity of a sample is R_1 at a time T_1 and R_2 at a time T_2. If the half life of the specimen is T, the number of atoms that have disintegrated in the time $(T_2 - T_1)$ is equal to

(A) $(R_1T_1 - R_2T_2)$ (B) $(R_1 - R_2)$ (C) $(R_1 - R_2) / T$ (D)$(R_1 - R_2)T/0.693$

Q.16 The analysis of a mineral of uranium reveals that ratio of mole of ^{206}Pb and ^{238}U in sample is 0.2. If effective decay constant of process $^{238}U \longrightarrow {}^{206}Pb$ is λ then age of rock is

(A) $\frac{1}{\lambda} \ln\left(\frac{5}{4}\right)$ (B) $\frac{1}{\lambda} \ln\left(\frac{5}{1}\right)$ (C) $\frac{1}{\lambda} \ln\left(\frac{4}{1}\right)$ (D) $\frac{1}{\lambda} \ln\left(\frac{6}{5}\right)$

Q.17 Wooden article and freshly cut tree show activity of 7.6 and 15.2 min^{-1} gm^{-1} of carbon ($t_{1/2}$ = 5760 years) respectively. The age of article in years, is

(A) 5760 (B) $5760 \times \left(\frac{15.2}{7.6}\right)$ (C) $5760 \times \left(\frac{7.6}{15.2}\right)$ (D) $5760 \times (15.2 - 7.6)$

Q.18 Symbol is needed to complete the nuclear equation $^{63}_{29}Cu(p,.....)^{62}_{29}Cu$

(A) $_1H^2$ (B) $_0n^1$ (C) $_2He^4$ (D) $_{-1}n^0$

Q.19 Consider the following nuclear reactions:

$^{238}_{92}M \rightarrow {}^{X}_{Y}N + 2\ {}^{4}_{2}He;$

$^{X}_{Y}N \rightarrow {}^{A}_{B}L + 2\beta^{+}$

The number of neutrons in the element L is

(A) 142 (B) 144 (C) 140 (D) 146

Q.20 The number of neutrons accompanying the formation of $_{54}X^{139}$ and $_{38}Sr^{94}$ from the absorption of slow neutron by $_{92}U^{235}$ followed by nuclear fision is

(A) 0 (B) 2 (C) 1 (D) 3

EXERCISE (O-2)

Q.1 Helium nuclie combines to form an oxygen nucleus. The energy released per nucleon of oxygen nucleus is if m_0 = 15.834 amu and m_{He} = 4.0026 amu

(A) 10.27 MeV (B) 0 MeV (C) 5.24 MeV (D) 164.3 MeV

Q.2 A radioactive element gets spilled over the floor of a room. Its half-life period is 30 days. If the initial activity is ten times the permissible value, after how many minimum days will it be safe to enter the room?

(A) 1000 days (B) 300 days (C) 10 days (D) 100 days

Q.3 The radioactive sources A and B of half lives of t hr and 2t hr respectively, initially contain the same number of radioactive atoms. At the end of t hours, their rates of disintegration are in the ratio :

(A) $2\sqrt{2}$: 1 (B) 1 : 8 (C) $\sqrt{2}$: 1 (D) 1 : $\sqrt{2}$

Q.4 The average (mean) life at a radio nuclide which decays by parallel path is

$A \xrightarrow{\lambda_1} B$; $\lambda_1 = 1.8 \times 10^{-2}$ sec^{-1}

$A \xrightarrow{\lambda_2} C$; $\lambda_2 = 2 \times 10^{-3}$ sec^{-1}

(A) 52.63 sec (B) 500 sec (C) 50 sec (D) None

Q.5 A sample of $^{14}CO_2$ was to be mixed with ordinary CO_2 for a biological tracer experiment. In order that 10 cm^3 of diluted gas at STP should have 10^4 dis/min, what activity (in μCi) of radioactive carbon is needed to prepare 60 L of diluted gas at STP. [1 Ci = 3.7×10^{10} dps]

(A) 270 μCi (B) 27 μCi (C) 2.7 μCi (D) 2700 μCi

Multiple correct :

Q.6 Select **correct** statement(s):

(A) The emission of gamma radiation involves transtition between energy levels within the nucleus.

(B) ^4_2He is formed due to emission of beta particle from tritium ^3_1H.

(C) When positron ($^0_{+1}e$) is emitted, $\frac{n}{p}$ ratio increases.

(D) Decay constant of radioactive substance is independent of temperature.

Q.7 Select the correct statements

(A) A radioactive element decays by emitting one α and two β-particles. The daughter element formed is an isotope of the parent element.

(B) The daughter product formed by the emission of α-particle has mass number less by 4 units than the parent nuclide.

(C) $^{27}_{13}Al$ is a stable isotope hence $^{29}_{13}Al$ is expected to disintegrate by β-emission.

(D) Emission of a β-particle by a radioactive nuclide results in decrease in n / p ratio.

Q.8 Select the correct statements

(A) The decay constant of the end product of a radioactive series is zero

(B) Positron has same mass as that of an electron.

(C) $^{14}_9N$ and $^{16}_8O$ are isotones.

(D) The S.I.unit of activity is Curie (Ci).

Q.9 Select the correct statements

(A) Half-life period of a radioactive substance can be changed by using some suitable catalyst.

(B) The nuclides with same difference of number of neutrons and number of protons are called isodiaphers

(C) Half life for certain radioactive element is 15 min. Four nuclei of that element are observed at a certain instant of time. After fifteen minutes, it can be definitely said that two nuclei will be left undecayed.

(D) 5α and $4\beta^-$ are emitted during the radioactive decay chain starting from $^{226}_{88}Ra$ and ending at $^{206}_{82}Pb$

Q.10 Select the correct statement(s) -

(A) $_{15}P^{29}$ may emit positron to increase n / p ratio

(B) During β^- emission, neutron changes into proton in nucleus

(C) Energy liberated during nuclear fission or fusion is mainly due to mass defect

(D) Binding energy per nucleon increases continuously with mass number

Assertion & Reason

Q.11. **Statement-1** : $^{238}UF_6$ and ^{238}U both have same specific activity.

Statement-2 : ^{238}U has same half life whether in free state or bonded state.

(A) Statement-1 is true, statement-2 is true and statement-2 is correct explanation for statement-1.

(B) Statement-1 is true, statement-2 is true and statement-2 is NOT the correct explanation for statement-1.

(C) Statement-1 is true, statement-2 is false.

(D) Statement-1 is false, statement-2 is true.

Q.12. **Statement-1** : An element may belong to more than one disintegration series.

Statement-2 : Mass number of an element decides the disintegration series to which it belongs.

(A) Statement-1 is true, statement-2 is true and statement-2 is correct explanation for statement-1.

(B) Statement-1 is true, statement-2 is true and statement-2 is NOT the correct explanation for statement-1.

(C) Statement-1 is true, statement-2 is false.

(D) Statement-1 is false, statement-2 is true.

Q.13 **STATEMENT-1 :** The plot of atomic number (y-axis) versus number of neutrons (x-axis) for stable nuclei shows a curvature towards x-axis from the line of 45° slope as the atomic number is increased.

and

STATEMENT-2 : Proton-proton electrostatic repulsions begin to overcome attractive forces involving protons and neutrons in heavier nuclides. **[JEE 2008]**

(A) STATEMENT-1 is True, STATEMENT-2 is True ; STATEMENT-2 is a correct explanation for STATEMENT-1

(B) STATEMENT-1 is True, STATEMENT-2 is True ; STATEMENT-2 is NOT a correct explanation for STATEMENT-1

(C) STATEMENT-1 is True, STATEMENT-2 is False

(D) STATEMENT-1 is False, STATEMENT-2 is True

❑ **COMPREHENSION :**

Paragraph for Q.14 to 15

Mass defect in the nuclear reactions may be expressed in terms of the atomic masses of the parent and daughter nuclides in place of their nuclear masses.

Q.14 The mass defect of nuclear reaction: ${}_4Be^{10} \rightarrow {}_5B^{10} + e^{-}$ is

(A) Δm = At. mass of ${}_4Be^{10}$ – At. mass of ${}_5B^{10}$

(B) Δm = At. mass of ${}_4Be^{10}$ – At. mass of ${}_5B^{10}$ – mass of one electron

(C) Δm = At. mass of ${}_4Be^{10}$ – At. mass of ${}_5B^{10}$ + mass of one electron

(D) Δm = At. mass of ${}_4Be^{10}$ – At. mass of ${}_5B^{10}$ – mass of two electrons

Q.15 The mass defect of the nuclear reaction: ${}_5B^{8} \rightarrow {}_4Be^{8} + e^{+}$ is

(A) Δm = At. mass of ${}_5B^{8}$ – At. mass of ${}_4Be^{8}$

(B) Δm = At. mass of ${}_5B^{8}$ – At. mass of ${}_4Be^{8}$ – mass of one electron

(C) Δm = At. mass of ${}_5B^{8}$ – At. mass of ${}_4Be^{8}$ + mass of one electron

(D) Δm = At. mass of ${}_5B^{8}$ – At. mass of ${}_4Be^{8}$ – mass of two electrons

Q.16 **Match the Column-I with Column-II**

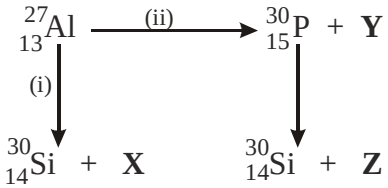
	Column-I		**Column-II**
(A)	${}_1^2D + {}_1^3T \rightarrow {}_2^4He + {}_0^1n$ + energy	(P)	β-emission
(B)	${}_4^9Be + {}_2^4He \rightarrow {}_6^{12}C + {}_0^1n$	(Q)	Artificial transmutation
(C)	${}_{12}^{24}Mg + {}_2^4He \rightarrow {}_{14}^{27}Si + {}_0^1n$	(R)	Discovery of neutrons
(D)	${}_0^1n \longrightarrow {}_1^1H + {}_{-1}^0e$	(S)	Hydrogen bomb

Q.17

	Column-I		**Column-II**
(A)	$n \longrightarrow p$ + ...	(P)	Positron emission
(B)	$p \longrightarrow n$ + ...	(Q)	β-emission
(C)	X-ray emission	(R)	K-electron capture
(D)	$4[{}_1^1H] \longrightarrow$ .....+ $2\beta^+$ + energy	(S)	α-emission

EXERCISE : J-ADVANCED

Q.1 Bombardment of aluminium by α-particle leads to its artificial disintegration in two ways, (i) and (ii) as shown. Products **X, Y** and **Z** respectively are : **[JEE 2011]**



(A) proton, neutron, positron (B) neutron, positron, proton

(C) proton, positron, neutron (D) positron, proton, neutron

Q.2 The periodic table consists of 18 groups. An isotope of copper, on bombardment with protons, undergoes a nuclear reaction yielding element **X** as shown below. To which group , element **X** belongs in the periodic table ? **[JEE 2012]**

$$^{63}_{29}Cu + {}^{1}_{1}H \rightarrow 6\,{}^{1}_{0}n + \alpha + 2\,{}^{1}_{1}H + \mathbf{X}$$

Q.3 In the nuclear transmutation **[JEE 2013]**

$^{9}_{4}Be + X \rightarrow {}^{8}_{4}Be + Y$

(X, Y) is(are)

(A) (γ, n) (B) (p, D) (C) (n, D) (D) (γ , D)

Q.4 A closed vessel with rigid walls contains 1 mol of $^{238}_{92}U$ and 1 mol of air at 298 K. Considering complete decay of $^{238}_{92}U$ to $^{206}_{82}Pb$, the ratio of the final pressure to the initial pressure of the system at 298 K is - **[JEE 2015]**

Q.5 A plot of the number of neutrons (N) against the number of protons (P) of stable nuclei exhibits upwards deviation from linearity for atomic number, Z > 20. For an unstable nucleus having N/P ratio less than 1, the possible mode(s) of decay is(are) - **[JEE 2016]**

(A) β^- decay (β emission) (B) orbital or K-electron capture

(C) Neutron emission (D) β^+ decay (positron emission)

ANSWER KEY

EXERCISE (S-1)

Q.1 Ans. $^{114}_{49}In$, odd number of nucleons

Q.2 Ans. beta emitter : ^{49}Ca, ^{30}Al, ^{94}Kr, positron emitter : ^{195}Hg, ^{8}B, ^{150}Ho

Q.3. Ans. (a) No. of α-particles = 8, No. of β-particles = 6 ; (b) $_{82}Pb^{207}$

Q.4 Ans. (8)

Q.5 Ans. 1.44×10^{15} dpm.

Q.6 Ans. 1.06×10^{-15}

Q.7 Ans. 2.67×10^{5} dps

Q.8 Ans. $\lambda = 2.079$ hr $^{-1}$

Q.9 Ans. 4.5 hr

Q.10 Ans. 6.25 %

Q.11 Ans. 9

Q.12 Ans. (8)

Q.13 Ans. 33.62 years

Q.14 Ans.(5)

Q.15 Ans. 4.5×10^{9} year

Q.16 Ans. (i) $^{40}_{19}K \longrightarrow {}^{40}_{18}Ar + {}_{+1}\beta^{0} + \nu$ (ii) 2.8×10^{9} years

Q.17 Ans (4)

Q.18 (a) $^{1}_{1}H$, (b) $^{1}_{0}n$, (c) $^{6}_{3}Li$, (d) $^{0}_{+1}e$, (e) $^{0}_{-1}e$, (f) p (proton)

(g) $_{1}H^{1}$ (h) $_{28}Ni^{64}$ (i) $^{0}_{-1}e$ (j) $_{0}n^{1}$

Q.19 Ans. 24

Q.20 Ans. $\Delta E = 14.904$ MeV

EXERCISE (S-2)

Q.1 Ans.160 MeV.

Q.2 Ans.23.6 MeV

Q.3 Ans. $\alpha = \frac{a-b}{4}$; $\beta = d + \frac{(a-b)}{2} - c$

Q.4 Ans.(i) $t_{means} = 14.43$ s (ii) 40 seconds

Q.5 Ans.7.07×10^{-7} gm

Q.6 Ans.(5)

Q.7 Ans. Ans.1648.6

Q.8 Ans.6.67×10^{5}

Q.9 Ans.($6.30 \times 10^{-4}\,yr^{-1}$, $3.087 \times 10^{-2}\,yr^{-1}$)

Q.10. Ans.100

EXERCISE (O-1)

Q.1	Ans.(A)	**Q.2**	Ans.(C)	**Q.3**	Ans.(B)	**Q.4**	Ans.(C)
Q.5	Ans.(A)	**Q.6**	Ans.(B)	**Q.7**	Ans.(D)	**Q.8.**	Ans.(C)
Q.9	Ans(C)	**Q.10**	Ans.(B)	**Q.11**	Ans.(C)	**Q.12**	Ans.(C)
Q.13	Ans.(C)	**Q.14**	Ans.(B)	**Q.15.**	Ans.(D)	**Q.16**	Ans.(D)
Q.17	Ans.(A)	**Q.18**	Ans.(A)	**Q.19**	Ans.(B)	**Q.20**	Ans.(D)

EXERCISE (O-2)

Q.1	**Ans.(A)**	**Q.2**	**Ans.(D)**	**Q.3**	**Ans.(C)**	**Q.4**	**Ans.(C)**
Q.5	**Ans.(B)**	**Q.6**	**Ans.(A,C,D)**	**Q.7**	**Ans.(A,B,C,D)**	**Q.8**	**Ans.(A,B)**
Q.9	**Ans.(B,D)**	**Q.10.**	**Ans (A,B,C)**	**Q.11.**	**Ans.(D)**	**Q.12.**	**Ans.(A)**
Q.13	**Ans.(A)**	**Q.14**	**Ans.(A)**	**Q.15**	**Ans.(D)**		

Q.16 **Ans. (A) - S ; (B) - Q, R ; (C) - Q ; (D) - P**

Q.17 **Ans. (A) - Q ; (B) - P ; (C) - R ; (D) - S**

EXERCISE (J-ADVANCED)

Q.1	**Ans. (A)**	**Q.2**	**Ans. (8)**
Q.3	**Ans. (A,B)**	**Q.4**	**Ans. (9)**
Q.5	**Ans.(B, D)**		