Short Answer Questions – I (PYQ)

Q. 1. (i) What characteristic property of nuclear force explains the constancy of binding energy per nucleon (BE/A) in the range of mass number 'A' lying 30 < A < 170?

(ii) Show that the density of nucleus over a wide range of nuclei is constant independent of mass number A. [CBSE Delhi 2012, 2015]

Ans. (i) Saturation or short range nature of nuclear forces.

(ii) The radius (size) R of nucleus is related to its mass number (A) as

$$R = R_0 A^{1/3} \qquad \text{where } R_0 = 1.1\times10^{-15}\text{ m}$$

If m is the average mass of a nucleon, then mass of nucleus = mA, where A is mass number

$$\text{Volume of nucleus} = \frac{4}{3}\pi R^3 = \frac{4}{3}\pi(R_0 A^{1/3})^3 = \frac{4}{3}\pi R_0^3 A$$

$$\therefore \text{ Density of nucleus, } \rho_N = \frac{\text{mass}}{\text{volume}} = \frac{\text{mA}}{\frac{4}{3}\pi R_0^3 A} = \frac{m}{\frac{4}{3}\pi R_0^3} = \frac{3m}{4\pi R_0^3}$$

Clearly nuclear density ρ_N is independent of mass number A.

Q. 2. (i) Write the basic nuclear process involved in the emission of β+ in a symbolic form, by a radioactive nucleus. [CBSE Central 2016]

(ii) In the reactions given below:

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

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

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

Ans. (i) Basic nuclear reaction for β^+ decay is the conversion of proton to neutron.

$p \rightarrow n + e^+ + \nu$

(ii)

a. $x = \beta^{+} / {}^{0}_{1}e$, $y = 5$, $z = 11$ (b) $a = 10$, $b = 2$, $c=4$

b. $a = 10$, $b = 2$, $c=4$

Q. 3. Calculate the energy in fusion reaction: [CBSE Delhi 2016]

$${}^{2}_{1}H + {}^{2}_{1}H \rightarrow {}^{3}_{2}\mathrm{He} + n, \text{ where BE of } {}^{2}_{1}H = 2.23 \text{ MeV and of } {}^{3}_{2}\mathrm{He} = 7.73 \text{ MeV}$$

Ans. Initial binding energy

BE_1= (2.23 + 2.23) = 4.46 MeV

Final binding energy

BE_2 = 7.73 MeV

∴ Energy released = (7.73 – 4.46) MeV = 3.27 MeV

Q. 4. Why is it found experimentally difficult to detect neutrinos in nuclear β-decay?
[CBSE (AI) 2014]

Ans. Neutrinos are charge less (neutral) and almost massless particles that hardly interact with matter.

Q. 5. State three properties of nuclear forces. [CBSE Allahabad 2015]

Ans. Properties of nuclear forces

(i) Nuclear forces are the strongest attractive forces.

(ii) Nuclear forces are short ranged upto 10^{-15} m.

(iii) Nuclear forces are charge independent.

Q. 6. Answer the following questions [CBSE (F) 2015]

(i) Write the β-decay of tritium in symbolic form.

(ii) Why is it experimentally found difficult to detect neutrinos in this process?

Ans. (i)

$${}_{1}^{3}H \xrightarrow{\beta} {}_{2}^{3}\mathrm{He} + {}_{1}^{0}e + \bar{\nu} + Q$$

(ii) It is due to very weak interaction with matter.

Q. 7. The half-life of ${}_{92}^{238}U$ against α-decay is 4.5×10^9 years. Calculate the activity of 1g sample of ${}_{92}^{238}U$. [Given Avogadro's number 6 × 10^{26} atoms/K mol] [CBSE East 2016]

Ans.

$$T_{1/2} = 4.5\times10^9 \text{ years} = 4.5\times10^9 \times 3.15\times10^7 \text{seconds}$$

$$\text{Number of atoms in 1 } g \text{ sample of } {}_{92}^{238}U \text{ is } N = 6.023\times10^{23}\times\frac{1}{238}$$

$$\text{Activity of sample } A = \lambda N = \frac{\log_e 2}{T_{1/2}} \times N$$

$$= \left(\frac{0.6931}{4.5\times10^9\times3.15\times10^7}\right)\times 6.023\times10^{23}\times\frac{1}{238}$$

$$= 1.237\times10^4 \text{ becquerel}$$

Q. 8. A heavy nucleus X of mass number 240 and binding energy per nucleon 7.6 MeV is split into two fragments Y and Z of mass numbers 110 and 130. The binding energy per nucleon in Y and Z is 8.5 MeV per nucleon. Calculate the energy Q released per fission in MeV. [CBSE Delhi 2010]

Ans. Energy released $Q = (M_Y+M_Z)\,c^2 - M_X\,c^2$

= 8.5 (110 + 130) MeV – 7.6 × 240 MeV

= (8.5 – 7.6) × 240 MeV

= 0.9 × 240 MeV **= 216 MeV**

Q. 9. When four hydrogen nuclei combine to form a helium nucleus, estimate the amount of energy in MeV released in this process of fusion. (Neglect the masses of electrons and neutrinos) Given:

(i) Mass of $^{1}_{1}H$ = 1.007825 u

(ii) Mass of helium nucleus = 4.002603 u, 1 u = 931 MeV/c^2 [CBSE (F) 2011]

Ans.

Energy released $= \Delta m \times 931$ MeV

$$\Delta m = 4m = (^{1}_{1}H) - m(^{4}_{2}\text{He})$$

Energy released $(Q)\ [4.m(^{1}_{1}H) - m(^{4}_{2}\text{He})] \times 931\,\text{MeV}$

$= [4 \times 1.007825 - 4.002603] \times 931$ MeV

= 26.72 MeV

Short Answer Questions – I (OIQ)

Q. 1. Prove that the instantaneous rate of change of the activity of a radioactive substance is inversely proportional to the square of its half-life. [HOTS]

Ans. Activity of a radioactive substance

$$R\left(= -\frac{dN}{dt}\right) = \lambda N \qquad \ldots(i)$$

Rate of change of activity

$$\frac{dR}{dt} = \lambda\left(\frac{dN}{dt}\right) = \lambda.(-\lambda N) = -\lambda^2 N$$

As $\lambda = \frac{\log_e 2}{T_{1/2}}$ $\quad\therefore\quad$ $\frac{dR}{dt} = -\left(\frac{\log_e 2}{T_{1/2}}\right)^2 N$

$\therefore$ Instantaneous activity, $\frac{dR}{dt} \propto \frac{1}{T_{1/2}^2}$

Q. 2. Explain how radioactive nuclei can emit β-particles even though atomic nuclei do not contain these particles? Hence explain why the mass number of radioactive nuclide does not change during β-decay? [HOTS]

Ans. Radioactive nuclei do not contain electrons (β-particles), but β-particles are formed due to conversion of a neutron into a proton according to equation

$$ {}_0^1n \rightarrow {}_1^1p + \underset{\beta\text{-particle}}{{}_{-1}^{0}\beta} + \underset{\text{antineutrino}}{\bar{v}} $$

The β-particle so formed is emitted at once. In this process one neutron is converted into one proton; so that the number of nucleons in the nucleus remains unchanged; hence mass number of the nucleus does not change during a β-decay.

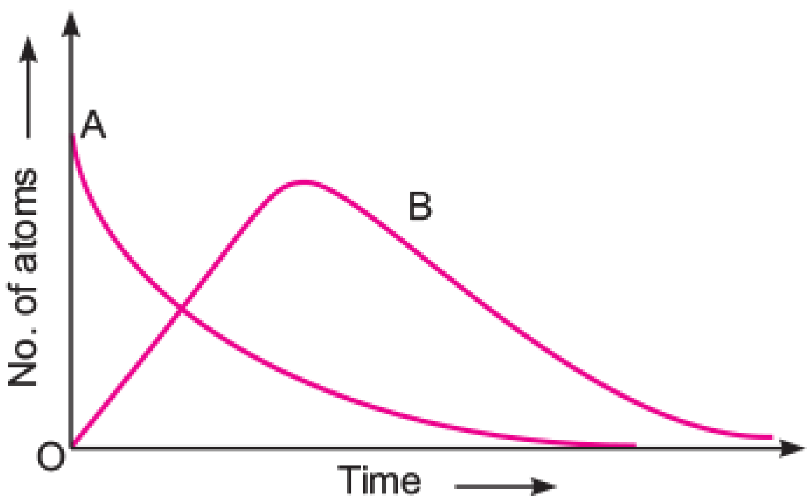
Q. 3. Why do stable nuclei never have more protons than neutrons? [NCERT Exemplar] [HOTS]

Ans. Protons are positively charged and repel one another electrically. This repulsion becomes so great in nuclei with more than 10 protons or so, that an excess of neutrons which produce only attractive forces, is required for stability.

Q. 4. Consider a radioactive nucleus A which decays to a stable nucleus C through the following sequence:

A → B → C

Here B is an intermediate nuclei which is also radioactive. Considering that there are N_0 atoms of A initially, plot the graph showing the variation of number of atoms of A and B versus time. [NCERT Exemplar] [HOTS]



Ans. At $t = 0$, $N_A = N_0$ while $N_B = 0$. As time increases, N_A falls off exponentially, the number of atoms of B increases, becomes maximum and finally decays to zero at ∞ (following exponential decay law).

Q. 5. A nuclide 1 is said to be the mirror isobar of nuclide 2 if $Z_1 = N_2$ and $Z_2 = N_1$. [NCERT Exemplar] [HOTS]

(i) What nuclide is a mirror isobar $^{23}_{11}$Na of?

(ii) Which nuclide out of the two mirror isobars has greater binding energy and why?

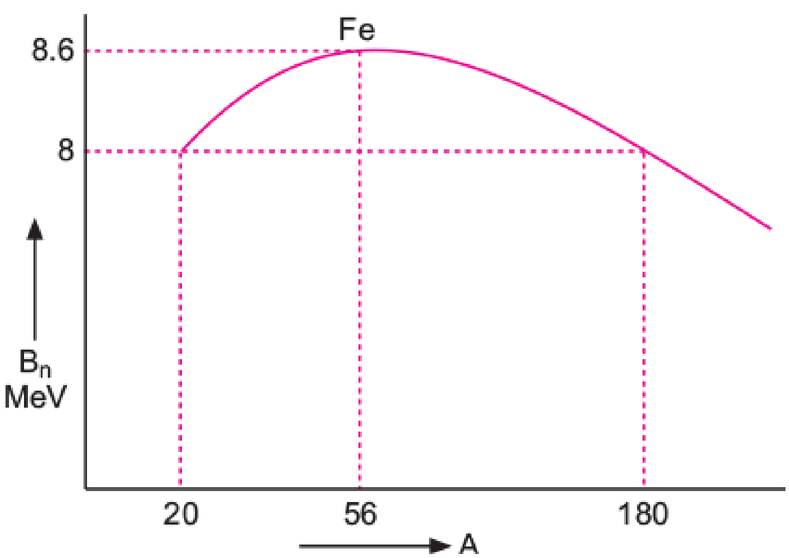
Ans. (i)

$$^{23}_{11}\text{Na} \ : Z_1 = 11, \ N_1 = 12$$

$$\therefore \ \text{Mirror isobar of } ^{23}_{11}\text{Na} = {}^{23}_{11}\text{Mg}.$$

(ii) Since $Z_2 > Z_1$, Mg has greater binding energy than Na.

Q. 6. Draw the graph showing the variation of binding energy per nucleon with mass numbers. Give the reason for the decrease of binding energy per nucleon for nuclei with higher mass number.



Ans. The graph of the binding energy per nucleon versus mass number A is shown in figure. The decrease of the binding energy per nucleon for nuclei with high mass number is due to increased coulomb repulsion between protons inside the nucleus.

Q. 7. If both the number of protons and number of neutrons are conserved in each nuclear reaction, in what way is mass converted into energy (or vice-versa) in a nuclear reaction?

Ans. In fact the number of protons and number of neutrons are same before and after a nuclear reaction, but the binding energies of nuclei present before and after a nuclear reaction are different. This difference is called the mass defect. This mass defect appears as energy of reaction. In this sense a nuclear reaction is an example of mass-energy interconversion.

Q. 8. What is obtained by fusion of two deuterons?

Ans. By fusion of two deuterons, either tritium $\left({}_1^3H\right)$ or an isotope of helium $\left({}_2^3He\right)$ is obtained with release of energy. The reactions are

$$ {}_1^2H + {}_1^2H \rightarrow \underset{(\text{tritium})}{{}_1^3H} + {}_1^1H + 4.03 \text{ MeV} $$

$$ {}_1^2H + {}_1^2H \rightarrow \underset{(\text{isotope of helium})}{{}_2^3\text{He}} + {}_0^1n + 3.27 \text{ MeV} $$

Q. 9. Distinguish between isotopes and isobars. Give one example for each of the species.

Ans.

Isotopes	Isobars
The nuclides having the same atomic number (Z) But different atomic masses (A) are called isotopes. Examples : ${}_1^1H, {}_1^2H, {}_1^3H$	The nuclides having the same atomic mass (A) but Different atomic numbers (Z) are called isobars. Examples : ${}_1^3H, {}_2^3He$

Q. 10. A radioactive nucleus A undergoes a series of decay according to following scheme:

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

The mass number and atomic number of A are 180 and 72 respectively. What are these numbers for A_4?

Ans. The decay scheme may completely be represented as

${}_{72}^{180}A \xrightarrow{\alpha} {}_{70}^{176}A_1 \xrightarrow{\beta} {}_{71}^{176}A_2 \xrightarrow{\alpha} {}_{69}^{172}A_3 \xrightarrow{\gamma} {}_{69}^{172}A_4$ Clearly, mass number of A_4 is 172 and atomic number is 69.

Q. 11. Assuming the nuclei to be spherical in shape, how does the surface area of a nucleus of mass number A_1 compare with that of a nucleus of mass number A_2?

Ans. Radius of nucleus of mass number A is

$R = R_0 A^{1/3}$ where $R_0 = 1.2 \times 10^{-15}$ m = constant

Surface area of nucleus, $S = 4\pi R^2 \propto R^2$

$$\therefore \qquad \frac{S_1}{S_2} = \left(\frac{R_1}{R_2}\right)^2 = \left(\frac{A_1}{A_2}\right)^{2/3}$$

Q. 12. The half-life of $^{14}_{6}C$ is 5700 years. What does it mean? Two radioactive nuclei X and Y initially contain an equal number of atoms. Their half-lives are 1 hour and 2 hours respectively. Calculate the ratio of their rates of disintegration after two hours.

Ans. The half-life of $^{14}_{6}C$ is 5700 years. It means that one half of the present number of radioactive nuclei of $^{14}_{6}C$ will remain undecayed after 5700 years.

$$\text{Number of nuclei } X \text{ after 2 hours, } N_X = N_0\left(\frac{1}{2}\right)^{\frac{t}{T/2}} = \frac{N_0}{4}$$

$$\text{Number of nuclei } Y \text{ after 2 hours, } N_Y = N_0\left(\frac{1}{2}\right)^{\frac{2}{2}} = \frac{N_0}{2}$$

$$\therefore \text{ Ratio of rates of disintegration } \frac{R_X}{R_Y} = \frac{N_0/4}{N_0/2} = \frac{1}{2}$$

Q. 13. Explain with example, whether the neutron-proton ratio in a nucleus increases or decreases due to β-decay.

Ans. In β-decay a neutron is converted into a proton, so the neutron-proton ratio decreases. Equation of β-decay is

$$_{Z}X^{A} \rightarrow Z +_1 Y^{A} +_{-1} \beta^0 + \overline{\nu}$$

$$_{90}\mathrm{Th}^{234} \rightarrow\ _{91}\mathrm{Pa}^{234} +\ _{-1}\beta^0 + \overline{\nu}$$

$$\text{Neutron to proton ratio before } \beta\text{-decay} = \frac{234-91}{90} = \frac{144}{90} = 1.60$$

$$\text{Neutron to proton ratio after } \beta\text{-decay} = \frac{234-91}{91} = \frac{143}{91} = 1.57$$

$\frac{143}{91} < \frac{144}{90}$, so neutron to proton ratio in β-decay decreases.

Q. 14. With the help of an example, explain how the neutron to proton ratio changes during α-decay of a nucleus.

Ans.

Let us take the example of α-decay of $^{238}_{92}U$. The decay scheme is

$$^{238}_{92}U \rightarrow\ ^{234}_{90}\mathrm{Th} + ^{4}_{2}\alpha\ (\text{or } ^{4}_{2}\mathrm{He})$$

$$\text{Neutron to proton ratio before } \alpha\text{-decay} = \frac{238-92}{92} = \frac{146}{92} = 1.59$$

$$\text{Neutron to proton ratio after } \alpha\text{-decay} = \frac{238-90}{90} = \frac{144}{90} = 1.60$$

$$\frac{146}{92} < \frac{144}{90}$$

This shows that the neutron to proton ratio increases during α-decay of a nucleus.

Q. 15. A radioactive isotope has a half-life of 5 years. After how much time is its activity reduced to 3.125%of its original activity?

Ans.

We know $\frac{R}{R_0} = \left(\frac{1}{2}\right)^n$

Given $\frac{R}{R_0} = 3.125\,\% = \frac{3.125}{100}$

$\therefore$ $\frac{3.125}{100} = \left(\frac{1}{2}\right)^n$ or $\frac{1}{32} = \left(\frac{1}{2}\right)^n$

or $\left(\frac{1}{2}\right)^5 = \left(\frac{1}{2}\right)^n \Rightarrow n = 5$

Given T=5 years

As $n = \frac{t}{T}$

$\therefore$ $\frac{t}{T} = 5$

or $t = 5 \times 5 = \mathbf{25\ years}$

Q. 16. Calculate the binding energy per $^{40}_{20}$ CA nucleon nucleus.

[Given: m $\left(^{40}_{20}Ca\right)$ =39.962589 u

***m*n(mass of a neutron) =1.008665 u**

***m*p(mass of a proton) =1.007825 u**

1 u = 931 MeV/c^2]

Ans.

Total Binding energy of $^{40}_{20}$Ca nucleus $= 20m_p + 20m_n - M(^{40}_{20}\text{Ca})$

= 20×1.007825 + 20 × 1.008665 – 39.962589

= 0.367211 u = 0.367211 × 931 MeV = 341.87 MeV

∴ Binding energy per nucleus = $\frac{341.87}{40}$ MeV/nucleon

= 8.55 MeV/nucleon