Nuclei

Multiple Choice Questions

Choose and write the correct option(s) in the following questions.

1. **The size of the atom is proportional to**

   (*a*) A (*b*) $A^{1/3}$ (*c*) $A^{2/3}$ (*d*) $A^{-1/3}$

2. **The gravitational force between a H-atom and another particle of mass m will be given by Newton's law:** [*NCERT Exemplar*]

   $F = G\frac{M.m}{r^2}$, **where r is in km and**

   (*a*) $M = m_{proton} + m_{electron}$

   (*b*) $M = m_{proton} + m_{electron} - \frac{B}{c^2} (B = 13.6 \text{ eV})$

   (*c*) M is not related to the mass of the hydrogen atom.

   (*d*) $M = m_{proton} + m_{electron} - \frac{|V|}{c^2}$ ($|V|$ = magnitude of the potential energy of electron in the H-atom).

3. **If radius of the $^{27}_{13}Al$ nucleus is taken to be R_{Al}, then the radius of $^{125}_{53}Te$ nucleus is nearly**

   (*a*) $\frac{3}{5}R_{Al}$ (*b*) $\left(\frac{13}{53}\right)^{1/3} R_{Al}$ (*c*) $\left(\frac{53}{13}\right)^{1/3} R_{Al}$ (*d*) $\frac{5}{3}R_{Al}$

4. **The mass density of a nucleus of mass number A is** [*CBSE 2023 (55/1/1)*]

   (*a*) proportional to $A^{1/3}$ (*b*) proportional to $A^{2/3}$
   (*c*) proportional to A^3 (*d*) independent of A

5. **The nuclei of the isotopes of an element contain the same number of a certain particle. What is this particle?**

   (*a*) Electron (*b*) Neutron (*c*) Nucleon (*d*) Proton

6. **How much energy will approximately be released if all the atoms of 1 kg of deuterium could undergo fusion? [Assume energy released per deuterium nucleus is 2 MeV]**

   (*a*) 2×10^7 kWh (*b*) 9×10^{13} J (*c*) 6×10^{27} calorie (*d*) 9×10^{13} MeV

7. **A nuclear reaction is given below. The masses in amu of reactant and product nuclei are given in brackets:**

   $$\underset{(1.002)}{A} + \underset{(1.004)}{B} \longrightarrow \underset{(1.001)}{C} + \underset{(1.003)}{D} + Q \text{ Mev}$$

   The value of energy Q is

   (*a*) 1.234 MeV (*b*) 0.91 MeV (*c*) 0.465 MeV (*d*) 1.862 MeV

8. **The curve of binding energy per nucleon as a function of atomic mass number has a sharp peak for helium nucleus. This implies that helium nueleus is** [*CBSE 2023 (55/2/1)*]

   (*a*) radioactive (*b*) unstable
   (*c*) easily fissionable (*d*) more stable nucleus than its neighbourss

9. **Fusion reactions take place at a high temperature because**

   (*a*) atoms are ionised at high temperature
   (*b*) molecules break up at high temperature
   (*c*) nuclei break up at high temperature
   (*d*) kinetic energy is high enough to overcome repulsion between nuclei

10. If $M(A, Z)$, M_P and M_n denote the masses of the nucleus ${}^A_Z X$, proton and neutron respectively in units of u ($1u = 931.5$ MeV/c^2) and BE represents its binding energy in MeV, then

(*a*) $M(A, Z) = ZM_P + (A - Z) M_n - BE/c^2$
(*b*) $M(A, Z) = ZM_P + (A - Z) M_n + BE$
(*c*) $M(A, Z) = ZM_P + (A - Z) M_n - BE$
(*d*) $M(A, Z) = ZM_P + (A - Z) M_n + BE/c^2$

11. The average binding energy per nucleon is maximum for the nucleus

(*a*) ${}^4_2\text{He}$
(*b*) ${}^{16}_8\text{O}$
(*c*) ${}^{238}_{92}\text{U}$
(*d*) ${}^{56}_{26}\text{Fe}$

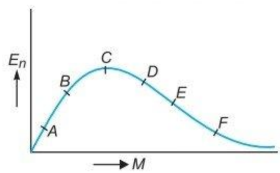
12. O_2 molecule consists of two oxygen atoms. In the molecule, nuclear force between the nuclei of the two atoms

(*a*) is not important because nuclear forces are short-ranged
(*b*) is as important as electrostatic force for binding the two atoms
(*c*) cancels the repulsive electrostatic force between the nuclei
(*d*) is not important because oxygen nucleus have equal number of neutrons and protons

13. Which of the following statements is not true for the nuclear force?

(*a*) It is attractive in nature.
(*b*) It is charge dependent.
(*c*) It is short range.
(*d*) It decreases very quickly with distance between two nucleons.

14. Fig. shows a plot of binding energy per nucleon E_n against the nuclear mass M. A, B, C, D, E, F correspond to different nuclei. Consider four reactions: [*HOTS*]



(*i*) $A + B \to C + \varepsilon$
(*ii*) $C \to A + B + \varepsilon$
(*iii*) $D + E \to F + \varepsilon$
(*iv*) $F \to D + E + \varepsilon$

where ε is the energy released. In which reaction ε is positive?

(*a*) (*i*) and (*iv*)
(*b*) (*i*) and (*iii*)
(*c*) (*ii*) and (*iv*)
(*d*) (*ii*) and (*iii*)

15. The energy in nuclear reactor is obtained due to

(*a*) nuclear fission
(*b*) nuclear fusion
(*c*) photoelectric effect
(*d*) spontaneous radioactive decay

16. Heavy stable nuclei have more neutrons than protons. This is because of the fact that [*NCERT Exemplar*]

(*a*) neutrons are heavier than protons.
(*b*) electrostatic force between protons are repulsive.
(*c*) neutrons decay into protons through beta decay.
(*d*) nuclear forces between neutrons are weaker than that between protons.

17. In a nuclear reactor, moderators slow down the neutrons which come out in a fission process. The moderator used have light nuclei. Heavy nuclei will not serve the purpose because [*NCERT Exemplar*]

(*a*) they will break up.
(*b*) elastic collision of neutrons with heavy nuclei will not slow them down.
(*c*) the net weight of the reactor would be unbearably high.
(*d*) substances with heavy nuclei do not occur in liquid or gaseous state at room temperature.

18. **Pick out the possible fusion reaction from the following:**

(a) ${}_6C^{13} + {}_1H^1 \longrightarrow {}_6C^{14} + 4.3\text{ MeV}$

(b) ${}_1H^1 \longrightarrow {}_0n^1 + {}_1\beta^0 + \nu$

(c) ${}_7N^{14} + {}_1H^1 \longrightarrow {}_8O^{15} + 7.3\text{ MeV}$

(d) ${}_{92}U^{235} + {}_0n^1 \longrightarrow {}_{54}Xe^{140} + {}_{38}Sr^{94} + 2({}_0n^1) + \gamma + 200\text{ MeV}$

19. **The minimum kinetic energy needed to separate a proton from a nucleus containing Z proton and N neutrons is (m_p = mass of protons)**

(a) $\left(M_Z^{A-1} + m_n - M_Z^A\right)c^2$

(b) $\left(M_Z^{A-1} + m_p - M_Z^A\right)c^2$

(c) $\left(M_Z^{A+1} - M_Z^A - m_p\right)c^2$

(d) 8 MeV

20. **The binding energy per nucleon in ${}_3^7Li$ and ${}_2^4He$ are 7.06 MeV and 5.60 MeV respectively, then in the reaction: $p + {}_3^7Li \rightarrow 2\left({}_2^4He\right)$ the energy of proton must be** [*NCERT Exemplar*]

(a) 28.24 MeV

(b) 17.28 MeV

(c) 1.46 MeV

(d) 39.2 MeV

21. **When two nuclei ($A \leq 10$) fuse together to form a heavier nucleus, the** [*CBSE 2020 (55/2/1)*]

(a) binding energy per nucleon increases.

(b) binding energy per nucleon decreases.

(c) binding energy per nucleon does not change.

(d) total binding energy decreases.

22. **The energy required to release a nucleon from a nucleus is E_n and that required to release an electron from an atom is E_e then**

(a) $E_n = E_e$

(b) $E_n > E_e$

(c) $E_n < E_e$

(d) may be greater than, equal to or less than depending on the nature of nucleus and atom

23. **Fast neutrons can be slowed down by**

(a) using lead shielding

(b) passing them through heavy water

(c) elastic collisions with heavy nuclei

(d) applying strong electric field

24. **Mass of a proton is m_p, mass of a neutron is m_n; mass of ${}_{10}Ne^{20}$ nucleus is M_1 and that of ${}_{20}Ca^{40}$ nucleus in M_2. Then**

(a) $M_2 = 2\,M_1$

(b) $M_2 > 2\,M_1$

(c) $M_1 > 10\,(m_n + m_p)$

(d) $M_1 < 20\,(m_n + m_p)$

Answers

1. (b)	**2.** (b)	**3.** (d)	**4.** (d)	**5.** (d)	**6.** (b)	**7.** (d)
8. (d)	**9.** (d)	**10.** (a)	**11.** (c)	**12.** (a)	**13.** (d)	**14.** (a)
15. (a)	**16.** (b)	**17.** (b)	**18.** (b), (d)	**19.** (c), (d)	**20.** (b)	**21.** (a)
22. (b)	**23.** (b)	**24.** (d)				

Assertion-Reason Questions

In the following questions, a statement of Assertion (A) is followed by a statement of Reason (R). Choose the correct answer out of the following choices.

(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.***

1. **Assertion** (*A*) : The nucleus ${}^{7}_{3}X$ is more stable than the nucleus ${}^{4}_{3}Y$.

   Reason (*R*) : ${}^{7}_{3}X$ contains more number of protons. [*CBSE 2023 (55/3/1)*]

2. **Assertion**(*A*) : Neutrons penetrate matter more readily as compared to proton.

   Reason (*R*) : Neutrons are slightly more massive than protons.

3. **Assertion**(*A*) : Energy is released in nuclear fission.

   Reason (*R*) : Total binding energy of fission fragments is larger than the total binding energy of the parent nucleus.

4. **Assertion**(*A*) : Forces acting between proton-proton (f_{pp}), proton-neutron (f_{pn}) and neutron-neutron (f_{nn}) are such that $f_{pp} < f_{pn} = f_{nn}$.

   Reason (*R*) : Electrostatic force of repulsion between two protons reduces net nuclear forces between them. [*AIIMS 2015*]

5. **Assertion**(*A*) : The elements produced in the fission are radioactive.

   Reason (*R*) : The fragments have abnormally high proton to neutron ratio.

6. **Assertion**(*A*) : The fusion process occurs at extremely high temperatures.

   Reason (*R*) : For fusion of two nuclei, enormously high kinetic energy is required.

7. **Assertion**(*A*) : A neutrino is chargeless and has a spin.

   Reason (*R*) : Neutrino exists inside the nucleus.

8. **Assertion**(*A*) : Mass is not conserved, but mass and energy are conserved as a single entity called mass-energy.

   Reason (*R*) : Mass and energy are inter-convertible in accordance with Einstein's relation, $E = mc^2$. [*AIIMS 2018*]

9. **Assertion**(*A*) : Thermonuclear fusion reactions may become the source of unlimited power for the mankind.

   Reason (*R*) : A single fusion event involving isotopes of hydrogen produces more energy than energy from nuclear fission of ${}^{235}_{93}\text{U}$. [*AIIMS 2017*]

10. **Assertion**(*A*) : The large angle scattering of α-particle is only due to nuclei.

    Reason (*R*) : Nucleus is very heavy as compared to electrons.

Answers

1. (*c*) **2.** (*b*) **3.** (*a*) **4.** (*a*) **5.** (*c*) **6.** (*a*) **7.** (*c*)
8. (*a*) **9.** (*c*) **10.** (*b*)

Case-based/Passage-based Questions

Read the paragraph given below and answer the questions that follow:

Nuclear Holocaust: A nuclear holocaust, nuclear apocalypse or atomic holocaust is a theoretical scenario where the mass detonation of nuclear weapons causes globally widespread destruction and radioactive fall out. Under such scenario, large parts of the earth are made uninhabitable by nuclear warfare, potentially causing the collapse of civilization.

In a single uranium fission about 0.9×235 MeV (≈ 200 MeV) of energy is liberated. If each nucleus of about 50 kg of $^{235}U_{92}$ undergoes fission, the amount of energy involved is about 4×10^{15} J. This energy is equivalent to about 20,000 tons of TNT, enough for a super explosion. Uncontrolled release of large nuclear energy is called an atomic explosion.

(*i*) **In a nuclear reactor, moderators slow down the neutrons which comes out in a fission process. The moderator used have light nuclei. Heavy nuclei will not serve the purpose because**

(*a*) substance with heavy nuclei do not occur in liquid or gaseous state at room temperature
(*b*) the net weight of the reaction would be unbearably high
(*c*) elastic collision of neutrons with heavy nuclei will not slow down the neutrons
(*d*) they will break up

(*ii*) **In an atomic bomb, the energy is released due to**

(*a*) chain reaction of neutrons and U_{92}^{240}
(*b*) chain reaction of neutrons and U_{92}^{238}
(*c*) chain reaction of neutrons and U_{92}^{236}
(*d*) chain reaction of neutrons and U_{92}^{235}

(*iii*) **Energy released in nuclear fission is due to**

(*a*) total binding energy of fragments is more than the binding energy of parental element
(*b*) total binding energy of fragments is less than the binding energy of parental element
(*c*) total binding energy of fragments is equal to the binding energy of parental element
(*d*) some mass is converted into energy

(*iv*) **Solar energy is mainly caused due to**

(*a*) gravitational contraction
(*b*) fusion of proton during synthesis of heavier elements
(*c*) fission of uranium present in the sun
(*d*) burning of hydrogen in the oxygen

OR

Heavy stable nuclei have more neutrons than protons. This is because of the fact that

(*a*) electrostatic force between protons are repulsive
(*b*) neutrons decay into protons through beta decay
(*c*) nuclear forces between neutrons are weaker than that between protons
(*d*) neutrons are heavier than protons

Explanations

(i) (c) For elastic collision masses of both must be equal so that they can exchange the velocities. To slow down the speed of neutron, substance should be made up of 1 proton for perfectly elastic *i.e.*, we need light nuclei not heavy. In heavy nuclei only direction will change and not the speed.

(ii) (d) In an atomic bomb, the energy is released due to the chain reaction of neutrons and U_{92}^{235} nuclei.

(iii) (a) Energy released in nuclear fission is due to the fact that total binding energy of fragments is more than the binding energy of the parent nucleus.

(iv) (b) Solar energy is mainly caused due to the fusion of protons during the synthesis of heavier elements.

OR

(a) Electrostatic force between proton-proton is repulsive which cause the unstability of nucleus. So, more neutrons are needed to maintain the gap between protons and to stabilize the nucleus.

CONCEPTUAL QUESTIONS

Q. 1. Write two characteristic features of nuclear force which distinguish it from Coulomb's force. [*CBSE (AI) 2011*]

Ans. Characteristic Features of Nuclear Force:

(i) Nuclear forces are short range **attractive forces** (range 2 to 3 fm) while Coulomb's forces have range upto infinity and may be attractive or repulsive.

(ii) Nuclear forces are charge independent forces; while Coulomb's force acts only between charged particles.

Q. 2. The nuclear radius of $^{27}_{13}Al$ is 3.6 fermi. Find the nuclear radius of $^{64}_{29}Cu$. [*CBSE 2020 (55/1/1)*]

Ans. As we know, $R = R_0(A)^{\frac{1}{3}}$

$$\therefore \quad \frac{R_2}{R_1} = \left(\frac{A_2}{A_1}\right)^{\frac{1}{3}} \Rightarrow \frac{R_2}{3.6} = \left(\frac{64}{27}\right)^{\frac{1}{3}}$$

$$\Rightarrow \quad R_2 = 3.6\left(\frac{64}{27}\right)^{\frac{1}{3}} = 3.6 \times \frac{4}{3} = \mathbf{4.8\ fermi}$$

Q. 3. Which one of the following cannot emit radiation and why?

Excited nucleus, excited electron [*NCERT Exemplar*]

Ans. Excited electron cannot emit radiation. This is because energy of electronic energy levels is in the range of eV only not in MeV and γ–radiation has energy in MeV.

Q. 4. In pair annihilation, an electron and a positron destroy each other to produce gamma radiation. How is the momentum conserved? [*NCERT Exemplar*]

Ans. 2γ-photons are produced which move in opposite directions to conserve momentum.

Q. 5. ^3_2He and ^3_1H nuclei have the same mass number. Do they have the same binding energy? [*NCERT Exemplar*] [*HOTS*]

Ans. No, the binding energy of ^3_1H is greater. This is because ^3_2He has 2 proton and 1 neutron, whereas ^3_1H has 1 proton and 2 neutron. Repulsive force between protons in ^3_1H is absent.

Q. 6. 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?

Ans. The daughter nucleus would have a higher binding energy per nucleon.

Q. 7. The mass of H-atom is less than the sum of the masses of a proton and electron. Why is this so? [*NCERT Exemplar*] [*HOTS*]

Ans. Einstein's mass-energy equivalence gives $E = mc^2$. Thus the mass of an H-atom is $m_p + m_e - \frac{B}{C^2}$ where $B \approx 13.6$ eV is the binding energy. It is less than the sum of masses of a proton and an electron.

Q. 8. Write two distinguishing features of nuclear forces. [*CBSE 2019 (55/3/1)*]

Ans. Nuclear force:

(*i*) The nuclear force is much stronger than coulomb's force.

(*ii*) The nuclear force between two nucleons falls rapidly to zero as their distance is more than few femto metres.

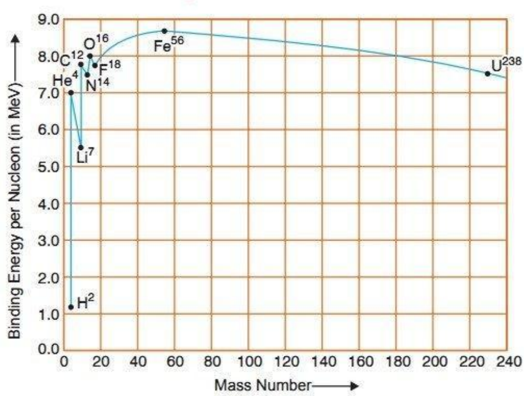
(*iii*) Nuclear force does not depend on the electric charge.

Very Short Answer Questions

Each of the following questions are of 2 marks.

Q. 1. Draw a graph showing the variation of binding energy per nucleon as a function of mass number A. The binding energy per nucleon for heavy nuclei ($A > 170$) decreases with the increase in mass number. Explain. [*CBSE 2023 (55/3/1)*]

Ans.



The binding energy per nucleon for heavy nuclei ($A > 170$) decreases with the increase in mass number because of more coulomb force of repulsion between protons of heavier nuclei. This results in less stability of heavier nuclei.

Q. 2. (*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 2023 (55/2/1)*]

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

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

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

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

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

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

Clearly nuclear density ρ_N is independent of mass number A.

Q. 3. Define the term, mass defect. How is it related to stability of the nucleus? **[*CBSE 2023 (55/2/1)*]**

Ans. The difference between mass of nucleus and the sum of the masses of its nucleons (*i.e.*, proton (p) and neutron (n)) is called its mass defect.

This mass defect is in the form of binding energy of nucleus, which is responsible for binding the nucleons in to a small nucleons. Hence, higher mass defect, higher is the stability of the nucleus.

Q. 4. Calculate the energy in fusion reaction: **[*CBSE Delhi 2016*]**

$$^2_1\text{H} + ^2_1\text{H} \longrightarrow ^3_2\text{He} + \text{n}, \text{ where BE of } ^2_1\text{H} = 2.23 \text{ MeV and of } ^3_2\text{He} = 7.73 \text{ MeV}$$

Ans. Initial binding energy,

$$BE_1 = (2.23 + 2.23)$$
$$= 4.46 \text{ MeV}$$

Final binding energy,

$$BE_2 = 7.73 \text{ MeV}$$

$\therefore$ Energy released = $BE_2 - BE_1$ = (7.73 – 4.46) MeV = **3.27 MeV**

Q. 5. The electron in a hydrogen atom is typically found at a distance of about 5.3×10^{-11} m from the nucleus which has a diameter of about 1.0×10^{-15}m. Assuming the hydrogen atom to be a sphere of radius 5.3×10^{-11} m, what fraction of its volume is occupied by the nucleus?

[*CBSE 2022 (55/3/3), Term-2*]

Ans.

(a) Given radius of atom (r_a) = radius of electron orbit = 5.3×10^{-11} m

radius of nucleus (r_n) = $\frac{\text{diameter}}{2} = \frac{1.0\times10^{-15}\text{ m}}{2} = 5\times10^{-16}$ m

Volume of atom = $\frac{4}{3}\pi r_a^3$

Volume of nucleus = $\frac{4}{3}\pi r_n^3$

⇒ Fraction of its volume occupied by the nucleus = $\frac{(\text{Volume})_{\text{nucleus}}}{(\text{Volume})_{\text{atom}}} = \frac{\frac{4}{3}\pi r_n^3}{\frac{4}{3}\pi r_a^3}$

$= \left(\frac{r_n}{r_a}\right)^3$

$= \left(\frac{5}{5.3}\times10^{-5}\right)^3$

$= \frac{125}{5.3\times5.3\times5.3}\times10^{-15}$

Ans: Thus, fraction of value volume of hydrogen atom occupied by its nucleus

$= \boxed{8.395 \times 10^{-16}}$

140450
148877

8.395
1489) 12800
11912
8880
4467
14130
13401
7290

1489 × 8 = 11912
1489 × 9 = 13401
1489 × 5 = 7445

[*Topper's Answer 2022*]

Q. 6. **(*i*) Distinguish between isotopes and isobars.**

(*ii*) Two nuclei have different mass numbers A_1 and A_2. Are these nuclei necessarily the isobars of the same element? Explain. **[*CBSE 2022 (55/3/1), (55/3/3), Term-2*]**

Ans.

1.

(a)

(i)

ISOTOPES	ISOBARS
→ The atoms which have the same atomic number but different mass number are isotopes (atoms of ~~same elements~~)	→ The atoms which have different atomic number but same mass number are isobars (atoms of different elements)
→ Isotopes have same number of protons in them	→ Isobars have different number of protons in them
→ Their (p+n) no. is not constant	→ Their (p+n) number is constant.
→ Eg: H_1^1, H_1^2, H_1^3	→ Eg: Ar_{18}^{40}, Ca_{18}^{40}

(ii) Isotopes have same atomic number but different mass number. In other words isotopes have equal number of protons but only differ in number of neutrons

Given two nuclei ~~A1 and A2~~ have different mass numbers A1 and A2. These two nuclei can be isotope only if they have the same atomic number.

For eg: He_2^4 and H_1^2 have different mass number but they are not isotopes

H_1^1 and H_1^2 also have different mass number but they are isotopes

Ans: Thus, if two nuclei have different mass numbers A_1 and A_2 they cannot necessarily be isotopes of the same element.

[*Topper's Answer 2022*]

Q. 7. A given coin has a mass of 3.0 g. Calculate the nuclear energy that would be required to separate all the neutrons and protons from each other. For simplicity assume that the coin is entirely made of $^{63}_{29}Cu$ atoms (of mass 62.92960 u). The masses of proton and neutrons are 1.00783 u and 1.00867 u respectively. [*NCERT*]

Ans. Masses of protons and neutrons in 63 u of Cu

$$= Zm_p + (A-Z)m_n = 29m_p + (63-29)m_n$$

$$= 29 \times 1.00783 + (34 \times 1.00867) = 29.22707 + 34.29478 = 63.52185 \text{ u}$$

Mass of $^{63}_{29}Cu$ atom = 62.92960 u

Mass defect = 63.52185 – 62.92960 = 0.59225 u

Energy released in $^{63}_{29}Cu$ atom = 0.59225 × 931 MeV = 551.385 MeV

Number of atoms in 3 g of copper $= \dfrac{6.02\times10^{23}}{63}\times 3 = 2.87\times10^{22}$

∴ Energy required to separate all nucleons (neutrons and protons) from each other

$$= 2.87\times10^{22}\times 551.385 \text{ MeV} = \mathbf{1.6 \times 10^{25} \text{ MeV}}$$

Q. 8. 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. 6. A nuclide 1 is said to be the mirror isobar of nuclide 2 if $Z_1 = N_2$ and $Z_2 = N_1$.

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

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

[*NCERT Exemplar*] [*HOTS*]

Ans. (*a*) $^{23}_{11}Na : Z_1 = 11, N_1 = 12$

∴ Mirror isobar of $^{23}_{11}Na = ^{23}_{12}Mg$.

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

Q. 5. Two nuclei may have the same radius, even though they contain different number of protons and neutrons. Explain. [*CBSE 2022 (55/3/3), Term-2*]

Ans.

(b) Radius of a nuclei is given by

$R = R_0 A^{1/3}$

where $R_0 = 1.2 \times 10^{-15}$ m

A = mass number of the nucleus
= No of nucleons in the nucleus (n+p)

Let two nuclei are there A and B,
A has n_1 neutrons and p_1 protons
B has n_2 neutrons and p_2 protons

Such that $n_2 \neq n_1$, and $p_2 \neq p_1$

$n_1 + P_1 = n_2 + P_2$

Mass number of A = Mass number of B

but if two nuclei have same mass numbers they would have equal radius

$R_A = R_B$

Ans: Hence two nuclei having different number of protons and neutrons may have the same radius. [Equality holds if the sum of the number of proton and neutrons in both of them are same]

[*Topper's Answer 2022*]

Short Answer Questions

Each of the following questions are of 3 marks.

Q. 1. In a typical nuclear reaction, *e.g.*,

$$^{2}_{1}H + ^{2}_{1}H \longrightarrow ^{3}_{2}He + n + 3.27\ MeV,$$

although number of nucleons is conserved, yet energy is released. How? Explain.

[*CBSE Delhi 2013*]

Ans. In nuclear reaction

$$^{2}_{1}H + ^{2}_{1}H \longrightarrow ^{3}_{2}He + n + 3.27\ MeV$$

Cause of the energy released:

(*i*) Binding energy per nucleon of $^{3}_{2}He$ becomes more than the (BE/A) of $^{2}_{1}H$.

(*ii*) Mass defect between the reactant and product nuclei

$$\Delta E = \Delta m\, c^2 = [2m(^{2}_{1}H) - m(^{3}_{2}He) + m(n)]c^2$$

Q. 2. (*a*) In the following nuclear reaction

$$n + ^{235}_{92}U \longrightarrow ^{144}_{Z}Ba + ^{A}_{36}X + 3n,$$

assign the values of *Z* and *A*.

(*b*) If both the number of protons and the number of neutrons are conserved in each nuclear reaction, in what way is the mass converted into energy? Explain. [*CBSE Guwahati 2015*]

Ans. (*a*) $n + ^{235}_{92}U \longrightarrow ^{144}_{Z}Ba + ^{A}_{36}X + 3n,$

From law of conservation of atomic number

$$0 + 92 = Z + 36$$

$$\Rightarrow \quad Z = 92 - 36 = \mathbf{56}$$

From law of conservation of mass number,

$$1 + 235 = 144 + A + 3 \times 1$$

$$A = 236 - 147 = \mathbf{89}$$

(*b*) (*i*) BE of ${}^{235}_{92}U$ < BE of (${}^{144}_{56}Ba + {}^{89}_{36}X$) and due to difference in BE of the nuclides. A large amount of the energy will released in the fission of ${}^{235}_{92}U$.

(*ii*) Mass number of the reactant and product nuclides are same but there is an actual mass defect. This difference in the total mass of the nuclei on both sides, gets converted into energy, *i.e.*, $\Delta E = \Delta mc^2$.

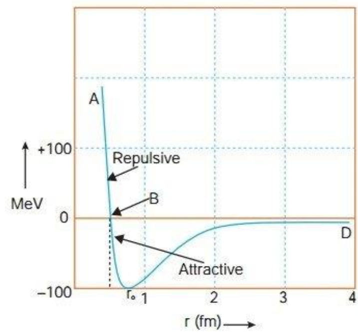
Q. 3. Draw a graph showing the variation of potential energy between a pair of nucleons as a function of their separation. Indicate the regions in which the nuclear force is (*i*) attractive, (*ii*) repulsive.

Write two important conclusions which you can draw regarding the nature of the nuclear forces. **[*CBSE 2019 (55/4/2), 2020 (55/3/1)*]**

Ans. Conclusions:

(*i*) The potential energy is minimum at a distance r_0 of about 0.8 fm.

(*ii*) Nuclear force is attractive for distance larger than r_0.



(*iii*) Nuclear force is repulsive if two are separated by distance less than r_0.

(*iv*) Nuclear force decreases very rapidly at r_0/equilibrium position.

Q. 4. The Q-value of a nuclear reaction

$$A + B \longrightarrow C + D$$

is defined by $Q = (m_A + m_B - m_C - m_D)\,c^2$

where the masses refer to the nuclear rest masses. Determine from the given data whether the following 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:

$m({}^{1}_{1}H) = 1.007825$ u $m({}^{2}_{1}H) = 2.014102$ u

$m({}^{3}_{1}H) = 3.016049$ u $m({}^{12}_{6}C) = 12.00000$ u

$m({}^{20}_{10}Ne) = 19.992439$ u $m({}^{4}_{2}He) = 4.002603$ u

Take 1 u = 931 MeV [*NCERT*]

Ans. (*i*) Nuclear reaction is

$${}^{1}_{1}H + {}^{3}_{1}H \rightarrow {}^{2}_{1}H + {}^{2}_{1}H + Q$$

Mass of LHS = $m({}^{1}_{1}H) + m({}^{3}_{1}H)$ = 1.007825 + 3.016049 = 4.023874 u

Mass of RHS = $m({}^{2}_{1}H) + m({}^{2}_{1}H)$ = 2.014102 + 2.014102 = 4.028204 u

$$Q = [(m_A + m_B - m_C - m_D) \text{ in kg}] \times c^2 \text{ joule}$$
$$= [(m_A + m_B - m_C - m_D)u] \times 931 \text{ MeV}$$
$$= \left[\{m({}_1^1\text{H}) + m({}_1^3\text{H})\} - \{m({}_1^2\text{H}) + m({}_1^2\text{H})\}\right] \times 931 \text{ MeV}$$
$$= [4.023874 - 4.028204] \times 931 \text{ MeV}$$
$$= -0.00433 \times 931 \text{ MeV} = \mathbf{-4.031\ MeV}$$

As Q is negative, energy must be supplied for the reaction; hence the reaction is **endothermic**.

(*ii*) Nuclear reaction: ${}_6^{12}\text{C} + {}_6^{12}\text{C} = {}_{10}^{20}\text{Ne} + {}_2^4\text{He}$

$$Q = [\{m({}_6^{12}\text{C}) + m({}_6^{12}\text{C})\} - \{m({}_{10}^{20}\text{Ne}) + m({}_2^4\text{He})\}] \times c^2 \text{ joule}$$
$$= [(12.000000 + 12.000000) - (19.992439 + 4.002603)] \times c^2 \text{ joule}$$
$$= (24.000000 - 23.995042) \times 931 \text{ MeV} = 0.004958 \times 931 \text{ MeV} = \mathbf{4.616\ MeV}$$

As Q is positive, the energy will be liberated in the reaction, hence the reaction is **exothermic**.

Q. 5. (*i*) Distinguish between nuclear fission and fusion giving an example of each.

(*ii*) Explain the release of energy in nuclear fission and fusion on the basis of binding energy per nucleon curve. [*CBSE 2023 (55/2/1)*]

Ans. (*i*) **Nuclear fission:** It is a process in which a heavy nucleus when excited (say on bombarding by a slow moving neutron) splits into two lighter nuclei of nearly comparable masses with a release of large amount of energy.

Example of nuclear fission

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

Nuclear fusion: It is a process in which two lighter nuclei fuse (at extremely high temperature) to form a heavy nucleus and large amount of energy is released.

Example of nuclear fusion

(1) ${}_1^1H + {}_1^1H \longrightarrow {}_1^2H + e^+ + \nu + Q_1$

(2) ${}_1^2H + {}_1^2H \longrightarrow {}_2^3H_e + n + Q_2$

(3) ${}_1^2H + {}_1^2H \longrightarrow {}_1^3H + {}_1^1H + Q_3$

(*ii*) The binding energy per nucleon of the products in the nuclear reactions (nuclear fission and nuclear fusion) is greater than that of the reactants.

Long Answer Questions

Each of the following questions are of 5 marks.

Q. 1. Draw the graph showing the variation of binding energy per nucleon with the mass number for a large number of nuclei $2 < A < 240$. What are the main inferences from the graph? How do you explain the constancy of binding energy in the range $30 < A < 170$ using the property that the nuclear force is short-ranged? Explain with the help of this plot the release of energy in the processes of nuclear fission and fusion.

[*CBSE (AI) 2010, 2011, Chennai 2015, South 2016, 2020 (55/5/2)*]

OR

Draw a diagram to show the variation of binding energy per nucleon with mass number for different nuclei and mention its two features. Why do lighter nuclei usually undergo nuclear fusion? *[CBSE 2023 (55/2/1)]*

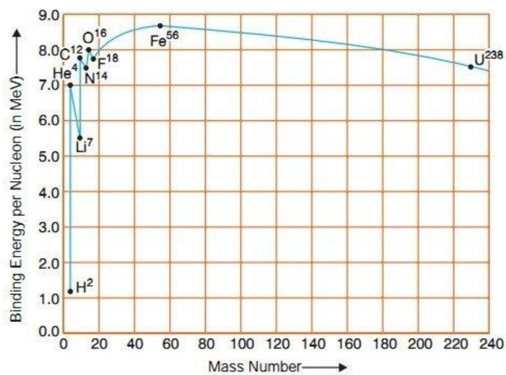
Ans. The variation of binding energy per nucleon versus mass number is shown in figure.

Inferences from graph

1. The nuclei having mass number below 20 and above 180 have relatively small binding energy and hence they are unstable.
2. The nuclei having mass number 56 and about 56 have maximum binding energy – 8·8 MeV and so they are most stable.
3. Some nuclei have peaks, *e.g.*, ${}_2^4He$, ${}_6^{12}C$, ${}_6^{12}O$; this indicates that these nuclei are relatively more stable than their neighbours.

(*i*) **Explanation of constancy of binding energy:** Nuclear force is short ranged, so every nucleon interacts with its neighbours only, therefore binding energy per nucleon remains constant.

(*ii*) **Explanation of nuclear fission:** When a heavy nucleus ($A \geq 235$ say) breaks into two lighter nuclei (nuclear fission), the binding energy per nucleon increases *i.e*, nucleons get more tightly bound. This implies that energy would be released in nuclear fission.



(*iii*) **Explanation of nuclear fusion:** When two very light nuclei ($A \leq 10$) join to form a heavy nucleus, the binding is energy per nucleon of fused heavier nucleus more than the binding energy per nucleon of lighter nuclei, so again energy would be released in nuclear fusion.

Q. 2. (*i*) **Define the following terms:**

(*a*) **Nucleons,** (*b*) **Atomic number,** (*c*) **Mass number,** (*d*) **Nuclear mass**

(*ii*) **What are (*a*) isotopes, (*b*) isobars and (*c*) isotones?**

Ans. (*i*) (*a*) **Nucleons:** The constituents of nucleus *i.e.*, protons and neutrons are considered as nucleons.

(*b*) **Atomic number:** The number of protons present in the nucleus is called the atomic number of the element. It is denoted by Z.

(*c*) **Mass number:** The total number of nucleons *i.e.*, sum of protons and neutrons present in a nucleus is called the mass number of the element. It is denoted by *A*.

(*d*) **Nuclear mass:** The total mass of protons and neutrons present in a nucleus is called the nuclear mass.

(*ii*) (*a*) **Isotopes:** The atoms of an element having same atomic number (*Z*) but different mass numbers (*A*) are called isotopes.

(*b*) **Isobars:** The elements having same mass number (*A*) and different atomic number (*Z*) are called isobars.

(*c*) **Isotones:** The nuclei containing the same number of neutrons are called isotones.

Q. 3. (*i*) What is nuclear fission? Give one representative equation.

(*ii*) (*a*) What is nuclear fusion? Give one representative equation.

(*b*) State the necessary conditions for nuclear fusion to occur.

Ans. (*i*) **Nuclear fission:** The phenomenon in which a heavy nucleus ($A > 230$) when excited splits into two smaller nuclei of nearly comparable masses is called nuclear fission. For example, when a uranium target is bombarded by slow moving neutrons, a $^{235}_{92}U$ nucleus gets excited by capturing a slow moving neutron and splits into two nearly equal fragments like $^{141}_{56}Ba$ and $^{92}_{36}Kr$ alongwith the emission of 3 neutrons. The nuclear reaction involved can be written as

$$^{235}_{92}U + ^{1}_{0}n \longrightarrow ^{236}_{92}U \longrightarrow ^{141}_{56}Ba + ^{92}_{36}Kr + 3\,^{1}_{0}n + Q$$

Fission does not always produce barium and krypton. A number of other pairs are formed.

For example,

$$^{235}_{92}U + ^{1}_{0}n \longrightarrow ^{236}_{92}U \longrightarrow ^{133}_{51}Sb + ^{99}_{41}Nb + 3\,^{1}_{0}n + Q$$

$$^{235}_{92}U + ^{1}_{0}n \longrightarrow ^{236}_{92}U \longrightarrow ^{140}_{54}Xe + ^{94}_{38}Sr + 2\,^{1}_{0}n + Q$$

(*ii*) (*a*) 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.

For example, the fusion of two deuterons into a triton takes place as follows:

$$_1H^2 + _1H^2 \longrightarrow _1H^3 + ^1_1H + 4.0\text{ MeV energy}$$

Alternatively the fusion of three deuterons into an α – particle can take place as follows:

$$_1H^2 + _1H^2 \longrightarrow _2He^3 + _0n^1 + 3.3\text{ MeV energy}$$

$$_2He^2 + _1H^2 \longrightarrow _2He^4 + _1H^1 + 18.3\text{ MeV energy}$$

(*b*) The necessary conditions for nuclear fusion are:

High temperature: The high temperature is necessary for the light nuclei to have sufficient kinetic energy so that they can overcome the repulsion force between them.

High density: High density or pressure increases the frequency of collision of light nuclei and hence increases the rate of fusion.

Questions for Practice

1. Choose and write the correct option in the following questions.

(*i*) How does the binding energy per nucleon vary with the increase in the number of nucleons

(*a*) decrease continuously with mass number

(*b*) first decreases and then increases with increase in mass number

(*c*) first increases and then decreases with increase in mass number

(*d*) increases continuously with mass number

(*ii*) Two spherical nuclei have mass numbers 216 and 64 with their radii R_1 and R_2 respectively. The ratio, $\frac{R_1}{R_2}$ is equal to

(*a*) 3 : 2 (*b*) 1 : 3

(*c*) 1 : 2 (*d*) 2 : 3

(*iii*) If number of nucleons in nuclei increases, the binding energy per nucleon

(*a*) increases

(*b*) decreases

(*c*) first increases and then decreases

(*d*) remains unchanged

(*iv*) A nucleus disintegrates into two nuclear parts, which have their velocities in the ratio 2 : 1. The ratio of their nuclear sizes will be

(*a*) $2^{1/3} : 1$ (*b*) $1 : 3^{1/2}$

(*c*) $3^{1/2} : 1$ (*d*) $1 : 2^{1/3}$

(*v*) The difference in mass ^{7}X nucleus and total mass of its constituent nucleons is 21.00 u. The binding energy per nucleon for this nucleus is equal to the energy equivalent of

[*CBSE 2023 (55/4/1)*]

(*a*) 3 u (*b*) 3.5 u

(*c*) 7 u (*d*) 21 u

2. ***In the following questions, a statement of Assertion (A) is followed by a statement of Reason (R). Choose the correct answer out of the following choices.***

(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.***

Assertion (*A*) : Density of all nuclei is same.

Reason (*R*) : The radius of nucleus is directly proportional to the cube root of mass number.

3. 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.

4. Two nuclei have mass numbers in the ratio 2 : 5. What is the ratio of their nuclear densities?

5. What is the nuclear radius of ^{125}I, if that of ^{27}Al is 3.6 fermi? [*CBSE (AI) 2008*]

6. Write the relationship between the size of a nucleus and its mass number (A). [*CBSE (F) 2012*]

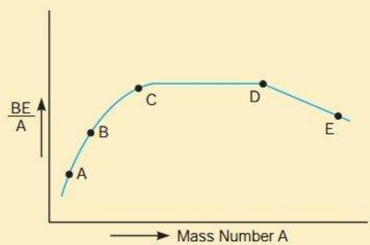
7. Two nuclei have mass numbers in the ratio 1 : 2. What is the ratio of their nuclei densities? [*CBSE Delhi 2009*]

8. Two nuclei have mass numbers in the ratio 1 : 8. What is the ratio of their nuclear radii? [*CBSE (AI) 2009*]

9. 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*]

10. A heavy nucleus P of mass number 240 and binding energy 7.6 MeV per nucleon splits into two nuclei Q and R of mass number 110, 130 and binding energy per nucleon 8.5 MeV and 8.4 MeV respectively. Calculate the energy released in the fission. [*CBSE 2020 (55/5/1)*]

11. The figure shows the plot of binding energy (BE) per nucleon as a function of mass number A. The letters A, B, C, D and E represent the positions of typical nuclei on the curve. Point out, giving reasons, the two processes (in terms of A, B, C, D and E), one of which can occur due to nuclear fission and the other due to nuclear fusion.



12. Calculate for how long will the fusion of 2.0 kg deuterium keep 800 W electric lamp glowing. Take the fusion reaction as [*CBSE 2020 (55/5/3)*]

$$^{2}_{1}H + ^{2}_{1}H \longrightarrow ^{3}_{2}He + ^{1}_{0}n + 3.27\ MeV$$

13. (*a*) The density of the nuclear matter is tremendously larger than the physical density of the material. Explain.

(*b*) The nuclear forces are not coulomb forces between nucleons. Explain.

(*c*) Draw a plot of the potential energy between a pair of nucleons as a functions distance between them inside a nucleus. [*CBSE 2020 (55/3/1)*]

14. 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*]

15. (*a*) Distinguish between isotopes and isobars, giving one example for each.

(*b*) Why is the mass of a nucleus always less than the sum of the masses of its constituents? Write one example to justify your answer. **[*CBSE 2019 (55/5/1)*]**

16. (*a*) Classify the following six nuclides into

(*i*) isotones, (*ii*) isotopes, and (*iii*) isobars:

$${}^{12}_{6}C, {}^{3}_{2}He, {}^{198}_{80}Hg, {}^{3}_{1}H, {}^{197}_{79}Au, {}^{14}_{6}C$$

(*b*) How does the size of a nucleus depend on its mass number? Hence explain why the density of nuclear matter should be independent of the size of the nucleus. **[*CBSE 2019 [55/5/1)*]**

17. (*a*) (*i*) Depict the variation of the potential energy of a pair of nucleons with the separation between them.

(*ii*) Imagine the 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: $m\left({}^{56}_{26}Fe\right) = 55{\cdot}93494$ u, $m\left({}^{28}_{13}Al\right) = 27{\cdot}98191$u. **[*CBSE 2022 (55/2/1), Term-2*]**

18. 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:

$${}^{2}_{1}H + {}^{3}_{1}H \longrightarrow {}^{3}_{2}He + n$$

Using the data:

$m({}^{2}_{1}H) = 2.014102$ u $\quad m({}^{3}_{1}H) = 3.016049$ u $\quad m({}^{3}_{2}He) = 4.002603$ u

$m_n = 1.008665$ u $\quad 1u = 931.5\ MeV/c^2$

19. 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. **[*CBSE 2020 (55/5/2)*]**

20. (*a*) In a typical nuclear reaction, *e.g.*,

$${}^{2}_{1}H + {}^{2}_{1}H \longrightarrow {}^{3}_{2}He + n + 3.27\ MeV,$$

although number of nucleons is conserved, yet energy is released. How? Explain.

(*b*) Show that nuclear density in a given nucleus is independent of mass number *A*.

21. Obtain the binding energy of the nuclei ${}^{56}_{26}Fe$ and ${}^{209}_{83}Bi$ in units of MeV from the following data. $m_H = 1.007825$ u, $m_n = 1.008665$ u, $m({}^{56}_{26}Fe) = 55.934939$ u, $m({}^{209}_{83}Bi) = 208.980388$ u, 1 u = 931.5 MeV. Which nucleus has greater binding energy per nucleon? **[*NCERT*]**

22. How long an electric lamp of 100 W can be kept glowing by fusion of 2.0 kg of deuterium? The fusion reaction can be taken as: **[*NCERT*] [*HOTS*]**

$${}^{2}_{1}H + {}^{2}_{1}H \longrightarrow {}^{3}_{2}He + n + 3.2\ MeV$$

Answers

1. (*i*) (*c*) (*ii*) (*a*) (*iii*) (*c*) (*iv*) (*d*) (*v*) (*a*)

2. (*a*)

3. 216 MeV

4. 1 : 1

5. 6 fermi

8. 1 : 2

9. 216 MeV

10. 203 MeV

12. 1.96×10^{11} s

14. 26.72 MeV

18. 17.59 MeV

21. 8.79 MeV/nueleon, 7.848 MeV/nueleon

22. 4.9×10^{4} years