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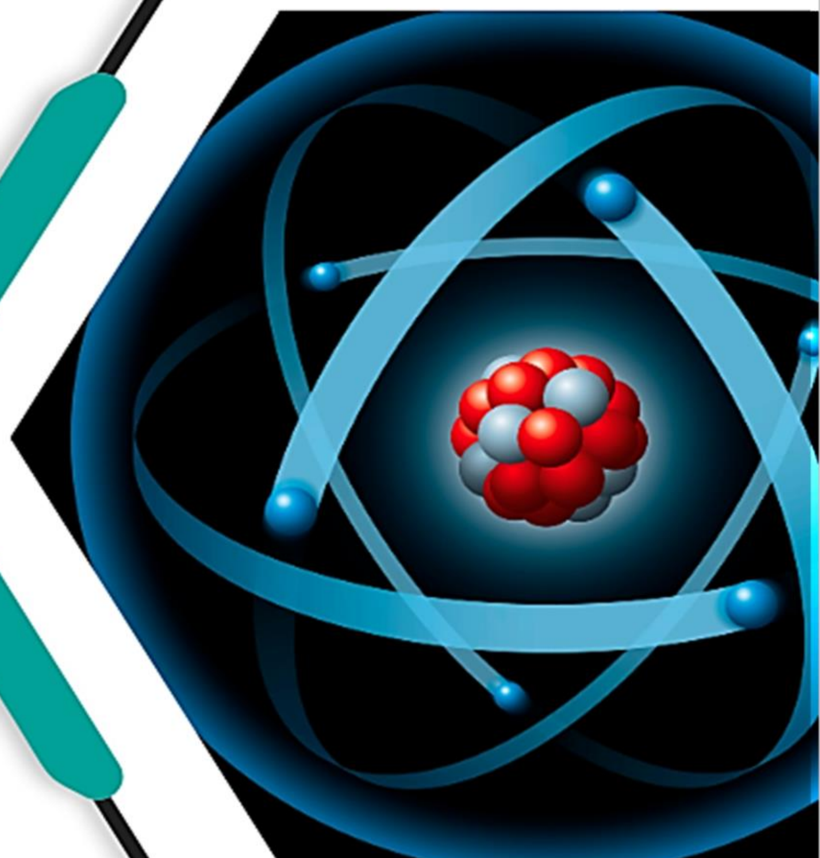

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NUCLEI
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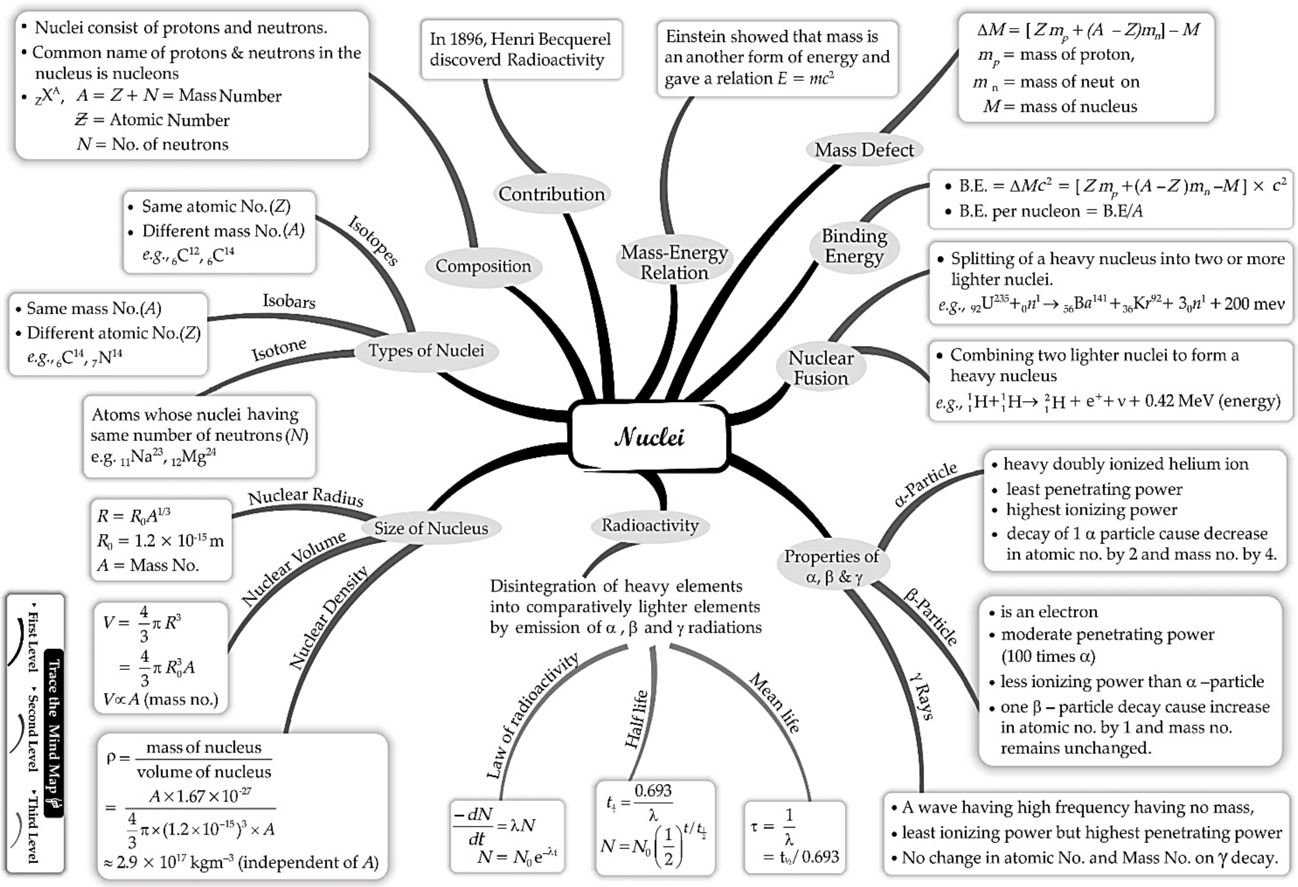

Nuclei
Composition
• Nuclei consist of protons and neutrons.
• Common name of protons & neutrons in the nucleus is nucleons
• $_ZX^A$, $A = Z + N$ = Mass Number, Z = Atomic Number, N = No. of neutrons
Contribution
In 1896, Henri Becquerel discoverd Radioactivity
Mass-Energy Relation
Einstein showed that mass is an another form of energy and gave a relation $E = mc^2$
Mass Defect
$\Delta M = [Zm_p + (A - Z)m_n] - M$
m_p = mass of proton,
m_n = mass of neut on
M = mass of nucleus
Binding Energy
• B.E. = $\Delta Mc^2 = [Zm_p + (A - Z)m_n - M] \times c^2$
• B.E. per nucleon = B.E/A
Nuclear Fusion
• Splitting of a heavy nucleus into two or more lighter nuclei.
e.g., $_{92}U^{235} + _0n^1 \rightarrow _{56}Ba^{141} + _{36}Kr^{92} + 3_0n^1$ + 200 mev
• Combining two lighter nuclei to form a heavy nucleus
e.g., $_1^1H + _1^1H \rightarrow _1^2H + e^+ + \nu$ + 0.42 MeV (energy)
Types of Nuclei
Isotopes
• Same atomic No.(Z)
• Different mass No.(A)
e.g., $_6C^{12}$, $_6C^{14}$
Isobars
• Same mass No.(A)
• Different atomic No.(Z)
e.g., $_6C^{14}$, $_7N^{14}$
Isotone
Atoms whose nuclei having same number of neutrons (N)
e.g. $_{11}Na^{23}$, $_{12}Mg^{24}$
Size of Nucleus
Nuclear Radius
$R = R_0A^{1/3}$
$R_0 = 1.2 \times 10^{-15}$ m
A = Mass No.
Nuclear Volume
$V = \frac{4}{3}\pi R^3 = \frac{4}{3}\pi R_0^3 A$
$V \propto A$ (mass no.)
Nuclear Density
$\rho = \frac{\text{mass of nucleus}}{\text{volume of nucleus}} = \frac{A \times 1.67 \times 10^{-27}}{\frac{4}{3}\pi \times (1.2 \times 10^{-15})^3 \times A}$
$\approx 2.9 \times 10^{17}$ kgm^{-3} (independent of A)
Radioactivity
Disintegration of heavy elements into comparatively lighter elements by emission of α, β and γ radiations
Law of radioactivity
$-\frac{dN}{dt} = \lambda N$
$N = N_0 e^{-\lambda t}$
Half life
$t_{1/2} = \frac{0.693}{\lambda}$
$N = N_0\left(\frac{1}{2}\right)^{t/t_{1/2}}$
Mean life
$\tau = \frac{1}{\lambda} = t_{1/2}/0.693$
Properties of α, β & γ
α-Particle
• heavy doubly ionized helium ion
• least penetrating power
• highest ionizing power
• decay of 1 α particle cause decrease in atomic no. by 2 and mass no. by 4.
β-Particle
• is an electron
• moderate penetrating power (100 times α)
• less ionizing power than α –particle
• one β – particle decay cause increase in atomic no. by 1 and mass no. remains unchanged.
γ Rays
• A wave having high frequency having no mass,
• least ionizing power but highest penetrating power
• No change in atomic No. and Mass No. on γ decay.
Trace the Mind Map
• First Level
• Second Level
• Third Level

NUCLEI

Syllabus

- *Composition and size of nucleus; Radioactivity; Alpha, Beta and Gamma particles/rays and their properties; Radioactive decay law. half life and mean life.*
- *Mass-energy relation; mass defect; Binding energy per nucleon and its variation with mass number; Nuclear fission; Nuclear fusion.*

Trend Analysis

List of Concepts	2018		2019		2020	
	OD	D	OD	D	OD	D
Nucleus and Mass Energy Relation		1 Q (1 M) 1 Q (2 M) 1 Q (3 M)	1 Q (3 M)		1 Q (1 M) 1 Q (2 M)	1 Q (3 M)
Radioactivity and Nuclear Reactor		1 Q (1 M) 2 Q (3 M)	1 Q (3 M)	2 Q (3 M)	2 Q (1 M) 1 Q (5 M)	1 Q (2 M) 2 Q (3 M)

TOPIC-1
Nucleus and Mass-Energy Relation

Revision Notes

- As per Rutherford scattering experiment, it is established that radius of atom is 10^4 times of its nucleus. Hence, volume of nucleus is 10^{-12} times smaller than atom. This concludes that atom is almost empty.
- For measuring atomic mass and its sub-particles, new unit of mass is introduced as atomic mass unit 'u'.

$$1\text{ u} = \frac{\text{Mass of one } {}^{12}_{6}C \text{ atom}}{12}$$

$$1\text{ u} = 1.660539 \times 10^{-27}\text{ kg}$$

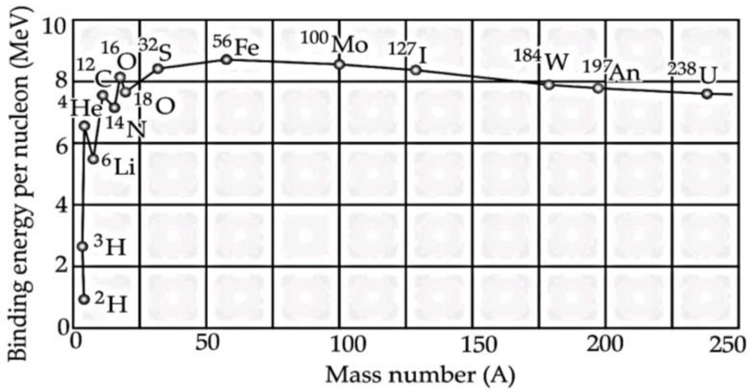
- Atomic mass unit is not an integral multiple of u due to presence of isotopes (atoms of same element with different atomic masses).
- All mass and positive charge of an atom is concentrated in its centre known as nucleus.
- Chadwick discovered a new sub-particle in nucleus known as neutron. It is electrically neutral in nature.

$$\text{Mass of neutron, } m_n = 1.00866\text{ u} = 1.6749 \times 10^{-27}\text{ kg}$$

- The composition of a nucleus can now be described using the following terms and symbols :
  - Z = Atomic number = Number of protons (equal to the number of electrons)
  - N = Neutron number = Number of neutrons
  - A = Atomic mass number = $(Z + N)$ = Total number of protons and neutrons
- An atom is represented by ${}^{A}_{Z}X$ where

X = Symbol of element
A = Atomic mass number
Z = Atomic number

- **Isotopes :** Two atoms of an element having same atomic number (Z is same) but different atomic mass number (due to the different number of neutrons) are said to be isotopes.
- **Isobars :** Two atoms of different elements having same mass number but different atomic numbers are said to be isobars.
- **Isotones :** Two atoms of different elements having different mass numbers and atomic numbers such that their difference is same are said to be isotones. It means they have same number of neutrons.
- **Size of the nucleus :** A nucleus of mass number A has a radius
$$R = R_0 A^{1/3} \qquad \text{where, } R_0 = 1.2 \times 10^{-15} \text{ m}$$
- Nuclear matter density $= 2.3 \times 10^{17}$ kgm^{-3}
- Earlier, it was believed that anything in the universe can be classified into matter or radiation. Einstein proposed that there are two forms of energy which are interconvertible.
$$E = mc^2; \qquad \text{where, } c \text{ is speed of light.}$$
- With this relation, we may calculate 1 u = 931.5 MeV
- **Mass defect :** The difference in mass of a nucleus and its constituents, ΔM, is called the mass defect, and is given by,
$$\Delta M = [Zm_p + (A - Z)m_n] - M.$$
- **Binding energy :** Binding energy of a nucleus is that quantity of energy which when given to nucleus, its nucleons will become free and will leave the nucleus. It is having negative sign.
$$E_b = \Delta M c^2$$
where, E_b is binding energy.
- **Binding energy per nucleons (E_b/A) :** A measure of the binding between the constituents of the nucleus is the binding energy per nucleon, E_{bn} or E_b/A, which is the ratio of the binding energy E_b of a nucleus to the number of the nucleons, A, in that nucleus.
$$E_{bn} = \frac{E_b}{A}$$
- **Relation between E_b/A and Stability of elements**



  - Higher the Binding Energy per Nucleons, more stable is the element. Higher binding energy per nucleon means we have to supply more energy to free nucleons or it is difficult to break the nucleus.
  - Most of the atoms where atomic mass number are in the range $30 < A < 200$, the binding energy per nucleon is fairly constant and quite high. It is maximum for $A = 56$ about 8.75 MeV.
  - For $A < 30$ and $A > 170$; Binding energy per nucleon is quite low.
- If a nucleus of lower binding energy is converted into higher binding energy, then energy is released.
- There are two methods of converting lower binding energy nucleons into higher binding energy nucleons.
  - **Fission :** A heavy nucleus (low binding energy per nucleon) is broken into two lighter nuclei (higher binding energy per nucleon) with the release of energy. This process is known as fission.

    Example : ${}_0^1n + {}_{92}^{235}\text{U} \rightarrow {}_{92}^{236}\text{U} \rightarrow {}_{56}^{144}\text{Ba} + {}_{36}^{89}\text{Kr} + 3{}_0^1n + 200 \text{ MeV}$
  - **Fusion :** Two light nucleus (low binding energy per nucleon) are joined to form one nucleus of higher binding energy per nucleon and energy is released. This process is known as fusion.

    Example : ${}_1^1\text{H} + {}_1^1\text{H} \rightarrow {}_1^2\text{H} + e^+ + \nu + 0.42 \text{ MeV}$

- **Nuclear force :**
  - The binding energy per nucleon is approximately 8 MeV, which is much larger than the binding energy in atoms.
  - This high binding energy per nucleon counters the repulsive force between protons and bind both protons and neutrons into the tiny nuclear volume.
  - The nuclear force is much stronger than the Coulomb force acting between charges or the gravitational forces between masses but it's a short range force $\left(\propto \frac{1}{r^7}\right)$

Know the Formulae

- Size of the nucleus:
  $R = R_0 A^{1/3}$ where $R_0 = 1.2 \times 10^{-15}$ m
- Mass defect :$\Delta M = [Zm_p + (A - Z)m_n] - M$
- Binding energy :$E_b = \Delta M c^2$
- Binding energy per nucleon (BE/N) :$E_{bn} = \frac{E_b}{A}$

Very Short Answer Type Questions (1 mark each)

Q. 1. In decay of free neutron, name the elementary particle emitted along with proton and electron in nuclear reaction. R [SQP 2020-21]

Ans. Antineutrino. 1

Q. 2. In the following nuclear reaction, Identify unknown labelled X.

$$^{22}_{11}\text{Na} + \text{X} \rightarrow ^{22}_{10}\text{Ne} + \text{V}_e$$

U [SQP 2020-21]

Ans. Electron 1

Detailed Answer:

$^{22}_{11}$Na in beta decay (electron) emitting a positron into $^{22}_{10}$Ne.

Q. 3. Four nuclei of an element undergo fusion to form a heavier nucleus, with release of energy. Which of the two — the parent or the daughter nucleus — would have higher binding energy per nucleon? U [CBSE 2018]

Ans. Daughter nucleus 1
[CBSE Marking Scheme, 2018]

Detailed Answer:

Daughter nuclei will have higher binding energy per nucleon.

The mass of heavier nucleus (daughter) is less than the sum of masses of combining nuclei. So, mass defect is more in daughter nuclei resulting into more binding energy per nucleon.

Q. 4. How the mass density of a nucleus varies with mass number ? U

Ans. Mass density is independent of mass number. 1

Q. 5. The binding energies per nucleon for deutron and an alpha-particle are x_1 and x_2 respectively. Find the amount of energy released in the following reactions.

$$^2\text{H}_1 + ^2\text{H}_1 \rightarrow ^4\text{He}_2 + \text{Q}.$$

U

Ans. $4(x_2 - x_1)$. 1

Q. 6. If the atomic number of an element is 11 and the atomic mass is 24, how many electrons does it have? U

Ans. Atomic number of any element gives the number of protons which is equal to the number of electrons in an atom. Sodium has atomic number 11, this shows that Sodium atom has 11 protons in its nucleus and has 11 electrons surrounding its nucleus. 1

Q. 7. What do you mean by mass defect of a nucleus? R

Ans. The difference between the rest mass of a nucleus and the sum of the rest masses of its constituent nucleons is called its mass defect. It is given by

$$\Delta m = Zm_p + (A - Z)\, m_n - m$$ 1

Q. 8. What do you mean by binding energy per nucleon? R

Ans. The binding energy per nucleon may be defined as the energy required to break up a nucleus into its constituent protons and neutrons and to separate them to such a large distance so that they may not interact with each other. It may also be defined as the surplus energy which the nucleons give up by virtue of their attractions when they become bound together to form a nucleus.

The binding energy of a nucleus is given by

$$\Delta m = Zm_p + (A - Z)m_n - m_{nuc}$$
$$E_b = (\Delta m)c^2.$$ 1

Q. 9. Which particle will be emitted spontaneously in the following nuclear reaction ?

$$^{32}_{15}\text{P} \rightarrow ^{32}_{16}\text{S} + \nu + \_\_\_\_\_$$

U [CBSE OD SET 1 2020/MODIFIED]

Ans. e^{-1}. 1

Short Answer Type Questions-I

(2 marks each)

Q. 1. A heavy nucleus P of mass number 240 and binding energy 7.6 MeV per nucleon splits in to two nuclei Q and R of mass numbers 110 and 130 and binding energy per nucleon 8.5 MeV and 8.4 MeV, respectively. Calculate the energy released in the fission.

R [CBSE DEL SET 1, 2020]

Ans. Total BE of P = 240 × 7.6 = 1824 MeV

BE of Q = 110 × 8.5 = 935 MeV

BE of R = 130 × 8.4 = 1092 MeV

Total BE of Q and R = (935 +1092) = 2027 MeV **1**

Total energy released in the fission

= 2027 – 1824

= 203 MeV **1**

Q. 2. Calculate for how many years the fusion of 2.0 kg deuterium will keep 800 W electric lamp glowing. Take the fusion reaction as

$$^2_1H + ^2_1H \rightarrow ^3_2He + ^1_0n + 3.27\,MeV$$

R [CBSE DEL SET 3, 2020]

Ans. The given fusion reaction is:

$$^2_1H + ^2_1H \rightarrow ^3_2He + ^1_0n + 3.27\,MeV$$

Amount of deuterium, $m = 2$ kg

1 mole, *i.e.*, 2 g of deuterium contains 6.023×10^{23} atoms.

So, 2.0 kg of deuterium contains $\frac{6.023 \times 10^{23}}{2}$

$\times 2000 = 6.023 \times 10^{26}$ atoms

Two atoms of deuterium fuse to release 3.27 MeV energy. **1**

So, total energy released

$= \frac{3.27}{2} \times 6.023 \times 10^{26}$ MeV

$= \frac{3.27}{2} \times 6.023 \times 10^{26} \times 10^{6} \times 1.6 \times 10^{-19}$ J

$= 15.75 \times 10^{13}$ J

Power of the electric lamp, $P = 800$ W = 800 J/s

Hence, the energy consumed by the lamp per second = 800 J

So, the electric lamp will glow for

$$\frac{15.75 \times 10^{13}}{800}\,s = 0.0197 \times 10^{13}\,s$$

$$= \frac{0.0197 \times 10^{12}}{60 \times 60 \times 24 \times 365} = 6246.8 \text{ years}$$ **1**

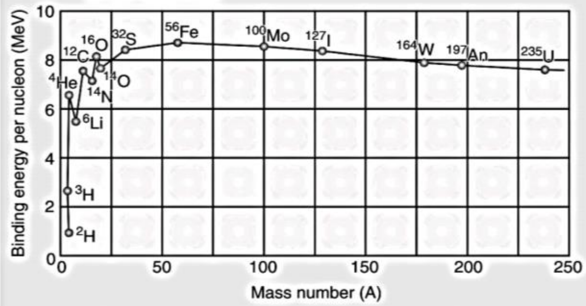
Q. 3. Explain the processes of nuclear fission and nuclear fusion by using the plot of binding energy per nucleon (BE/A) versus the mass number A.

R [CBSE 2018]

Ans. (a) Drawing the plot **1**

Explaining the process of Nuclear fission and Nuclear fusion **½ + ½**

The plot of (B.E. / nucleon) verses mass number is as shown.



1

[Note :Also accept the diagram that just shows the general shape of the graph]. From the plot we note that

(i) During nuclear fission

A heavy nucleus in the larger mass region ($A > 200$) breaks into two middle level nuclei, resulting in an increase in B.E/ nucleon. This results in a release of energy. **½**

(ii) During nuclear fusion

Lighter nuclei in the lower mass region ($A < 20$) fuse to form a nucleus having higher B.E. / nucleon. Hence Energy gets released. **½**

[**Alternatively** :As per the plot,during nuclear fission as well as nuclear fusion, the final value of B.E/ nucleon is more than its initial value. Hence energy gets released in both these processes.]

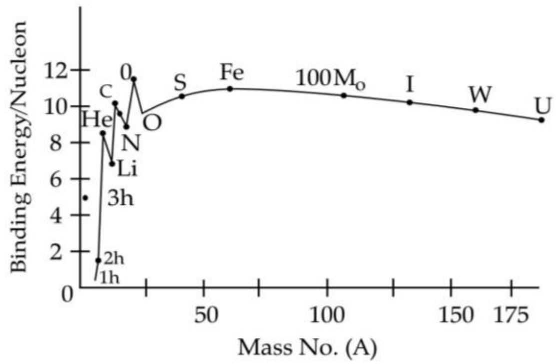
[CBSE Marking Scheme, 2018]

Detailed Answer :

(a) Plot of binding energy per nucleon is shown in the figure. From B.E./nucleon curve, we note that first B.E. increases rapidly and then decreases slowly and B.E is max i.e. 8.8 Mev for ^{56}Fe atom. Again by decreasing slowly, B.E. become 8.5 Mev for uranium atom $^{238}_{92}U$. This shows that nucleus with mass number $A < 20$ are less stable, but some nucleus as ^{4}He, ^{12}C, ^{16}O (even–even) nuclei are stable. Thus the nuclei with mass number $A < 20$ shows fusion reaction as ^{2}H and ^{3}H have very low BE/nucleon in comparison to ^{4}He. Thus when two lighter nuclei ($A \leq 10$ say) fuse to form a heavy nucleus, the B.E/A of fused heavier nucleus is more than the B.E/A of lighter nuclei. This implies release of energy in nuclear fusion.

Similarly, due to fission of a very heavy nucleus, the B.E/A of the product (as daughter nuclei) increases which implies the release of huge amount of energy.

Thus for lighter nuclei, nuclear fusion and for heavier nuclei nuclear fission takes place and huge amount of energy is released. **½+½**



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Q. 4. A nucleus with mass number $A = 240$ and $BE/A = 7.6$ MeV breaks into two fragments each of $A = 120$ with $BE/A = 8.5$ MeV. Calculate the released energy. A **[CBSE DEL SET 1, 2016]**

Ans. Calculation of energy released

Binding energy of nucleus with mass number 240,

$E_{bn} = 240 \times 7.6$ MeV ½

Binding energy of two fragments

$= 2 \times 120 \times 8.5$ MeV ½

Energy released $= 240(8.5 - 7.6)$ MeV ½

$= 240 \times 0.9$

$= 216$ MeV ½

[CBSE Marking Scheme, 2016]

Commonly Made Error

- Many students calculated the released energy per nucleon instead of total released energy.

Answering Tip

- The calculation part in the numerical should be done carefully.

Q. 5. Calculate the energy in fusion reaction :

$^2_1H + ^2_1H \rightarrow ^3_2He + n$ where, BE of $^2_1H = 2.23$ MeV and $^3_2He = 7.73$ MeV.

R **[CBSE DEL SET 1, 2016]**

Ans. Calculation of Energy in fusion reaction

Total Binding energy of initial system

i.e., $^2_1H + ^2_1H = (2.23 + 2.23)$ MeV

$= 4.46$ MeV 1

Binding energy of final system *i.e.,* ^3_2He

$= 7.73$ MeV

Hence energy released $= 7.73$ MeV $- 4.46$ MeV 1

$= 3.27$ MeV

[CBSE Marking Scheme, 2016]

AI **Q. 6. Show that the density of nucleus over a wide range of nuclei is constant and independent of mass number.** U

Ans. We have

$$R = R_0 A^{1/3} \quad ½$$

$\therefore$ Density,

$$\rho = \frac{mA}{\frac{4}{3}\pi\left(R_0 A^{1/3}\right)^3} \quad ½$$

$$= \frac{m}{\frac{4}{3}\pi R_0^3} \quad ½$$

Hence ρ is independent of A.

(Here m is the mass of the nucleus.) ½

[CBSE Marking Scheme, 2013]

Detailed Answer :

Mass of nucleus M = Volume of nucleus × Nuclear density

$$M = V \times \rho$$

$$M = \frac{4}{3}\pi R^3 \rho$$

(R = radius of the nucleus)

$$R^3 = \frac{3M}{4\pi\rho}$$

$$R = \left(\frac{3}{4\pi\rho}\right)^{\frac{1}{3}} M^{\frac{1}{3}} \quad \text{...(i) ½}$$

If m = Mass of one nucleon

$M = mA$, where A = mass number ($Z + N$)

Putting the value of M in eq. (i), we get

$$R = \left(\frac{3}{4\pi\rho}\right)^{\frac{1}{3}} (mA)^{\frac{1}{3}} \quad ½$$

We know that

$$R = R_0 A^{\frac{1}{3}}$$

Hence,

$$R_0 A^{\frac{1}{3}} = \left(\frac{3}{4\pi\rho}\right)^{\frac{1}{3}} (mA)^{\frac{1}{3}} \quad ½$$

Cubing both sides

$$R_0^3 A = \frac{3}{4\pi\rho} mA$$

or,

$$\rho = \frac{3m}{4\pi R_0^3}$$

Hence, nuclear density ρ, over a wide range of nuclei is constant and independent of mass number A. ½

Short Answer Type Questions-II

(3 marks each)

Q. 1. (a) Give one point of difference between nuclear fission and nuclear fusion.

(b) Suppose we consider fission of a $^{56}_{26}Fe$ into two equal fragments of $^{28}_{13}Al$ nucleus. Is the fission energetically possible? Justify your answer by working out Q value of the process.

Given (m) $^{56}_{26}Fe$ = 55.93494 u and (m) $^{28}_{13}Al$ = 27.98191 R & A **[SQP 2020-21]**

Ans. One difference between nuclear fission and nuclear fusion

Calculating Q = ((m) Fe – 2 (m) A*l*) c^2

= – 26.90 MeV **1**

Justification not possible **1**

Detailed Answer :

(a) Difference between nuclear fission and nuclear fusion:(any one)

(i) Fission is the splitting of a large atom into two or more smaller ones.

Fusion is the fusing of two or more lighter atoms into a larger one.

(ii) Fission reaction does not normally occur in nature.

Fusion occurs in stars, such as the sun.

(iii) For fission, little energy is required.

For fusion, extremely high energy is required.

(iv) For fission, Uranium is the primary fuel used in power plants.

Deuterium and Tritium are the primary fuel used in experimental fusion power plants. **2**

(b) Let us consider the fission of a $^{56}_{26}$Fe into two equal fragments of $^{28}_{13}$Al nucleus.

Q value = (55.93494 – 2 × 27.98191) × 931.5

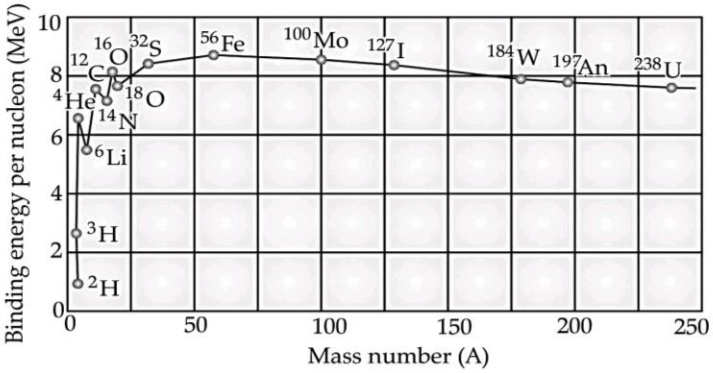
= – 26.9 MeV

Q is negative. Hence fission is not possible. **1**

Q. 2. Draw the curve showing the variation of binding energy per nucleon with the mass number of nuclei. Using it explain the fusion of nuclei lying on ascending part and fission of nuclei lying on descending part of this curve.

R & U **[CBSE DEL SET, 2 2020]**

Ans.



From the graph, it is clear that it has a peak near A = 60. Nuclei around this are most stable. (Example :Iron)

The shape of this curve suggests two possibilities for converting significant amounts of mass into energy :

(i) Fission reactions: From the curve, the heaviest nuclei are less stable than the nuclei near A = 60. This suggests that energy can be released if heavy nuclei split apart into smaller nuclei. This process is called *fission.*

(ii) Fusion reactions: The curve also suggests energy can be released from the lighter elements (like hydrogen and helium) as they are less stable than heavier elements up to A~60. Thus, sticking two light nuclei together to form a heavier nucleus can also release energy. This process is called *fusion.*

In both fission and fusion reactions, the total masses after the reaction are less than those before. This "missing mass" appears as energy.

Q. 3. (a) State two distinguishing features of nuclear force.

(b) Draw a plot showing the variation of potential energy of a pair of nucleons as a function of their separation. Mark the regions on the graph where the force is (i) attractive, and (ii) repulsive.

R & U **[CBSE OD SET 1, 2019]**

Ans. (a) Stating distinguishing feature of nuclear force. 1

(b) Draw a plot showing variation of potential energy. 1

(c) Marking the regions. ½+½

(a) Distinguishing feature:

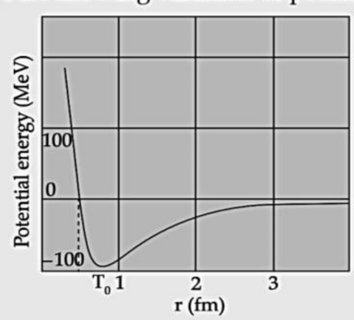
(1) Short range force

(2) Strongest force

(3) Attractive in nature

(4) Does not depend on charge (any two) **1**

(b) Plot showing variation of potential energy:



1

(c) Making the regions:

$r < r_0$: repulsive force ½

$r > r_0$: attractive force ½

Q. 4. Distinguish between nuclear fission and fusion. Show how in both these processes energy is released.

Calculate the energy release in MeV in the deuterium-tritium fusion reaction :

$$ {}^{2}_{1}\mathrm{H} + {}^{3}_{1}\mathrm{H} \rightarrow {}^{4}_{2}\mathrm{He} + {}_{0}n^{1} $$

Using the data :

$$ m\left({}^{2}_{1}\mathrm{H}\right) = 2.014102 \text{ u} $$

$$ m\left({}^{3}_{1}\mathrm{H}\right) = 3.016049 \text{ u} $$

$$ m\left({}^{4}_{2}\mathrm{He}\right) = 4.002603 \text{ u} $$

$$ m_n = 1.008665 \text{ u} $$

$$ 1 \text{ amu} = 931.5 \text{ MeV}/c^2 $$

U **[Delhi I, II, III 2015]**

Ans. Nuclear Fission is the breaking down of heavier nucleus into smaller fragments while nuclear fusion is combining of lighter nuclei to form heavier nucleus. We see that binding energy per nucleon of daughter nuclei in both fission and fusion processes is more than that of parent nuclei. Further, the difference in binding energy is released, in form of energy while in both the processes certain masses get converted into energy. **1+1**

In both processes, some mass get converted into energy.

Energy Released,

$$ Q = \left[m\left({}^{2}_{1}\mathrm{H}\right) + m\left({}^{3}_{1}\mathrm{H}\right) - m\left({}^{4}_{2}\mathrm{He}\right) - m(n)\right] \times 931.5 \text{ MeV} $$

$$ = [2.014102 + 3.016049 - 4.002603 - 1.008665] \times 931.5 \text{ MeV} $$

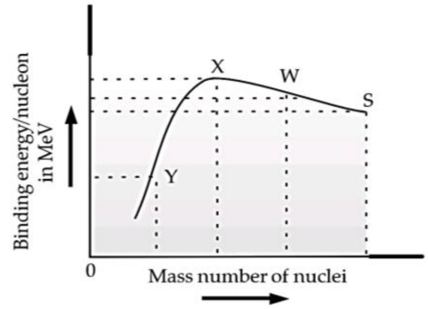
$$ = 0.018883 \times 931.5 \text{ MeV} $$

$$ = 17.59 \text{ MeV} $$ **1**

[CBSE Marking Scheme, 2015]

Q. 5. Binding energy per nucleon versus mass number curve is as shown.

${}^{A}_{Z}S$, ${}^{A1}_{Z1}W$, ${}^{A2}_{Z2}X$ and ${}^{A3}_{Z3}Y$ are four nuclei indicated on the curve.



Based on the graph :

(a) Arrange *X*, *W* and *S* in the increasing order of stability.

(b) Write the relation between the relevant *A* and *Z* values for the following nuclear reaction.

$S \rightarrow X + W$

(c) Explain why binding energy for heavy nuclei is low. **[CBSE 2018]**

Ans. (a) *S, W, X* **1**

(b) $Z = Z_1 + Z_2$ **½**

$A = A_1 + A_2$ **½**

(c) Reason for low binding energy :

In heavier nuclei, the Coulombian repulsive effects can increase considerably and can match/ offset the attractive effects of the nuclear forces. This can result in such nuclei being unstable. **1**

[CBSE Marking Scheme, 2018]

Q. 6. (a) Write the basic nuclear process involved in the emission of β^+ in a symbolic form, by a radioactive nucleus.

(b) In the reactions given below:

(i) ${}^{11}_{6}C \rightarrow {}^{z}_{y}B + x + v$

(ii) ${}^{12}_{6}C + {}^{12}_{6}C \rightarrow {}^{20}_{a}Ne + {}^{c}_{b}He$

Find the values of *x*, *y*, and *z* and *a*, *b* and *c*.

U & A **[CBSE OD SET 1, 2016]**

Ans. **(a)** Basic nuclear process **1**

(b) (i) value of *x*, *y*, *z* **1**

(ii) value of *a*, *b*, *c* **1**

(a) Basic nuclear reaction

$P \rightarrow n + e^+ + \nu$ **1**

(b) (i) $x = \beta^+/{}^{0}_{1}e$, $y = 5$, $z = 11$ **1**

(ii) $a = 10$, $b = 2$, $c = 4$ **1**

[CBSE Marking Scheme, 2016]

TOPIC-2

Radioactivity

Revision Notes

- **Radioactivity :**When atoms become very heavy, neutrons become unable to bind and some nucleons keep on leaving the nucleus. These atoms/elements are known as radioactive elements. This process of spontaneous ejection of nucleons or radiations is known as radioactivity.
- There are three types of radioactive decay in nature.
  - **α-decay :**In this decay, α-particles (${}^{4}_{2}\mathrm{He}$ nucleus) eject out.

- **β-decay :** In this decay, electrons or positrons (particles with the same mass as electrons, but with a charge exactly opposite to that of electron) eject out.
- **γ-decay :** In this case, high energy photons are emitted but no loss in atomic number and mass number.

➢ **Properties of α-rays :**

- α-rays consist of doubly ionised helium atoms.
- After α-decay, a nucleus is transformed into another nucleus.

  Examples :
  $${}_Z^AX \rightarrow {}_{Z-2}^{A-4}Y + {}_2^4He$$
  $${}_{92}^{238}U \rightarrow {}_{90}^{234}Th + {}_2^4He$$

- The difference between the initial mass energy and the final mass energy of the decay products is called the Q value of the process or the disintegration energy. Thus, the Q value of an alpha decay can be expressed as
  $$Q = (m_X - m_Y - m_{He})c^2$$
- α-rays are deflected by the electric field and the magnetic field.
- The velocity of α-rays is about 10% of the velocity of light.
- α-rays affect the photographic plate.
- In α-decay, mass number of daughter nucleus changes by 4 units and atomic number changes by 2 units.

➢ **Properties of β-rays :**

- β-rays consist of fast moving electrons or positrons.
- In beta minus (β^-) decay, an electron is emitted by the nucleus. A neutron is converted into proton and electron, whereas an electron is emitted out along with antineutrino. Hence, there is no change in mass number and atomic number is increased by 1.

  Example : $${}_{15}^{32}P \rightarrow {}_{16}^{32}S + {}_{-1}e^0 + \bar{\nu} \quad (T_{1/2} = 14.3\ d)$$

- In beta plus (β^+) decay, a positron is emitted by the nucleus. A proton is converted into neutron and positron is emitted out along with neutrino. Hence, there is no change in mass number and atomic number is decreased by 1.

  Example : $${}_{11}^{22}Na \rightarrow {}_{10}^{22}Ne + {}_1e^0 + \nu \quad (T_{1/2} = 2.6\ y)$$

- In these equations ν, $\bar{\nu}$ are known as neutrino and anti neutrino particles respectively. They have no charge, approximately no mass and are unreactive.
- β-rays are deflected by the electric field and the magnetic field.
- The velocity of β-rays is up to 90% of the velocity of light.
- β-rays affect the photographic plate.

➢ **Properties of γ-rays**

- When an excited state nucleus makes a transition to a lower energy state, it undergoes electromagnetic radiation. As the energy differences between levels in a nucleus are of the order of MeV, the emitted photons are of same energies which are called gamma rays.
- Most radionuclides, after an alpha decay or a beta decay, leave the daughter nucleus in an excited state. Then this excited daughter nucleus come to ground state by radiating γ-rays.
- γ-rays are photons of very short wavelength of the order of 10^{-11} m to 10^{-13} m.
- γ-rays carry no charge and not deflected by the electric field and the magnetic field.
- γ-rays move with the speed of light.
- γ-rays affect the photographic plate.

➢ **Laws of Radioactive decay :**

- Rate of decay $\frac{\Delta N}{\Delta t} \propto N$ where, N = Number of nuclei in the sample

  For very small time interval,
  $$\frac{dN}{dt} = -\lambda N$$ where, λ is disintegration constant

  Integrating on both sides, ...(i)
  $$N(t) = N_0 e^{-\lambda t}$$

- Rate of disintegration, Differentiating *eqn* (i)
  $$R = \lambda N_0 e^{-\lambda t}$$
  or, $$R = \lambda N$$

where, $$R = \frac{-dN}{dt}$$

The rate of disintegration R (= $-dN/dt$) is more important than N itself. It gives us the number of nuclei decaying per unit time.

- **Alternative form of law of radioactive decay :**

$$R = R_0 e^{-\lambda t}$$

where, R_0 is the radioactive decay rate at time $t = 0$, and R is the rate at any subsequent time t.
The SI unit for rate of radioactive decay is becquerel. One becquerel (Bq) is one decay per second.

$$1 \text{ curie} = 3.7 \times 10^{10} \text{ Bq}$$

- **Measurement of life of radionuclide :**
  - **Half lifetime ($T_{1/2}$) :**It is the time period in which both N and R reduce half of initial quantity.

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

- **Mean life (τ) :**It is the time at which both N and R have been reduced to e^{-1} of their initial values.

$$\tau = 1/\lambda$$

- **Relation between half life time and mean life :**

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

- We may also derive from above formulae of half lifetime and radioactive decay rate that

$$\frac{N}{N_0} = \left(\frac{1}{2}\right)^n \qquad (\text{where, } n = \frac{t}{T_{1/2}})$$

- **Nuclear energy by artificial fission and fusion processes**
  - **Fission :** When a heavy nucleus is broken into two smaller nuclei, the process is known as fission. In this process, huge amount of energy is released.
    When a neutron was bombarded on a uranium target, the uranium nucleus broke into two nearly equal fragments releasing huge amount of energy.
  - Some combination of products of above reaction are

$${}_0^1n + {}_{92}^{235}\text{U} \rightarrow {}_{92}^{236}\text{U} \rightarrow {}_{56}^{144}\text{Ba} + {}_{36}^{89}\text{Kr} + 3{}_0^1n$$

$${}_0^1n + {}_{92}^{235}\text{U} \rightarrow {}_{92}^{236}\text{U} \rightarrow {}_{51}^{133}\text{Ba} + {}_{41}^{99}\text{Nb} + 4{}_0^1n$$

$${}_0^1n + {}_{92}^{235}\text{U} \rightarrow {}_{54}^{140}\text{Xe} + {}_{38}^{94}\text{Sr} + 2{}_0^1n$$

  - The energy released (the Q value) in the fission reaction of nuclei like uranium is of the order of 200 MeV per fissioning nucleus.

Nuclear reactor :

- **Nuclear fusion :** Two light nuclei (low binding energy per nucleon) join and form one nucleus of higher binding energy per nucleon, energy is released. This process is known as Fusion.
  Some Examples of nuclear fusion are

$${}_1^1\text{H} + {}_1^1\text{H} \rightarrow {}_1^2\text{H} + e^+ + \nu + 0.42\text{MeV}$$

$${}_1^2\text{H} + {}_1^2\text{H} \rightarrow {}_2^3\text{He} + n + 3.27\text{MeV}$$

$${}_1^2\text{H} + {}_1^2\text{H} \rightarrow {}_1^3\text{H} + {}_1^1\text{H} + 4.03\text{MeV}$$

- Nuclear fusion is the source of energy for the stars.
- Fusion process gives more energy than fission process. In the above examples of fusion and fission, energy from one unit mass by fusion is 6.7 MeV and from fission, it is 1 MeV
- **Advantages of Nuclear fusion reactor :**
  - It is a clean fuel. No radioactive wastage in this process.
  - Hydrogen is available in plenty.
- **Problems of nuclear fusion reactor :**
  - Cannot be stopped unless the whole stock is burnt.
  - Storage of hydrogen plasma.
- Hydrogen bomb is uncontrollable nuclear fusion reaction.
- **Thermal nuclear fusion reaction in Sun :**Fusion of hydrogen nuclei into helium nuclei is the source of energy of all stars including our Sun.

$${}_1^1\text{H} + {}_1^1\text{H} \rightarrow {}_1^2\text{H} + e^+ + \nu + 0.42 \text{ MeV} \qquad \text{...(i)}$$

$$e^+ + e^- \rightarrow \gamma + \gamma + 1.02 \text{ MeV} \qquad \text{...(ii)}$$

$$ {}_{1}^{2}\mathrm{H} + {}_{1}^{1}\mathrm{H} \rightarrow {}_{2}^{3}\mathrm{He} + \gamma + 5.49 \text{ MeV} \quad \text{...(iii)} $$

$$ {}_{2}^{3}\mathrm{H} + {}_{2}^{3}\mathrm{H} \rightarrow {}_{2}^{4}\mathrm{He} + {}_{1}^{1}\mathrm{H} + {}_{1}^{1}\mathrm{H} + 12.86 \text{ MeV} \quad \text{...(iv)} $$

The combined effect of above reactions is

$$ 4\,{}_{1}^{1}\mathrm{H} + 2e^{-} \rightarrow {}_{2}^{4}\mathrm{He} + 2\nu + 6\gamma + 26.7\,\text{MeV} $$

Know the Formulae

- **Law of Radioactive decay :**

$$ N = N_o e^{-\lambda t} $$

- **Rate of disintegration**

$$ R = \lambda N_o e^{-\lambda t} $$

or,

$$ R = \lambda N $$

- **Alternative form of law of Radioactive decay:**

$$ R = R_0 e^{-\lambda t} $$

- **Measurement of life of radionuclide :**
  Half lifetime ($T_{1/2}$) :

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

Mean life :

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

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

- $$ \frac{N}{N_0} = \left(\frac{1}{2}\right)^n \qquad \left(\text{where, } n = \frac{t}{T_{1/2}}\right) $$

How is it done on the GREENBOARD?

Q. 1. Half life of ${}_{92}^{238}U$ against α-decay is 4.5×10^9 years. Calculate the activity of 1 gram sample of ${}_{92}^{238}U$? Given Avagadro's number $= 6 \times 10^{26}$ atoms/kmol.

U **[OD East 2016]**

Solution:

Step I: 238 g of Uranium = 1 mole atoms

According to the question

238×10^3 g of sample Uranium contain

$= 6 \times 10^{26}$ atoms

1 g of sample Uranium contain

$$ = \frac{6 \times 10^{26}}{238 \times 10^3} $$

$= 2.52 \times 10^{21}$ atoms

or $= 2.52 \times 10^{21}$ nuclei 1

Step II: Activity, $R = \lambda N$

where, $\lambda = \frac{0.693}{T_{1/2}}$ ($T_{1/2} = 4.5 \times 10^9$ years)

$$ = \frac{0.693}{4.5 \times 10^9 \times 365 \times 24 \times 60 \times 60} $$

(half life time is converted into seconds)

$$ = \frac{0.693}{1.42 \times 10^{17}} $$ 1

Step III: Hence, $R = \frac{0.693}{1.42 \times 10^{17}} \times 2.52 \times 10^{21}$

$R = 1.23 \times 10^4 \text{ s}^{-1}$ 1

Mnemonics

Isotopes, Isobars and Isotones:

ISO

TOPE — BAR — TONE

TOPE	BAR	TONE
Note **P** in Tope, So, only PROTON NOS. are same.	There is no P, no N in BAR, i.e. PROTON NOS. are different.	Note **N** in TONE. So, only NEUTRON NUMBERS are same.

In ISOTOPES→ Number of protons are same. Number of neutrons are different.
In ISOTONES→ Number of neutrons are same. Number of protons are different.
In ISOBARS→ Number of neutrons are different. Number of protons are also different But the total number of nucleons remain same

Objective Type Questions

(1 mark each)

[A] Very Short Answer Type Questions

Q. 1. A neutron is converted into which particles in a β-decay ? R **[CBSE OD SET 2, 2020 / MODIFIED]**

Ans. e^{-1} and antineutrino. **1**

Q. 2. Write the nuclear reaction when a neutron bombards an $^{10}_{5}B$ nucleus and an α-particle is emitted. U **[CBSE OD SET 3, 2020 / MODIFIED]**

Ans. $^{1}_{0}n + ^{10}_{5}B \rightarrow ^{4}_{2}He + ^{7}_{3}Li$ **1**

Q. 3. Four nuclei of an element undergo fusion to form a heavier nucleus, with release of energy. Which of the two — the parent or the daughter nucleus — would have higher binding energy per nucleon? U **[CBSE 2018]**

Ans. Daughter nucleus will have higher binding energy per nucleon. **1**

Q. 4. When radioactive substance emits an α-particle, its position in the periodic table is lowered by how many positions ? U

Ans. When an α−particle is emitted from the nucleus of a radioactive atom, the atomic number is reduced by 2 and mass number is reduced by 4. **1**

Q. 5. A radioactive material has a half-life of 10 days. What fraction of the material would remain after 30 days? A

Ans. Here $n = \frac{t}{T_{1/2}} = \frac{30}{10} = 3$ **1**

$$\frac{N}{N_0} = \left(\frac{1}{2}\right)^n = \left(\frac{1}{2}\right)^3 = \frac{1}{8} = 0.125.$$ **1**

Q. 6. On the basis of which relation mass to energy conversion in nuclear fusion and fission is explained ? R

Ans. Since, Nuclear Fission and Fusion are processes in which mass is converted into energy. Hence, nuclear fission and fusion can be explained on the basis of Einstein mass-energy equivalence relation. **1**

Q. 7. Where the emitted beta particles are produced in a radioactive decay ? R

Ans. Inside the nucleus. **1**

Q. 8. The half life of radium is 1600 years. What fraction of the sample would remain after 6400 years ?

Ans. Here, $n = \frac{t}{T_{1/2}} = \frac{6400}{1600} = 4$

$$\frac{N}{N_0} = \left(\frac{1}{2}\right)^n = \left(\frac{1}{2}\right)^4 = \frac{1}{16}$$ **1**

Q. 9. What will be the mass number of $^{115}_{48}Cd$ after two successive beta decays ? U

Ans. 115. **1**

Q. 10. What do you mean by activity of the radioactive sample? R

Ans. Activity of radioactive substance is defined as the number of disintegration taking place in the given sample per second.
Its SI unit is Becquerel (Bq).
1 Bq is one disintegration per second. **1**

Q. 11. A radioactive substance has a half-life period of 30 days. What is the value of disintegration constant? A

Ans.
$$\frac{N}{N_0} = \left(\frac{1}{2}\right)^{\frac{t}{T}}$$

Here, $N = N_0 - \frac{3}{4}N_0$

$$N = \frac{1}{4}N_0$$

$$\frac{1}{4} = \left(\frac{1}{2}\right)^{\frac{t}{30}}$$

or, $$\left(\frac{1}{2}\right)^2 = \left(\frac{1}{2}\right)^{\frac{t}{30}}$$

$\frac{t}{30} = 2$ or $t = 60$ days **1**

Q. 12. Identify the nucleides X and Y in the nuclear reactions.

${}_5B^{11} + {}_1H^1 \rightarrow {}_4Be^8 + X, {}_6C^{14} \rightarrow Y + {}_{-1}e^0.$ U

Ans. Using conservation of mass number and charge number

${}_{5+1-4=2}X^{11+1-8=4}$, i.e., ${}_2X^4$

${}_{6-(-1)=7}Y^{14-0=14}$, i.e., ${}_7Y^{14}$

[B] ASSERTION REASON TYPE QUESTIONS

For the following questions, two statements are given-one labelled as Assertion (A) and the other labelled as Reason (R). Select the correct answer to these questions from the codes (a), (b), (c) and (d) as given below. (a) Both A and R are true and R is the correct explanation of A (b) Both A and R are true but R is not the correct explanation of A (c) A is true but is false (d) A is false and R is also false.

1. Assertion (A): Radioactive nuclei emit β^{-1} particles.
Reason (R): Electrons exist inside the nucleus.

Ans. (c) **1**

Explanation: When the ratio of neutrons to protons in the nucleus is too high, an excess neutron transforms into a proton and an electron. The proton stays in the nucleus and the electron is ejected energetically.

${}_0^1n \rightarrow {}_1^1P + {}_{-1}^{0}e$. So assertion is true.

Only neutrons and protons are present inside the nucleus. There is no electron inside. Hence the reason is false.

2. Assertion (A): ${}_Z^AX$ undergoes two α-decay, two β-decay and two γ-decay and the daughter product is ${}_{Z-2}^{A-8}Y$.

Reason (R): In α-decay, the mass number decreases by 4 and atomic number decreases by 2. In β-decay the mass number remains unchanged, but atomic number increases by 1. In γ-decay, there is no change in mass number and atomic number.

Ans. (a) **1**

Explanation: After two α-decay, the mass number becomes A – 8 and atomic number becomes Z – 4. After β-decay, the mass no. remains A – 8 and atomic number becomes Z – 2. For γ decay, no change occurs. Hence the daughter product is ${}_{Z-2}^{A-8}Y$. So, the assertion is true.

Since α-particle means ${}_2^4$He, one α decay causes decrease in mass number by 4 and decrease in atomic number by 2. Since β-particle means ${}_{-1}^{0}\beta$, one β decay causes no change in mass number and increase in atomic number by 1. γ decay causes no change in mass number and atomic number . So, the reason is also true and properly explain the assertion.

3. Assertion (A): Density of all the nuclei is same.
Reason (R): Radius of nucleus is directly proportional to the cube root of mass number.

Ans. (a) **1**

Explanation: Radius of nucleus= $R = R_0A^{1/3}$.

So, Volume of nucleus $= V = \frac{4}{3}\pi R_0^3 A$

Considering mass of proton = mass of neutron $= m$

The mass of the nucleus $= M = mA$

So, density $= M/V = \dfrac{mA}{\frac{4}{3}\pi R_0^3 A} = \dfrac{m}{\frac{4}{3}\pi R_0^3}$

So, the mean density is independent of mass number.

So, assertion and reason both are true and the reason properly explains the assertion.

Short Answer Type Questions-I (2 marks each)

Q. 1. (a) Define one Becquerel.

(b) A radioactive substance disintegrates into two types of daughter nuclei, one type with disintegration constant λ_1 and the other type with disintegration constant λ_2. Determine the half-life of the radioactive substance.

R & A **[CBSE DEL SET 1, 2020]**

Ans. (a) Becquerel :One Becquerel is defined as the activity of a quantity of radioactive material in which one nucleus decays per second. **1**

(b) $\lambda = \lambda_1 + \lambda_2$

or, $\frac{0.693}{T_{1/2}} = \lambda_1 + \lambda_2$

$\therefore \quad T_{1/2} = \frac{0.693}{\lambda_1 + \lambda_2}$ **1**

Q. 2. The following table shows some measurements of the decay rate of a radio nuclei sample. Find the disintegration constant.

Time (min)	ln R (Bq)
36	5.08
100	3.29
164	1.52
218	1.00

U

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

where,

τ = mean life 1

Alternatively,

The decay constant is equal to the ratio of $\ln_e 2$ to the half-life of the given radioactive element.

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

Where, $T_{1/2}$ = Half-life

Alternatively,

The decay constant of a radioactive element, is the reciprocal of the time in which the number of its nuclei reduces to 1/e of its original number. 1

[Note :Do not deduct any mark of this definition, if a student does not write the formula in support of the definition]

We have ½

$$R = \lambda N$$
$$R\ (20\text{ hrs}) = 10000 = \lambda N_{20}$$
$$R\ (30\text{ hrs}) = 5000 = \lambda N_{30}$$
$$\therefore \quad \frac{N_{20}}{N_{30}} = 2 \qquad ½$$

This means that the number of nuclei, of the given radioactive nucleus, gets halved in a time of (30 – 20) hours = 10 hours

$\therefore$ Half life = 10 hours ½

This means that in 20 hours (=2 half lives), the original number of nuclei must have gone down by a factor of 4.

Hence Rate of decay at t = 0

$$\lambda N_0 = 4\lambda N_{20}$$

=4 × 10000 = 40,000 disintegrations per second ½

[**Note**: Award full marks of the last part of this question even if student does not calculate initial number of nuclei and calculates correctly rate of disintegration at t=0]

i.e., R_0 = 40,000 disintegrations per second

$$N_0 = \frac{40000}{\lambda} = \frac{40000}{\ln 2} \times 10 \times 60 \times 60$$

$$N_0 = \frac{144 \times 10^7}{0.693} = 2.08 \times 10^9 \text{ nuclei} \qquad ½$$

[CBSE Marking Scheme, 2019]

Q. 4. (a) Write the relation between half life and average life of a radioactive nucleus.

(b) In a given sample two isotopes, A and B are initially present in the ratio of 1 : 2. Their half lives are 60 years and 30 years respectively. How long will it take so that the sample has these isotopes in the ratio of 2 : 1 ? R **[CBE DEL SET 2, 2019]**

Ans. (a) Relation between Average life and half life 1

(b) Finding the required time 2

(a) $$T = \frac{1}{\lambda}$$

$$\text{Alternatively} = \left(\frac{T_{1/2}}{\ln 2}\right) / \left(\frac{T_{1/2}}{0.6931}\right) / 1.44\, T_{1/2}$$

(b) We have $N = N_0 e^{-\lambda t}$ 1

Here, $\frac{N_{01}}{N_{02}} = \frac{1}{2}, \ \frac{N_1}{N_2} = \frac{2}{1}$

$$\therefore \quad \frac{N_1}{N_2} = \frac{N_{01}}{N_{02}} \exp(-(\lambda_1 - \lambda_2)t) \qquad ½$$

$$\therefore \quad 2 = \frac{1}{2}\exp(-(\lambda_1 - \lambda_2)t) \qquad ½$$

$$\Rightarrow \exp(-(\lambda_1 - \lambda_2)t) = 4$$

$$\Rightarrow \quad -(\lambda_1 - \lambda_2)t = 2\ln 2 \qquad ½$$

$$\Rightarrow -\ln 2\left(\frac{1}{60} - \frac{1}{30}\right)t = 2$$

$$\Rightarrow \quad \frac{t}{60} = 2$$

$$\Rightarrow \quad t = 120 \text{ years} \qquad ½$$

(**Note :**Also accept if the student gets the answer just through reasoning without using this formula based approach) **[CBSE Marking Scheme, 2019]**

Q. 5. Why is it difficult to detect the presence of an anti-neutrino during beta (β)-decay ? Define the term decay constant of a radioactive nucleus and derive the expression for its mean life in terms of the decay constant. [O.D. I,II 2019]

Ans. Reason for difficulty in detecting presence of anti-neutrino during β-decay ½

Define decay constant of radioactive nucleus ½

Derive expression for mean life in terms of decay constant 2

- Penetrating power is high
- Do not interact with matter (weak interaction) ½ **(any one)**
- Decay constant is the reciprocal of the time duration in which undecayed radioactive nuclei reduce to 1/e times the nuclei present initially. 1

$$\tau = \frac{\text{Total life time of all nuclei}}{\text{Total number of nuclei}} \qquad ½$$

$$\tau = \frac{\int_0^\infty t\,dN}{N_0} \qquad ½$$

$$\tau = \frac{\int_0^\infty t(N_0 \lambda \varepsilon^{-\lambda t} dt)}{N_0} = \lambda \int te^{-\lambda t} dt$$

$$\tau = \frac{1}{\lambda} \qquad ½$$

Detailed Answer :

Since, in beta minus (β^-) decay, an electron is emitted by the nucleus. In this, a neutron is converted into proton and electron and electron is emitted out along with antineutrino. ½

(i) Let there be N_0 radioactive nuclei at $t = 0$

If N is the number of nuclei left over at $t = t$, we get

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

or, $$\frac{-dN}{dt} = \lambda N \quad (\lambda = \text{decay constant})$$

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

or, $$\ln N = -\lambda t + \text{constant}$$

$\therefore$ At $t = 0$ we have, $\ln N_0 = \text{constant}$

So, $$\ln N = -\lambda t + \ln N_0$$

or, $$\ln\left(\frac{N}{N_0}\right) = -\lambda t$$

$\therefore$ $$N = N_0 e^{-\lambda t}$$ 1

Mean Life :

The number of nuclei which decay in time interval t to $t + \Delta t$ is, $R(t)\Delta t = \lambda N_0 e^{-\lambda t}$

$$\tau = \frac{\lambda N_0 \int_0^\infty t e^{-\lambda t} dt}{N_0} = \lambda \int_0^\infty t e^{-\lambda t} dt$$

$$= -\lambda \left[\left(\frac{te^{-\lambda t}}{-\lambda}\right)_\infty^0 - \int_\infty^0 \frac{e^{-\lambda t}}{-\lambda} dt\right]$$ ½

$$= -\lambda \left[0 - \frac{1}{-\lambda}\left(\frac{e^{-\lambda t}}{-\lambda}\right)_\infty^0\right]$$

$$= \frac{\lambda}{\lambda^2}\left(e^{-\lambda t}\right)_\infty^0$$

$$= \frac{1}{\lambda}(e^0 - e^{-\infty}) = \frac{1}{\lambda}$$

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

Q. 6. (a) Explain the processes of nuclear fission and nuclear fusion by using the plot of binding energy per nucleon (*BE*/*A*) versus the mass number *A*.

(b) A radioactive isotope has a half-life of 10 years. How long will it take for the activity to reduce to 3.125%? U & A **[CBSE 2018]**

Ans. (a) Drawing the plot 1

Explaining the process of Nuclear fission and Nuclear fusion ½ + ½

(b) Finding the required time 1

(a) Try yourself. See Q. 2 of 3 Marks Questions of Topic 1. 2

(b) We have

$$3.125\% = \frac{3.125}{100} = \frac{1}{32} = \frac{1}{2^5}$$

Half life = 10 years

$\therefore$ Required time = 5 × 10 years = 50 Years 1

[CBSE Marking Scheme, 2018]

Detailed Answer :

(b) Let the initial activity be R_0 and final activity be R then we have

$$\frac{R}{R_0} = \left(\frac{1}{2}\right)^{t/T_{1/2}}$$

Given $R = 3.125\%$,

$$R = \frac{3.125}{100} R_o, \quad T_{\frac{1}{2}} = 10 \text{ years.}$$

$$R = 0.03125 R_0$$

$\Rightarrow$ $$\frac{R}{R_0} = 0.03125 = \left(\frac{1}{2}\right)^5$$

$\Rightarrow$ $$\left(\frac{1}{2}\right)^5 = \left(\frac{1}{2}\right)^{t/T_{1/2}}$$

$\Rightarrow$ $$\frac{t}{T_{1/2}} = 5 \text{ or } t = 5T_{1/2}$$

$\Rightarrow$ $$t_2 = 5 \times 10$$

$\Rightarrow$ $$\boxed{t = 50 \text{ years}}$$ ½

Q. 7. (a) Draw a plot showing the variation of potential energy of a pair of nucleons as a function of their separation. Mark the regions where the nuclear force is

(i) attractive and (ii) repulsive.

In the nuclear reaction

$${}_0n^1 + {}^{235}_{92}\text{U} \rightarrow {}^{a}_{54}\text{Xe} + {}^{94}_{b}\text{Sr} + 2\,{}_0n^1$$

determine the values of *a* and *b*.

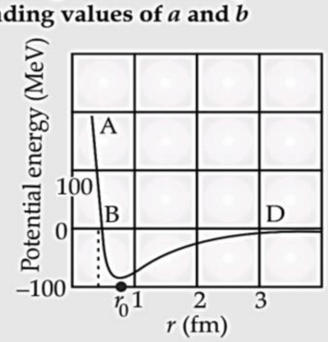
U & A **[CBSE Comptt. 2018]**

Ans. (a) Drawing the plot 1

Marking the relevant regions ½+½

(b) Finding values of *a* and *b* ½+½

(a)



1

(a) Try Yourself See Q. No. 3 (c) of 3 marks Questions of Topic 1. ½+½

(b) We have,

$$1 + 235 = a + 94 + 2 \times 1$$ ½

$\therefore$ $$a = 236 - 96 = 140$$

Also $$0 + 92 = 54 + b + 2 \times 0$$

$\therefore$ $$b = 92 - 54 = 38$$ ½

[CBSE Marking Scheme, 2018]

Q. 8. A radioactive nucleus 'A' undergoes a series of decays as given below :

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

The mass number and atomic number of A_2 are 176 and 71 respectively.

(i) Determine the mass and atomic numbers of A_4 and A.

(ii) Write the basic nuclear processes underlying β^+ and β^- decays. U & A **[CBSE DEL SET 1, 2017]**

Ans. (i) Determine the mass and atomic numbers of A_4 and A. ½ × 4

(ii) Basic nuclear processes of β^+ and β^- decays. ½ + ½

(i) A_4 Mass Number :172
Atomic Number :69 ½
A :Mass Number :180
Atomic Number :72 ½

[**Alternatively** :Give full credit if student considers decay and find atomic and mass numbers accordingly.]

$${}^{180}_{72}A \xrightarrow{\alpha} {}^{176}_{70}A_1 \xrightarrow{\beta^+} {}^{176}_{71}A_2 \xrightarrow{\alpha} {}^{172}_{69}A_3 \xrightarrow{\gamma} {}^{172}_{69}A_4$$

Gives the values quoted above.
If the student takes β^+ decay

$${}^{180}_{74}A \xrightarrow{\alpha} {}^{176}_{72}A_1 \xrightarrow{\beta^+} {}^{176}_{71}A_2 \xrightarrow{\alpha} {}^{172}_{69}A_3 \xrightarrow{\gamma} {}^{172}_{69}A_4$$

This would give the answers :
(A_4 :172, 69); (A : 180, 74)] ½ + ½

(ii) Basic nuclear process for β^+ decay.

$$p \to n + {}^{0}_{1}e + \nu \quad ½$$

For β^- decay,

$$n \to p + {}^{0}_{-1}e + \bar{\nu} \quad ½$$

[**Note** :Give full credit of this part, if student writes the processes as conversion of proton into neutron for decay and neutron into proton for decay.] **[CBSE Marking Scheme 2017]**

Q. 9. (i) State the law of radioactive decay. Write the SI unit of 'activity'.

(ii) There are $4\sqrt{2} \times 10^6$ radioactive nuclei in a given radioactive sample. If the half life of the sample is 20 s, how many nuclei will decay in 10 s ? R A **[Foreign 1, 2017]**

Ans. (i) Statement : Rate of decay of a given radioactive sample is directly proportional to the total number of undecayed nuclei present in the sample **1**

[**Alternatively :** $-\frac{dN}{dt} \propto N$]

Unit → becquerel (Bq) ½

(ii)
$$N = N_0 e^{-\lambda t} \quad ½$$
$$\frac{N}{N_0} = \left(\frac{1}{2}\right)^n \quad ½$$
$$n = \frac{t}{T_{1/2}} = \frac{10}{20} = \frac{1}{2} \quad ½$$
$$\Rightarrow N = 4\sqrt{2}\times 10^6 \times \left(\frac{1}{2}\right)^{1/2}$$
$$= 4 \times 10^6 \text{ nuclei} \quad ½$$

Number of nuclei decayed $= N_0 - N$
$$= 4\sqrt{2}\times 10^6 - 4\times 10^6$$
$$= 4 \times 10^6(\sqrt{2}-1)$$
$$= 4\times 0.414\times 10^6 = 1.656\times 10^6 \quad ½$$

[CBSE Marking Scheme, 2017]

Q. 10. (i) Write the process of β^--decay. How can radioactive nuclei emit β^- particles even though they do not contain them ? Why do all electrons emitted during β^- decay not have the same energy ?

(ii) A heavy nucleus splits into two lighter nuclei. Which one of the two - parent nuclei or the daughter nuclei has more binding energy per nucleon ? U **[Foreign II 2017]**

Ans. (i) A nucleus, that spontaneously decays by emitting an electron, or a positron, is said to undergo β decay.

[**Alternatively,** ${}^{A}_{Z}X \to {}_{Z+1}^{A}Y + e^- + \bar{\nu}$ (antineutrino)

${}^{A}_{Z}X \to {}_{Z-1}^{A}Y + e^+ + \nu$ (neutrino) **(Any one) 1**

During β decay, nucleons undergo a transformation.

$$n \to p + e^- + \bar{\nu}$$

A neutron converts into a proton and an electron.

[**Alternatively,**

$$p \to n + e^+ + \nu \quad 1$$

A proton converts into a neutron and a positron]

It is because the neutrinos, or antineutrino, carry off different amounts of energy. ½

(ii) Try Yourself. See Q. No. 3 of 1 Mark questions. ½

[CBSE Marking Scheme, 2017]

Detailed Answer :

(i) Kindly refer 'Revision Notes' of this topic for description of β-decay.

Radioactive nuclei can emit β-particles *i.e.*, electrons or positrons even though they do not contain them. The reason is that neutron or proton present in the nucleus get interconverted and emit electron or positron.

Electrons or positrons are emitted in β-decay process along with neutrino or antineutrino. The energy of these emitted neutrino or antineutrino are different which effect the energy of electrons or positrons.

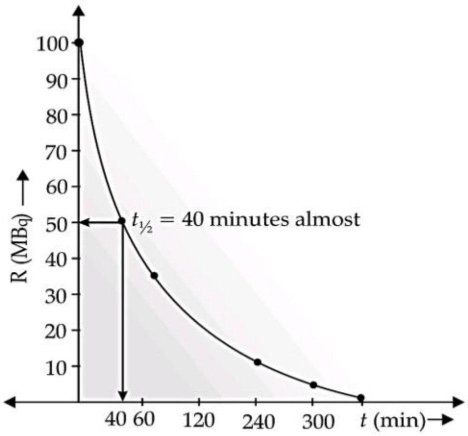
Q. 11. The activity R of an unknown nuclide is measured at hourly intervals. The results found are tabulated as follows :

$t(h)$	0	1	2	3	4
R(MBq)	100	35.36	12.51	1.56	1.56

(i) Plot the graph of R versus t and calculate half life from the graph.

(ii) Plot the graph of ln (R/R_0) versus t and obtain the value of half life from the graph. U

Ans. (i)



From the graph we can calculate half life ≈ 40 minutes **1**

(ii)

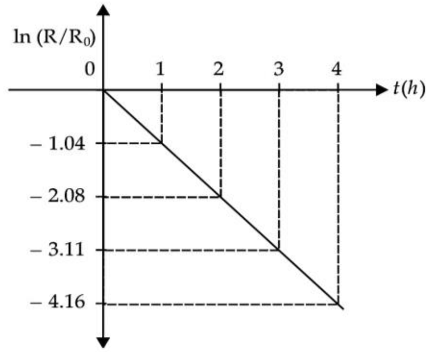
$$R = R_0 e^{-\lambda t}$$

$$\ln R = \ln R_0 - \lambda t$$

$$\ln \frac{R}{R_0} = -\lambda t \qquad ½$$

$$\lambda = -\frac{\ln \frac{R}{R_0}}{t} \qquad ½$$

$$= -\frac{y}{x} \qquad \mathbf{1}$$



From the graph

$$\lambda = \frac{0-(-1.04)}{1-0}$$

$$= 1.04 \text{ hour}^{-1}$$

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

$$T_{1/2} = \frac{0.693}{1.04}$$

$$= 0.66 \text{ hour}$$

$$= 0.66 \times 60 \text{ min}$$

$$= 39.6 \text{ minutes} \qquad \mathbf{1}$$

Long Answer Type Questions **(5 marks each)**

Q. 1. (a) Derive the law of radioactive decay $N = N_o e^{-\lambda t}$.

(b) The half life of $^{238}_{92}U$ undergoing α-decay is 4.5×10^9 years. Find its mean life.

(c) What fraction of the initial mass of a radioactive substance will decay in five half-life periods ?

A [CBSE OD SET 1, 2020]

Ans. (a) Radioactive decay law : The rate of disintegration of a radioactive substance at an instant is directly proportional to the number of nuclei in the radioactive substance at that time .

$N = N_o e^{-\lambda t}$, where symbols have their usual meanings **1**

Let us consider a radioactive substance having N_o atoms initially at time ($t = 0$).

After time (t), number of atoms left undecayed be N.

If dN is the number of atoms decayed in time dt, then according to radioactive decay law :

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

$$\text{Or,} \quad -\frac{dN}{dt} = \lambda N \qquad \text{.... (i)}$$

Here, λ is decay constant and negative sign indicates that a radioactive sample goes on decreasing with time. **1**

Equation (i) can also be written as

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

Integrating

$$\ln N = -\lambda t + K \qquad \text{...(ii)}$$

Here, K is constant of integration

At $t = 0$, $N = N_0$

$$\therefore \quad K = \ln N_0$$

Substituting K in equation (ii),

$$\ln N = -\lambda t + \ln N_0$$

$$\ln \frac{N}{N_o} = -\lambda t$$

$$\text{or,} \quad \frac{N}{N_o} = e^{-\lambda t}$$

$$\therefore \quad N = N_0\, e^{-\lambda t} \qquad \mathbf{1}$$

(b) Half-life = (Mean life) × ln2

or, 4.5×10^9 years = (mean life) × ln 2

$$\text{or,} \quad \text{Mean life} = \left(\frac{4.5 \times 10^9}{\ln 2}\right) \text{years}$$

$$\text{or,} \quad \text{Mean life} = \left(\frac{4.5 \times 10^9}{0.693}\right) \text{years}$$

$$= 6.5 \times 10^9 \text{ years} \qquad \mathbf{1}$$

(c) No. of half lives = 5

$$\text{So,} \quad \frac{N}{N_o} = \left(\frac{1}{2}\right)^5$$

$= \frac{1}{32} =$ Fraction of mass of the radioactive substance left undecayed

So, fraction of mass decayed $= 1 - \frac{1}{32} = \frac{31}{32}$ **1**

Q. 2. (i) Define the terms (a) half-life ($T_{½}$) and (b) average life (τ). Find out their relationships with the decay constant (λ).

(ii) A radioactive nucleus has a decay constant, λ = 0.3465 $(day)^{-1}$. How long would it take the nucleus to decay to 75% of its initial amount ? R U

Ans. (i) (a) Half life : The time taken by a radioactive nuclei to reduce to half of the initial number of radio- nuclei. **1**

(b) Average life :The ratio of total life time of all radioactive nuclei to the total number of nuclei in the sample. **1**

Relation between half-life and decay constant:

$$T_{½} = \frac{0.693}{\lambda} \quad ½$$

Relation between average life and decay constant:

$$\tau = \frac{1}{\lambda} \quad ½$$

(ii)

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

$$N = \frac{3}{4} N_0$$

$$\frac{3}{4} N_0 = N_0 e^{-(0.3465)t}$$

$$(\because N = 75\% \text{ of } N_0) \quad ½$$

$$e^{(0.3465)t} = \frac{4}{3} \quad ½$$

$$0.3465 \times t = \log_e (4/3)$$

$$0.3465 \times t = 2.303 [\log 4 - \log 3]$$

$$0.3465 \times t = 2.303 [0.6020 - 0.4771] \quad ½$$

$$0.3465 \times t = 2.303 \times 0.1249$$

or,

$$t = \frac{2.303 \times 0.1249}{0.3465}$$

$$\therefore \quad t = 0.83 \text{ days or } 19.92 \text{ hours} \quad ½$$

Q. 3. (a) How are β rays emitted from the nucleus when it does not contain electrons?

(b) The activity of sample is X at time t_1 and Y at time t_2. The mean life of the sample is τ. What is the number of nuclei that have disintegrated in time $(t_2 - t_1)$? U & A

Ans. (a) Nucleus does not contain electrons. It contains only protons and neutrons.

When the ratio of neutrons to protons in the nucleus is too high, then an excess neutron transforms into a proton and an electron. The proton stays in the nucleus and the electron is ejected energetically. **1**

$${}_0^1n \rightarrow {}_1^1P + {}_{-1}^{0}e$$

This process decreases the number of neutrons by one and increases the number of protons by one.

Since the number of protons in the nucleus of an atom determines the element, therefore the conversion of a neutron to a proton actually changes the radionuclide to a different element. **2**

(b) At $t = t_1$,

$$X = \frac{dN}{dt} = \lambda N_1 = \lambda N_0 e^{\lambda t_1}$$

$$\therefore \quad N_1 = N_0 e^{\lambda t_1} = \frac{x}{\lambda}$$

Similarly,

At $t = t_2$,

$$Y = \frac{dN}{dt} = \lambda N_2 = \lambda N_0 e^{\lambda t_2}$$

$$\therefore \quad N_2 = N_0 e^{\lambda t_2} = \frac{y}{\lambda}$$

So, No,. of nuclei disintegrated $= N_1 - N_2$

$$= \frac{X}{\lambda} - \frac{Y}{\lambda}$$

$$= \frac{X - Y}{\lambda}$$

$$= (X - Y)\tau \qquad [\text{since } \tau = \frac{1}{\lambda}] \ 2$$

Visual Case-based Questions (1×4=4 marks)

Attempt any 4 sub-parts from each question. Each question carries 1 mark.

Q. 1. India's atomic energy programme : The atomic energy programme in India was launched around the time of independence under the leadership of Homi J. Bhabha (1909-1966). An early historic achievement was the design and construction of the first nuclear reactor in India (named Apsara) which went critical on August 4, 1956. India indigenously designed and constructed plutonium plant at Trombay, which ushered in the technology of fuel reprocessing (separating useful fissile and fertile nuclear materials from the spent fuel of a reactor). Research reactors that have been subsequently commissioned include ZERLINA, PURNIMA (I, II and III), DHRUVA and KAMINI. KAMINI is the country's first large research reactor that uses U-233 as fuel. The main objectives of the Indian Atomic Energy programme are to provide safe and reliable electric power for the country's social and economic progress and to be self reliant in all aspects of nuclear technology. Exploration of atomic minerals in India undertaken since the early fifties has indicated that India has limited reserves of uranium, but fairly abundant reserves of thorium. Accordingly, our country has adopted a three stage strategy of nuclear power generation. The first stage involves the use of natural uranium as a fuel, with heavy water as moderator. The Plutonium-239 obtained from reprocessing of the discharged fuel from the reactors then serves as a fuel for the second stage — the fast breeder reactors. They are so called because they use fast neutrons for sustaining the chain reaction (hence no moderator is needed) and, besides generating power, also breed more fissile species (plutonium) than they consume. The third stage, most significant in the long term, involves using fast breeder reactors to produce fissile Uranium-233 from Thorium-232 and to build power reactors based on them.

(i) India's atomic energy programme was launched by :
(a) Shanti Swarup Bhatnagar
(b) Homi J. Bhabha
(c) Meghnad Saha
(d) Daulat Singh Kothari

Ans. (b) **1**
Explanation: The atomic energy programme in India was launched around the time of independence under the leadership of Homi J. Bhabha (1909- 1966).

(ii) First nuclear reactor of India :
(a) APSARA **(b)** ZEWRELINA
(c) DHRUBA **(d)** KAMINI

Ans. (a) **1**
Explanation: An early historic achievement was the design and construction of the first nuclear reactor in India named APSARA.

(iii) Which one of the following is not a nuclear reactor?
(a) PURNIMA **(b)** DHRUVA
(c) KAMINI **(d)** ARYABHATTA

Ans. (d) **1**
Explanation: ARYABHATTA is an Indian artificial satellite.

(iv) The main objectives of the Indian Atomic Energy programme :
(a) Development of Nuclear weapons for success in warfare
(b) Generation of safe and reliable electric power
(c) Efficient medical treatment
(d) To breed more fissile species

Ans. (b) **1**
Explanation: The main objectives of the Indian Atomic Energy programme are to provide safe and reliable electric power for the country's social and economic progress and to be self -reliant in all aspects of nuclear technology.

(v) India has limited reserves of ...., but fairly abundant reserves of .... :
(a) Plutonium, Thorium **(b)** Thorium, Uranium
(c) Plutonium, Uranium **(d)** Uranium, Thorium

Ans. (d) **1**
Explanation: Exploration of atomic minerals in India undertaken since the early fifties has indicated that India has limited reserves of uranium, but fairly abundant reserves of thorium.

Q. 2. GRAND UNIFICATION THEORY :There are four fundamental forces in the universe :

- Gravitational force
- Electromagnetic force
- The weak nuclear force
- The strong nuclear force

The weak and strong forces are effective only over a very short range and dominate only at the level of subatomic particles.

Gravitational force and Electromagnetic force have infinite range.

The Four Fundamental Forces and their strengths

(i) Gravitational Force – Weakest force; but has infinite range.
(ii) Weak Nuclear Force – Next weakest; but short range.
(iii) Electromagnetic Force – Stronger, with infinite range.
(iv) Strong Nuclear Force – Strongest; but short range.

Unification :

- The weak nuclear force and electromagnetic force have been unified under the Standard Electroweak Theory, (Glashow, Weinberg and Salaam were awarded the Nobel Prize for this in 1979).
- Grand unification theories attempt to treat both strong nuclear force and electroweak force under the same mathematical structure.
- Theories that add gravitational force to the mix and try to unify all four fundamental forces into a single force are called Superunified Theories. It has not yet been successful.

(i) What are the 4 fundamental forces ?
(a) Gravitational force, electromagnetic force, nuclear force, Tension force
(b) Gravitational force, electromagnetic force, nuclear force, Frictional force
(c) Gravitational force, electromagnetic force, weak nuclear force, strong nuclear force
(d) Frictional force, electric force, nuclear force, magnetic force

Ans. (c) **1**
Explanation: There are four fundamental forces in the universe :

- Gravitational force
- Electromagnetic force
- the weak nuclear force
- the strong nuclear force

(ii) Which fundamental force is always attractive ?
(a) Electric force
(b) Magnetic force
(c) Gravitational force
(d) Strong Nuclear force

Ans. (c) **1**
Explanation: Gravitational force is always attractive. There is no repulsive gravitational force.

(iii) Which two fundamental forces have been unified by Standard Electroweak Theory ?
(a) Weak nuclear force and electromagnetic force
(b) Strong nuclear force and electromagnetic force
(c) Gravitational force and electromagnetic force
(d) Weak nuclear force and strong nuclear force

Ans. (a) **1**
Explanation: The weak nuclear force and electromagnetic force have been unified under the Standard Electroweak Theory. For this Glashow, Weinberg and Salaam were awarded the Nobel Prize in 1979.

(iv) Which one is the weakest force ?
(a) Weak nuclear force
(b) Electromagnetic force
(c) Strong magnetic force
(d) Gravitational force

Ans. (d) **1**
Explanation: Gravitational force is the weakest force.

(v) Which of the following forces have infinite ranges?
(a) Weak nuclear force and strong nuclear force
(b) Gravitational force and Electromagnetic force
(c) Weak nuclear force and Gravitational force
(d) All the forces

Ans. (b) **1**
Explanation: Electromagnetic force are extended upto infinity.

SELF ASSESSMENT PAPER-8

Time : 1 Hours **Maximum Marks : 25**

SECTION - A

1. (i) What is the approximate wavelength of a photon needed to remove a proton from a nucleus which is bound to the nucleus with 1 MeV energy ? **1**

(ii) Four nuclei of an element undergo fusion to form a heavier nucleus, with release of energy. Which of the two — the parent or the daughter nuclei — would have higher binding energy per nucleon ? **1**

(iii) What is the maximum number of spectral lines emitted by a hydrogen atom when it is in the third excited state ? **1**

(iv) What do you mean by mass defect of a nucleus? **1**

2. For question number 2 two statements are given-one labelled Assertion (A) and the other labelled Reason (R). Select the correct answer to these questions from the codes (a), (b), (c) and (d) as given below.

(a) Both A and R are true and R is the correct explanation of A

(b) Both A and R are true but R is NOT the correct explanation of A

(c) A is true but R is false

(d) A is false and R is also false

(i) Assertion(A) : Bohr's postulate says that electron in stationary orbit around a nucleus does not radiate.
Reason(R) : Classical theory says that moving electron radiates. **1**

(ii) Assertion(A) : All nuclei have the same density.
Reason(R) : Radius of nucleus is directly proportional to the cube root of mass number. **1**

3. Read the Passage given below and answer any 4 Questions.

India's atomic energy programme : The atomic energy programme in India was launched around the time of independence under the leadership of Homi J. Bhabha (1909-1966). An early historic achievement was the design and construction of the first nuclear reactor in India (named Apsara) which went critical on August 4, 1956. India indigenously designed and constructed plutonium plant at Trombay, which ushered in the technology of fuel reprocessing (separating useful fissile and fertile nuclear materials from the spent fuel of a reactor). Research reactors that have been subsequently commissioned include ZERLINA, PURNIMA (I, II and III), DHRUVA and KAMINI. KAMINI is the country's first large research reactor that uses U-233 as fuel. The main objectives of the Indian Atomic Energy programme are to provide safe and reliable electric power for the country's social and economic progress and to be self reliant in all aspects of nuclear technology. Exploration of atomic minerals in India undertaken since the early fifties has indicated that India has limited reserves of uranium, but fairly abundant reserves of thorium. Accordingly, our country has adopted a threestage strategy of nuclear power generation. The first stage involves the use of natural uranium as a fuel, with heavy water as moderator. The Plutonium- 239 obtained from reprocessing of the discharged fuel from the reactors then serves as a fuel for the second stage — the fast breeder reactors. They are so called because they use fast neutrons for sustaining the chain reaction (hence no moderator is needed) and, besides generating power, also breed more fissile species (plutonium) than they consume. The third stage, most significant in the long term, involves using fast breeder reactors to produce fissile Uranium-233 from Thorium-232 and to build power reactors based on them. **4**

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(ii) First nuclear reactor of India :

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(iv) The main objectives of the Indian Atomic Energy programme :

(a) Development of Nuclear weapons for success in warfare
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(c) Efficient medical treatment

(d) To breed more fissile species

(v) India has limited reserves of ...., but fairly abundant reserves of .... :

(a) Plutonium, Thorium (b) Thorium, Uranium

(c) Plutonium, Uranium (d) Uranium, Thorium

SECTION - B

4. Write two important limitations of Rutherford's nuclear model of the atom. **2**

5. Show that the density of nucleus over a wide range of nuclei is constant and independent of mass number. **2**

SECTION - C

6. Distinguish between nuclear fission and fusion. Show how in both these processes energy is released. Calculate the energy release in MeV in the deuterium-tritium fusion reaction :

$$^{2}_{1}\text{H} + ^{3}_{1}\text{H} \rightarrow ^{4}_{2}\text{He} + {}_{0}n^{1}$$

$$m\left(^{2}_{1}\text{H}\right) = 2.014102\text{ u}$$

$$m\left(^{2}_{1}\text{H}\right) = 3.016049\text{ u}$$

$$m\left(^{4}_{2}\text{He}\right) = 4.002603\text{ u}$$

$$m_n = 1.008665\text{ u}$$

$$1\text{ amu} = 931.5\text{ Me}\frac{\text{V}}{c^2}$$ **3**

7. Using Bohr's postulates, derive the expression for the orbital period of the electron moving in the n^{th} orbit of hydrogen atom. **3**

SECTION - D

8. (i) Using Bohr's postulates, derive the expression for the total energy of the electron in the stationary states of the hydrogen atom.

(ii) Using Rydberg formula, calculate the wavelengths of the spectral lines of the first member of the Lyman series and of the Balmer series. **5**