**Theory: Nuclear Chemistry**

### Nature and Characteristics of Radioactivity
1. The atomic numbers of all natural radioactive elements are comparatively high (>83). The nuclei of these elements contain a large number of neutrons (n) and protons (p) and the n/p ratio becomes greater than 1.5. Therefore, the nucleus becomes unstable and spontaneously emits alpha, beta, or gamma radiation.

2. The ratio of emission of these rays can neither be increased nor be decreased by a change in temperature, pressure, environment, or concentration. The spontaneous emission of the rays remains unchanged either in extreme cold or at high temperature, in sunlight, or even in the dark.

3. Radioactivity is a nuclear phenomenon. It is dependent upon the nuclear particles. It is an atomic phenomenon.

4. The radioactive process is governed by the law of radioactive decay, which states that the quantity of a radioactive element which disintegrates in unit time is directly proportional to the amount of radioactive element present at that instant.

5. A radioactive change is always a irreversible process and is never reversible.

6. The radiation emitted by natural radioactive substance consists of 3 types of rays-alpha, beta, and gamma rays.

### Nature and Properties of α, β, and γ Rays

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>α-Rays</th>
<th>β-rays</th>
<th>γ-rays</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Nature</td>
<td>Particle (Helium nucleus)</td>
<td>Particle (Electrons)</td>
<td>Electromagnetic radiation</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(No charge)</td>
</tr>
<tr>
<td>2. Velocity</td>
<td>$2 \times 10^7$ to $3 \times 10^7$ meter per second</td>
<td>$2.36 \times 10^8$ to $2.83 \times 10^8$ meter per second</td>
<td>Same as light velocity $3 \times 10^8$ meter per second</td>
</tr>
<tr>
<td>3. Penetrating power</td>
<td>Minimum 0.1 mm thick Al foil can stop it</td>
<td>50 times more than that of α particle. It is stopped by a 5 mm-thick Al foil</td>
<td>Maximum even 750 mm thick Pb plate cannot stop it</td>
</tr>
<tr>
<td>4. Mass</td>
<td>4 a.m.u</td>
<td>0.000548 a.m.u</td>
<td>No mass</td>
</tr>
<tr>
<td></td>
<td>$= \frac{1}{1836}$ of H atom</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. Ionising power</td>
<td>Maximum</td>
<td>Less than α-ray but more than γ-rays</td>
<td>Very low, comparable to X-ray</td>
</tr>
<tr>
<td>6. Effect on electric and magnetic field</td>
<td>Small deflection from its path. Deflection towards negative pole.</td>
<td>Large deflection from its path. Deflection towards positive pole.</td>
<td>Remains unaffected</td>
</tr>
<tr>
<td>7. Action on Photographic plate</td>
<td>Affects photographic plate</td>
<td>Affects photographic plate</td>
<td>Affects photographic plate</td>
</tr>
<tr>
<td>8. Kinetic energy</td>
<td>Large</td>
<td>Small</td>
<td>Nil</td>
</tr>
</tbody>
</table>
Theory of Radioactive Disintegration

The mass number, atomic number, and other properties of the daughter elements are controlled by the emission of only $\alpha$ and $\beta$ particles. Loss of $\gamma$-rays does not affect these properties.

Loss of $\alpha$-Particle

Loss of one $\alpha$-particle causes a decrease of 4 units of mass number and 2 units of atomic number i.e., the daughter element will have mass number less by 4 units and atomic number less by 2 units than its parent element.

E.g., $^{226}_{88}\text{Ra} \rightarrow ^{222}_{86}\text{Rn} + ^{4}_{2}\text{He}$ ($\alpha$-particle)

Loss of $\beta$-particle

When a radioactive element emits a $\beta$-particle, no change in atomic mass of the daughter element is observed, since the mass of electron ($\beta$-particle) is negligible. But the emission causes an increase of one unit in atomic number.

E.g., $^{234}_{90}\text{Th} \rightarrow ^{234}_{91}\text{Pa} + ^{0}_{-1}\text{e}$

Disintegration Series

According to the theory of radioactive disintegration, radio elements emit $\alpha$ or $\beta$ particles (but never $\alpha$ and $\beta$ simultaneously) until a non-radioactive stable isotope is formed. Most of the natural radioactive elements exist in nature as radioactive isotopes. All the known species belong to one of three definite chains of successive decays. These chains constitute the radioactive families. Three such radioactive disintegration series have been recorded in nature. These are

1. Uranium series (4n + 2)
2. Actinium series (4n + 3) and
3. Thorium series (4n)

The three series are sometimes known as the 4n (Thorium), 4n + 2 (Uranium) and 4n + 3 (Actinium) series as the mass numbers of the particular series are either divisible by 4 or divisible by 4 with remainders of 2 and 3.

Four disintegration series are given below:

<table>
<thead>
<tr>
<th>Name of series</th>
<th>Starting nuclide</th>
<th>Final nuclide</th>
<th>Particle $\alpha$</th>
<th>Particle $\beta$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. 4n (Thorium) series</td>
<td>$^{232}_{90}\text{Th}$</td>
<td>$^{208}_{82}\text{Pb}$</td>
<td>6</td>
<td>4</td>
</tr>
<tr>
<td>2. 4n + 1 (Neptunium) series</td>
<td>$^{237}_{93}\text{Np}$</td>
<td>$^{209}_{83}\text{Bi}$</td>
<td>7</td>
<td>4</td>
</tr>
<tr>
<td>3. 4n + 2 (Uranium) series</td>
<td>$^{238}_{92}\text{U}$</td>
<td>$^{206}_{82}\text{Pb}$</td>
<td>8</td>
<td>6</td>
</tr>
<tr>
<td>4. 4n + 3 (Actinium) series</td>
<td>$^{227}_{89}\text{Ac}$</td>
<td>$^{207}_{82}\text{Pb}$</td>
<td>5</td>
<td>3</td>
</tr>
</tbody>
</table>

The (4n + 1) i.e., neptunium series is observed only with certain artificially radioactive elements whereas the rest three are natural series. The end product in (4n + 1) series is bismuth but in the other three series a stable isotope of lead is the end product. (4n + 1) series actually starts from plutonium but neptunium is the longest lived element of this series and so it is known as neptunium series.
Law of Radioactive Decay

The law of radioactive decay states that the rate of decay of radioactive species, that is, the number of atoms disintegrating per unit interval of time is directly proportional to the total number of atoms of that species present at that instant. Hence, the decay of radioactivity follows first order kinetics.

If \( dN \) be the number of radioactive atoms which disintegrate in a small time \( dt \), then the rate of disintegration is equal to \( \frac{-dN}{dt} \) and this is proportional to the number of atoms \( N \) present at that instant.

i.e., \( \frac{-dN}{dt} \propto N \) or \( \frac{-dN}{dt} = \lambda N \)

Or \( \lambda = \frac{2.303}{t} \log \frac{N_0}{N} \)

Or \( N = N_0 e^{-\lambda t} \)

Half-Life Period

\( t_{1/2} = \frac{0.693}{\lambda} \)

Average or Mean Life Period (\( \tau \))

Average life is the reciprocal of decay constant.

\( t_{1/2} = \frac{0.693}{\lambda} \quad \text{and} \quad \tau = \frac{1}{\lambda} \)

So, the average life period

\( \tau = \frac{1}{\lambda} = \frac{t_{1/2}}{0.693} = 1.44 \ t_{1/2} \)

The average life of a radioactive element is 1.44 times greater than its half-life period.

Units of Radioactivity

The rate of disintegration is expressed as the number of disintegrations taking place per second, that is, the number of atoms which split up in one second.

1 curie (C) = \( 3.7 \times 10^{10} \) dps
[\( \text{dps} = \text{disintegration per second} \)]
1 millicurie (mc) = \( 3.7 \times 10^{7} \) dps
1 microcurie (\( \mu \)c) = \( 3.7 \times 10^{4} \) dps
1 Rutherford (rd) = \( 10^{6} \) dps

The S.I unit of radioactivity is Becquerel (Bq).

(Bq) = 1 disintegration per second

Cause of Radioactivity Neutron-pro Structure

All nuclei with atomic number greater than 83 are radioactive.

Nuclei with a total number of 2, 8, 20, 50, 82 or 126 protons or neutrons have been found to be particularly stable than the nuclei in their vicinity in the periodic table. These numbers are called magic numbers.

Nuclei having the number of protons or neutrons just above the magic numbers are less stable and hence these nuclei may emit some particles to attain the magic numbers.

Nuclei having even number of protons and neutrons are more stable and hence more abundant in nature than those with odd number of protons and neutrons.
The nucleus stability is found to be related to the neutron-proton (n/p) ratio. It is known that neutrons are responsible for holding the protons within the nucleus. Hence, as the number of protons increases (when atomic number increases) the number of neutrons must also increase rapidly in order to produce a stable nucleus. Consequently the n/p ratio of the stable nuclei must increase with the increase in atomic number.

![Graph showing the relationship between n/p ratio and atomic number.]

The region within this steep graph where all stable nuclei (non radioactive elements) lie is known as zone or belt of stability. The majority of radioactive isotopes lie outside this belt.

(a) It has been observed that for light elements of atomic number upto 20, n/p ratio is 1.0. E.g., $^{20}_{20}\text{Ca}$ contains 20 protons and 20 neutrons (n/p = 1).

(b) If the n/p ratio of a nucleus exceeds 1.5, the nucleus becomes unstable and emits α or β rays and attains stability by adjusting its n/p ratio below 1.5.

(c) If the (n/p) ratio of a nucleus occurs below or above the belt of stability, the nucleus will be unstable and would disintegrate in such a way so as to approach the actual n/p plot. Two cases of radioactive decay are considered below.

**Case I: When the n/p ratio is too high.**

When the n/p ratio is too high, that is, when the nucleus of an element contains too many neutrons, its n/p ratio places it above the zone of stability. This nucleus would be unstable and would tend to lower the ratio by emitting β-particles and, thus, move towards the zone of stability. β-emission decreases the number of neutrons and increases the number of protons.

\[
\begin{align*}
\text{n}^1 \downarrow & \quad \text{H}^1 + \text{e}^0 \\
0 & \quad 1 & -1 \\
\text{neutrons} & \quad \text{proton} & \quad \beta\text{-particle (electron)}
\end{align*}
\]

Thus, a radio iodine of mass number 133 of n/p ratio 1.51 emits a β-particle and attains stability.

\[
^{53}_{133}\text{I} \rightarrow ^{54}_{133}\text{Xe} + ^{-1}_{0}\text{e}^0
\]

**Case II: When the n/p ratio is too low.**

When the n/p ratio is too low, that is, when the nucleus contains excess protons, its (n/p) ratio places it below the zone of stability. Consequently, it will be unstable. This nucleus will tend to come within the zone of stability by converting one of its proton to a neutron. This is affected either by the emission of an alpha particle or a positron or by capturing an orbital electron (K-electron capture).

Both the modes of decay decrease the number of protons and increase the number of neutrons. Thus

(a) Sodium-20 or Nitrogen-13 of very low n/p ratio suffer positron emission.

\[
^{11}_{1}{\text{Na}}^{20} \rightarrow ^{10}_{1}{\text{Na}}^{20} + ^{+1}_{0}\text{e}^0
\]

Positron
\[ _{7}^{13}N \rightarrow _{6}^{13}C + _{1}^{0}e \]

(b) Rb-82 captures an electron from the K shell.
\[ ^{37}_{85}Rb^{82} + _{1}^{0}e \rightarrow ^{36}_{82}Kr^{82} \]

(c) \( \alpha \)-emission occurs from the nuclei of elements having atomic number more than 83 (actinium-89).

These nuclei lie beyond the upper right edge of zone of stability. The heavy nuclei are generally \( \alpha \)-emitter.

\[ ^{235}_{92}U \rightarrow ^{231}_{90}Th + ^{4}_{2}He \]

\( \alpha \)-particle

\[ ^{232}_{90}Th \rightarrow ^{228}_{88}Ra + ^{4}_{2}He \]

The daughter nuclei in the above case are not stable; they emit \( \alpha \) or \( \beta \)-particle and by successive disintegration finally change into non-radioactive lead.

Fission reaction.
The nucleus breaks into two or more fragments with the release of huge amount of energy

\[ ^{235}_{92}U + ^{0}_{1}n \rightarrow ^{141}_{56}Ba + ^{36}_{92}Kr + 2 \text{ or } 3 ^{0}_{1}n + 200 \text{ MeV} \]

The neutrons in turn attack other uranium-235 nuclei, thus setting up a chain reaction.

Fusion reaction.
It involves the formation of a bigger nucleus by the fusion of nuclei of very light elements.

\[ ^{2}_{1}H + ^{3}_{1}H \rightarrow ^{4}_{2}He + ^{1}_{0}n + 17.8 \text{ MeV} \]
OBJECTIVE QUESTIONS

Only Single Correct Answer Type Questions

1. Th$_{90}^{234}$ disintegrates to give Pb$_{82}^{206}$ as the final product. $\alpha$ and $\beta$ particles emitted during the process are
   (A) 7 and 6           (B) 6 and 7           (C) 2 and 4           (D) 4 and 2

2. The half-life period of $^{125}_{53}$I is 60 days. What percent of the original radioactivity will be present after 180 days?
   (A) 50%           (B) 20.5%         (C) 12.5%         (D) 25%

3. A radioisotope undergoes decomposition which follows two parallel paths as shown below

   $A \xrightarrow{k_1} B \xrightarrow{k_2} C$

   The percentage distribution of ‘B’ and ‘C’ are
   (A) 80% of ‘B’ and 20% of ‘C’           (B) 76.83% ‘B’ and 23.17% ‘C’
   (C) 90% ‘B’ and 10% ‘C’               (D) 60% ‘B’ and 40% ‘C’

4. An old piece of wood has 25.6% as much C$^{14}$ as ordinary wood today has $t_{1/2}$ of ^{14}C is 5760 years. The age of the wood is:
   (A) 11329 y           (B) 2880 y       (C) 26800 y       (D) 12420 y

5. If uranium (mass number 238 and atomic number 92) emits an ‘$\alpha$’ particle, the product respectively has mass number and atomic number as:
   (A) 236, 92           (B) 234, 90       (C) 238, 90       (D) 236, 90

6. The increasing order for the values of e/m (charge / mass) is:
   (A) e, p, n, $\alpha$           (B) n, p, e, $\alpha$       (C) n, p, $\alpha$, e       (D) n, $\alpha$, p, e

7. The half-life period of a radio element is 140 days. After 560 days, 1 g of the element will reduce to:
   (A) 1/2 g           (B) 1/4 g       (C) 1/8 g       (D) 1/16 g

8. The energy equivalent to one atomic mass unit is
   (A) 921 MeV           (B) 931 MeV     (C) 941 MeV     (D) 951 MeV

9. Which of the following isotopes is used in establishing the reaction mechanism of photosynthesis in plants?
   (A) $^{12}_{6}$C           (B) $^{13}_{6}$C      (C) $^{14}_{6}$C      (D) $^{2}_{1}$H

10. The average life period of an isotope is
    (A) $\frac{1}{t_{0.5}}$           (B) $\frac{1}{\lambda}$       (C) $(t_{0.5})^2$       (D) 0.75 $t_{0.5}$

11. If the quantity of a radioactive element is doubled, the rate of disintegration
    (A) becomes half           (B) becomes double       (C) slightly increases       (D) remains same
12. Consider the reaction \( ^{84}_{210}\text{Po} \rightarrow ^{82}_{206}\text{Pb} + ^{2}_{4}\text{He} \), and find out the position of polonium in the periodic table. Lead belongs to group 14.
   (A) 2.0  (B) 4.0  (C) 6.0  (D) 16

13. The half-life of a radioactive element depends upon
   (A) the amount of the element     (B) temperature
   (C) pressure                     (D) none of the above

14. The particle *neutrino* has
   (A) charge +1, mass 1             (B) charge 0, mass 0
   (C) charge −1, mass 1            (D) charge 0, mass 1

15. When \( ^{14}_{7}\text{N} \) is bombarded with \( \alpha \)-particles, the product formed is
   (A) \( ^{17}_{9}\text{F} + ^{0}_{1}\text{n} \)  (B) \( ^{17}_{8}\text{O} + ^{1}_{1}\text{H} \)
   (C) \( ^{18}_{8}\text{O} + ^{0}_{1}\text{e} \)  (D) none of the above

16. When a \( ^{92}_{235}\text{U} \) nuclide is bombarded with slow neutrons, the uranium nuclide undergoes
   (A) fusion  (B) fission  (C) radioactive decay  (D) no change

17. Which of the following isotopes is likely to be the most stable?
   (A) \( ^{71}_{30}\text{Zn}^{71} \)  (B) \( ^{66}_{30}\text{Zn}^{66} \)
   (C) \( ^{64}_{30}\text{Zn}^{64} \)  (D) \( ^{68}_{30}\text{Zn}^{68} \)

18. Identify ‘\( X \)’ in the nuclear reaction given below:
   \( ^{14}_{7}\text{N} + ^{1}_{0}\text{n} \rightarrow ^{15}_{8}\text{O} + ^{0}_{1}\text{e} \)
   (A) \( ^{1}_{1}\text{H} \)  (B) \( ^{1}_{0}\text{n} \)
   (C) \( ^{0}_{1}\text{e} \)  (D) \( ^{0}_{1}\text{e} \)

19. In nuclear reactors, the speed of neutrons is slowed down by
   (A) heavy water  (B) lead rods  (C) zinc rods  (D) molten caustic soda

20. In the reaction \( ^{3}_{6}\text{Li} + (?) \rightarrow ^{2}_{4}\text{He} + ^{3}_{1}\text{H} \), the missing particle is
   (A) electron  (B) neutron  (C) proton  (D) deuteron

21. How many alpha particles are emitted in the nuclear transformation:
   \( ^{84}_{215}\text{Po} \rightarrow ^{82}_{211}\text{Pb} \)
   (A) 0  (B) 1  (C) 2  (D) 3

22. A radioactive element has a half-life of 20 minutes. How much time should elapse before the element is reduced to 1/8th of the original mass?
   (A) 40 minutes  (B) 60 minutes  (C) 80 minutes  (D) 160 minutes

23. A radioactive substance disintegrates to \( \frac{1}{16} \)th of its original mass in 160 days. Its half-life period is
   (A) 30 days  (B) 40 days  (C) 50 days  (D) 60 days

24. What is the half-life of a radioactive substance, if 87.5 % of a given amount of substance disintegrates in 40 minutes?
   (A) 10 minutes  (B) 20 minutes  (C) 160 minutes  (D) 13 minutes and 20 seconds
25. Which of the following can be used for the dating of archaeological specimens?
   (A) $^{14}_6$C   (B) $^{18}_8$O   (C) $^{92}_{92}$U$^{235}$   (D) $^{56}_{56}$Ba$^{141}$

26. The radioisotope used for treating cancer is:
   (A) P - 30   (B) Co - 60   (C) C - 14   (D) P - 32

27. If U$^{235}$ is bombarded with neutrons, the atom splits into:
   (A) Sr + Pb   (B) Ba + Kr   (C) Kr + Cd   (D) Ba + Xe

28. The atomic mass and atomic number of lead are 208 and 82 respectively. The atomic mass and atomic number of bismuth are 209 and 83 respectively. The ratio of neutrons to protons is
   (A) higher in lead   (B) higher in bismuth   (C) same in both   (D) cannot be obtained

29. $^{40}_{20}$Ca and $^{40}_{19}$K are
   (A) isomers   (B) isotopes   (C) isotones   (D) isobars

30. The nuclear reaction in which emission of neutron takes place is
   (A) $^{13}_{13}$Al$^{27}_4 + ^2_4$He$^4$ $\rightarrow ^{15}_{15}$P$^{30}_3$   (B) $^{6}_{6}$C$^{12}_2 + ^1_1$H$^1$ $\rightarrow ^7_{7}$N$^{13}_3$
   (C) $^{15}_{15}$P$^{30}_3$ $\rightarrow ^{14}_{14}$Si$^{30}_2 + ^0_0$e$^0$   (D) $^{96}_{96}$Am$^{241}_2 + ^4_2$He$^4$ $\rightarrow ^{97}_{97}$BK$^{245}_3 + ^0_0$e$^0$

31. The fuel used in a nuclear reactor is
   (A) heavy water   (B) graphite   (C) lead   (D) uranium

32. If 2.0 g of a radioactive isotope has a half-life of 20 hours, the half life of 0.5 g of the same substance is
   (A) 20 h   (B) 80 h   (C) 5 h   (D) 10 h

33. Which of the following isotopes is dangerously radioactive?
   (A) $^2_1$H   (B) $^3_1$H   (C) $^{14}_6$C   (D) $^{12}_6$C

34. The nucleus resulting from $^{238}_{92}$U after successive loss of two alpha and four beta particles is
   (A) $^{90}_{90}$U$^{230}_2$   (B) $^{94}_{94}$Pu$^{230}_2$   (C) $^{88}_{88}$Ra$^{230}_2$   (D) $^{92}_{92}$U$^{230}_2$

35. Which of the following is used as neutron absorber in a nuclear reactor?
   (A) water   (B) deuterium   (C) U-compounds   (D) cadmium

36. Which of the following elements belongs to the $4n$ series?
   (A) Pb - 207   (B) Bi - 209   (C) Pb-208   (D) Ra - 230

37. In carbon dating
   (A) the decay rate of $^6_{14}$C is studied   (B) the rate of accumulation of $^6_{14}$C is studied
   (C) the rate of formation of $^6_{12}$C is studied   (D) the rate of formation of $^6_{13}$C is studied

38. The reaction $^2_1$D $+ ^3_1$T $\rightarrow ^4_2$He $+ ^0_0$n is an example of
   (A) nuclear fission   (B) artificial radioactivity
   (C) nuclear fusion   (D) a normal disintegration reaction
39. Starting with 10 g of a radioactive substance 0.1 g is left after 10 days. The disintegration constant is
(A) $0.92 \text{ day}^{-1}$  (B) $0.4606 \text{ day}^{-1}$  (C) $100 \text{ day}^{-1}$  (D) $0.001 \text{ day}^{-1}$

40. If three-fourth quantity of a radioactive substance disintegrates in 2 hours, its half life will be
(A) one hour  (B) 45 minutes  (C) 30 minutes  (D) 15 minutes

41. A certain nuclide has a half-life period of 30 min. If a sample containing 600 atoms is allowed to decay for 90 minutes in a vessel, how many atoms will be left in the vessel?
(A) 200 atoms  (B) 450 atoms  (C) 75 atoms  (D) 150 atoms

42. The half-life period of a radioelement is 30 min. $\frac{1}{16}$ th of the original quantity of the element will remain unchanged after
(A) one hour  (B) sixteen hours  (C) four hours  (D) two hours

43. The activity of a radio nuclide ($X^{100}$) is 6.023 curie at a time ‘t’. If the disintegration constant is $3.7 \times 10^4 \text{ sec}^{-1}$, the mass of ‘X’ after ‘t’ seconds is
(A) $10^{-3} \text{ g}$  (B) $10^{-6} \text{ g}$  (C) $10^{-14} \text{ g}$  (D) $10^{-15} \text{ g}$

44. The half-life period of polonium is 140 days. If one starts with 1.0 g of polonium, 75% of it will have undergone disintegration in
(A) 420 days  (B) 280 days  (C) 105 days  (D) 35 days

45. Which of the following has maximum n/p ratio?
(A) $^{16}\text{Ne}$  (B) $^{16}\text{O}$  (C) $^{16}\text{F}$  (D) $^{16}\text{N}$

46. Choose the incorrect option :
(A) Among $\alpha$, $\beta$ and $\gamma$ rays, $\gamma$ ray has highest penetration power
(B) $\gamma$ ray has highest velocity
(C) $\gamma$ ray has highest ionization power
(D) $\alpha$ particle is also called helium nucleus.

47. In the nuclear reaction $^{238}_{92}\text{U} \rightarrow ^{206}_{82}\text{Pb}$ The number of $\alpha$ and $\beta$ particles emitted are–
(A) 7$\alpha$, 5$\beta$  (B) 6$\alpha$, 4$\beta$  (C) 4$\alpha$, 3$\beta$  (D) 8$\alpha$, 6$\beta$

48. The end product of $(4n + 2)$ disintegration series the–
(A) $^{204}_{82}\text{Pb}$  (B) $^{208}_{82}\text{Pb}$  (C) $^{209}_{82}\text{Pb}$  (D) $^{206}_{82}\text{Pb}$

49. Element $M^A$ emits one $\alpha$(alpha) particle followed by two $\beta$(beta) particles. Which of the following is daughter element ?
(A) $^\zeta \rightarrow z^A$ $M^{A-4}$  (B) $z^A$ $M^{A-4}$  (C) $z^A$ $M^{A-4}$  (D) $z^A$ $M^{A-4}$

50. $\beta$-emission is caused by the transformation of one neutron into a proton. This results in the formation of a new element having –
(A) Nuclear charge higher by 1 unit  (B) Nuclear charge lower by 1 unit
(C) Same nuclear charge  (D) None of these

51. What are the $\alpha$ and $\beta$ particles are emitted in the nuclear reaction $^{90}_{38}\text{Th}^{228} \rightarrow ^{83}_{33}\text{Bi}^{212}$
(A) Four alpha and one beta  (B) Three alpha and seven beta
(C) Eight alpha and one beta  (D) One alpha and four beta
52. In the decay series

A \rightarrow^{\alpha} \rightarrow^{\beta} B \rightarrow^{\beta} C \rightarrow^{\alpha} D

(A) A and B are isobars (B) A and C are isobars
(C) A and D are isotopes (D) B and C are isotopes

53. A radioactive element has atomic mass 90 amu and a half-life of 28 years. The number of disintegrations per second per gm of the element is–

(A) $5.24 \times 10^{10}$ (B) $5.24 \times 10^{8}$ (C) $5.24 \times 10^{-10}$ (D) $5.24 \times 10^{12}$

54. If 8.0 g of a radioactive isotope has a half life of 10 h, the half-life of 2.2 g of the same substance is –

(A) 2.6 h (B) 5 h (C) 10 h (D) 40 h

55. If the amount of radioactive substance is increases three times, the number of disintegrating atoms per unit time will be–

(A) Doubled (B) One - third (C) Triple (D) Uncharged

56. A human body required the 0.01 µ activity of radioactive substance after 24 hours. Half life of adioactive is 6 hours. Then injection of maximum activity of radioactive substance that can be injected :

(A) 0.08 (B) 0.04 (C) 0.16 (D) 0.32

57. An old sample of wood from an archaeological excavation was found to have a radioactivity of about 8.8 counts per minute due to $^{14}C$ ($t_{1/2} = 5700$ years) as against 15.3 counts per minute for that of a freshly cut piece of wood. The age of the old sample of wood is nearly–

(A) 9000 years (B) 7000 years (C) 4500 years (D) 2500 years

58. In the reaction $^{9}_4$Be + X $\rightarrow^{10} B + \gamma , X$ is–

(A) proton (B) deuteron (C) $\alpha$-particle (D) neutron

59. The reaction $^1_2$D + $^3_1$T $\rightarrow^{4} He + {\gamma} n$ , is an example of–

(A) nuclear fission (B) nuclear fusion (C) artificial radioactivity (D) radioactive disintegration

60. Which of the following nuclear changes is incorrect–

(A) $^{20}_{\alpha}$Ca$^{40} + _{0}^1n^{1} \rightarrow^{_{10}}K^{40} + _{1}^{1}H^{1}$ (B) $^{12}_{\alpha}$Mg$^{24} + _{\alpha}^{\alpha} \rightarrow^{_{14}}Si^{27} + _{0}^1n^{1}$
(C) $^{48}_{\alpha}$Cd$^{113} + _{0}^1n^{1} \rightarrow^{_{48}}Od^{112} + _{2}^{1}e^{0}$ (D) $^{20}_{\alpha}$Ca$^{43} + _{\alpha}^{\alpha} \rightarrow^{_{21}}Sc^{46} + _{1}^{1}H^{1}$

61. 1 mole of an $\alpha$-emitting nuclide $zX^{A}(t_{1/2} = 10$ hours) was placed in a sealed container. The time required for the accumulation of $4.52 \times 10^{23}$ helium atoms in the container is–

(A) 4.52 hrs. (B) 9.40 hrs. (C) 10.0 hrs. (D) 20.0 hrs.

62. In the radioactive change

$^2P^A \rightarrow^{_{2}}^{_{2}} Q \rightarrow^{_{2}}^{_{-1}} R \rightarrow^{_{2}}^{_{-1}} S$

the radiations emitted in sequence are

(A) $\alpha , \beta , \gamma$ (B) $\beta , \alpha , \gamma$ (C) $\gamma , \alpha , \beta$ (D) $\beta , \gamma , \alpha$

63. Which one of the following particles is used to bombarded $^{15}_{\alpha}$Al$^{39}$ to give $^{15}_{\alpha}$P$^{31}$ and a neutron–

(A) $^{1}_{0}$H$^{2}$ (B) $^{1}_{0}$He$^{2}$ (C) $^{1}_{0}\alpha$ (D) $^{1}_{0}\beta$
64. How many $\alpha$-particle are emitted in the nuclear transformation?

$$^{215}_{84}\text{Po} \rightarrow ^{211}_{82}\text{Pb} + \underline{\quad}$$
(A) 0 (B) 1 (C) 2 (D) 3

65. What is $X$ in the nuclear reaction:

$$^{14}_7\text{N} + ^1_1\text{H} \rightarrow ^{15}_8\text{O} + X$$
(A) $^1\text{H}$ (B) $^0\text{n}$ (C) $\gamma$ (D) $^0\text{e}$

66. The activity of radioactive nuclide ($X^{100}$) is 6.023 Curie. If its disintegration constant is $3.7 \times 10^4 \text{sec}^{-1}$, the mass of $X$ is:

(A) $10^{-3} \text{g}$ (B) $10^{-15} \text{g}$ (C) $10^{-6} \text{g}$ (D) $10^{-14} \text{g}$

67. Review the nuclear reaction:

$$^{226}_{88}\text{Ra} \rightarrow ^{224}_{86}\text{Rn} \rightarrow ^{220}_{86}\text{Po} \rightarrow ^{216}_{82}\text{Pb} \rightarrow ^{212}_{82}\text{Bi}$$
Point out the correct statement:
(A) Ra, Rn, Po, Pb (isodiapheres), Pb and Bi (isobars)
(B) Ra, Rn (isotopes) Po, Pb, Bi (isobars)
(C) Rn, Po, Pb (isotopes) Ra, Pb, Bi (isobars)
(D) none of these

One or More than One Correct Answer Type Questions

68. Which of the following statements is incorrect?
(A) Positron has same mass as that of electron
(B) Positron has same charge as that of proton
(C) Positron has same $e/m$ ratio as $\alpha$-particles
(D) Emission of a positron results in increase in number of protons in the daughter nuclide.

69. $^{232}_{90}\text{Th}$ decays to $^{208}_{82}\text{Pb}$ through a number of $\alpha$ and $\beta$ emissions. Which of the following is true?

(A) Number of $\alpha$-particles emitted is 8 (B) Number of $\beta$-particles emitted is 6
(C) Number of $\beta$-particles emitted is 8 (D) Number of $\alpha$-particles emitted is 6.

70. Consider the nuclear change:

$$^{214}_{82}\text{Pb} \rightarrow ^{210}_{82}\text{A} \rightarrow ^{206}_{82}\text{B} \rightarrow ^{202}_{82}\text{C}$$
Which of the following statement is correct?
(A) C is an isotope of $^{214}\text{Pb}$ (B) A is an isobar of $^{214}\text{Pb}$
(C) C is an isotope of A (D) B is an isobar of A.

71. A radioactive nuclide emits one $\alpha$-particle and two $\beta$-particles, in succession. The daughter nuclide formed has–

(A) same number of protons as the parent nuclide
(B) same number of nucleons as the parent nuclide
(C) mass number less by four than the parent nuclide
(D) same number of neutrons as the parent nuclide

72. Which of the following is/are correct?

(A) $\alpha$-rays are more penetrating than $\beta$-rays
(B) $\alpha$-rays have greater ionizing power than $\beta$-rays
(C) $\beta$-particles are not present in the nucleus, yet they are emitted from the nucleus
(D) $\gamma$-rays are not emitted simultaneously with $\alpha$ and $\beta$-rays.
True/False Type Questions

73. In the reaction, $\text{Li}_7 + Z \rightarrow \text{Be}_7 + n_0$ the bombarding particle Z is deuteron.

74. Emission of a $\beta$-particle by a radioactive nuclide results in decrease in N/P ratio.

75. When an alkaline earth element emits an $\alpha$-particles, the daughter element formed belongs to group 18.

Fill in the blank types

76. A radioactive element has decay constant of $6.93 \times 10^{-3}$ s$^{-1}$. Its half-life is ...... minutes.

77. SI unit of nuclear activity is ..........

78. Graphite is used as .......... in nuclear reactors.

Column Matching Type Question

Match the items of column I to those of column II:

79. Column I                        Column II
    (A) Disintegration constant      (p) $1.44 \ t_{1/2}$
    (B) Average life                (q) 1 dps
    (C) One curie                   (r) $\frac{0.693}{t_{1/2}}$
    (D) One Becquerel                (s) $3.7 \times 10^{10}$ dps

80. Column I                        Column II
    (A) Nuclear fusion              (p) 4n series
    (B) Carbon dating               (q) (4n + 3) series
    (C) Thorium series              (r) Age of dead
    (D) Actinium series             (s) Hydrogen bomb

Subjective Type Questions

81. $^{90}\text{Y}$ has a half-life of 64 hours and $^{90}\text{Sr}$, 28 years. $^{90}\text{Sr}$ decays to $^{90}\text{Y}$ by $\beta$-emission. What will be the amount of $^{90}\text{Y}$ in equilibrium with 1g of $^{90}\text{Sr}$?

82. The activity of 1 g of radium is 0.5 curie. Calculate the half-life period of radium and the time required for the decay of radium from 2.0 g to 0.25 g.

83. What mass of $^{14}\text{C}$ isotope will have an activity equal to one curie? $t_{1/2}$ of $^{14}\text{C}$ is 5730 years.

84. A certain radioisotope $^{A}_{Z}\text{X}$ ($t_{1/2} = 10$ days) decays to give $^{A-4}_{Z-2}\text{Y}$. If 1.0 g atom of $^{A}_{Z}\text{X}$ is kept in a sealed vessel, how much helium will collect in 20 days?
85. In nature a decay chain series starts with $^{232}_{90}$Th and terminates at $^{208}_{82}$Pb. A thorium ore sample was found to contain $8 \times 10^{-5}$ mL of helium at STP and $5 \times 10^{-7}$ g of $^{232}$Th. Find the age of the ore sample, assuming the source of helium to be only due to decay of $^{232}$Th. Also, assume complete retention of He within the ore. ($t_{1/2}$ of $^{232}$Th = $1.39 \times 10^{10}$ y)

86. A wooden article undergoes $^{14}$C disintegrations per minute per gram of carbon. What is the approximate age of the article? $t_{1/2}$ of $^{14}$C is 5730 years and radioactivity of wood recently cut down is 15 disintegrations per minute per gram of carbon.

87. The half-life of $^{90}_{38}$Sr is 20 years. If the sample of this nuclide has an initial activity of 8000 disintegrations per minute today, what will be its activity after 80 years?

88. $^{227}$Ac has a half-life of 22.0 years w.r.t. radioactive decay. The decay follows two parallel paths. One leads to $^{227}$Th and the other to $^{223}$Fr. The percentage yield of these two daughter nuclides are 2.0 and 98.0 respectively. What are the decay constants for each separate paths?

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**IIT-JEE PROBLEMS (PREVIOUS YEARS)**

1. If $^{23}$Na is stable, then $^{24}$Na will undergo:
   (A) $\alpha$-emission (B) $\beta^-$-emission (C) $\beta^+$-emission (D) k-electron capture  
   [IIT-2003]

2. A positron is emitted from $^{23}_{11}$Na. The ratio of the atomic mass and atomic number of the resulting nuclide is:
   (A) 22/10 (B) 22/11 (C) 23/10 (D) 23/12  
   [IIT-2007]

### Passage

Carbon-14 is used to determine the age of organic material. The procedure is based on the formation of $^{14}$C by neutron capture in the upper atmosphere $^{14}_{7}$N + $^{0}_{1}$n $\rightarrow^{14}_{6}$C + $^{1}$p. $^{14}$C is absorbed by living organisms during photosynthesis. The $^{14}$C content is constant in living organism once the plant or animal dies, the uptake of carbon dioxide by it ceases and the level of $^{14}$C in the dead being, falls due to the decay which $^{14}$C undergoes $^{14}_{6}$C $\rightarrow$ N + $\beta^-$. The half life period of $^{14}$C is 5770 years. The decay constant ($\lambda$) can be calculated by using the following formula $\lambda = \frac{0.693}{t_{1/2}}$. The comparison of the $\beta^-$ activity of the dead matter with that of the carbon still in circulation enables measurement of the period of the isolation of the material from the living cycle. The method however, ceases to be accurated over periods longer than 30,000 years. The proportion of $^{14}$C to $^{12}$C in living matter is 1 : 10$^{12}$.  

[IIT-2006]

3. Which of the following is correct?
   (A) Rate of exchange of carbon between atmosphere and living thing is slower than decay of $^{14}$C   
   (B) Carbon dating can be used to find out the age of earth crust and rocks  
   (C) Rate of exchange of $^{14}$C between atmosphere and living organism is so fast that an equilibrium is set up between the intake of $^{14}$C by organism and its exponential decays   
   (D) Carbon dating can not be used to determine concentration of $^{14}$C in dead beings.
4. What should be the age of fossil for meaningful determination of its age?
   (A) 6 years  
   (B) 6000 years  
   (C) 60,000 years  
   (D) It can be used to calculate any age

5. A nuclear explosion has taken place leading to increase in concentration of $^{14}$C in nearby areas. $^{14}$C concentration is $C_1$ in nearby areas and $C_2$ in areas far away. If the age of the fossil is determined to be $T_1$ and $T_2$ at the places respectively then :
   (A) The age of the fossil will increase at the place where explosion has taken place and $T_1 - T_2 = \frac{1}{\lambda} \ln \frac{C_1}{C_2}$
   (B) The age of the fossil will decrease at the place where explosion has taken place and $T_1 - T_2 = \frac{1}{\lambda} \ln \frac{C_1}{C_2}$
   (C) The age of fossil will be determined to be same.
   (D) $\frac{T_1}{T_2} = \frac{C_1}{C_2}$

6. The total number of $\alpha$ and $\beta$ particles emitted in the nuclear reaction $^{238}_{92}U \rightarrow ^{214}_{82}Pb$ is. [IIT-2009]

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

8. The nuclidic ratio of $^3H$ to $^1H$ in a sample of water is $8.0 \times 10^{-18}: 1$. Tritium undergoes decay with a half life period of 12.3 year. How many tritium atoms would 10.0 g of such a sample contains 40 year after the original sample is collected? [IIT-1992]
ANSWER KEY
EXERCISE # 1

1. (A)  2. (C)  3. (B)  4. (A)  5. (B)  6. (D)  7. (D)
8. (B)  9. (C)  10. (B)  11. (B)  12. (D)  13. (D)  14. (B)
15. (B)  16. (B)  17. (C)  18. (C)  19. (C)  20. (B)  21. (B)
22. (B)  23. (B)  24. (D)  25. (A)  26. (B)  27. (B)  28. (A)
29. (C)  30. (A)  31. (D)  32. (A)  33. (B)  34. (D)  35. (D)
36. (C)  37. (A)  38. (C)  39. (B)  40. (A)  41. (C)  42. (D)
43. (D)  44. (B)  45. (D)  46. (C)  47. (D)  48. (D)  49. (C)
50. (A)  51. (A)  52. (C)  53. (D)  54. (C)  55. (C)  56. (C)
57. (C)  58. (A)  59. (B)  60. (C)  61. (D)  62. (B)  63. (C)
64. (B)  65. (C)  66. (B)  67. (A)  68. (CD)  69. (BD)  70. (AB)
71. (AC)  72. (BCD)  73. False  74. True  75. True  76. 1.67
77. Becquerel  78. Moderator  79. (A) – r ; (B) – p ; (C) – s ; (D) – q
80. (A) – s ; (B) – r ; (C) – p ; (D) – q  81. 2.609 × 10^-4
82. 3 × 3164 = 9492 years  82. 0.2244 g  83. \(\frac{3}{4} = 16,800 \text{ cm}^3\)
84. 4.89 × 10^{10} y  85. 4224.47 years  86. 500 dis. per second
87. 6.3 × 10^{-4} y^{-1} and 0.3087 y^{-1}

EXERCISE # 2

1. (B)  2. (C)  3. (C)  4. (B)  5. (A)  6. (6, 2)
7. (4)  8. A = 5.6223 × 10^5 atoms