Nuclear Physics

- **Discovered by:** Rutherford
- **Constituents:** neutrons (n) and protons (p) [collectively known as nucleons]

  (i) Neutron: It is a neutral particle. It was discovered by J. Chadwick.

  Mass of neutron, $m_n = 1.6749286 \times 10^{-27}$ kg.

  (ii) Proton: It has a charge equal to +e. It was discovered by Goldstein.

  Mass of proton, $m_p = 1.6726231 \times 10^{-27}$ kg
- **Representation**

  $_Z X^A$ or $^A_Z X$

  where : X $\Rightarrow$ symbol of the atom, Z $\Rightarrow$ Atomic number = number of protons,

  A $\Rightarrow$ Atomic mass number = total number of nucleons. = no. of protons + no. of neutrons.
- **Size of nucleus :** Order of 10^{-15} m (fermi)

  Radius of nucleus : $R = R_0 A^{1/3}$; where $R_0 = 1.1 \times 10^{-15}$ m (which is an empirical constant)

  A = Atomic mass number of atom.
- **Density**

  $$\text{density} = \frac{\text{mass}}{\text{volume}} \cong \frac{Am_p}{\frac{4}{3}\pi R^3} = \frac{Am_p}{\frac{4}{3}\pi (R_0 A^{1/3})^3} = \frac{3m_p}{4\pi R_0^3} = \frac{3 \times 1.67 \times 10^{-27}}{4 \times 3.14 \times (1.1 \times 10^{-15})^3} = 3 \times 10^{17}\ \text{kg/m}^3$$

  Nuclei of almost all atoms have almost same density as nuclear density is independent of the mass number (A) and atomic number (Z).

Atomic Mass Unit (a.m.u.)

1 a.m.u. = 1/12 [mass of one atom of $_6C^{12}$ atom at rest and in ground state] = 1.66×10^{-27} kg

Energy equivalence of 1 amu = $1.66 \times 10^{-27} \times (3 \times 10^8)^2$ J = 931.5 MeV

Some Definitions

(i) Isotopes: The nuclei having the same number of protons but different number of neutrons are called isotopes.

(ii) Isotones: Nuclei with the same neutron number but different atomic number(Z) are called isotones.

(iii) Isobars: The nuclei with the same mass number but different atomic number are called isobars.

Example 1:

Calculate the radius of ^{70}Ge.

Solution:

We have,

$R = R_0 A^{1/3} = (1.1 \text{ fm}) (70)^{1/3} = (1.1 \text{ fm}) (4.12) = 4.53 \text{ fm}$

2. Mass Defect & Binding Energy

Mass Defect

The difference between sum of individual masses of constituent masses and actual mass of nucleus is known as mass defect.

Binding Energy

It is the minimum energy required to break the nucleus into its constituent particles.

or

Amount of energy released during the formation of nucleus by its constituent particles and bringing them from infinite separation.

Binding Energy (B.E.) = Δmc^2

BE = Δm (in amu) × 931 MeV/amu = Δm × 931 MeV

Note : If binding energy per nucleon is more for a nucleus then it is more stable.

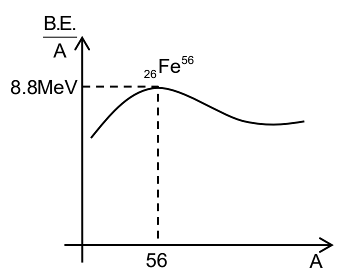
For example

If $\left(\frac{B.E_1}{A_1}\right) > \left(\frac{B.E_2}{A_2}\right)$

then nucleus 1 would be more stable.

Variation of Binding Energy Per Nucleon with Mass Number

The binding energy per nucleon first increases on an average and reaches a maximum of about 8.8 MeV for A = 56. For still heavier nuclei, the binding energy per nucleon slowly decreases as A increases.



Binding energy per nucleon is maximum for $_{26}Fe^{56}$, which is equal to 8.8 MeV. Binding energy per nucleon is minimum for deuterium ($_1H^2$)

Example 2:

Following data is available about 3 nuclei P, Q & R. Arrange them in decreasing order of stability

	P	Q	R
Atomic mass numebr (A)	10	5	6
Binding Energy (MeV)	100	60	56

Solution:

$$\left(\frac{B.E.}{A}\right)_P = \frac{100}{10} = 10$$

$$\left(\frac{BE}{A}\right)_Q = \frac{60}{5} = 12$$

$$\left(\frac{B.E.}{A}\right)_R = \frac{66}{6} = 11$$

$\therefore$ Stability order is Q > R > P.

Example 3:

The three stable isotopes of neon: ${}^{20}_{10}Ne$, ${}^{21}_{10}Ne$ and ${}^{22}_{10}Ne$ have respective abundances of 90.51% 0.27% and 9.22%. The atomic masses of three isotopes are 19.99 u, 20.99 u and 22.00 u respectively. Obtain the average atomic mass of neon.

Solution:

$$m = \frac{90.51 \times 19.99 + 0.27 \times 20.99 + 9.22 \times 22}{100} = 20.18 \text{ u}$$

Example 4:

A nuclear reaction is given as : A + B $\rightarrow$ C + D

Binding energies of A, B, C and D are given as B_1, B_2, B_3 and B_4. Find the energy released in the reaction

Solution:

$(B_3 + B_4) - (B_1 + B_2)$

Example 5:

Calculate the binding energy of an alpha particle from the following data:

mass of ${}^{1}_{1}H$ atom = 1.007826 u, mass of neutron = 1.008665 u, mass of ${}^{4}_{2}H$ atom = 4.00260 u

Take 1 u = 931 MeV/c^2.

Solution:

The alpha particle contains 2 protons and 2 neutrons. The binding energy is

$B = (2 \times 1.007826 \text{ u} + 2 \times 1.008665 \text{ u} - 4.00260 \text{ u})c^2 = (0.03038 \text{ u})c^2 = 0.03038 \times 931 \text{ MeV} = 28.4 \text{ MeV}$.

Example 6:

Find the binding energy of ${}^{56}_{26}Fe$. Atomic mass of ${}^{56}Fe$ is 55.9349 u and that of ${}^{1}H$ is 1.00783 u. Mass of neutron = 1.00867 u.

Solution:

The number of protons in ${}^{56}_{26}Fe$ = 26 and the number of neutrons = 56 − 26 = 30.

The binding energy of ${}^{56}_{26}Fe$ is

$= [26 \times 1.00783 \text{ u} + 30 \times 1.00867 \text{ u} - 55.9349 \text{ u}]\, c^2$

$= (0.52878 \text{ u})\, c^2 = (0.52878 \text{ u})\, (931 \text{ MeV/u}) = 492 \text{ MeV}$.

Concept Builder-1

Q.1 The masses of neutron and proton are 1.0087 amu and 1.0073 amu respectively. If two neutrons and two protons combine to form a helium nucleus of mass 4.0015 amu, the B.E. of the helium nucleus will be:

(1) 28.4 MeV (2) 20.8 MeV (3) 27.1 MeV (4) 14.2 MeV

Q.2 The binding energies of the nuclei of ${}^{4}_{2}He$, ${}^{7}_{3}Li$, ${}^{12}_{6}C$ and ${}^{14}_{7}N$ are 28, 52, 90 and 98 MeV, respectively. Which of these are most stable?

(1) ${}^{4}_{2}He$ (2) ${}^{7}_{3}Li$ (3) ${}^{12}_{6}C$ (4) ${}^{14}_{7}N$

Q.3 The binding energy per nucleon of deuteron ${}_{1}H^{2}$ is 1.112 MeV and α-particle ${}_{2}He^{4}$ is 7.047 MeV. Then in the relation ${}_{1}H^{2} + {}_{1}H^{2} \longrightarrow {}_{2}He^{4} + Q$ the energy Q released is:

(1) 1 MeV (2) 11.9 MeV (3) 23.8 MeV (4) 931 MeV

Q.4 The nuclei involved in the nuclear reaction $A_1 + A_2 \rightarrow A_3 + A_4$ have the binding energies E_1, E_2, E_3, and E_4. Find the energy released (Q value) of this reaction.

Q.5 The binding energy per nucleon of O^{16} is 7.97 MeV and that of O^{17} is 7.75 MeV. Find the energy (in MeV) required to remove a neutron from O^{17}.

Q.6 The Q value of a nuclear reaction $A + b \rightarrow C + d$ is defined by

$Q = [\,m_A + m_b - m_C - m_d]c^2$

where the masses refer to the respective nuclei. Determine from the given data the Q-value of the following reactions and state whether the reactions are exothermic or endothermic.

(i) ${}^{1}_{1}H + {}^{3}_{1}H \rightarrow {}^{2}_{1}H + {}^{2}_{1}H$

(ii) ${}^{12}_{6}C + {}^{12}_{6}C \rightarrow {}^{20}_{10}Ne + {}^{4}_{2}He$

Atomic masses are given to be

$m({}^{1}_{1}H) = 1.007825u$, $m({}^{2}_{1}H) = 2.014102u$, $m({}^{3}_{1}H) = 3.016049u$, $m({}^{12}_{6}C) = 12.000000u$,

$m({}^{20}_{10}Ne) = 19.992439u$

mass of He atom is 4.0015 amu

Q.7 Calculate the binding energy of ${}_{17}C^{135}$ if mass of ${}_{17}C^{135}$ nucleus is 34.98 amu, mass of neutron is 1.008665 amu and mass of proton is 1.007277 amu.

Q.8 Two nuclei have their mass numbers in ratio 1 : 3. What is the ratio of nuclear densities ?

3. Radioactivity

It was discovered by Henry Becquerel.

Spontaneous emission of radiations (α, β, γ) from unstable nucleus is called **radioactivity**. Substances which shows radioactivity are known as **radioactive substance**.

Radioactivity was studied in detail by Rutherford.

In radioactive decay, an unstable nucleus emits α particle or β particle. After emission of α or β the remaining nucleus may emit γ-particle, and converts into more stable nucleus.

α-Particle

It is a doubly charged helium nucleus. It contains two protons and two neutrons.

Mass of α-particle = Mass of ${}_2He^4$ atom – $2m_e$ 4 m_p

Charge of α-particle = + 2 e

β-Particle

(a) β^- (Electron)

Mass = m_e; Charge = –e

(b) β^+ (Positron)

Mass = m_e; Charge = +e

positron is an antiparticle of electron.

γ-Particle

They are energetic photons of energy of the order of MeV and having rest mass zero.

Antiparticle

A particle is called antiparticle of other if on collision both can annihilate (destroy completely) and converts into energy. for example: (i) electron (– e, m_e) and positron (+ e, m_e) are anti particles. (ii) neutrino (ν) and antineutrino () are anti particles.

Radioactive Decay (Displacement Law)

(i) α-Decay

Nuclides decays is by emitting α-particles. α-particles are generally emitted by very heavy nuclei containing to many nucleons to remain stable.

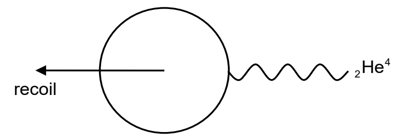
$${}_ZX^A \rightarrow {}_{Z-2}Y^{A-4} + {}_2He^4 + Q$$

Q value : Rest mass energy of reactants –Rest mass energy of products

Q value : $[M_x - (M_y + 2m_e) - (M_{He} - 2_{me})]c^2 = [M_x - M_y - M_{He}]c^2$

- Q-value is the energy released in decay. If initial decaying nucleus is at rest, the Q-values given the total kinetic energy of all the decay products. i.e., $Q = K_Y + K_{He}$

Calculation of Kinetic Energy of Final Products



Momentum of $\alpha_{particle}$ (m_α v) + momentum of daughter nuclei (p_D) = 0

Assuming parent nuclei to be at rest initially

$\vec{p}_\alpha + \vec{p}_D = 0$

$|\vec{p}_\alpha| = |\vec{p}_D|$

If Q is released energy of Q value of reaction.

$\Rightarrow K_\alpha = \left[\frac{A-4}{A}\right]Q$; Similarly, $K_D = \frac{4}{A}Q$

Note : Experimental result shows α-particle have different kinetic energies and these energies are quantised. As all daughter nuclei produced are not in their ground state but some are excited state and they emit photons to acquire their ground state.

(ii) β Decay

When neutron-proton ratio inside a nucleus is not suitable for it be stable (either less of more) then β-decay takes place. Due to a special type of interaction called weak interaction a neutron gets converted into a proton and electron or a proton gets converted into a neutron and a position. Electrons or positrons are emitted from the nucleus just after their creation. This emission of electron or positron from nucleus is called β-decay.

(a) Negative β Decay (β^- Decay)

Neutrons inside nucleus is transformed into proton.

$n \rightarrow p + e^- + \bar{v}$ (Antineutrino)

$_ZX^A \rightarrow {}_{Z+1}Y^A + e + \bar{v}$ + energy released

Equation corresponding to nuclear mass

$\Delta m = M\left[{}_ZX^A\right] - \left\{M\left[{}_{Z+1}Y^A\right] + Me\right\}$

Equation corresponding to atomic mass

$\Delta m = M\left[{}_ZX^A\right] - M\left[{}_{Z+1}Y^A\right]$

energy released $E = \Delta mc^2$

(b) Positive β decay (β^+ Decay)

Proton inside nucleus is transformed into neutron.

$p \rightarrow n + e^+$ (positron) + ν (neutrino)

Positron is anti-particle of electron. It is highly reactive.

${}_{Z}X^{A} \rightarrow {}_{Z-1}Y^{A} + e^{+} + \nu$ + energy released.

Equation corresponding to nuclear mass

$$\Delta m = M\left[{}_{Z}A^{X}\right] - \left\{M\left[{}_{Z-1}Y^{A}\right] + Me\right\}$$

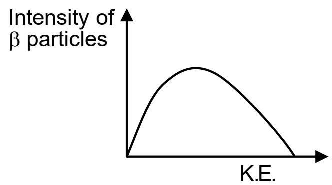
Equation corresponding to atomic mass

$$\Delta m = M\left[{}_{Z}A^{X}\right] - \left\{M *_{Z-1} Y^{A} - 2Me\right\}$$

Energy released

$E = \Delta mc^{2}$

Experiments shows that β-particles are emitted with continuous range of kinetic energy.

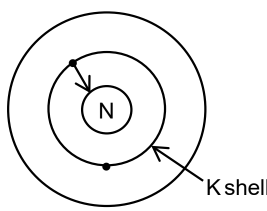


(c) Electron Capture

Nuclei having an excess of protons may capture an electron from one of the orbits which immediately combines with a proton in the nucleus to form a neutron. This process is called electron capture (EC.) The electron is normally captured from innermost orbit (the K- shell), and, consequently, this process is sometimes called K-capture.

$p + {}_{-1}e^{0} \rightarrow n + \nu$

If X and Y are atoms then reaction is written as :



${}_{Z}X^{A} \rightarrow {}_{Z-1}Y^{A} + \nu + Q$ + characteristic x-rays of Y.

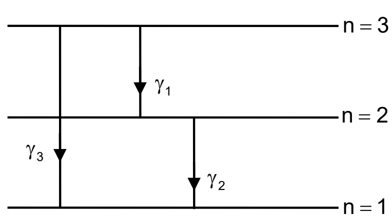
If X and Y are taken as nucleus, then reaction is written as :

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

(iii) γ Decay

When α and β-particle are emitted from nucleus then the daughter nucleus in the excited state. When excited nucleus returns to the ground state then γ-photon is emitted

${}_{Z}^{A}X^{*} \rightarrow {}_{Z}^{A}A + \gamma$



Group-Displacement Law

(1) When a nuclide emits one α-particle ($_2He^4$), its mass number (A) decreased by 4 units and atomic number (Z) decreases by two units.

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

(2) When a nuclide emits a β^- particle, its mass number unchanged but atomic number increases by one unit.

$_ZX^A \rightarrow {}_{Z+1}Y^A + {}_{-1}e^0 + \bar{\nu}$ + Energy

($\bar{\nu}$ is antineutrino)

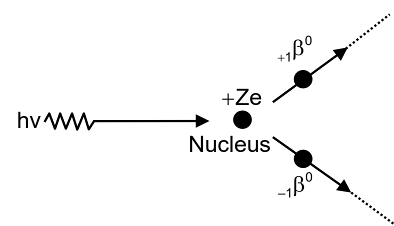
(3) When a nuclide emits a β^+ particle, its mass number remains unchanged but atomic number decreases by one unit

$_ZX^A \rightarrow {}_{Z-1}Y^A + {}_{+1}e^0 + \nu$ + Energy

(ν is neutrino)

(4) When a γ produced, both atomic and mass number remain constant.

Pair Production & Pair Annihilation



Collision of γ-ray photon by a nucleus & production of electron positron pair is known as pair production. The rest mass of each of the electron & positron is 9.1×10^{-31} kg. so, the rest mass energy of each of them is

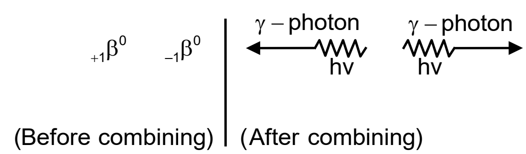
$E_0 = m_0 c^2$

$= (9.1 \times 10^{-31})(3 \times 10^8)^2$

$= 8.2 \times 10^{-14}$ joule

$= 0.51$ MeV

Hence for pair-production, it is essential that the energy of γ-photon must be at least $2 \times 0.51 = 1.02$ MeV.



$$\underset{\text{(positron)}}{_{+1}\beta^0} + \underset{\text{(electron)}}{_{-1}\beta^0} = \underset{(\gamma-\text{photon})}{h\nu} + \underset{(\gamma-\text{photon})}{h\nu}$$

Neutrino and Anti-Neutrino

(1) It has zero electric charge, hence shows no electromagnetic interaction.

(2) Rest mass is possibly zero. Recent experiments show that mass is neutrino is less than $\left(\frac{7}{c^2}\text{eV}\right)$.

(3) It travels with speed of light.

(4) It has spin quantum number 1/2. A spin of 1/2 satisfies the law of conservation of angular momentum when applied to β-decay.

(5) It shows very weak interactions with matter.

(6) Whenever a neutron is produced, a neutrino is also produced.

(7) Whenever a neutron is converted into a proton, an antineutrino is produced.

Example 7:

When $_{90}Th^{228}$ transforms to $_{83}Bi^{212}$, then find number of the emitted α and β-particles.

Solution:

$_{Z=90}Th^{A} \rightarrow {}_{Z'=83}Bi^{A'=212}$

Number of α-particles emitted

$n_\alpha = \frac{A - A'}{4} = \frac{228 - 212}{4} = 4$

Number of β-particles emitted

$n_\beta = 2n_\alpha - Z + Z'$

$= 2 \times 4 - 90 + 83 = 1.$

Example 8:

A stationary Pb^{200} nucleus emits an α-particle with K.E., K = 5.77 MeV. Find the recoil velocity of daughter nucleus. What fraction of the total energy liberated in this decay is accounted for the recoil energy of the daughter nucleus?

Solution:

The momentum of the a-particle is given by,

$P_d = P_\alpha = \sqrt{2m_\alpha K}$ ....(i)

Let the recoil momentum of the daughter nucleus be $P_d = m_d v_d$, where m_d and v_d are the mass and velocity of daughter uncles. Using the principle of conservation of momentum, we get,

$P_d = P_\alpha = \sqrt{2m_\alpha K}$

$\Rightarrow \quad V_d = \frac{\sqrt{2m_\alpha K}}{m_d}$ .....(ii)

$\Rightarrow \quad V_d = \frac{1}{196}\sqrt{\frac{2 \times 4 \times K}{m_P}} = \frac{2}{196}\sqrt{\frac{2K}{m_P}}$

Where m_P is the mass of proton,

$\Rightarrow \quad V_d = 3.39 \times 10^5$ m/s

Let the K.E. of the daughter nucleus be K' then,

$\frac{K'}{K} = \frac{m_\alpha}{m_d}$

As the momenta are same

$\therefore \quad \frac{K'}{K} = \frac{m_\alpha}{m_\alpha + m_d}$

$\Rightarrow \quad K' = \frac{m_\alpha}{m_\alpha + m_d} K_t = \frac{K'}{K} \frac{4}{196 + 4} K_t$

$\Rightarrow \quad K' = 0.02\ K_t$

$\Rightarrow \quad \frac{K'}{K_t} = 0.02$

Example 9:

Calculate the-

(a) energy released in α-decay of ^{238}U

(b) maximum KE of the emitted α-particle. The atom A masses of thorium, uranium and α-particle are 234.04364u, 238.05084u and 4.0026u respectively.

Solution:

The reaction can be given as

$^{238}U \to {}^{234}Th + \alpha$

(X) (Y)

(a) The energy of reaction is

$Q = [m_X - (m_Y + m_\alpha)]$ 931.5 meV]

= [238.0508 – (234.0436 + 4.0026)] × 931.5 MeV = 4.28 MeV

(b) The KE of the α-particle is

$$K_a = \frac{m_Y}{m_Y + m_\alpha} Q$$

$$= \frac{234.0436}{234.0438 + 4.0026} \text{ (4.28)MeV = 4.03MeV}$$

Example 10:

A nucleus with mass number 220 initially at rest emits an α-particle. If the Q value if the reaction is 5.5 MeV, calculate the kinetic energy of the α-particle.

Solution: $^{220}X \to {}^{216}Y + {}^{4}He(\alpha) + 5.5$ meV

$$K_\alpha = \frac{M_Y}{M_X} \times 5.5 \text{ meV}$$

$$= \frac{216}{220} \times 5.5 \text{ meV} = 5.4 \text{ MeV}$$

Example 11:

Calculate the Q-value in the following decays :

(a) $^{19}O \to {}^{19}F + e^- +$

(b) $^{25}Al \to {}^{25}Mg + e^+ + \nu$.

The atomic masses needed are as follows:

^{19}O	^{19}F	^{19}Al	^{25}Mg
19.9003576 u	18.998403 u	24.990432 u	24.985839 u

Solution:

(a) The Q-value of β^- -decay is

$Q = [m(^{19}O) - m(^{19}F)]c^2$

= [19.003576 u – 18.998403 u] (931 MeV/u)

= 4.816 MeV

(b) The Q-value of β^+ -decay is

$Q = [m(^{25}Al) - m(^{25}Mg) - 2m_e]c^2$

$= \left[24.99032u - 24.985839u - 2 \times 0.511\dfrac{MeV}{c^2}\right]c^2$

= (0.004593 u) (931 MeV/u) – 1.022 MeV

= 4.276 MeV – 1.022 MeV = 3.254 MeV.

Example 15:

Neon-23 decays in the following way

$^{23}_{10}Ne \rightarrow ^{23}_{11}Na + ^{0}_{-1}e + \bar{\nu}$

Find the minimum and maximum kinetic energy that the beta particle ($^{0}_{-1}e$) can have. The atomic masses of ^{23}Ne and ^{23}Na are 22.9945 u and 22.9898 u, respectively.

Solution:

Here, atomic masses are given (not the nuclear masses), but still we can use them for calculating the mass defect because mass of electron get cancelled both sides. Thus, Mass defect

Δm = (22.9945 – 22.9898) = 0.0047 u

$\therefore$ Q = (0.0047 u) (931.5 MeV/u) = 4.4 MeV

Hence, the energy of beta particles can range from 0 to 4.4 MeV

Example 16:

A gamma ray photon creates an electron-positron pair. If the rest mass energy of an electron is 0.5 MeV and the total kinetic energy of the electron-positron pair is 0.78 MeV, then what will be the energy of the gamma ray photon?

(1) 0.78 MeV (2) 1.78 MeV (3) 1.28 MeV (4) 0.28 MeV

Solution:

Energy of γ-rays photon

= 0.5 + 0.5 + 0.78 = 1.78 MeV

Concept Builder-2

Q.1 A nucleus with mass number 220 initially at rest emits an α-particle. If the Q value of the reaction is 5.5 MeV. Calculate the kinetic energy of the α-particle.

Q.2 During negative β decay, an antineutrino is also emitted along with the emitted electron. Then:

(1) only linear momentum will be conserved

(2) total linear momentum and total angular momentum but not total energy will be conserved

(3) total linear momentum and total energy but not total angular momentum will be conserved

(4) total linear momentum, total angular momentum and total energy will be conserved

Q.3 $_{92}U^{238} \xrightarrow{\alpha} \xrightarrow{+\beta^0} {}_aX^b$, find a & b.

Q.4 $_aX^b \xrightarrow{-\beta^0} \xrightarrow{\alpha} {}_cY^{215} \xrightarrow{-\beta^0} {}_{110}Y^d$ Find a, b, c and d.

Q.5 $_{92}U^{238} \xrightarrow{n\alpha, n'-\beta^0} {}_{82}Pb^{206}$. Find n & n'

Q.6 Thorium isotope $_{90}Th^{232}$ emits some α–particles and some β–particles and gets transformed into lead isotope $_{82}Pb^{200}$. Find the number of α and β particles emitted.

Q.7 A radioactive nucleus undergoes a series of decays according to the following scheme :

$$A \xrightarrow{\alpha} A_1 \xrightarrow{\beta^-} A_2 \xrightarrow{\alpha} A_3 \xrightarrow{\gamma} A_4$$

If the mass number and atomic number of A are 180 and 72 respectively, what are these numbers for A_4?

Q.8 Write nuclear reaction equations for

(i) α - decay of $^{226}_{88}Ra$ (ii) α - decay of $^{242}_{94}Pu$

(iii) β^- - decay of $^{32}_{15}P$ (iv) β^- - decay of $^{210}_{83}Bi$

(v) β^+ - decay of $^{11}_{6}C$ (vi) β^+ - decay of $^{97}_{43}Tc$

(vii) Electron capture of $^{120}_{54}Xe$

Nuclear Force

- Strong nuclear force is created between nucleons by exchange of particles called mesons.
- It is strongest force within nuclear dimensions
- It is short range force (acts only inside the nucleus)
- It is not due to mass or charge of the particle
- It is not due to interaction of particles with field.
- Nuclear force is not a central force. It does not act along the line joining the particle.
- It is non-conservation in nature.
- If distance between nucleons is smaller than 1 fm then nuclear force is repulsive.
- Strong nuclear force is responsible for binding of nucleus.
- Nuclear force is same for all nucleons at same distance.
  $F_{PP} = F_{NN} = F_{NP}$
- The nuclear force is stronger if spins of nucleons are parallel (i.e both nucleons ms = + 1/2 or – 1/2) and is weaker if the spins are anti-parallel.

Conservation Laws in nucleus

(1) Conservation of mass & energy: In nuclear reaction, mass and energy are not conserved separately.
Mass is a form of energy. Total mass and energy will be conserved.
mass + energy $\rightarrow$ conserved

(2) Conservation of linear momentum: In any nuclear reaction, total linear momentum is always conserved.

(3) Conservation of angular momentum: In any nuclear reaction, total angular momentum remains conserved.

(4) Conservation of charge: In any nuclear reaction, total charge is always conserved.

(5) Conservation of mass no.: In any nuclear reaction, sum of no. of neutrons and protons remains conserved.

Rutherford-Soddy Law (Statistical Law)

The disintegration of a radioactive substance is random and spontaneous.

Radioactive decay is purely a nuclear phenomenon and is independent of any physical and chemical conditions.

Rate of disintegration is proportional is no. of nuclear present.

Mathematically,

$$-\frac{dN}{dt} \propto N$$

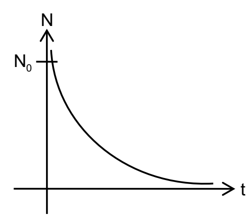
$$\Rightarrow \frac{dN}{dt} = -\lambda N \qquad \text{(where } \lambda \text{ is called as decay of disintegration constant.)}$$

Let N_0 be the number of nuclei at time t = 0, N be the number of nuclei after time t, then

$$\Rightarrow \frac{dN}{N} = -\lambda dt$$

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

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



Half Life ($T_{1/2}$)

The period in which one-half of the radioactive substance is disintegrated. If N_0 be the number of nuclei at t = 0, then in half-life ($T_{1/2}$) the number of nuclei decayed will be $N_0/2$

$$N_t = N_0 e^{-\lambda t} \qquad \text{......(i)}$$

$$\Rightarrow \frac{N_0}{2} = N_0 e^{-\lambda T} \qquad \text{......(ii)}$$

From (i) & (ii)

$$\frac{N_1}{N_0} = \left(\frac{1}{2}\right)^{t/T_{1/2}}$$

The half-life ($T_{1/2}$) and decay constant (λ) are related as: $T_{1/2} = \dfrac{0.693}{\lambda}$

Mean Life / Average Life (T_m)

The mean life (T_m) of a radioactive substance is equal to the sum of life times of all atoms divided by the number of all atoms and is given follows

$$T_m = \frac{\int t\,dN}{\int dN} = \frac{\int_0^\infty t\lambda e^{-\lambda t}dt}{\int_0^\infty \lambda e^{-\lambda t}dt}$$

$$T_m = \frac{1}{\lambda}$$

Activity (A or R)

Activity is defined as rate of radioactive decay of nuclei

$A = \lambda N$

If a radioactive substance changes only due to decay then

$$A = \frac{dN}{dt}$$

As in that case, $N = N_0\, e^{-\lambda t}$

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

$\Rightarrow \quad A = A_0\, e^{-\lambda t}$

Specific Activity: The activity per unit mass is called specific activity.

SI Unit of Activity: becquerel (Bq).

The popular unit of activity is curie (Ci) and Rutherford (Rd).

1Bq = 1 decays/s, 1 Ci = 3.7×10^{10} Bq (which is activity of 1 gm Radium) and 1 Rd = 10^6 Bq

Survival Probability and Decay Probability for a Finite Time Interval

The probability of survival (i.e., not decaying) in time t is

$$P_{survival} = \frac{N_0 e^{-\lambda t}}{N_0} = e^{-\lambda t}$$

Hence the probability of decay is

$P_{decay} = 1 - e^{-\lambda t}$

Example 17:

A radioactive sample has 6.0×10^{18} active nuclei at a certain instant. How many of these nuclei will still be in the same active state after two half-lives?

Solution:

In one half-life the number of active nuclei reduces to half the original number. Thus, in two half-lives the number is reduced to $\left(\frac{1}{2}\right) \times \left(\frac{1}{2}\right)$ of the original number. The number of remaining active nuclei is, therefore, $6.0 \times 10^{18} \times \left(\frac{1}{2}\right) \times \left(\frac{1}{2}\right) = 1.5 \times 10^{18}$.

Example 18:

The number of ^{238}U atoms in an ancient rock equals the number of ^{206}Pb atoms. The half-life of decay of ^{238}U is 4.5×10^{9} y. Estimate the age of the rock assuming that all the ^{206}Pb atoms are formed from the decay of ^{238}U.

Solution:

Since the number of ^{206}Pb atoms equals the number of ^{238}U atoms, half of the original ^{238}U atoms have decayed. It takes one half-life to decay half of the active nuclei. Thus, the sample is 4.5×10^{9} year old.

Example 19:

The half-life of a radioactive nuclide is 20 hours. What fraction of original activity will remain after 40 hours?

Solution:

40 hours means 2 half-lives.

Thus, $A = \frac{A_0}{2^2} = \frac{A_0}{4}$

or, $= \frac{A}{A_0} = \frac{1}{4}$.

So, one fourth of the original activity will remain after 40 hours.

Example 20:

The half-life of ^{198}Au is 2.7 days. Calculate (a) the decay constant, (b) the average-life and (c) the activity of 1.00 mg of ^{198}Au. Take atomic weight of ^{198}Au to be 198 g/mol.

Solution:

(a) The half-life and the decay constant are related as

$$t_{1/2} = \frac{\ln 2}{\lambda} = \frac{0.693}{\lambda} \text{ or, } \lambda = \frac{0.693}{t_{1/2}}$$

$$= \frac{0693}{2.7\text{days}} = \frac{0.693}{2.7 \times 24 \times 3600\text{s}} = 2.9 \times 10^{-6}\ \text{s}^{-1}.$$

(b) The average-life is $t_{av} = \frac{1}{\lambda} = 3.9$ days.

(c) The activity is $A = \lambda N$. Now, 198 g of ^{198}Au has 6×10^{23} atoms.

The number of atoms in 1.00 mg of ^{198}Au is

$$N = 6 \times 10^{23} \times \frac{1.0\text{mg}}{198\text{g}} = 3.03 \times 10^{18}.$$

Thus, $A = \lambda N = (2.9 \times 10^{-6}\ \text{s}^{-1})(3.03 \times 10^{18})$

$$= 8.8 \times 10^{12} \text{ disintegrations/s} = \frac{8.8 \times 10^{12}}{3.7 \times 10^{10}} \text{ Ci} = 240 \text{ Ci}.$$

Example 21:

The decay constant for the radioactive nuclide ^{64}Cu is $1.516 \times 10^{-5}\ s^{-1}$. Find the activity of a sample containing 1 μg of ^{64}Cu. Atomic weight of copper = 63.5 g/mole. Neglect the mass difference between the given radioisotope and normal copper.

Solution:

63.5 g of copper has 6×10^{23} atoms. Thus, the number of atoms in 1 μg of Cu is

$$N = \frac{6 \times 10^{23} \times 1\mu g}{63.5g} = 9.45 \times 10^{15}$$

The activity = λN

$= (1.516 \times 10^{-5}\ s^{-1}) \times (9.45 \times 10^{15})$

$= 1.43 \times 10^{11}$ disintegrations/s

$$= \frac{1.43 \times 10^{11}}{3.7 \times 10^{10}}\ Ci = 3.86\ Ci.$$

Example 22:

Suppose, the daughter nucleus in a nuclear decay is itself radioactive. Let λ_p and λ_d be the decay constants of the parent and the daughter nuclei. Also, let N_p and N_d be the number of parent and daughter nuclei at time t. Find the condition for which the number of daughter nuclei becomes constant.

Solution:

The number of parent nuclei decaying in a short time interval t to t + dt is $\lambda_p N_p dt$. This is also the number of daughter nuclei decaying during the same time interval is $\lambda_d N_d dt$. The number of the daughter nuclei will be constant if

$$\lambda_p N_p dt = \lambda_d N_d dt$$

or, $\quad \lambda_p N_p = \lambda_d N_d$.

Example 23:

A radioactive nucleus can decay by two different processes. The half-life for the first process is t_1 and that for the second process is t_2. Show that the effective half-life t of the nucleus is given by. $\frac{1}{t} = \frac{1}{t_1} + \frac{1}{t_2}$

Solution:

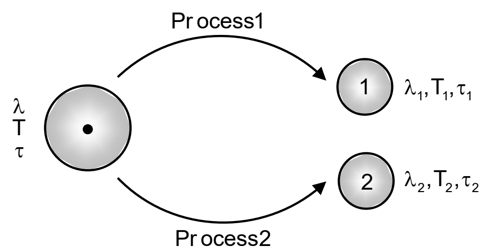
The decay constant for the first process is $\lambda_1 = \frac{\ln 2}{t_1}$ and for the second process it is $\lambda_2 = \frac{\ln 2}{t_1}$. The probability that an active nucleus decays by the first process in a time interval dt is $\lambda_1 dt$. Similarly, the probability that it decays by the second process is $\lambda_2 dt$. The probability that it either decays by the first process or by the second process is $\lambda_1 dt + \lambda_2 dt$. If the effective decay constant is λ, this probability is also equal to λdt. Thus.

$\lambda dt = \lambda_1 dt + \lambda_2 dt$

or, $\lambda = \lambda_1 + \lambda_2$ or, $\frac{1}{t} = \frac{1}{t_1} + \frac{1}{t_2}$.

(To be remembered)

If a nuclide can decay simultaneously by two different process which have decay constant λ_1 and λ_2, half-life T_1 and T_2 and mean lives τ_1 and τ_2 respectively then



$\Rightarrow$ $\lambda = \lambda_1 + \lambda_2$

$\Rightarrow$ $T = \frac{T_1T_2}{T_1 + T_2}$ $\Rightarrow \tau = \frac{\tau_1\tau_2}{\tau_1 + \tau_2}$

Concept Builder-3

Q.1 The half lives of radioactive elements x and y are 3 minute and 27 minute respectively. If the activities of both are same, then calculate the ratio of number of atoms of x and y.

Q.2 Carbon has two stable isotopes. Natural carbon has 98.9% carbon–12 and 1.1% carbon–13, calculate the average atomic weight of carbon.

Q.3 A radioactive isotope has a half life of T. After how much time is its activity reduced to 6.25% of its original activity ?

Q.4 $\frac{2}{3}$ fraction of a sample disintegrates in 7 days. How much fraction of it will decay in 21 days ?

Q.5 The half life of radium is 1600 years. After how many years 25% of radium block remains undecayed ?

Q.6 A radioactive isotope has a half-life of T years. How long will it take the activity to reduce to (a) 3.125%, (b) 1% of its original value?

Q.7 Obtain the amount of $^{60}_{27}Co$ necessary to provide a radioactive source of 8.0 mCi strength. The half-life of $^{60}_{27}Co$ is 5.3 years.

4. Nuclear Fission & Fusion

(i) Nuclear Fission

The splitting of heavy nucleus into two or more fragments of comparable masses, with an enormous release of energy is called nuclear fission.

- When slow neutrons are bombarded on $_{92}U^{235}$, the fission takes place according to reaction

$$_{92}U^{235} + {}_0n^1 \rightarrow {}_{56}Ba^{141} + {}_{36}Kr^{92} + 3({}_0n^1) + 200 \text{ MeV}$$

(a) In nuclear fission the sum of masses before reaction is greater than the sum of masses after reaction, the difference in mass being releases in the form fission energy.

(b) The phenomenon of nuclear fission was discovered by Otto Hans and F. Strassman in 1939 and was explained by N. Bohr and J.A. Wheeler on the basis of liquid drop model of nucleus.

(c) It may be pointed out that it is not necessary that in each fission we get same daughter nuclides. if uranium breaks in two fragments Ba^{141} and Kr^{92} are formed but they may be any stable isotopes of middle weight atoms. The most probable division is into two fragments containing about 40% and 60% of the original nucleus with the emission of 2 or 3 neutrons per fission. So, average number of neutrons produced per fission is 2.5.

(d) Most of energy released appears in the kinetic energy of fission fragments.

(e) The fission of U^{238} takes place by fast neutrons.

Chain Reaction

If on average more than one of the neutrons produced in each fission are capable of causing further fission, the number of fissions taking placed at successive stages goes increasing at a rapid rate, giving rise to self-sustained sequence of fission known as chain reaction. the chain reaction takes place only if the size of the fissionable material is greater than a certain size the critical size.

Uncontrolled Chain Reaction

In this process the number of fissions in a given interval on the average goes on increasing and the system will have the explosive tendency. This forms the principle of atom bomb. If a nuclear reaction is uncontrolled then in about 1 μs, energy of order of 2×10^3 J is released.

Controlled Chain Reaction

In this process the number of fissions in a given interval is maintained constant by absorbing a desired number of neutrons. This forms the principle of nuclear retort, consisting of the following parts:

(a) Fuel: The fuel is U^{235} or U^{233} or Pu^{239}

(b) Moderator: A moderator is a suitable material to slow down neutrons produced in the fission. The best choice as moderator are heavy water (D_2O) and graphite (C).

(c) Controller: To maintain the steady rate of fission, the neutron absorbing material known as controller is used. The control rods are made of cadmium or Boron-steel.

(d) Coolant: To remove the considerable amount of heat produced in the fission process, suitable cooling fluids known as coolants, are used. The usual coolants are water, carbon-dioxide, air etc.

(e) Reactor shield: The intense neutrons and gamma radiation produced in nuclear reactors are harmful for human body. To protect the workers from such radiations, the reactor core is surrounded by concrete wall, called the reactor shield.

(f) U^{238} is non - fissile, it cannot support a chain reaction.

Critical Mass

If the amount of uranium is too small, then the liberated neutrons have large scope to escape from the surface and the chain reaction may stop before enough energy is released for explosion. Therefore, in order for explosion to occur, the mass uranium has to be greater than some minimum value, called the **critical mass**.

Reproduction Factor

It is the ratio of the rate of neutron production and the rate at which the neutrons disappear. Whether a mass of active material will sustain a chain reaction or not is determined by the reproduction factor (K). If K 1, the chain reaction will be sustained. If K = 1, the mass is said to be critical.

(ii) Nuclear Fusion

The phenomenon of combination of two or more light nuclei to form a heavy nucleus with release of enormous amount of energy is called the nuclear fusion. The sum of masses before fusion must be greater than the sum of masses after fusion, the difference in mass appearing as fusion energy. The fusion of two deuterium nuclei into helium is expressed as

$_1H^2 + {}_1H^2 \rightarrow {}_2He^4 + 23.8\text{ MeV}$

It may be pointed out that fusion reaction does not actually occur. Due to huge quantity of energy release, the helium nucleus $_2He^4$ has got such a large value of excitation energy that it breaks up by the emission of a proton or a neutron as soon as it is formed, giving rise to the following reactions.

$_1H^2 + {}_1H^2 \rightarrow {}_2He^3 + {}_0n^1 + Q(= 3.26\text{ MeV})$

$_1H^2 + {}_1H^2 \rightarrow {}_1H^3 + {}_1H^1 + Q(= 4.04\text{ MeV})$

The fusion process occurs at extremely high temperature and high pressure just as it takes place at sun where temperature is 10^7K. So, fusion reactions are also called Thermo-nuclear reactions.

- Nuclear fusion has the possibility of being a much better source of energy than fission due to the following reasons.

  (a) In fusion there is no radiation hazard as no radioactive material is used.

  (b) The fuel needed for fission (U-235 etc.) is not available easily whereas hydrogen needed for fusion can be obtained in huge quantity.

  (c) The energy released per nucleon is much more in fusion than in fission.

  However, the very high temperature and pressure required for fusion cannot be easily created and maintained and as such it has not been possible as yet to use fusion for power generation.

Example 24:

In a nuclear reactor, fission is produced in 1 g for U^{235} (235.0439) in 24 hours by slow neutrons (1.0087 u). Assume that $_{35}Kr^{92}$ (91.8973 u) and $_{56}Ba^{141}$ (140.9139 amu) are produced in all reactions and no energy is lost.

(i) Write the complete reaction (ii) Calculate the total energy produced in kilowatt hour.

Given 1 u = 931 MeV.

Solution:

The nuclear fission reaction is $_{92}U^{235} + {}_0n^1 \rightarrow {}_{56}Ba^{141} + {}_{36}Kr^{92} + 3{}_0n^1$

Mass defect $\Delta m = [(m_u + m_n) - (m_{Ba} + m_{Kr} + 3\ m_n)] = 236.0526 - 235.8373 = 0.2153$ u

Energy released Q = 0.2153 × 931 = 200 MeV. Number of atoms in 1 g = $\frac{6.02 \times 10^{23}}{235} = 2.56 \times 10^{21}$

Energy released in fission of 1 g of U^{235} is $E = 200 \times 2.56 \times 10^{21} = 5.12 \times 10^{23}$ MeV

$= 5.12 \times 10^{23} \times 1.6 \times 10^{-13} = 8.2 \times 10^{10}$ J

$= \frac{8.2 \times 10^{10}}{3.6 \times 10^{6}}$ kWh $= 2.28 \times 10^{4}$ kWh

Concept Builder-4

Q.1 Calculate the energy released by the fission of 2 g of $_{92}U^{235}$ in kWh. Given that the energy released per fission is 200 MeV.

Q.2 If the energy released in the fission of one nucleus is 3.2×10^{-11}J, then find number of nuclei required per second in a power plant of 16 kW.

Q.3 Find out the mass of Uranium required per day to generate 10 MW power from the fission of $_{92}U^{235}$.

Q.4 The mass defect in a nuclear fusion reaction is 0.3 percent. What amount of energy will be liberated in one kg fusion reaction ?

Uses of Radioactive isotopes:

(i) In Medicine:

- Co^{60} for treatment of cancer
- Na^{24} for circulation of blood
- I^{131} for thyroid
- Sr^{90} for treatment of skin & eye
- Fe^{59} for location of brain tumor
- Radiographs of castings and teeth

(ii) In Industries:

- For detecting leakage in water and oil pipe lines
- For investigation of wear & tear, study of plastics & alloys, thickness measurement.

(iii) In Agriculture:

- C^{14} to study kinetics of plant photosynthesis.
- P^{32} to find nature of phosphate which is best for given soil & crop
- Co^{60} for protecting potato crop from earth worm.
- Sterilization of insects for pest control.

(iv) In Scientific research:

- K^{40} to find age of meteorites
- S^{35} in factories

(v) Carbon dating:

- It is used to find age of earth and fossils
- The age of earth is found by Uranium disintegration and fossil age by disintegration of C^{14}.
- The estimated age of earth is about 5×10^9 years.
- The half-life of C^{14} is 7500 years.

(vi) As Tracers:

- A very small quantity of radio isotope present in any specimen is called tracer.
- This technique is used to study complex biochemical reactions, in detection of cracks, blockage etc., tracing sewage or silt in sea

(vii) In Geology:

- for dating geological specimens like ancient rocks, lunar rocks using Uranium
- for dating archaeological specimens, biological specimens using C^{14}.

ANSWER KEY FOR CONCEPT BUILDERS

CONCEPT BUILDER-1

1. (1) **2.** (3) **3.** (3)

4. $(E_3 + E_4) - (E_1 + E_2)$ **5.** 4.23 MeV

6. (i) −4.031 MeV, endothermic

(ii) 5.64 MeV, exothermic

7. 278.92 MeV **8.** 1 : 1

CONCEPT BUILDER-2

1. 5.4 MeV **2.** (4)

3. a = 89, b = 234

4. a = 110, b = 219, c = 109, d = 215

5. n = 8, n' = 6 **6.** $N_\alpha = 8, N_\beta = 8$

7. Mass number = 172 and

Atomic number = 69

8. (i) ${}^{226}_{88}Ra \xrightarrow{-\alpha} {}^{222}_{86}Rn + {}^{4}_{2}He$

(ii) ${}^{242}_{94}Ra \xrightarrow{-\alpha} {}^{238}_{92}U + {}^{4}_{2}He$

(iii) ${}^{32}_{15}P \xrightarrow{-\beta^-} {}^{32}_{16}S + {}^{0}_{-1}\beta + \overline{\upsilon}$

(iv) ${}^{210}_{83}Bo \xrightarrow{-\beta^-} {}^{210}_{84}Po + {}^{0}_{-1}\beta + \overline{\upsilon}$

(v) ${}^{11}_{6}C \xrightarrow{-\beta^+} {}^{11}_{5}B + {}^{0}_{+1}\beta + \upsilon$

(vi) ${}^{97}_{43}Tc \xrightarrow{-\beta^+} {}^{97}_{42}Mo + {}^{0}_{+1}\beta + \upsilon$

(vii) ${}^{120}_{54}Xe + {}_{-1}e^0 \xrightarrow{\text{electron capture}} {}^{120}_{53}I + X\text{-}Ray + \upsilon$

CONCEPT BUILDER-3

1. $\frac{1}{9}$ **2.** 12.011 amu **3.** 4T

4. $\frac{26}{27}$ **5.** 3200 years

6. (a) 5T, (b) 6.64T **7.** 7 μg

CONCEPT BUILDER-4

1. 4.55×10^4 kWh. **2.** 5×10^{14}

3. 10.5 g **4.** 2.7×10^{14} J

Exercise - I

1. The stable nucleus that has a radius 1/3 that of Os^{189} is -

(1) $_3Li^7$ (2) $_2He^4$

(3) $_5B^{10}$ (4) $_6C^{12}$

2. The mass numbers of nuclei A and B are respectively 125 and 64. The ratio of their radii is:

(1) 1 : 3 (2) 5 : 4

(3) $\sqrt{27} : 1$ (4) $1 : \sqrt{27}$

3. If M_0 is the mass of an oxygen isotope $_8O^{17}$, M_p and M_n are the masses of a proton and a neutron, respectively the nuclear binding energy of the isotope is

(1) $(M_0 - 8M_p)\ C^2$

(2) $(_8M_P + 9M_n - M_0)\ C^2$

(3) M_0c^2

(4) $(M_0 - 17\ Mn)\ C^2$

4. Two substances have different atomic masses and same atomic number. They are :

(1) isotopes (2) isobars

(3) isotones (4) none of these

5. 1 amu is equivalent to :

(1) 931 MeV (2) 0.51eV

(3) 9.31 MeV (4) 1.02 MeV

6. The uncle of which one of the following pairs of nuclei are isotones:

(1) $_{34}Se^{74}, _{31}Ga^{71}$ (2) $_{38}Sr^{84}, _{38}sr^{86}$

(3) $_{42}Mo^{92}, _{40}Zr^{92}$ (4) $_{20}Ca^{40}, _{16}S^{32}$

7. Masses of nucleus, neutron and protons are M, n_m and m_p respectively. If nucleus has been divided in to neutrons and protons, then

(1) $M = (A - Z)\ m_n + Zm_p$

(2) $M = Zm_n + (A - Z)\ m_p$

(3) $M < (A - Z)\ m_n + Zm_p$

(4) $M > (A - Z)m_n + Zm_p$

8. As the mass number A increases, the binding energy per nucleon in a nucleus

(1) increases

(2) decreases

(3) remains the same

(4) varies in a way that depends on the actual value of A.

9. A nucleus has mass represented by M(A, Z). If M_p and M_n denote the mass of proton and neutron respectively and BE the binding energy (in MeV), then:

(1) $BE = [M(A,Z) - ZM_p - (A - Z)\ M_n]c^2$

(2) $BE = [ZM_p + (A - Z)\ M_n - M\ (A, Z)]c^2$

(3) $BE = [ZM_p + AM_n - M\ (A,Z)]c^2$

(4) $BE = M\ (A,Z) - ZM_p - (A - Z)\ M_n$

10. If the nucleus $^{27}_{13}Al$ has a nuclear radius of about 3.6 fm, then $^{125}_{52}Te$ would have its radius approximately as :

(1) 6.0 fm (2) 9.6 fm

(3) 12.0 fm (4) 4.8 fm

11. Two nuclei have their mass numbers in the ratio of 1 : 3. The ratio of their nuclear densities would be :

(1) 1 : 3 (2) 3 : 1

(3) $(3)^{1/3} : 1$ (4) 1 : 1

12. The mass of a $^{7}_{3}Li$ nucleus is 0.042 u less than the sum of the masses of all its nucleons. The binding energy per nucleon of $^{7}_{3}Li$ nucleus is nearly:

(1) 46 MeV (2) 5.6 MeV
(3) 3.9 MeV (4) 23 MeV

13. Which of the following is a wrong description of binding energy of a nucleus?

(1) It is the energy required to break a nucleus into its constituent nucleons.
(2) It is the energy released when free nucleons combine to from a nucleus.
(3) It is the sum of the rest mass energies of its nucleons minus the rest mass energy of the nucleus.
(4) It is the sum of the kinetic energy of all the nucleons in the nucleus.

14. The energy of the reaction $Li^7 + p \rightarrow 2\ He^4$ is (the binding energy per nucleon in Li^7 and He^4 nuclei are 5.60 and 7.06 MeV respectively.)

(1) 17.3 MeV
(2) 1.73 MeV
(3) 1.46 MeV
(4) depends on binding energy of proton

15. An α-particle is bombarded on ^{14}N. As a result, a ^{17}O nucleus is formed and a particle is emitted. This particle is a

(1) neutron (2) proton
(3) electron (4) positron

16. A free neutron decays into a proton, an electron and :

(1) A neutrino (2) An antineutrino
(3) An α-particle (4) A β-particle

17. In one average-life

(1) half the active nuclei decay
(2) less than half the active nuclei decay
(3) more than half the active nuclei decay
(4) all the nuclei decay

18. A freshly prepared radioactive source of half-life 2 h emits radiation 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 :

(1) 6 h (2) 12 h
(3) 24 h (4) 128 h

19. 10 grams of ^{57}Co kept in an open container decays β–particle with a half-life of 270 days. The weight of the material inside the container after 540 days will be very nearly:

(1) 10 g (2) 7.5 g
(3) 5 g (4) 2.5 g

20. After a time equal to four half lives, the amount of radioactive material remaining undecayed is-

(1) 6.25 % (2) 12.50 %
(3) 25.0 % (4) 50.0 %

21. The decay constant of the parent nuclide in Uranium series is λ. Then the decay constant of the stable end product of the series will be-

(1) $\lambda/238$ (2)$\lambda/206$
(3) $\lambda/208$ (4) zero

22. The half-life of thorium (Th^{232}) is 1.4×10^{10} years. Then the fraction of thorium atoms decaying per year is very nearly -

(1) 1×10^{-11} (2) 4.95×10^{-11}
(3) 0.69×10^{-11} (4) 7.14×10^{-11}

23. If mass of the fissionable material is less than the critical mass, then

(1) fission and chain reactions both are impossible.

(2) fission is possible but chain reaction is impossible.

(3) fission is impossible but chain reaction is possible.

(4) fission and chain reaction both are possible.

24. Which of the following materials is used for controlling the fission?

(1) heavy water (2) graphite

(3) cadmium (4) Beryllium oxide

25. $_{92}U^{235}$ nucleus absorbs a slow neutron and undergoes fission into $_{54}X^{139}$ and $_{38}Sr^{94}$ nuclei. The other particles produced in this fission process are

(1) 1 β and 1 α (2) 2 β and 1 neutron

(3) 2 neutrons (4) 3 neutrons

26. Fusion reaction is possible at high temperature because -

(1) atoms are ionised at high temperature

(2) molecules break-up at high temperature

(3) nuclei break-up at high temperature

(4) kinetic energy is high enough to overcome repulsion between nuclei.

27. Let F_{pp}, F_{pn} and F_{nn} denote the magnitudes of the nuclear force by a proton on a proton, by a proton on a neutron and by a neutron on a neutron respectively. When the separation is 1 fm,

(1) $F_{pp} > F_{pn} = F_{nn}$ (2) $F_{pp} = F_{pn} = F_{nn}$

(3) $F_{pp} > F_{pn} > F_{nn}$ (4) $F_{pp} < F_{pn} = F_{nn}$

28. When a β^{-}-particle is emitted from a nucleus, the neutron-proton ratio :

(1) is decreased (2) is increased

(3) remains the same (4) first (1) then (2)

29. Two radioactive sources *A* and *B* initially contain equal number of radioactive atoms. Source *A* has a half-life of 1 hour and source *B* has a half-life of 2 hours. At the end of 2 hours, the ratio of the rate of disintegration of *A* to that of *B* is :

(1) 1 : 2 (2) 2 : 1

(3) 1 : 1 (4) 1 : 4

30. A free neutron decays to a proton but a free proton does not decay to a neutron. This is because

(1) neutron is a composite particle made of a proton and an electron whereas proton is fundamental particle.

(2) neutron is an uncharged particle whereas proton is a charged particle.

(3) neutron has larger rest mass than the proton.

(4) weak forces can operate in a neutron but not in a proton.

31. Two isotopes P and Q of atomic weight 10 and 20, respectively are mixed in equal amount by weight. After 20 days their weight ratio is found to be 1 : 4. Isotope P has a half-life of 10 days. The half-life of isotope Q is

(1) zero (2) 5 days

(3) 20 days (4) infinite

32. Half-lives of two radioactive substances A and B are respectively 20 min and 40 min. Initially the samples of A and B have equal number of nuclei. After 80 min the ratio of remaining number of A and B nuclei is :

(1) 1 : 16 (2) 4 : 1

(3) 1 : 4 (4) 1 : 1

33. A nucleus ${}_{n}X^{m}$ emits one α and two β particles. The resulting nucleus is :

(1) ${}_{n}X^{m-4}$ (2) ${}_{n-2}y^{m-4}$

(3) ${}_{n-4}Z^{m-4}$ (4) none of these

34. Complete the equation for the following fission process :

${}_{92}U^{235} + {}_{0}n^{1} \rightarrow {}_{38}Sr^{90} + ...$

(1) ${}_{54}Xe^{143} + 3\ {}_{0}n^{1}$ (2) ${}_{54}Xe^{145}$

(3) ${}_{57}Xe^{142}$ (4) ${}_{54}Xe^{142} + {}_{0}n^{1}$

35. Alpha particles are :

(1) 2 free protons

(2) helium atoms

(3) singly ionized helium atoms

(4) doubly ionized helium atoms

36. When a proton is accelerated through 1V its kinetic energy will be :

(1) 1540 eV (2) 13.6 eV

(3) 1 eV (4) zero

37. In one α and 2β -emissions :

(1) mass number reduces by 2

(2) mass number reduces by 6

(3) atomic number reduces by 2

(4) atomic number remains unchanged

38. Which ray contain (+Ve) charge particle :-

(1) α-rays (2) β-rays

(3) γ-rays (4) X-rays

39. Half life of radioactive element is 12.5 Hour and its quantity is 256 gm. After how much time its quantity will remain 1 gm :

(1) 50 Hrs (2) 100 Hrs

(3) 150 Hrs (4) 200 Hrs

40. M_n and M_p represent the mass of neutron and proton respectively An element having mass M has N neutron and Z-protons, then the correct relation will be :

(1) $M < \{N.m_n + Z.M_p\}$ (2) $M > \{N.m_n + Z.M_p\}$

(3) $M = \{N.m_n + Z.M_p\}$ (4) $M = N\ \{.m_n + M_p\}$

41. If half-life of a substance is 38 days and its quantity is 10.38 g. Then quantity remaining left after 19 days will be :

(1) 0.151 (2) 7.0

(3) 0.51 (4) 0.16

42. Which of the followings is a correct statement?

(1) beta rays are same as cathode rays.

(2) gamma rays are high energy neutrons.

(3) alpha particles are singly-ionized helium atoms.

(4) protons and neutrons have exactly the same mass.

43. A sample of radioactive element containing 4×10^{16} active nuclei. Half life of element is 10 days, then number of decayed nuclei after 30 days :

(1) 0.5×10^{16} (2) 2×10^{16}

(3) 3.5×10^{16} (4) 1×10^{16}

44. A nuclear reaction given by

${}_{z}X^{A} \longrightarrow {}_{z+1}Y^{A} + {}_{-1}e^{0} +$ represents

(1) β-decay (2) γ-decay

(3) fusion (4) fission

45. An α – particle is bombarded on, ${}_{7}N^{14}$ As. a result, a ${}_{8}O^{17}$ -nucleus is formed and a particle X is emitted. The particle X is :

(1) neutron (2) proton

(3) electron (4) positron

46. In the reaction ${}_{92}X^{234} \longrightarrow {}_{87}Y^{222}$ How many α-particles and β-particles are emitted ?

(1) 3 and 5 (2) 5 and 3

(3) 3 and 3 (4) 3 and 1

47. The decay constant of a radioactive substance is λ. The half-life and mean life of substance are respectively given by

(1) $\frac{1}{\lambda}$ and $\frac{\log_e 2}{\lambda}$ (2) $\frac{\log_e 2}{\lambda}$ and $\frac{1}{\lambda}$

(3) $\frac{\lambda}{\log_e 2}$ and $\frac{1}{\lambda}$ (4) $\frac{\lambda}{\log_e 2}$ and 2λ

48. If N_0 is the original mass of the substance of half-life period $t_{1/2}$ = 5 years, then the amount of substance left after 15 years is :

(1) N_0 / 8 (2) N_0 / 16

(3) N_0 / 2 (4) N_0 / 4

49. The half-life of radioactive substance is 4 days. Its 100 g is kept for 16 days. After this period, the amount of substance remained is:

(1) 25 g (2) 15 g

(3) 10 g (4) 6.25 g

50. A nucleus of mass number 232 and z = 90. After many disintegrations of α and β radiations, decays into other nucleus whose mass number is 220 and atomic number is 86. The numbers of α and β radiations will be :

(1) 4, 0 (2) 3, 6

(3) 3, 2 (4) 2, 1

51. A radioactive element has half-life of 3.6 days. In what time will it be left 1/32nd undecayed ?

(1) 4 days (2) 12 days

(3) 18 days (4) 24 days

52. The functions of moderators in nuclear reactor is:

(1) decrease the speed of neutrons

(2) Increase the speed of neutrons

(3) decrease the speed of electrons

(4) decrease the speed of electrons

53. A chain reaction in fission of uranium is possible, because:

(1) two intermediate sized nuclear fragments are formed

(2) three neutrons are given out in each fission

(3) fragments in fission are radioactive

(4) large amount of energy is released

54. A nuclei X with mass number A and charge number Z, disintegrates into one -particle and one -particle. The resulting R has atomic mass and atomic number, equal to:

(1) (A – Z) and (Z – 1)

(2) (A – Z) and (Z – 2)

(3) (A – 4) and (A – 2)

(4) (A – 4) and (Z – 1)

55. M_P and M_N are masses of proton and neutron, respectively, at rest. If they combine to form deuterium nucleus. The mass of the nucleus will be:

(1) less than M_P

(2) less than (M_P + M_N)

(3) less than (M_P + $2M_N$)

(4) greater than (M_P + $2M_N$)

56. If a sample of 16 g radioactive substance disintegrate to 1g in 120 days, then what will be the half-life of the sample ?

(1) 15 days (2) 7.5 days

(3) 30 days (4) 60 days

57. Nuclear fusion is common to the pair :

(1) thermonuclear rector, uranium based nuclear reactor

(2) energy production in sun, uranium based nuclear reactor

(3) energy production of heavy nuclei hydrogen bomb

(4) disintegration of heavy nuclei hydrogen bomb

58. In a sample of radioactive material, what percentage of the initial number of active nuclei will decay during one mean life ?

(1) 37% (2) 50%

(3) 63% (4) 69.3%

59. For the stability of any nucleus:
(1) binding energy per nucleon will be more
(2) binding energy per nucleon will be less
(3) number of electrons will be more
(4) none of the above

60. If the half-life of any sample of radioactive substance is 4 days, then the fraction of sample will remain undecayed after 2 days, will be
(1) $\sqrt{2}$ (2) $\frac{1}{\sqrt{2}}$
(3) $\frac{\sqrt{2}-1}{\sqrt{2}}$ (4) $\frac{1}{2}$

61. in radioactive decay process the negatively charged emitted β – particles are
(1) the electrons present inside the nucleus
(2) the electrons produced inside as a result of the decay of neutrons inside the nucleus
(3) the electrons produced as a result of collisions between atoms
(4) the electrons orbiting around the nucleus

62. In gamma ray emission from a nucleus
(1) both the neutron number and the proton number change
(2) there is no change in the proton number and the neutron number
(3) only the neutron number changes
(4) only the proton number changes

63. A radioactive sample at any instant has its disintegration rate 5000 disintegrations per minute. After 5 min, the rate is 1250 disintegrations per min. then the decay constant (per – minute) is
(1) 0.4 In2 (2) 0.2 In2
(3) 0.1 In2 (4) 0.8 In2

64. A nucleus with Z = 92 emits the following in a sequence : $\alpha\ \beta^-, \beta^-, \alpha\ \alpha\ \alpha\ \alpha\ \alpha; \beta^-, \beta^-, \alpha, \beta^+, \beta^+, \alpha$. The Z of the resulting nucleus is:
(1) 76 (2) 78
(3) 82 (4) 74

65. Which of the following cannot be emitted by radioactive substances during the plates of a capacitor, The capacitor
(1) Protons (2) Neutrinos
(3) Helium nuclei (4) Electrons

66. If a radioactive substance decays $\frac{1}{16}$th of its original amount in 2 h, then the half-life of that substance is
(1) 15 min (2) 30 min
(3) 45 min (4) None of these

67. If the disintegration series
$${}^{238}_{92}U \xrightarrow{\alpha} X \xrightarrow{\beta^-} {}^{A}_{Z}Y$$
the values of Z and A respectively will be **:**
(1) 92, 236 (2) 88, 230
(3) 90, 234 (4) 91, 234

ANSWER KEY

Que.	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**
Ans.	1	2	2	1	1	1	3	4	2	1	4	2	4	1	2	2	3	2	1	1	4	2	2	3	4
Que.	**26**	**27**	**28**	**29**	**30**	**31**	**32**	**33**	**34**	**35**	**36**	**37**	**38**	**39**	**40**	**41**	**42**	**43**	**44**	**45**	**46**	**47**	**48**	**49**	**50**
Ans.	4	2	1	3	3	4	3	1	1	4	3	4	1	2	1	2	1	3	1	2	4	2	1	4	3
Que.	**51**	**52**	**53**	**54**	**55**	**56**	**57**	**58**	**59**	**60**	**61**	**62**	**63**	**64**	**65**	**66**	**67**								
Ans.	3	1	2	4	2	3	3	3	1	2	2	2	1	2	1	2	4								

Exercise - II

1. If N_0 is the original mass of the substance of half-life period $t_{1/2}$ = 5 years, then the amount of substance left after 15 years is-

(1) $\frac{N_0}{8}$ (2) $\frac{N_0}{16}$

(3) $\frac{N_0}{2}$ (4) $\frac{N_0}{4}$

2. At a specific instant emission of radioactive compound is deflected in a magnetic field. The compound can emit-

(i) electrons (ii) protons

(iii) He^{2+} (iv) neutrons

The emission at the instant can be-

(1) i, ii, iii (2) i, ii, iii, iv

(3) iv (4) ii, iii

3. Which of the following radiations has the least wavelength ?

(1) γ-rays (2) β-rays

(3) α-rays (4) X-rays

4. When U^{238} nucleus originally at rest, decays by emitting an alpha particle having a speed u, the recoil speed of the residual nucleus is-

(1) $\frac{4u}{238}$ (2) $-\frac{4u}{234}$

(3) $\frac{4u}{234}$ (4) $-\frac{4u}{238}$

5. A radioactive sample at any instant has its disintegration rate 5000 disintegration per minute. After 5 minutes, the rate is 1250 disintegrations per minute. Then, the decay constant (per minute) is-

(1) 0.4 ln 2 (2) 0.2 ln 2

(3) 0.1 ln 2 (4) 0.8 ln 2

6. A nucleus with Z = 92 emits the following in a sequence : $\alpha, \alpha, \beta^-, \beta^-, \alpha, \alpha, \alpha, \alpha, \beta^-, \beta^-, \alpha, \beta^+, \beta^+, \alpha$. The Z of the resulting nucleus is-

(1) 76 (2) 78

(3) 82 (4) 74

7. Which of the following cannot be emitted by radioactive substances during their decay ?

(1) Protons (2) Neutrinos

(3) Helium nuclei (4) Electrons

8. In the nuclear fusion reaction, ${}_1^2H + {}_1^3H \rightarrow {}_2^4He + n$ given that the repulsive potential energy between the two nuclei is 7.7×10^{-14} J, the temperature at which the gases must be heated to initiate the reaction is nearly [Boltzmann's constant $k = 1.38 \times 10^{-23}$ J/K]

(1) 10^7 K (2) 10^5 K

(3) 10^3 K (4) 10^9 K

9. A nucleus disintegrates into two nuclear parts which have their velocities in the ratio 2 : 1 The ratio of their nuclear sizes will be:

(1) $2^{1/3} : 1$ (2) $1 : 3^{1/2}$

(3) $3^{1/2} : 1$ (4) $1 : 2^{1/3}$

10. The binding energy per nucleon of deuteron (${}_1^2H$) and helium nucleus (${}_2^4He$) is 1.1 MeV and 7 MeV respectively. If two deuteron nuclei react to form a single helium nucleus, then the energy released is:

(1) 13.9 MeV (2) 26.9 MeV

(3) 23.6 MeV (4) 19.2 MeV

11. An α-particle of energy 5 MeV is scattered through 180° by a fixed uranium nucleus. The distance of the closest approach is of the order of:

(1) 1 Å (2) 10^{-10} cm
(3) 10^{-12} cm (4) 10^{-15} cm

12. Starting with a sample of pure ^{66}Cu, 7/8 of it decays into Zn in 15 min. The corresponding half-life is:

(1) 10 min (2) 15 min
(3) 5 min (4) $7\frac{1}{2}$ min

13. If radius of the $^{27}_{13}Al$ nucleus is estimated to be 3.6 fermi, then the radius of $^{125}_{52}Te$ nucleus be nearly:

(1) 6 fermi (2) 8 fermi
(3) 4 fermi (4) 5 fermi

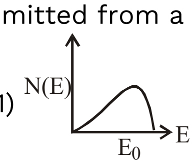
14. A nuclear transformation is denoted by $X(n, \alpha) \rightarrow {}^{7}_{3}Li$. Which of the following is the nucleus of element X ?

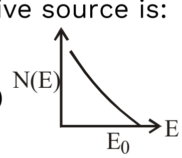
(1) $^{12}_{6}C$ (2) $^{10}_{5}B$
(3) $^{9}_{5}B$ (4) $^{11}_{4}Be$

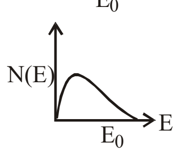
15. An alpha nucleus of energy $\frac{1}{2}mv^2$ bombards a heavy nuclear target of charge Ze. Then the distance of closest approach for the alpha nucleus will be proportional to:

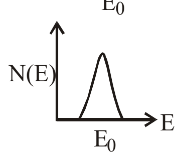
(1) v^2 (2) 1/m
(3) $1/v^4$ (4) 1/Ze

16. The energy spectrum of β-particles [number N(E) as a function of β-energy E] emitted from a radioactive source is:

(1) 

(2) 

(3) 

(4) 

17. If the binding energy per nucleon in $^{7}_{3}Li$ and $^{4}_{2}He$ nuclei are 5.60 MeV and 7.06 MeV respectively, then in the reaction :

$p + {}^{7}_{3}Li \rightarrow 2\,{}^{4}_{2}He$ energy of proton must be-

(1) 28.24 MeV
(2) 17.28 MeV
(3) 1.46 MeV
(4) 39.2 MeV

18. If M_0 is the mass of an oxygen isotope $_8O^{17}$, M_p and M_n are the masses of a proton and a neutron, respectively, the nuclear binding energy of the isotope is-

(1) $(M_o - 8M_p)c^2$
(2) $(M_o - 8Mp - 9M_n)c^2$
(3) M_oc^2
(4) $(M_o - 17M_n)c^2$

19. In gamma ray emission from a nucleus

(1) both the neutron number and the proton number change
(2) there is no change in the proton number and the neutron number
(3) only the neutron number changes
(4) only the proton number changes

20. The half-life period of a radioactive element X is same as the mean life time of another radioactive element Y. Initially they have the same number of atoms. Then-

(1) X will decay faster than Y
(2) Y will decay faster than X
(3) Y and X have same decay rate initially
(4) X and Y decay at same rate always

21. This question contains Statement-1 and Statement-2. Out of the four choices given after the statements, choose the one that best describes the two statements.

Statement-1 : Energy is released when heavy nuclei undergo fission or light nuclei undergo fusion.

Statement-2 : For heavy nuclei, binding energy per nucleon increases with increasing Z while for light nuclei it decreases with increasing Z.

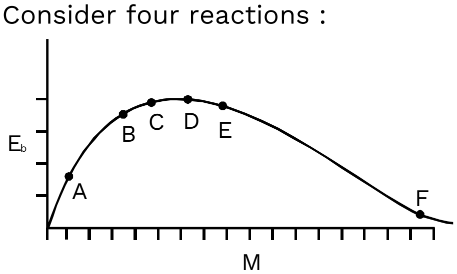
(1) Statement-1 is false, Statement-2 is true.

(2) Statement-1 is true, Statement-2 is true; Statement-2 is a correct explanation for Statement-1.

(3) Statement-1 is true, Statement-2 is true; Statement-2 is not a correct explanation for Statement-1.

(4) Statement-1 is true, Statement-2 is false.

22. The above is a plot of binding energy per nucleon E_b, against the nuclear mass M; A, B, C, D, E, F correspond to different nuclei. Consider four reactions :



(i) $A + B \rightarrow C + \varepsilon$ (ii) $C \rightarrow A + B + \varepsilon$

(iii) $D + E \rightarrow F + \varepsilon$ (iv) $F \rightarrow D + E + \varepsilon$

where ε is the energy released ? In which reactions is ε positive ?

(1) (ii) and (iv)

(2) (ii) and (iii)

(3) (i) and (iv)

(4) (i) and (iii)

Directions : Paragraph are based on the following paragraph.

A nucleus of mass $M + \Delta m$ is at rest and decays into two daughter nuclei of equal mass $\frac{M}{2}$ each. Speed of light is c.

23. The speed of daughter nuclei is :

(1) $c\sqrt{\frac{\Delta m}{M+\Delta m}}$ (2) $c\frac{\Delta m}{M+\Delta m}$

(3) $c\sqrt{\frac{2\Delta m}{M}}$ (4) $c\sqrt{\frac{\Delta m}{M}}$

24. The binding energy per nucleon for the parent nucleus is E_1 an that for the daughter nuclei is E_2. Then :

(1) $E_1 = 2E_2$ (2) $E_2 = 2E_1$

(3) $E_1 > E_2$ (4) $E_2 > E_1$

25. A radioactive nucleus (initial mass number A and atomic number Z) emits 3 α-particles and 2 positrons. The ratio of number of neutrons to that of protons in the final nucleus will be:

(1) $\frac{A-Z-4}{Z-2}$ (2) $\frac{A-Z-8}{Z-4}$

(3) $\frac{A-Z-4}{Z-8}$ (4) $\frac{A-Z-12}{Z-4}$

26. The half life of a radioactive substance is 20 minutes. The approximate time interval $(t_2 - t_1)$ between the time t_2 when $\frac{2}{3}$ of it has decayed and time t_1 when $\frac{1}{3}$ of it had decayed is :

(1) 20 min

(2) 28 min

(3) 7 min

(4) 14 min

27. After absorbing a slowly moving neutron of mass m_N (momentum ~0) a nucleus of mass M breaks into two nuclei of masses m_1 and $5m_1$ ($6m_1 = M + m_N$), respectively. If the de Broglie wavelength of the nucleus with mass m_1 is λ, then de Broglie wavelength of the other nucleus will be:

(1) $25\ \lambda$ (2) 5λ

(3) $\frac{\lambda}{5}$ (4) λ

28. **Statement-1:** A nucleus having energy E_1 decays be β^- emission to daughter nucleus having energy E_2, but the β^- rays are emitted with a continuous energy spectrum having end point energy E_1-E_2.

Statement-2 : To conserve energy and momentum in β-decay at least three particles must take part in the transformation.

(1) Statement-1 is incorrect, statement-2 is correct

(2) Statement-1 is correct, statement-2 is incorrect

(3) Statement-1 is correct, statement-2 correct; statement-2 is the correct explanation of statement-1

(4) Statement-1 is correct, statement-2 is correct; statement -2 is not the correct explanation of statement-1.

29. Assume that a neutron breaks into a proton and an electron. The energy released during this process is :

(Mass of neutron = 1.6747×10^{-27} kg

Mass of proton = 1.6725×10^{-27} kg

Mass of electron = 9×10^{-31} kg)

(1) 5.4 MeV (2) 0.73 MeV

(3) 7.10 MeV (4) 6.30 MeV

30. If in a nuclear fusion process the masses of the fusing nuclei be m_1 and m_2 and the mass of the resultant nucleus be m_3 , then :

(1) $m_3 = |m_1 - m_2|$ (2) $m_3 < (m_1 + m_2)$

(3) $m_3 > (m_1 + m_2)$ (4) $m_3 = m_1 + m_2$

31. The half-life of radium is about 1600 years. Of 100g of radium existing now, 25g will remain undocked after:

(1) 6400 years (2) 2400 years

(3) 3200 years (4) 4800 years

32. In the reaction ${}_1^2H + {}_1^3H \rightarrow {}_2^4H + {}_0^1n$. If the binding energies of ${}_1^2H$, ${}_1^3H$ and ${}_2^4He$ are respectively a, b and c (in MeV), then the energy (in MeV released in this reaction is)

(1) a + b + c (2) c + a + b

(3) c – (a + b) (4) a + b + c

33. In any fission process the ratio $\frac{\text{mass of fission products}}{\text{maas of parent nucleus}}$ is:

(1) Greater than 1

(2) Depends on the mass of the parent nucleus

(3) Less than 1

(4) equal of 1

34. Fission of nuclei is possible because the binding energy in nucleon in them:

(1) Decreases with mass number at low mass numbers

(2) Increases with mass number at low mass numbers

(3) Decreases with mass number at high mass numbers

(4) Increases with mass number at high mass numbers

35. For the radioactive material half-life period is 600 s. If initially there are 600 number of molecules find the time taken for disintegration of 450 molecules and the rate of disintegration.

(1) 1200 sec, 0.113 disintegrations/s

(2) 1200 sec, 0.173 disintegrations/s

(3) 900 sec, 0.273 disintegrations/s

(4) None of these

36. The binding energy of deuteron is 2.2 MeV and that of He is 28 MeV. If two deuterons are fused to form one He then the energy released is :

(1) 25.8 MeV (2) 23.6 MeV

(3) 19.2 MeV (4) 30.2 MeV

37. In a radioactive material the activity at time t_1 is R_1 and at a later time t_2, it is R_2. If the decay constant of the material is λ, then:

(1) $R_1 = R_2\, e^{-\lambda\,(t1-t2)}$ (2) $R_1 = R_2\, e^{\lambda(t1-t2)}$

(3) $R_1 = R_2\,(t_1 / t_2)$ (4) $R_1 = R_2$

38. In radioactive decay process, the negatively charged emitted β-particles are :

(1) the electrons present inside the nucleus

(2) the electrons produced as a result of the decay of neutrons inside the nucleus

(3) the electrons produced as a result of collisions between atoms

(4) the electrons orbiting around the nucleus

39. Two radioactive materials X_1 and X_2 have decay constants 5λ and λ respectively. If initially they have the same number of nuclei, than the ratio of the number of nuclei of X_1 to that of X_2 will be 1/e after a time

(1) λ (2) $\frac{1}{2}\lambda$

(3) $\frac{1}{4\lambda}$ (4) $\frac{e}{\lambda}$

40. undergoes a decay by emitted then write its complete equation. Given the mass value of $m({}_6C^{11}) = 11.011434$ u, $m({}_5B^{11}) = 11.009305$ u. $m_e = 0.000548$ u and 1 u = 931.5 MeV/c^2

Calculate the Q-value of reaction.

(1) 0.962 MeV (2) 1.962 MeV

(3) 0.548 MeV (4) None

41. In the nuclear decay given below

$${}^{A}_{Z}X \longrightarrow {}^{A}_{Z+1}Y \longrightarrow {}^{A-4}_{Z-1}B^{o} \longrightarrow {}^{A-4}_{Z-1}B,$$

the particles emitted in the sequence are

(1) β, α, γ (2) γ, β, α

(3) β, γ, α (4) α, β, γ

42. The number of beta particles emitted by a radioactive substance is twice the number of alpha particles emitted by it. The resulting daughter is an:

(1) isobar of parent (2) isomer of parent

(3) isotone of parent (4) isotope of parent

43. A radioactive nucleus X converts in to stable nucleus Y. Half-life of X is 50 yr. Calculate the age of radioactive sample when the radio of X and Y is 1 : 15.

(1) 100 years (2) 200 years

(3) 50 years (4) 150 years

44. The activity of a radioactive sample is measured as N_0 counts per minute at t = 0 and N_0/e counts per minute at t = 5 minutes. The time (in minutes) at which the activity reduces to half its value is:

(1) $\log_e \frac{2}{5}$

(2) $\frac{5}{\log_e 2}$

(3) $5 \log_{10} 2$

(4) $5 \log_e 2$

45. The decay constant of a radio isotope is λ. If A_1 and A_2 are its activities at times t_1 and t_2 respectively, the number of nuclei which have decayed during the time $(t_2 - t_1)$

(1) $A_1t_1 - A_2t_2$
(2) $A_1 - A_2$
(3) $(A_1 - A_2)/\lambda$
(4) $\lambda(A_1 - A_2)$

46. The binding energy per nucleon in deuterium and helium nuclei are 1.1 MeV and 7.0 MeV, respectively. When two deuterium nuclei fuse to form a helium nucleus the energy released in the fusion is:

(1) 23.6 MeV
(2) 2.2 MeV
(3) 28.0 MeV
(4) 30.2 MeV

ANSWER KEY

Que.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Ans.	1	1	1	3	1	2	1	4	4	3	3	3	1	2	2	3	2	2	2	2	4	3	3	4	3
Que.	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46				
Ans.	1	4	3	2	2	3	3	3	3	2	2	1	2	3	1	1	4	2	4	3	1				

Exercise – III (Previous Year Question)

1. Two radioactive nuclei P and Q, in a given sample decay into a stable nucleolus R. At time t = 0, number of P species are 4 N_0 and that of Q are N_0. Half-life of P (for conversion to R) is 1 minute where as that of Q is 2 minutes. Initially there are no nuclei of R present in the sample. When number of nuclei of P and Q are equal, the number of nuclei of R present in the sample would be: **[AIPMT 2011]**

(1) $3N_0$ (2) $\frac{9N_0}{2}$

(3) $\frac{5N_0}{2}$ (4) $2N_0$

2. The half-life of a radioactive isotope 'X' is 50 years. It decay to another element 'Y' which is stable. The two elements 'X' and 'Y' were found to be in the ratio of 1 : 15 in a sample of a given rock. The age of the rock was estimated to be : **[AIPMT-2011]**

(1) 150 years (2) 200 years

(3) 250 years (4) 100 years

3. The power obtained in a reactor using U^{235} disintegration is 1000 kW. The mass decay of U^{235} per hour is : **[AIPMT-2011]**

(1) 10 microgram (2) 20 microgram

(3) 40 microgram (4) 1 microgram

4. A radioactive nucleus of mass M emits a photon of frequency ν and the nucleus recoils. The recoil energy will be : **[AIPMT-2011]**

(1) $Mc^2 - h\nu$ (2) $h^2\nu^2 / 2Mc^2$

(3) zero (4) $h\nu$

5. A nucleus ${}^{m}_{n}X$ emits one α–particle and two β^- particles. The resulting nucleus is : **[AIPMT-2011, AIIMS-2012]**

(1) ${}^{m-6}_{n-4}Z$ (2) ${}^{m-6}_{n}Z$

(3) ${}^{m-4}_{n}X$ (4) ${}^{m-4}_{n-2}Y$

6. Fusion reaction takes place at high temperature because : **[AIPMT-2011]**

(1) nuclei break up at high temperature

(2) atoms get ionised at high temperature

(3) kinetic energy is high enough to overcome the coulomb repulsion between nuclei

(4) molecules break up at high temperature

7. If the nuclear radius of ${}^{27}Al$ is 3.6 Fermi, the approximate nuclear radius of ${}^{64}Cu$ in Fermi is : **[AIPMT_Pre_2012]**

(1) 2.4 (2) 1.2

(3) 4.8 (4) 3.6

8. A mixture consists of two radioactive materials A_1 and A_2 with half-lives of 20s and 10 s respectively. Initially the mixture has 40 g of A_1 and 160 g of A_2. The amount of the two in the mixture will become equal after : **[AIPMT_Pre_2012]**

(1) 60 s (2) 80 s

(3) 20 s (4) 40 s

9. The half-life of a radioactive nucleus is 50 days. The time interval $(t_2 - t_1)$ between the time t_2 when 2/3 of it has decayed and the time t_1 when 1/3 of it had decayed is : **[AIPMT-2012]**

(1) 30 days (2) 50 days

(3) 60 days (4) 15 days

10. A certain mass of Hydrogen is changed to Helium by the process of fusion. The Mass defect in fusion reaction is 0.02866 u. The energy liberated per u is :
(given 1u = 931 MeV) **[NEET_2013]**
(1) 26.7 MeV (2) 6.675 MeV
(3) 13.35 MeV (4) 2.67 MeV

11. The half-life of a radioactive isotope 'X' is 20 years. It decays to another element 'Y' which is stable. The two elements 'X' and 'Y' were found to be in the ratio 1 : 7 in a sample of a given rock. The age of the rock is estimated to be : **[NEET-2013]**
(1) 60 years (2) 80 years
(3) 100 years (4) 40 years

12. The binding energy per nucleon of ${}^{7}_{3}Li$ and ${}^{4}_{2}He$ nuclei are 5.60 MeV and 7.06 MeV, respectively. In the nuclear reaction ${}^{7}_{3}Li + {}^{1}_{1}H \rightarrow 2\,{}^{4}_{2}He + Q$, the value of energy Q released is : **[AIPMT 2014]**
(1) 19.6 MeV (2) –2.4 MeV
(3) 8.4 MeV (4) 17.3 MeV

13. A radio isotope 'X' with a half-life 1.4×10^9 years decays to 'Y' which is stable. A sample of the rock from a cave was found to contain 'X' and 'Y' in the ratio 1 : 7. The age of the rock is : **[AIPMT 2014]**
(1) 4.20×10^9 years (2) 8.40×10^9 years
(3) 1.96×10^9 years (4) 3.92×10^9 years

14. If radius of the Al nucleus is taken to be $R_{A\ell}$ then the radius of Te nucleus is nearly :
[AIPMT 2015]
(1) $\frac{5}{3}R_{Al}$ (2) $\frac{3}{5}R_{Al}$
(3) $\left(\frac{13}{53}\right)^{1/3}R_{Al}$ (4) $\left(\frac{53}{13}\right)^{1/3}R_{Al}$

15. When an α-particle of mass 'm' moving with velocity 'v' bombards on a heavy nucleus of charge 'Ze' its distance of closest approach from the nucleus depends on m as: **[NEET 2016]**
(1) m (2) $\frac{1}{m}$
(3) $\frac{1}{\sqrt{m}}$ (4) $\frac{1}{m^2}$

16. The half-life of a radioactive substance 30 minutes. The time (in minutes) taken between 40% decay and 85% decay of the same radioactive substance is:**[NEET 2016]**
(1) 45 (2) 60
(3) 15 (4) 30

17. Radioactive material 'A' has decay constant '8λ' and material 'B' has decay constant 'λ'. Initially they have same number of nuclei. After what time, the ratio of number of nuclei of material 'A' to that 'B' will be 1/e? **[NEET 2017]**
(1) $\frac{1}{\lambda}$ (2) $\frac{1}{7\lambda}$
(3) $\frac{1}{8\lambda}$ (4) $\frac{1}{9\lambda}$

18. For a radioactive material, half-life is 10 minutes. If initially there are 600 number of nuclei, the time taken (in minutes) for the disintegration of 450 nuclei is:
[NEET 2018]
(1) 20 (2) 10
(3) 30 (4) 15

19. α-particle consists of : **[NEET 2019]**
(1) 2 electrons and 4 protons only
(2) 2 protons only
(3) 2 protons and 2 neutrons only
(4) 2 electrons, 2 protons and 2 neutrons

20. The rate of radioactive disintegration at an instant for a radioactive sample of half-life 2.2×10^{9} s is 10^{10} s^{-1}. The number of radioactive atoms in that sample at that instant is, **[NEET 2019]**

(1) 3.17×10^{20} (2) 3.17×10^{17}

(3) 3.17×10^{18} (4) 3.17×10^{19}

21. The energy equivalent of 0.5 g of a substance is : **[NEET-2020]**

(1) 1.5×10^{13} J (2) 0.5×10^{13} J

(3) 4.5×10^{16} J (4) 4.5×10^{13} J

22. When a uranium isotope $^{235}_{92}U$ is bombarded with a neutron, it generates t $^{89}_{36}Kr$ three neutrons and : **[NEET-2020]**

(1) $^{101}_{36}Kr$ (2) $^{103}_{36}U$

(3) $^{144}_{56}Ba$ (4) $^{91}_{40}Zr$

23. What happens to the mass number and atomic number of an element when it emits γ-radiation? **[NEET-Covid-2020]**

(1) Mass number decreases by four and atomic number decreases by two.

(2) Mass number and atomic number remain unchanged.

(3) Mass number remains unchanged while atomic number decreases by one.

(4) Mass number increases by four and atomic number increases by two.

24. A radioactive nucleus $^{A}_{Z}X$ undergoes spontaneous decay in the sequence $^{A}_{Z}X \rightarrow _{Z-1}B \rightarrow _{Z-3}C \rightarrow _{Z-2}D$, where Z is the atomic number of element X. The possible decay particles in the sequence are : **[NEET-2021]**

(1) α, β^-, β^+ (2) α, β^+, β^-

(3) β^+, α, β^- (4) β^-, α, β^+

25. The half-life of a radioactive nuclide is 100 hours. The fraction of original activity that will remain after 150 hours would be : **[NEET-2021]**

(1) 1/2 (2) $\frac{1}{2\sqrt{2}}$

(3) $\frac{2}{3}$ (4) $\frac{2}{3\sqrt{2}}$

26. A nucleus with mass number 240 breaks into two fragments each of mass number 120, the binding energy per nucleon of unfragmented nuclei is 7.6 MeV while that of fragments is 8.5 MeV. The total gain in the Binding Energy in the process is : **[NEET-2021]**

(1) 0.9 MeV (2) 9.4 MeV

(3) 804 MeV (4) 216 MeV

27. In the given nuclear reaction, the element X is: $^{22}_{11}Na \rightarrow X + e^{+} + \upsilon$ **[NEET-2022]**

(1) $^{23}_{11}$ Na (2) $^{23}_{10}$ Ne

(3) $^{22}_{10}$ Ne (4) $^{22}_{12}$ Mg

ANSWER KEY

Que.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Ans.	2	2	3	2	3	3	3	4	2	1	1	4	1	1	2	2	2	1	3	4	4	3	2	3	2
Que.	26	27																							
Ans.	4	3																							