7. NUCLEAR CHEMISTRY AND ENVIRONMENTAL CHEMISTRY

NUCLEAR CHEMISTRY

1. INTRODUCTION

Nuclear chemistry is deals with nuclear reaction, radioactivity, nuclear processes and nuclear properties. It includes the study of radioactivity and use of radioactive sources for a range of processes.

1.1 Stability of Nucleus

Some nuclei are stable while others are unstable. The stability of an atom has been explained in terms of Columbic forces of attraction and forces of motion. The stability of the nucleus cannot be explained in terms of these forces because of similar charged particles present in nucleus. No single rule allows us to predict whether a particular nucleus is radioactive and how it might decay.

2. SOME IMPORTANT TERMINOLOGIES

2.1 Mass Defect

The mass difference between a nucleus and its constituent nucleons responsible for binding energy, is called the mass defect.

2.2 Binding Energy

The total energy given out during binding up of nucleons in the nucleus is known as **binding energy.** Greater the binding energy, lesser is the energy level of nucleus and thus, more is its stability.

Therefore, $B.E. = \Delta m \times c^2$ erg (m in g) (c in cm/sec)

$= 1.6605 \times 10^{-24} \times \Delta m' \times c^2$ erg ($\Delta m'$ in amu)

$= 1.6605 \times 10^{-24} \times \Delta m' \times (2.9979 \times 10^{10})^2$ erg

$= 14.923 \times 10^{-4} \times \Delta m'$ erg $= 14.923 \times 10^{-11} \times \Delta m'$ J (10^7 erg = 1 J)

$= \dfrac{14.923 \times 10^{-11} \times \Delta m'}{1.602 \times 10^{-19}}$ eV (1.602×10^{-19} J = 1 eV)

$$= \frac{14.923 \times 10^{-11} \times \Delta m'}{1.602 \times 10^{-19} \times 10^{6}} \text{MeV} \qquad (10^6 \text{ eV} = 1 \text{ MeV})$$

$$\simeq 931.478 \times \times \Delta m' \text{ MeV} \qquad \text{(Mega or Million electron volt)}$$

If m′ = 1 amu then, B.E. = 931.478 MeV, i.e., decay of 1 amu produces 931.478 MeV energy.

Also, 1 amu = 931.478 MeV

B.E. per nucleon, $\bar{B} = \frac{\text{Total B.E.}}{\text{No. of nucleons}}$

B.E. / nucleon has been found to increase with increase in atomic number (Fig. 1) and becomes maximum for $_{26}Fe$ at 8.78 MeV. After Fe, it continuously decreases and becomes almost constant at 7.6 MeV for $_{82}Pb$ and onwards.

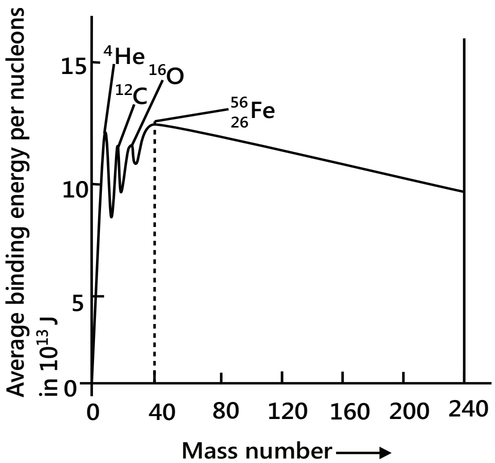


Figure 7.1: Plot of nuclear binding energy per nucleon against the mass number for naturally occurring nucleoids

PLANCESS CONCEPTS

The greater the binding energy per nucleon, the more stable is the nucleus and thus $^{56}_{26}Fe$ is the most stable nucleus.

Vaibhav Krishan (JEE 2009, AIR 22)

Illustration 1: The atomic masses of Li, He and proton are 6.041amu, 4.002602 amu and 1.00715 amu respectively.

Calculate the energy evolved in the reaction: $^{7}_{3}Li + ^{1}_{1}H \longrightarrow 2^{4}_{2}He + \Delta E$ **(JEE MAIN)**

Sol: First determine the total mass change after the reaction, it is calculated as follows,

Δm = (total mass of reactant)-(total mass of product)

And then determine the energy using the following expression

B.E =931.478 × × Δm′ MeV

Mass of elements undergoing decay = Mass of Li + Mass of proton = 7.01823 + 1.00715 = 8.02538 amu

Mass of products after decay = 2 × Mass of helium = 2 × 4.00387 = 8.00774 amu

∴ Mass decayed = 8.02538 – 8.00774 = 0.01764 amu

∴ Energy evolved during reaction = 0.01764 × 931.478 = 16.43 MeV

Illustration 2: Calculate the loss in mass during the change: $^{7}_{3}Li + ^{1}_{1}H \longrightarrow 2^{4}_{2}He + 17.25 \text{ MeV}$ **(JEE MAIN)**

Sol: Here change in energy is given by using the following relation loss in mass can be determined.

$\because \quad \Delta E = \Delta m \times 931.478; \quad \therefore \Delta m = \frac{\Delta E}{931.478} = \frac{17.25}{931.478} = 0.0185 \text{ amu}; \quad \Delta m = 3.07 \times 10^{-26} \text{ g}$

Illustration 3: 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. **(JEE ADVANCED)**

Sol: Mass defect can be calculated by calculating the mass difference between a nucleus and its constituent nucleons. From the calculated mass defect binding energy can be calculated as B.E =931.478 × × Δm′ MeV

Mass of an α-particle = Mass of 2p + Mass of 2n = 2 × 1.0073 + 2 × 1.0087 = 4.032 amu

∵ Actual mass of α-particle = 4.0028 amu

∴ Mass decay = 4.032 – 4.0028 = 0.0292 amu, Also, B.E. = 0.0292 × 931.478 = 27.20 MeV

∴ B.E./nucleons = (27.19/4) = 6.80 MeV

Illustration 4: 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 and ^4_2He = 4.00260 amu. **(JEE ADVANCED)**

Sol: Mass decay, Δm per molecule of LiH = m($^6_3Li\,^2_1H$) – 2 × m ^4_2He

= (6.01512 + 2.01410) – 2 × 4.0026 = 0.02402 amu

Thus, energy produced during the mass decay

= Δm × 931.478 MeV = 0.02402 × 931.478 = 22.37 MeV = 22.37 × 10^6eV

= 22.37 × 10^6 × 1.602 × 10^{-19} J= 3.58 × 10^{-12} J

Now energy produced for 1 mole of LiH = 3.58 × 10^{-12} × 6.023 × 10^{23} = 21.56 × 10^{11} J mol^{-J}

Energy produced for 1 g of $^6Li^2H$ = $\frac{21.55\times10^{11}}{8}Jg^{-1}$ per day

Energy produced for 1 g of $^6Li^2H$ per sec = $\frac{21.55\times10^{11}}{8\times24\times3600}Jg^{-1}s^{-1}$ = 3.12 × 10^6 wg^{-1} = 3.12 Mwg^{-1} (Js^{-1} = 1w–1–)

2.3 The Neutron To Proton N/Z

Neutrons apparently help to hold protons together within the nucleus. The number of neutrons necessary to create a stable nucleus increases rapidly as the number of protons increases; the number of neutron to proton ratio of stable nuclei increases with increasing atomic number. The area within which all stable nuclei are found is known as the **belt of stability**. The majority of radioactive nuclei occur outside this belt.

The type of radioactive decay that a particular radio isotope will undergo depends to a large extent on its neutron to proton ratio.

(a) A nucleus with high n/p ratio which is placed above the belt of stability emits a b-particle in order to lower n/p ratio and move towards the belt of stability.

$^1_0n \longrightarrow {}^1_1p + {}^0_{-1}e + \overline{\nu}$ ($\overline{\nu}$ is Anti neutrino)

e.g., $^{82}_{34}Se \longrightarrow {}^{82}_{36}Kr + 2\,{}^0_{-1}e$

(b) A nucleus with low n/p ratio (less than 1) which is placed below the belt of stability either emits protons or undergoes electron capture.

$^1_1p \longrightarrow {}^1_0n + {}^0_{+1}e$; e.g. $^1_1p \longrightarrow {}^1_0n + {}^0_{+1}e$

(Position emission)

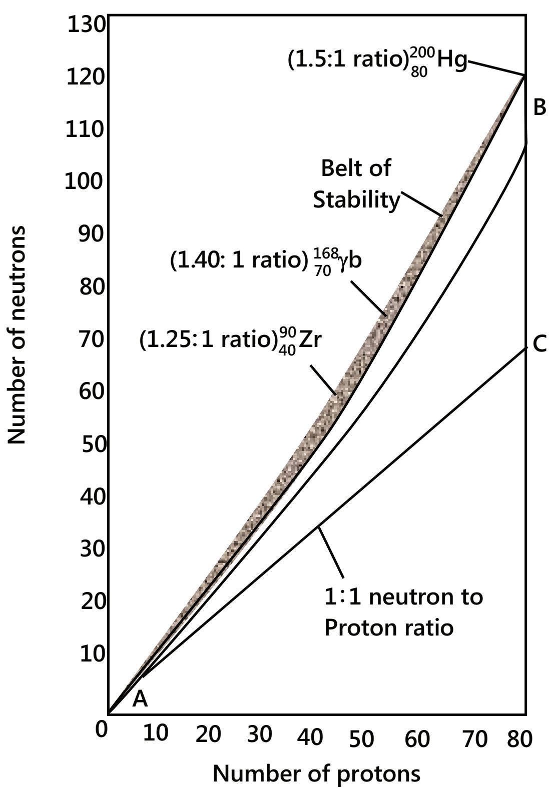


Figure 7.2: Plot of number of neutron vs number of proton

$^{1}_{+1}P + ^{0}_{-1}e \longrightarrow ^{1}_{0}n + X-\text{rays}$ (Electron capture); e.g. $^{133}_{56}Ba + \underset{(K-\text{electron})}{^{0}_{-1}e} \longrightarrow ^{133}_{55}Cs + X-\text{rays}$

(c) The nuclei lying beyond the upper right edge (i.e., nuclei with atomic number > 83) outside the belt of stability undergo α-emission. Emission of an α-particle decreases both the number of protons and neutrons and thereby increases n/p ratio.

$^{238}_{92}U \rightarrow ^{234}_{90}Th + ^{4}_{2}He$; Thus, $\frac{n}{z} \geq 1.0$, unstable nuclei; $\frac{n}{z} \geq 1.0$, stable nuclei

PLANCESS CONCEPTS

$\frac{n}{z} \geq 1.0$, unstable nuclei; $\frac{n}{z} \leq 1.0$, stable nuclei

- The number of stable nuclides is the maximum when both Z and n are even numbers. About 60% of stable nuclides have both Z and n even.
- The number of stable nuclides in which either the Z or n is odd is about one third of those, where both are even.

Nikhil Khandelwal (JEE 2009, AIR 94)

Table 7.1: Number of Stable nuclides

Z	n	Number of stable nuclides
even	even	166
even	odd	57
odd	even	53
odd	odd	8

2.3.1 The Magic Numbers

The nuclear shell model of nuclear structure is analogous to the electron shell model of atomic structure. Just as certain numbers of electrons (2, 8, 18, 36, 54 and 86) correspond to stable closed shell electron configuration, certain number of nucleons leads to closed shell in nuclei. The protons and neutrons can achieve a closed shell. Nuclei with 2, 8, 20, 28, 50 or 82 protons or 2, 8, 20, 28, 50, 82 or 126 neutrons correspond to closed nuclear shell. Closed shell nuclei are more stable than those that do not have a closed shell. These numbers of nucleons that correspond to closed nuclear shells are called magic numbers.

Illustration 5: There is an analogy between the stability of the nucleus ^{208}Pb and the lack of reactivity of argon gas. Comment. **(JEE MAIN)**

Sol: $^{40}_{18}Ar$ has a closed shell of electrons (2, 8, 8) which limits its reactivity. ^{208}Pb has a closed shell of protons and neutrons which leads to nuclear stability.

Illustration 6: Of the isotopes $^{114}_{48}Cd$, $^{118}_{50}Sn$ and $^{114}_{50}In$, which is likely to be radioactive and why? **(JEE MAIN)**

Sol: $^{114}_{49}In$ It has odd number of protons and odd number of neutrons.

2.3.2 Radioactivity

Henry Becquerel (1891) observed the spontaneous emission of invisible, penetrating rays from potassium uranyl sulphate $K_2UO_2\ (SO_4)_2$, which influenced photographic plate in dark and were able to produce luminosity in substances like ZnS. Later on, Marie Curie and her husband Pierre Curie named this phenomenon of spontaneous emission of penetrating rays as radioactivity. They also pointed out that radioactivity is a characteristic property of an unstable or excited nucleus, i.e., a nuclear property and is independent of all the external conditions, the nature of other atoms associated with the unstable atom but depends upon the amount of unstable atom.

PLANCESS CONCEPTS

Radioactivity is a nucleus phenomenon and does not depend upon environmental conditions.

Rutherford identified two types of these penetrating rays and named them alpha (a) and beta (b) particles. Later on P. Villard identified and named, the third category as gamma (g) rays.

Vaibhav Krishan (JEE 2009, AIR 22)

Table 7.2: Properties of α, β-particles and γ-rays, Becquerel radiations

S.N.	Properties	Alpha	Beta	Gamma
1.	Nature	Fast moving He nuclei	Fast moving electron	High energy radiations
2.	Notation	$_2He^4$ or α	$_{-1}e^0$ or β	γ or $^0_0\gamma$
3.	Charge	2 unit (+ve)	1 unit (–ve)	No charge
4.	Typical source	Ra-226	C-14	Tc-99 m
5.	Velocity	1/10 of light	33% to 90% of light	Same as light waves
6.	Nature of path	Straight line	Crooked	Waves
7.	Relative penetrating power	1 or (0.01 mm of Al foil)	100 or (0.1 cm of Al foil)	10,000 or (8 cm lead or 25 cm steel)
8.	Travel distance in air	2-4 cm	200-300 cm	500 cm
9.	Tissue depth	0.05 mm	4-5 mm	50 cm or more
10.	Shielding	Paper, clothing	Heavy clothing, labcoats, gloves	Lead, thick concrete
11.	Mass g/particle	6.65×10^{-24}	9.11×10^{-28}	0
12.	Relative ionizing power	10,000	100	1
13.	Electrical or magnetic field's influence	Deflected towards –ve pole	Deflected towards +ve pole	Not deflected

PLANCESS CONCEPTS

- β-particles are deflected more towards magnetic or electric field than α-particles because of their lower mass,
- γ-rays are identical to X-rays but their wavelength is much shorter than X-rays.

Saurabh Gupta (JEE 2010, AIR 443)

Illustration 7: Why does α-particles cause more damage to tissues than β-particles? **(JEE MAIN)**

Sol: Explain this by considering penetrating power of α-particles and β-particles.
Penetrating power of α being less and thus they provide all their energy at one spot damaging tissues.

Illustration 8: Why is an α-emitter more hazardous to an organism internally then externally, whereas γ-emitter is equally hazardous internally and externally? **(JEE ADVANCED)**

Sol: α-particles move relatively slowly and cannot penetrate too much externally. However inside the body α-particles give up their energy to surrounding tissues. Gamma rays move at the speed of light and have too much penetrating power. Thus, they are equally hazardous internally and externally.

3. THEORY OF NUCLEAR INTEGRATION: RUTHERFORD AND SODDY

The ejection of α, β particles and γ-rays from a radioactive material has been satisfactorily explained by Rutherford and Soddy.

Step I: An excited nucleus (a nucleus of low B.E. or higher energy level) tries to attain lower energy level in order to attain stability. Therefore, α-particles are emitted from the nucleus as an energy carrier.

Step II: During α-decay no doubt that energy level comes down but n/p ratio increases and therefore to decrease n/p ratio and attain stability, nucleus undergoes neutron decay or neutron transformation to show emission of β-particles. $\quad {}_{0}^{1}n \longrightarrow {}_{+1}^{1}P + {}_{-1}^{0}e + v$

The energy of β-particles does not account for the difference in energy between the parent and daughter nuclei during neutron decay and therefore missing energy gave the existence of another particle called anti-neutrino.

Step III: The resultant nucleus after α-, β-emission still possesses higher energy level than required for its stability and this difference of energy comes out in form of γ-rays. Thus, gammaradiations are given off by the nuclei in an excited state.

Therefore, α, β-emissions are primary whereas γ-emissions are secondary emissions.

Illustration 9: Though a nucleus does not contain any particle of-ve charge, still the nucleus of a radioactive element emits β-rays. Explain. **(JEE MAIN)**

Sol: Neutron decay on account of higher n/p brings in β-emission: $\quad {}_{0}^{1}n \longrightarrow {}_{1}^{1}p + {}_{?1}^{0}e + \bar{v}$

Illustration 10: Explain with reason the nature of emitted particle by: **(JEE ADVANCED)**

(A) ${}_{20}^{38}Ca$ (B) ${}_{18}^{35}Ar$ (C) ${}_{32}^{80}Ge$ (D) ${}_{79}^{173}Au$ (E) ${}_{20}^{40}Ca$ (F) ${}_{11}^{22}Na$ (G) ${}_{92}^{238}U$ (H) ${}_{16}^{35}S$ (I) ${}_{9}^{17}F$ (J) ${}_{4}^{10}Be$

Sol: By taking into account neutron to proton ratio suggest the nature of particle emitted by different isotopes.

(A) ${}_{20}^{38}Ca$ It has n/p $= \frac{18}{20} = 0.9$, which lies below the belt of stability and thus, positron emitter.

$${}_{20}^{38}Ca \longrightarrow {}_{19}^{38}K + {}_{+1}^{0}e$$

(B) ${}_{18}^{35}Ar$: It has $= \frac{n}{p} = \frac{17}{18} = 0.994$, which lies below the belt of stability and thus, positron emitter

$${}_{18}^{35}Ar \longrightarrow {}_{17}^{35}Cl + {}_{+1}^{0}e$$

(C) ${}_{32}^{80}Ge$: It has n/p $= \frac{48}{32} = 1.5$, which lies above the belt of stability and thus, β-emitter.

$${}_{32}^{80}G \longrightarrow {}_{33}^{80}As + {}_{-1}^{0}e$$

(D) ${}_{79}^{173}Au$: It has $\frac{n}{p} = \frac{94}{79} = 1.19$, which lies above the belt of stability and thus, β-emitter,

$${}_{79}^{173}Au \longrightarrow {}_{80}^{173}Hg + {}_{-1}^{0}e$$

(E) ${}_{11}^{22}Na$: It has both magic numbers p = 20, n =20 and thus, stable.

(F) ${}_{11}^{22}Na$: n/p = 1 and shows, positron emission. $\quad {}_{11}^{22}Na \longrightarrow {}_{11}^{22}Na + {}_{+1}^{0}e$

(G) $^{238}_{92}U$ = n/p = 1.58 and shows, α-emission. $^{238}_{92}U \longrightarrow ^{234}_{90}Th + ^{4}_{2}He$

(H) $^{10}_{4}Be$: n/p = 1.18 and shows, (β-emission. $^{35}_{16}S \longrightarrow ^{354}_{17}Cl + ^{0}_{-1}e$

(I) $^{10}_{4}Be$: n/p = 0.88 and shows, positron emission. $^{17}_{9}F \longrightarrow ^{17}_{8}O + ^{0}_{+1}e$

(J) $^{10}_{4}Be$: n/p = 1.5, and shows β-emission. $^{10}_{4}Be \longrightarrow ^{10}_{5}B + ^{0}_{-1}e$

3.1 SODDY-FAJAN'S Rule or Group Displacement Law

(a) A radioactive atom on losing an α-particle shows a loss in mass no. by 4 units and a loss in atomic no. by 2 units. Thus, the newly formed element occupies two positions left to the parent element in the periodic table.

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

(b) A radioactive atom on decay of a β-particle shows a gain in its atomic no. by 1 unit whereas, mass no. remains the same. Thus, newly formed element occupies one position right to the parent element in the periodic table.

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

Illustration 11: $^{14}_{6}C$ Nuclide undergoes β-decay. What stable nuclide is formed? Give equation. **(JEE MAIN)**

Sol: $^{14}_{6}C \longrightarrow ^{14}_{7}N + ^{0}_{-1}e$

Illustration 12: Which one is more chemically reactive and which is more radioactive among $^{1}_{1}H$, $^{2}_{1}H$, $^{3}_{1}H$

(JEE MAIN)

Sol: Reactivity order: $^{1}_{1}H > ^{2}_{1}H > ^{3}_{1}H$, Radioactive: only $^{3}_{1}H$ is radioactive and β-emitter.

Illustration 13: Which of the following processes given below gives rise to (i) an increase in atomic no. (ii) an increase in n/p ratio (iii) a decrease in atomic no. (iv) a decrease in n/p ratio (v) emission of X-rays definitely.

(a) α-emission (b) β-emission (c) positron emission (d) K-electron capture **(JEE ADVANCED)**

Sol: (i) Increase in at. No: β-emission

(ii) Increase in n/p ratio: α-emission, K-electron capture

(iii) Decrease in at. no: positron emission, α-emission

(iv) Decrease in n/p ratio: β-emission

(v) X-rays emission: K-electron capture

Illustration 14: Calculate no. of α- and β-particles emitted when $^{238}_{92}U$ changes into radioactive $^{206}_{82}Pb$

(JEE ADVANCED)

Sol: Let a, b are the number of α-particles and β-particles given out during the change of $^{238}_{92}U$ to $^{206}_{82}Pb$, then

$$^{238}_{92}U \longrightarrow ^{206}_{82}Pb + a\,^{4}_{2}He + b\,^{0}_{-1}e$$

Equating mass no. on both sides of nuclear reaction 238=206 + 4a +b × 0 $\therefore$ a = 8

Now equating atomic no. on both sides of nuclear reaction

92 = 82+2a + b (–1) = 82 + 2 × 8 + b (–1) $\therefore$ b = 6

Thus, No. of α-particles emitted out = 8; No. of β-particles emitted out = 6

4. RATE OF RADIOACTIVE DECAY

Radioactive disintegration is an example of first order reaction, i.e. the rate of decay is directly proportional to the no. of atoms (amount) of the element present at that particular time.

A $\rightarrow$ Decay product (N_0 = No. of atoms at t = 0)

(N = No. of atoms left after t = t)

$-\frac{dN}{dt} \propto [N]^1 = \lambda N$. The negative sign indicates the decreasing trend of N with increasing time.

Where λ is the proportionality constant and is known as decay or disintegration or radioactive constant. Integration of this equation gives,

$-\ln N = \lambda + A$ (A is integration constant)

At t = 0, $N = N_0$ $\therefore$ $A = -\ln N_0$ $\therefore -\ln N = \lambda - \ln N_0$

OR $\ln \frac{N_0}{N} = \lambda$ or $\frac{N_0}{N} = e^{\lambda}$ ... (i)

OR $N = N_0 e^{-\lambda}$ ... (ii)

OR $\lambda = \frac{1}{t} \ln \frac{N_0}{N}$ ... (iii)

OR $\lambda = \frac{2.303}{t} \log_{10} \frac{N_0}{N}$ ... (iv)

OR $N = N_0 10^{-\lambda/2.303}$ ... (v)

Characteristics of rate of decay

(a) Rate of decay continuously decreases with time and obeys Ist order kinetics.

(b) Rate of decay as well as λ are independent of P and T.

(c) (a) Unit of rate of decay: disintegration per time (b) Unit of decay constant: time^{-1}.

(d) Time required to complete a definite fraction is independent of initial number of atoms (amount) of radioactive species, i.e. time required to complete nth fraction, $t_{1/n}$ $t_{1/n} \propto [N_0]^0$

(e) Fraction of atoms decayed or degree of decay (α) in time, t

$$\alpha = \frac{N_0 - N}{N_0} = 1 - \frac{N}{N_0} = 1 - e^{-\lambda t} \quad \text{... (vi)}$$

PLANCESS CONCEPTS

Time required to complete a definite fraction is independent of initial number of atoms (amount) of radioactive species,

Neeraj Toshniwal (JEE 2009, AIR 21)

Half-life period: $t = \frac{2.303}{\lambda} \log_{10}\left(\frac{N_0}{N}\right)$ If $t = t_{1/2}$; $N = \frac{N_0}{2}$, then $t_{1/2} = \left(\frac{2.303}{\lambda}\right) \log_{10}\left[\frac{N_0}{(N_0/2)}\right]$

or $t_{1/2} = \frac{2.303 \log_{10} 2}{\lambda} = \frac{2.303 \times 0.3010}{\lambda}$ $t_{1/2} = \frac{0.693}{\lambda}$ ... (vi)

It is clear from this expression that $t_{1/2}$ is independent of the initial no. of atoms.

Note: $t_{1/2}$ is independent of the initial no of atoms.

Average life: $T_{av} = \dfrac{\text{Sum of lives of all atoms}}{\text{Total number of atoms}}$

Average life: $T_{av} = \dfrac{\text{Total life of all atoms}}{N_0} = \int_0^{\infty} \dfrac{t\,dN}{N_0} = \int_0^{\infty} \dfrac{-t\lambda N dt}{N_0}$ $\left(\because -\dfrac{dN}{dt} = \lambda.N\right)$

$= \int_0^{\infty} \dfrac{-t\lambda N_0 e^{-\lambda t} dt}{N_0}$ $(\because N = N_0 e^{-\lambda})$

$T_{av} = \dfrac{1}{\lambda} = \int_0^{\infty} -t\lambda e^{-\lambda t}\,dt = \dfrac{1}{\lambda}$; $N = N_0 e^{-\lambda}$, if $t = \dfrac{1}{\lambda} = N_0 e^{-1} = \dfrac{N_0}{e} = \dfrac{N_0}{2.718} = 0.37\,N_0$

Decay constant can also be defined as the reciprocal of time in which radioactive atoms of a species reduces to 37% of its initial value.

Amount left after I half = $\dfrac{N_0}{2}$; Amount left after II half = $\dfrac{N_0}{2^2}$

$\therefore$ Amount left after n halves = $\dfrac{N_0}{2^n}$ $\therefore$ Amount decayed after n halves = $N_0 - \dfrac{N_0}{2^n} = \dfrac{N_0[2^n - 1]}{2^n}$

Total time (T) = no. of halves × half life $T = n \times t_{1/2}$

Note: Amount left after n halves = $\dfrac{N_0}{2^n}$

Illustration 15: Half-life for a radioactive substance is 5 hours. Calculate the % left in 2.5 and 10 hours? When will whole of the matter disappear? Will the decay law always apply? **(JEE MAIN)**

Sol: $T = n \times t_{1/2}$, $n = \dfrac{2.5}{5} = \dfrac{1}{2}$

$\therefore$ Amount left in 2.5 hours= $\dfrac{100}{(2)^{1/2}} = 70.71\,\%$ Also, $T = n \times t_{1/2}$; $n = \dfrac{10}{5} = 2$

$\therefore$ Amount left = $\dfrac{100}{2^2}$ =25%

The whole matter will never disappear. The decay law does not apply when the matter contains minimum amount or number of atoms say one atom.

Illustration 16: The number of radioactive atoms of a radio isotope falls to 12.5% in 90 days. Compute the half-life and decay constant of isotope. **(JEE MAIN)**

Sol: Using the equation of radioactive decay first calculate the disintegration constant and then by using the relation of disintegration constant and half-life term calculate the half-life of the radioactive atom.

Given, N = 12.5, N_0 = 100, t = 90 days

$\therefore \quad \lambda = \dfrac{2.303}{t}\log\dfrac{N_0}{N} = \dfrac{2.303}{90}\log\dfrac{100}{12.5} = 2.31 \times 10^{-2}\ \text{day}^{-1}$ and $t_{1/2} = \dfrac{0.693}{\lambda} = \dfrac{0.693}{2.31\times 10^{-2}} = 30$ days

Illustration 17: Prove that time required for 99.9% decay of a radioactive species is almost 10 times to its half-life period. **(JEE ADVANCED)**

Sol: N_0 = 100, for 99.9% decay N = 100 – 99.9 = 0.1

$\therefore\ t_{99.9\%} = \dfrac{2.303}{\lambda}\log\dfrac{100}{0.1} = \dfrac{2.303}{\lambda}\log 1000 = \dfrac{2.303}{\lambda}\times 3$ ... (i)

Also for 50% decay: N = 100 – 50 = 50

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

By equation (i) and (ii) $t_{99.9\%} \approx t_{50\%} \times 10$

Illustration 18: The rate of decay of a radioactive species is r_1 at time t_1 and r_2 at time t_2. If $t_2 > t_1$, what is the mean life of the sample? Also calculate the number of atoms disintegrated in the time $(t_2 - t_1)$ if half-life is $t_{1/2}$.

(JEE ADVANCED)

Sol: $r_1 = \lambda.\ N_1$ ... (i)

$r_2 = \lambda.\ N_2$ ... (ii)

$\frac{r_1}{r_2} = \frac{N_1}{N_2}$ Let initial rate be r_0 $t_1 = \frac{2.303}{\lambda}\log\frac{r_0}{r_1}$ $t_2 = \frac{2.303}{\lambda}\log\frac{r_0}{r_2}$

$t_2 - t_1 = \frac{2.303}{\lambda}\,[\log r_0 - \log r_2 - \log r_0 + \log r_1]$; $t_2 - t_1 = \frac{2.303}{\lambda}\log\frac{r_1}{r_2}$

Also Average life is $\frac{1}{\lambda} = \frac{t_2 - t_1}{2.303\log\frac{r_1}{r_2}}$

From (i) and (ii) $\frac{r_1 - r_2}{\lambda} = N_1 - N_2$ (atoms decayed) in time $(t_2 - t_1)$ $\therefore N_1 - N_2 = \frac{r_1 - r_2}{0.693} \times t_{1/2}$

5. ACTIVITY OF A RADIOACTIVE SUBSTANCE: ITS DETECTION AND UNITS

Activity = Rate of disintegration of radioactive substance $-\frac{dN}{dt} \propto N$ or $-\frac{dN}{dt} = IN$

or Activity = λN Activity = $\frac{0.693 \times N}{t_{1/2}}$ i.e. Activity = $\frac{0.6931 \times \text{Number of atoms present}}{\text{Half-life}}$

This shows that the activity of a radioactive substance is inversely proportional to its half-life. The greater the half-life of the substance, lesser is its activity and vice-versa.

PLANCESS CONCEPTS

The greater the half-life of the substance, lesser is its activity and vice-versa.

Curie: If a radioactive substance disintegrates at the rate of 3.7×10^{10} disintegrations per second, its activity is said to be one Curie, i.e., one Curie = 1 Ci = 3.7×10^{10} disintegrations per sec (dps). Sometimes smaller units are also used viz.

1 millicurie = 1m Ci = 10^{-3} Ci ; 1 microcurie = 1 μ Ci = 10^{-6} Ci

The S.I. unit of radioactivity is proposed as Becquerel or Bq which refers to one dps.

Rohit Kumar (JEE 2012, AIR 79)

Illustration 19: Calculate the time in which the activity of an element reduces to 90% of its original value. The half-life period of element is 1.4×10^{10} year. **(JEE MAIN)**

Sol: Here activity is given, as radioactive decay is directly proportional to no of atoms substitute the value for $\frac{N_0}{N_1}$ in the equation of radioactive decay and calculate the time.

Given $r_1 = (90/100) r_0$ at time t

$\therefore \quad \frac{r_0}{r_1} = \frac{100}{90}$ at time t ; $\quad \because \quad$ Rate of decay $\propto$ No. of atoms

$\frac{r_0}{r_1} = \frac{N_0}{N_1} = \frac{100}{90}$ Now, $t = \frac{2.303}{\lambda}\log\frac{N_0}{N_1}$; $t = \frac{2.303 \times 1.4 \times 10^{10}}{0.693}\log\frac{100}{90}$ $t = 2.128 \times 10^9$ year

Illustration 20: What mass of ^{14}C with $t_{1/2}$ = 5730 years has activity equal to one curie? **(JEE MAIN)**

Sol: 1 curie = 3.7×10^{10} disintegration per second; Rate = 3.7×10^{10} dps

Since, Rate = λ × No. of atoms; $3.7 \times 10^{10} = \frac{0.693}{5730 \times 365 \times 24021560 \times 60}$ × Number of atoms

No of atoms = 9.65×10^{21} Q 6.023×10^{23} atoms of ^{14}C = 14 g

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

Illustration 21: The decay constant for an α-decay of ^{232}Th is 1.58×10^{-10} sec^{-1}. Find the number of α-decays that occur for a 1 g sample in 365 days. **(JEE ADVANCED)**

Sol: By using the expression for radioactive decay calculate the no of atom undergoing radioactive decay from this Find the number of α-decay that occur from 1 g sample in 365 day.

$t = \frac{2.303}{\lambda}\log\frac{N_0}{N}$ ($\because$ N_0/N is ratio and thus it may be taken as ratio of atoms, weights or g-atoms of elements undergoing decay)

$\therefore 365 \times 24 \times 60 \times 60 = \frac{2.303}{1.58 \times 10^{-10}}\log\frac{1}{N}$ $(N_0 = 1\ g)$ $\quad \therefore \quad$ N = 0.995 g

$\therefore$ Amount of Th undergoing decay = $N_0 - N$ = 1 – 0.995 = 0.005 g $\because$ ^{232}Th is an α-emitter

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

$\therefore$ 0.005 g Th on decay produces = $\frac{6.023 \times 10^{23} \times 0.005}{232}$ = 1.298×10^{19} α-atoms

Illustration 22: Calculate the decay constant and the average life of ^{55}Co radio nuclide if its activity is known to decrease 4% per hour. Assume that decay product of ^{55}Co is non-radioactive. **(JEE ADVANCED)**

Sol: $A_0 = \lambda N_0$ $\quad A = \lambda.N \quad \frac{A_0}{A} = \frac{N_0}{N} = e^{\lambda t}$ $\quad$ or $\quad \frac{A}{A_0} = e^{-\lambda t}$

The decrease in A_0 when t = 1 hr is 4%, i.e. a decrease of 0.04 A_0, i.e. 0.04

Activity (A) left after 1 hr = $A_0 - 0.04 A_0 = 0.96 A_0$

$\therefore \frac{A_0}{0.96A_0} = e^{\lambda.1}$ or $\quad 0.96 = e^{-\lambda}$ $\quad \lambda = 4.08 \times 10^{-2}\ hr^{-1} = 1.14 \times 10^{-5}\ sec^{-1}$

6. RADIOACTIVE SERIES

A series of nuclear reactions that begins with an unstable nucleus and terminates with a stable one is known as radioactive series or a nuclear disintegration series.

$^{232}_{90}Th \longrightarrow {}^{208}_{82}Pb + 6\,^{4}_{2}He + 4\,^{0}_{-1}e$ (4n series)

$^{238}_{92}U \longrightarrow {}^{206}_{82}Pb + 8\,^{4}_{2}He + 6\,^{0}_{-1}e$ (4n + 2 series)

$^{235}_{92}U \longrightarrow {}^{207}_{82}Pb + 7\,^{4}_{2}He + 4\,^{0}_{-1}e$ (4n + 3 series)

The parent element, intermediates and final stable element of ^{232}Th series have masses which are integral multiples of 4. That is why this series is known as 4n series. Similarly, ^{238}U and ^{235}U series are known as (4n + 2) and (4n + 3) series.

Illustration 23: In which radioactive series does the following appear during disintegrations **(JEE MAIN)**

(A) $^{228}_{89}Ac$ (B) $^{227}_{89}Ac$ (D) $^{214}_{84}Po$

Sol: (A) 4n, (B) 4n + 3, (C) 4n + 2

7. RADIOACTIVE EQUILIBRIUM

Radioactive change is an irreversible process but it shows equilibrium when a daughter element disintegrates at the same rate at which it is formed from parent element.

$$\underset{\text{Parent}}{A} \longrightarrow \underset{\substack{\text{Intermediate}\\ \text{daughter}}}{B} \longrightarrow C$$

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→B→C). Also if the 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 constant of A and B respectively, then number of atoms of daughter element B after time t is, $N_B = \frac{N_0\lambda_A}{\lambda_B - \lambda_A}[e^{-\lambda_A t} - e^{-\lambda_B .t}]$

Maximum activity of daughter element can be expressed as t_{max}: $t_{max.} = \frac{2.303}{\lambda_B - \lambda_A}\log_{10}\left[\frac{\lambda_B}{\lambda_A}\right]$

Illustration 24: The half-life of ^{212}Pb is 10.6 hours. It undergoes decay to its daughter (unstable) element ^{212}Bi of half-life 60.5 minutes. Calculate the time at which the daughter element will have maximum activity? **(JEE ADVANCED)**

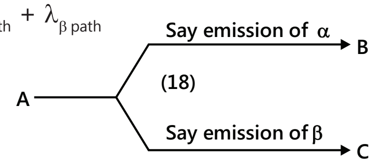
Sol: First find out the disintegration constant for parent and daughter element. By substituting the value in the following equation will give you t_{max} (time at which daughter element will have maximum activity)

$t_{max.} = \frac{2.303}{\lambda_{Bi} - \lambda_{Pb}}\log_{10}\frac{\lambda_{Bi}}{\lambda_{Pb}}$; $\lambda_{Pb} = \frac{0.693}{10.6 \times 60} = 1.0896 \times 10^{-3}$; $\lambda_{Bi} = \frac{0.693}{60.5} = 11.45 \times 10^{-3}$

$t_{max.} = \frac{2.303}{\lambda_{Bi} - \lambda_{Pb}}\log_{10}\frac{\lambda_{Bi}}{\lambda_{Pb}} = \frac{2.303}{10.3604 \times 10^{-3}}\log_{10}\frac{11.45 \times 10^{-3}}{1.0896 \times 10^{-3}}$ $t_{max.} = 227.1$ minute

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

The average decay constant for the element A can be expressed as: $\lambda_{average} = \lambda_{\alpha\ path} + \lambda_{\beta\ path}$



$\lambda_{\alpha\ path}$ = [Fractional yield of B] × $\lambda_{average}$

$\lambda_{\beta\ path}$ = [Fractional yield of C] × $\lambda_{average}$

Illustration 25: The mean lives of a radioactive substance are 1620 years and 405 years 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. **(JEE ADVANCED)**

Sol: For successive α, β-emissions.

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

Let $\frac{3}{4}$ sample decays in time t hr, then N = (N_0/4) ; $\because t = \frac{2.303}{\lambda}\log\frac{N_0}{N}$; $\therefore t = \frac{2.303 \times 1620}{5}$ log4 = 449.24 year

8. SOME IMPORTANT TERMS

Isotopes: 1.Atoms of same the element having the same atomic no. but different mass no. are known as isotopes, e.g., ${}^{16}_{8}O$, ${}^{17}_{8}O$, ${}^{18}_{8}O$

Isobars: 1. Atoms of different elements having same mass no. are known isobars, e.g. ${}^{40}_{18}Ar$, ${}^{40}_{19}K$, ${}^{40}_{20}Ca$

Isotones: 1. Atoms having same no. of neutrons are called isotones, e.g. ${}^{2}_{1}H$ and ${}^{3}_{2}He$

2. Mass no. – atomic no. = constant (i.e. no. of neutrons)

Isoelectronics: 1. Atom and ions having same no. of electrons are called as isoelectronics.

2. E.g. N^{3-}, O^{2-}, F^{-}, Ne, Na^{+} Mg^{2+}, Al^{3+}

Isodiaphers: 1. Atoms having the same difference of neutron and proton or same isotopic number.

2. Nuclide and its decay product formed after β-emission are called isodiaphers.

Isosters: 1. Molecules having the same no. of atoms and same no. of electrons.

2. E.g. CO_2 and N_2O.

Nuclear Isomers: Nuclides having identical atomic no. and mass no. but differing in radioactive decay are known as nuclear isomers.

E.g. ${}^{60}Co$ and ${}^{60m}Co$, ${}^{69}Zn$ and ${}^{69m}Zn$, ${}^{80}Br$ and ${}^{80m}Br$ or like U_A and Uz.

The symbol m with mass no. represents the metastable state of parent element.

$${}^{60m}Co \xrightarrow[\text{transition}]{\text{Isomeric}} {}^{60}Co + \gamma\text{-rays}$$

Illustration26: Match the followings: **(JEE MAIN)**

A. Isotopes	A. ${}^{16}_{8}O$ and ${}^{17}_{8}O$
B. Isobars	B. Na^{+}, Mg^{2+}, F^{-}
C. Nuclear isomers	C. ${}^{2}_{1}H$ and ${}^{3}_{2}He$
D. Isosters	D. U_A and U_Z
E. Isotones	E. CO_2 and N_2O
F. Isoelectronics	F. ${}^{Z}_{A}X$, ${}^{Z-4}_{A-2}Y$
G. Isodiaphers	G. ${}^{40}_{20}Ca$ and ${}^{40}_{19}K$

Sol: A → p, B → v, C → s, D → t, E → r, F → q, G → u

9. NUCLEAR REACTIONS

Types of nuclear reactions: Some of the nuclear reactions are cited below:

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

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

$${}^{10}_{5}B + {}^{4}_{2}He \longrightarrow {}^{13}_{7}N + {}^{1}_{0}n \xrightarrow[\text{Artificial radioactivity}]{\text{Nuclear reaction, Vis-a-Vis}} {}^{13}_{6}C + {}^{0}_{+1}e$$

(b) Nuclear Fission:

(i) The phenomenon of splitting up of a heavy nucleus, on bombarΔment 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.

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

(iii) A loss in mass occurs releasing a vast quantity of energy $\simeq 2.041 \times 10^{10}$ kJ per mol of ^{235}U

(iv) Fission of 1 g ^{235}U releases energy = $\frac{20.41 \times 10^9}{235}$ kJ = 8.68×10^7 kJ

Fission of 1 mole ^{235}U releases energy = 20.41×10^9 kJ

Fission of one atom of ^{235}U releases energy = 211.5 MeV

(v) The secondary neutrons (formed during fission) further cause fission and thus, set up chain reaction, giving out huge amounts of energy. Nuclear fission reactions are self-multiplying or self-sustaining reactions. Once, a nuclear fission starts, it continues till the end and does not need bombardment of neutron from outside as neutrons formed by decay of ^{235}U are used for further decay with a small lump of mass of ^{235}U. Most of the neutrons released during fission escape but if the mass of ^{235}U exceeds a definite value (called critical mass) neutrons emitted during fission (on an average 2.5 neutrons per ^{235}U nucleus) are absorbed by ^{235}U to develop a chain reaction. This minimum amount of fissionable nuclei which develops a self-sustaining chain reaction is called critical mass. If mass of fissionable nuclei is lesser (i.e. subcritical mass) than the critical mass, the neutrons released during fission escape and the fission stops, but if the mass of fissionable nuclei is more (i.e. super critical mass) than the critical mass, the fission develops violently producing explosion. For a chain reaction, multiplication factor (K) should be greater than 1 and is given by:

$$K = \frac{\text{Number of neutrons produced in one step of fission}}{\text{Number of neutrons produced in one step to this fission}}$$

(vi) Nuclear fission is an uncontrolled reaction in an atom bomb whereas, in nuclear reactors, it is controlled by using a control rod of boron, steel or Cd which capture some of the neutrons so that chain reaction does not become violent, slowing down the speed of neutrons using moderators, e.g., D_2O, graphite, so that neutrons can be captured more readily by the fuel. A circulating coolant (water, molten Na) is employed to extract the heat from the reactor which is used for power production. The coolant liquid can also serve as the neutron moderator.

(vii) ^{238}U does not show fission by slow speed neutrons and that is why refining of uranium is necessary before it is used as nuclear fuel in nuclear reactors. Natural uranium consists of 99.3% ^{238}U + 0.7% ^{235}U.

(viii) A breeder reactor is one that produces more fissionable nuclei than it consumes, e.g. when $^{238}_{92}U$ is bombarded with fast neutron, it produces ^{239}Pu, a fissionable nuclei.

$$^{238}_{92}U + ^{1}_{0}n \longrightarrow ^{239}_{92}U \longrightarrow ^{239}_{93}Np + ^{0}_{-1}e\ ;\ ^{239}_{93}Np \longrightarrow ^{239}_{94}Pu + ^{0}_{-1}e\ ;\ ^{239}_{94}Pu + ^{1}_{0}n \rightarrow \text{Fission products} + 2 \text{ or } 3\left(^{1}_{0}n\right)$$

(c) Nuclear Fusion:

(i) The phenomenon of joining up of two light nuclei into a heavier nucleus is called fusion,

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

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

(iii) About 0.231% of total mass decay occurs to liberate fantastically high energy during fusion.

(iv) The temperature corresponding to nuclear fusion is about 1.2×10^7 K. This requisite condition for fusion reaction exists in the stars and in the sun. Although the sun's surface temperature is only about 6000 K, its internal temperature is as high as 1.5 × 10^7 K. Under these conditions, H nuclei undergo fusion to form helium nuclei and in the process a continuous emission of solar energy occurs. Therefore, fusion is also referred as thermonuclear reactions.

(v) It is an uncontrolled reaction and the principle is used in the formation of H-bombs.

Illustration 27: Complete the following: **(JEE MAIN)**

(i) ${}^{9}_{4}Be + {}^{4}_{2}He \longrightarrow {}^{12}_{6}C + ?$; (ii) ${}^{3}_{1}T + {}^{2}_{1}D \longrightarrow {}^{4}_{2}He + ?$;

Sol: (i) ${}^{9}_{4}Be + {}^{4}_{2}He \longrightarrow {}^{12}_{6}C + {}^{1}_{0}n$; (ii) ${}^{3}_{1}T + {}^{2}_{1}D \longrightarrow {}^{4}_{2}He + {}^{1}_{0}n$;

Illustration 28: When ${}^{24}Mg$ is bombarded with neutrons, protons are ejected. Complete the equation and report the new element formed. **(JEE MAIN)**

Sol: ${}^{24}_{12}Mg + {}^{1}_{0}n \longrightarrow {}^{24}_{11}Na + {}^{1}_{1}H$

Illustration 29: Write a balanced equation for the following nuclear reaction

${}^{235}_{92}U$ bombarded with neutron to given ${}^{90}_{38}Sr$ and ${}^{143}_{54}Xe$ **(JEE ADVANCED)**

Sol: ${}^{235}_{92}U + {}^{1}_{0}n \longrightarrow {}^{90}_{38}Sr + {}^{143}_{54}Xe + 3{}^{1}_{0}n$

Illustration 30: What are X and Y in each of the reaction? **(JEE MAIN)**

(a) ${}^{99}_{42}Mo \longrightarrow {}^{99}_{43}Tc + X$; ${}^{99}_{43}Tc \longrightarrow {}^{99}_{44}Ru + Y$

(b) ${}^{14}_{7}N + {}^{4}_{2}He \longrightarrow {}^{17}_{8}O + X$ (c) ${}^{1}_{1}H + {}^{7}_{2}Li \longrightarrow 2X$ (d) $2\,{}^{2}_{1}D \longrightarrow {}^{3}_{2}He + X$

Sol: (a) ${}^{99}_{42}Mo \longrightarrow {}^{0}_{-1}e + {}^{99}_{43}TC$ ${}^{99}_{43}Tc \longrightarrow {}^{0}_{-1}e + {}^{99}_{44}Ru$

(b) ${}^{14}_{7}N + {}^{4}_{2}He \longrightarrow {}^{17}_{8}O + {}^{1}_{1}H$ (c) ${}^{1}_{1}H + {}^{7}_{3}Li \longrightarrow 2{}^{4}_{2}He$ (d) $2\,{}^{2}_{1}D \longrightarrow {}^{3}_{2}He + {}^{1}_{0}n$

10. APPLICATIONS OF RADIOACTIVITY AND RADIOISOTOPE

(a) Artificial transmutation: Many isotopes of elements which were either found in traces or not found in nature were made by nuclear reactions.

${}^{14}_{7}N + {}^{1}_{0}n \longrightarrow {}^{14}_{6}C + {}^{1}_{1}p$ (n, p) type; ${}^{1}_{1}H + {}^{1}_{0}n \longrightarrow {}^{2}_{1}H + \gamma$ (n, γ) type

${}^{27}_{13}Al + {}^{1}_{0}n \longrightarrow {}^{26}_{13}Al + 2{}^{1}_{0}n$ (n, 2n) type; ${}^{19}_{19}F + {}^{4}_{2}He \longrightarrow {}^{22}_{10}Ne + {}^{1}_{1}p$ (α, p) type

${}^{59}_{26}Fe + {}^{4}_{2}He \longrightarrow {}^{63}_{29}Cu + {}^{0}_{-1}e$ (α, β) type; ${}^{16}_{8}O + {}^{1}_{1}p \longrightarrow {}^{13}_{7}N + {}^{4}_{2}He$ (p, α) type

${}^{11}_{5}B + {}^{1}_{1}p \longrightarrow {}^{11}_{6}C + {}^{1}_{0}n$ (p, n) type; ${}^{12}_{6}C + {}^{1}_{1}p \longrightarrow {}^{13}_{7}N + \gamma$ (p, γ) type

${}^{9}_{4}Be + {}^{1}_{1}p \longrightarrow {}^{8}_{4}Be + {}^{2}_{1}H$ (p, D) type; ${}^{31}_{15}P + {}^{2}_{1}H \longrightarrow {}^{13}_{15}P + {}^{1}_{0}n$ (D, p) type

${}^{27}_{13}Al + \gamma \longrightarrow {}^{24}_{11}Na + 2{}^{1}_{1}p + {}^{1}_{0}n$

(b) Dating: The determination of the age of minerals and rocks, an important part of geological studies involves determination of either a species formed during a radioactive decay or the residual activity of an isotope which is undergoing decay. For example ${}^{238}_{92}U$ undergoes a decay ($t_{1/2}$ 4.5 × 10^9 yrs) series forming a stable isotope ${}^{206}_{82}Pb$ and

He. Helium obtained as a result of decay of $^{238}_{92}U$ has almost certainly been formed from α-particles. Thus, if ^{238}U and He contents are known in a rock we can determine the age of rock sample (1 g of ^{238}U in equilibrium with its decay products produces about 10^{-7} g He in a year). Also, by assuming that initially the rock does not contain ^{206}Pb and it is present in rock due to decay of ^{238}U, we can calculate the age of rocks and mineral by measuring the ratio of ^{238}U and ^{206}Pb. The amount of ^{206}Pb is supposed to be obtained by decay of ^{238}U Thus, $^{238}_{92}U \longrightarrow ^{206}_{82}Pb + 8^4_2He + 6^{\ 0}_{-1}e$

Mole of ^{238}U left = N at time t i.e. N_t ; Mole of ^{206}Pb formed = N′ at time t

∵ Initial mole of ^{238}U = N + N′ (at time 0) i.e., (N_0)

Thus, time t can be evaluated by $t = \frac{2.303}{\lambda}\log\frac{N_0}{N_t}$

Illustration 31: On analysis, a sample of uranium are was found to contain 0.277 g of $^{206}_{82}Pb$ and 1.667 g of $^{238}_{92}U$. The half-life period of ^{238}U is 4.51 × 10⁹ years. If all the lead were assumed to have come from decay of $^{238}_{92}U$, what is the age of earth? **(JEE ADVANCED)**

Sol: Given, at time t; $^{238}_{92}U$ = 1.667 g = (1.667/238) mole ; $^{206}_{82}Pb$ =0.277 g = (0.277/206) mole

Since, all lead has been formed from ^{238}U, therefore moles of U decayed = Moles of Pb formed = (0.277 / 206)

∴ Total moles of U before decay (N_0) = Moles of U at time t (N) + Moles of U decayed

$= \frac{1.667}{238} \times \frac{0.277}{206}$ $\because t = \frac{2.303}{\lambda}\log\frac{N_0}{N} = \frac{2.303\times4.51\times10^9}{0.693}\log\frac{(1.667/238)+(0.277/206)}{(1.667/238)}$ ∴ $t = 1.147\times10^9$ years

Illustration 32: The activity of the hair of an Egyptian mummy is 7 disintegrations minute^{-1} of ^{14}C. Find the age of the mummy, given $t_{0.5}$ of ^{14}C is 5770 years and disintegration ratio of fresh sample of ^{14}C is 14 disintegration minute^{-1} **(JEE MAIN)**

Sol: r_0 = 14 dpm and r_1 = 7 dpm $\therefore \frac{r_0}{r} = \frac{14}{7} = 2 = \frac{N_0}{N}$ $(\because r_0 \propto N_0)$

$$t = \frac{2.303}{\lambda}\log\frac{N_0}{N} = \frac{2.303\times5770}{0.693}\log 2 = 5771 \text{ year}$$

Illustration 33: The half period of ^{14}C is 5760 years. A piece of wood when buried in the earth had 1% ^{14}C. Now as charcoal it has only 0.25% ^{14}C. How long has the piece of wood been buried? **(JEE MAIN)**

Sol: Given, $N_{0_{^{14}C}}$ = 1% ; $N_{^{14}C}$ = 0.25% and $t_{1/2}$ = 5760 year

$$t = \frac{2.303}{\lambda}\log\frac{N_0}{N} = \frac{2.303\times5760}{0.693}\log\frac{1}{0.25} = 11524 \text{ year}$$

PROBLEM SOLVING TACTICS

Nuclear radius (r)= $R_0A^{1/3}$, where A= Mass no. , = 1.4×10^{-15}m

For calculation of geological dating :

(i) Calculation λ from $t_{1/2}, \lambda = \frac{0.693}{t_{1/2}}$

(ii) Calculate uranium converted into lead

(iii) Calculate total initial amount of uranium initially present

(iv) Apply , $t = \frac{2.3030}{\lambda}\log\frac{N_0}{N}$

For calculation in carbon dating method

(i) Calculated from $t_{1/2}$

(ii) m% activity of C-14 now present means $\frac{N_0}{N} = \frac{m}{100}$

(iii) Apply, $\lambda = \frac{2.3030}{t}\log\frac{N_0}{N}$

POINTS TO REMEMBER

Kinetics of Radioactive Disintegration: All radioactive isotopes decays spontaneously following first order kinetics, i.e, rate of decay (-dN/dt) is directly proportional to the amount of radioactive isotope (N).	$-\frac{dN}{dt} \propto N \Rightarrow -\frac{dN}{dt}\lambda N$ Where, 'λ' is decay constant. Integrating the above rate law gives $\lambda t = \text{In}\left(\frac{N_0}{N}\right)$; N_0= Initial number of nuclides N= Number of nuclides remaining after time t. Also $N=N_0e^{-\lambda t}$.
Half-life $(t_{1/2})$: Time in which half of the nuclides are decayed	$t_{1/2} = \frac{1}{\lambda}\text{In}\left(\frac{N_0}{N_0/2}\right) = \frac{\text{In}2}{\lambda}$
Activity (A) It is the instantaneous rate of decay.	$A = -\frac{dN}{dt} = \lambda N \Rightarrow$ Initial activity $(A_0) = \lambda N_0$ Also $A = A_0e^{-\lambda t}$
Units of Radioactivity: Curie (Ci) and Rutherford (Rd) Gray (Gy): 1Gy = 1 kg tissue receiving 1 J energy. If w0 gram of a radioisotope decay for 'n' half-lives, the amount of radio-isotope remaining undecayed (w) is given by the expression. It is a derived unit of ionizing radiation.	$1Ci=3.7 \times 10^{10}$ dps $1Rd = 10^6$ dps $w = w_0\left(\frac{1}{2}\right)$

Total Binding Energy (BE) : It is the total energy released when a nucleus is formed from nucleons. BE is determined from mass defect (Δm) as BE = $(\Delta m)C^2$

$\Delta m=\Sigma$(Mass of nucleons – Mass of nucleus) (Δm = 1u correspond to BE=931 MeV)

Unstable nuclei decay by spontaneous emission of radioactive rays. Stability of a nucleus is accounted qualitatively by its N/P ratio (N=Number of neutrons and P=number of protons).

Up to Z=20, for stable nuclei, N/P=1 is required.

Above Z=20, more neutrons are required to shield the strong electrostatic repulsion between large number of like charged protons in a small nuclear volume, hence N/P> 1 is required for stability in case unstable nuclei, if N/P ratio is greater than that required for stability, β–emission takes place, eg,

$_7N^{16} \rightarrow _8O^{16} + \beta\left(_{-1}e^0\right)$

If N/P ratio is less than that required for stability, radio nuclide may decay by one of the following modes:

(i) Positron emission $_5B^8 \rightarrow _4Be^8 + _{+1}\beta^0\left(\text{Positron} + _{+1}e^0\right)$

(ii) Electron capture $_{20}Ca^{38} + _{-1}e^0 \rightarrow _{19}K^{38}$

Alpha (α) emission occurs when Z>82.

Solved Examples

JEE Main/Boards

Example 1: 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.

Sol: Comparative rates are given, as we know rate of disintegration is proportional to no.of atoms substitute the value of N and N_0 in the rate equation and calculate integration constant. From integration constant it is easy to calculate half-life of the sample.

r_0 = 4750 dpm, r_t = 2700 dpm

$\therefore \frac{r_0}{r_t} = \frac{N_0}{N_t} = \frac{4750}{2700}$; $\lambda = \frac{2.303}{t}\log\frac{N_0}{N}$

$\therefore \lambda = \frac{2.303}{5}\log\frac{4750}{2700}$ = 0.113 min–1

$\therefore t_{1/2} = \frac{0.693}{\lambda} = \frac{0.693}{0.113}$ = 6.13 min

Example 2: It is known that 1 g of ^{226}Ra emits 11.6 × 10^{17} atoms of α per year. Given the half-life of ^{226}Ra be 1600 year. Compute the value of Avogadro's no.

Sol: ∵ Rate = λN_0(No. of atoms in 1 g Ra) = (Av. No./226)

$\therefore 11.6\times10^{17} = \frac{0.693}{1600}\times\frac{\text{Avogadro Number}}{226}$

∴ Avogadro No. = 6.052 × 10^{23}

Example 3: Half-life of an element is t second. Calculate the percentage left undecayed in t/2 sec.

Sol: $\frac{t}{2} = \frac{2.303\times t}{0.693}\times\log\frac{N_0}{N}$

$\therefore \frac{N_0}{N}$ = 1.414 or N = 0.707 × N_0 or 70.7%

Example 4: At a certain instant, a piece of radioactive material contains 10^{12} atoms. The half-life of material is 30 days. Calculate the number of disintegration in the first second.

Sol: The disintegration number of atoms in first second means the initial rate of decay.

i.e., Rate = –(dN / dt) = λN_0

Where N_0 is initial number of atoms.

Given, $N_0=10^{12}$atoms and $t_{1/2}$ = 30 × 24 × 60 × 60 sec

∵ Rate = $0.693\times10^{12}/(30\times24\times60\times60) = 2.674\times10^5$ disintegration per second.

Example 5: At radioactive equilibrium, the ratio between two atoms of radioactive elements A and B are 3.1 × 10^9: 1. If half-life period of A is 2 × 10^{10} years, what is half-life of B?

Sol: Use the relation between no. of atoms, integration constant and half-life.

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

At radioactive equilibrium; A → B

$\frac{N_A}{N_B} = \frac{\lambda_B}{\lambda_A} = \frac{t_{1/2A}}{t_{1/2B}}$ $\therefore \frac{3.1\times10^9}{1} = \frac{2\times10^{10}}{t_{1/2B}}$

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

Example 6: Write equations for the following transformation:

(a) ${}^{14}_{7}N(n,p)$ (b) ${}^{39}_{19}K(n,\alpha)$

Sol: (a) ${}^{14}_{7}N + {}^{1}_{0}n \longrightarrow {}^{14}_{6}C + {}^{1}_{1}H$

(b) ${}^{39}_{19}K + {}^{1}_{0}n \longrightarrow {}^{36}_{17}Cl + {}^{4}_{2}He$

Example 7: Write equations for:

(a) Position emission by ${}^{18}_{9}F$

(b) β-emission by ${}^{35}_{16}S$

(c) α-emission by ${}^{235}_{92}U$

(d) Nuclear fusion

(e) Gamma rays emission from ${}^{13}_{7}N$

(f) β^+ -emission by ${}^{22}_{11}Na$

Sol: (a) ${}^{18}_{9}F \longrightarrow {}^{18}_{8}O + {}^{0}_{+1}e$

(b) ${}^{35}_{16}S \longrightarrow {}^{35}_{17}Cl + {}^{0}_{-1}e$

(c) ${}^{235}_{92}U \longrightarrow {}^{231}_{90}Th + {}^{4}_{2}He$

(d) ${}^{2}_{1}H + {}^{3}_{1}H \longrightarrow {}^{4}_{2}He + {}^{1}_{0}n + 17.6\,MeV$

(e) ${}^{13}_{7}N \longrightarrow {}^{13}_{7}N + \gamma$

(f) ${}^{22}_{11}Na \longrightarrow {}^{22}_{10}Ne + {}^{0}_{+1}e$

Example 8: One g of ${}^{198}_{79}Au$ ($t_{1/2}$ = 65 hrs) decays by β-emission to produced stable Hg.

(i) Write the nuclear reaction for process

(ii) How much Hg will be present after 260 hrs?

Sol: (i) The nuclear reaction is $^{198}_{79}Au \longrightarrow ^{198}_{80}Hg + ^{0}_{-1}e$
(ii) Given, $t_{1/2}$ = 65 hour;

T = 260 hour and amount of Au = 1 g

$\therefore$ T = $t_{1/2}$ × n $\therefore$ n = 260/65 = 4

Therefore, amount left undecayed = $N_0/2^4$ = $1/2^4$ = (1/16) g

$\therefore$ Amount of Au decayed = [1 – (1/16)] = (15/16) g

$\therefore$ 198 g Au on decay gives 198 g Hg

$\therefore \frac{15}{16}$ g Au on decay gives $\frac{198\times15}{16\times198}=\frac{15}{16}$gHg

Example 9: One of the hazards of nuclear explosion is the generation of ^{90}Sr and its subsequent incorporation in bones. This nuclide has a half-life of 28.1 years. Suppose one microgram was absorbed by a new-born child, how much ^{90}Sr will remain in his bones after 20 year?

Sol: Here we are provided with half-life period and initial amount of the sample.

By substituting the value in equation of radioactive decay amount of sample present at that time can be calculated.

Given $t_{1/2}$ = 28.1 year; N_0 = 10^{-6} g

t = 20 year; N =? Qt = $\frac{2.303}{\lambda}\log\frac{N_0}{N}$

$\therefore$ 20 = $\frac{2.303\times28.1}{0.693}\log\frac{10^{-6}}{N}$ $\therefore$ N= 6.1 × 10^{-7} g

Example 10: 54.5 mg Na_3PO_4 contains ^{32}P (15.6%) and ^{31}P atoms. Assuming only ^{32}P atoms are radioactive, calculate the rate of decay for the given sample of Na_3PO_4. The half-life period for ^{32}P = 14.3 days; mol. wt. of Na_3PO_4 = 161.2.

Sol: First find out mole of ^{32}P preset in the given sample of Na_3PO_4 from mole calculate no of atoms present

(no. of atom present = mole x Avogadro no)

And then by using rate and integration constant relationship calculate the rate.

Mole of Na_3PO_4 = $\frac{54.5\times10^{-3}}{161.2}$

Mole of P-atoms = $\frac{54.5\times10^{-3}}{161.2}$

$\therefore$ Mole of ^{32}P atoms = $\frac{54.5\times10^{-3}}{161.2}\times\frac{15.6}{100}$ = 5.27×10^{-5}

$\therefore$ Atom of ^{32}P = 5.27 × 10^{-5} ×6.023 × 10^{23}

Now, Rate=λ.

N = $\frac{0.693}{14.3\times24\times60\times60}$ ×5.27×10^{-5}× 6.023 × 10^{23}

Rate = 1.78 × 10^{13} dps.

JEE Advanced/Boards

Example 1: A sample of radioactive substance shows an intensity of 2.3 millicurie at a time t and an intensity of 1.62 millicurie 600 seconds later. What is half-life and average life of radioactive material?

Sol: In order to find out the half-life and average life of radioactive material we have to first calculate integration constant using equation for radioactive decay.

r_1 = 2.3 × 10^{-3} curie, when t = t_1

r_2 = 1.62 × 10^{-3} curie, when t = (600 + t_1) sec

$\frac{r_1}{r_2}=\frac{2.3\times10^{-3}}{1.62\times10^{-3}}=\frac{N_1}{N_2}$

Now, λ = $\frac{2.303}{t}\log\frac{N_1}{N_2}=\frac{2.303}{600}\log\frac{2.3}{1.62}$ =5.84×10^{-4} sec^{-1}

$\therefore$ $t_{1/2}$ = $\frac{0.693}{\lambda}=\frac{0.693}{5.84\times10^{-4}}$ = 1186.15 second

Also, τ = $\frac{1}{\lambda}$ = $\frac{1}{5.84\times10^{-4}}$ =1712.33 second

Example 2: How much energy would be evolved per hour from 1 curie of ^{14}C source if all the energy of beta decay were imprisoned? Atomic masses of ^{14}C and ^{14}N are 14.00324 and 14.00307 amu respectively.

Sol: Using the relation for binding energy and mass defect calculate the energy term. And the calculated value of binding energy calculate energy would be evolved per hour from 1 curie of ^{14}C source

$^{14}_{6}C \longrightarrow ^{14}_{7}N + ^{0}_{-1}e$

Δm = 14.00324– 14.00307 = 0.00017 amu

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

= Δm × 931.478 MeV = 0.00017 × 931.478 MeV

= 0.158 MeV = 0.158 × 10^6 eV

= 0.158 × 10^6 × 1.602 × 10^{-19}J = 2.54 × 10^{-14}J

Now 1 curie of ^{14}C means decay of 3.70 × 10^{10} dps. Thus, energy produced during decay of 1 curie mass of ^{14}C

= 3.70 × 10^{10} × 2.53 × 10^{-14} Js^{-1} = 9.36 × 10^{-4} J

$\therefore$ Energy produced in 1 hr = 9.36 ×10^{-4} × 60×60 = 3.37 J

Example 3: What amount of energy is evolved by a curie of Rn (an α-emitter) (a) in one hour (b) its mean life? Given KE of one α-particles is 5.5 MeV and $\lambda = 2 \times 10^{-6}$ sec^{-1}

Sol: For Rn: Rate = λN_0 ($\because$Rn=1 curie; Rate = 3.7×10^{10} dps)

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

$\therefore N_0$ i.e., Number of atom of Rn at t = 0

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

(a) Let amount of Rn left after 1 hr be N

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

$60 \times 60 = \frac{2.303}{2\times10^{-6}}\log\frac{1.85\times10^{16}}{N}$

$\therefore N = 1.837 \times 10^{16}$

Thus, number of α formed = Number of Rn decayed (Rn is an α-emitter)

$= N_0 - N = (1.85 \times 10^{16}) - (1.837\times10^{16}) = 0.013 \times 10^{16}$

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

$= 0.013 \times 10^{16} \times 5.5 \times 10^{6}$ eV

$= 0.013 \times 10^{22} \times 5.5 \times 1.602 \times 10^{-19}$ J = 114.5 J

(b) Let amount of Rn left after t = ($1/\lambda$) is N, then

$\frac{1}{\lambda} = \frac{2.303}{\lambda}\log\frac{1.85\times10^{16}}{N}$

$N = 0.6806 \times 10^{16}$

Again number of α formed = $N_0 - N$

$= 1.85 \times 10^{16} - 0.6806 \times 10^{16} = 1.1694 \times 10^{16}$

$\therefore$ Energy released $= 1.1694\times10^{16}\times5.5\times10^{6}\times1.602\times10^{-19}$J

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

Example 4: Complete the following nuclear reactions:

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

(b) $2\,{}^{3}_{1}H \longrightarrow {}^{4}_{2}He + ...$

(c) ${}^{53}_{29}Cu \longrightarrow {}^{53}_{28}Ni + ...$

(d) ${}^{235}_{92}U + {}^{1}_{0}n \longrightarrow {}^{95}_{37}Rb + ... + 3\,{}^{1}_{0}n$

Sol: (a) ${}^{1}_{1}H$ (b) $2\,{}^{1}_{0}n$ (c) ${}^{0}_{+1}e$ (d) ${}^{138}_{55}Cs$

Example 5: The isotopic masses of ${}^{2}_{1}H$ and ${}^{4}_{2}He$ are 2.0141 and 4.0026 amu respectively. Calculate the quantity of energy liberated when two moles of ${}^{2}_{1}H$ undergo fission to form1 mole of ${}^{4}_{2}He$. The velocity of light in vacuum is 2.998×10^{8} m/sec.

Sol: Fusion reaction is $2\,{}^{2}_{1}H \longrightarrow {}^{4}_{2}He + \text{energy}$

Mass defect = 2 × Mass of ${}^{2}_{1}H$ – Mass of ${}^{4}_{2}He$

= 2 × 2.0141 – 4.0026 = 0.0256 amu

$\therefore$ Energy liberated during fusion of 2 atoms of ${}^{2}_{1}H = \Delta mc^2$

$= 0.0256\times1.66\times10^{-27}\times(2.998\times10^{8})^2$ J $= 3.8 \times 10^{-12}$ J

Energy liberated during fusion of 2 N atoms of ${}^{2}_{1}H$ to give N atoms (or 1 mole ${}^{4}_{2}He$) $= 3.8 \times 10^{-12} \times 6.023 \times 10^{23}$

$= 2.3 \times 10^{12}$ J

Example 6: The radioactive disintegration of ${}^{239}_{94}Pu$ and α-emission process is accompanied by the loss of 5.24 MeV/dis. If $t_{1/2}$ of ${}^{239}_{94}Pu$ is 2.44×10^{4} years, calculate the energy released per year from 1.0 g sample of ${}^{239}_{94}Pu$ in kJ.

Sol: First calculate the rate of disintegration and by multiplying it with energy lost during α emission will give us the value of energy released per year from 1.0 g sample of ${}^{239}_{94}Pu$ in kJ.

Rate = $\lambda N = \frac{0.693\times6.023\times10^{23}}{2.44\times10^{4}\times239} = 7.157 \times 10^{16}$ dis/year

$\therefore$ Loss in energy per year $= 5.24 \times 7.157 \times 10^{16}$ MeV

$= 5.24 \times 7.157 \times 10^{16} \times 10^{6}$ eV

$= 5.24\times7.157\times10^{16}\times10^{6}\times1.602\times10^{-19}\times10^{-3}$ kJ = 60.08 kJ

Example 7: A certain radioisotope ${}^{A}_{Z}X$ ($t_{1/2}$=10 day) decays to give ${}^{A-4}_{Z-2}Y$. If one g-atom ${}^{A}_{Z}X$ is kept in a sealed vessel, how much He will accumulate in 20 day at STP?

Sol: The nuclear reaction is ${}^{A}_{Z}X \longrightarrow {}^{A-4}_{Z-2}Y + {}^{4}_{2}He$

Given, $t_{1/2}$ = 10 day; T = 20 day;

N_0 = 1 g-atoms $\therefore$ n = 2 ($\because n = T/t_{1/2}$)

$\therefore$ Amount left in 2 halves $= 1/2^2 = \frac{1}{4}$ g-atom

$\therefore$ Amount of X decayed in 2 halved $= \left(1-\frac{1}{4}\right) = \frac{3}{4}$

g-atom or Amount of He formed$=\frac{3}{4}$ g-atom

(Since, 1 g-atom of X gives 1 g-atom of He)

$\therefore$ Volume of He formed = $\frac{3}{4}\times 22400$ = 16800 mL at STP

Example 8: A radioactive isotope ${}^{m}_{Z}A$ ($t_{1/2}$ = 10 day) decays to give ${}^{m-12}_{Z-6}B$ 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?

Sol: The nuclear reaction is ${}^{m}_{Z}A \longrightarrow {}^{m-12}_{Z-6}B + 3\,{}^{4}_{2}He$

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

N_0 = mg = 1 g-atom $\therefore$ n = 2 ($\because$ n = T/$t_{1/2}$)

$\therefore$ Amount left in 2 halves$=(1/2)^2 = \frac{1}{4}$ g-atom

$\therefore$ Amount of A decayed in 2 halves

$= \left(1-\frac{1}{4}\right) = \frac{3}{4}$ g-atom

$\because$ 1 g-atom of A gives 3 moles of He at STP

$\therefore$ $\frac{3}{4}$ g-atom of A give $3\times\frac{3}{4}$

moles of He at STP = (9/4) moles of He at STP

$\therefore$ Volume of He at STP = (9/4) × 22.4 litre = 50.4 litre at STP

Example 9: The rate of decay of a radioactive sample is 3.02×10^6 dpm at time 10 mins and 1.20×10^6 dpm at a time 20 mins. Evaluate the decay constant, half-life and average life of sample.

Sol: $r_1 = \lambda.N_1$, $r_2 = \lambda.N_2$

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

$$\text{Also, } 10 = \frac{2.303}{\lambda}\log\frac{N_0}{N_1} \quad 20 = \frac{2.303}{\lambda}\log\frac{N_0}{N_2}$$

By eqs. (ii) – (i)

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

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

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

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

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

Example 10: Two radioactive nuclides P and Q have their decay constant in the ratio 3: 2. One mole of each is taken separately and allowed to decay, for a time interval of three times of the half-life of A. If 0.2 mole of P are left, what moles of Q will be left?

Sol: Let decay constant λ_P and λ_Q be 3a and 2a respectively.

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

At T = 3 × $t_{1/2}$ of;

$$P = \frac{3\times0.693}{3a} = \frac{0.693}{a}$$

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

$$\text{For P: } \frac{0.693}{a} = \frac{2.303}{2a}\log\frac{1}{n_P}$$

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

$$= \frac{\log\frac{1}{n_P}}{\log\frac{1}{n_Q}} = \frac{3}{2} \quad \text{Or} \quad \log\frac{1}{n_P} = \frac{3}{2}\log\frac{1}{n_Q}$$

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

Or $n_P = (n_Q)^{2/3}$ if n_P = 0.2, then n_Q = 0.09

JEE Main/Boards

Exercise 1

Q.1 One mole of A present in a closed vessel undergoes decay as: ${}^{m}_{Z}A \longrightarrow {}^{m-8}_{Z-2}B + 2\left({}^{4}_{2}He\right)$ What will be the volume of helium gas collected at STP after 20 days ($t_{1/2}$ of A = 10 days)?

Q.2 ${}^{131}I$ has half-life period 13.3 hours, after 79.8 hours, what fraction of ${}^{131}I$ will remain?

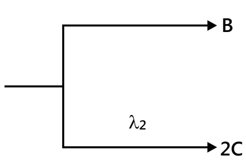
Q.3 With what velocity should an α-particle travel towards the nucleus of a copper atom so as to arrive at a distance of 10^{-13}meters from the nucleus of the copper atom?

Q.4 A radioactive isotope ${}^{m}_{Z}A$ ($t_{1/2}$ = 10 day) decays to give ${}^{m-12}_{Z-6}B$ 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 days at STP?

Q.5 A solution contains 1 millicurie of L-phenyl alanine ${}^{14}C$ (uniformly labelled) in 2.0 mL solution. The specific activity of labeled sample is given as 150 millicurie/milli-mol. Calculate: (A) the concentration of the sample in the solution in mol/litre.
(B) The activity of the solution in terms of counting per minute/mL at a counting efficiency of 80%.

Q.6 ${}^{40}_{19}K$ consists of 0.012% of the potassium in nature. The human body contains 0.35% potassium by weight. Calculate the total radioactivity resulting from ${}^{40}_{19}K$ decay in a 75 kg human. Half-life for ${}^{40}_{19}K$ is 1.3 × 10^{9} year.

Q.7 A follows a parallel path I order reaction giving B and C. If the initial concentration of A is 0.25 M, calculate the concentration of C after 5 hours of reaction.



[Given: λ_1 = 1.5 × 10^{-5} s^{-1}, λ_2 =5× 10^{-6} s^{-1}]

Q.8 Calculate the energy associated with the following nuclear reaction:

$${}^{27}_{13}Al \quad + \quad {}^{2}_{1}H \quad \longrightarrow \quad {}^{25}_{12}Mg \quad + \quad {}^{4}_{2}He$$

26.9815amu 2.0141amu 24.9858 amu 4.0026 amu

Q.9 On analysis, a sample of uranium 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} yrs. If all the lead were assumed to have come from decay of ${}_{92}U^{238}$, what is the age of the earth?

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

Exercise 2

Single Correct Choice Type

Q.1 Atoms ${}_{7}X^{A}$, ${}_{8}Y^{B}$ and ${}_{9}Z^{17}$ are such that ${}_{8}Y$ is an isobar of ${}_{7}X$ and atom ${}_{9}Z^{17}$ is isotone of ${}_{8}Y$. Mass no. of X and no. of neutrons in Y are respectively as follows:

(A) 8, 8 (B) 17, 7 (C) 9, 8 (D) 16, 8

Q.2 The number of neutrons accompanying in the formation of ${}_{54}X^{139}$ and ${}_{38}Sr^{194}$ by the absorption of slow neutron by ${}_{92}U^{235}$ followed by nuclear fission is:

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

Q.3 The activity of a radioactive nuclide (X^{100}) is 6.023 curie at a certain time 't'. If its disintegration constant is 3.7 × 10^{4} s^{-1} the mass of X after t sec is:

(A) 6.022×10^{6} g (B) 10^{-13} g

(C) 10^{-15} g (D) 10^{-17} g

Q.4 The half-life of ${}_{6}C^{14}$ is 5730 years. What fraction of its original C^{14} would be left after 22920 years of storage?

(A) 0.50 (B) 0.25 (C) 0.125 (D) 0.0625

Q.5 A radioactive sample had an initial activity of 56 dpm. After 69.3 minutes, it was found to have an activity of 28 dpm. Find the number of atoms in a sample having an activity of 100 dpm.

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

Q.6 A sample of radioactive substance is found 90% of its initial amount after one day. What % of the original sample can be found after 3 days?

(A) 81 (B) 72.9 (C) 25 (D) 65.61

Q.7 The present activity of the hair of Egyptian mummy is 1.75 dpm. $t_{1/2}$ of $_6C^{14}$ is 5770 years and disintegration rate of fresh sample of C^{14} is 14 dpm. Find out the age of the mummy,

(A) 23080 years (B) 138480 years

(C) 11998.3 years (D) 17313.6 years

Q.8 20% of the initial weight of a radioactive element undergoing decay is left after certain period of time r. How many such periods should elapse from the start for 50% of the element to be left over?

(A) 3 (B) 4 (C) 5 (D) None

Q.9 The half-life of Tc^{99} is 6.0 hrs. The total residual activity in a patient 30 hrs after receiving an injection containing Tc^{99} must be more than 0.01 μC_i, What is the maximum activity (in μC_i) that the sample injected can have?

(A) 0.16 (B) 0.32 (C) 0.64 (D) 0.08

Q.10 A pure radio-chemical preparation was observed to disintegrate at the rate of 2140 counts/minutes at 12.35 P.M. At 3.55 P.M. of the same day, the disintegration rate of the sample was only 535 count/minutes. What is the half-life of the material?

(A) 50 min (B) 100 min (C) 200 min (D) None

Q.11 A radioactive substance decays 25% in 10 minutes. If at start there are 4×10^{20} atoms present, after what time will the number of atoms be reduced to 10^{20} atoms?

(A) 10.98 min (B) 21.97 min (C) 48.19 min (D) None

Q.12 The time of decay for a nuclear reaction is given by $t = 4t_{1/2}$. The relation between the mean life (T) and time of decay (t) is given by:

(A) 2 Tln 2 (B) 4Tln 2 (C) $2T^4$ln 2 (D) $\frac{1}{T_2}\ln 2$

Q.13 Two radio isotopes A and B of atomic weight X and Y are mixed in equal amount by weight. After 20 days, their weight ratio is found to be 4: 1. Isotope A has a half-life of 1 day. The half-life of isotope B is:

(A) $1.11\,\frac{y}{x}$ day (B) $0.11\,\frac{y}{x}$ day

(C) 0.6237 day (D) 1.11 day

Q.14 Two radioactive nuclides A and B have half-lives 50 mins and 10 mins respectively. A fresh sample contains the nuclide of B to be eight times that of A. How much time should elapse so that the number of nuclides of A becomes double of B?

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

Q.15 A radioactive nuclide is produced at a constant rate of α per second. Its decay constant is λ If N_0 is the no. of nuclei at time t = 0, then max. number of nuclei possible are:

(A) N_0 (B) α/λ (C) $N_0 + \frac{\alpha}{\lambda}$ (D) $\frac{\lambda}{\sigma} + N_0 s$

Q.16 An analysis of the rock shows that the relative number of Sr^{87} and Rb^{87} ($t_{1/2} = 4.7 \times 10^{10}$years) atoms is 0.05. What is the age of the rock? Assume all Sr^{87} to be formed from Rb^{87} only,

(A) 7.62×10^9 year (B) 1.43×10^9 year

(C) 3.28×10^9 year (D) 4.32×10^8 year

Q.17 There are two radio nuclei A and B. A is a α-emitter and B is β-emitter, their disintegration constants are in the ratio of 1: 2. What should be the number of atoms of two at time t = 0, so that probability of getting α and β-particles are same at time t = 0

(A) 2: 1 (B) 4: 1 (C) 1: 2 (D) 1: 4

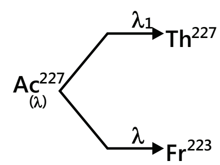
Q.18 A radioactive substance (parent) decays to its daughter element, the age of the radioactive substance (t) is related to the daughter (D)/parent (p) ratio by the equation:

(A) $t = \frac{1}{\lambda}\ln\left(1+\frac{p}{d}\right)$ (B) $t = \frac{1}{\lambda}\ln\left(1+\frac{d}{p}\right)$

(C) $t = \frac{1}{\lambda}\ln\left(\frac{d}{p}\right)$ (D) $t = \frac{1}{\lambda}\ln\left(\frac{p}{d}\right)$

Q.19 C^{227} has a half-life of 22 years.

The decay follows two parallel paths: What are the decay constants (λ) for Th and Fr respectively?



(A) 0.03087, 0.00063 (B) 0.00063, 0.03087

(C) 0.02, 0.98 (D) None of these

Q.20 $_{84}Po^{218}$ ($t_{1/2}$ =183 secs) decay to $_{82}Pb$ ($t_{1/2}$ = 161 secs) by α-emission, while Pb^{214} is an a β-emitter. In an experiment starting with 1 mole of pure Po^{218}, how much time would be required for the number of nuclei of $_{82}Pb^{214}$ to reach maximum?

(A) 147.5 (B) 247.5 (C) 182 (D) 304

Previous Years' Questions

Q.1 The radionuclide $^{234}_{90}Th$ undergoes two successive β decays followed by one α-decay. The atomic number and the mass number respectively of the resulting radionuclide are ***(2003)***

(A) 92 & 234 (B) 94 & 230 (C) 90 & 230 (D) 92 & 230

Q.2 A photon of hard gamma radiation knocks a proton out of $^{24}_{12}Mg$ nucleus to form ***(2005)***

(A) The isotope of parent nucleus

(B) The isobar of parent nucleus

(C) The nuclide $^{23}_{11}Na$

(D) The isobar of $^{23}_{11}Na$

Q.3 The reaction which disintegrates neutrons or neutron is emitted (which completes first) ***(2005)***

(A) ${}_{96}Am^{240} + {}_{2}He^{4} \rightarrow {}_{97}Bk^{244} + {}_{+1}e^{0}$ (B) ${}_{15}P^{30} \rightarrow {}_{14}Si^{30} + {}_{1}e^{0}$

(C) ${}_{6}C^{12} + {}_{1}H^{1} \rightarrow {}_{7}N^{13}$ (D) ${}_{13}Al^{27} + {}_{2}He^{4} \rightarrow {}_{15}P^{30}$

Q.4 Consider the following nuclear reactions.

$^{238}_{92}M \longrightarrow {}^{x}_{y}N + 2\,{}^{4}_{2}He;\ {}^{x}_{y}N \rightarrow {}^{A}_{B}L + 2\beta^{+}$

The number of neutrons in the element L is ***(2004)***

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

Q.5 β-particle is emitted in radioactivity by ***(2004)***

(A) Conversion of proton to neutron

(B) From outermost orbit

(C) Conversion of neutron to proton

(D) α-particle is not emitted

Q.6 A freshly prepared radioactive source of half-life 2 hours emits radiations of intensity which is 64 times the permissible safe level. The minimum time after which it would be possible to work safely with this source is ***(1988)***

(A) 6 hours (B) 12 hours (C) 24 hours (D) 128 hours

Q.7 The half-life period of a radioactive element is 140 days. After 560 days, one gram of the element will reduce to ***(1999)***

(A) 1/2 g (B) 1/4 g (C) 1/8 g (D) 1/16 g

Q.8 Disintegration constant for a radioactive substance is 0.58 hr^{-1}. Its half-life period is ***(2004)***

(A) 8.2 hr (B) 5.2 hr (C) 1.2 hr (D) 2.4 hr

Q.9 Radium has atomic weight 226 and a half-life of 1600 years. The number of disintegrations produced per second from 1 g are: ***(1990)***

(A) 4.8×10^{10} (B) 9.2×10^{6} (C) 3.7×10^{10} (D) Zero

Q.10. The half-life of a radioisotope is four hours. If the initial mass of the isotope was 200 g, the mass remaining after 24 hours undecayed is ***(2004)***

(A) 3.125 g (B) 2.084 g (C) 1.042 g (D) 4.167 g

Q.11 In the transformation of $^{238}_{92}U$ to $^{234}_{92}U$, if one emission is an α-particle, what should be the other emission(s) ***(2006)***

(A) Two β^{-} (B) Two β^{-} and one β^{+}

(C) One β^{-} and one γ (D) One β^{+} and one β^{-}

Q.12 Carbon-14 dating method is based on the fact that ***(1997)***

(A) Carbon-14 fraction is the same in all objects

(B) Carbon-14 is highly insoluble

(C) Ratio of carbon-14 and carbon-12 is constant

(D) All of these

Q.13 Which of the following nuclear reactions will generate an isotope ***(2007)***

(A) Neutron particle emission (B) Positron emission

(C) α-particle emission (D) β-particle emission

Q.14 The half-life of a radioactive isotope is three hours. If the initial mass of the isotope were 256 g, the mass of it remaining undecayed after 18 hours would be ***(2003)***

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

JEE Advanced/Boards

Exercise 1

Q.1 α-particle accelerated by 3×10^5 volt bombarded a boron target. This resulted in the nuclear reaction. ${}_2^4He + {}_5^{10}B \longrightarrow {}_6^{13}C + {}_1^1H + \gamma$

If the combined energy of ^{13}C and ^1H is 5×10^5 eV, calculate energy, frequency and g of g-rays. 1×10^5 eV energy is used in penetration of the nucleus. Given H = 1.008 amu.He = 4.0026 amu, B = 10.0129 amu, C =13.0036 amu and 1 amu = 931 MeV.

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

Q.3 The rate of decay of a radioactive sample is 3.02 $\times 10^6$ dpm at time 10 mins and 1.20×10^6 dpm at a time 20 mins. Evaluate the decay constant, half-life and average life of the sample.

Q.4 A solution contains a mixture of isotopes of ${}_XA_1$($t_{1/2}$ = 14 day) and ${}_XA_2$ ($t_{1/2}$ =25 day). The total activity is 1 curie at t = 0. The activity reduces by 50% in 20 days. Find:

(A) The initial activities of ${}_XA_1$ and ${}_XA_2$

(B) The ratio of their initial no. of nuclei.

Q.5 For the following sequential reaction

$A \xrightarrow{\lambda_1} B \xrightarrow{\lambda_2} C$,

find out the concentration of C at time t = 1 day, given the λ_1, $=1.8 \times 10^{-5}\ s^{-1}$ and $\lambda_2 = 1.1 \times 10^{-2}\ s^{-1}$and initial molar concentration of A is 1.8 M.

Q.6 A radioactive isotope decays as

${}_Z^mA \longrightarrow {}_{Z-2}^{m-4}B \longrightarrow {}_{Z-1}^{m-4}C$

The half-lives of A and B are 10 months and 6 months respectively. Assuming that initially only A was present, will it be possible to achieve radioactive equilibrium for B. If so what would be the ratios of A and B at equilibrium? What would happen if the half-lives of A and B were 6 months and 10 months respectively?

Q.7 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 $1.52 \times 10^{-10}\ yr^{-1}$, how old could be the pitch blende deposits?

Q.8 A sample contains two radioactive nuclei x and y with half-lives 2 hours and 1 hour respectively. The nucleus x-decays to y and y-decays into a stable nucleus z. At t = 0 the activities of the components in the same were equal. Find the ratio of the number of the active nuclei of y at t = 4 hours to the number at t = 0.

Q.9 ^{64}Cu (half-life-12.8 hrs) 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.

Q.10 Tritium ${}_1^3T$ (an isotope of H) combines with fluorine to form a weak acid TF which ionizes to give T^+. Tritium is radioactive and is a β-emitter. A freshly prepared dilute aqueous solution of TF has a pT (equivalent of pH) of 1.7 and freezes at –0.372°C. If 600 mL of freshly prepared solution were allowed to stand for 24.8 years, calculate:

(i) Ionization constant of TF.

(ii) Charge carried by β-particles

Emitted by tritium in Faraday.

[Given: K_f for H_2O= 1.86,$t_{1/2}$ (T) = 12.4 yrs.]

Q.11 The half-life of ^{212}Pb is 10.6 hours. It undergoes decay to its daughter (unstable) element ^{212}Bi of half-life 60.5 minutes. Calculate the time at which the daughter element will have maximum activity.

Q.12 Prove that time required for 99.9% decay of a radioactive species is almost ten times its half-life period.

Q.13 The sun radiates energy at the rate of 4×10^{26} J sec^{-1}. If the energy of fusion process is 27 MeV, calculate the amount of hydrogen that would be consumed per day for the given process. $4\,{}_1^1H \longrightarrow {}_2^4He + 2\,{}_1^0e$.

Exercise 2

Single Correct Choice Type

Q.1 Upon irradiating californium with neutrons, a scientist discovered a new nuclide having mass number of 250 and a half-life of 30 min. After 90 min. of irradiation, the observed radioactivity T due to nuclide was 100 dis/min. How many atoms of the nuclide were prepared initially?

(A) 2.4×10^4 (B) 3.46×10^4 (C) 1900 (D) 800

Q.2. A radioactive isotope X with half-life of 6.93×10^9 years decays to Y which is stable. A sample of rock from the moon was found to contain both the elements X and Y in the mole ratio1: 7. What is the age of the rock?

(A) 2.079×10^{10} years (B) 1.94×10^{10} years

(C) 1.33×10^9 years (D) 10^{10} years

Q.3 The average (mean) life of a radio nuclide which decays by parallel path is

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

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

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

Q.4 The radioactive decay $_{83}Bi^{211} \rightarrow {}_{81}Tl^{207}$, takes place in 100 L closed vessel at 27°C. Starting with 2 moles of $_{83}Bi^{211}$ ($t_{1/2}$ = 130 secs), the pressure development in the vessel after 520 secs will be:

(A) 1.875 atm (B) 0.2155 atm

(C) 0.4618 atm (D) 4.618 atm

Q.5 A fresh radioactive mixture containing short lived species A and B. Both emitting α-particles initially of 8000 α-particles per minute. 20 minutes later, they emit at the rate of 3500 α-particles per minute. If the half-lives of the species A and B are 10 minutes and 500 hours respectively, then the ratio of activities of A:B in the initial mixture was:

(A) 4:6 (B) 6: 4 (C) 3: 4 (D) 3: 1

Q.6 In order to determine the volume of blood in an animal, 1.0 mL sample of solution of 10^3 dpm of $_1H^3$ is injected into the animal blood stream. After sufficient time for circulatory equilibrium to be established, 2 mL of blood is found to have activity to 10 dpm. The volume of blood in animal is:

(A) 199 mL (B) 198 mL (C) 200 mL (D) 20 mL

Q.7. The ratio of the activities of two radio nuclides X and Y in a mixture at time t = 0 was found to be 4: 1. After two hours, the ratio of the activities becomes 1: 1. If the $t_{1/2}$ of radio nuclide X is 20 mins then $t_{1/2}$ [in minutes] of radio nuclide Y is:

(A) 10 (B) 20 (C) 30 (D) 40

Q.8. Find the age of an ancient Egyptian wooden article (in years) from the given information.

(i) Activity of 1 g of carbon obtained from ancient wooden article = 7 counts/min/g

(ii) Activity of 1 g carbon obtained from fresh wooden sample = 15.4 counts per min/g

(iii) Percentage increase in level ofC^{14} due to nuclear explosions in the past 100 years is 10%

(iv) $t_{1/2}$ of $_6C^{14}$ = 5770 years

(A) 5.770×10^3 (B) 16.87×10^3

(C) 2488 (D) None of these

Multiple Correct Choice Type

Q.9 Select the correct statement(s):

(A) α-particles are simply helium atoms

(B) γ-rays travel with higher speed as compare to α-particle and have higher ionization power as compared to b-particles.

(C) A loss of β-particles results in the production of isobars

(D) β-particles are considered as the best bombarding particles

Q.10 Select the correct statement(s):

(A) In the reaction $_{92}U^{235} + {}_0n^1 \rightarrow {}_{56}Ba^{140} + 2\ {}_0n^1 + x$, produced x is $_{36}Kr^{94}$

(B) In the reaction $_{11}Na^{23} + z \rightarrow {}_{12}Mg^{23} + {}_0n^1$ the bombarding particle z is deuteron

(C) Very large amounts of energy is produced during nuclear fission and nuclear fusion

(D) In a fission reaction, a loss in mass occurs releasing a vast amount of energy

Q.11 Select the correct statement(s):

(A) SI unit of radioactivity is Becquerel (Bq)

(B) 1 Ci = 3.7×10^7 Bq

(C) $_3Li^7 + {}_1H^1 \longrightarrow {}_2He^4$ is (P, α) type reaction

(D) The half-life of a particular radio active isotope is a characteristic constant of that isotope

Q.12 Select the correct statement (s):

(A) On bombarding $_7N^{14}$ nuclei with α-particle, the nuclei of the product formed after release of proton would be $_8O^{17}$

(B) Decay constant does not depend upon temperature

(C) Nuclide and its decay product after α-emission are called isodiaphers

(D) Half-life of radium is 1580 years.

Its average life will be 1097.22 years.

Q.13 In the decay process

$$A \xrightarrow{-\alpha} B \xrightarrow{-\beta} C \xrightarrow{-B} D$$

(A) A and B are isobars

(B) A and D are isotopes

(C) B, C and D are isobars

(D) A and C are isotones

Comprehension Type

Paragraph 1: Radioactive disintegration is a first order reaction and its rate depends only upon the nature of the nucleus and does not depend upon external factors like temperature and pressure. The rate of radioactive disintegration (Activity) is represented as $-\frac{dN}{dt} = \lambda N$

Where λ = decay constant; N = N_0 of nuclei at time t; N_0 = initial no. of nuclei

The above equation after integration can be represented as $\lambda = \frac{2.303}{t}\log\left(\frac{N_0}{N}\right)$

Q.14 Half-life period of U^{237} is 2.5 × 10^5 years. In how much time will the amount of U^{237} remaining be only 25% of the original amount?

(A) 2.5 × 10^5 years (B) 1.25 × 10^5 years

(C) 5 × 10^5 years (D) 10^6 years

Q.15 Calculate the half-life period of a radioactive element which remains only 1/16 of its original amount in 4740 years:

(A) 1185 years (B) 2370 years

(C) 52.5 years (D) None of these

Q.16 What is the activity in Ci (curie) of 1.0 mole of Plutonium-239? ($t_{1/2}$ = 24,000 years)

(A) 1.49 Ci (B) 14.9 Ci

(C) 5.513 × 10^{11} Ci (D) None

Paragraph 2: Size of nucleus was obtained by the equation $r = R_0A^{1/3}$, where r is the radius of nucleus of mass number A and R_0 is a constant whose value is equal to 1.5 × 10^{15} metres. (Given 1 amu =1.66×10^{-24} g)

Q.17 What is the density of a nucleus of mass number A?

(A) $\frac{4}{3}\pi\,(1.5 \times 10^{-15})^3$ (B) 1.17 × 10^{17} g/cm^3

(C) 1.17 × 10^{-17} kg/m^3 (D) None of these

Q.18 Nucleus radius of $_6C^{12}$ is 3 × 10^{-15} metres. What is the density ratio of d_C / d_{H_2O} ?

(A) 1.76 × 10^{17} (B) 1.76 × 10^{14}

(C) 17.6 × 10^7 (D) 17.6 × 10^{17}

Match the Columns

Q.19

Column I	Column II
(A) Isotones	(p) $_{19}Pa^{234}$&$_{90}Th^{234}$
(B) Isobars	(q) $_6C^{12}$&$_6C^{14}$
(C) Isotopes	(r) $_{19}K^{39}$and$_9F^{19}$
(D) Isodiaphers	(s) $_{18}Ar^{39}$and $_{19}K^{40}$

Q.20

Column I	Column II
(A) α-emission no.	(p) Change in mass
(B) β-emission	(q) No change in atomic no and mass no
(C) γ-emission decreases	(r) Atomic no.
(D) β^+ (Positron)	(s) Atomic no. increases

Previous Years' Questions

Q.1 If uranium (mass number 238 and atomic number 92) emits an α-particle, the product has mass number and atomic number ***(1981)***

(A) 236 and 92 (B) 234 and 90

(C) 238 and 90 (D) 236 and 90

Q.2 An isotope of Ge^{76}_{32} is ***(1984)***

(A) Ge^{77}_{32} (B) As^{77}_{33}

(C) Se^{77}_{34} (D) Se^{78}_{34}

Q.3 The radiation from a naturally occurring radioactive substance, as seen after deflection by a magnet in one direction, are ***(1984)***

(A) Definitely alpha rays

(B) Definitely beta rays

(C) Both alpha and beta rays

(D) Either alpha rays or beta rays

Q.4 $^{27}_{13}Al$ is a stable isotope $^{29}_{13}Al$ is expected to decay by ***(1996)***

(A) α-emission (B) β-emission

(C) Positron emission (D) Proton emission

Q.5 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 ***(1999)***

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

Q.6 $_{23}Na$ is the more stable isotope of Na. Find out the process by which $^{24}_{11}Na$ can undergo radioactive decay. ***(2003)***

(A) β-emission (B) α-emission

(C) β-emission (D) K-electron capture

Q.7 A positron is emitted from $^{23}_{11}Na$. The ratio of the atomic mass and atomic number of the resulting nuclide is ***(2007)***

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

Q.8 The nuclear reactions accompanied with emission of neutron(s) are ***(1988)***

(A) $^{17}_{13}Al + ^{4}_{2}He \longrightarrow ^{30}_{15}P$

(B) $^{12}_{6}C + ^{1}_{1}H \longrightarrow ^{13}_{7}N$

(C) $^{30}_{15}P \longrightarrow ^{30}_{14}Si + ^{0}_{1}e$

(D) $^{241}_{96}Am + ^{4}_{2}He \longrightarrow ^{244}_{97}Bk + ^{0}_{1}e$

Q.9 Decrease in atomic number is observed during ***(1998)***

(A) Alpha emission (B) Beta emission

(C) Positron emission (D) Electron capture

Read the following questions and answer as per the direction given below:

(A) Statement-I is true; statement-II is true; statement-II is the correct explanation of statement-I.

(B) Statement-I is true; statement-II is true; statement-II is not the correct explanation of statement-I.

(C) Statement-I is true; statement-II is false.

(D) Statement-I is false; statement-II is true.

Q.10 Statement-I: Nuclide $^{30}_{13}Al$ is less stable than $^{40}_{20}Ca$.

Statement-II: Nuclides having odd number of protons and neutrons are generally unstable. ***(1998)***

Q.11 The number of neutrons emitted when $^{235}_{92}U$ undergoes controlled nuclear fission to $^{142}_{54}Xe$ and $^{90}_{38}Sr$ is ***(2010)***

Q.12 $_{92}X^{234} \xrightarrow[-6\beta]{-7\alpha} Y$. Find out atomic number, mass number of y and identify it. ***(2004)***

Q.13 The total number of α and β particles emitted in the nuclear reaction $_{92}U^{238} \rightarrow {}_{82}Pb^{214}$ is ...... ***(2009)***

(A) Statement I is true; statement-II is true; statement-II is the correct explanation of statement-I.

(B) Statement-I is true; statement-II is true; statement-II is not the correct explanation of statement-I.

(C) Statement-I is true; statement-II is false.

(D) Statement-I is false; statement-II is true.

Q.14 Statement-I: The plot of atomic number (y-axis) versus number of neutrons (x-axis) for stable nuclei shows a curvature towards x-axis from the line of 45° slope as the atomic number is increased.

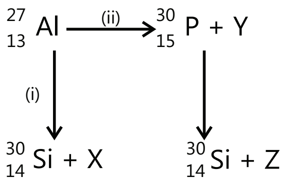
Statement-II: Proton-proton electrostatic repulsions begin to overcome attractive forces involving protons and neutrons and neutrons in heavier nuclides. ***(2008)***

Q.15 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 ***(2009)***

(A) 55.85 (B) 55.95

(C) 55.75 (D) 56.05

Q.16 Bombarment of aluminum by aparticle leads to its artificial disintegration in two ways, (i) and (ii) as shown. Products X, Y and Z respectively are, ***(2011)***



(A) Proton, neutron, positron

(B) Neutron, positron, proton

(C) Proton, positron, neutron

(D) Positron, proton, neutron

Q.17 The periodic table consists of 18 groups. An isotope of copper, on bombarment with protons, undergoes a nuclear reaction yielding element X as shown below. To which group, element X belongs in the periodic table? ***(2012)***

$$^{30}_{15}Cu + ^{1}_{1}H \rightarrow 6\,^{1}_{0}n + \alpha + 2\,^{1}_{1}H + X$$

Q.18 In the nuclear transmutation ***(2013)***

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

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

Q.19 A closed vessel with rigid walls contains 1 mol of $^{238}_{92}U$ and 1 mol of air at 298 K. Considering complete decay of $^{238}_{92}U$ to $^{206}_{82}Pb$, the ratio of the final pressure to the initial pressure of the system at 298 K is ***(2015)***

PlancEssential Questions

JEE Main/Boards

Exercise 1

Q.1 Q.6 Q.11

Exercise 2

Q.2 Q.7 Q.9 Q.15

Previous Years' Questions

Q.4 Q.14

JEE Advanced/Boards

Exercise 1

Q.1 Q.5 Q.10 Q.14

Exercise 2

Q.4 Q.6 Q.8 Q.13

Previous Years' Questions

Q.3

Answer Key

JEE Main/Boards

Exercise 1

Q.1 33.6 litre **Q.2** $\frac{1}{64}$ **Q.3** 6.3×10^{6} m sec^{-1} **Q.4** 50.4 litre at STP

Q.5 3.33×10^{-3} M, 88.8×10^{7} cpm/mL **Q.6** 4.81×10^{5} dpm **Q.7** 7.56×10^{-3} M

Q.8 6.70 MeV **Q.9** 1.143×10^{9} years **Q.10** 16800mL at STP

Exercise 2

Single Correct Choice Type

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

Previous Years' Questions

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

JEE Advanced/Boards

Exercise 1

Q.1 $\lambda = 3.4 \times 10^{-13}$ m **Q.2** 1.443 atm **Q.3** $T_{avg} = 10.87$ min **Q.4** $\frac{N_0^{A_1}}{N_0^{A_2}} = 0.3255$

Q.5 $[C]_t = 1.42$ M **Q.6** 1.66 **Q.7** $t = 3.3 \times 10^8$ year **Q.8** $\frac{[N_y]_t}{[N_y]_0} = 0.25$

Q.9 $t_{1/2}$ for electron capture = 29.78 hr **Q.10** 0.054 Faraday **Q.11** 227.1 min

Q.12 10 **Q.13** 5.31×10^{19} g

Exercise 2

Single Correct Choice Type

Q.1 B **Q.2** A **Q.3** C **Q.4** C **Q.5** D **Q.6** A **Q.7** C **Q.8** A

Multiple Correct Choice Type

Q.9 C **Q.10** A, C, D **Q.11** A, C, D **Q.12** A, B, C **Q.130** B, C

Comprehension Type

Paragraph 1: **Q.14** C **Q.15** A **Q.16** B
Paragraph 2: **Q.17** B **Q.18** B

Match the Columns

Q.19 $A \rightarrow s$; $B \rightarrow p$; $C \rightarrow q$; $D \rightarrow r$ **Q.20** $A \rightarrow p, r$; $B \rightarrow s$; $C \rightarrow q$; $D \rightarrow r$

Previous Years' Questions

Q.1 B **Q.2** A **Q.3** D **Q.4** B **Q.5** B **Q.6** A
Q.7 C **Q.8** A,D **Q.9** A, C, D **Q.10** B **Q.11** 3 **Q.12** Y is ${}_{84}Po^{206}$
Q.13 8 **Q.14** A **Q.15** B **Q.16** A **Q.17** 8 **Q.18** A, B
Q.19 9

ENVIRONMENTAL CHEMISTRY

1. ENVIRONMENT AND ENVIRONMENTAL POLLUTION

1.1 Environmental Pollution

It is the effect of undesirable changes in our surroundings that have harmful effects on plants, animals and human beings.

1.2 Pollutant

A substance, which causes pollution, is known as a pollutant. Pollutants can be solid, liquid or gaseous substances present in greater concentration than in natural abundance.

1.3 Classification of Pollutants

(a) Pollutants can be Natural or Anthropogenic

- **(i)** **Natural pollutants:** These are produced due to natural happenings like volcano eruptions etc.
- **(ii)** **Anthropogenic pollutants:** These are produced due to human activities.

(b) Pollutants can be Biodegradable or Non-biodegradable

- **(i)** **Biodegradable Pollutants:** These are the pollutants which are rapidly broken down by natural processes. Example: discarded vegetables.
- **(ii)** **Non-biodegradable pollutants:** These are the pollutants which are slowly degradable, and remain in the environment in an unchanged form for many decades. For example: DDT, plastic materials, heavy metals, many chemicals, nuclear wastes etc.

1.4 Types of Environmental Pollution

Environmental pollution is of three types.

(b) **Atmospheric pollution:**

(i) Tropospheric pollution **(ii)** Stratospheric Pollution

(b) **Water pollution**

(c) **Soil and land pollution**

2. ATMOSPHERIC POLLUTION

2.1 Atmospheric Pollution: An Introduction

Atmospheric pollution occurs when in the normal composition of the air, a new chemical substance is added or formed and builds up to undesirable proportions causing harm to humans, other animals, vegetation and materials.

2.2 Layers of Atmosphere

Earth's atmosphere can be divided (called atmospheric stratification) into five main layers. From highest to lowest, these layers are:

(a) Exosphere: > 700 km (> 440 miles)

(b) Thermosphere: 80 to 700 km (50 to 440 miles)

(c) Mesosphere: 50 to 80 km (31 to 50 miles)

(d) Stratosphere: 12 to 50 km (7 to 31 miles)

(e) Troposphere: 0 to 12 km (0 to 7 miles)

2.3 Tropospheric Pollution

Tropospheric pollution: It is caused because of two types of pollutants:

(a) **Gaseous air pollutants:** These are oxides of sulphur, nitrogen and carbon, hydrogen sulphide, hydrocarbons, ozone and other oxidants.

(b) **Particulate pollutants:** Particulate pollutants are the minute solid particles or liquid droplets in air. These are present in vehicle emissions, smoke particles from fires, dust particles and ash from industries. Examples of particulate pollutants are dust, mist, fumes, smoke, smog etc.

2.4 Gaseous Air Pollutants

2.4.1 Oxides of Sulphur as Pollutant

Sources: Burning of fossil fuels containing sulphur

Harmful effects:

(a) Causes respiratory diseases e.g., asthma, bronchitis, emphysema in human beings.

(b) Sulphur dioxide causes irritation to the eyes, resulting in tears and redness.

(c) High concentration of sulphur dioxide leads to stiffness of flower buds which eventually fall off from plants.

2.4.2 Oxides of Nitrogen as Pollutant

Sources:

(a) At high altitudes when lightning strikes, dinitrogen and dioxygen combine to form oxides of nitrogen.

(b) During the burning of fossil fuel in an automobile engine, at high temperature, dinitrogen and dioxygen combine to yield significant quantities of nitric oxide (NO) and nitrogen dioxide (NO_2).

$$N_2(g) + O_2(g) \xrightarrow{1483K} 2\,NO(g); \qquad 2NO(g) + O_2(g) \longrightarrow 2NO_2(g)$$

Harmful effects:

(a) Damage the leaves of plants and retard the rate of photosynthesis

(b) Nitrogen dioxide is a lung irritant that can lead to an acute respiratory disease in children

(c) It is toxic to living tissues also

(d) Nitrogen dioxide is also harmful to various textile fibers and metals

2.4.3 Hydrocarbons as Pollutant

Source: Incomplete combustion of fuel used in automobiles.

Harmful effect:

(a) Hydrocarbons are carcinogenic, i.e., they cause cancer

(b) They harm plants by causing ageing, breakdown of tissues and shedding of leaves, flowers and twigs

2.4.4 Oxides of Carbon as Pollutant

(b) Carbon Monoxide

Source:

(a) Incomplete combustion of carbon of coal, firewood, petrol, etc.

(b) By automobile exhaust

Harmful Effects: It is highly poisonous to living beings because of its ability to block the delivery of oxygen to the organs and tissues. It binds to hemoglobin to form carboxyhemoglobin, which is about 300 times more stable than the oxygen-hemoglobin complex. In blood when the concentration of carboxyhemoglobin reaches about 3-4 percent, the oxygen carrying capacity of blood is greatly reduced. This oxygen deficiency, result into headache, weak eyesight, nervousness and cardiovascular disorder.

(c) Carbon Dioxide

Source:

(a) Respiration

(b) Burning of fossil fuels for energy

(c) By decomposition of limestone during the manufacture of cement

(d) By volcanic eruptions

(e) Deforestation

Harmful Effects: Causes global warming

2.5 Greenhouse Effect and Global Warming

(a) Greenhouse effect: About 75% of the solar energy reaching the earth is absorbed by the earth's surface, which increases its temperature. The rest of the heat radiates back to the atmosphere. Some of the heat is trapped by gases such as carbon dioxide, methane, ozone, chlorofluorocarbon compounds (CFCs) and water vapors in the atmosphere. Thus, they add to the heating of the atmosphere. This causes global warming.

This trapping of the sun's heat near the earth's surface and keeping it warm is called natural greenhouse effect. It maintains the temperature and makes the earth perfect for life.

If the amount of carbon dioxide crosses the delicate proportion of 0.03 percent, the natural greenhouse balance may get disturbed. This may lead to global warming.

(b) Green house: In a greenhouse, visible light passes through the transparent glass and heats up the soil and the plants. The warm soil and plants emit infrared radiations. Since glass is opaque to infrared (heat) radiations, it partly reflects and partly absorbs these radiations. This mechanism keeps the energy of the sun trapped in the greenhouse.

(c) Global Warming: An increase in the average temperature of the earth's atmosphere (especially a sustained increases that causes climatic changes) which may be caused by additional heat being trapped by greenhouse gases.

(d) Acid Rain: Normally rain water has a pH of 5.6 due to the presence of H^+ ions formed by the reaction of rain water with carbon dioxide present in the atmosphere.

$$H_2O(l) + CO_2(g) \rightleftharpoons H_2CO_3(aq); \qquad H_2CO_3(aq) \rightleftharpoons 2H^+ + CO_3^{2-}$$

(e) Source: Burning of fossil fuels (which contain sulphur and nitrogenous matter) such as coal and oil in power stations and furnaces or petrol and diesel in motor engines produce sulphur dioxide and nitrogen oxides. SO_2 and NO_2 after oxidation and reaction with water are major contributors to acid rain, because polluted air usually contains particulate matter that catalysis the oxidation.

$$2SO_2\,(g) + O_2(g) + 2H_2O(l) \longrightarrow 2H_2SO_4(aq); \quad 4NO_2\,(g) + O_2(g) + 2H2O(l) \longrightarrow 4HNO_3(aq)$$

(f) Harmful Effects:

- Harmful for agriculture, trees and plants as it dissolves and washes away nutrients needed for their growth.
- Causes respiratory ailments in human beings and animals.
- Affects plant and animal life in aquatic ecosystem when acid rain falls and flows as ground water to reach rivers, lakes etc.
- Corrodes water pipes resulting in the leaching of heavy metals such as iron, lead and copper into the drinking water.
- Damages building and other structures made of stone or metal. The Taj Mahal in India has been affected by acid rain.

2.6 Particulate Pollutants

Particulates in air may be Viable or Non-Viable.

(a) Viable are minute living organisms that are dispersed in the atmosphere.

Example: bacteria, fungi, moulds, algae etc.

(b) Non-viable particulates may be classified as:

(i) **Smoke particulates:** Consist of solid or mixture of solid and liquid particles formed during combustion of organic matter.

Example: cigarette smoke, smoke from burning of fossil fuel, garbage and dry leaves, oil smoke etc.

(ii) **Dust:** Composed of fine solid particles (over 1mm in diameter), produced during crushing, grinding and attribution of solid materials. Sand from sand blasting, saw dust from wood works, pulverized coal, cement and fly ash from factories, dust storms etc., are some typical examples of this type of particulate emission.

(iii) **Mists:** Are produced by particles of spray liquids and by condensation of vapors in air. Example: Sulphuric acid mist and herbicides and insecticides that miss their targets and travel through air and form mists.

(iv) **Fumes:** Are generally obtained by the condensation of vapors during sublimation, distillation, boiling and several other chemical reactions. Generally, organic solvents, metals and metallic oxides form fume particles.

2.7 Smog

Smoke is a mixture of smoke, dust particles and small drops of fog.

Table 7.3: Classification of smog

	Classical Smog		Photochemical Smog
1.	It occurs in cool humid climate.	1.	It occurs in warm, dry and sunny climate..
2.	It is a mixture of smoke, fog and sulphur dioxide.	2.	Components of photochemical smog result from the action of sunlight on unsaturated hydrocarbons & oxides of nitrogen produced by automobiles and factories.
3	It is also called reducing smog.	3.	It is also called oxidizing smog.

2.7.1 Formation of Photochemical Smog

Burning of fossil fuels

↓

Emission of a variety of pollutants (hydrocarbons and nitric oxide to troposphere)

↓

At high levels, lead to

↓

Chain reaction between pollutants and sunlight:

$$2NO(g) + O_2(g) \xrightarrow{\text{sunlight}} 2NO_2(g)$$

$$NO_2(g) \xrightarrow{\text{sunlight}} NO(g) + O(g)$$

$$O(g) + O_2(g) \rightleftharpoons O_3(g)$$

$$O_3(g) + NO(g) \longrightarrow NO_2(g) + O_2(g)$$

↓

NO_2 and O_3 are strong oxidizing agents and can react with the unburnt hydrocarbons in the polluted air to produce chemicals such as formaldehyde, acrolein and Peroxyacetyl Nitrate (PAN).

2.7.2 Effects of Photochemical Smog

- Ozone and PAN act as powerful eye irritants.
- Ozone and nitric oxide irritate the nose and throat and their high concentration causes headache, chest pain, and dryness of the throat, cough and difficulty in breathing.
- Photochemical smog leads to cracking of rubber and extensive damage to plant life.
- It also causes corrosion of metals, stones, building materials, rubber and painted surfaces.

2.7.3 Control of Photochemical Smog

- Use of catalytic converters in automobiles, which prevent the release of nitrogen oxide and hydrocarbons to the atmosphere.
- Certain plants e.g., Pinus, Juniparus, Quercus, Pyrus and Vitis can metabolize nitrogen oxide and therefore, their plantation could help in this matter.

2.8 Stratospheric Pollution

Stratospheric pollution is basically due to ozone layer depletion

2.8.1 Formation of Ozone in Stratosphere

$O_2(g) \xrightarrow{\nu} O(g) + O(g)$; $O(g) + O_2(g) \rightleftharpoons O_3(g)$

2.8.2 Depletion of Ozone Layer

Release of chlorofluorocarbon compounds (CFCs), also known as freons lead to their mixing with the normal atmospheric gases and eventually reach the stratosphere.

In stratosphere, $CF_2Cl_2(g) \xrightarrow{UV} \dot{Cl}(g) + \dot{C}F_2Cl(g)$

$$\dot{Cl}(g) + O_3(g) \longrightarrow Cl\dot{O}(g) + O_2(g)$$

$$Cl\dot{O}(g) + O(g) \longrightarrow \dot{Cl}(g) + O_2(g)$$

This way, the chlorine radicals are continuously regenerated and cause the breakdown of ozone layer.

2.8.3 Ozone Hole Over Antarctica

In summer season, nitrogen dioxide and methane react with chlorine monoxide and chlorine atoms forming chlorine sinks, preventing much ozone depletion.

$Cl\dot{O}(g) + NO_2(g) \longrightarrow \dot{Cl}ONO_2(g)$; $\dot{Cl}(g) + CH_4(g) \longrightarrow \dot{C}H_3(g) + HCl(g)$

In winter, special type of clouds called polar stratospheric clouds are formed over Antarctica. These polar stratospheric clouds provide surface on which chlorine nitrate formed gets hydrolysed to form hypochlorous acid.

$ClONO_2(g) + H_2O(g) \longrightarrow HOCl(g) + HNO_3(g)$

It also reacts with hydrogen chloride produced to give molecular chlorine.

$ClONO_2(g) + HCl(g) \longrightarrow Cl_2(g) + HNO_3(g)$

When sunlight returns to the Antarctica in the spring, the sun's warmth breaks up the clouds and HOCl and Cl_2 are photolysed by sunlight.

$HOCl(g) \xrightarrow{h\nu} \dot{O}H(g) + \dot{Cl}(g)$; $Cl_2(g) \xrightarrow{h\nu} 2\dot{Cl}(g)$

The chlorine radicals thus formed, initiate the chain reaction for ozone depletion.

2.8.4 Effects of Depletion of the Ozone Layer

With the depletion of ozone layer, more UV radiation filters into troposphere. UV radiations lead to:

- Ageing of skin, cataract, sunburn and skin cancer etc. in human beings
- Killing of many phytoplanktons
- Damage to fish productivity
- Affect the plant proteins which lead to the harmful mutation of cells
- Increases the evaporation of surface water through the stomata of the leaves and decreases the moisture content of the soil
- Increases in UV radiations damage paints and fibres, causing them to fade faster

3. WATER POLLUTION

Water pollution is the contamination of water bodies (e.g. lakes, rivers, oceans, aquifers and groundwater). Water pollution occurs when pollutants are directly or indirectly discharged into water bodies without adequate treatment to remove harmful compounds.

Table 7.4: Sources and harmful effects of water pollutions

Major water pollutants	Sources	Harmful effects
Pathogens (Micro-organisms)	Domestic sewage	Cause gastrointestinal diseases.
Organic wastes (leaves, grass, trash)	Domestic sewage, animal excreta and waste, decaying animals and plants, discharge from food processing factories	Lead to decreases in concentration of dissolved oxygen in water and lead to death of aquatic life
Plant nutrients	Chemicals fertilizers	
Toxic heavy metals (cadmium, mercury, nickel)	Industries and chemical factors	Can damage kidneys, central nervous system, liver etc
Sediments	Erosion of soil by agriculture and strip mining	
Pesticides (insecticides, herbicides, fungicides)	Chemicals used for killing insects, fungi and weeds	Leads to eutrophication
Radioactive substances	Mining of uranium containing minerals	
Heat	Water used for cooling in industries	

Biochemical Oxygen Demand (BOD): The amount of oxygen required by bacteria to break down the organic matter present in a certain volume of a sample of water is called BOD.

Eutrophication: The process in which nutrient enriched water bodies support a dense plant population, which kills animal life by depriving it of oxygen and results in subsequent loss of biodiversity, is known as eutrophication.

Table 7.5: Major constituents of Drinking Water

Constituent	Maximum Concentration	Harmful effects of higher concentration
Fluoride	1ppm or 1 mg d m^{-3}	Causes brown mottling of teeth
Lead	50 ppb	Can damage kidney, liver, reproductive system etc
Sulphate	500 ppm	Causes laxative effect
Nitrate	50 ppm	Causes disease such as methemoglobinemia (‘blue baby’ syndrome)
Metals		
Fe	0.2 ppm	
Al	0.05 ppm	
Mn	0.2 ppm	
Cu	3.0 ppm	

Constituent	Maximum Concentration	Harmful effects of higher concentration
Zn	5.0 ppm	
Cd	0.005 ppm	

4. SOIL POLLUTION

Soil pollutions is defined or can be described as the contamination of soil of a particular region. Soil pollution mainly is a result of penetration of harmful pesticides and insecticides, which on one hand serve whatever their main purpose is, but on the other hand bring about deterioration in the soil quality, thus making it contaminated and unfit for use later.

Pesticides: They are basically synthetic toxic chemicals with ecological repercussions.

Herbicides: They are used to kill weeds or undesirable vegetation.

Example: Sodium chlorate ($NaClO_3$), sodium arsinite (Na_3AsO_3).

5. STRATEGIES TO CONTROL ENVIRONMENTAL POLLUTION

5.1 Water Management

Segregate the waste as biodegradable and non-biodegradable waste

(a) Biodegradable waste:

- **(i)** Generated by cotton mills, food processing units, paper mills, and textile factories.
- **(ii)** **Management:** are deposited in landfills and are converted into compost

(b) Non-biodegradable water:

- **(i)** Generated by thermal power plants which produce fly ash; integrated iron and steel plants which produce blast furnace slag and steel melting slag
- **(ii)** Management
  - Recycling
  - Toxic wastes are usually destroyed by controlled incineration

6. GREEN CHEMISTRY

Green chemistry is a strategy to design chemical processes and products that reduces or eliminates the use and generation of hazardous substances. The chemical reactions should be such that the reactants are fully converted into useful environment friendly products by using an environment friendly medium so that there would be no chemical pollutants introduced in the environment.

6.1 Green Chemistry in Everyday Life

Table 7.5: Examples of green chemicals

Purpose	Earlier	Now
Dry cleaning of clothes	Tetrachloroethene ($Cl_2C = CCl_2$) which contaminates the ground water	Liquefied carbon dioxide, with a suitable detergent
Bleaching of Paper	Chlorine gas	Hydrogen peroxide (H_2O_2) with suitable catalyst

Solved Examples

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Example 1 Explain giving reasons "The presence of CO reduces the amount of heaemoglobin available in the blood for carrying oxygen to the body cells."

Sol: CO combines with haemoglobin of the red blood corpuscles (RBCs) about 200 times more easily than oxygen to form carboxyhaemoglobin reversibly as follows:

$Hb + CO \rightleftharpoons HbCO$.

Thus, it is not able to combine with oxygen to form oxyhaemoglobin and transport of oxygen to different body cells cannot take place.

Example 2 What is the composition of 'photochemical smog'?

Sol: It is a mixture of a number of irritation causing compounds like NO_2, O_3, peroxyacylnitrates (PAN), aldehydes, ketones, hydrocarbons and CO.

Example 3 What is COD? Why is it preferred over BOD? How is it determined?

Sol: COD stands for Chemical Oxygen Demand. It is preferred over BOD (Biochemical Oxygen Demand) because BOD takes a number of days, e,g., BOD5 takes 5 days whereas COD can be determined in a very short time. For method of determination of COD, refer to page 14/28.

Example 4 Give three examples in which green chemistry has been applied.

Sol: (i) In dry cleaning, use of liquefied CO_2 in place of tetrachloroethene

($Cl_2C = CCl_2$).

(ii) In bleaching of paper using H_2O_2 in place of chlorine.

(iii) In the manufacture of chemicals like ethanol using environment-friendly chemicals and conditions.

Example 5 A farmer was using pesticides on his farm. He used the produce of his farm as food for rearing fishes. He was told that fishes were not fit for human consumption because large amount of pesticides had accumulated in the tissue of fishes. Explain how did this happen?

Sol: From the soil, the pesticides traveled into the crops produced by the farmer. From the crops, used as food for rearing fish, the pesticides entered into water from where they finally entered into the bodies of the fishes.

Example 6 How can you apply green chemistry for the following:

(i) To control photochemical smog.

(ii) To avoid use of halogenated solvents in dry cleaning and that of chlorine in bleaching.

(iii) To reduce use of synthetic detergents.

(iv) To reduce the consumption of petrol and diesel.

Sol: (i) Refer to 'control of photochemical smog'.

(ii) In dry cleaning, liquefied CO_2 along with a suitable detergent is used and for bleaching, hydrogen peroxide is used which gives better results and is not harmful.

(iii) Soaps should be used in place of detergents because soaps are 100% biodegradable and do not cause any pollution problem. Now a days, soft detergents are available which are biodegradable. They can used in place of 'hard detergents' which are non-biodegradable.

(iv) (a) CNG (Condensed Natural Gas) may be used as it causes much less pollution.

(b) Electrical vehicles should be used which have zero pollution. We expect a large number of electrical cars and two wheelers on the road in near future.

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Exercise 1

Q.1 What are the primary and secondary pollutants of the air?

Q.2 Ozone is a gas heavier than air. Why does ozone layer not settle down near the earth?

Q.3 What are the main components of our environment? Explain each of them briefly

Q.4 What are the different regions of the atmosphere? Explain each of them briefly.

Q.5 As we go up above the earth's surface, does temperature decrease continuously? Explain.

Q.6 What is air pollution? What are the main sources of air pollution? Write a few lines about each of them.

Q.7 What are major air pollutants?

Q.8 What do you understand by?

(i) Mists (ii) Smoke (iii) Fumes and (iv) Dust?

Q.9 Why we should not use Freon as coolants in refrigerating equipment's?

Q.10 How is photochemical smog formed? What are its effects? How can it be controlled?

Exercise 2

Single Correct Choice Type

Q.1 Which of the following is the coldest region?

(A) Troposphere (B) Mesosphere

(C) Stratosphere (D) Thermosphere

Q.2 Which of the following is a secondary pollutant?

(A) CO_2 (B) N_2O (C) SO_2 (D) PAN

Q.3 All are primary pollutants except

(A) SO_2 (B) H_2SO_4

(C) NO_2 (D) Particulate matter

Q.4 The most abundant hydrocarbon pollutant is

(A) Methane (B) Ethane (C) Propane (D) Butane

Q.5 The size of particulates of H_2SO_4 fog lies in the range

(A) 5-100 nm (B) 100-500 nm

(C) 500-1000 nm (D) 1000-10,000 nm

Q.6 The aromatic compounds present as particulates are

(A) Benzene (B) Toluene

(C) Nitrobenzene (D) Polycyclic hydrocarbons

Q.7 'White lung cancer' is caused by

(A) Asbestos (B) Silica (C) Textile (D) Paper

Q.8 Ozone layer is present in

(A) Troposphere (B) stratosphere

(C) Mesosphere (D) Exosphere

Q.9 Depletion of ozone layer causes

(A) Blood cancer (B) Lung cancer

(C) Skin cancer (D) Breast cancer

Q.10 Which one of the following is responsible for depletion of the ozone layer in the upper strata of the atmosphere?

(A) Polyhalogens (B) Ferrocene

(C) Fullerenes (D) Freons

Q.11 London smog is found in

(A) Summer during day time

(B) Summer during morning time

(C) Winter during morning time

(D) Winter during day time

Q.12 Photochemical smog is formed in

(A) Summer during morning time

(B) Summer during day time

(C) Winter during morning time

(D) Winter during day time

Q.13 Which of the following is true about photochemical smog?

(A) It is reducing in nature

(B) It is formed in winter

(C) It is a mixture of smoke and fog

(D) It causes irritation in eyes

Q.14 The smog is essentially caused by the presence of

(A) O_2 and O_3 (B) O_2 and N_2

(C) Oxides of sulphur and nitrogen (D) O_3 and N_2

Q.15 Pick up the correct statement:

(A) CO which is a major pollutant resulting from the combustion of fuels in automobiles which plays a major role in photochemical smog

(B) Classical smog has an oxidizing character while the photochemical smog is reducing in character

(C) Photochemical smog occurs in day time whereas the classical smog occurs in the morning hours

(D) During formation of smog the level of ozone in the atmosphere goes down

(E) Classical smog is good for health but not photochemical smog.

Previous Years' Questions

Q.1 When rain is accompanied by a thunderstorm, the collected rain water will have a pH value ***(2003)***

(A) Slightly higher than that when the thunderstorm is not there

(B) Uninfluenced by occurrence of thunderstorm

(C) Which depends on the amount of dust in air

(D) Slightly lower that that of rain water without thunderstorm

Q.2 The smog is essentially caused by the presence of ***(2004)***

(A) O_2 and O_3 (B) O_3 and N_2

(C) Oxides of sulphur and nitrogen (D) O_2 and O_3

Q.3 Identify the wrong statements in the following: ***(2008)***

(A) Chlorofluorocarbons are responsible for ozone layer depletion

(B) Greenhouse effect is responsible for global warming

(C) Ozone layer does not permit infrared radiation from the sun to reach the earth

(D) Acid rains is mostly because of oxides of nitrogen and sulphur

Q.4 The gas leaked from a storage tank of the Union Carbide plant in Bhopal gas tragedy was ***(2013)***

(A) Methylisocyanate (B) Methylamine

(C) Ammonia (D) Phosgene

Q.5 Assertion: Nitrogen and Oxygen are the main components in the atmosphere but these do not react to form oxides of nitrogen.

Reason: The reaction between nitrogen and oxygen requires high temperature. ***(2015)***

(A) Both Assertion and reason are correct, and the reason is the correct explanation for the assertion.

(B) Both Assertion and reason are correct, but the reason is the not correct explanation for the assertion.

(C) The Assertion is incorrect, but the reason is correct.

(D) Both the Assertion and Reason are incorrect.

Q.6 What is DDT among the following: ***(2012)***

(A) Greenhouse gas

(B) A fertilizer

(C) Biodegradable pollutant

(D) Non–biodegradable pollutant

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Exercise 1

Q.2 Q.9 Q.10

Exercise 2

Q.5 Q.7 Q.10

Answer Key

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Exercise 2

Single Correct Choice Type

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

Previous Years' Questions

Q.1 D	**Q.2** C	**Q.3** C	**Q.4** A	**Q.5** A	**Q.6** D

Solutions

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Exercise 1

Nuclear Chemistry

Sol 1: We know that.

$N = N_0\left(\frac{1}{2}\right)^n$ where, N = remaining mole of A

$N = 1\left(\frac{1}{2}\right)^n = \frac{1}{4}$

Number of decayed moles $= 1 - \frac{1}{4} = \frac{3}{4}$

Number of moles of helium formed

$= 2 \times$ number of decayed moles of A $= 2 \times \frac{3}{4} = \frac{3}{2}$

Volume of helium at STP $= \frac{3}{2} \times 22.4 = 33.6$ litre

Sol 2: $N = N_0\left(\frac{1}{2}\right)^n \qquad \therefore \frac{N}{N_0} = \left(\frac{1}{2}\right)^6 = \frac{1}{64}$

Sol 3: $\frac{1}{2}mu^2 = \frac{1}{4\pi \in_0} \times \frac{2Ze^2}{r}$ or $u^2 = \frac{Ze^2}{\pi \in_0 .m.r}$

$$u_2 = \frac{29\times(1.6\times10^{-19})^2}{3.14\times8.85\times10^{-12}\times(4\times1.672\times10^{-27})\times10^{-13}}$$

$u = 6.3 \times 10^6$ m sec^{-1}

Sol 4: The nuclear reaction ${}^{m}_{Z}A \longrightarrow {}^{m-12}_{Z-6}B + 3\,{}^{4}_{2}He$

Given, $t_{1/2}$ = 10 day;

t = 20 day, N_0 = mg = 1 g-atom

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

$\therefore$ Amount left in 2 halves $= (1/2)^2 = \frac{1}{4}$ g-atom

$\therefore$ Amount of A decayed in 2 halves

$= \left(1 - \frac{1}{4}\right) = \frac{3}{4}$ g-atom

$\because$ 1 g-atom of A gives 3 moles of He at STP

$\therefore \frac{3}{4}$ g-atom of A give $3 \times \frac{3}{4}$ moles of He at STP

$= \left(\frac{9}{4}\right)$ moles of He at STP = (9/4) moles of He at STP

$\therefore$ Volume of He at STP = (9/4) × 22. 4 litre

= 50.4 litre at STP

Sol 5: (a)1 m mole = 150 m curie

m curie = 1/150 m mole

Now, concentration $= \frac{\text{m mole}}{\text{V in mL}} = \frac{1}{150\times2} = 3.33 \times 10^{-3}$ M

(b) 1 curie $= 3.7 \times 10^{10}$ dps

$= 3.7 \times 10^{10} \times 60$ dpm $= 3.7 \times 10^{10} \times 60 \times (80/100)$ counting per minute

$\therefore$ 1 millicurie $= 3.7 \times 10^{10} \times 60 \times (80/100) \times 10^{-3}$ cpm

$\therefore$ cpm/mL = 3.7 × 10^{10} × 60 × (80/100) × (10^{-3}/2)

= 88.8 × 10^7 cpm/mL

Sol 6: Total amount of $^{49}_{19}K$

$= \frac{0.012}{100} \times \frac{0.35}{100} \times 75 \times 10^3 = 3.15 \times 10^{-2}$ g

$= \frac{3.15 \times 10^{-2} \times 6.023 \times 10^{23}}{40} = 4.74 \times 10^{20}$ atoms

$\therefore$ Rate = λ × Number of atoms

$$\frac{0.693}{1.3 \times 10^9 \times 365 \times 24 \times 60} \times 4.74 \times 10^{20}$$

Rate = 4.81 × 10^5 dpm

Sol 7: $\lambda_A = l_1 + l_2 = 1.5 \times 10^{-5} + 5 \times 10^{-6} = 20 \times 10^{-6}\ s^{-1}$

Also, $2.303 \log \frac{[A]_0}{[A]_t} = \lambda \times t$

$\therefore\ 2.303 \log \frac{0.25}{[A]_t} = 20 \times 0^{-6} \times 5 \times 60 \times 60$

$[A]_t$ = 0.1744 M

$\therefore$ [A] decomposed = $[A]_0 - [A]_t$ = 0.25 – 0.1744

= 0.0756 M

Fraction of C formed

$= \left[\frac{\lambda}{\lambda_1 + \lambda_2}\right] \times [A]_{decomposed} \times \frac{2}{5}$

$= 0.0756 \times \frac{5 \times 10^{-6}}{20 \times 10^{-6}} \times \frac{2}{5} = 7.56 \times 10^{-3}$ M

Note that, 5 moles of A are used to give 2 mole of C.

Sol 8: Mass defect

= (26. 9815 + 2.0141) **–** (24. 9858 + 4.0026) = 0.0072 amu

Energy of the reaction = 0.0072 × 931 MeV = 6.70 MeV

Sol 9: Moles of $U^{218} = \frac{1.667}{238}$

Moles of $Pb^{206} = \frac{0.277}{206}$

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

$$t = \frac{2.303}{\lambda} \log \frac{N_0}{N} = \frac{2.303 \times 4.51 \times 10^9}{0.693} \log_{10} \frac{\frac{1.667}{238} + \frac{0.277}{206}}{\frac{1.667}{238}}$$

= 1.143 × 10^9 years

Sol 10: The nuclear reaction is

$$^{A}_{Z}X \longrightarrow {}^{A-4}_{Z-2}Y + {}^{4}_{2}He$$

Given, t1/2 = 10 day, T = 20 day;

N0 = 1-atoms

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

$\therefore$ Amount left in 2 halves = 1/22 = $\frac{1}{4}$ g-atom

$\therefore$ Amount of X decayed in 2 halves

$= \left(1 - \frac{1}{4}\right) = \frac{3}{4}$ g-atom

Or amount of He formed = $\frac{3}{4}$ g-atom

(since 1 g-atom of X gives 1 g-atoms of He)

$\therefore$ Volume of He formed $= \frac{3}{4} \times 22400 = 16800$ mL at STP

Exercise 2

Single Correct Choice Type

Sol 1: (D) Isotones have same number of neutron:

17 – 9 = B – 8

B = 16

Isobars have same mass number

A = B = 16

Number of neutrons 16 – 8 = 8

Sol 2: (D) $_{92}U^{235} + _0n^1 \longrightarrow _{54}X^{139} + _{38}Sr^{194} + 3_0n^1$

Sol 3: (C) A = λN

6.023 × 3.7 × 10^{10} = 3.7 × 10^4 N

N = 6.023 × 10^6 atoms

1 mole of 6.023 × 10^{23} atoms = 100 g of X

$\therefore$6.023 × 10^6 atoms

$\Rightarrow \frac{100}{6.023 \times 10^{23}} \times 6.023 \times 10^6 = 10^{-15}$ g

Sol 4: (D) Four half-lives (Total time = n × f-life so, n = 4), hence 0.0625

Sol 5: (D) $\lambda = \frac{0.693}{69.3} = 10^{-2}\ min^{-1}$

$$N = \frac{-\frac{dN}{dt}}{\lambda} = \frac{100}{10^{-2}} = 10{,}000$$

Sol 6: (B) Equal fraction decay in equal periods of time, fraction of sample remaining after 3 days

$\Rightarrow (0.9)^3 = 0.729$

Sol 7: (D) $t = \frac{1}{\lambda}\ln\left(\frac{A_0}{A}\right) \Rightarrow t = \frac{5770}{0.693}\ln 8$

$\Rightarrow$ 17313. 6 year

Sol 8: (D) t for 20% left

$\Rightarrow t_1 = \frac{2.303}{\lambda}\log\frac{1}{1-0.8} = \frac{\ln 5}{\lambda}$

t for 50% left

$\Rightarrow t_2 = \frac{1}{\lambda}\ln 2$

$\frac{t_2}{t_1} = \frac{\frac{1}{\lambda}\ln 2}{\frac{1}{\lambda}\ln 5} = 0.43$

$t_2 = 0.43\ t_1$

Sol 9: (B) Total time = $nt_{1/2}$;

n = 5; $\frac{\text{Initial activity}}{2^n}$

Initial activity = $0.01 \times 2^5 = 0.32\ \mu C_1$

Sol 10: (B) $\lambda t = \ln\left(\frac{A_0}{A}\right) = \frac{0.693}{t_{1/2}} \times 200 = \ln\left(\frac{2140}{535}\right)$

$= t_{1/2} = 100$ min.

Sol 11: (C)

$\lambda = \frac{1}{10}\ln\left(\frac{100}{100-25}\right)$

$t = \frac{1}{\lambda}\ln\left(\frac{N_0}{N}\right)$

$t = \frac{10}{\ln\left(\frac{4}{3}\right)} \times \ln\left(\frac{4\times 10^{20}}{10^{20}}\right)$

t = 48.19

Sol 12: (B) $t_{1/2} = \frac{t}{4}$; $t_{1/2} = T\ln 2$

so $\frac{t}{4} = T\ln 2$; $t = 4t\ln 2$

Sol 13: (D) W_0 = initial wt ;

W $\Rightarrow$ wt. after 20 days

$\lambda_A = \frac{2.303}{t}\log\left(\frac{W_0}{W_A}\right)$; $\lambda_B = \frac{2.303}{t}\log\left(\frac{W_0}{W_B}\right)$

$\lambda_A - \lambda_B = \frac{2.303}{t}\log\left(\frac{W_B}{W_A}\right)$

So $\lambda_B = 0.6237$

$\therefore (t_{1/2})_B = \frac{0.693}{0.6237}\log\left(\frac{W_B}{W_A}\right) = 1.11$ day

Sol 14: (C) Given $(n_0)B = 8 \times (n_0)_A$; $(n)_A = 2 \times (n)_B$

$\lambda_A - \lambda_B = \frac{2.303}{t}\log\left[\frac{(N_A)_0}{(N_A)} \times \frac{(N_B)}{(N_B)_0}\right]$

$T = \frac{\ln\left(\frac{1}{16}\right)}{\frac{0.693}{50} - \frac{0.693}{10}} = 50$ min

Sol 15: (B) As per given $\frac{dN}{dt} = \alpha \propto \lambda N$ for max. Number of nuclei

$\frac{dN}{dt} = 0$; $\alpha = \lambda.\ N$, $N = \frac{\alpha}{\lambda}$

Sol 16: (C) $\frac{\text{Atoms of Sr}}{\text{Atoms of Rb}} = 0.05$

or $\frac{\text{Atoms of (Sr+Rb)}}{\text{Atoms of Rb}} = 1.05$

so, $\frac{\text{Initial number of atoms of Rb}}{\text{Present number of atoms Rb}} = 1.05$

$t = \frac{2.303}{\lambda}\log(n_0/n) = \frac{2.303}{0.693} \times 4.7 \times 10^{10}\log(1.05)$

$= 3.28 \times 10^9$ year

Sol 17: (A) $\lambda_A N_A = \lambda_B N_B$

($\because$ rate of disintegration are same)

$\frac{N_A}{N_B} = \frac{\lambda_B}{\lambda_A} = \frac{2}{1}$

Sol 18: (B) $N = N_0.e^{-\lambda t}$

When N = parent remaining (p) and

N_0 = Initial parent

= Parent remaining (p) + daughter formed (D)

$P = (p + d).e^{-\lambda t}$ or $\ln \frac{(p+d)}{p} = \lambda.t$

$t = \frac{1}{\lambda}\ln\left(1+\frac{d}{p}\right)$

Sol 19: (B) $\lambda = \lambda_1 + \lambda_2$; $\lambda = \frac{0.693}{22}$ and $\frac{\lambda_1}{\lambda_2} = \frac{2}{98}$

$\lambda_1 = 0.00063$ year^{-1}; $\lambda_2 = 0.03087$ year^{-1}

Sol 20: (B) $_{84}Pb^{218} \rightarrow {}_{82}Pb^{219} + {}_{2}He^{4} \rightarrow {}_{83}Bi^{214} + {}_{-1}e^{0}$

Pb^{214} to reach maximum number of nuclei

$t_{max.} = \frac{1}{\lambda_1 - \lambda_2}\ln\frac{\lambda_1}{\lambda_2} = 247.5$ sec

Where, $\lambda_1 = \frac{0.693}{183}$; $\lambda_2 = \frac{0.693}{161}$

Previous Years' Questions

Sol 1: (C) $_{90}Th^{234} \xrightarrow{-\beta} {}_{91}X^{234} \xrightarrow{-\beta} {}_{92}Y^{234} \xrightarrow{-\alpha} {}_{90}Z^{230}$

Sol 2: (C) ${}^{24}_{12}Mg + \gamma \longrightarrow {}^{23}_{11}Na + {}^{1}_{1}H$

Sol 3: (D) Equate mass number and atomic number

Sol 4: (B)

$_{92}M^{238} \longrightarrow {}_{y}N^{X} + 2\ {}_{2}He^{4}$

$_{y}N^{x} \longrightarrow {}_{B}L^{A} + 2b^{+}$

$_{y}N^{x} = {}_{(92-2\times2)}N^{(238-4\times2)} = {}_{88}N^{230}$

$_{88}N^{230} \xrightarrow{2\beta^{+}} {}_{(88-2)}L^{(230)} = {}_{86}L^{230}$

Total number of neutrons in $_{86}L^{230}$

230 – 86 = 144

Sol 5: (C) β-particle is emitted in radioactivity by Conversion of neutron to proton

Sol 6: (B) $N = \frac{N_0}{64} = \frac{N_0}{2^6}$ $\therefore n = 6$

Thus total time = 2 × 6 = 12 hr.

Sol 7: (D) $N = \frac{N_0}{2^n}$ and $n = \frac{560}{140} = 4$; $N = \frac{1}{2^4} = \frac{1}{16}$g

Sol 8: (C) $k = \frac{0.693}{t_{1/2}}$

$\Rightarrow t_{1/2} = \frac{0.693}{k} = \frac{0.693}{0.58} = 1.2$ hr

Sol 9: (C)

$r = \frac{0.693}{t_{1/2}} \times N_0 = \frac{0.693}{1600\times365\times24\times60\times60} \times \frac{6.023\times10^{23}}{226}$

$= 3.7 \times 10^{10}$ dps

Sol 10: (A) $\frac{N}{N_0} = \left(\frac{1}{2}\right)^{\frac{1}{t_{1/2}}}$; $\frac{N}{200} = \left(\frac{1}{2}\right)^{\frac{24}{4}}$; $\frac{N}{200} = \left(\frac{1}{2}\right)^{6}$

$N = \frac{200}{64} = 3.125$ g

Sol 11: (A) ${}^{238}_{92}U \xrightarrow[\text{emission}]{\lambda\alpha\text{ Particle}} {}^{234}_{90}Th \xrightarrow[\text{emission}]{2\beta\text{ particles}} {}^{234}_{92}U$

Sol 12: (C) A basis of for the C-14 dating technique.

Sol 13: (A) ${}^{A}_{Z}X \longrightarrow {}^{A-1}_{Z}X + {}^{1}_{0}n$

Sol 14: (A)

$n = \frac{18}{8} = 6$ half lives

$\therefore N = \frac{N_0}{2^n} = \frac{256}{2^6} = 4.0$ g

JEE Advanced/Boards

Exercise 1

Sol 1: Energy supplied to α-particle q × υ

$= 2 \times 1.602 \times 10^{-19} \times 3 \times 10^{5}$ J

$= \frac{2\times1.602\times10^{-19}\times3\times10^{5}}{1.602\times10^{-19}}$ eV $= 6 \times 10^{5}$ eV

The energy given is used up to overpower the penetration of nucleus and imparting energy to C and H atoms, i.e., 1×10^5 eV + 5×10^5 eV $=6 \times 10^5$ eV.

Thus, extra energy given to α-particles is used in imparting velocity to C and H and to overpower the forces of repulsion. The mass decayed during the course of reaction is responsible for emission γ-rays.

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 x 931 MeV = 3.6309 MeV= 3.6309 x 10^6 eV

= 3.6309 × 10^6 × 1.602 × 10^{-19} J = 5.816 x 10^{-13} J

also, E = hυ

5.816 x 10^{-13} = 6.625 × 10^{-34} × υ

υ = 8.77 × 10^{20} Hz

and $\upsilon = c/\lambda$

$\therefore$8.77 x 10^{20} = (3.0 × 10^8)/λ

$\therefore$ λ = 3.4 × 10^{-13} m

Sol 2: ${}^{266}_{88}Ra \longrightarrow {}^{222}_{86}Rn + {}^{4}_{2}He$

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

t = 800 year

Now, $t = \frac{2.303}{K}\log\frac{N_0}{N}$

$800 = \frac{2.303\times1600}{0.693}\ \log\frac{1}{N}$

($\because$ N = 0.707 g-atom)

$\therefore$ Amount of Ra decayed = 1 – 0.707 = 0.293

$\therefore$ Moles of Rn formed = 0.293 and

moles of He formed = 0.293

$\because$ PV = nRT

$\therefore$ Total pressure of He and Rn is

$P = \frac{2\times0.293}{5}\times0.0821\times300 = 2.887$ atm

$\therefore$ P_{He} = P × mole fraction of He

$= 2.887\times\frac{1}{2} = 1.443$ atm

Sol 3: $n = \lambda.N_1$, $r_2 = \lambda.N_2$

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

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

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

By eqs. (ii) – (i)

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

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

$\therefore$ λ = 0.092 min^{-1}

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

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

Sol 4: Let activity of ${}_xA_1$ and ${}_xA_2$ be m and n curie respectively at t = 0

$\therefore$ m + n = 1 ..... (i)

Also, $\because$ Rate $\propto$ Number of atoms

$\because$ For ${}_xA_1$ decay

$t = \frac{2.303}{\lambda}\log\frac{N_0}{N} = \frac{2.303}{\lambda}\log\frac{r_0}{r}$

$20 = \frac{2.303\times14}{0.693}\log\frac{m}{r_1}$ $\therefore$ r_1 = 0.3716

Similarly, for ${}_xA_2$ decay

$t = \frac{2.303}{\lambda}\log\frac{r_0}{r}$;

$20 = \frac{2.303\times25}{0.693}\ \log\frac{n}{r_2}$ $\therefore$ r_2 = 0.5744 n

Given that activity after 20 day remains $\frac{1}{2}$ of original activity

$\therefore$ 0.3716 m + 0.5744 n = $\frac{1}{2}$ ..... (ii)

Solving eqs. (i) and (ii) m = 0.3669 curie;

n = 0.6331 curie

For ratio of atoms, i.e., $\left(N_0^{A_1}/N_0^{A_2}\right)$, we can write

$\frac{r_0^{A_1}}{r_0^{A_2}} = \frac{\lambda^{A_1}}{\lambda^{A_2}}\times\frac{N_0^{A_1}}{N_0^{A_2}}$ ($\because$ $r = \lambda.N_0$)

or $\frac{0.3669}{0.6331} = \frac{0.693\times25}{14\times0.693}\frac{N_0^{A_1}}{N_0^{A_2}}$ or $\frac{N_0^{A_1}}{N_0^{A_2}} = 0.3255$

Sol 5: We know, $A \xrightarrow{\lambda_1} B \xrightarrow{\lambda_2} C$

Given, $[A]_0$ = 1.8 M, $\lambda_1 = 1.8 \times 10^{-5}\ s^{-1}$ and $\lambda_2 = 1.1 \times 10^{-2}\ s^{-1}$

Since, $\lambda_1 << \lambda_2$, thus, B will be converted to C at higher rate than A is converted to B. Thus, sequential reaction may therefore, be written as :

$A \xrightarrow{\lambda_1} C$

$\therefore\ [A]_0 = [A]_t + [C]_t$ ... (i)

For 1 order reaction, rate expression in integrated form gives

$[A]_t = [A]_0 e^{-\lambda_1 t}$ ... (ii)

Thus, by eqs. (i) and (ii).

$[A]_0 = [A]_0 e^{-\lambda_1 t} + [C]_t$ or $[C]_t = [A]_0[1 - e^{-\lambda_1 t}]$

$= 1.8\ [1 - e^{-1.8} \times 10^{-5} \times 24 \times 3600]$

$[C]_t = 1.42$ M

Sol 6: ${}^{m}_{Z}A \xrightarrow{-\alpha} {}^{m-4}_{Z-2}B \xrightarrow{-\beta} {}^{m-4}_{Z-1}C$

$(t_{1/2})_A$ = 10 month $(t_{1/2})_B$ = 6 month

The radioactive equilibrium is attached then, at equilibrium the ratio of atoms of A and B left is :

$$\frac{N_A}{N_B} = \frac{t_{1/2}A}{t_{1/2}B} = \frac{10}{6} = 1.66$$

If half-life of A = 6 month and B is 10 month, then since $t_{1/2}A < t_{1/2}B$ or $\lambda_A > \lambda_B$ and thus no equilibrium will be set.

Note: Radioactive process are first order in nature and any radioactive species completely decays only at infinite time.

Sol 7: Uranium present

$$= \frac{50}{100} g = \frac{0.50}{2.38} g - \text{atom} = 2.10 \times \times 10^{-3}\ \text{g-atom}$$

Pb formed from uranium decay

$$= \frac{2.425 \times 93}{100 \times 206 \times 100} = 0.109 \times 10^{-3}\ \text{g-atom}$$

Thus, N = 2.10×10^{-3} g-atom

$N_0 = (2.10 + 0.109) \times 10^{-3}$ g-atom

$= 2.209 \times 10^{-3}$ g-atom

Now, $$t = \frac{2.303}{\lambda} \log_{10} \frac{N_0}{N} = \frac{2.303}{1.52 \times 10^{-10}} \log_{10} \frac{2.209 \times 10^{-3}}{2.10 \times 10^{-3}}$$

R = 3.3×10^8 year

Sol 8: We know, $x \xrightarrow{\lambda_x} y \xrightarrow{\lambda_y} z$

t = 0, $[r_x]_0$ $[r_y]_0$

t = 4 $[r_x]_t$ $[r_y]_t$

$[r_x]_0 = [r_y]_0$ (Given)

$\therefore\ 1_x[N_x]_0 = 1_y[N_y]0$ or $\frac{[N_x]_0}{[N_y]_0} = \frac{\lambda_y}{\lambda_x}$

Now maximum yield of $y(N_y)t$

at t = 4 hr. is :

$$[N_y]_t = \frac{[N_x]_0 . \lambda_x}{\lambda_y - \lambda_x}[e^{-\lambda_x . t} - e^{-\lambda_y . t}] + [N_y]_0 e^{-\lambda_y . t}$$

$$= \frac{\lambda_y [N_y]_0 . \lambda_x}{\lambda_x[\lambda_y - \lambda_x]}[e^{-\lambda_x . t} - e^{-\lambda_y . t}] + [N_y]_0 e^{-\lambda_y . t}$$

$$= \frac{\lambda_y [N_y]_0}{[\lambda_y - \lambda_x]}[e^{-\lambda_x . t} - e^{-\lambda_y . t}] + [N_y]_0 e^{-\lambda_y . t}$$

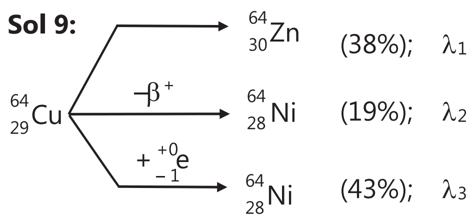
$$\therefore \frac{[N_y]_t}{[N_y]_0} = \left[\frac{\lambda_y}{\lambda_y - \lambda_x} . e^{-\lambda_x . t} - \frac{\lambda_y}{\lambda_y - \lambda_x} e^{-\lambda_y . t} + e^{-\lambda_y . t}\right]$$

$$= \left[\frac{0.693}{2 \times \left[\frac{0.693}{1} - \frac{0.693}{2}\right]} \times e^{\frac{-0.693}{2} \times 4} + \frac{0.693}{2 \times \left[\frac{0.693}{1} - \frac{0.693}{2}\right]} \times e^{\frac{-0.693 \times 4}{1}} + e^{\frac{-0.693 \times 4}{1}}\right]$$

= 0.25 + 0.06 + 0.06

$$\frac{[N_y]_t}{[N_y]_0} = 0.25$$

Sol 9:



Given, $\lambda_{av.} = \frac{0.693}{12.8}\ hr^{-1}$

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

$\lambda_1 + \lambda_2 + \lambda_3 = 5.41 \times 10^{-2}\ hr^{-1}$ ..... (i)

Also for parallel path decay

λ_1 = Fractional yield of $^{64}_{30}Zn \times \lambda_{av}$ ..... (ii)

λ_2 = Fraction yield of $^{64}_{28}Ni \times \lambda_{av}$ ..... (iii)

λ_3 = Fractional yied of $^{64}_{28}Ni \times \lambda_{av}$ .... (iv)

$\therefore \frac{\lambda_1}{\lambda_2} = \frac{28}{19}$ ..... (v)

and $\frac{\lambda_1}{\lambda_3} = \frac{38}{43}$ ..... (vi)

From eqs. (i), (v) and (vi); $\lambda_1 = 2.056 \times 10^{-2}$

$\lambda_2 = 1.028 \times 10^{-2}$; $\lambda_3 = 2.327 \times 10^{-2}\ hr^{-1}$

$\therefore$ $t_{1/2}$ 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

Sol 10: $TF \rightleftharpoons T^+ + F^-$

	1	0	0
	$(1-\alpha)$	α	α

Given, pT = 1.7 (like pH)

$[T^+] = 0.02 = Ca$

Since $\Delta T = 0 - (-0.372) = 0.372$ for solution of TF

$\Delta T_f = K_f \times (1 + \alpha) \times \text{molality} = K_f(1 + \alpha) \times C$

($\because$ Molality = molarity for dilute solution)

$\therefore \Delta T_f = K_f(C + C\alpha)$

$0.372 = 1.86(C + 0.02)$

$\therefore C = 0.2 - 0.02 = 0.18$ M

Thus, $K_a = \frac{[T^+][F^-]}{[TF]} = \frac{0.02 \times 0.02}{(0.18 - 0.02)} = 2.5 \times 10^{-3}$

Also, 0.18 mole of TF contain 0.18 mole of T (including T^+) per litre.

Thus, mole of TF in 600 mL = $\frac{0.18 \times 600}{1000}$ = 0.108

T has half-life = 12. 4 year; $N_0 = 0.108$

$\therefore$ Amount left in 24. 8 year = $\frac{N_0}{2}$ = 0.054

or 0.05 mole of tritium undergoes β -eission. Since, one tritium atom emits one β-particle.

Number of β-emitted = $[0.108 - 0.054] \times 6.023 \times 10^{23}$

$\therefore$ Total charge emitted

$= \frac{3.25 \times 10^{22} \times 1.602 \times 10^{-19}}{96500}$ Faraday = 0.054 faraday

Sol 11: $\lambda_{Pb} = \frac{0.693}{10.6 \times 60} = 1.0896 \times 10^{-3}\ min^{-1}$

$\lambda_{Bi} = \frac{0.693}{60.5} = 11.45 \times 10^{-3}\ min^{-1}$

$t_{max.} = \frac{2.303}{\lambda_{Bi} - \lambda_{Pb}} - \log \frac{\lambda_{Bi}}{\lambda_{Pb}}$

$= \frac{2.303}{(11.45 \times 10^{-3} - 1.0896 \times 10^{-3})} \times \log \frac{11.45 \times 10^3}{1.0896 \times 10^3}$

= 227.1 min

Sol 12: We know, that, $t = \frac{2.303}{\lambda} \log \frac{N_0}{N}$

$N_0 = 100$, $N = (100 - 99.9) = 0.1$

So,Time required for 99.9% decay,

$t = \frac{2.303}{\lambda} \log \frac{100}{0.1} = \frac{2.303}{\lambda} \times 3$

Half life period = $\frac{0.693}{\lambda}$

So, $\frac{\text{Time required for 99.9\% decay}}{\text{Half life period}}$

$= \frac{2.303 \times 3}{\lambda} \times \frac{\lambda}{0.693} \simeq 10$

Sol 13: 27 MeV = $27 \times 10^6 \times 1.6 \times 10^{-19} = 43.2 \times 10^{-13}$ J

Energy radiated by the sun per day

$= 4 \times 10^{26} \times 3600 \times 24\ J\ day^{-1} = 34.56 \times 10^{30}\ J\ day^{-1}$

43.2×10^{-13} J of energy is obtained from

$= 4$ amu of H $= 4 \times 1.66 \times 10^{-24}$ g of H

34.56×10^{30} J of energy is obtained from

$= \frac{4 \times 1.66 \times 10^{-24}}{43.2 \times 10^{-13}} \times 34.56 \times 10^{30} = 5.31 \times 10^{19}$ g

Exercise 2

Single Correct Choice Type

Sol.1: (B)

$\lambda.t = \ln\left(\frac{A_0}{A}\right)$ **=** $\frac{0.693}{30} \times 90 = \ln \frac{A_0}{A} = A_0 = A \times 8$

$\therefore N_0 = \frac{A_0}{\lambda} = \frac{800}{0.693} \times 30$ = 3.46 × 10^4 atoms

Sol 2: (A) At time $\underset{n_0 - x}{X} \longrightarrow \underset{x}{Y}$;

$\frac{n_0 - x}{x} = \frac{1}{7}$; $n_0 = \frac{8x}{7}$;

$\lambda = \frac{0.693}{6.93 \times 10^9}$ Þ 10^{10} years^{-1}

$t = \frac{2.303}{\lambda} \log\left(\frac{W_0}{W_0 - x}\right)$

$t = \frac{2.303}{10^{-10}} \log(8)$ = 2.097 × 10^{10} years

Sol 3: (C) λ_{net} or $\lambda = \lambda_1 + 2\lambda_2 = 1.8 \times 10^{-3} + 2 \times 10^{-3}$
= 2 × 10^{-2}

Average life (T_{av}) = $\frac{1}{\lambda} = \frac{1}{2 \times 10^{-2}} = 50$ sec

Sol 4: (C) ${}_{83}Bi^{211} \rightarrow {}_{81}Tl^{207} + {}_{2}He^{4}$; total time = n × half-life

Moles of substance left after n halves

$= \frac{\text{initialmoles}}{2^n} = \frac{2}{2^4} = 0.125$

Mole of He produced = 2 – 0.125 = 1.875

Pressure developed due to He

$= \frac{1.875 \times 0.0821 \times 300}{100}$ = 0.4618 atm

Sol 5: (D) Let initial activities of A and B are A_0 and B_0

($\because$ after 2 half-lives of activity of A will remain $\frac{A_0}{4}$)

$A_0 + B_0$ = 8000 and

also $\frac{A_0}{4} + B_0$ = 3500

(we can assume that activity of B remains constant due to larger half-life)

So $\frac{3A_0}{4}$ = 4500

A_0 = 6000; B_0 = 2000

$\frac{A_0}{B_0} = \frac{6000}{2000} = \frac{3}{1}$

Sol 6: (A) No change in activity of sample during establishment of circulatory equilibrium.

Let volume of blood is V mL, so total vol. = (V + 1) mL after injection of sample.

2 mL sample has activity of 10 dpm, so (V + 1) mL sample has activity of $\frac{10}{2} \times (V+1)$

Since rate is constant so $\frac{10}{2} \times (V+1)$ = 1000; V = 199 mL

Sol 7: (C) $\frac{A_{0(X)}}{A_{0(Y)}} = \frac{4}{1}$; $\frac{A_x}{A_y} = 1$,

$\lambda_y - \lambda_x = \frac{1}{t} \ln\left(\frac{(A_0)_y}{(A_0)_x} \times \frac{A_x}{A_y}\right)$

$(\lambda_y - \lambda_x)t = \ln\left(\frac{1}{4}\right)$; $(t_{1/2})y$ = 30 min.

Sol 8: (A) Corrected C^{14} count :

Let initial C^{14} count = A_0;

$A_0 + A_0/10$ = 15. 4; A_0 = 14

$t = \frac{1}{\lambda} \log\frac{14}{7}$ =5.770 × 10^3 years;

$t = \frac{\ln 2}{\lambda} = t_{1/2}$; t = 5770 years

Multiple Correct Choice Type

Sol 9: (C) A loss of β-particles results in the production of isobars

Sol 10: (A, C, D)

(A) In the reaction ${}_{92}U^{235} + {}_{0}n^{1} \longrightarrow {}_{56}Ba^{140} + 2{}_{0}n^{1} + x$, produced x is ${}_{36}Kr^{94}$

(C) Very large amounts of energy is produced during nuclear fission and nuclear fusion

(D) In a fission reaction, a loss in mass occurs releasing a vast amount of energy

Sol 11: (A, C, D)

(A) SI unit of radioactivity is Becquerel (Bq)

(C) ${}_{3}Li^{7} + {}_{1}H^{1} \longrightarrow {}_{2}He^{4}$ is (P, α) type reaction

(D) The half-life of a particular radioactive isotope is a characteristic constant of that isotope

Sol 12: (A, B, C)

(A) On bombarding $_7N^{14}$ nuclei with α-particle, the nuclei of the product formed after release of proton would be $_8O^{17}$

(B) Decay constant does not depend upon temperature

(C) Nuclide and its decay product after α-emission are called isodiapheres

Sol 13: (B, C) In the decay process

$$A \xrightarrow{-\alpha} B \xrightarrow{-\beta} C \xrightarrow{-B} D$$

A and D are isotopes

B, C and D are isobars

Comprehension Type

Paragraph 1

Sol 14: (C) $\lambda = \dfrac{0.693}{t_{1/2}}$

$$t = \frac{2.303}{\lambda}\log\left(\frac{N_0}{N}\right) = 5\times10^5 \text{ years}$$

Sol 15: (A) $\dfrac{N}{N_0} = \left(\dfrac{1}{x}\right)^n$; where n = number of halves;

$$\frac{N}{N_0} = \frac{1}{10} = \left(\frac{1}{x}\right)^n = n = 4$$

Total time = n × $t_{1/2}$ = 4740 = 4 × $t_{1/2}$

$t_{1/2}$ = 1185 years

Sol 16: (B) $-\dfrac{dN}{dt} = \lambda \times N$

$$\Rightarrow \frac{0.693}{t_{1/2}}\times n\times N_A \; -\frac{dN}{dt}$$

$$-\frac{dN}{dt} = \frac{0.693}{24,000\times365\times24\times60\times60\times1\times6.02}\times10^{23} \text{ dps}$$

Paragraph 2

Sol 17: (B) $r = R_0A^{1/3}$

$\therefore$ Volume of nucleus = $(4/3)\pi r^3$ = $\dfrac{4}{3}\pi(1.5\times10^{-15})^3 Am^3$

Density $d = \dfrac{m}{V} = \dfrac{A\times1.66\times10^{-27}kg}{\frac{4}{3}\pi(1.5\times10^{-15})^3 A} = 1.17\times10^{17}$ kg/m^3

Sol 18: (B) $d_C = \dfrac{\text{Mass}}{\text{Volume}} = \dfrac{12\times1.66\times10^{-27}}{\frac{4}{3}\times3.14\times(3\times10^{-15})^3}$

= 1.76×10^{17} kg/m^3

$$d_{H_2O} = 1000\,kg/m^3$$

$$\frac{d_C}{d_{H_2O}} = \frac{1.76\times10^{17}}{1,000} = 1.76\times10^{14}$$

Match the Columns

Sol 19: A → s; B → p; C → q; D → r

(A) Isotones- $_{18}Ar^{39}$ and $_{19}K^{40}$

(B) Isobars - $_{91}Pa^{234}$ and $_{90}Th^{234}$

(C) Isotopes- $_6C^{12}$ and $_6C^{14}$

(D) Isodiapheres - $_{19}K^{39}$ and $_9F^{19}$

Sol 20: A → p, r; B → s; C → q; D → r

(A) α-emission no.- Change in mass, Atomic no.

(B) β-emission- Atomic no. increases

(C) γ-emission decreases - No change in atomic no & mass no

(D) β^+ (Positron)- Atomic no

Previous Years' Questions

Sol 1: (B) The nuclear reaction $_{92}U^{238} \rightarrow {}_2He^4(\alpha) + {}_{90}Th^{234}$

Sol 2: (A) Isotopes have same atomic numbers (Z) but different mass number (A). Therefore, $_{32}Ge^{76}$ and $_{32}Ge^{77}$ are isotopes.

Sol 3: (D) Both α-rays and β-rays are deflected by magnetic field.

Sol 4: (B) $_{13}Al^{29}$ is neutron rich isotope, will decay by β–emission converting some of its neutron into proton as $_0n^1 \rightarrow {}_{-1}b^0 + {}_1H^1$

Sol 5: (B) The balanced nuclear reaction is

$2\,_0n^1 + {}_{92}U^{235} \rightarrow {}_{54}Xe^{139} + {}_{38}Sr^{94}$

Sol 6: (A) In stable isotope of Na, there are 11 protons and 12 neutrons. In the given radioactive isotope of sodium (N^{24}), there are 13 neutrons, one neutron more than that required for stability. A neutron rich isotope always decay by β-emission as ${}_0n^1 \rightarrow {}_{-1}b^0 + {}_1H^1$

Sol 7: (C) The required nuclear reaction is

${}_{11}Na^{23} \rightarrow {}_{+1}e^0 + {}_{10}Ne^{23}$

Sol 8: (A, D) If sum of mass number of product nuclides in less than the same of parent nuclides, neutron emission will occur. In both (A) and (D), sum of mass numbers of product nuclides is one unit less than the same for parent nuclides, neutron emission will balance the mass numbers.

Sol 9: (A, C, D) In the following nuclear reaction, there occur decrease in atomic number (Z):

${}_ZX^A \rightarrow {}_2He^4 + {}_{Z-2}Y^{A-4}$ ..... α-emission

${}_ZX^A \rightarrow {}_{+1}e^0 + {}_{Z-1}Y^A$ ..... positron emission

${}_ZX^A + {}_{-1}e^0 \rightarrow {}_{Z-1}Y^A$..... electrons capture

In beta emission, increase in atomic number is observed:

${}_ZX^A \rightarrow {}_{-1}e^0 + {}_{Z+1}Y^A$ ..... β-emission

Sol.10: (B) Up to atomic number 20, stable nuclei possess neutron to proton ratio (n/p) = 1

$\frac{n}{p}({}_{13}Al^{30}) = \frac{17}{13} = 1.3 > 1$, unstable, b-emitters

$\frac{n}{p}({}_{20}Ca^{40}) = \frac{20}{20} = 1$, stable

Also, nuclei with both neutrons and protons are usually unstable but it does not explain the assertion appropriately.

Sol 11: (3) ${}_{92}U^{235} \rightarrow {}_{54}Xe^{142} + {}_{38}Sr^{90} + 3{}_0n^1$

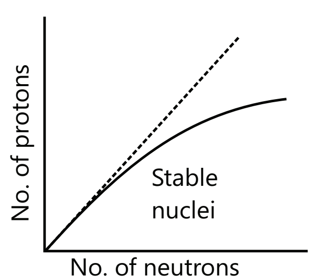
Sol 12: ${}_{92}X^{234} \rightarrow 7\,{}_2He^4 + 6\,{}_{-1}e^0 + {}_{84}Y^{206}$

Y is ${}_{84}Po^{206}$

Sol 13: ${}_{92}U^{238} \rightarrow {}_{82}Pb^{214} + 6\,{}_2He^4 + 2\,{}_{-1}e$

$\Rightarrow$ Number of $(\alpha + \beta) = 6 + 2 = 8$

Sol 14: (A)



If the curve does not bend down towards the x axis then the proton-proton repulsion would overcome the attractive force of proton and neutron. Therefore, the curve bends down.

Sol 15: (B) $\bar{A} = \frac{\sum A_i x_i}{\sum x_i}$

$\bar{A} = 54 \times 0.05 + 56 \times 0.90 + 57 \times 0.05$ (where $\bar{A}$ is atomic mass of Fe)

$\bar{A} = 55.95$

Sol 16: (A) ${}^{27}_{13}Al + {}_2\alpha^4 \rightarrow {}^{30}_{14}Si + {}_1p^1(X)$

${}^{27}_{13}Al + {}_2\alpha^4 \rightarrow {}^{30}_{15}Si + {}_0n^1(Y)$

${}^{30}_{15}P \rightarrow {}^{30}_{14}Si + {}_{+1}\beta^0(Z)$

Sol 17: (8) ${}^{63}_{29}Cu + {}_1H^1 \rightarrow 6{}_0n^1 + {}^4_2He + 2{}_1H^1 + {}^A_ZX$

Mass number: 63 + 1 = 1 × 6 + 4 + 1 × 2 + A

A = 64 – 12 = 52

Atomic number: 29 + 1 = 6 × 0 + 2 + 2 × 1 + Z

Z = 30–4 = 26

${}^A_ZX = {}^{52}_{26}Fe$

Hence X is in group '8' in the periodic table.

Sol 18: (A, B)

${}^9_4Be + \gamma \longrightarrow {}^8_4Be + {}^1_0n$

${}^9_4Be + {}^1_1P \longrightarrow {}^8_4Be + {}^2_1H$

Hence (A) and (B) are correct

Sol 19: In conversion of ${}^{238}_{92}U$ to ${}^{206}_{82}Pb$,

8α - particles and 6β particles are ejected.

The number of gaseous moles initially = 1 mol

The number of gaseous moles finally = 1 + 8 mol; (1 mol from air and 8 mol of ${}_2He^4$)

So the ratio = 9/1 = 9

Solutions

JEE Main/Boards

Exercise 1

Environmental Chemistry

Sol 1: Primary pollutants are those which after their formation remain as such, e.g., NO. Secondary pollutants are those which are formed as a result of reaction between primary pollutants, e.g., PAN (peroxyacylnitrate).

Sol 2: Ozone layer is formed in the stratosphere at an altitude of about 25-30 km from earth's surface. At this altitude, the force of gravitation is negligible.

Sol 3: The term "Environment" literally means "surrounding". It comprises of the following four major components:

(1) Atmosphere

(2) Hydrosphere

(3) Lithosphere and

(4) Biosphere

(1) Atmosphere: Atmosphere is a cover of gases that extends to a height of about 1600 km above the surface of the earth and protects the life on the life on the earth from the harmful radiations (cosmic rays) coming from the sun or the outer space.

(2) Hydrosphere: It forms that part of the environment which contains water in the form of sea, oceans, rivers, lakes, ponds, etc. About 75 percent of the earth's surface is covered by hydrosphere. Most of it is in the oceans and contains about 3.5% of the dissolved salt. Fresh water is present in lakes or rivers or ponds which flows into them from rain or melting of snow, etc.

(3) Lithosphere: It is the solid component of the earth consisting of soil, rocks, mountains etc. The outermost (8-40 km) thick solid part of the earth is called the crust. The uppermost part of the earth's crust contains weathered rocks as well as organic matter and is called soll. This is the most important part of lithosphere because we grow plants on this part. It is also a store-house of minerals.

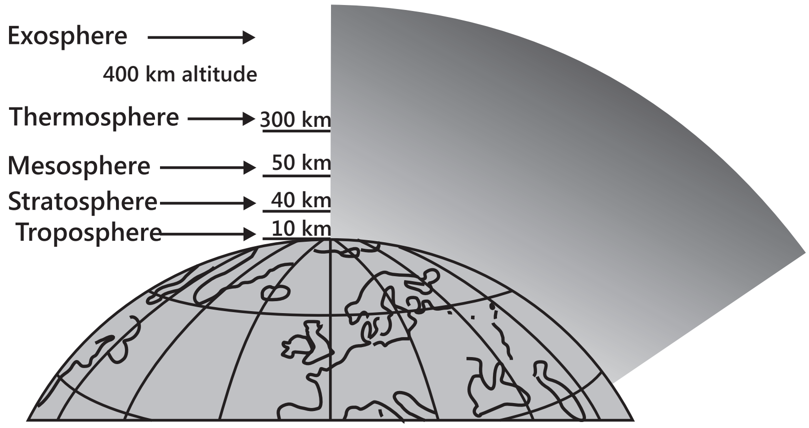
(4) Biosphere: It is that part of the lithosphere, hydrosphere and atmosphere where living organisms interact with these parts and thus live together. For example, green plants during photosynthesis give out oxygen which is added into the atmosphere, animals inhale oxygen and give out carbon dioxide which is used by plants for photosynthesis.

Sol 4: Structure of Regions of the Atmosphere: The atmosphere may be considered to be divided mainly into four regions above the surface of the earth. These regions are defined by the temperature variation with height in addition to the decrease in density and chemical composition. The names of these regions, the altitudes at which they exist, their temperature range and their chemical composition are given in Table 14.1 below:

Region	Altitude from earth's surface	Temperature Range	Gases/Species present
(i) Troposphere	0-11 km	Decreases from 15 to –56ºC	N_2,O_2,CO_2,H_2O vapor
(ii) Stratosphere	11-50 km	Increases from – 56 to –2ºC	N_2,O_2,O_3, O-atoms
(iii) Mesosphere	50-85 km	Decreases from –2 to –92ºC	N_2,O2, O_2^+, NO^+
(iv) Thermosphere	85-500 km	Increases from –92 to 1200ºC	O_2^+, O^+, NO^+, e^-

Troposphere: is the most important region of the atmosphere because it is the domain of all living organisms including animals and plants. This is the region which is greatly affected by air pollution. Further, this is the region which contains water vapor which is essential for living organisms (Above 10 km, water is present as ice crystals). 80% of the mass of the atmosphere is in this region. The temperature of this region decreases with altitude and is minimum at about 11 km. This point is called **tropopause.** In the next region, namely **stratosphere,** the temperature begins to increase. Thus, tropopause is the point of **temperature inversion.** The ozone present in the stratosphere absorbs the harmful ultraviolet radiation coming from the sun and thus acts as an umbrella for the ultraviolet radiation for the living organisms on the earth. Due to presence of ozone layer, this region is also called **ozonosphere.** The rise in temperature is due to absorption of ultraviolet rays which is converted into heat. **Mesosphere** and **thermosphere** (collectively called Ionosphere) contain gases in the ionized form. These ions reflect back the radiowaves to the earth. This forms the basis of wireless communication.

These regions may be represented diagrammatically as shown in figure.



There is one region above the thermosphere. It is called **exosphere** and is considered to the highest region of the atmosphere. It lies in the range of 500-1600 km and contains mainly atomic and ionic oxygen, hydrogen and helium. Beyond exosphere is the unbounded area called interstellar space.

Sol 5: No, temperature does not decrease continuously. From 0-11 km (called troposphere), temperature decreases. From 11-50 km (called stratosphere), temperature increases. From 50-85 km (called mesosphere), temperature again decreases and finally from 85-100 km (called thermosphere), temperature again increases.

Sol 6: Air pollution is defined as the addition of undesirable materials into the atmosphere either due to natural phenomena or due to human activity on the earth which adversely affect the quality of the air and hence affects the life on the earth.

The main sources of air pollution may be classified into two categories as follows:

(a) Natural sources. A few examples of the natural sources of pollution are as under:

- **(i)** Volcanic eruptions emitting poisonous gases like CO, H_2S, SO_2, etc.
- **(ii)** Forest fires and coal-refuse fires.
- **(iii)** Vegetation decay
- **(iv)** Pollen grains of flowers.

(b) Man-made sources, i.e., sources due to human activity. A few examples may be cited as follows:

- **(i)** **Burning of fossil fuels** (wood, coal, etc.) which produce some poisonous gases as by-products such as CO, SO_2, oxides of nitrogen (NO_x), CH_4, etc.
- **(ii)** Combustion of gasoline in the automobiles, e.g., cars, scooters, buses, trucks, etc. They emit out poisonous gases like CO, oxides of nitrogen and unburnt hydrocarbons in addition to the particles of lead.

(iii) Increases in population: This is one of the major causes of pollution. More the population, more are the needs, greater are the unnatural methods adopted which disturb the balance or equilibrium of the atmosphere.

(iv) Deforestation: Man has been cutting trees indiscriminately to meet his needs. This has resulted in increase in the percentage of CO_2 and decrease in the percentage of oxygen in the air (because plants take up CO_2 for photosynthesis and give out O_2)

(v) Fast industrialization: In the last few years, the number of industries in different parts of the world and their production has increased manifold. These include paper mills, sugar mills, rubber and plastic industries, metallurgical industries using smelters, leather industries, petroleum refineries, refrigeration, mining, etc. The smoke coming out of these industries contains not only carbon particles but a number of poisonous gases like CO, CO_2, SO_2, H_2S, NO, NO_2. etc. These industries are responsible for about 20% of the total air pollution.

(vi) Agricultural activities: The pesticides added to the soil or the sprays done over the crops are carried by the wind to different parts of the town where they give a feel smell and affect the health of animals and human beings.

(vii) Wars: The nuclear weapons used during wars emit out radiations which adversely affect the health and prove to be fatal.

Sol 7: The five major pollutants present in the troposphere are:

(1) Carbon monoxide (CO)

(2) Hydrocarbons, (C_xH_y)

(3) Oxides of nitrogen (NO_x)

(4) Oxides of sulphur (SO_x)

(5) Particulates.

Sol.8: The **non-viable** particulates are formed as a result of the disintegration of large size materials or by condensation of small size particles or droplets. The atmosphere contains four types of non-viable particulates. These are mist, smoke, fumes and dust.

Mists are produced from the particles of the spray liquids, e.g., from herbicides and insecticides and the condensation of the vapors in the air.

Smoke consists of small soot particles produced as a result of the combustion of organic matter, e.g., oil, tobacco, carbon smoke. etc.

Fumes are the vapors of certain materials present in the air, e.g., metallurgical fumes (fumes of metals) and alkali fumes.

Dust denotes fine particles produced during certain industrial processes, e.g., crushing grinding. It consists of limestone particles, sand, pulverized coal, cement, fly ash, silicon dust, etc.

Sol.9: Freon (chlorofluorocarbons) has a very long life. They stay in the atmosphere for years and ultimately reach the upper layer where they undergo photochemical reaction with ozone. Thus, ozone layer is destroyed producing an ozone hole through which ultraviolet radiation from the sun can pass through and affect life on earth.

Sol 10: Photochemical smog or Los Angeles smog: This type of smog was first observe in Los Angeles in 1950 and hence is named as "Los Angeles smog". It is formed when the air contains NO_2 and hydrocarbons and the mixture is exposed to sunlight. As the reaction takes place in the presence of sunlight to form the smog, it is called photochemical smog. Further, as strong sunlight is needed, this type of smog is formed in the months of summer during the day time when NO_2 and hydrocarbons are present in very large amounts due to heavy vehicular traffic.

Formation of photochemical smog: The mechanism of the formation of photochemical smog may be explained as follows:

In the presence of sunlight, NO_2 undergoes photolysis to form NO and atomic oxygen. Atomic oxygen then combines with the molecular oxygen in the presence of some molecule M (which acts as a source of transfer of energy) to form ozone, O_3. The ozone thus formed reacts with NO to regenerate NO_2 and O_2. Thus, NO_2 cycle is completed.

The reactions taking place may be represented as follows:

$$NO_2 \xrightarrow{h\nu} NO + O$$

$$O + O_2 \longrightarrow O_3$$

$$O_3 + NO \longrightarrow NO_2 + O_2$$

Thus, NO and O_3 produced are used up and no extra NO_2 is added into the atmosphere. But the trouble arises if hydrocarbons are also present in the atmosphere. These hydrocarbons combine with the oxygen atom produced by the photolysis of NO_2 to form highly reactive intermediates called free radicals (which are reactive species containing unpaired electrons) which may be represented by the general formula RCO*. (dot indicates an unpaired electron). These free radicals initiate a variety of reactions, some of which may be as follows:

$$RCO^{+} + O_2 \longrightarrow RCO_3^{\bullet}$$

$$RCO_3^{\bullet} + \text{Hydrocarbons} \longrightarrow RCHO\ R_2C = O$$

$$RCO_3^{\bullet} + NO \longrightarrow RCO_2 + NO_2$$

$$RCO_3^{\bullet} + O_2 \longrightarrow O_3 + RCO_2$$

$$RCO_3^{\bullet} + NO_2 \longrightarrow \underset{\text{Peroxyacylnitrates (PAN)}}{RCO_3NO_2}$$

As a result, concentration of ozone, peroxyacylnitrates (PAN) and aldehydes (RCHO) and ketones (R_2CO) builds up in the atmosphere

As this type of smog contains O_3 and NO_2, it is oxidizing in character.

Harmful effects of photochemical smog:

(i) All these compounds (particularly ozone and PAN) produce irritation in the eyes and also in the respiratory system.

(ii) They also damage many materials such as metals, stones, building materials, etc.

(iii) Ozone is particularly destructive to rubber (in which cracks are developed).

(iv) It is also harmful to fabrics, crops and ornamental plants.

(v) NO_2 present gives a brown colour to the photochemical smog which reduces visibility. Airplane pilots are familiar with this type of fog hanging over the cities.

The word "smog" is a misnomer here because photochemical smog contains neither smoke nor fog. It is a mixture of a number of irritation-causing compounds like NO_2, O_3, PAN, aldehydes, ketones, hydrocarbons and CO.

Control of Photochemical Smog: The formation of photochemical smog can be controlled or suppressed by adopting the following methods.

(i) By fitting efficient catalytic converters in the automobiles so that the emission of nitrogen oxides and hydrocarbons by these automobiles into the atmosphere can be prevented.

(ii) By spraying certain compounds into the atmosphere which generate free radicals that readily combine with the free radicals that initiate the reactions forming toxic compounds of the photochemical smog.

(iii) Certain plants such as Pinus, Juniparus, Pyrus, Vitis etc. can metabolize oxides of nitrogen. Hence, their plantation could be helpful.

Exercise 2

Sol 1: (B) Troposphere is the coldest region of the earth's atmosphere.

Sol 2: (D) PAN is a secondary pollutant.

Sol 3: (B) All are primary pollutants except H2SO4

Sol 4: (A) The most abundant hydrocarbon pollutant is Methane.

Sol 5: (C) The size of particulates of H2SO4 fog lies in the range 500-1000 nm

Sol 6: (D) The aromatic compounds present as particulates are polycyclic hydrocarbons.

Sol 7: (C) 'White lung cancer' is caused by Textile.

(A) Asbestos (B) Silica

(C) Textile (D) Paper

Sol 8: (B) Ozone layer is present in stratosphere

Sol 9 : (C) Depletion of ozone layer causes Skin cancer

Sol 10 (D) Freons are responsible for depletion of the ozone layer in the upper strata of the atmosphere?

Sol 11 : (C) London smog is found in winter during morning time.

Sol 12 : (B) Photochemical smog is formed in summer during day time

Sol 13: (D) Photochemical smog causes irritation in eyes

Sol 14: (C) The smog is essentially caused by the presence of Oxides of sulphur and nitrogen.

Sol 15 : (C) Conceptual fact

Previous Years' Questions

Sol 1: (D) The rain water after thunderstorm contains dissolved acid and therefore the pH is less than rain water without thunderstorm.

Sol 2: (**C)** Smog is Smoke + Fog. Smog contains mainly and.

Sol 3: (C) Ozone layer does not allow ultraviolet radiation from sun to reach earth.

Sol 4: (A) It is called MIC gas

Sol 5: (A) N_2 has triple bond and O_2 has double bond.

Sol 6: (D) DDT – non–biodegradable pollutant.