4 Radioactivity

Binding energy: The total energy given out during binding up of nucleons in nucleus is known as binding energy.

Mass defect: 1. A stable nucleus has less mass than its constituent particles. This difference is known as mass defect, *i.e.*,

Δm = sum of the masses of constituents – mass of stable nucleus

2. The difference in mass is converted into energy (known as BE) according to Einstein mass-energy relationship, *i.e.*,

$$E = mc^2 \qquad ...(1)$$

3. Thus, Binding energy $= \Delta m \times c^2$ ...(2)

where, BE is in erg, Δm in g and c in cm sec^{-1}

$$\therefore \quad BE = 1.66 \times 10^{-24} (\Delta m') \times (3 \times 10^{10})^2 \text{ erg} \qquad (\Delta m' \text{ in amu})$$

$$= 14.94 \times 10^{-4} \times \Delta m' \text{ erg}$$

$$= 14.94 \times 10^{-11} \times \Delta m' \text{ joule}$$

$$= \frac{14.94 \times 10^{-11}}{1.602 \times 10^{-19}} \times \Delta m' \text{ eV} \qquad (\because 1.602 \times 10^{-19} \text{ J} = 1 \text{ eV})$$

$$= \frac{14.94 \times 10^{-11}}{1.602 \times 10^{-19} \times 10^6} \times \Delta m' \text{ MeV} \qquad (\because 10^6 \text{ eV} = 1 \text{ MeV})$$

$$BE \approx 931.478 \times \Delta m' \text{ MeV} \qquad ...(3)$$

or $\quad 1 \text{ amu mass} \equiv 931.478 \text{ MeV} \qquad ...(4)$

4. $$\text{BE per nucleons} = \frac{\text{Total BE}}{\text{No. of nucleons}} \qquad ...(5)$$

Stability of nucleus

(1) Greater is the mass defect, more is BE, Lesser is the energy level of nucleus, more is its stability.

(2) If neutron-proton ratio, *i.e.*, $n/p > 1.5$ the nucleus is unstable.

(3) The no. of stable nucleide is maximum when both at. no. and no. of neutrons are even numbers.

The radioactive emissions: The radioactive disintegrations are accompanied with α, β particles and γ rays.

α-particle emission: 1. An excited nucleus having higher energy level allows α-particles (mass 4 units, charge 2 units) to come out as energy carrier in order to bring down the lower energy level to excited nucleus.

2. α-particles are identified as ${}_2\text{He}^4$, *i.e.*, fastly moving He nucleus.

3. n/p ratio increases during α-emission.

β-particle emission: 1. After α-emission, n/p ratio increases and thus to bring it down, neutron decay occurs which results in emission of β-particles as

$${}_0n^1 \longrightarrow {}_{+1}\text{H}^1 + {}_{-1}e^0$$

2. β-particles are identified as fastly moving electrons, *i.e.*, ${}_{-1}e^0$.

3. n/p ratio decreases during β-emission.

γ-rays emission: 1. If the resultant nucleus formed after α, β emission still possesses higher energy level than required for its stability, the difference in energy comes out in the form of electromagnetic waves or γ-rays.

2. γ-rays are represented as $h\nu$.

Soddy and Fajan's Group Displacement Law

(1) A radioactive element on losing an α-particle shows a loss in its mass no. by 4 units and loss in atomic no. by 2 units.

That is why a newly formed element occupies two positions left to the parent element in periodic table.

$$\underset{\text{II group}}{{}_{88}\text{Ra}^{226}} \xrightarrow{-\alpha} \underset{\text{zero group}}{{}_{86}\text{Rn}^{222}} \xrightarrow{-\alpha} \underset{\text{VI group}}{{}_{84}\text{Po}^{218}}$$

(2) A radioactive element on decay of a β-particle shows a gain in its atomic no. by 1 unit, whereas mass no. remains the same.

That is why newly formed element occupies one position right to the parent element in periodic table.

$$\underset{\text{IV group}}{{}_{82}\text{Pb}^{214}} \xrightarrow{-\beta} \underset{\text{V group}}{{}_{83}\text{Bi}^{214}} \xrightarrow{-\beta} \underset{\text{VI group}}{{}_{84}\text{Po}^{214}}$$

Note : While reporting the position of a new element in periodic table formed after emission of α, β-particles, one should keep in mind that:

1. Elements with at. no. 89, 90 to 103 are placed in III gp.
2. Elements with at. no. 57, 58 to 71 are placed in III gp.
3. Elements with at. no. 26, 27, 28; 44, 45, 46; 76, 77, 78 are placed in VIII gp.

Rutherford's theory of rate of radioactive disintegration or rate of decay: Radioactive decays occur at their characteristic rates, following first order kinetics, independent of temperature, pressure and all external factors. The rate of decay depends upon the amount of element present. Consider, an element A undergoes decay to form B.

$$A \longrightarrow B$$

$t = 0$, no. of atoms $\quad N_0$

$t = t$, no. of atoms $\quad N$

The rate of decay $\neq \dfrac{N_0 - N}{t}$ because rate continuously decreases with time.

Suppose dN atoms are decayed in an infinitesimal small time dt, then

$$\text{Activity or rate of decay} = -\frac{dN}{dt} = \lambda (N) \qquad ...(6)$$

The negative sign indicates for a decrease in no. of atoms with time. K is characteristic constant for given substance known as decay constant, independent of all external factors such as P, T......, etc.

On integrating Eq. (1) $\quad -\int \frac{dN}{N} = \lambda \int dt$

$$-\ln N = \lambda t + c$$

at $t = 0, N = N_0$

$\therefore$
$$c = -\ln N_0$$
$$-\ln N = \lambda t - \ln N_0$$

or
$$\ln \frac{N_0}{N} = \lambda t \qquad ...(7)$$

or
$$\frac{N_0}{N} = e^{\lambda t} \qquad ...(8)$$

or
$$2.303 \log_{10} \frac{N_0}{N} = \lambda t \qquad ...(9)$$

or
$$\frac{N}{N_0} = e^{-\lambda t} = 10^{-\lambda t / 2.303} \qquad ...(10)$$

Characteristics of Rate of Decay

1. Half-life period: The time required to complete half of the decay, *i.e.*, if $t = t_{1/2}$, $N = \dfrac{N_0}{2}$;

On substituting these in Eq. (1), $\quad \lambda = \dfrac{0.693}{t_{1/2}} \qquad ...(11)$

2. Average life: $\quad$ Average life $(\tau) = \dfrac{1}{\lambda} \qquad ...(12)$

Average life of a radioactive species is the time in which species reduces to 37% of its initial value.

3. The time required to disintegrate a definite fraction is independent of initial concentration, *i.e.*, $t_{1/n} \propto (N_0)^0$, where $t_{1/n}$ is time required to complete $1/n$ decay. Therefore, half decay is also written as,

$$t_{1/2} \propto (N_0)^0$$

4. Amount left after n halves $= \dfrac{N_0}{2^n} \qquad ...(13)$

$\therefore$ Amount used in n halves

$$= N_0 - \frac{N_0}{2^n} = \frac{N_0[2^n - 1]}{2^n} \qquad ...(14)$$

Also, $\quad$ No. of halves $(n) = \dfrac{\text{total time}}{\text{half - life period}} = \dfrac{T}{t_{1/2}} \qquad ...(15)$

5. $\quad$ Activity $= \dfrac{0.693 \times \text{Number of atoms present}}{\text{Half - life}} \qquad ...(16)$

Unit of radioactivity: The unit of radioactivity of an element is measured by the rate at which it changes into daughter element. It has been derived on the scale of disintegration of Ra.

Consider 1 g Ra ($t_{1/2} = 1600$ year) undergoes decay, then

Rate of decay $= \lambda \times$ No. of atoms of Ra in 1 g

$$= \frac{0.693}{1600 \times 365 \times 24 \times 60 \times 60} \times \frac{6.023 \times 10^{23}}{226}$$

$= 3.7 \times 10^{10}$ dps $= 3.7 \times 10^{10}$ Becquerrel (or Bq.) $\qquad ...(17)$

$= 1$ curie $\qquad (\because 3.7 \times 10^{10} \text{ dps} = 1 \text{ ci}) \qquad ...(18)$

$= 3.7 \times 10^4$ Rutherford $\qquad (\because 10^6 \text{ dps} = 1 \text{ rd}) \qquad ...(19)$

The S.I. unit of radioactivity is dps or Becquerrel. The other units to express rate of decay are,

Microcurie $= 10^{-6}$ curie $= 3.7 \times 10^4$ dps

Millicurie $= 10^{-3}$ curie $= 3.7 \times 10^7$ dps

Radioactive series: A series of radioactive nucleide, each except the first being the decay product of previous one. **The three naturally occurring series are,**

(1) Thorium series or $4n$ series with parent element Th^{232}

(2) Uranium series or $(4n + 2)$ series with parent element U^{238}

(3) Actinium series or $(4n + 3)$ series with parent element U^{235}

One is Artificial Series

(4) Naptunium series or $(4n + 1)$ series with parent element Np^{237}

The significance of 'n' lies in the fact that mass number of each member of a given series is an integer multiple of n with residue 0, 1, 2, 3 respectively for $4n$, $4n + 1$, $4n + 2$ and $4n + 3$ series. In all the series except Np series, there exists an element of zero group (at. no. 86) in gaseous state.

Radioactive equilibrium: A state ultimately reached when a radioactive substance of slow decay yields a radioactive product on disintegration. This product also decays to give a further radioactive substance and so on to produce a radioactive series. The amount of any daughter radioactive product present, after equilibrium has been reached, remains constant, the loss due to decay being counter balanced by gain from the decay of immediate product.

$$A \longrightarrow B \longrightarrow C$$

At equilibrium, rate of formation of B = rate of decay of B

$$\lambda_A \cdot N_A = \lambda_B \cdot N_B$$

or
$$\frac{\lambda_A}{\lambda_B} = \frac{N_B}{N_A}$$

$\therefore$
$$\frac{\lambda_A}{\lambda_B} = \frac{N_B}{N_A} = \frac{t_{1/2B}}{t_{1/2A}} = \frac{\tau_B}{\tau_A} \quad ...(20)$$

λ is decay constant and $\lambda \propto \frac{1}{\tau}$ and $\lambda \propto \frac{1}{t_{1/2}}$

Note: 1. Eq. (2) holds good only when $\lambda_A >>> \lambda_B$ or $t_{1/2}\, A >>> t_{1/2} B$. This is called **secular equilibrium.**

2. If $t_{1/2}\, A \simeq t_{1/2}\, B$ and $\lambda_A < \lambda_B$, then

$$\frac{N_A}{N_B} = \frac{\lambda_B - \lambda_A}{\lambda_A} \quad ...(21)$$

This is called **transient equilibrium.**

3. If $\lambda_A > \lambda_B$ or $t_{1/2}\, A < t_{1/2}\, B$, no state of equilibrium is attained.

Maximum yield of daughter element: A radioactive element A decays to give a daughter element B which further decays to another daughter element C and so on till a stable element is formed ($A \rightarrow B \rightarrow C$). Also if number of daughter atoms at $t = 0$ is zero and parent atom is much more lived than daughter (*i.e.*, $\lambda_A < \lambda_B$), where λ_A and λ_B are decay constants of A and B respectively, then number of atoms of daughter element B after time t is

$$N_B = \frac{N_0 \lambda_A}{\lambda_B - \lambda_A}[e^{-\lambda_A t} - e^{-\lambda_B t}] \quad ...(22)$$

Maximum activity of daughter element can be expressed at t_{max} :

$$t_{max} = \frac{2.303}{\lambda_B - \lambda_A} \log_{10}\left[\frac{\lambda_B}{\lambda_A}\right] \quad ...(23)$$

Parallel path decay: A radioactive element A decays to B and C in two parallel paths as:

$$A \begin{cases} \xrightarrow{\text{Say emission of } \alpha} B \\ \xrightarrow{\text{Say emission of } \beta} C \end{cases}$$

The average decay constant for the element A can be expressed as

$$\lambda_{average} = \lambda_{\alpha\ path} + \lambda_{\beta\ path} \quad ...(24)$$

Eq. (24) can be expressed in Eq. (25) and (26) as:

$$\lambda_{\alpha\ path} = [\text{Fractional yield of } B] \times \lambda_{av.} \quad ...(25)$$

$$\lambda_{\beta\ path} = [\text{Fractional yield of } C] \times \lambda_{av.} \quad ...(26)$$

$$\textbf{Average atomic mass } (\bar{A}) = \frac{\Sigma A_1 X_1}{\Sigma X_{Total}} \quad ...(27)$$

Nuclear reactions

The phenomenon of interaction of nucleons giving rise to the formation of a new nucleus or a process in which one nuclide is converted to another by interaction with another nuclide. The **first ever nuclear reaction** in laboratory was carried out by Rutherford when he bombarded N atoms with α-particles.

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

Another, method of representing this nuclear reaction is ${}^{14}_{7}N(\alpha : p)\, {}^{17}_{8}O$. Like chemical reactions, nuclear reactions also involve energy changes, represented by the symbol Q. If Q is negative, the reaction is endoergic, *i.e.*, energy is absorbed and if Q is positive, energy is released, *i.e.*, exoergic. The value of Q can be determind from the difference in the total mass of reactants and products of the reaction.

Types of nuclear reactions

Some of the nuclear reactions are cited below :

(i) Induced radioactivity : The phenomenon of converting stable nuclei into unstable one by the interaction of nucleons or a nuclear reaction yielding a product nuclei of radioactive nature, is known as induced or artificial radioactivity (Irene Curie and F. Joliot).

$${}^{10}_{5}B + {}^{4}_{2}He \longrightarrow {}^{13}_{6}C + {}^{1}_{1}H \text{ Nuclear reaction}$$

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

$\downarrow$ Nuclear reaction, *Vis-a-Vis*

$${}^{13}_{6}C + {}^{0}_{+1}e \text{ Artificial radioactivity}$$

(ii) Nuclear Fission : (a) The phenomenon of splitting up of a heavy nucleus, on bombardment with slow speed neutrons, into two fragments of comparable mass, with the release of two or more fast moving neutrons and a large amount of energy, is known as nuclear fission.

$$\text{(b) } {}^{235}_{92}U + {}^{1}_{0}n \longrightarrow {}^{236}_{92}U \begin{cases} \longrightarrow {}^{140}_{56}Ba + {}^{93}_{36}Kr + 3{}^{1}_{0}n \\ \longrightarrow {}^{144}_{54}Xe + {}^{90}_{38}Sr + 2{}^{1}_{0}n \\ \longrightarrow {}^{144}_{55}Cs + {}^{90}_{37}Rb + 2{}^{1}_{0}n \end{cases}$$

A loss in mass occurs releasing a huge amount of energy $\simeq 2.041 \times 10^{10}$ kJ per mol of ${}^{235}U$.

(iii) Nuclear fusion : (a) The phenomenon of joining up of two light nuclei into a heavier nucleus is called fusion, *e.g.*,

$${}^{2}_{1}H + {}^{3}_{1}H \longrightarrow {}^{4}_{2}He + {}^{1}_{0}n; (\Delta H = -17.6 \text{ MeV})$$

(b) Huge amount of energy is required to overpower the Coulombic forces of repulsion in between two nuclei which is obtained by triggering on nuclear fission.

(iv) Spallation reacton : Spallation is a reaction in which the excitation energy of the target nucleus is sufficiently high and results in the emission of several particles such as α-particles and protons, leaving behind a number of product nuclei of sufficiently smaller masses than the target, *e.g.*,

$${}^{75}_{33}As + {}^{2}_{1}H \longrightarrow {}^{56}_{25}Mn + 9{}^{1}_{1}H + 12{}^{1}_{0}n$$

• NUMERICAL PROBLEMS •

1. Calculate the binding energy for $_1H^2$ atom. The mass of $_1H^2$ atom is 2.014102 amu, where $1n$ and $1p$ have their masss 2.016490 amu. Neglect mass of electron.
2. (a) Although nucleus is a part of atom but number of electrons present in the atom has no role in deciding binding energy of nucleus. Explain.
   (b) The atomic mass of $_8O^{16} = 15.9949$ amu. Calculate the BE/nucleon for this atom. Mass of $1n$ and $1p$ is 2.016490 amu and $m_e = 0.00055$ amu.
3. The atomic masses of Li, He and proton are 7.01823 amu, 4.00387 amu and 1.00715 amu respectively. Calculate the energy evolved in the reaction,
   $$_3Li^7 + {_1p^1} \longrightarrow 2\,{_2He^4} + \Delta E$$
   Given 1 amu = 931 MeV.
4. Calculate the energy released in joules and MeV in the following nuclear reaction:
   $$^2_1H + {^2_1H} \longrightarrow {^3_2He} + {^1_0n}$$
   Assume that the masses of ^2_1H, ^3_2He and neutron (n) respectively are 2.0141, 3.0160 and 1.0087 in amu.
5. How much heat would be developed per hour from 1 curie of C^{14} source if all the energy of beta decay were imprisoned? Atomic masses of C^{14} and N^{14} are 14.00324 and 14.00307 amu respectively.
6. Calculate the loss in mass during the change:
   $$_3Li^7 + {_1H^1} \longrightarrow 2\,{_2He^4} + 17.25\text{ MeV}$$
7. An isotopic species of lithium hydride $^6Li^2H$ is used as a potential nuclear fuel following the nuclear reaction:
   $$^6_3Li\ {^2_1H} \longrightarrow 2\,{^4_2He}$$
   Calculate the expected power production of megawatt (Mw) associated with 1.00 g of $^6Li\,^2H$ per day assuming 100% efficiency. Given $^6_3Li = 6.01512$ amu; $^2_1H = 2.01410$ amu ; $^4_2He = 4.00260$ amu.
8. Calculate the mass defect and binding energy per nucleon for an alpha particle whose mass is 4.0028 amu. $m_P = 1.0073$ and $m_N = 1.0087$ amu.
9. Calculate mass no., atomic no. and group in the periodic table for RaC in the following change.
   $$_{88}Ra^{226} \xrightarrow{-\alpha} Rn \xrightarrow{-\alpha} RaA \xrightarrow{-\beta} RaB \xrightarrow{-\alpha} RaC$$
10. (a) Calculate no. of α and β-particles emitted when $_{92}U^{238}$ changes into radioactive $_{82}Pb^{206}$. **(IIT 2000)**
    (b) Th^{234} disintegrates and emits 6β – and 7α-particles to form a stable element. Find the atomic number and mass number of the stable product. Also identify the element. **(IIT 2004)**
11. Calculate the group of elements formed in the final stage of radioactive changes given below:
    (a) $\underset{\text{III group}}{_{92}U^{235}} \xrightarrow{-\alpha} {_{90}Th^{231}}$ (b) $\underset{\text{III group}}{_{90}Th^{231}} \xrightarrow{-\beta} {_{91}X^{231}}$
    (c) $\underset{\text{III group}}{_{91}X^{231}} \xrightarrow{-\alpha} {_{89}Ac^{227}}$ (d) $_{90}Th^{231} \xrightarrow{-\alpha} {_{88}Ra^{227}}$
12. Calculate the number of neutrons in the remaining atom after emission of an α-particle from $_{92}X^{238}$ atoms. Also report the mass no. and atomic no. of resultant atom.
13. If a $_{92}U^{235}$ nucleus upon being struck by a neutron changes to $_{56}Ba^{145}$, three neutrons and an unknown product. What is the unknown product?
14. Prove that the time required for 99.9% decay of a radioactive substance is almost 10 times to its half-life period.
15. Represent and derive mathematically the half-life period of radioactive substance.
16. 1 g of $_{79}Au^{198}$ ($t_{1/2} = 65$ hr) decays by β-emission to produce stable Hg.
    (a) Write nuclear reaction for process.
    (b) How much Hg will be present after 260 hr.
17. The rate of decay of a radioactive sample is 3.02×10^6 dpm at time 10 min and 1.20×10^6 dpm at a time 20 min. Evaluate the decay constant, half-life and average life of sample.
18. A sample of $^{153}_{53}I$, as iodide ion, was administered to a patient in a carrier consisting of 0.10 mg of stable iodide ion. After 4 day, 67.7% of the initial activity was detected in the thyroid gland of the patient. What mass per cent of the stable iodide ion had migrated to the thyroid gland? $t_{1/2}$ for I = 8 day.
19. The half-life period of $_{53}I^{125}$ is 60 day. What % of radioactivity would be present after 180 day?
20. One of the hazards of nuclear explosion is the generation of Sr^{90} and its subsequent incorporation in bones. This nucleide has a half life of 28.1 year. Suppose one microgram was absorbed by a new-born child, how much Sr^{90} will remain in his bones after 20 year? **(IIT 1995)**
21. At a certain instant, a piece of radioactive material contains 10^{12} atoms. The half-life of material is 30 day. Calculate the no. of disintegrations in the first second.
22. The activity of a radioactive isotope falls to 12.5% in 90 day. Compute the half-life and decay constant of isotope.
23. A radioactive element ($t_{1/2} = 30$ day) is spread over a room. Its activity is 50 times the permissible value of

safe working. Calculate the number of day after which the room will be available for safe working.

24. Calculate the ratio of N / N_0 after an hour has passed for a radioactive material of half-life 47.2 second.

25. Two radioactive nucleide P and Q have their decay constant in the ratio 3:2. 1 mole of each is taken separately and allowed to decay for a time interval of three times of half-life of A. If 0.2 mole of P are left, what moles of Q will be left?

26. The activity of a radioactive sample drops to 1/64th of its original value in 2 hr. Find the decay constant for sample.

27. It is known that 1 g of Ra^{226} emits 11.6×10^{17} atoms of α per year. Given the half-life of Ra^{226} be 1600 years. Compute the value of Avogadro's no.

28. The disintegration rate of a certain radioactive sample at any instant is 4750 dpm. Five minutes later, the rate becomes 2700 dpm. Calculate half-life of sample.

29. The radioactive disintegration of $_{94}Pu^{239}$ an α-emission process is accompanied by the loss of 5.24 MeV/dis. If $t_{1/2}$ of $_{94}Pu^{239}$ is 2.44×10^4 year, calculate the energy released per year from 1.0 g sample of $_{94}Pu^{239}$ in kJ.

30. 1 g Ra^{226} is placed in an evacuated tube whose volume is 5 cc. Assuming that each Ra nucleus yields four He-atoms which are retained in the tube, what will be the pressure of He produced at 27°C after the end of 1590 year? $t_{1/2}$ for Ra is 1590 year.

31. The decay constant for an α-decay of Th^{232} is 1.58×10^{-10} sec^{-1}. Find out the no. of α-decays that occur from 1 g sample in 365 day.

32. A certain radio isotope $_Z X^A$ ($t_{1/2} = 10$ day) decays to give $_{Z-2}Y^{A-4}$. If one g-atom of $_Z X^A$ is kept in a sealed vessel, how much He will accumulate in 20 day at STP?

33. 10 g-atoms of an α-active radioactive isotope are disintegrating in a sealed container. In one hour, the He gas collected at STP is 11.2 cm^3. Calculate half-life of the radioactive isotope.

34. A radioactive isotope $_Z A^m$ ($t_{1/2} = 10$ day) decays to give $_{Z-6}B^{m-12}$ stable atom along with α-particles. If m g of A are taken and kept in a sealed tube, how much He will accumulate in 20 day at STP?

35. 1 g-atom of Ra^{226} is placed in an evacuated tube of volume 5 litre. Assuming that each $_{88}Ra^{226}$ nucleus is an α-emitter and all the contents are present in tube, calculate the total pressure of gases and partial pressure of He collected in tube at 27°C after the end of 800 year. $t_{1/2}$ of Ra is 1600 year. Neglect volume occupied by undecayed Ra.

36. The activity of the hair of an egyptian mummy is 7 disintegration $minute^{-1}$ of C^{14}. Find the age of mummy. Given $t_{0.5}$ of C^{14} is 5770 year and disintegration rate of fresh sample of C^{14} is 14 disintegration $minute^{-1}$.

37. What mass of C^{14} with $t_{1/2} = 5730$ year has activity equal to one curie?

38. A sample of $^{14}CO_2$ was mixed with ordinary $^{12}CO_2$ for studying a biological tracer experiment. The 10 mL of this mixture at STP possess the rate of 10^4 disintegration per minute. How many millicurie of radioactive carbon is needed to prepare 60 litre of such a mixture?

39. 0.1 g-atom of radioactive isotope $_Z X^A$ (half-life 5 day) is taken. How many number of atoms will decay during eleventh day?

40. $_{84}Po^{210}$ decays with α-particle to $_{82}Pb^{206}$ with a half-life of 138.4 day. If 1.0g of $_{84}Po^{210}$ is placed in a sealed tube, how much helium will accumulate in 69.2 day? Express the answer in cm^3 at STP. Also report the volume of He formed if 1 g of $Po^{210}O_2$ is used. **(Roorkee 1991)**

41. A solution contains 1 milli curie of L-phenyl alanine C^{14} (uniformly labelled) in 2.0 mL solution. The activity of labelled sample is given as 150 milli curie/milli mole. Calculate:

(a) the concentration of sample in the solution in mole/litre.

(b) the activity of the solution in terms of counting per minute/mL at a counting efficiency of 80%.

42. The $_6C^{14}$ and $_6C^{12}$ ratio in a piece of wood is 1/16 part that of atmosphere. Calculate the age of wood. $t_{1/2}$ of C^{14} is 5577 years.

43. The half-life period of C^{14} is 5760 year. A piece of wood when buried in the earth had 1% C^{14}. Now as charcoal it has only 0.25% C^{14}. How long has the piece of wood been buried?

44. A sample of U^{238} (half-life = 4.5×10^9 yr) ore is found to contain 23.8g of U^{238} and 20.6 g of Pb^{206}. Calculate the age of the ore. **(Roorkee 1996)**

45. (a) On analysis a sample of uranium ore was found to contain 0.277 g of $_{82}Pb^{206}$ and 1.667 g of $_{92}U^{238}$. The half-life period of U^{238} is 4.51×10^9 year. If all the lead was assumed to have come from decay of $_{92}U^{238}$, what is the age of earth?

(b) An ore of $_{92}U^{238}$ is found to contain $_{92}U^{238}$ and $_{82}Pb^{206}$ in the mass ratio of 1:0.1. The half life period of $_{92}U^{238}$ is 4.5×10^9 year. Calculate the age of ore. **(IIT 2000)**

46. A sample of pitch blende is found to contain 50% uranium and 2.425% lead. Of this lead only 93% was Pb^{206} isotope. If the disintegration constant is 1.52×10^{-10} yr^{-1}, how old could be the pitch blende deposits?

47. The isotopes U^{238} and U^{235} occur in nature in the ratio 140 : 1. Assuming that at the time of earth formation, they were present in equal ratio, make an estimation of the age of earth. The half-life period of U^{238} and U^{235} are 4.5×10^9 and 7.13×10^8 year respectively.

48. In nature a decay chain series starts with $_{90}Th^{232}$ and finally terminates at $_{82}Pb^{208}$. A thorium ore sample was found to contain 8×10^{-5} mL of He at STP and 5×10^{-7} g of Th^{232}. Find the age of ore sample assuming that source of He to be only due to decay of Th^{232}. Also assume complete retention of He within the ore. $t_{1/2}Th^{232} = 1.39 \times 10^{10}$ year. **(Roorkee 1992)**

49. The half-life of ^{32}P is 14.3 day. Calculate the specific activity of a phosphorus containing specimen having 1.0 part per million ^{32}P (Atomic mass of P = 31).

50. A mixture of Pu^{239} and Pu^{240} has a specific activity of 6×10^9 dps per g sample. The half-lives of the isotopes are 2.44×10^4 year and 6.58×10^3 year respectively. Calculate the composition of mixture.

51. In a sample of radioactive element, radium disintegrates at an average rate of 2.24×10^{13} α-particles per minute. Each α-particle takes up 2 electrons from the air and becomes a neutral helium atom. After 420 days, the He gas collected was 0.5 mL measured at 27°C and 750 nm of mercury pressure. From the above data, calculate Avogadro's no.

52. An experiment requires minimum β-activity produced at the rate of 346 β-particles per minute. The half-life period of $_{42}Mo^{99}$ which is a β-emitter is 66.6 hrs. Find the minimum amount of $_{42}Mo^{99}$ required to carry out the experiment in 6.909 hours.

53. A solution contains a mixture of isotopes of X^{A_1} ($t_{1/2} = 14$ days) and X^{A_2} ($t_{1/2} = 25$ days). Total activity is 1 curie at $t = 0$. The activity reduces by 50% in 20 days. Find:

(a) the initial activities of X^{A_1} and X^{A_2}.

(b) the ratio of their initial no. of nuclei.

54. What amount of energy is evolved by one curie of Rn (an α-emitter) in:

(a) one hour (b) its mean life?

Given that kinetic energy of one α-particle is 5.5 MeV and $\lambda = 2 \times 10^{-6}$ sec^{-1} for Rn.

55. 54.5 mg of Na_3PO_4 contains P^{32} (15.6% of sample) and P^{31} atoms. Assuming only P^{32} atoms radioactive, calculate the rate of decay for the given sample of Na_3PO_4. The half-life period for $P^{32} = 14.3$ day; molar mass of $Na_3PO_4 = 161.2$.

56. $_{19}K^{40}$ consists of 0.012% of the potassium in nature. The human body contains 0.35% potassium by mass. Calculate the total radioactivity resulting from $_{19}K^{40}$ decay in a 75 kg human. Half-life for $_{19}K^{40}$ is 1.3×10^9 year.

57. 32 mg of pure $_{94}Pu^{238}O_2$ has an activity of 6.4×10^7 dps. Calculate (i) the half-life of $_{94}Pu^{238}$. (ii) the amount PuO_2 left, if 100 mg of PuO_2 is kept for 5000 year.

58. A small amount of solution containing Na^{24} radio nucleide with activity $A = 2 \times 10^3$ dps was administered into blood of a patient in a hospital. After 5 hours, a sample of the blood drawn out from the patient showed an activity of 16 dpm per cc $t_{1/2}$ for $Na^{24} = 15$ hrs. Find:

(a) Volume of the blood in patient.

(b) Activity of blood sample drawn after a further time of 5 hrs. **(IIT 1994)**

59. There is a stream of neutrons with kinetic energy 0.0327 eV. If the half-life of neutron is 700 sec, what fraction of neutron will decay before they travel a distance of 100 metre? $m_n = 1.675 \times 10^{-27}$ kg.

60. Nuclei of a radioactive element A are being produced at a constant rate α. The element A has a decay constant λ. At time $t = 0$, there are N_0 nuclei of element A.

(a) Calculate the number of nuclei (N) of A at any time t.

(b) If $\alpha = 2\lambda N_0$, calculate the number of nuclei of A after one half-life of A and also the limiting value of N as $t \to \infty$.

61. A radionucleide of ^{32}P with half-life 14.3 day are produced in a nuclear reactor at a constant rate, $q = 2.7 \times 10^9$ nuclei per second. How soon after the beginning of production of that nucleide will its activity be equal to 1.7×10^9 dis / s?

62. At radioactive equilibrium, the ratio between two atoms of radioactive elements A and B are $3.1 \times 10^9 : 1$. If half-life period of A is 2×10^{10} year, what is half-life of B?

63. In an experiment on two radioactive isotopes of an element (which do not decay into each other), their molar ratio at a given instant is 3. The rapidly decaying isotope has larger mass and an initial activity of 1.0 μCi. The half-lives of the two isotopes are 12 and 16 hr respectively. What would be the activity of each isotope and their molar ratio after two day?

64. The nucleidic ratio of $_1H^3$ to $_1H^1$ in a sample of water is 8.0×10^{-18} : 1. Tritium undergoes decay with a half-life period of 12.3 year. How many tritium atoms would 10.0 g of such a sample contains 40 year after the original sample is collected? **(IIT 1992)**

65. The mean lives of a radioactive substance are 1620 year and 405 year for α-emission and β-emission respectively. Find out the time during which three fourth of a sample will decay if it is decaying both by α-emission and β-emission simultaneously.

66. Consider an α-particle just in contact with a $_{92}U^{238}$ nucleus. Calculate the coulombic repulsion energy (*i.e.*, the height of coulombic barrier between U^{238} and α-particle) assuming that the distance between them is equal to the sum of their radii.

67. With what velocity should an α-particle travel towards the nucleus of a copper atom so as to arrive at a distance 10^{-13} metre from the nucleus of the copper atom? **(IIT May 1997)**

68. α-particles accelerated by 3×10^5 volt bombarded a boron target. This results in the nuclear reaction.

$$_2He^4 +_5 B^{10} \longrightarrow {}_6C^{13} +_1 H^1 + \gamma$$

If the combined energy of ^{13}C and H^1 is 5×10^5 eV, calculate the energy, frequency and wavelength of γ-rays. 1×10^5 eV energy is used in penetrating the nucleus.

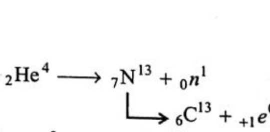
(He = 4.0026 amu, B = 10.0129 amu, C = 13.0036 amu)

69. A positron and an electron collide and annihilated to emit two gamma photons of same energy. Calculate the wavelengths corresponding to this gamma emission.

70. Ac^{227} has a half-life of 22 year in its 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? **(IIT 1996)**

71. ^{64}Cu (half-life = 12.8 hr) decays by β^--emission (38%), β^+-emission (19%) and electron capture (43%). Write the decay products and calculate partial half lives for each of the decay processes.

72. A follows parallel path I order reactions giving *B* and *C* as:



If initial concentration of *A* is 0.25 *M*, calculate the concentration of *C* after 5 hour of reaction.

Given, $\lambda_1 = 1.5\times10^{-5}\ s^{-1}$, $\lambda_2 = 5\times10^{-6}\ s^{-1}$

73. There is a stream of neutrons with a kinetic energy of 0.0327 eV. If the half-life of neutrons is 700 second, what fraction of neutrons will decay before they travel a distance of 10 km? (Mass of neutron $=1.675\times10^{-27}$ kg).

74. The isotopic masses of $_1H^2$ and $_2He^4$ are 2.0141 and 4.0026 amu respectively. Calculate the quantity of energy liberated when two mole of $_1H^2$ undergo fission to form 1 mole of $_2He^4$. The velocity of light in vacuum is 2.998×10^8 m / sec.

75. The half-life of Pb^{212} is 10.6 hour. It undergoes decay to its daughter (unstable) element Bi^{212} of half-life 60.5 minute. Calculate the time at which daughter element will have maximum activity.

76. Match the following:

1. Isotopes	A. $_8O^{16}$ and $_8O^{17}$
2. Isobars	B. Na^+, Mg^{2+}, F^-
3. Nuclear isomers	C. $_1H^2$ and $_2H^3$
4. Isosters	D. U_A and U_Z
5. Isotones	E. CO_2 and N_2O
6. Isoelectronics	F. $_AX^Z$, $_{A-2}X^{Z-4}$
7. Isodiaphers	G. $_{20}Ca^{40}$ and $_{19}K^{40}$

77. Naturally occurring *B* consists of two isotopes, whose atomic masss are 10.01 and 11.01. The atomic mass of natural boron is 10.81. Calculate the % of each isotope in natural boron.

78. Cl^{35} and Cl^{37} are the naturally occurring Cl isotopes, what % of Cl^{35} accounts for the atomic mass of 35.453 in mixture?

79. The abundance of three isotopes of oxygen, each containing 8, 9 and 10 neutrons respectively has the % of one isotope (containing 8 neutrons) 90%. What are the other % if the atomic mass of oxygen is 16.12?

80. Write equations for the following transformations:

(a) $_7N^{14}$ (*n, p*) (b) $_{19}K^{39}$ (*p*, α)

(c) K-electron capture (d) β^+-decay by $_{11}Na^{22}$

81. Complete the following:

(1) $_{92}U^{235} +_0 n^1 \longrightarrow {}_{55}A^{142} +_{37} B^{92} + ...$ **(IIT 2005)**

(2) $2_1H^3 \longrightarrow {}_2He^4 + ...$

(3) $_{34}Se^{82} \longrightarrow ... + 2_{-1}e^0$ **(IIT 2005)**

82. Name the process represented below:

(a) $_{13}Al^{27} + {}_2He^4 \longrightarrow {}_{15}P^{30} + {}_0n^1$
$\quad\quad \hookrightarrow {}_{14}Si^{30} + {}_{+1}e^0$

(b) $_5B^{10} + {}_2He^4 \longrightarrow {}_6C^{13} + {}_1H^1$

(c) $_5B^{10} + {}_2He^4 \longrightarrow {}_7N^{13} + {}_0n^1$
$\quad\quad \hookrightarrow {}_6C^{13} + {}_{+1}e^0$

(d) $_{33}As^{75} + {}_1H^2 \longrightarrow {}_{25}Mn^{56} + 9{}_1H^1 + 12{}_0n^1$

83. To which radioactive series the following appears during disintegrations:

$$_{89}Ac^{228};\ _{89}Ac^{227}$$

84. Following reactions are given. Which one is more hazardous for civilization?

Fission :

$$_{92}U^{235} + {}_0n^1 \longrightarrow {}_{56}Ba^{141} + {}_{36}Kr^{92} + 2\sim3{}_0n^1 + 200\ MeV$$

Fusion : $_1H^2 + {}_1H^3 \longrightarrow {}_2He^4 + {}_0n^1 + 17.6\ MeV$

SOLUTIONS (Numerical Problems)

1. Mass of neutron and proton in $_1H^2 = 2.016490$ amu

Actual mass of $_1H^2 = 2.014102$ amu

$\therefore$ Mass defect $= 2.388 \times 10^{-3}$ amu

$\therefore$ Binding energy $= 2.388 \times 10^{-3} \times 931$ MeV

$= \mathbf{2.2232\ MeV}$

2. (a) Although binding energy is referred to nucleus, it is more convenient to use the mass of whole atom (nuclide) in calculation. If m_a is the atomic mass of atom X and m_e is mass of electron

$$m_{\text{nucleus}} = m_a - Z \times m_e \quad \text{...(i)}$$

Also for $^1_1$H atom, $m_{\text{H-atom}} = m_p$

$$m_{^1_1\text{H}_{\text{nucleus}}} = m_p - m_e \quad \text{...(ii)}$$

where m_p is mass of proton

Now for a nucleus having Z protons and $(A - Z)$ neutrons where Z and A are atomic number and mass number of given atom

$$\text{Mass decay} = Z \times m_{^1_1\text{H}_{\text{nucleus}}} + (A - Z) \times m_n - m_{\text{nucleus}} \quad \text{...(iii)}$$

By (i), (ii) and (iii)

Mass decay

$$= Z \times m_p - Z \times m_e + (A - Z) \times m_n - m_a + Z \times m_e$$
$$= Z \times m_p + (A - Z) \times m_n - m_a \quad \text{...(iv)}$$
$$\therefore \text{B.E.} = [Z \times m_p + (A - Z)m_n - m_a] \times c^2 \quad \text{...(v)}$$

It is thus evident that electron's mass has no role in calculating binding energy.

(b) Mass of $1n + 1p = 2.016490$ amu

$\therefore$ Mass of $8n + 8p = 8 \times (2.016490)$ amu

$\therefore$ Total mass of O^{16} nucleus $= m(p + n)$

$= 8 \times (2.016490) = 16.13192$ amu

$\therefore$ Mass defect $= 16.13192 - 15.9949 = 0.13702$ amu

$\therefore$ BE = Mass defect × 931.478 MeV

$\therefore$ $= 0.13702 \times 931.478 = 127.63$ MeV

$\therefore$ BE/nucleon $= \dfrac{\text{Total BE}}{\text{No. of nucleons}}$

$= \dfrac{127.63}{16} = \mathbf{7.977\ MeV}$

3. Mass of reactants = mass of Li + mass of p

$= 7.01823 + 1.00715 = 8.02538$ amu

Mass of products = 2 × mass of He = 2 × 4.00387

$= 8.00774$ amu

$\therefore$ Mass loss during change $= 8.02538 - 8.00774$

$= 0.01764$ amu

$\therefore$ Energy evolved during reaction

$= 0.01764 \times 931 = \mathbf{16.423\ MeV}$

4. $\Delta m = [2 \times 2.0141] - 3.0160 - 1.0087$

$= 3.5 \times 10^{-3}$ amu

$\therefore$ $\Delta E = \Delta m \times 931.478$

$\Delta E = 3.5 \times 10^{-3} \times 931.478$

$= \mathbf{3.260\ MeV}$

Also $\Delta E = \mathbf{5.223 \times 10^{-13}\ J}$

5. $_6C^{14} \longrightarrow {}_7N^{14} + {}_{-1}e^0$

$\Delta m = 14.00324 - 14.00307 = 0.00017$ amu

$\therefore$ Energy produced during this decay of 1 atom

$= \Delta m \times 931.478$ MeV

$= 0.00017 \times 931.478$ MeV

$= 0.158$ MeV

$= 0.158 \times 10^6$ eV

$= 0.158 \times 10^6 \times 1.602 \times 10^{-19}$ J

$= 2.53 \times 10^{-14}$ J

Now, 1 curie of C^{14} means decay of 3.70×10^{10} dps

Thus, energy produced during decay of 1 curie mass of C^{14}

$= 3.70 \times 10^{10} \times 2.53 \times 10^{-14}$ J s^{-1}

$= 9.36 \times 10^{-4}$ J

$\therefore$ Energy produced during 1 hr

$= 9.36 \times 10^{-4} \times 60 \times 60 = \mathbf{3.37\ J}$

6. Total energy change during reaction = 17.25 MeV

Energy = mass defect × 931

Now, $\Delta E = \Delta m \times 931$

$\therefore$ $\Delta m = \dfrac{\Delta E}{931} = \dfrac{17.25}{931} = 0.0185$ amu

$= \mathbf{0.0185\ amu = 3.07 \times 10^{-26}\ g}$

7. Mass decay, Δm per molecule of LiH

$= m(^6_3\text{Li}\ ^2_1\text{H}) - 2 \times m_2\text{He}^4$

$= (6.01512 + 2.01410) - 2 \times 4.0026$

$= 0.02402$ amu

Thus, energy produced during this mass decay

$= \Delta m \times 931.478$

$= 0.02402 \times 931.478 = 22.35$ MeV

$= 22.35 \times 10^6$ eV

$= 22.35 \times 10^6 \times 1.602 \times 10^{-19}$ J

$= 3.58 \times 10^{-12}$ J

Now energy produced for 1 mole of LiH

$= 3.58 \times 10^{-12} \times 6.023 \times 10^{23}$

$= 21.55 \times 10^{11}$ J mol^{-1}

$\therefore$ Energy produced for 1 g of

$^6\text{Li}\ ^2\text{H} = \dfrac{21.55 \times 10^{11}}{8}$ J g^{-1} per day

$\therefore$ Energy produced for 1 g of ^{6}Li ^{2}H per sec

$= \dfrac{21.55 \times 10^{11}}{8 \times 24 \times 3600}$ J g^{-1} s^{-1}

$= 3.12 \times 10^6$ wg^{-1} (Js^{-1} = 1 w)

$= \mathbf{3.12\ Mwg^{-1}}$

8. α-particle has $2P$ and $2N$

∴ Mass of $2P + 2N$ in α-particle

$= 2\times 1.0073 + 2\times 1.0087 = 4.032\,\text{amu}$

Actual mass of α-particle (given) $= 4.0028\,\text{amu}$

∴ Mass defect $= 4.032 - 4.0028 = \mathbf{0.0292\ amu}$

Now, $\text{BE} = \text{Mass defect} \times 931$

$= 0.0292 \times 931$

$= 27.1852\,\text{MeV}$

∴ $\text{BE/nucleon} = \frac{27.1852}{4} = \mathbf{6.7963\ MeV}$

9. Emission of an α shows a loss in mass no. by 4 units and loss in at. no. by 2 units.

Emission of a β shows a gain in at. no. by one unit; mass no. remains same.

Thus, for change

$$\underset{\text{II group}}{_{88}\text{Ra}^{226}} \xrightarrow{-_2\text{He}^4} \underset{\text{zero group}}{_{86}\text{Rn}^{222}} \xrightarrow{-_2\text{He}^4} \underset{\text{VI group}}{_{84}\text{Ra}A^{218}} \xrightarrow{-_{-1}e^0}$$

$$\underset{\text{VII group}}{_{85}\text{Ra}B^{218}} \xrightarrow{-_2\text{He}^4} \underset{\text{V group}}{_{83}\text{Ra}C^{214}}$$

At. no. of $\text{Ra}C = 83$

Mass no. of $\text{Ra}C = 214$

Group of element RaC is V from configuration 2, 8, 18, 32, 18, 5.

The no. of electrons in outer shell of an element suggest for its group.

10. (a) Let x α and y β-particles be given out during the change.

∴ $_{92}\text{U}^{238} \longrightarrow {_{82}\text{Pb}^{206}} + x\,_2\text{He}^4 + y\,_{-1}e^0$

Equating mass no. on both sides,

∴ $238 = 206 + 4x + y\times 0$

$x = 8$

Equating atomic no. on both sides

$92 = 82 + 2x + y(-1) = 82 + 2\times 8 + y(-1)$

∴ $y = \mathbf{6}$

∴ No. of α-particles $= \mathbf{8}$

No. of β-particles $= \mathbf{6}$

(b) $_{90}\text{Th}^{234} \longrightarrow 7\,_2\text{He}^4 + 6\,_{-1}e^0 + {_Z A^m}$

Equating atomic number

$90 = 14 + 6\times(-1) + Z$

∴ $Z = 82$

Equating mass number

$234 = 28 + m$

∴ $m = 206$

Thus, the element with atomic number 82 and mass number 206 is $_{82}\text{Pb}^{206}$.

11. (a) $_{92}\text{U}^{235} \longrightarrow {_{90}\text{Th}^{231}} + {_2\text{He}^4}$

∵ Elements 89 and 90 to 103 are in III gp. known as actinides.

∴ **Th is in III gp.**

(b) $_{91}X^{231}$ is also in **III gp.**

(c) $_{89}\text{Ac}^{227}$ is also in **III gp.**

(d) $_{88}\text{Ra}^{227}$ is in **II gp.**

12. $_{92}X^{238} \longrightarrow {_A X^m} + {_2\text{He}^4}$

Equating mass no. on both sides

$238 = m + 4$

∴ $m = 234$

Equating at. no. on both sides

$92 = A + 2$

∴ $A = 90$

∴ X has at no. $= 90$

Mass no. $= 234$

∴ No. of neutrons $= 234 - 90 = \mathbf{144}$

13. $_{92}\text{U}^{235} + {_0n^1} \longrightarrow {_{56}\text{Ba}^{145}} + {_A X^m} + 3\,{_0n^1}$

Equating mass no. on both sides

$235 + 1 = 145 + m + 3\times 1$

∴ $m = 88$

Equating at. no. on both sides

$92 + 0 = 56 + A + 3\times 0$

∴ $A = 36$

∴ Unknown product is $_{36}X^{88}$, *i.e.*, $\mathbf{_{36}Kr^{88}}$.

14. We have $t = \frac{2.303}{\lambda}\log\frac{N_0}{N}$

For 99.9% decay $N_0 = 100$

$N = 100 - 99.9 = 0.1$

∴ $t_{99.9\%} = \frac{2.303}{\lambda}\log\frac{100}{0.1}$

$t_{99.9\%} = \frac{2.303}{\lambda}\times 3$ ...(1)

For 50% decay $N_0 = 100$; $N = 50$

∴ $t_{50\%} = \frac{2.303}{\lambda}\log\frac{100}{50} = \frac{2.303}{\lambda}\times 0.3010$ ...(2)

By Eqs. (1) and (2) $t_{99.9\%} \approx t_{50\%} \times \mathbf{10}$

15. For half life, $t = t_{1/2}$ then $N = N_0/2$

∵ $t = \frac{2.303}{\lambda}\log_{10}\frac{N_0}{N}$

or $t_{1/2} = \frac{2.303}{\lambda}\log_{10}\frac{N_0}{N_0/2} = \frac{2.303}{\lambda}\log 2$

$= \frac{2.303}{\lambda}\times 0.3010$

$t_{1/2} = \mathbf{\frac{0.693}{\lambda}}$

16. (a) $_{79}\text{Au}^{198} \longrightarrow {_{80}\text{Hg}^{198}} + {_{-1}e^0}$

(b) $t_{1/2} = 65\,\text{hr}$

$T = 260\,\text{hr}$

∵ $T = t_{1/2}\times n$

∴ No. of halves $(n) = \frac{260}{65} = 4$

Now Au left undecayed $(N) = \frac{N_0}{2^4} = \frac{1}{2^4} = \frac{1}{16}\,\text{g}$

∴ Au decayed $= \frac{15}{16}\,\text{g}$

∵ 198 g Au gives 198 g Hg

∴ 15/16 g Au gives **15/16 g Hg**

17. $r_1 = \lambda \cdot N_1$, $r_2 = \lambda \cdot N_2$

$\because$ $\frac{r_1}{r_2} = \frac{N_1}{N_2} = \frac{3.02\times10^6}{1.20\times10^6} = 2.52$

Also, $10 = \frac{2.303}{\lambda}\log\frac{N_0}{N_1}$ ...(1)

$20 = \frac{2.303}{\lambda}\log\frac{N_0}{N_2}$ ...(2)

By Eqs. (2) – (1)

$\therefore$ $20 - 10 = \frac{2.303}{\lambda}\left[\log\frac{N_0}{N_2} - \log\frac{N_0}{N_1}\right]$

$10 = \frac{2.303}{\lambda}\left[\log\frac{N_1}{N_2}\right] = \frac{2.303}{\lambda}\log 2.52$

$\therefore$ $\lambda = \mathbf{0.092\ min^{-1}}$

$t_{1/2} = \frac{0.693}{\lambda} = \frac{0.693}{0.092} = \mathbf{7.50\ min}$

$T_{av} = \frac{1}{\lambda} = \frac{1}{0.092} = \mathbf{10.87\ min}$

18. $t = \frac{2.303}{\lambda}\log_{10}\frac{A_0}{A}$ $\left(t = 4;\ \lambda = \frac{0.693}{8}\right)$

$\therefore$ $\frac{A}{A_0} = 0.707$ or 70.7%

Now after 4 day $\frac{A}{A_0}$ in thyroid gland is 67.7%; Thus,

unstable iodide present in thyroid $= \frac{67.7}{70.7}\times 100 = \mathbf{95.8\%}$.

Since, it is carried by stable iodide ion and thus same per cent of stable iodide is present in thyroid gland.

19. $t_{1/2} = 60\text{day}$, $T = 180\text{day}$

$\therefore$ $n = \frac{T}{t_{1/2}} = \frac{180}{60} = 3$

$\therefore$ % of radioactivity left after 3 halves

$= \frac{N_0}{2^3} = \frac{100}{2^3} = \mathbf{12.5\%}$

20. Given, $t_{1/2} = 28.1\text{ year}$, $N_0 = 10^{-6}$ g, $t = 20\text{ year}$, $N = ?$

$\because$ $t = \frac{2.303}{\lambda}\log_{10}\frac{N_0}{N}$

$\therefore$ $20 = \frac{2.303\times 28.1}{0.693}\log_{10}\frac{10^{-6}}{N}$

$\therefore$ $N = \mathbf{6.1\times10^{-7}\ g}$

21. Given, $t_{1/2} = 30\text{day}$, $N_0 = 10^{12}$ atoms

The disintegration in first second means initial rate of disintegration

$\text{rate} = \frac{-dN}{dt} = \lambda . N_0 = \frac{0.693}{30\times24\times60\times60}\times10^{12}$

$= \mathbf{2.674\times10^5}$ **disintegrations in first second**

22. Given, if $r_0 = 100$; $r = 12.5$; $t = 90\text{day}$;

$\frac{r_0}{r} = \frac{N_0}{N} = \frac{100}{12.5}$

$\because$ $\lambda = \frac{2.303}{t}\log_{10}\frac{N_0}{N} = \frac{2.303}{90}\log_{10}\frac{100}{12.5}$

$= \mathbf{2.31\times10^{-2}\ day^{-1}}$

$\therefore$ $t_{1/2} = \frac{0.693}{\lambda} = \frac{0.693}{2.31\times10^{-2}} = \mathbf{30\ day}$

Alternate solution $\frac{N_0}{N} = \frac{100}{12.5} = 8$

$\therefore$ $N = \frac{N_0}{8} = \frac{N_0}{2^3} = \frac{N_0}{2^n}$

Now, No. of halves $(n) = 3$

$\because$ $T = t_{1/2}\times n$

$90 = t_{1/2}\times 3$

$\therefore$ $t_{1/2} = \mathbf{30\ day}$

23. Given, $r_0 = 50r$ where r is activity for safe working

Now, $t = \frac{2.303}{\lambda}\log_{10}\frac{r_0}{r}$ $(\because r_0 \propto N_0 \text{ and } r \propto N)$

$\therefore$ $t = \frac{2.303\times30}{0.693}\log_{10}\frac{50r}{r} = \mathbf{169.38\ day}$

24. We have $\lambda = \frac{2.303}{t}\log_{10}\frac{N_0}{N}$

$\lambda = \frac{0.693}{47.2}\sec^{-1}$

$t = 1\times60\times60\sec$

$\therefore$ $\frac{0.693}{47.2} = \frac{2.303}{60\times60}\log_{10}\frac{N_0}{N}$

$\therefore$ $\frac{N}{N_0} = \mathbf{1.12\times10^{-23}}$

25. Let the decay constant λ_P and λ_Q be $3a$ and $2a$ respectively.

$t_{1/2}$ of $P = \frac{0.693}{3a}$; $t_{1/2}$ of $Q = \frac{0.693}{2a}$;

at $T = 3\times t_{1/2}$ of $P = \frac{3\times0.693}{3a} = \frac{0.693}{a}$

$\because$ $T = \frac{2.303}{\lambda}\log\frac{a}{a-x}$

For *P*: $\frac{0.693}{a} = \frac{2.303}{3a}\log\frac{1}{n_P}$

For *Q*: $\frac{0.693}{a} = \frac{2.303}{2a}\log\frac{1}{n_Q} = \frac{\log\frac{1}{n_P}}{\log\frac{1}{n_Q}} = \frac{3}{2}$

or $\log\frac{1}{n_P} = \frac{3}{2}\log\frac{1}{n_Q}$

$\log\frac{1}{n_P} = \log\left(\frac{1}{n_Q}\right)^{3/2}$ or $n_P = (n_Q)^{2/3}$

if $n_P = 0.2$, then $n_Q = \mathbf{0.09}$.

26. Rate at time $t = \frac{1}{64}\times$ rate at $t = 0$
(r_t) (r_0)

$\therefore$ $\frac{r_0}{r_t} = 64$

Since, $r_0 \propto N_0$; $r_t \propto N_t$

$\therefore$ $\frac{r_0}{r_t} = \frac{N_0}{N_t} = 64$ or $N_t = \frac{N_0}{64} = \frac{N_0}{2^6}$

$\therefore$ No. of halves, *i.e.*, $n = 6$

$\text{Time} = t_{1/2}\times n$ $(\because t = 2\text{ hr})$

$2\times60\times60 = t_{1/2}\times6$ or $t_{1/2} = 1200\sec$

$\therefore$ $\lambda = \frac{0.693}{1200} = \mathbf{5.775\times10^{-4}\ sec^{-1}}$

27. $\because$ Rate $= \lambda \cdot N_0$

$\because$ 226 g Ra has atoms $= N_A$ (N_A is Avogadro's number)

$\therefore$ 1 g Ra has $= \frac{\text{Av. no.}}{226}$ atoms $= N_0$

$$11.6\times10^{17} = \frac{0.693}{1600}\times\frac{\text{Av. No.}}{226}$$

$\therefore$ Av. No. $= \mathbf{6.052 \times 10^{23}}$

28. $r_0 = 4750$ dpm at $t = 0$

$r_t = 2700$ dpm, at $t = 5$ min

$\therefore$ $\frac{r_0}{r_t} = \frac{4750}{2700}$

Also, Rate $\propto$ No. of atoms

$\therefore$ $\frac{r_0}{r_t} = \frac{N_0}{N_t} = \frac{4750}{2700}$

$\therefore$ $t = \frac{2.303}{\lambda}\log_{10}\frac{N_0}{N_t}$

$$5 = \frac{2.303}{\lambda}\log_{10}\frac{4750}{2700}$$

$\lambda = \mathbf{0.113\ minute^{-1}}$

$\therefore$ $t_{1/2} = \frac{0.693}{0.113} = \mathbf{6.13\ minute}$

29. Rate $= \lambda \cdot N$

$$= \frac{0.693\times6.023\times10^{23}}{2.44\times10^4\times239} = 7.157\times10^{16}\ \text{dis./year}$$

$\therefore$ Loss in energy per year $= 5.24\times7.157\times10^{16}$ MeV

$= 5.24\times7.157\times10^{16}\times10^6$ eV

$= 5.24\times7.157\times10^{16}\times10^6\times1.602\times10^{-19}$ J

$= 5.24\times7.157\times10^{16}\times10^6\times1.602\times10^{-19}\times10^{-3}$ kJ

$= \mathbf{60.08\ kJ}$

30. $N_0 = \frac{1}{226}$ or $N = \frac{1}{226} - x$

where x is the mole of Ra disintegrated in time $t = 1590$ year

$\because$ $\lambda = \frac{2.303}{t}\log_{10}\frac{N_0}{N}$

$$\frac{0.693}{1590} = \frac{2.303}{1590}\log_{10}\frac{1/226}{\frac{1}{226}-x} = \frac{2.303}{1590}\log_{10}\frac{1}{(1-226x)}$$

$\therefore$ $x = 2.21\times10^{-3}$

$\because$ 1 atom of Ra on decay gives 4 atoms of He

Mole of He formed $= 4\times2.21\times10^{-3}$

Now for pressure, $PV = nRT$

$$P\times\frac{5}{1000} = 4\times2.21\times10^{-3}\times0.0821\times300$$

$\therefore$ $P = \mathbf{43.54\ atm}$

31. $t = \frac{2.303}{\lambda}\log_{10}\frac{N_0}{N}$

$\because$ $\frac{N_0}{N}$ is ratio and thus taken in atoms, mass or mole as desired

$\therefore$ $365\times24\times60\times60 = \frac{2.303}{1.58\times10^{-10}}\log_{10}\frac{1}{N}$

$\therefore$ $N = 0.995$ g

$\therefore$ Mass of Th^{232} undergoing decay

$= N_0 - N = 1 - 0.995\text{ g} = 0.005$ g

$\because$ 232 g Th on decay produces 6.023×10^{23} α-particles

$\therefore$ 0.005 g Th on decay produces

$= \frac{6.023\times10^{23}\times0.005}{232}$ α-particles

$= \mathbf{1.298\times10^{19}}$ **α-particles**

32. The decay equation is,

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

$t_{1/2} = 10$ day $\quad N_0 = 1$ g-atom

$T = 20$ day

$\therefore$ $n = 2$ $\quad (\because n = T/t_{1/2})$

$\therefore$ Amount of X left after 2 halves $= \frac{1}{2^2}$ g-atom

$\therefore$ Amount of X used in 2 halves $= 1 - \frac{1}{2^2} = \frac{3}{4}$ g-atom

$\because$ 1 g-atom of X gives 1 mole of He or 22400 mL He

$\therefore$ $\frac{3}{4}$ g-atom of X gives $\frac{3}{4}$ mole of He or $\frac{22400\times3}{4}$ mL He

$= \mathbf{16800\ mL\ He}$

33. $N_0 = 10$ g-atoms $= 10\times6.023\times10^{23} = 6.023\times10^{24}$ atoms

Volume of He collected $= 11.2$ mL $= \frac{11.2}{22400}$ mole

$= 5\times10^{-4}$ mole

$= 5\times10^{-4}\times6.023\times10^{23}$ atoms

$= 3.01\times10^{20}$ atoms

The helium atoms formed = No. of atoms of radioactive substance decayed

$\therefore$ No. of atoms of radioactive substance left

$= (N) = 6.023\times10^{24} - 3.01\times10^{20} = 6.0227\times10^{24}$ atoms

$\because$ $\lambda = \frac{2.303}{t}\log_{10}\frac{N_0}{N}$

$$\lambda = \frac{2.303}{1}\log_{10}\frac{6.023\times10^{24}}{6.0227\times10^{24}}$$

$\lambda = 4.982\times10^{-5}\ \text{hr}^{-1}$

$\therefore$ $t_{1/2} = \frac{0.693}{\lambda} = \frac{0.693}{4.982\times10^{-5}} = \mathbf{13910.29\ hour}$

Note : N_0 and N can be put directly in terms of mole or g-atoms but in this problem it will lead to a problem in solving log values.

Alternate solution

Rate $= \lambda \cdot N$

mole formed/hr = rate $= \frac{11.2}{22400}$

$\therefore$ $\frac{11.2}{22400} = \frac{0.693}{t_{1/2}}\times10$

$\therefore$ $t_{1/2} = \frac{0.693\times10\times22400}{11.2} = \mathbf{13860\ hour}$

34. $_ZA^m \longrightarrow {}_{Z-6}B^{m-12} + 3\ {}_2He^4$

Given, Mass of $A = mg$

$\therefore$ Mole of $A\ (N_0) = 1$ mole

Also, $t = 20$ day; $t_{1/2} = 10$ day

$\therefore$ $n = 2$ $(\because\ t = t_{1/2} \times n)$

$\therefore$ $_ZA^m$ left in 2 halves $= \frac{1}{2^2}$ mole $= \frac{1}{4}$ mol

$\therefore$ $_ZA^m$ decayed in 2 halves $= 1 - \frac{1}{4} = \frac{3}{4}$ mol

$\therefore$ He formed $= 3 \times \frac{3}{4}$ mole $= \frac{9}{4}$ mol

($\because$ decay of 1 mole gives 3 mole He)

$\therefore$ Volume of He at STP $= \frac{22.4 \times 9}{4} =$ **50.4 litre**

35. $_{88}Ra^{226} \longrightarrow {}_{86}Rn^{222} + {}_2He^4$

$N_0 = 1$ g-atom, $t_{1/2}$ Ra $= 1600$ year, $t = 800$ year

Now, $t = \frac{2.303}{\lambda} \log_{10} \frac{N_0}{N}$

$$800 = \frac{2.303 \times 1600}{0.693} \log_{10} \frac{1}{N}$$

$\therefore$ $N = 0.707$ g-atom

$\therefore$ Amount of Ra decayed $= 1 - 0.707 = 0.293$ g-atom

$\therefore$ Rn formed $= 0.293$ mol

and Mole of He formed $= 0.293$ mol

Total mole of gases $= 0.293 + 0.293 = 0.586$

$\because$ $PV = nRT$

$\therefore$ Total pressure of He and Rn is,

$$P = \frac{0.586}{5} \times 0.0821 \times 300 = \textbf{2.887 atm}$$

$\therefore$ $P'_{He} = P \times$ mole fraction of He $= 2.887 \times \frac{1}{2}$

$= \textbf{1.443 atm}$

36. $r_0 = 14$ dpm, $r = 7$ dpm

$\therefore$ $\frac{r_0}{r} = 2$

Also, Rate at any time $\propto$ no. of atoms

$\therefore$ $\frac{r_0}{r} = \frac{N_0}{N} = 2$

Now, $t = \frac{2.303}{\lambda} \log_{10} \frac{N_0}{N} = \frac{2.303 \times 5770}{0.693} \log_{10} 2$

$t =$ **5770 year**

37. 1 curie $= 3.7 \times 10^{10}$ disintegration sec^{-1}

i.e., Rate $= 3.7 \times 10^{10}$ dps

Now, Rate $= \lambda \times$ no. of atoms

$$3.7 \times 10^{10} = \frac{0.693}{5730 \times 365 \times 24 \times 60 \times 60} \times \text{no. of atoms}$$

$\therefore$ No. of atoms $= 9.65 \times 10^{21}$

Now, 6.023×10^{23} atoms of $C^{14} = 14$ g

$\therefore$ 9.65×10^{21} atoms of $C^{14} = \frac{14 \times 9.65 \times 10^{21}}{6.023 \times 10^{23}} =$ **0.2243 g**

38. Rate of decay of 10 mL gas $= 10^4$ dis/min

$= \frac{10^4}{60}$ dis/sec or dps

Thus, rate of decay of 60 litre gas

$= \frac{10^4 \times 60 \times 1000}{60 \times 10} = 10^6$ dps

Now, $\because$ 3.7×10^{10} dps is shown by 1 curie of C^{14}

$\therefore$ 10^6 dps is shown by $\frac{10^6}{3.7 \times 10^{10}}$ curie of C^{14}

$\therefore$ milli curie of carbon $= \frac{10^6}{3.7 \times 10^{10}} \times 10^3$

($\because$ 10^3 millicurie $= 1$ curie)

$= \textbf{0.027 mCi}$

39. $N_0 = 0.1$ g-atom

$t = 10$ day and $t_{1/2} = 5$ day

$$\lambda = \frac{2.303}{t} \log_{10} \frac{N_0}{N}$$

$$\frac{0.693}{5} = \frac{2.303}{10} \log_{10} \frac{0.1}{N}$$

$\therefore$ N_{10}, *i.e.*, species left after 10 day $= 0.0250$ g-atom

Similarly if $t = 11$ day

$$\frac{0.693}{5} = \frac{2.303}{11} \log_{10} \frac{0.1}{N}$$

$\therefore$ N_{11}, *i.e.*, species left after 11 day $= 0.0218$ g-atom

$\therefore$ Species decayed in 11th day $= N_{10} - N_{11}$

$= 0.0250 - 0.0218 = 3.2 \times 10^{-3}$ g-atoms

$= 3.2 \times 6.023 \times 10^{23} \times 10^{-3}$ atoms

$= \textbf{1.93} \times \textbf{10}^{\textbf{21}}$ **atoms**

40. $t_{1/2} = 138.4$ day, $t = 69.2$ day

$\therefore$ No. of halves $n = \frac{t}{t_{1/2}} = \frac{69.2}{138.4} = \frac{1}{2}$

$\therefore$ Po left after $\frac{1}{2}$ halves $= \frac{1}{(2)^{1/2}}$ g $= 0.707$ g

$\therefore$ Po used in $\frac{1}{2}$ halves $= 1 - 0.707 = 0.293$ g

Now, $_{84}Po^{210} \longrightarrow {}_{82}Pb^{206} + {}_2He^4$

$\because$ 210 g Po on decay will produce $= 4$ g He

$\therefore$ 0.293 g Po on decay will produce $= \frac{4 \times 0.293}{210}$

$= 5.581 \times 10^{-3}$ g He

$\therefore$ Volume of He at STP $= \frac{5.581 \times 10^{-3} \times 22400}{4}$

$= \textbf{31.25 mL} = \textbf{31.25 cm}^3$

Also Po^{210} in 1 g $PoO_2 = \frac{210}{242} = 0.868$

$\therefore$ Po^{210} left after 1/2 halves

$= \left[\frac{210}{242}\right] \times \frac{1}{2^{1/2}} = 0.614$ g

$\therefore$ Po^{210} used after 1/2 halves

$= 0.868 - 0.614 = 0.254$ g

$\therefore$ Mass of He formed $= \frac{4\times0.254}{210} = 4.84\times10^{-3}$ g

$\therefore$ Volume of He at STP $= \frac{4.84\times10^{-3}\times22400}{4}$

$= \mathbf{27.104\ cm^3}$

41. (a) 1 m mole $\equiv$ 150 m curie

$\therefore$ 1 m curie $\equiv \frac{1}{150}$ m mole

Now, concentration $= \frac{\text{m mole}}{\text{V in mL}} = \frac{1}{150\times2}$

$= \mathbf{3.33\times10^{-2}\ M}$

(b) 1 curie $= 3.7\times10^{10}$ dps $= 3.7\times10^{10}\times60$ dpm

$= 3.7\times10^{10}\times60\times\frac{80}{100}$ counting per minute

$\therefore$ 1 millicurie $= 3.7\times10^{10}\times60\times\frac{80}{100}\times10^{-3}$ cpm

$\therefore$ cpm/mL $= 3.7\times10^{10}\times60\times\frac{80}{100}\times\frac{10^{-3}}{2}$

$= \mathbf{88.8\times10^7\ cpm/mL}$

42. Given, $\frac{N_{C^{14}}}{N_{C^{12}}} = \frac{1}{16}\frac{N_{0C^{14}}}{N_{0C^{12}}}$

Since, only C^{14} undergoes decay

$\therefore$ $N_{C^{12}} = N_{0C^{12}}$

or $\frac{N_{0C^{14}}}{N_{C^{14}}} = \frac{16}{1}$

$\therefore$ $t = \frac{2.303}{\lambda}\log_{10}\frac{16}{1} = \frac{2.303}{0.693}\times5577\log_{10}2^4$

$t = 5577\times4 = \mathbf{22308\ year}$

43. $t_{1/2}$ of $C^{14} = 5760$ year

$\therefore$ $\lambda = \frac{0.693}{5760}\ yr^{-1}$

$N_{0C^{14}} = 1\%$

$N_{C^{14}} = 0.25\%$

$\therefore$ $t = \frac{2.303}{\lambda}\log_{10}\frac{N_0}{N}$

$= \frac{2.303\times5760}{0.693}\log_{10}\frac{1}{0.25} = \frac{2.303\times5760}{0.693}\log_{10}2^2$

$t = \mathbf{11520\ year}$

Note : Always cancel 2.303 $\log_{10}2$ with 0.693. Otherwise the answer will be approximate.

44. ${}_{92}U^{238} \longrightarrow {}_{82}Pb^{206} + 8\,{}_2He^4 + 6\,{}_{-1}e^0$

Pb present $= \frac{20.6}{206} = 0.1$ g-atom $=$ U decayed

U present $= \frac{23.8}{238} = 0.1$ g-atom

Thus, $N = 0.1$ g-atom

$N_0 =$ U present + U decayed

$= 0.1 + 0.1 = 0.2$ g-atom

Now, $t = \frac{2.303}{\lambda}\log_{10}\frac{N_0}{N}$

$t = \frac{2.303\times4.5\times10^9}{0.693}\log_{10}\frac{0.2}{0.1}$

$t = \mathbf{4.5\times10^9\ year}$

45. (a) Let, Time $= t$ year

${}_{92}U^{238} = 1.667\text{g} = \frac{1.667}{238}$ mole

${}_{82}Pb^{206} = 0.277\text{g} = \frac{0.277}{206}$ mole

$\because$ All the lead has come from decay of U. Therefore,

Pb formed $= \frac{0.277}{206}$ mol

$\therefore$ U decayed $= \frac{0.277}{206}$ mol

$\therefore$ Total mole of uranium before decay, *i.e.*,

$N_0 = \frac{1.667}{238} + \frac{0.277}{206}$

Also, N for $U^{238} = \frac{1.667}{238}$

$\because$ For U^{238} $t = \frac{2.303}{\lambda}\log_{10}\frac{N_0}{N}$

$= \frac{2.303\times4.51\times10^9}{0.693}\log_{10}\frac{\frac{1.667}{238}+\frac{0.277}{206}}{\frac{1.667}{238}}$

$t = \mathbf{1.143\times10^9\ year}$

[Ans. (b) 7.097×10^8 year]

46. Uranium present $= \frac{50}{100}\text{g} = \frac{0.50}{238}$ g-atom

$= 2.10\times10^{-3}$ g-atom

Pb present $= \frac{2.425}{100}\text{g} = \frac{2.425}{100\times206}$ g-atom

Pb formed from uranium decay $= \frac{2.425\times93}{100\times206\times100}$

$= 0.109\times10^{-3}$ g-atom

$N = 2.10\times10^{-3}$ g-atom

$N_0 = (2.10+0.109)\times10^{-3} = 2.209\times10^{-3}$ g-atom

Now $t = \frac{2.303}{\lambda}\log_{10}\frac{N_0}{N}$

$= \frac{2.303}{1.52\times10^{-10}}\log_{10}\frac{2.209\times10^{-3}}{2.10\times10^{-3}}$

$t = \mathbf{3.3\times10^8\ years}$

47. In nature $\frac{N_{U^{238}}}{N_{U^{235}}} = \frac{140}{1}$ at $t = t$

At the time of earth formation,

$\frac{N_{0U^{238}}}{N_{0U^{235}}} = \frac{1}{1}$ at $t = 0$

$\therefore$ $\frac{N_{0U^{238}}}{N_{0U^{235}}}\times\frac{N_{U^{235}}}{N_{U^{238}}} = \frac{1}{140}$

$\therefore$ For U^{238}: $\frac{N_{0U^{238}}}{N_{U^{238}}} = e^{\lambda_{238}\cdot t}$ ...(1)

For U^{235}: $$\frac{N_{0U^{235}}}{N_{U^{235}}} = e^{\lambda^{235} \cdot t} \quad ...(2)$$

$\therefore$ $$\frac{N_{0U^{238}}}{N_{0U^{235}}} \times \frac{N_{U^{235}}}{N_{U^{238}}} = e^{(\lambda^{238} - \lambda^{235})t}$$

or $$\frac{1}{140} = e^{(\lambda^{238} - \lambda^{235})t}$$

$$(\lambda^{238} - \lambda^{235})t = \log_e 1 - \log_e 140$$

or $$\left[\frac{0.693}{4.5 \times 10^9} - \frac{0.693}{7.13 \times 10^8}\right] t = -2.303 \log_{10} 140$$

$$= -4.9416$$

$\therefore$ $$t = \mathbf{6.04 \times 10^9}\ \textbf{year}$$

48. $${}_{90}Th^{232} \longrightarrow {}_{82}Pb^{208} + 6\ {}_2He^4 + 4\ {}_{-1}e^0$$

$\because$ 6×22400 mL He is formed by 232 g Th decay

$\therefore$ 8×10^{-5} mL He is formed by

$$= \frac{232 \times 8 \times 10^{-5}}{6 \times 22400} \text{ g Th decay}$$

$$= 1.38 \times 10^{-7} \text{ g Th decay}$$

At $t = t$, sample has Th $= 5 \times 10^{-7}$ g $\propto N$

At $t = 0$, sample had Th $= 5 \times 10^{-7} + 1.38 \times 10^{-7} \propto N_0$

$$= 6.38 \times 10^{-7} \text{ g}$$

For Th decay $\because$ $$t = \frac{2.303}{\lambda} \log_{10} \frac{N_0}{N}$$

$$= \frac{2.303 \times 1.39 \times 10^{10}}{0.693} \log_{10} \frac{6.38 \times 10^{-7}}{5 \times 10^{-7}}$$

$$= \mathbf{4.89 \times 10^9}\ \textbf{year}$$

49. The specific activity of a radioactive nucleus is its activity of disintegration rate per g of specimen.

$$1 \text{ g of } {}^{31}P \text{ has } \frac{N}{31} \text{ atoms of } {}^{31}P$$

The sample contains 10^6 part of it as ${}^{32}P$

Thus, ${}^{32}P$ in 1 g specimen

$$= \frac{N}{31 \times 10^6} \text{ atoms of } {}^{32}P$$

Thus, $$\text{rate} = \lambda \cdot N$$

$$= \frac{0.693}{14.3 \times 24 \times 60 \times 60} \times \frac{N}{31 \times 10^6}$$

$$= \frac{0.693 \times 6.023 \times 10^{23}}{14.3 \times 24 \times 60 \times 60 \times 31 \times 10^6}$$

Rate $= 1.09 \times 10^{10}$ dps per g specimen

or specific activity $= 1.09 \times 10^{10}$ dps per g

$$= \frac{1.09 \times 10^{10}}{3.7 \times 10^{10}} \text{ curie per g}$$

$$= \mathbf{0.295\ Ci\ per\ g}$$

50. Given,

Specific activity of sample $= 6 \times 10^9$ dps per g of mixture

Let the masses of Pu^{239} and Pu^{240} are a and b g respectively, then

$$a + b = 1 \quad ...(1)$$

For Pu^{239}: $$r_1 = \lambda \cdot N_1$$

$$r_1 = \frac{0.693 \times 6.023 \times 10^{23} \times a}{2.44 \times 10^4 \times 365 \times 24 \times 60 \times 60 \times 239} \text{ dps g}^{-1}$$

$$= 2.77 \times 10^9 \times a \text{ dps g}^{-1}$$

For Pu^{240}: $$r_1 = \frac{0.693 \times 6.023 \times 10^{23} \times b}{6.58 \times 10^3 \times 365 \times 24 \times 60 \times 60 \times 240}$$

$$= 8.38 \times 10^9 \times b \text{ dps g}^{-1}$$

$\therefore$ $$2.27 \times 10^9 \times a + 8.38 \times 10^9 \times b = 6 \times 10^9$$

or $$2.27a + 8.38b = 6 \quad ...(2)$$

By Eqs. (1) and (2)

$a = \mathbf{0.3895}$ or **38.95%**

$b = \mathbf{0.6105}$ or **61.05%**

51. No. of α-particles or He formed $= 2.24 \times 10^{13}$ min^{-1}

$\therefore$ No. of He particles formed in 420 day

$$= 2.24 \times 10^{13} \times 420 \times 24 \times 60 = 1.355 \times 10^{19}$$

Also at 27° C and 750 mm of P, He = 0.5 mL

From $$PV = nRT$$

$$\frac{750}{760} \times \frac{0.5}{1000} = n \times 0.0821 \times 300$$

$\therefore$ $$n = 2.0 \times 10^{-5} \text{ mole}$$

Given, 2.0×10^{-5} mole He $= 1.355 \times 10^{19}$ particles He

$\therefore$ $$1 \text{ mole He} = \frac{1.355 \times 10^{19}}{2.0 \times 10^{-5}} = 6.775 \times 10^{23} \text{ particles}$$

Therefore, Avogadro's no. $= \mathbf{6.775 \times 10^{23}}$ **particle / mol**

52. To carry out experiment,

Rate of β-emission required = 346 particle min^{-1}

$\therefore$ $$\text{Rate} = \lambda . N$$

or desired no. of atoms to carry out experiment after 6.909 hr

$$= \frac{\text{rate}}{\lambda} = \frac{346 \times 66.6 \times 60}{0.693} = 1.995 \times 10^6 \text{ atoms}$$

Now, when $N = 1.995 \times 10^6$ atoms of Mo at $t = 6.909$ hrs

N_0 can be evaluated as

$$t = \frac{2.303}{\lambda} \log_{10} \frac{N_0}{N}$$

$$6.909 = \frac{2.303 \times 66.6}{0.693} \log_{10} \frac{N_0}{N}$$

$\therefore$ $$\frac{N_0}{N} = 1.0745$$

$\therefore$ $$N_0 = N \times 1.0745 = 1.995 \times 10^6 \times 1.0745$$

$$= 2.1436 \times 10^6 \text{ atoms of } Mo^{99}$$

$\therefore$ Mass of Mo required to carry out experiment in 6.909 hour

$$= \frac{2.1436 \times 10^6 \times 99}{6.023 \times 10^{23}} \text{ g} = \mathbf{3.56 \times 10^{-16}\ g}$$

53. Let activity of X^{A_1} and X^{A_2} are a and b curie respectively at $t = 0$

$\therefore$ $$a + b = 1 \text{ curie} \quad ...(1)$$

Now, Rate $\propto$ No. of atoms

$\therefore$ For X^{A_1} $\quad t = \frac{2.303}{\lambda}\log_{10}\frac{N_0}{N} = \frac{2.303}{\lambda}\log_{10}\frac{r_0}{r}$

$$20 = \frac{2.303\times 14}{0.693}\log_{10}\frac{a}{r_1}$$

$\therefore$ $\quad r_1 = 0.3716a$

For X^{A_2} $\quad t = \frac{2.303}{\lambda}\log_{10}\frac{N_0}{N} = \frac{2.303}{\lambda}\log_{10}\frac{r_0}{r}$

$$20 = \frac{2.303\times 25}{0.693}\log_{10}\frac{b}{r_2}$$

$$r_2 = 0.5744b$$

Given activity after 20 day $= \frac{1}{2}$ curie

$$0.3716a + 0.5744b = \frac{1}{2}$$

or $\quad 0.7432a + 1.1488b = 1 \quad$ ...(2)

By Eqs. (1) and (2)

$$a = \mathbf{0.3669\ Ci} = 0.3669\times 3.7\times 10^{10}\text{ dps}$$

$$b = \mathbf{0.6331\ Ci} = 0.6331\times 3.7\times 10^{10}\text{ dps}$$

Now, $\quad \text{Rate} = \lambda\cdot N \quad (\because a = 0.3669\text{ curie})$

For X^{A_1} $\quad 0.3669\times 10^{10}\times 3.7 = \frac{0.693}{14\times 24\times 60\times 60}N_0^{A_1}$

For X^{A_2} $\quad 0.6331\times 10^{10}\times 3.7 = \frac{0.693}{25\times 24\times 60\times 60}N_0^{A_2}$

$\therefore$ $\quad \frac{N_0^{A_1}}{N_0^{A_2}} = \mathbf{0.3245}$

54. $\quad {}_{86}Rn \longrightarrow {}_2He^4 + {}_{84}X \quad$ (an α-emitter)

$$\text{Rate} = \lambda\cdot N_0$$

$$3.7\times 10^{10} = 2\times 10^{-6}\times N_0$$

$\therefore$ N_0, *i.e.*, number of atoms of Rn at $(t = 0)$

$$= 1.85\times 10^{16}\text{ atoms}$$

(a) Rn left after 1 hr is calculated by

$$t = \frac{2.303}{\lambda}\log_{10}\frac{N_0}{N}$$

$$60\times 60 = \frac{2.303}{2\times 10^{-6}}\log_{10}\frac{N_0}{N}$$

$\therefore$ $\quad \frac{N_0}{N} = 1.0072$

$\therefore$ $\quad N = \frac{1.85\times 10^{16}}{1.0072} = 1.837\times 10^{16}$ atoms

$\therefore$ No. of α-particles formed = No. of Rn atoms decayed

$$= 1.85\times 10^{16} - 1.837\times 10^{16} = 0.013\times 10^{16}\text{ atoms}$$

$\therefore$ Energy $= 0.013\times 10^{16}\times 5.5 = 0.0715\times 10^{16}$ MeV

$$= 0.0715\times 10^{22}\text{ eV}$$

$$= 0.0715\times 10^{22}\times 1.602\times 10^{-19}\text{ J} = \mathbf{114.5\ J}$$

(b) Rn left after $t = \frac{1}{\lambda}$

$$\frac{1}{\lambda} = \frac{2.303}{\lambda}\log_{10}\frac{N_0}{N}$$

$$\frac{N_0}{N} = 2.718$$

$\therefore$ $\quad N = \frac{1.85\times 10^{16}}{2.718} = 0.6806\times 10^{16}$

$\therefore$ No. of α-particles formed

$$= 1.85\times 10^{16} - 0.6806\times 10^{16}$$

$$= 1.1694\times 10^{16}$$

$\therefore$ Energy $= 1.1694\times 10^{16}\times 5.5$

$$= 6.4317\times 10^{16}\text{ MeV} = 6.4317\times 10^{16}\times 10^{6}\text{ eV}$$

$$= 6.4317\times 10^{22}\times 1.602\times 10^{-19}\text{ J}$$

$$= \mathbf{1.03\times 10^4\ J}$$

55. $\quad Na_3PO_4 = \frac{54.5\times 10^{-3}}{161.2}$ mol

$\therefore$ P atoms $= \frac{54.5\times 10^{-3}}{161.2}$ mol

$\therefore$ g-atoms P^{32} atoms $= \frac{54.5\times 10^{-3}}{161.2}\times\frac{15.6}{100} = 5.27\times 10^{-5}$

$\therefore$ $\quad$ Atoms of $P^{32} = 5.27\times 10^{-5}\times 6.023\times 10^{23}$

Now, Rate

$$= \lambda\cdot N = \frac{0.693}{14.3\times 24\times 60\times 60}\times 5.27\times 10^{-5}\times 6.023\times 10^{23}$$

Rate $= \mathbf{1.78\times 10^{13}\ dps}$

56. Total mass of ${}_{19}K^{40} = \frac{0.012}{100}\times\frac{0.35}{100}\times 75\times 10^3$ g

$$= 3.15\times 10^{-2}\text{ g}$$

$$= \frac{3.15\times 10^{-2}\times 6.023\times 10^{23}}{40}\text{ atoms}$$

$\therefore$ Rate $= \lambda\times$ No. of atoms

$$= \frac{0.693}{1.3\times 10^9\times 365\times 24\times 60}\times\frac{3.15\times 10^{-2}\times 6.023\times 10^{23}}{40}$$

Rate $= \mathbf{4.81\times 10^5\ dpm}$

57. (i) $\quad PuO_2 = \frac{32\times 10^{-3}}{270}$ mol

$\therefore$ $\quad Pu = \frac{32\times 10^{-3}}{270}$ mol

$\therefore$ Atoms (N) of Pu $= \frac{32\times 10^{-3}}{270}\times 6.023\times 10^{23}$

Now, $\quad$ rate $= \lambda\cdot N$

$\therefore$ $\quad 6.4\times 10^7 = \lambda\times\frac{32\times 10^{-3}\times 6.023\times 10^{23}}{270}$

$\therefore$ $\quad \lambda = 8.97\times 10^{-13}\text{ sec}^{-1}$

$\therefore$ $\quad t_{1/2} = \frac{0.693}{\lambda} = \frac{0.693}{8.97\times 10^{-13}} = \mathbf{7.73\times 10^{11}\ sec}$

(ii) Also, $\quad PuO_2 = \frac{100\times 10^{-3}}{270}$ mol

$\therefore$ $\quad Pu = \frac{100\times 10^{-3}}{270}$ mol

Now, $\quad t = \frac{2.303}{\lambda}\log_{10}\frac{N_0}{N}$

$5000\times 365\times 24\times 60\times 60$

$$= \frac{2.303\times 7.73\times 10^{11}}{0.693}\log_{10}\frac{100\times 10^{-3}}{270\times N}$$

$\therefore \quad N = \mathbf{3.21 \times 10^{-4}}$

$\therefore \quad$ Pu left $= 3.21 \times 10^{-4}$ mol

$\therefore \quad PuO_2$ left $= 3.21 \times 10^{-4}$ mol

or Mass of PuO_2 left $= 3.21 \times 10^{-4} \times 270$ g

$= \mathbf{86.67\ mg}$

58. Let V mL blood is present in patient

(a) r_0 of $Na^{24} = 2 \times 10^3$ dps $= 2 \times 10^3 \times 60$ dpm

$= 120 \times 10^3$ dpm for V mL blood

r of $Na^{24} = 16$ dpm/mL at $t = 5$ hr $= 16 \times V$ dpm/V mL

$\because \quad \frac{r_0}{r} = \frac{N_0}{N}$

$\therefore \quad \frac{N_0}{N} = \frac{120 \times 10^3}{16V}$

$\because \quad t = \frac{2.303}{\lambda} \log_{10} \frac{N_0}{N}$

$$5 = \frac{2.303 \times 15}{0.693} \log_{10} \frac{120 \times 10^3}{16V}$$

$\therefore \quad V = \mathbf{5.95 \times 10^3\ mL}$

(b) Activity of blood sample after 5 hr more, *i.e.*, $t = 10$ hr

$$t = \frac{2.303}{\lambda} \log_{10} \frac{N_0}{N}$$

$$10 = \frac{2.303 \times 15}{0.693} \log_{10} \frac{120 \times 10^3}{A}$$

$\therefore \quad A = 75.6 \times 10^3$ dpm per 5.95×10^3 mL

$= \frac{75.6 \times 10^3}{5.95 \times 10^3}$ dpm per mL

$= 12.71$ dpm per mL

$= \mathbf{0.2118\ dps\ per\ mL}$

59. $\frac{1}{2} mu^2 = 0.0327 \times 1.6 \times 10^{-19}$ J

$$\therefore \quad u^2 = \frac{2 \times 0.0327 \times 1.6 \times 10^{-19}}{1.675 \times 10^{-27}} = 625 \times 10^4$$

$\therefore \quad u = 2500$ m/s

Time taken to travel 100 metre $= \frac{100}{2500} = 0.04$ sec

Thus, $\quad \frac{dN}{N} = \lambda \cdot dt$

$$\therefore \quad \frac{dN}{N} = \frac{0.693}{700} \times 0.04 = \mathbf{3.96 \times 10^{-5}}$$

60. (a) $\quad A \longrightarrow$ Decay product

$t=0 \quad N_0$

Since, α is the number of A atoms produced at constant rate. Note that N is the number of nuclei left at time t then $-\frac{dN}{dt} = \lambda \cdot N$. Hence, rate of accumulation of radionuclide $\left(\frac{dN}{dt}\right)$;

$$\therefore \quad \frac{dN}{dt} = (\alpha - \lambda N) \quad \text{or} \quad \frac{dN}{(\alpha - \lambda N)} = dt$$

on integrating N_0 to N and time 0 to t.

$$\int_{N_0}^{N} \frac{dN}{(\alpha - \lambda N)} = \int_0^t dt$$

$$-\frac{1}{\lambda} \log_e [\alpha - \lambda N]_{N_0}^{N} = t$$

or $\quad (\alpha - \lambda N) = (\alpha - \lambda N_0) e^{-\lambda t}$

$$\therefore \quad N = \frac{1}{\lambda}[\alpha - (\alpha - \lambda N_0)_e^{-\lambda t}]$$

(b) If $\alpha = 2\lambda N_0$, then

$N = 2N_0 - N_0 e^{-\lambda t}$

at $\quad t = t_{1/2} = 0.693/\lambda$

$$N = 2N_0 - N_0 e^{\left(\frac{-\lambda \times 0.693}{\lambda}\right)}$$

$= 2N_0 - N_0/2 = 3N_0/2$

If $t \to \infty$, then $N = \lim_{t \to \infty} [2N_0 - N_0 e^{-\lambda t}]$

$= 2N_0 - N_0 e^{-\infty} = \mathbf{2N_0} \quad (e^{-\infty} \to 0)$

61. The radio nuclide is formed at a constant rate q.

The decay rate $-\frac{dN}{dt} = \lambda \cdot N$

The rate of accumulation $\frac{dN}{dt} = (q - \lambda N)$

or $\quad \int_0^N \frac{dN}{(q - \lambda N)} = \int_0^t dt$

or $\quad -\frac{1}{\lambda}[\log_e (q - \lambda N)]_0^N = t$

or $\quad t = -\frac{1}{\lambda}[\log_e (q - \lambda N) - \log_e q]$

or $\quad t = -\frac{1}{\lambda} \log_e \frac{q - \lambda N}{q} = \frac{1}{\lambda} \log_e \left[\frac{q}{q - \lambda N}\right]$

$\therefore \quad t = \frac{2.303}{\lambda} \log \left[\frac{q}{q - \lambda N}\right]$

$t = \frac{2.303}{\lambda} \log \left[\frac{q}{q - A}\right] \quad (\because A = \lambda N)$

$$= \frac{2.303 \times 14.3}{0.693} \log \frac{2.7 \times 10^9}{1.7 \times 10^9} = \mathbf{9.5\ day}$$

62. At radioactive equilibrium $A \longrightarrow B$

$$\frac{N_A}{N_B} = \frac{\lambda_B}{\lambda_A} = \frac{t_{1/2A}}{t_{1/2B}}$$

$$\therefore \quad \frac{3.1 \times 10^9}{1} = \frac{2 \times 10^{10}}{t_{1/2B}}$$

$\therefore \quad t_{1/2B} = \mathbf{6.45\ year}$

63. Isotope *A*:

Mole of $A = a$; $t_{1/2} = 12$ hr

(rapidly decaying has more mass)

$[r_A]_0 = 1.0\mu$Ci $= 1.0 \times 10^{-6}$ Ci

$= 1.0 \times 10^{-6} \times 3.7 \times 10^{10}$ dps

Isotope *B*:

Mole of $B = b$; $t_{1/2} = 16$ hr

$\therefore$ Given $\frac{a}{b} = 3$

For *A*: $\quad [r_A]_0 = \lambda_A \times a \times N_A$ (N_A is Av. no.)

$$1.0 \times 10^{-6} \times 3.7 \times 10^{10} = \frac{0.693}{12 \times 60 \times 60} \times a \times 6.023 \times 10^{23}$$

$\therefore \quad a = 3.82\times10^{-15}$ mole of A

$\therefore \quad b = \frac{a}{3} = \frac{3.82\times10^{-15}}{3} = 1.28\times10^{-15}$ mole of B

For *B*:

$$[r_B]_0\ \lambda\cdot N_B = \frac{0.693}{16\times60\times60}\times1.28\times10^{-15}\times6.023\times10^{23}$$

$$[r_B]_0 = 9.275\times10^3 \text{ dps}$$

For *A*: $\quad t = \frac{2.303}{\lambda}\log\frac{r_0}{r} \qquad \left(\because \frac{r_0}{r} = \frac{N_0}{N}\right)$

$t = 2\times24$ hr; $\lambda = \frac{0.693}{12}$;

$r_0 = 1.0\times10^{-6}\times3.7\times10^{10} = 3.7\times10^4$ dps

$$2\times24 = \frac{2.303\times12}{0.693}\log\frac{3.7\times10^4}{r_A}$$

$\therefore \quad r_A = \mathbf{2315.40\ dps = 6.26\times10^{-8}\ Ci = 0.0626\ \mu Ci}$

For *B*: $\quad t = \frac{2.303}{\lambda}\log\frac{r_0}{r}$

$$2\times24 = \frac{2.303\times16}{0.693}\log\frac{9.275\times10^3}{r_B}$$

$\therefore \quad r_B = \mathbf{1.159\times10^3\ dps = 3.13\times10^{-8}\ Ci = 0.0313\ \mu Ci}$

Also, after 2 day $r_A = \lambda_A\cdot N_A$; $\quad r_B = \lambda_B\cdot N_B$

$\therefore \quad \frac{r_A}{r_B} = \frac{N_A}{N_B}\times\frac{\lambda_A}{\lambda_B}$

or $\quad \frac{N_A}{N_B} = \frac{r_A}{r_B}\times\frac{\lambda_B}{\lambda_A}$

$$= \frac{0.0626}{0.0313}\times\frac{0.693}{16}\times\frac{12}{0.693} = \mathbf{1.5}$$

64. $\therefore$ 18 g H_2O has $2N$ H atoms in it and $H^3 : H^1 :: 8\times10^{-18} : 1$

$\therefore$ 18 g H_2O has ${}_1H^3$ atoms $= 8\times10^{-18}\times6.023\times10^{23}\times2$

$\therefore$ 10 g H_2O has ${}_1H^3$ atoms

$$= \frac{8\times10^{-18}\times6.023\times10^{23}\times2\times10}{18}$$

i.e., $\quad N_0$ of ${}_1H^3 = 5.354\times10^6$ atoms

Now, $\quad t = \frac{2.303}{\lambda}\log_{10}\frac{N_0}{N}$

$$40 = \frac{2.303\times12.3}{0.693}\log_{10}\frac{5.354\times10^6}{N}$$

$\therefore \quad N = \mathbf{5.624\times10^5\ atoms.}$

65. For successive α, β-emissions in parallel paths,

$$\lambda_{\text{average}} = \lambda_\alpha + \lambda_\beta = \frac{1}{1620} + \frac{1}{405} = \frac{5}{1620}\ \text{year}^{-1}$$

Given at $t = t \quad N = \frac{1}{4}N_0 \qquad$ (since 3/4 part decays)

$\because \quad t = \frac{2.303}{\lambda_{\text{average}}}\log_{10}\frac{N_0}{N}$

$$t = \frac{2.303\times1620}{5}\log 4 = \mathbf{449.24\ year}$$

66. $r_{\text{nucleus}} = 1.3\times10^{-13}\times(A)^{1/3}$; $\qquad$ where A is mass number

$r_{U^{238}} = 1.3\times10^{-13}\times(238)^{1/3} = 8.06\times10^{-13}$ cm

$r_{He^4} = 1.3\times10^{-13}\times(4)^{1/3} = 2.06\times10^{-13}$ cm

$\therefore$ Total distance in between uranium and α-nuclei

$= 8.06\times10^{-13} + 2.06\times10^{-13} = 10.12\times10^{-13}$ cm

Now repulsion energy

$$= \frac{Q_1Q_2}{r} = \frac{92\times4.8\times10^{-10}\times2\times4.8\times10^{-10}}{10.12\times10^{-13}}\ \text{erg}$$

$= 418.9\times10^{-7}$ erg $= 418.9\times10^{-7}\times6.242\times10^{11}$ eV

$$= \frac{418.9\times10^{-7}\times6.242\times10^{11}}{10^6}\ \text{MeV} = \mathbf{26.14\ MeV}$$

67. At closest distance kinetic energy should be equal to repulsion energy

$$\frac{1}{2}mu^2 = \frac{1}{4\pi\varepsilon_0}\times\frac{2Ze^2}{r}$$

where repulsion term is given by

$$\frac{q_1\cdot q_2}{r} = \frac{2e.Z.e}{r} = \frac{2Ze^2}{r}$$

$\therefore \quad u^2 = \frac{Ze^2}{\pi\varepsilon_0 mr}$

$$u = \sqrt{\frac{29\times(1.6\times10^{-19})^2}{3.14\times8.85\times10^{-12}\times(4\times1.672\times10^{-27})\times10^{-13}}}$$

$u = \mathbf{6.3\times10^6\ m\ sec^{-1}}$

68. Total mass before reaction

$= 4.0026 + 10.0129 = 14.0155$ amu

Total mass after reaction

$= 13.0036 + 1.008 = 14.0116$ amu

$\therefore$ Mass decay during reaction

$= 14.0155 - 14.0116 = 0.0039$ amu

$\therefore$ Total energy given out

$= 0.0039\times931$ MeV $= 3.6309\times10^6$ eV

$= 3.6309\times10^6\times1.602\times10^{-19}$ J

$= \mathbf{5.816\times10^{-13}\ J}$

Now, $\quad E = h\nu$

$5.816\times10^{-13} = 6.625\times10^{-34}\ \nu$

$\therefore \quad$ Frequency, $\nu = \mathbf{8.77\times10^{20}\ Hz}$

and $\quad \nu = \frac{c}{\lambda}$

$\therefore \quad \lambda = \frac{c}{\nu} = \frac{3.0\times10^8}{8.77\times10^{20}} = \mathbf{3.4\times10^{-13}\ m}$

Note : Energy supplied to α-particle $= q\times\nu$

$= 2\times1.602\times10^{-19}\times3\times10^5$ J

$$= \frac{2\times1.602\times10^{-19}\times3\times10^5}{1.602\times10^{-19}}\ \text{eV} = \mathbf{6\times10^5\ eV}$$

This energy is used up to over power the penetration of nucleus and imparting energy to C and H atoms, *i.e.*,

1×10^5 eV $+ 5\times10^5$ eV $= \mathbf{6\times10^5\ eV}$

69. $\quad {}_{+1}e^0 + {}_{-1}e^0 \longrightarrow 2\gamma \quad$ (photons of same energy)

The mass of two electrons is converted into energy

The energy produced during emission of two photons

$= 2\times m_e\times c^2$

$= 2 \times 9.108 \times 10^{-31} \times (3.0 \times 10^8)^2$

$= 163.9 \times 10^{-15}$ J

$\therefore$ Energy of one photon $= \frac{16.39 \times 10^{-14}}{2} = 8.195 \times 10^{-14}$ J

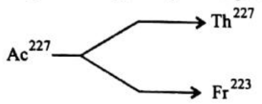
Now, $E = \frac{hc}{\lambda}$

or $8.195 \times 10^{-14} = \frac{6.625 \times 10^{-34} \times 3.0 \times 10^8}{\lambda}$

or $\lambda = 2.425 \times 10^{-12}$ m $=$ **2.425 pm**

70. $\lambda_{Ac} = \frac{0.693}{22} = 3.15 \times 10^{-2}$ year^{-1}

For the decay involving two parallel paths,



We have $\lambda_{Ac} = \lambda_{Th\ path} + \lambda_{Fr\ path}$

$\therefore$ $\lambda_{Ac} \times$ Fraction of Th $= \lambda_{Th\ path}$ ...(1)

$\lambda_{Ac} \times$ Fraction of Fr $= \lambda_{Fr\ path}$ ...(2)

or $\lambda_{Ac} \times (1 -$ Fraction of Th$) = \lambda_{Fr\ path}$ ...(3)

Thus, by Eqs. (1) and (3), we get

$\lambda_{Ac} = \lambda_{Th\ path} + \lambda_{Fr\ path}$

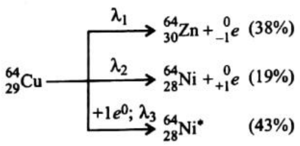
Thus, Fractional yield of Th $= \frac{\lambda_{Th\ path}}{\lambda_{Ac\ path}}$

or $\lambda_{Th\ path} = 3.15 \times 10^{-2} \times \frac{2}{100} =$ **6.30×10^{-4} yr^{-1}**

Also, Fractional yield of Fr $= \frac{\lambda_{Fr\ path}}{\lambda_{Ac\ path}}$

$\therefore$ $\lambda_{Fr} = 3.15 \times 10^{-2} \times \frac{98}{100} =$ **3.087×10^{-2} yr^{-1}**

71.



Given, $\lambda_{av} = \frac{0.693}{128}$ hr^{-1}

$\therefore$ $\lambda_1 + \lambda_2 + \lambda_3 = \lambda_{av} = \frac{0.693}{12.8}$

$= 5.41 \times 10^{-2}$ hr^{-1} ...(1)

Also for parallel path decay

$\lambda_1 =$ Fractional yield of ${}^{64}_{30}Zn \times \lambda_{av}$

$\lambda_2 =$ Fractional yield of ${}^{64}_{28}Ni \times \lambda_{av}$

$\lambda_3 =$ Fractional yield of ${}^{64}_{28}Ni^* \times \lambda_{av}$

$\therefore$ $\frac{\lambda_1}{\lambda_2} = \frac{38}{19}$ ...(2)

and $\frac{\lambda_1}{\lambda_3} = \frac{38}{43}$ ...(3)

From Eqs. (1), (2) and (3) $\lambda_1 = 2.056 \times 10^{-2}$ hr^{-1};

$\lambda_2 = 1.028 \times 10^{-2}$ hr^{-1}; $\lambda_3 = 2.327 \times 10^{-2}$ hr^{-1}

$\therefore$ $t_{1/2}$ for β^--emission $= \frac{0.693}{2.056 \times 10^{-2}} =$ **33.70 hr**

$t_{1/2}$ for β^+-emission $= \frac{0.693}{1.028 \times 10^{-2}} =$ **67.41 hr**

$t_{1/2}$ for electron capture $= \frac{0.693}{2.327 \times 10^{-2}} =$ **29.78 hr**

72. $\lambda_A = \lambda_1 + \lambda_2 = 1.5 \times 10^{-5} + 5 \times 10^{-6}$

$= 20 \times 10^{-6}$ s^{-1}

Also, $2.303 \log \frac{[A]_0}{[A]_t} = \lambda \times t$

$\therefore$ $2.303 \log \frac{0.25}{[A]_t} = 20 \times 10^{-6} \times 5 \times 60 \times 60$

$\therefore$ $[A]_t = 0.1744\ M$

$\therefore$ $[A]$ decomposed $= [A]_0 - [A]_t$

$= 0.25 - 0.1744 = 0.0756\ M$

Fraction of C formed $= \left[\frac{\lambda_2}{\lambda_1 + \lambda_2}\right] \times [A]_{decomposed} \times \frac{2}{5}$

$= 0.0756 \times \frac{5 \times 10^{-6}}{20 \times 10^{-6}} \times \frac{2}{5}$

$=$ **7.56×10^{-3} *M***

Note that 5 mole of A are used to give 2 mole of C.

73. Kinetic energy $= \frac{1}{2} mu^2$

$0.0327 \times 1.602 \times 10^{-19} = \frac{1}{2} \times 1.675 \times 10^{-27} \times u^2$

(1eV $= 1.602 \times 10^{-19}$ J)

$\therefore$ $u = 2500.0$ m/sec $= 2.50$ km/sec

Thus, time taken to move 10 km $= \frac{10}{2.5} = 4.0$ sec

Now, neutrons left (N) after 4.0 sec can be obtained by

$\lambda = \frac{2.303}{t} \log \frac{N_0}{N}$

$\frac{0.693}{700} = \frac{2.303}{4} \log \frac{N_0}{N}$

$\frac{N_0}{N} = 1.004$

$\therefore$ $N = 99.60\%$ $(N_0 = 100)$

$\therefore$ No. of neutrons decayed $=$ **0.4%** or **0.004**

74. Fusion reaction is $2\ {}_1H^2 \longrightarrow {}_2He^4 +$ energy

Mass defect $= 2 \times$ mass of ${}_1H^2 -$ mass of ${}_2He^4$

$= 2 \times 2.0141 - 4.0026 = 0.0256$ amu

$\therefore$ Energy liberated during fusion of 2 atoms of ${}_1H^2 = \Delta mc^2$

$= 0.0256 \times 1.66 \times 10^{-27} \times (2.998 \times 10^8)^2$

$= 3.8 \times 10^{-12}$ J

$\therefore$ Energy liberated during fusion of $2N$ atoms of ${}_1H^2$ to give

N atoms (or 1 mole ${}_2He^4$) $= 3.8 \times 10^{-12} \times 6.023 \times 10^{23}$

$=$ **2.3×10^{12} J**

75.
$$\lambda_{Pb} = \frac{0.693}{10.6\times 60} = 1.0896\times 10^{-3}$$
$$\lambda_{Bi} = \frac{0.693}{60.5} = 11.45\times 10^{-3}$$
$$t_{max} = \frac{2.303}{\lambda_{Bi} - \lambda_{Pb}} \log_{10}\frac{\lambda_{Bi}}{\lambda_{Pb}}$$
$$= \frac{2.303}{10.3604\times 10^{-3}} \log_{10}\frac{11.45\times 10^{-3}}{1.0896\times 10^{-3}}$$
$$= \mathbf{227.1\ minute}$$

76. Isotopes: 1. Atoms of same element having same at. no. but different mass no. are known as isotopes.

2. Nucleides and its decay product after one α and two β-particles are isotopes.

3. *e.g.*, $_1H^1$, $_1H^2$ and $_1H^3$; each has same at. no.

∴ Correct choice **1 – A**

Isobars: 1. Atoms of different elements having same mass no. are isobars.

2. Nucleide and its decay product after β-emission are isobars.

3. *e.g.*, $_1H^3$ and $_2He^3$; each has same mass no.

∴ Correct choice **2 – G**

Nuclear isomers: 1. Atoms of an element of the same atomic mass but possessing different rate of decay as a result of being in different quantum states.

2. *e.g.*, U_A and U_Z; Co^{60m} and Co; Br^{80} and Br^{80m}

∴ Correct choice **3 – D**

Isosters: 1. Molecules having same no. of atoms and same no. of electrons are isosters.

2. *e.g.*, CO_2 and N_2O each has three atoms and 22 electrons.

∴ Correct choice **4 – E**

Isotones: 1. Nucleide containing same no. of neutrons but different no. of protons.

2. *e.g.*, $_1H^2$ and $_2H^3$; each has one neutron.

∴ Correct choice **5 – C**

Isoelectronics: 1. Atom and ions having same no. of electrons are isoelectronics.

2. *e.g.*, N^{3-}, O^{2-}, F^-, Ne, Na^+, Mg^{2+}, Al^{3+}; each has 10 electrons.

∴ Correct choice **6 – B**

Isodiaphers: 1. Atoms having the same difference of neutrons and protons or same isotopic no.

2. Nucleide and its decay product after α-emission are isodiaphers.

3. *e.g.*, $_ZA^m \xrightarrow{-\alpha} {}_{Z-2}B^{m-4}$; each has the same difference of *n* and *p*, *i.e.*, $(n-p) = m - 2Z$.

∴ Correct choice **7 – F**

77. Average atomic mass $(\bar{A}) = \Sigma A_1X_1 / \Sigma X_{Total}$.

$$= \frac{\text{\% of one isotope} \times \text{its relative atomic mass} + \text{\% of other} \times \text{its relative atomic mass}}{100}$$

Let % of isotope of mass 10.01 be *a*.

$$\therefore \quad 10.81 = \frac{10.01\times a + 11.01\,(100-a)}{100}$$

∴ $a = 20$

∴ % of isotope of mass 10.01 = **20**

∴ % of isotope of mass 11.01 = **80**

78. Average atomic mass $(\bar{A}) = \Sigma A_1X_1 / \Sigma X_{Total}$.

$$= \frac{\text{\% of one isotope} \times \text{its relative at. mass} + \text{\% of other} \times \text{its relative at. mass}}{100}$$

Let % of Cl^{35} be '*a*'.

$$\therefore \quad 35.453 = \frac{35\times a + 37(100-a)}{100}$$

∴ $a = \mathbf{77.35\%}$

79. Mass number of isotope of O with 8 neutrons = 16 and is 90%.

Mass number of isotope of O with 9 neutrons = 17 Let *a* %

Mass number of isotope of O with 10 neutrons = 18

∴ $(10-a)\%$

∴ Average atomic mass of O $(\bar{A}) = \Sigma A_1X_1 / \Sigma X_{Total}$

$$= \frac{\text{\% of } O^{16} \times \text{its mass} + \text{\% of } O^{17} \times \text{its mass} + \text{\% of } O^{18} \times \text{its mass}}{100}$$

$$\therefore \quad 16.12 = \frac{90\times 16 + 17(a) + 18(10-a)}{100}$$

∴ $a = 8$

∴ % of O^{17} = **8%**

% of O^{18} = 10 − 8 = **2%**

80. (a) $_7N^{14}$ (*n*, *p*) indicates that N^{14} on bombardment with neutrons gives proton.

$$\therefore \quad {}_7N^{14} + {}_0n^1 \longrightarrow {}_ZX^m + {}_1p^1$$

on equating at. no. and mass no. on both sides, we get

$$\mathbf{{}_7N^{14} + {}_0n^1 \longrightarrow {}_6C^{14} + {}_1p^1}$$

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

(c) In some nucleus, the nucleus may capture an electron from the *K* shell. The vacancy created is filled by electrons from higher levels giving rise to characteristics X-rays. This is called as *K*-electron capture or simply *K*-capture.

$$\mathbf{{}_{56}Ba^{133} + {}_{-1}e^0 \longrightarrow {}_{55}Cs^{133} + X\text{-rays}}$$

(d) $$\mathbf{{}_{11}Na^{22} \longrightarrow {}_{10}Ne^{22} + {}_{+1}e^0}$$

(β^+ or positron)

81. (1) $_{92}U^{235} + {}_0n^1 \longrightarrow {}_{55}A^{142} + {}_{37}B^{92} + \ldots\ldots$

Equation is

$$\mathbf{{}_{92}U^{235} + {}_0n^1 \longrightarrow {}_{55}Cs^{142} + {}_{37}Rb^{92} + 2\,{}_0n^1}$$

(2) $$2\,{}_1H^3 \longrightarrow {}_2He^4 + {}_ZX^m$$

Equating at. no. on both sides and mass no. on both sides

$Z = 0 \qquad m = 2$

$$\therefore \quad \mathbf{2\,{}_1H^3 \longrightarrow {}_2He^4 + 2\,{}_0n^1}$$

(3) Equating at. no. and mass no. on both sides

$$_{34}Se^{82} \longrightarrow {}_{36}Kr^{82} + 2\,_{-1}e^{0}$$

82. (a) It is an example of **induced radioactivity** or **artificial radioactivity,** *i.e.*, conversion of a naturally stable element into radioactive element by bombarding it with high energy particles.

(b) It is an example of **nuclear reaction.** A reaction that involves a change in the nucleus of an atom due to interaction of nucleons.

(c) It is an example of **induced radioactivity** or **artificial radioactivity.**

(d) It is an example of **spallation reaction.** A nuclear reaction in which a high energy incident particle causes several particles or fragments to be emitted out from target nucleus. The mass no. and at. no. of target nucleus are reduced by several units.

83. For $_{89}Ac^{228}$: $\frac{\text{Mass No.}}{4} = \frac{228}{4} = 57.0$

i.e., 228 is completely divisible by 4 and therefore, $_{89}Ac^{228}$ is a member of **4*n* series.**

For $_{89}Ac^{227}$: $\frac{\text{Mass No.}}{4} = \frac{227}{4} = 56\frac{3}{4}$

$\therefore$ Ac^{227} is a member of **(4*n* + 3) series.**

84. Nuclear fission: A nuclear reaction in which a heavy atomic nucleus splits up into two approximately equal parts, at the same time emitting neutrons and releasing very large amount of energy.

Nuclear fusion: A nuclear reaction between light atomic nuclei as a result of which a heavier nucleus is formed and a large quantity of nuclear energy is released.

As given:

In fission 200 MeV is formed and mass involved = 236 g

In fusion 17.6 MeV is formed and mass involved = 2 + 3 = 5 g

$\therefore$ Energy released/g mass is more in fusion and thus fusion is more hazardous for civilization.

• SINGLE INTEGER ANSWER PROBLEMS •

1. $^{232}_{90}Th$ belongs to III gp. It forms a new element after emission of an α-particle belonging to gp.
2. n/p ratio of ^{12}C is .....
3. $_1H^3$ on decays forms a new element with mass number ......
4. Pair annihilation involves how much particles to produce γ-rays.
5. No. of α-particles emitted during the emission :
$$^{238}_{92}U \longrightarrow {}^{206}_{82}Pb + a\,{}^4_2He + b\,{}^0_{-1}e$$
6. Time required to complete 99% decay is how much to time required to complete 90% decay?
7. If 1 $Rd = 10^a$ dps, then a is ......
8. Total number of α-particles emitted in Actinium series is ......
9. Ratio of atoms of B and A left after the process of decay at secular equilibrium if their average life are 12 year and 3 year for A and B respectively.
$$\underset{T\ 12\text{ yr.}}{A} \longrightarrow \underset{3\text{ yr.}}{B} \longrightarrow C$$
10. The number of known isotopes of iron are ......
11. Nucleodic masses of $^{14}_7N$ and $^{15}_7N$ are mixed to give average atomic mass of 14.1. The ratio of ^{14}N and ^{15}N mixed is ......
12. The radius of nucleus varies with mass no. as $A^{1/n}$. The value of n is .....
13. If $t_{3/4}$ and $t_{1/2}$ are time required for completetion of 3/4 decay and 1/4 decay then $t_{3/4} = t_{1/2} \times n$, than n is ......
14. Nuclear fusion occurs at 10^n K. The value of n is ......
15. Atoms $_7A$, $_8B$ and $_9C$ are such that $_8B$ is an isobar of $_7A$ and atom $^{17}_9C$ is isotone to $_8B$. The number of neutrons in A are ......
16. Isotopic number of $^{58}_{26}Fe$ is ......
17. In a nuclear reaction : $\underset{(E.S.)}{^{19}_8O} \longrightarrow \underset{(G.S.)}{^{19}_8O}$;
$\Delta E = 4.5 \times 10^8$ kJ mol^{-1}. The mass difference in mg of excited state and ground state of ^{19}O is ......
18. The minimum number of particles required to show pair annihilation process.
19. The total number of α-and β-particles emitted in the nuclear reaction $^{238}_{92}U \longrightarrow {}^{214}_{82}Pb$. **(IIT 2009)**
20. The number of neutrons emitted when $^{235}_{92}U$ undergoes controlled nuclear fission to $^{142}_{54}Xe$ and $^{90}_{38}Sr$.
21. In a certain type of nuclear reaction, one neutron is a projectile (a reactant) and two neutrons are produced. Assume that each process takes 1 s. Suppose that half of all the product neutrons cause another event each, and the other half escape from the sample. How many neutrons will be produced in the third second ?
22. In the abundance of three isotopes of H, one of mass 2 is 6%. Calculate the % of other respective isotopes of ^3H in a mixture when the mean atomic mass of H is 1.12 at any time.
23. Number of neutrons in lighter isotope of $_8O$ is.....
24. Atoms $_7A$, $_8B$ and $^{17}_9C$ are such that $_8B$ is an isobar of $_7A$ and atom $^{17}_9C$ is isotone to $_8B$. The number of neutrons in $_7A$ are.....
25. A certain radio-isotope shows the change $^A_ZX \rightarrow {}^{A-8}_{Z-4}Y + 2\,{}^4_2He$ ($t_{1/2} = 10$ day). If 2g-atom of ^A_ZX are taken, pressure of He (in atm) accumulated in a sealed tube of 12 litre in 20 day at 300K is..... ($R = 0.08$ litre atm K^{-1} mol^{-1})
26. The n/p ratio in the daughter element formed after exposure of $^{24}_{12}Mg$ to deuterium which as a result loose an α-particle is.....
27. In the nuclear chain reaction
$$^{235}_{92}U \longrightarrow {}^{140}_{56}Ba + {}^{92}_{36}Kr + 3\,{}^1_0n + E$$
The number of neutrons given out after three steps is.....
28. In the problem 27 energy released in Three steps is nE, the value of n is.....
29. In a nuclear fission caused by the impact of a single neutron, two neutrons are produced in one step. The number of neutrons produced in 3rd step will be.....
30. 10 g of a radioactive sample has a half life of 4 hour. The half life of 5 g of the same substance is.....
31. The ratio of radii of the atom to the nucleus is 10^a. The value of a is.....
32. An element has a half life of 2 day. The time taken for seven by eight of a sample to decay is.....
33. Two radioactive nuclides A and B have half lives in the ratio 2 : 3 respectively. An experiment is started with one mole of each A and B. The molar ratio n_B/n_A left after three half lives of A is.....
34. In a nuclear reaction $^{19}_8O \longrightarrow {}^{19}_8O$; $\Delta E = 4.5 \times 10^8$ kJ mol^{-1}. The mass difference in excited state of ^{19}O and ground state of ^{19}O per mol in mg is....
35. Number of neutrons in parent nucleus after two successive β emission giving $^{14}_7N$ is.....
36. Area of cross section of nucleus is about 10^{-24} cm^2 or........ barn.
37. Two radioactive species A and B have their decay constant 10 : 1 respectively. Both have initially the same number of nuclei. After time t, the ratio of nuclei of A and B becomes $\frac{1}{e}$. The average life of A will be $a \times t$. What is a ?
38. If $t_{99.6} = n \times t_{1/2}$, then n is equal to ......

39. Assuming the nuclear chain reaction:

$$^{235}_{92}\text{U} \rightarrow \, ^{140}_{56}\text{Ba} + ^{92}_{36}\text{Kr} + 3\,^{1}_{0}n + E,$$

The number of neutrons released in three successive steps is ......

40. Packing fraction of element $^{12}_{6}\text{C}$ is ......

41. If $1u = 1.492 \times 10^{-a}$ erg ; the value of a is ......

42. The ratio of ^{35}Cl and ^{37}Cl isotope in Cl_2 gas is ......

43. $^{209}_{83}\text{Bi}$ is last product of series $(4n + a)$, the value of a is ......

44. The ratio of nuclear radius of two elements ^{64}A and ^{8}B is ....

45. $_{90}\text{Th}$ a member of 3rd group on loosing one α-particles forms the daughter element. The group of this element is ...... in periodic table.

46. The number of neutrons in lightest radioisotope is ......

47. The degree of decay in time t is equal to ...... if t is equal to zero.

48. The number of radioactive atom of a radioisotope falls to 12.5% in nine days. What is its half-life period in day?

49. The half-life of $^{90}_{38}\text{Sr}$ is 20 year. If a sample of this nucleide has activity of 8000 disintegration per minute, its activity after 80 year will be 5×10^{a} dpm. What is a?

50. In the abundance of three isotopes of H, one of mass 2 is 6%, the % of $^{3}_{1}\text{H}$ isotope of H in a mixture when the average atomic mass of H is 1.12 at any time ......

51. The half-life of a radioactive element is 100 minute. The time interval required between the two stages of decay, *i.e.*, 50% and 87.5% is $a \times 10^{2}$ minute. The value of a is ....

52. 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?

$$^{63}_{29}\text{Cu} + ^{1}_{1}\text{H} \longrightarrow 6\,^{1}_{0}n + \alpha + 2\,^{1}_{1}\text{H} + X$$ **(IIT 2012)**

ANSWERS

1. Two	**2.** One	**3.** Three	**4.** Two	**5.** Eight	**6.** Two	**7.** Six	**8.** Seven	**9.** Four	**10.** Four	**11.** Nine	**12.** Three
13. Two	**14.** Seven	**15.** Nine	**16.** Six	**17.** Five	**18.** Two	**19.** Eight	**20.** Four (one neutron is to be used to bring in fission)				
21. Two	**22.** Three	**23.** Eight	**24.** Nine	**25.** Six	**26.** One	**27.** Nine	**28.** Three	**29.** Eight	**30.** Four	**31.** Five	**32.** Six
33. Two	**34.** Five	**35.** Nine	**36.** One	**37.** Nine	**38.** Eight	**39.** Nine	**40.** Zero	**41.** Three	**42.** Three	**43.** One	**44.** Two
45. Two	**46.** Two	**47.** Zero	**48.** Three	**49.** Two	**50.** Three	**51.** Two	**52.** Eight				

OBJECTIVE PROBLEMS (One Answer Correct)

1. $^{60m}Co \longrightarrow {}^{60}Co$ emits γ-radiations of wavelength 3×10^{-10} m. Assuming each nuclei emits one wavelength, with what mass per mole of two nuclei differ?
(a) 4.43×10^{-9} g (b) 4.43×10^{-6} g
(c) 4.43×10^{-3} g (d) 4.43 g

2. A drug has radioactivity 80 dpm and after 20 minutes after its activity is 40 dpm. The number of atoms present initially were:
(a) 2375 (b) 2309
(c) 2409 (d) 2475

3. 1 g sample of ^{152}Sm has 27% purity and emits α-particles with half-life 10^{12} year. Calculate the number of α-particles approximately emitted in 1 sec:
(a) 24 (b) 48
(c) 16 (d) 32

4. The degree of decay of a radioactive species ($t_{1/2} = 12$ years) after six years is:
(a) 0.30 (b) 0.60
(c) 0.20 (d) 0.45

5. A radioactive element decays as:

$$\underset{t_{1/2}=2\text{ yrs}}{A} \longrightarrow \underset{t_{1/2}=4\text{ yrs}}{B} \longrightarrow C.$$

If 100 atoms of A present initially undergoes decay then at radioactive equilibrium:
(a) $N_B / N_A = 2$
(b) $\frac{N_B}{N_A} = 4$
(c) $\frac{N_B}{N_A} = \frac{0.693}{\ln 2}$
(d) the equilibrium does not exist

6. Emission of α-particle from a radioactive species produces its:
(a) Isotope (b) Isotone
(c) Isobar (d) Isodiapher

7. The activity of a radioactive sample reduces by 10% in 12.5 yr. The half-life of this radioactivity species when it is reduced to 90%:
(a) 28.20 yr (b) 82.20 yr
(c) 2.5 yr (d) 12.5 yr

8. The activity of ^{131}I is reduced to 60% in 4 yr. How much time it would require to reduce its amount by 40%?
(a) 6 yr (b) 0.2303 yr
(c) 2.2 yr (d) 4 yr

9. Specific activity of ^{226}Ra is:
(a) 10 curie (b) 226 curie
(c) 223 curie (d) 1000 millicurie

10. The abundance of three isotopes of oxygen (atomic mass 16.12) contains 8, 9, 10 neutrons respectively. One of the heaviest isotopes has 2% abundance. The other two are:
(a) 90, 8 (b) 80, 18
(c) 60, 38 (d) 18, 80

11. $^{232}_{90}Th$ belongs to III gp. It emits an α-particle. The daughter element belongs to:
(a) I gp. (b) II gp.
(c) III gp. (d) IV gp.

12. An heavier element continuously emits α- and β-particles. The finally stable element may belong to:
(a) 14^{th} gp. (b) 16^{th} gp.
(c) 10^{th} gp. (d) 12^{th} gp.

13. Conversion of energy to mass occurs in:
(a) α-emission (b) β-emission
(c) γ-emission (d) pair production

14. Two radioactive elements A and B (decay constant $= 10\lambda$ and λ respectively), initially have the same number of nuclei. The ratio of nuclei of A and B left will be $1/e$ after time:
(a) $(10\lambda)^{-1}$ (b) $(11\lambda)^{-1}$
(c) $11 \times (10\lambda)^{-1}$ (d) $(9\lambda)^{-1}$

15. A sample of radioactive element has rate R_1 at time t_1 and R_2 at time t_2 ($t_2 > t_1$). Which one is not correct if λ is rate constant and τ is average life?
(a) $R_1 > R_2$
(b) No. of atoms decayed in time $(t_2 - t_1) = \frac{R_1 - R_2}{\lambda}$
(c) No. of atoms decayed in time $(t_2 - t_1) = (R_1 - R_2) \times \tau$
(d) No. of atoms decayed in time $(t_2 - t_1) = \frac{R_2 - R_1}{\lambda}$

16. The number of neutrons accompanying the formation of $^{139}_{54}Xe$ and $^{94}_{38}Sr$ from the absorption of a slow neutron by $^{235}_{92}U$ followed by nuclear reaction is:
(a) 0 (b) 2
(c) 1 (d) 3

17. Select the incorrect statement:
(a) The adsorption of H_2 by Pd is known as occlusion.
(b) The number of electrons in the parent nucleus of $^{14}_{7}N$ after β-emission is 8.
(c) In electric field β-particles are deflected more than α-particles inspite of α-particles carry more charge.
(d) Nucleides having odd number of protons and neutrons are fairly stable.

18. The charge mass ratio for an alpha particle is about ...... coulombs/kg.
(a) 4.8×10^{7} (b) 2.41×10^{6}
(c) 2.41×10^{-7} (d) 2.41×10^{-6}

19. The activity of a radioactive substance is A_1 and A_2 at time t_1 and t_2 respectively. If $t_2 > t_1$, then the ratio of $\frac{A_2}{A_1}$ is:
(a) $e^{-\lambda(t_1+t_2)}$ (b) $e^{\lambda(t_1-t_2)}$
(c) $e^{\lambda(t_2-t_1)}$ (d) e^{t_2/t_1}

20. The time required for a radioactive species to decay $\frac{2}{3}$ of its initial amount is t. The fraction of radioactive species left after $0.5t$ is:
(a) $\frac{1}{\sqrt{3}}$ (b) $\frac{1}{\sqrt{5}}$
(c) $\sqrt{\frac{2}{3}}$ (d) $\frac{1}{3}$

21. A radioactive species involves four half life period in time t. The time t is related to mean life (T) by:
(a) $2T \ln 2$ (b) $2T^3 \ln 2$
(c) $2T^4 \ln 2$ (d) $4T \ln 2$

22. A radionuclide having decay constant λ is produced at a constant rate of α per sec. If N_0 be the number of nuclei at $t = 0$, then maximum number of nuclide possible are:
(a) $N_0 + \frac{\alpha}{\lambda}$ (b) $N_0 + \frac{\lambda}{\alpha}$
(c) $\frac{\alpha}{\lambda}$ (d) N_0

23. Two radioactive species A and B having half life in the ratio 3 : 2. If A goes to 25% decay in time t_1 and B goes to 75% decay in time t_2. The ratio of t_1 and t_2 is:
(a) 0.311 : 1 (b) 0.420 : 1
(c) 0.119 : 1 (d) 0.273 : 1

24. Half life period of lead is equal to:
(a) Zero (b) 0.693
(c) 1/0.693 (d) Infinity

25. N_0 atoms of a radioactive nuclide are decayed having decay constant λ. The degree of decay after t time is given by:
(a) $e^{-\lambda t}$ (b) $1 - e^{-\lambda t}$
(c) $e^{\lambda t}$ (d) $\frac{1}{1 - e^{\lambda t}}$

26. 5 g of radioactive species having molar mass 200 undergoes decay with decay constant of λ. The initial specific activity can be given by:
(a) 3×10^{23} λ dps (b) 3×10^{24} λ dps
(c) 3×10^{21} λ dps (d) 3×10^{20} λ dps

27. If E_i and E_n are the energy to remove an electron from shell and a nucleon from the nucleus respectively, then:
(a) $E_n > E_i$ (b) $E_i > E_n$
(c) $E_n = E_i$ (d) $E_n \geq E_i$

28. 4.0 mg of a β-emitter (^{210}X) has half life of 5 days and the average energy of emitted β-particles is 0.34 MeV. The rate of emission of energy in watt is:
(a) 2.0 (b) 1.0
(c) 1.5 (d) 1.0

29. The nucleus $^{115}_{48}Cd$, after two successive β-decay will give:
(a) $^{115}_{40}Pa$ (b) $^{114}_{49}In$
(c) $^{113}_{50}Sn$ (d) $^{115}_{50}Sn$

30. Nuclear-Fission is best explained by:
(a) Liquid droplet theory
(b) Yukawa π-meson theory
(c) Independent particle model of the nucleus
(d) Proton-proton cycle

31. M_n and M_p represents mass of neutron and proton respectively. An element having atomic mass M has n neutrons and Z protons, then:
(a) $M < [N \cdot M_n + Z \cdot M_p]$
(b) $M > [N \cdot M_n + Z \cdot M_p]$
(c) $M = [N \cdot M_n + Z \cdot M_p]$
(d) $M = N[M_n + M_p]$

32. Energy released in nuclear fission is due to:
(a) Few mass is converted into energy
(b) Total binding energy of fragments is more than the binding energy of parental element
(c) Total binding energy of fragments is less than the binding energy of parental element
(d) Total binding energy of fragments is equal to the binding energy of parental element

33. A 10 g sample of radioactive sample is present at $t = 0$. The approximate mass of this element in the sample after two mean life is:
(a) 1.35 g (b) 2.50 g
(c) 3.70 g (d) 6.30 g

34. In a nuclear fusion process masses of the fusing nuclei be m_1 and m_2 and the mass of resultant nucleus is m, then:
(a) $m = m_1 + m_2$ (b) $m = m_1 - m_2$
(c) $m < m_1 + m_2$ (d) $m > m_1 + m_2$

35. If M_p and M_n are masses of proton and neutron respectively. For a nucleus it binding energy is B and it contains Z protons and N neutrons, the correct relation for this nucleus it C is velocity of light is:
(a) $M(N, Z) = NM_n + ZM_p - BC^2$
(b) $M(N, Z) = NM_n + ZM_p + BC^2$
(c) $M(N, Z) = NM_n + ZM_p - \frac{B}{C^2}$
(d) $M(N, Z) = NM_n + ZM_p + \frac{B}{C^2}$

36. In the reaction $^2_1H + ^3_1H \rightarrow ^4_2He + ^1_0n$, if binding energies of ^2_1H, ^3_1H and ^4_2He are respectively a, b and c (in MeV), then the energy released in this reaction is:
(a) $a + b + c$ (b) $a + b - c$
(c) $c - (a + b)$ (d) $c + a - b$

37. Fission of nuclide is possible because the binding energy per nucleon in them:
(a) increases with mass no. at low mass number
(b) decreases with mass no. at low mass number
(c) increases with mass no. at high mass number
(d) decreases with mass no. at high mass number

38. $^{238}_{92}U$ emits 8α- and 6β-particles. The ratio of neutron /proton in product nuclei is:
(a) 60/41 (b) 62/41
(c) 61/62 (d) 61/40

39. The radius of Germanium nuclide is measured to be twice of the radius of $^{9}_{4}Be$. the number of nucleons in Ge are:
(a) 72 (b) 73
(c) 74 (d) 75

40. Two radioactive materials A_1 and A_2 have decay constant 5λ and λ respectively. If initially they have the same number of nuclei than ratio of nuclei of A_1 to A_2 will be $\frac{1}{e}$ after a time:
(a) $\frac{1}{4\lambda}$ (b) $\frac{e}{\lambda}$
(c) λ (d) $\frac{\lambda}{2}$

41. An α-particle of energy $\frac{1}{2}mu^2$ bombarded a heavy target of charge ze. The distance of closest approach for α-nucleus will be proportional to:
(a) $\frac{1}{ze}$ (b) u^2
(c) $\frac{1}{m}$ (d) $\frac{1}{u^4}$

42. The activity of a radioactive sample is A_0 at $t = 0$ and $\frac{A_0}{e}$ at $t = 5$ minute. The time in which activity is reduced to half of initial value is:
(a) $\ln\frac{2}{5}$ (b) $\frac{5}{\ln 2}$
(c) $5\log_{10} 2$ (d) $5\ln 2$

43. In nuclear reactions, we have conservation of :
(a) mass only
(b) energy only
(c) momentum only
(d) charge, total energy and momentum

44. Two nuclei have their mass no. in the ratio 1 : 3, the ratio of their nuclear densities is:
(a) $3^{1/3}:1$ (b) 1 : 1
(c) 1 : 3 (d) 3 : 1

45. In a nuclear fission, 0.1% mass is converted into energy. The energy released by fission of 1kg mass is:
(a) 9×10^{19} J (b) 9×10^{17} J
(c) 9×10^{16} J (d) 9×10^{13} J

46. A nuclide A undergoes α-decay and another nuclide undergoes β-decay, then :
(a) The α-particles emitted by A may have widely different speed
(b) All the β-particles emitted by B will have same speed
(c) The β-particles emitted by B have widely different speeds
(d) In both cases α- and β- have almost same speed.

47. If $^{238}_{92}U$ emits an α-particle, the product has mass no. and at. no.:
(a) 236, 92 (b) 234, 90
(c) 238, 90 (d) 236, 90

48. The radiations from a naturally occurring radioactive substance, as seen after deflection by a magnet in one direction, are:
(a) definitely alpha rays
(b) definitely beta rays
(c) both alpha and beta rays
(d) either alpha or beta rays

49. The radius of an atomic nucleus is of the order of:
(a) 10^{-10} cm (b) 10^{-13} cm
(c) 10^{-15} cm (d) 10^{-8} cm

50. The half-life period of a radioactive element is 140 days. After 560 days, one gram of element will reduce to:
(a) 1/2 g (b) 1/4 g
(c) 1/8 g (d) 1/16 g

51. $^{27}_{13}Al$ is a stable isotope, $^{29}_{13}Al$ is expected to disintegrate by:
(a) α emission (b) β emission
(c) positron emission (d) proton emission

52. The number of neutrons accompanying the formation of $^{139}_{54}Xe$ and $^{94}_{38}Sr$ from the absorption of a slow neutron by $^{235}_{92}U$, followed by nuclear fission is:
(a) 0 (b) 2
(c) 1 (d) 3

53. The decay constant of a radioactive species is λ for the process in which a parent element showing formation of a daughter element. After time t, P atoms of parent element are left and D atoms of daughter elements are formed. If $t_{1/2}$ is half life then which expression correctly represents decay of parent element :
(a) $t = \frac{t_{1/2}}{0.693}\ln\left(1+\frac{D}{P}\right)$ (b) $t = \frac{t_{1/2}}{0.693}\ln\left(1-\frac{D}{P}\right)$
(c) $t = \frac{t_{1/2}}{0.693}\ln\left(\frac{D}{P}\right)$ (d) $t = \frac{t_{1/2}}{0.693}\ln\left(\frac{P}{D}\right)$

54. Which is correct for a graph plotted between $\log\frac{r_n}{r_o}$. vs $\log A$ (where r_n is radius of nucleus and A is its mass no).
(a) a straight line with a slope 0.5
(b) a circle with radius 1.3×10^{-13}cm
(c) a straight line with slope 0.333
(d) an ellipse with minor and major axis in the ratio $\frac{1}{3}$

55. Isotopic number of $^{235}_{92}U$ is :
(a) 235 (b) 92
(c) 143 (d) 51

56. Total time (T) required for a species to reduce it to $\frac{1}{16}$ is correctly represented with its average life, by the relation :
(a) $\tau^2 \ln 2$ (b) $2\tau \ln 2$
(c) $\tau^4 \ln 2$ (d) $4\tau \ln 2$

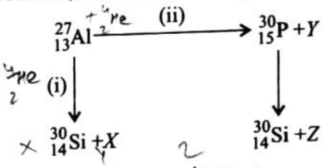
57. $^{23}_{11}Na$ is the most stable isotope of Na. Find the process by which $^{24}_{11}Na$ can undergo radioactive decay: **(IIT 2003)**
(a) β^--emission (b) α-emission
(c) β^+-emission (d) K-electron capture

58. A positron is emitted by $^{23}_{11}Na$. The ratio of the atomic mass and atomic number of the resulting nuclide is: **(IIT 2007)**
(a) 22/10 (b) 22/11
(c) 23/10 (d) 23/12

59. Given that the abundances of isotopes ^{54}Fe, ^{56}Fe and ^{57}Fe are 5%, 90% and 5% respectively, the atomic mass of Fe is: **(IIT 2009)**
(a) 55.85 (b) 55.95
(c) 55.75 (d) 56.65

60. The total no. of α- and β-particles emitted in the nuclear reaction: $^{238}_{92}U \rightarrow ^{214}_{82}Pb$ **(IIT 2009)**
(a) 8 (b) 6
(c) 4 (d) 2

61. Bombardment of aluminium by α -particles leads to the artificial disintegration in two ways (i) and (ii) as shown Products X, Y and Z respectively are **(IIT 2011)**



(a) Proton, neutron, positron
(b) Neutron, positron, proton
(c) Proton positron neutron
(d) Positron, proton neutron

SOLUTIONS (One Answer Correct)

1. (b) $E/\text{photon} = \frac{N \cdot hc}{\lambda}$ Also, $E = mc^2$

$\therefore \frac{N \cdot hc}{\lambda} = mc^2$

$\therefore m = \frac{N \cdot h}{c \cdot \lambda} = \frac{6.023\times10^{23}\times6.626\times10^{-34}}{3\times10^{8}\times3\times10^{-10}}$

$= 4.43\times10^{-9}\text{ kg} = 4.43\times10^{-6}\text{ g}$

2. (b) $t = \frac{2.303}{\lambda}\log\frac{N_0}{N} = \frac{2.303}{\lambda}\log\frac{\gamma_0}{\gamma}$

$\therefore 20 = \frac{2.303}{\lambda}\log\frac{80}{40}$

$\therefore \lambda = \frac{2.303\times0.3010}{20}$, Now, $\gamma_0 = \lambda \cdot N_0$

$\therefore 80 = \frac{2.303\times0.3010}{20}\times N_0$

$\therefore N_0 = 2309$

3. (a) $\lambda = \frac{0.693}{10^{12}\times365\times24\times60\times60} = 2.2\times10^{-20}\text{ sec}^{-1}$

$\therefore \gamma = \lambda\times N = 2.2\times10^{-20}\times\frac{1\times27\times6.023\times10^{23}}{100\times152}$

$= 24\ \alpha\text{-per sec}^{-1}$

4. (a) $\frac{N_0}{N} = e^{\lambda t}$; $\therefore N = N_0e^{-\lambda t}$,

Now, $\alpha = \frac{N_0 - N}{N_0} = \frac{N_0 - N_0e^{-\lambda t}}{N_0} = 1 - e^{-\lambda t}$

$\therefore \alpha = 1 - e^{-\frac{0.693}{12}\times6} = 0.29$

5. (d) If $t_{1/2}$ of daughter element is higher than parent element, radioactive equilibrium is not noticed.

6. (d) Emission of α-particles always leads to formation of isodiapher, *i.e.*, $(n-P)$ remains constant.

7. (b) Half-life of a species remains constant. $N = \frac{N_0\times90}{100}$,

Now $\lambda = \frac{2.303}{12.5}\log\frac{100}{90} = 8.43\times10^{-3}$

$\therefore t_{1/2} = \frac{0.693}{8.43\times10^{-3}} = 82.20\text{ yrs}$

8. (d) Time required to reduce activity by 40% = time required to reduce activity to 60%, *i.e.*, 40% is decayed.

9. (d) Specific activity ^{226}Ra = rate of decay of 1 g of ^{226}Ra = 1 curie = 1000 millicurie

It is the unit of radioactivity derived by assuming rate of decay of 1 g of Ra.

10. (a) $16.12 = \frac{16\times a + 17\times(98-a) + 18\times2}{100}$

$\therefore a = 90\%$ for ^{16}O and 2% for ^{17}O.

11. (b) $^{232}_{90}Th \longrightarrow ^{228}_{88}Ra + ^{4}_{2}He$; Note elements from 89 to 103 are placed in gp. III.

12. (a) Naptunium series ends at Bi (15^{th} gp.) and rest all series terminates at Pb (14^{th} gp.).

13. (d) Energy of photon can be converted entirely into an electron and a positron when the photon passes through matter. This is pair production ($h\nu = ^{0}_{-1}e + ^{0}_{+1}e$)

14. (d) $N_A = N_0e^{-\lambda t}$, $N_B = N_0e^{-\lambda t}$

$\therefore \frac{N_A}{N_B} = e^{-9\lambda t}$ Given, $\frac{N_A}{N_B} = e^{-1}$

$\therefore 9\lambda t = 1$ or $t = \frac{1}{9\lambda}$

15. (d) Rate decreases with time : $R_1 = \lambda N_1$, $R_2 = \lambda N_2$

$\therefore R_1 - R_2 = \lambda(N_1 - N_2)$

$\therefore$ No. of atoms decayed in time

$t_2 - t_1 = N_1 - N_2 = \frac{R_1 - R_2}{\lambda}$

$= (R_1 - R_2)\cdot\tau$

16. (d) $^{235}_{92}U + ^{1}_{0}n \longrightarrow ^{139}_{54}Xe + ^{94}_{38}Sr + 3^{1}_{0}n$

17. (d) Nuclides with odd number of neutrons and protons are unstable.

18. (a) $\frac{e}{m} = \frac{2\times1.602\times10^{-19}}{4\times1.66\times10^{-27}} = 4.8\times10^{7}$

19. (b) $\frac{A_1}{A_0} = e^{-\lambda t_1}$ and $\frac{A_2}{A_0} = e^{-\lambda t_2}$

$\therefore \frac{A_2}{A_1} = e^{\lambda(t_1 - t_2)}$

20. (a) $\lambda t = 2.303\log\frac{1}{1/3}$

$\lambda\times\frac{1}{2}t = 2.303\log\frac{1}{a}$

$\therefore 2 = \frac{\log 3}{\log\frac{1}{a}}$

$\log\frac{1}{a} = \frac{0.477}{2} = 0.2385$

$\frac{1}{a} = 1.7318$

$\therefore a = 0.5774 = \frac{1}{\sqrt{3}}$

21. (d) $t_{1/2}\times4 = t$

Also $T = \frac{1}{\lambda} = \frac{t_{1/2}}{0.693} = \frac{t_{1/2}}{\ln 2}$

$\therefore T = \frac{t/4}{\ln 2}$ or $t = 4T\ln 2$

22. (c) Rate of formation of nuclide, $\frac{dN}{dt} = \alpha - \lambda N$

(where λN is its rate of decay)

For maximum number, $\frac{dN}{dt} = 0$

$\therefore \ \alpha - \lambda N = 0$

or $\quad N = \frac{\alpha}{\lambda}$

23. (a) $\frac{t_{1/2}A}{t_{1/2}B} = \frac{3}{2}$

For A: $t_1 = \frac{2.303 \times t_{1/2}A}{0.693} \log \frac{4}{3}$

For B: $t_2 = \frac{2.303 \times t_{1/2}B}{0.693} \log 4$

$\therefore \ \frac{t_1}{t_2} = \frac{t_{1/2}A}{t_{1/2}B} \times \frac{\log 4/3}{\log 4}$

$= \frac{3}{2} \times 0.2075 = 0.311$

24. (d) Pb is not radioactive and thus $\lambda = 0$

or $t_{1/2} = \frac{0.693}{\lambda}$, $\quad \therefore \ t_{1/2} = \infty$

25. (b) $N = N_0 \cdot e^{-\lambda t}$

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

$= N_0[1 - e^{-\lambda t}]$

degree of decay $= \frac{N_0 - N}{N_0} = 1 - e^{-\lambda t}$.

26. (c) Specific activity = activity shown by 1 g species = rate shown per g by species

Activity $= \lambda \cdot N = \frac{\lambda \cdot N_A}{M} = \frac{6 \times 10^{23} \times \lambda}{200}$

$= \lambda \times 3 \times 10^{21}$ dps

where N is no. of atoms in 1 g

27. (a) $E_n > E_e$ as binding energy responsible for holding nucleons in nucleus is very high.

28. (b) Power = Energy of 1β (in J) × No. of β particles emitted/sec

No. of β particles emitted $= -\frac{dN}{dt} = \lambda \cdot N$

$= \frac{0.693}{5 \times 24 \times 60 \times 60} \times \frac{4 \times 10^{-3} \times 6.023 \times 10^{23}}{210}$

$= 1.84 \times 10^{13}$

$\therefore$ Power $= 0.34 \times 10^6 \times 1.6 \times 10^{-19} \times 1.84 \times 10^{13}$

= 1 watt

29. (d) ${}^{115}_{48}\text{Cd} \rightarrow {}^{115}_{50}\text{Sn} + 2\,{}^{0}_{-1}e$

30. (a) Nuclear fission has been explained in terms of liquid droplet theory.

31. (a) Total mass of atom is always less than sum of the masses of its constituent elements and this difference is given out in form of binding energy of nucleus.

32. (a) The decay releases energy due to mass decay, *i.e.*, $E = mc^2$.

33. (a) mean life $= \frac{1}{\lambda}$ $\quad \therefore t = \frac{2}{\lambda}$

$N = N_0 e^{-\lambda t} = N_0 e^{\frac{-2\lambda}{\lambda}} = N_0 e^{-2}$

$\therefore \ N = 10 \times 0.135 = 1.35$ g

34. (c) During fusion, mass decay also occurs to release huge amount of energy.

35. (c) Mass decay $= N \cdot M_n + Z \cdot M_p - M(N, Z)$

B.E. = Mass decay $\times C^2$

$\therefore$ Mass decay $= \frac{B}{C^2}$

$\frac{B}{C^2} = NM_n + ZM_p - M(N, Z)$

$\therefore M(N, Z) = NM_n + ZM_p - \frac{B}{C^2}$

36. (c) Mass decay = (mass of ${}^{4}_{2}$He + mass of ${}^{1}_{0}n$)

− (mass of ${}^{2}_{1}$H + mass of ${}^{3}_{1}$H)

$(\because \ \Delta m = E \times u^2)$

$= \frac{\text{B.E. of } {}^{4}_{2}\text{He} + 0 - \text{B.E. of } {}^{2}_{1}\text{H} - \text{B.E. of } {}^{3}_{1}\text{H}}{u^2}$

mass decay $= \frac{c - a - b}{u^2}$

Now E = mass decay $\times u^2 = \frac{c - a - b}{u^2} \times u^2 = c - a - b$

37. (d) It is a fact and therefore heavier nuclei show fission.

38. (b) ${}^{238}_{92}\text{U} \rightarrow {}^{206}_{82}\text{Pb} + 8\,{}^{4}_{2}\text{He} + 6\,{}^{0}_{-1}e$

$p = 82, n = 124$

$\therefore \ n/p = 124/82 = 62/41$

39. (a) $R = R_0(A)^{1/3}$

$\therefore \ \frac{R_B}{R_{Ge}} = \left(\frac{9}{m}\right)^{1/3}$

$\left[\frac{R_B}{R_{Ge}}\right]^3 = \frac{9}{m} = \left(\frac{1}{2}\right)^3$

$\therefore \ m = 9 \times 2^3 = 72$

40. (a) $N_A = N_0 e^{-\lambda_1 t} = N_0 e^{-5\lambda t}$

$N_B = N_0 e^{-\lambda_2 t} = N_0 e^{-\lambda t}$

$\therefore \ \frac{N_A}{N_B} = e^{-4\lambda t} = e^{-1}$ $\quad \left(\text{Given } \frac{N_A}{N_B} = \frac{1}{e}\right)$

$\therefore \ 4\lambda t = 1$

$t = \frac{1}{4\lambda}$

41. (c) For the closest approach

Final P.E. = Initial K.E.

$\frac{K \cdot ze \cdot 2e}{r_0} = \frac{1}{2} mu^2$

$\therefore \quad r_0 = \frac{4Kze^2}{mu^2}$

42. (d) $A = A_0 e^{-\lambda t}$

$\frac{A_0}{e} = A_0 e^{-\lambda 5}$

$\therefore \ e^{-1} = e^{-5\lambda}$

$\therefore \quad \lambda = \frac{1}{5}$

$t_{1/2} = \frac{\ln 2}{\lambda} = 5 \ln 2$

43. (d) All are conserved.

44. (b) Densities of nucleus are independent of mass no.

45. (d) $E = \Delta m \cdot c^2 = \frac{0.1 \times 1 \times (3 \times 10^8)^2}{100}$

$= 9 \times 10^{13}$ J

46. (c) During β-decay, the energy is distributed among β-particles and antineutrino

$${}_0^1n \rightarrow {}_{-1}^{0}e + {}_{+1}^{1}p + \bar{\nu}$$

47. (b) ${}_{92}^{238}U \xrightarrow{-\alpha} {}_{90}^{234}Th$

48. (d) A naturally occurring substance may emit alpha- or beta-rays.

49. (b) It is an experimental fact $[r_n = 1.33 \times 10^{-13}\ A\,cm^{1/3}]$

50. (d) $T = n \times t_{1/2}$

$\therefore \quad n = \frac{T}{t_{1/2}} = \frac{560}{140} = 4$

Now, $N_t = N_0\left(\frac{1}{2}\right)^n = 1 \times \left(\frac{1}{2}\right)^4 = \frac{1}{16}$ g

51. (b) The species ${}_{13}^{29}Al$ (No. of neutrons = 16) contains more neutrons than the stable isotope ${}_{13}^{27}Al$ (No. of neutrons = 14) due to higher n/p ratio. Neutron decays to show β emission.

$${}_0^1n \rightarrow {}_{+1}^{1}p + \underset{\beta-\text{particle}}{{}_{-1}^{0}e}$$

52. (d) ${}_{92}^{235}U + {}_0n^1 \rightarrow {}_{54}^{139}Xe + {}_{38}^{94}Sr + 3{}_0n^1$

53. (a) For $I \rightarrow D$

$t = \frac{1}{\lambda} \ln \frac{N_0}{N}$

$N_0 = P + D$

$N = P$

$t = \frac{1}{\lambda} \ln\left[\frac{P+D}{P}\right]$

$t = \frac{t_{1/2}}{0.693} \ln\left[1 + \frac{D}{P}\right]$

54. (c) $r_n = r_o \times A^{1/3}$ (where $r_o = 1.3 \times 10^{-13}$ cm)

$\frac{r_n}{r_o} = A^{1/3}$

$\log \frac{r_n}{r_o} = \frac{1}{3} \log A$ *i.e.*, a straight line with slope $\frac{1}{3}$

55. (d) Isotopic number = No. of neutron – no. of protons

56. (d) $N = \frac{N_0}{16} = \frac{N_0}{2^4}$ $\therefore$ No. of half lives = 4

$\therefore T = 4 \times t_{1/2}$

Also $t_{1/2} = \frac{\ln 2}{\lambda} = \tau \times \ln 2$ (τ is average life)

$\therefore T = 4\tau \ln 2$

57. (a) n/p of ${}_{11}^{24}Na > {}_{11}^{23}Na$

58. (c) ${}_{11}^{23}Na \longrightarrow {}_{10}^{23}Ne + {}_{+1}^{0}e$

59. (b) At. mass $= \frac{54 \times 5 + 56 \times 90 + 57 \times 5}{5 + 90 + 5} = 55.95$

60. (a) ${}_{92}^{238}U \longrightarrow {}_{82}^{214}Pb + 6{}_2^4He + 2{}_{-1}^{0}e$

61. (a) ${}_{13}^{27}Al + {}_2^4He \longrightarrow {}_{14}^{30}Si + {}_1^1p$

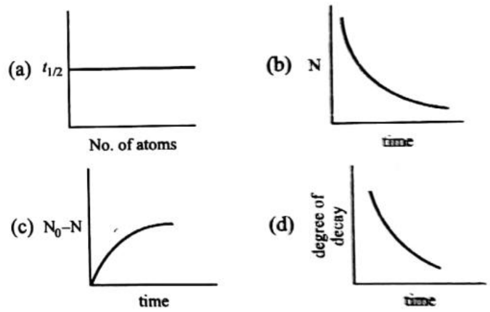
${}_{13}^{27}Al + {}_2^4He \longrightarrow {}_{15}^{30}P + {}_0^1n$

$\downarrow$

${}_{15}^{30}P + {}_{+1}^{0}e$

OBJECTIVE PROBLEMS (More Than One Answer Correct)

1. Decrease in atomic number is observed in:
   (a) α-emission (b) β-emission
   (c) positron emission (d) electron capture
2. Which of the following statements are correct?
   (a) *K*-electron capture always release X-rays
   (b) Gaseous emenation is not observed in neptunium series
   (c) γ-emissions are secondary emissions
   (d) Elements placed above the belt of stability show β-emission.
3. In which of the following decays n/p increases?
   (a) α-emission (b) *K*-electron capture
   (c) Positron emission (d) γ-emission
4. Select the correct statements:
   (a) α-decay produces isodiaphers
   (b) β-decay produces isobars
   (c) $^{11}_{6}C$ shows positron emission
   (d) $^{24}_{11}Na$ shows β-emission
5. Select the correct statements. Fusion in stars:
   (a) occurs at temperature 10^7 K through proton-proton cycle
   (b) occurs at temperature 10^8 K through proton-carbon cycle
   (c) is uncontrolled nuclear reaction
   (d) is thermonuclear reaction
6. Radioisotopes are used in:
   (a) deciding basicity of H_3PO_4 and H_3PO_3
   (b) deciding mechanism of photosynthesis
   (c) deciding mechanism of ester hydrolysis
   (d) calculating age of animal or vegetable objects by carbon dating technique
7. Select the correct statements:
   (a) Relative stabilities of radioactive isotopes are expressed in terms of their average life
   (b) The complete decay of radioactive species takes place in infinite time
   (c) The half-life of ^{14}C in charcoal or in cellulose is same
   (d) Average life is defined as the time to reduce rate of decay by 63%
8. Select the correct statements:
   (a) Mass of a stable nucleus can never be less than twice of its atomic number
   (b) Shorter the life of a radio element, longer is its range and greater the energy of the α-particles that it expels
   (c) Tritium dating is used for determining ages of comparatively recent dates
   (d) The first example of true artificial transmutation was $^{7}_{3}Li + ^{1}_{1}H \longrightarrow 2\,^{4}_{2}He$
9. The nuclear reactions accompanied with emission of neutron(s) are:
   (a) $^{27}_{13}Al + ^{4}_{2}He \rightarrow ^{30}_{15}P$
   (b) $^{12}_{6}C + ^{2}_{1}H \rightarrow ^{14}_{7}N$
   (c) $^{30}_{15}P \rightarrow ^{30}_{14}Si + ^{0}_{+1}e$
   (d) $^{241}_{95}Am + ^{4}_{2}He \rightarrow ^{244}_{97}Bk$
10. Decrease in atomic number is observed during:
   (a) alpha emmission (b) beta emission
   (c) positron emission (d) electron capture
11. For a radioactive species decaying with rate *r*, N is the number of atoms left after time *t*, *D* being the no. of daughter element formed and $t_{1/2}$ be the half-life period. Select the correct graphical representations :



12. Which of the following are used as moderator in nuclear reactor :
   (a) Graphite (b) Lithium
   (c) Beryllium (d) Heavy water
13. Which of the following emissions do not emit X-rays ?
   (a) β^+-decay (b) β^--decay
   (c) K-electron capture (d) α-decay
14. In which of the following radioactive process, electrical neutrality is maintained in daughter element.
   (a) α-decay (b) K-electron capture
   (c) γ-decay (d) β^--decay
15. In the nuclear transmutation
   $^{9}_{4}Be + X \longrightarrow ^{8}_{4}Be + Y$ (X, Y) is (are) :
   [JEE (Advanced) II 2013]
   (a) (γ, n) (b) (p, D)
   (c) (n, D) (d) (γ, p)

SOLUTIONS (More Than One Answer Correct)

1. (a,c,d) α-emission : ${}^{m}_{z}A \longrightarrow {}^{m-4}_{z-2}B + {}^{4}_{2}He$ (z decreases)

   β-emission : ${}^{m}_{z}A \longrightarrow {}_{z+1}{}^{m}B + {}_{-1}^{0}e$

   Positron emission : ${}^{1}_{1}p \longrightarrow {}^{1}_{0}n + {}^{-0}_{+1}e$ (z decreases)

   K-electron capture :

   ${}^{1}_{1}p + {}^{0}_{-1}e \longrightarrow {}^{1}_{0}n + \text{X-ray}$ (z decreases)

2. (a,b,c,d) For concepts follow Concepts of physical chemistry by P. Bahadur, Prakash Publications, Muzaffarnagar. Naptunium series does not produces Rn isotope as intermediate.

3. (a,b,c) In γ-emission n/p remains constant.

4. (a,b,c,d) ${}_{92}U^{235} \longrightarrow {}^{231}_{90}Th + {}^{4}_{2}He$ $(n-p) =$ constant

   ${}^{3}_{1}H \longrightarrow {}^{3}_{2}He + {}^{0}_{-1}e$ (${}^{3}_{1}H$ and ${}^{3}_{2}He$ have same mass number)

   ${}^{11}_{6}C \longrightarrow {}^{11}_{5}B + {}^{0}_{+1}e$ (n/p below the belt of stability)

   ${}^{24}_{11}Na \longrightarrow {}^{24}_{12}Mg + {}^{0}_{-1}e$ (n/p above the belt of stability)

5. (a,b,c,d) All are facts.

6. (a,b,c,d) —do—.

7. (a,b,c,d) —do—.

8. (b,c,d) ${}^{1}_{1}H$ is stable nucleus.

9. (a,d) ${}^{27}_{13}Al + {}^{4}_{2}He \rightarrow {}^{30}_{15}P + {}^{1}_{0}n$

   ${}^{241}_{95}Am + {}^{4}_{2}He \rightarrow {}^{244}_{97}Bk + {}^{1}_{0}n$

10. (a,c,d) ${}_{Z}X^{A} \xrightarrow{-\alpha} {}_{Z-2}Y^{A-4}$ (α-emission)

    ${}_{Z}X^{A} \xrightarrow{-\beta} {}_{Z+1}Y^{A}$ (β-emission)

    ${}_{Z}X^{A} \longrightarrow {}_{Z-1}Y^{A} - {}^{0}_{+1}e$ (positron-emission)

    ${}_{Z}X^{A} + {}^{0}_{-1}e \longrightarrow {}_{Z-1}Y^{A}$ (electron capture)

11. (a,b,c,d) $r = \lambda \cdot N$

    $$\frac{r}{N} = \lambda = \text{constant} = \frac{0.693}{t_{1/2}}$$

    Also $t_{1/2} \propto (N)^{\circ}$

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

    and $\alpha = 1 - e^{-\lambda t}$

12. (a,c,d) These are facts.

13. (a,b,d) Only K-electron capture leads to X-ray emission.

14. (a,b,c,d) Radioactive emission give rise to the formation of neutral atom.

15. (a, b) Equating mass no. and atomic no. of two sides of change.

    (a) ${}^{9}_{4}Be + \gamma \longrightarrow {}^{8}_{4}Be + {}_{0}n^{1}$

    (b) ${}^{9}_{4}Be + {}^{1}_{1}P \longrightarrow {}^{8}_{4}Be + {}^{2}_{1}H$

COMPREHENSION BASED PROBLEMS

Comprehension 1 : Radioactive decay obey I order kinetics and the rate of any radiospecies can be given by $r = K[N_0]$ where all letters represent their usual notations. A sample contains 10^{-2} kg of two substances A and B with half lives of 4 and 8 sec respectively (Given that atomic mass of B is twice of A).

[1] The mass of A and B left after 16 second is:
(a) 0.625 g, 2.50 g (b) 0.625 g, 0.252 g
(c) 0.8 g, 0.2 g (d) 0.8 g, 0.2 g

[2] The ratio of initial rate of decay of A and B is:
(a) 3:2 (b) 2:1
(c) 4:1 (d) 3:4

[3] The mass ratio of A and B that must be taken so that initial rate of decay remains same:
(a) 3:2 (b) 2:1
(c) 4:1 (d) 1:4

[4] The ratio of average life of A and B is:
(a) 1:2 (b) 2:1
(c) 1:4 (d) 4:1

Comprehension 2 : A radioactive nuclide having $n/p > 1.0$ undergoes α-decay, β-decay succesively. The parent element on α-decay looses its atomic no. by two unit and mass no. by four units. In β-decay the parent atom gains its atomic no. by one unit whereas mass number remains same. The γ-emission occurs only when daughter element possesses some higher energy than required for its stability.

[1] An element $^{234}_{90}Th$ looses an α-particle. If Th belongs to III gp, the daughter element belongs to:
(a) I gp (b) II gp
(c) III gp (d) zero gp

[2] If atomic mass of Th is 232.18 and its at no. is 90. If it looses $6-\alpha$ and $4-\beta$ particles, the mass no. of finally stable element is:
(a) 208.18 (b) 208
(c) 226 (d) 212

[3] In the nuclear decay of an element ($Z = 88$, electron $= 88$, neutron $= 145$) emitting out ^4_2He nuclei (an α-particle), the number of proton, electron and neutrons in daughter element is:
(a) 86, 88, 143 (b) 86, 86, 143
(c) 86, 88, 144 (d) 86, 86, 142

[4] In the nuclear reaction $\overset{60\,m}{Co} \longrightarrow \overset{60}{Co}$ the emission occurs as:
(a) X-rays (b) γ-rays
(c) α-particle (d) K-electron capture

Comprehension 3 : The emission of penetrating α, β-particles (^4_2He and $^0_{-1}e$ respectively) along with γ-radiation ($h\nu$) was noticed from unstable nucleus. All elements having $Z > 82$ show this phenomenon. The emission was explained in terms of low binding energy (giving α-decay), high n/p ratio (neutron decay). γ-emission from a radioactive nuclide is secondary emission. The emission of one kind of a particles occurs at one time, later on may be followed by other. In addition to these emission positron emission and X-ray emission is also noticed due to $n/p < 1$ and K-electron capture respectively.

[1] The neutron decay leads to emission of β-particles and :
(a) neutrino (b) antineutrino
(c) mesons (d) γ-rays

[2] The missing term in $^1_{+1}p + ^0_{-1}e \rightarrow ^1_0n + ?$ is:
(a) γ-rays (b) infra red
(c) X-rays (d) visible rays

[3] An element of group III with atomic no. 90 and mass number 238 undergoes decay of one α-particle. The newly formed element belongs to:
(a) I group (b) II group
(c) III group (d) IV group

[4] An element $^{238}_{92}U$ of III gp undergoes radioactive decay to finally produce a stable element. The finally formed stable element belongs to:
(a) I gp (b) 13th gp
(c) II gp (d) 14th gp

[5] The emission of penetrating rays from a radioactive species can be shielded by:
(a) Bi blocks (b) Pb blocks
(c) C blocks (d) Mg blocks

[6] The value of 'n' for the parent and finally stable element obtained from the decay of $(4n+1)$ series respectively is:
(a) 60, 52 (b) 58, 54
(c) 58, 51 (d) 60, 54

Comprehension 4 : In the upper atmosphere, neutrons present in cosmic rays causes the following nuclear reaction.

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

The isotope $^{14}_6C$ gets circulated in the atmosphere as well as in living species. In a place where nuclear explosion takes place, the concentration of ^{14}C increases both in the atmosphere as well as in living species. The isotope $^{14}_6C$ disintegrates according to the reaction.

$^{14}_6C \rightarrow ^{14}_7N + ^0_{-1}e + \bar{\nu}$ with a half life of 5760 years. When a species dies, the concentration of ^{14}C in it decreases due to the above disintegration reaction. the time at which species has died can be estimated from the knowledge of its ^{14}C content compared to that existing in atmosphere, Beyond 30,000 year, the activity of disintegration is too low to be used for the estimation of time period. **[IIT 2006]**

[1] In radiocarbon dating for finding the age of fossils, the correct statement is:

(a) During the life time ^{14}C assimilated by the human being is in equilibrium with the ^{14}C that decomposes by β emission resulting in the constant ratio of $^{14}C/^{12}C$ at a particular instant

(b) ^{14}C dating method is inappropriate for finding the life of a given sample because ^{14}C undergoes β emission and the ratio $^{14}C/^{12}C$ is not constant in human beings

(c) For a dead human being, the decay of ^{14}C depends in place to place

(d) None of the above

[2] Two organisms died on the same day. One died at a place where nuclear explosion had taken place while the other died at a place where no such explosion has occurred. The ratio of ^{14}C during life to that present in the fossil at an instant is r_1 for the former and r_2 for the latter. The age of the former was calculated at t_1 and for the latter as t_2. The correct choice for the timings t_1 and t_2 is:

(a) $t_1 > t_2$ (b) $t_1 < t_2$

(c) $t_1 = t_2$ (d) none of these

[3] In both the fossils are brought to a common place where no explosion has occurred then:

(a) $t_1 > t_2$ (b) $t_1 < t_2$

(c) $t_1 = t_2$ (d) none of these

SOLUTIONS

Comprehension 1

[1] (a) **For A :** $N_0 = 10^{-2} \times 10^3 = 10\,g$

$$t = \frac{2.303}{\lambda}\log\frac{N_0}{N}$$

$$16 = \frac{2.303 \times 4}{0.693}\log\frac{10}{w_A}$$

or $\log\frac{10}{w} = 1.2036 \quad \therefore\ w_A = \mathbf{0.625\ g}$

For B : $N_0 = 10^{-2} \times 10^3;\ N = 10g$

$$16 = \frac{2.303 \times 8}{0.693}\log\frac{10}{w_B}$$

$\therefore \quad w_B = \mathbf{2.50\ g}$

[2] (c) $r_A = \frac{0.693}{4} \times \frac{10}{a} \times N_A$

(Let a is atomic mass of A, then)

$r_B = \frac{0.693}{8} \times \frac{10}{2a} \times N_A$

$\therefore \quad \frac{r_A}{r_B} = 4$

[3] (d) $r'_A = \frac{0.693}{4} \times \frac{w_1}{a}$

$r'_B = \frac{0.693}{8} \times \frac{w_2}{2a}$

if $r'_A = r'_B$ then $\frac{0.693}{4} \times \frac{w_1}{a} = \frac{0.693}{8} \times \frac{w_2}{2a}$

$\therefore \quad \frac{w_1}{w_2} = \frac{1}{4}$

[4] (a) $T_A = \frac{1}{\lambda_A} = \frac{4}{0.693}$

$T_B = \frac{1}{\lambda_B} = \frac{8}{0.693}$

$\frac{T_A}{T_B} = \frac{1}{2}$

Comprehension 2

[1] (b) $^{230}_{88}Ra$ belongs to alkaline earth family.

[2] (b) $^{232}_{90}Th \longrightarrow ^{208}_{82}Pb + \sigma\,^4_2He + 4e^0_{-1}$

[3] (b) Excess electrons are lost due to exchange of electron with atmosphere. Radioactive decay leads to neutral atom.

[4] (b) γ-rays are given by unstable nuclide left after α, β-emissions and are known as secondary emission.

Comprehension 3

[1] (b) $^1_0n \rightarrow ^1_1P + ^0_{-1}e + \underset{\text{(antineutrino)}}{\bar{\nu}}$

[2] (c) K-electron capture always leads to emission of X-rays.

[3] (b) $\underset{\text{III gp}}{^{238}_{90}Th} \rightarrow \underset{\text{II gp}}{^{234}_{88}Ra} + ^4_2He$; Ra is alkaline earth metal.

[4] (d) The finally formed stable element for all three natural radioactive series is Pb belonging to gp 14.

[5] (b) Radioactive rays do not penetrate lead blocks.

[6] (a) $(4n+1)$ series has parent element ^{241}Pu and ^{209}Bi is finally formed stable element.

Comprehension 4

[1] (a) Follow text

[2] (a) $r_1 = \frac{[^{14}C]_{\text{living explosion}}}{[^{14}C]_{\text{dead}}}$ and $r_2 = \frac{[^{14}C]_{\text{living explosion}}}{[^{14}C]_{\text{dead}}}$

$\therefore \quad \frac{r_1}{r_2} = \frac{[^{14}C]_{\text{living explosion}}}{[^{14}C]_{\text{living no explosion}}} \because r_1 > r_2 \therefore\ t_1 > t_2$

[3] (c) Here $r_1 = r_2 \quad \therefore\ t_1 > t_2$

STATEMENT EXPLANATION PROBLEMS

In each sub question given below a statement (S) and explanation (E) is given. Choose the correct answers from the codes (a), (b), (c) and (d) given for each question:

(a) S is correct but E is wrong
(b) S is wrong but E is correct
(c) Both S and E are corect and E is correct explanation of S
(d) Both S and E are correct but E is not correct explanation of S

1. S: One will need a very powerful crane to lift a nuclear mass of even microscopic size.
   E: The density of nucleus is very high.
2. S: Proton, electron and neutron each has its antiparticle.
   E: Antiproton and antielectron has opposite charge to proton and electron are called antiproton and positron respectively. Antineutron possess only opposite spin.
3. S: Mesons have mass more than electron whereas hyperons have mass more than protons.
   E: Mesons (short lived) on decomposition gives mesons, electrons, positrons, neutrinos, antineutrinos and γ-rays. Hyperons too are short lived on decay gives hyperons, mesons, neutrons and protons.
4. S: The density of nucleus is about 1.8×10^{17} kg m^{-3} and all nucleus have approximately same density.
   E: The density of nucleus is independent of mass present in it.
5. S: The density of $^{12}_{6}C$ nuclide is about 1.8×10^{17} kg m^{3}.
   E: The ratio of density of $^{12}_{6}C$ nuclide and water is about 1.8×10^{14} kg m^{-3}.
6. S: Packing fraction
   $$= \frac{\text{isotopic mass} - \text{mass number}}{\text{mass number}} \times 10^4$$
   E: Positive value of packing fraction implies for the unstability of nucleus.
7. S: The exchange of energy during nuclear reaction takes place in form of kinetic energy in nuclear fission.
   E: The evolution of kinetic energy leads to other forms of energy during fission.
8. S: The half-life of a radioactive species is independent of temperature and mass of active species.
   E: Radioactive decay takes infinite time to complete decay a given sample.
9. S: An atom on losing an α-particle forms its isodiapher.
   E: Isodiaphers are the elements having same difference in their neutrons and protons.
10. S: The O_2 given out during photosynthesis in plants involves O-atoms of H_2O and not of CO_2.
    E: $CO_2^{18} + H_2O \longrightarrow \text{Starch} + O_2^{18}$.
11. S: Nuclear fission is a chain reaction.
    E: Extra neutrons generated during fission further attacks nuclide of fissionable material.
12. S: β-particles are deflected less than α-particles in electrical field.
    E: β-particles have very low mass.
13. S: Nuclear fusion are made at very high temperature, *i.e.*, 10^7 K.
    E: Nuclear fusion reactions are exoergic.
14. S: Radiolysis of water yields H_2.
    E: The reaction during radiolysis of water is disproportionation reaction.
15. S : $^{56}_{26}Fe$ is most stable nucleus.
    E : Binding energy per nucleon is maximum for $^{56}_{26}Fe$.
16. S : Neutron decay results in β-emission and emission of neutrino.
    E : Higher values of n/p ratio give rise to neutron decay.
17. S : K-electron capture leads to emission of neutron and X-rays.
    E : The vacancy created in K-shell is filled by electrons from higher levels and thus, X-rays are given out.
18. S : Binding energy/nucleons becomes almost constant at 7.6 for elements beyond Pb and onwards.
    E : The lower value of binding energy/nucleons is responsible for decay of transuranic elements.
19. S : Yukawa predicted the existance of π-mesons.
    E : π-mesons have their mass about 237 times more than electrons.
20. S : Parent element of $(4n+1)$ series is plutonium-241.
    E : It decays to give 8α and 5β-particles.
21. S : Rutherford studied the first nuclear reaction:
    $$^{14}_{7}N + ^{4}_{2}He \rightarrow ^{17}_{8}O + ^{1}_{1}H + 1.193 \text{ MeV}$$
    E : α-particles lesser than energy 7.6 MeV were found ineffective.
22. S : The first man made atom produced by artificial transmutation was T_c.

E : The phenomenon of converting a stable nuclei into radioactive one is called artificial radioactivity.

23. S : $t_{1/2}$ of C^{14} is same whether it is in CO_2 or in cellulose or in coal.

E : The rate of decay of an element is independent of all external factors.

24. S : The neutrons are better initiator of nuclear reactions than protons, deutrons or α-particles.

E : Neutrons being uncharged particles, not exert repulsion forces from nucleus.

25. S : Nuclide ${}^{30}_{13}Al$ is less stable than ${}^{40}_{20}Ca$.

E : Nuclides having odd number of protons and neutrons are generally unstable.

26. S : Elements having high n/p ratio are less stable and emit β-particles.

E : They tend to lower their energy level by β-emission.

27. S : Neutrons are better projectile than protons to bring in nuclear reaction.

E : The neutrons being neutral do not experience repulsion from positively charged nucleus.

28. S : The reaction : ${}_6C^{11} \rightarrow {}_5B^{11}$ takes place with positron decay.

E : n/p ratio decreases in this change.

29. S : During nuclear fission, the products formed are radioactive.

E : Nuclear fusion requires high temperature.

30. S : ${}_6C^{11}$ lies below the belt of stability and thus decays to emit β-particle.

E : An element lying below the belt of stability try to make it stable by losing positron.

31. S : The binding energy per nucleon is in the order ${}^{9}_{4}Be > {}^{7}_{3}Li > {}^{4}_{2}He$

E : The binding energy per nucleon increases linearly upto ${}_{26}Fe$.

32. S : The position of an element in periodic table after emission of $1\alpha + 2\beta$ particles remains the same.

E : The product formed in above case is isotope.

33. S: An example of K-electron capture is :

$${}^{133}_{56}Ba + e^- \longrightarrow {}^{133}_{55}Cs + X\text{ - ray}$$

E: The atomic number decreases by one unit as a result of K-electron capture.

34. S: The plot of atomic number (y-axis) *vs.* 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. **(IIT 2008)**

E: Proton-proton electrostatic repulsion begins to overcome attractive forces involving proton and neutrons in heavier nuclides.

ANSWERS (Statement Explanation Problems)

1. (c) Suppose we have to life a nuclear mass of microscopic size say $V = 10^{-5}$ cm^3. The mass of this particle in nucleus = volume of particle × density of nucleus

$$\text{Density of nucleus} = \frac{\text{Mass of nucleus}}{\text{Volume of nucleus}}$$

$$= \frac{A \times 1.66 \times 10^{-24}}{\frac{4}{3}\pi r^3}$$

$$= \frac{A \times 1.66 \times 10^{-24}}{4/3 \times 3.14 \times (1.33 \times 10^{-13} \times A^{1/3})^3}$$

$$= \frac{1.66 \times 10^{-24} \times 3}{4 \times 3.14 \times 2.35 \times 10^{-39}}$$

$$= 1.68 \times 10^{14}$$

mass of particle $= 10^{-5} \times 1.68 \times 10^{14}$ g

$= 1.68 \times 10^{9}$ g

$= \mathbf{1.68 \times 10^{6}}$ **kg**

2. (d) Proton ${}_{+1}^{1}p$, electron ${}_{-1}^{0}e$, neutron ${}_{0}^{1}n$ antiproton ${}_{-1}^{1}p$, positron ${}_{+1}^{0}e$, antineutron ${}_{0}^{1}n$
3. (d) Both are facts.
4. (d) —do—
5. (d) Density of each nucleus $= 1.8 \times 10^{17}$ kg / m^3; density of water $= 1 \times 1000$ kg/m^3.
6. (d) Both are facts. A negative value of packing fraction means mass number > isotopic mass, *i.e.*, some mass has been converted into binding energy to stabilize nucleus. This concept was primarily given to discuss the stability of nucleus.
7. (d) Both are facts.
8. (d) —do—
9. (c) ${}_{Z}^{m}A \longrightarrow {}_{Z-2}^{m-4}B + {}_{2}^{4}\text{He}$

   $n - p = (m - 2Z)$ $(m - 2Z)$
10. (a) $CO_2 + H_2{}^{18}O \longrightarrow (C_6H_{10}O_5)_n + {}^{18}O_2$. This is obtained from tracer technique.
11. (c) Explanation is correct reason for statement.
12. (b) β-particles are deflected more towards anode.
13. (d) Both are facts.
14. (c) $2H_2O \longrightarrow H_2O_2 + H_2$
15. (c) The binding energy per nucleons increases upto ${}_{26}Fe$ and becomes maximum at 8.7 MeV. It then decreases. More is binding energy, lesser is energy level of nucleus more is its stability.
16. (b) Neutron decay occurs due to high n/p ratio as

$${}_{0}^{1}n \rightarrow {}_{1}^{1}p + {}_{-1}e^{0} + \bar{\nu} \text{ (antineutrino)}$$

17. (b) Assertion represents K-electron capture.
18. (c) Follow answer 15.
19. (d) These are facts about π-mesons.
20. (c) Parent element of $(4n+1)$ series is ${}^{241}Pu$. The series gives 8α and 5β particles to give finally stable element ${}^{290}Bi$.
21. (d) α-particles with energy lesser than 7.6 MeV were not capable to penetrate nucleus and over power the repulsive forces.
22. (d) Both are facts.
23. (c) Explanation is correct reason for statement.
24. (c) Explanation is correct reason for statement.
25. (c) Al has 13 protons and 17 neutron. the stable atoms have even p-even n system and unstable atoms usually have odd p-odd neutron system.
26. (a) Elements having high n/p ratio tends to decrease it and thus neutron decay takes place to eject out β-particles.
27. (c) Positively charged particles are less suitable projectiles because they use a part of their kinetic energy to overpower the forces of repulsion from nucleus.
28. (a) A decay of ${}_{6}C^{11}$ takes place with positron emission but $\frac{n}{p}$ increases.
29. (b) Nuclear fusion requires as high as 10^7 K temperature.
30. (b) ${}_{6}C^{11} \rightarrow {}_{5}B^{11} + {}_{+1}e^{0}$. The given explanation is correct.
31. (c) Explanation is correct reason for statement.
32. (c) —do—
33. (d) Both are correct.
34. (c) Explanation is correct reason for statement.

MATCHING TYPE PROBLEMS

Type I : More Than One Match Are Possible

1.

List-A	List-B
(A) Nuclear fission	1. Conservation of mass and energy
(B) Nuclear fusion	2. Heavier atoms
(C) β-decay	3. Lighter atoms
(D) Pair production	4. Exoergic
(E) α-decay	5. Self sustaining reaction
	6. Thermonuclear reactions

2.

List-A	List-B
(A) $^{60m}_{27}Co$	1. γ-emitter
(B) $^{233}_{90}Th$	2. Cancer therapy
(C) $^{14}_{6}C$	3. β-emitter
(D) $^{232}_{90}Th$ series	4. α-emitter
	5. Branching decay in series
	6. Emenation

3.

List-A	List-B
(A) Proton rich nuclides	1. K-electron capture
(B) Artificially prepared elements	2. Proton emission
(C) $^{11}_{6}C$	3. Positron emission
(D) C—N cycle	4. $^{97}_{43}Tc$
(E) $^{43}_{21}Sc$	5. Transuranic elements

4.

List A	List B
(A) Only β-emitter	1. $^{14}_{6}C$
(B) Maximum n/p ratio	2. $^{3}_{1}H$
(C) Positron emitter	3. $^{11}_{6}C$
(D) α, β-emitter	4. $^{235}_{92}U$
(E) $(4n+3)$ series	5. $^{81}_{37}Rb$
(F) electron capture	6. $^{223}_{87}Fr$

Type II : Only One Match From Each List

5.

List-A	List-B	List-C
(A) α-emission	1. Isobar	a. proton rich nucleide lying below the belt of stability
(B) β^--emission	2. $^{32}_{15}P$	b. excited nucleus
(C) γ-emission	3. ^{60m}Co	c. higher n/p ratio
(D) K-electron	4. β^+-emission	d. high binding energy
(E) Positron emission	5. Isodiapher	e. X-rays

ANSWERS

1. A–1, 2, 4, 5; B–1, 3, 4, 6; C–1, 4; D–1; E–1, 4

2. A–1, 2; B–3; C–3; D–3, 4, 5, 6

3. A–1, 2, 3; B–4, 5; C–3; D–3; E–2

4. A–1, 2, 6; B–2; C–3; D–4; E–4,6; F–5

5. A–5–d; B–1–c; C–3–b; D–2–e; E–4–a