UNIT 13

NUCLEI

SECTION – A

Questions 1 to 10 carry 1 mark each.

1. The curve of binding energy per nucleon as a function of atomic mass number has a sharp peak for helium nucleus. The implies that helium nucleus is:
(a) radioactive
(b) unstable
(c) easily fissionable
(d) more stable nucleus than its neighbours.
Ans. (d) more stable nucleus than its neighbours
The curve of binding energy per nucleon as a function of atomic mass number shows the average amount of energy needed to remove one nucleon from a nucleus. This curve has a sharp peak for the helium nucleus, which implies that the helium nucleus has the highest binding energy per nucleon among all the nuclei. This means that the helium nucleus is more stable than its neighbouring nuclei.

2. Which of the following statement about nuclear forces is NOT true?
(a) The nuclear force between two nucleons falls rapidly to zero as their distance is more than a few femtometres.
(b) The nuclear force is much weaker than the Coulomb force.
(c) The force is attractive for distances larger than 0.8 fm and repulsive if they are separated by distances less than 0.8 fm.
(d) The nuclear force between neutron-neutron, proton-neutron and proton-proton is approximately the same.
Ans. (b) The nuclear force is much weaker than the Coulomb force.
As we know that nuclear forces are strongest in magnitude. But they are short range forces because the distance between the nucleons is 0.7 fermi which is very small. They are charge independent, so they result for interaction of every, nucleon with the nearest limited number of nucleons.

3. When two nuclei ($A \leq 10$) fuse together to form a heavier nucleus, the:
(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.
Ans. (a) binding energy per nucleon increases.
When two or more lighter nuclei fuse, they release a large amount of energy, that indicates the increase in the binding energy per nucleon.

4. Fusion reaction takes place at high temperature because:

(a) atoms get ionised at high temperature.
(b) kinetic energy is high enough to overcome the coulombic repulsion between nuclei.
(c) molecules break up at high temperature.
(d) nuclei break up at high temperature.
Ans. (b) kinetic energy is high enough to overcome the coulombic repulsion between nuclei.
For nuclear fusion in a bulk material, the temperature of the material has to be raised to 106 K, so that the colliding nuclei have enough kinetic energy due to their thermal motion and they can penetrate the coulombic barrier.

5. The ratio of order of magnitudes for nuclear density of Copper (Cu) (A = 63) and Aluminum (A = 27) is: ($m_p = 1.67 \times 10^{-27}$ kg)
(a) 9 : 1 (b) 1 : 9 (c) 1 : 1 (d) 1 : 3
Ans. (c) 1 : 1

6. Which of the following statements are NOT true about binding energy?
(I) Binding energy per nucleon increases linearly with the mass number.
(II) The larger value of binding energy means the nucleus is unstable.
(III) Binding energy per nucleon is maximum for iron (A = 56).
(a) (I) only (b) (II) only (c) (I) and (III) only (d) (I) and (II) only.
Ans. (d) (I) and (II) only

7. If the number of nucleons increases, then binding energy per nucleon of the nucleus:
(a) first increases and then decreases with mass number
(b) continuously increases with mass number
(c) continuously decreases with mass number
(d) remains constant with mass number
Ans. (a) first increases and then decreases with mass number
Binding energy per nucleon versus number of nucleons curve suggests that binding energy per nucleon increases initially (upto Fe) and then decreases.

8. Consider a proton moving towards a stationary alpha particle with speed v.
Which of the following statements is NOT true?
(a) Kinetic energy of the proton will get converted into the potential energy and it will stop at a distance from the alpha particle.
(b) The force responsible for proton stopping is the repulsive nuclear force.
(c) The nuclear force is attractive for distances larger than 0.8 fm and repulsive for distances shorter than 0.8 fm.
(d) None of the above.
Ans. (a) Kinetic energy of proton will get converted into the potential energy and it will stop at a distance from the alpha particle.
When the proton moves towards an alpha particle it experiences Coulomb's repulsion. The potential energy of the proton increases at the cost of its kinetic energy. At a certain point, when the kinetic energy of the proton becomes zero, it will stop moving. The force responsible is, thus, Coulomb force and not nuclear force.

In the following questions 9 and 10, a statement of assertion (A) is followed by a statement of reason (R). Mark the correct choice as:
(a) Both assertion (A) and reason (R) are true and reason (R) is the correct explanation of assertion (A).
(b) Both assertion (A) and reason (R) are true but reason (R) is not the correct explanation of assertion (A).
(c) Assertion (A) is true but reason (R) is false.
(d) Assertion (A) is false but reason (R) is true.

9. **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.

Ans. (c) Assertion (A) is true but reason (R) is false.
In nucleus ${}^{7}_{3}X$; Number of protons (p) = 3
Number of neutrons (n) = 7 – 3 = 4
In nucleus ${}^{4}_{3}Y$; Number of protons (p) = 3
Number of neutrons (n) = 4 – 3 = 1
Thus, for the same charge number Z, the nucleus with more neutrons is more stable. Therefore, ${}^{7}_{3}X$; is more stable.

10. Assertion (A): The curve between the binding energy per nucleon versus mass number drops at high mass number (A > 170) as well as at low mass numbers (A < 30).
Reason (R): Nuclei with middle mass numbers (30 < A < 170) have higher binding energy per nucleon.
Ans. (a) Both Assertion and Reason are true and Reason is correct explanation of Assertion.
Binding energy per nucleon is the minimum energy required to disassemble the nucleus of an atom into its constituent neutrons and protons. It defines the stability of the nucleus.

SECTION – B

Questions 11 to 14 carry 2 marks each.

11. How is the size of a nucleus found experimentally? Write the relation between the radius and mass number of a nucleus.
Ans. The size of the nucleus can be found experimentally using the scattering of charged particles like alpha particles, protons or electrons off the nuclei.
When a positively charged particle is fired at the nucleus, it experiences electrostatic repulsion due to the positive charge of the nucleus. As a result, the charged particle gets deflected from its original path. By measuring the angle of deflection, the size of the nucleus can be estimated.
The relation between the radius and mass number of a nucleus is given by the empirical formula:

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

Where, R is the radius of the nucleus, A is the mass number of the nucleus, and R_0 is a constant with a value of about 1.2×10^{-15} meters, known as the nuclear radius constant. This formula suggests that the size of the nucleus increases with the cube root of its mass number.

OR

Identify if the two nuclear reactions mentioned below are endothermic or exothermic. Show your calculations.

$${}^{1}_{1}p + {}^{7}_{3}Li \rightarrow 2({}^{4}_{2}He)$$
$${}^{7}_{3}Li + {}^{4}_{2}He \rightarrow {}^{1}_{0}n + {}^{10}_{5}B$$

Use the information below to answer the question:
${}^{1}_{1}p$ = 1.00728 amu, ${}^{7}_{3}Li$ = 7.0160 amu, ${}^{4}_{2}He$ = 4.0026 amu, ${}^{1}_{0}n$ = 1.0087 amu and ${}^{10}_{5}B$ = 10.01294 amu
Ans. For the first reaction,
mass of reactants = 1.00728 + 7.0160 = 8.02328 u
mass of products = 2 × 4.0026 = 8.0052
mass of reactants > mass of products
Hence, the reaction is exothermic.
For the second reaction,
mass of reactants = 7.0160 + 4.0026 = 11.0186 u
mass of products = 1.0087 + 10.1294 = 11.1381 u
mass of reactants < mass of products
Hence, the reaction is endothermic.

12. Define ionization energy. How would the ionization energy change when electron in hydrogen atom is replaced by a particle of mass 200 times that of the electron but having the same charge?

Ans. Ionization energy is the amount of energy required to knock out the valence electron from an isolated, gaseous atom in its ground state to form a cation. Ionization energy also depends on the orbit from which electron is to be removed.
When the electron in hydrogen atom is replaced by the particle of mass 200 times that of the electron but having the same charge then the atomic radius decreases. Smaller the radii of the atom, more is the atomic energy.
With the decrease in size, ionization energy increases due to valence electron being tightly held and more energy is required to remove it.

OR

Calculate the binding energy of an alpha particle in MeV. Given:
Mass of a proton = 1.007825 u
Mass of a neutron = 1.008665 u
Mass of He nucleus = 4.002800 u
$1u = 931\ MeV/c^2$.
Ans. Δm = Mass of total number of proton and neutron – Mass of α-particle
= 2 × (1.007825 + 1.008665) - 4.002800
= 4.03298 – 4.002800 = 0.0301 u
∴ Binding energy = Δmc^2
= 0.0301 × 931 MeV
= 28.09 MeV

13. (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.
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

$$\text{Volume of nucleus} = \frac{4}{3}\pi R^3 = \frac{4}{3}\pi(R_0A^{1/3})^3 = \frac{4}{3}\pi R_0^3 A$$

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

Clearly nuclear density ρ_N is independent of mass number *A*.

OR

Prove that the density of a nucleus is independent of its mass number.
Ans. As we know that volume of a nucleus is proportional to the cube of its radius, while the mass of a nucleus is proportional to its mass number A.
Therefore, we can write: Volume of nucleus ∝ *r*3
Mass of nucleus ∝ A
Density of nucleus = Mass of nucleus/Volume of nucleus
Substituting the above relations, we get: Density of nucleus ∝ A/r^3
Thus, the density of a nucleus is inversely proportional to the cube of its radius and directly proportional to its mass number

$$\text{Density of nucleus} \propto \frac{A}{(A^{1/3})^3} = 1$$

Therefore, the density of a nucleus is independent of its mass number.

14. Define the term, mass defect. How is it related to stability of the nucleus?
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.

OR

Calculate the energy in fusion reaction:

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

Ans. Initial binding energy, BE_1 = (2.23 + 2.23) = 4.46 MeV

Final binding energy, BE_2 = 7.73 MeV

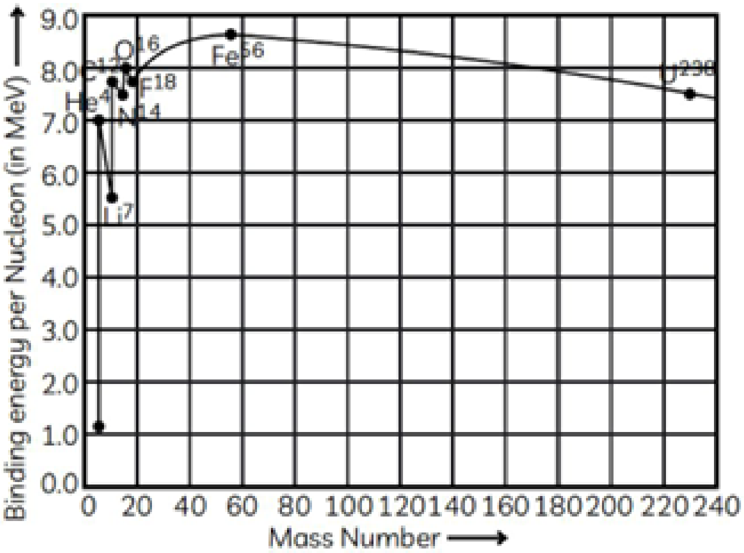
∴ Energy released = $BE_2 - BE_1$ = (7.73 – 4.46) MeV = **3.27 MeV**

SECTION – C

Questions 15 to 17 carry 3 marks each.

15. Explain the processes of nuclear fission and nuclear fusion by using the plot of binding energy per nucleon $\left(\frac{BE}{A}\right)$ versus the mass number A.

Ans.



Nuclear Fission: Heavier nuclei undergoes nuclear fission to form two stable daughter nuclei. As from the binding energy per nucleon curve, it is clear that for A > 120 the binding energy per nucleon starts decreasing i.e., their stability start decreasing and they tend to split themselves into smaller nuclei with greater binding energy for nuclei of range 20 < A < 120.

Nuclear Fission: As from the binding energy per nucleon curve it is clear that smaller nuclei with A < 20 have very less stability as their binding energy per nucleon is very less and thus they tend to fuse together to give bigger nuclei with greater binding energy and thus greater stability.

16. (a) Distinguish between nuclear fission and fusion giving an example of each.

(b) Explain the release of energy in nuclear fission and fusion on the basis of binding energy per nucleon curve.

Ans. (a) Nuclear fission and fusion are two different processes that involve the release or absorption of energy from the nucleus of an atom.

Nuclear fission is the process of splitting the nucleus of a heavy atom into smaller fragments using a neutron. This process releases a large amount of energy in the form of heat and radiation.

Example: ${}_{0}^{1}n + {}_{92}^{235}U \rightarrow {}_{54}^{140}Xe + {}_{38}^{94}Sr + 2\,{}_{0}^{1}n$

Nuclear fusion, on the other hand, is the process of combining two light nuclei into a heavier nucleus. This process also releases a large amount of energy in the form of heat and radiation.

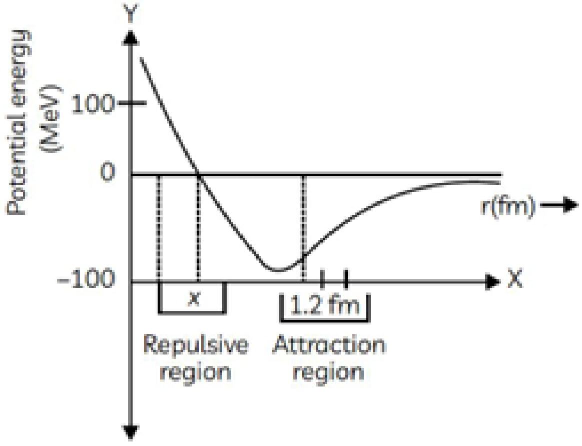
Example: ${}_{1}^{2}H + {}_{1}^{2}H \rightarrow {}_{2}^{4}He + Q$

(b) In nuclear fission, a heavy nucleus, such as uranium-235, is bombarded with a neutron, which causes it to split into two lighter nuclei and several neutrons. This process is accompanied by a large release of energy. The total binding energy of the two lighter nuclei produced is greater

than the binding energy of the original heavy nucleus. This increase in binding energy per nucleon results in the release of energy in the form of heat and radiation.
In nuclear fusion, two light nuclei, such as hydrogen-1 and hydrogen-2, combine to form a heavier nucleus and a neutron. This process also results in a release of energy, which is due to an increase in the binding energy per nucleon of the resulting nucleus.

OR

(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.
Ans. (a) Distinguish features of nuclear forces are:
(i) Nuclear forces are very strong binding forces (attractive force.)
(ii) It is independent of the charge of protons and neutrons (charge independent.)
(iii) It depends on the spins of the nucleons.
(b) Plot showing variation of potential energy of a pair of nucleons as a function of separation mark attractive and repulsive region.



X-axis shows separation between pair of nucleons and Y-axis shows variation of potential energy w.r.t. separation (in × 10^{-15} m).

17. 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).
Ans. Number of atoms in a 3 g coin
Each copper atom has 29 protons and 34 neutrons.
Thus, the mass defect of each atom is
29 × 1.00783 + 34 × 1.00867 – 62.92960 = 0.59225 u
Total mass defect of all atoms = 0.59225 u × 2.868 × 1022 = 1.6985 × 1022 u
Thus, the nuclear energy required = 1.6985 × 1022 × 931 MeV = 1.58 × 1025 MeV

OR

(i) Briefly discuss three characteristics of the forces between nucleons.
(ii) Which out of $^{8}_{4}X$ and $^{5}_{3}Y$ nuclei is more stable and why?
Ans. (i) Characteristics of Nuclear Forces
(a) These are very short range forces, which are effective only within the nucleus *i.e.*, in the range of 10^{-15} m.
(b) These forces are the strongest forces found in nature.
(c) These forces are the charge independent forces.
(ii) Nucleus $^{8}_{4}X$ has 4 protons and 8 – 4 = 4 neutrons.
∴ neutron : proton = 4 : 4 or 1 : 1
Nucleus $^{5}_{3}Y$ has 3 protons and 5 – 3 = 2 neutrons.
∴ neutron : proton = 2 : 3

∵ Neutron to proton ratio is higher for the nucleus ${}^{8}_{4}X$ hence nucleus ${}^{8}_{4}X$ is more stable.

SECTION – D

Questions 18 carry 5 marks.

18. Asha's mother read an article in the newspaper about a disaster that took place at Chernobyl. She could not understand much from the article and asked a few questions from Asha regarding the article. Asha tried to answer her mother's questions based on what she learnt in Class XII Physics.

(a) What was the installation at Chernobyl where the disaster took place? What, according to you, was the cause of this disaster?

(b) Explain the process of release of energy in the installation at Chernobyl.

(c) 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.

Ans. (a) The installation at Chernobyl was a nuclear reactor. In a nuclear reactor, nuclear fissions reaction takes place. Large amount of energy is released by this process. The large amount of energy may cause any sort of explosion. The fast moving nucleons are produced on the process and are also used. Some penetrating radiations are emitted by this process.

(b) The binding energies on the both sides i.e. reactants and products are different. In this process, a heavier nuclei disintegrates into two lights nuclei with higher binding energy. These nuclei are stable as compared to the initial. So a large amount of energy is released.

In nuclear fusion, the two lighter nuclei combine together to form a heavy nuclei. Here binding energy is increased and a large amount of energy is released.

(c) Binding energy of the nucleus, $B_1 = 7.6 \times 240 = 1824$ MeV

Binding energy of the product nucleus, $B_2 = 8.5 \times 120 = 1020$ MeV

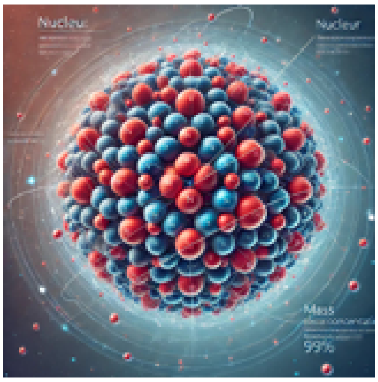
Then, energy released as the nucleus breaks, $E = 2B_2 - B_1$

$= (2 \times 1020) - 1824 = 2040 - 1824 = 216$ MeV

SECTION – E (Case Study Based Questions)

Questions 19 to 20 carry 4 marks each.

19. Nuclear Force: Neutrons and protons are identical particle in the sense that their masses are nearly the same and the force, called nuclear force, does into distinguish them. Nuclear force is the strongest force. Stability of nucleus is determined by the neutron proton ratio or mass defect or packing fraction. Shape of nucleus is calculated by quadrupole moment and spin of nucleus depends on even or odd mass number. Volume of nucleus depends on the mass number. Whole mass of the atom (nearly 99%) is centred at the nucleus.



(i) The correct statements about the nuclear force is/are

(a) change independent (b) short range force

(c) non-conservative force (d) all of these.

(ii) The range of nuclear force is the order of

(a) 2×10^{-10} m (b) 1.5×10^{-20} m (c) 1.2×10^{-4} m (d) 1.4×10^{-15} m

(iii) A force between two protons is same as the force between proton and neutron. The nature of the force is
(a) electrical force (b) weak nuclear force (c) gravitational force (d) strong nuclear force.

(iv) Two protons are kept at a separation of 40 Å. *Fn* is the nuclear force and *Fe* is the electrostatic force between them. Then
(a) $F_n << F_e$ (b) $F_n = F_e$ (c) $F_n >> F_e$ (d) $F_n \approx F_e$

OR

(v) All the nucleons in an atom are held by
(a) nuclear forces (b) van der Waal's forces
(c) tensor forces (d) coulomb forces

Ans. (i) (d) : All options are basic properties of nuclear forces. So, all options are correct.
(ii) (d) : The nuclear force is of short range and the range of nuclear force is the order of 1.4×10^{-15} m.
Now, volume $\propto R^3 \propto A$
(iii) (d)
(iv) (a) : Nuclear force is much stronger than the electrostatic force inside the nucleus i.e., at distances of the order of fermi. At 40 Å, nuclear force is ineffective and only electrostatic force of repulsion is present. This is very high at this distance because nuclear force is not acting now and the gravitational force is very feeble.
$F_{nuclear} << F_{electrostatic}$ in this case.

OR

(v) (a) nuclear forces

20. Nuclear Fission: In the year 1939, German scientist Otto Hahn and Strassmann discovered that when an uranium isotope was bombarded with a neutron, it breaks into two intermediate mass fragments.

It was observed that, the sum of the masses of new fragments formed were less than the mass of the original nuclei. This difference in the mass appeared as the energy released in the process. Thus, the phenomenon of splitting of a heavy nucleus (usually $A > 230$) into two or more lighter nuclei by the bombardment of proton, neutron, α-particle, etc with liberation of energy is called nuclear fission.

$${}_{92}U^{235} + {}_0n^1 \rightarrow \underset{\text{Unstable nucleus}}{{}_{92}U^{236}} \rightarrow {}_{56}Ba^{144} + {}_{36}Kr^{89} + 3\,{}_0n^1 + Q$$

(i) Nuclear fission can be explained on the basis of

(a) Millikan's oil drop method (b) Liquid drop model
(c) Shell model (d) Bohr's model.

(ii) For sustaining the nuclear fission chain reaction in a sample (of small size) of $^{235}_{92}U$, it is desirable to slow down fast neutrons by
(a) friction (b) elastic damping/scattering
(c) absorption (d) none of these.

(iii) Which of the following is/are fission reaction(s)?

$$\text{(I)} \quad {}^1_0n + {}^{235}_{92}U \rightarrow {}^{236}_{92}U \rightarrow {}^{133}_{51}Sb + {}^{99}_{41}Nb + 4{}^1_0n$$

$$\text{(II)} \quad {}^1_0n + {}^{235}_{92}U \rightarrow {}^{1.40}_{54}Xe + {}^{94}_{38}Sr + 2{}^1_0n$$

$$\text{(III)} \quad {}^2_1H + {}^2_1H \rightarrow {}^3_2He + {}^1_0n$$

(a) Both II and III (b) Both I and III (c) Only II (d) Both I and II

(iv) On an average, the number of neutrons and the energy of a neutron released per fission of a uranium atom are respectively
(a) 2.5 and 2 keV (b) 3 and 1 keV (c) 2.5 and 2 MeV (d) 2 and 2 keV

OR

(v) In any fission process, ratio of mass of daughter nucleus to mass of parent nucleus is
(a) less than 1 (b) greater than 1
(c) equal to 1 (d) depends on the mass of parent nucleus.

Ans. (i) (b)
(ii) (b) : Fast neutrons are slowed down by elastic scattering with light nuclei as each collision takes away nearly 50% of energy.
(iii) (d) : Reactions I and II represent fission of uranium isotope $^{235}_{92}U$, when bombarded with neutrons that breaks it into two intermediate mass nuclear fragments. However, reaction III represents two deuterons fuses together to from the light isotope of helium.
(iv) (c) : On an average 2.5 neutrons are released per fission of the uranium atom.
The energy of the neutron released per fission of the uranium atom is 2 MeV.

OR

(v) (a) : In fission process, when a parent nucleus breaks into daughter products, then some mass is lost in the form of energy.
Thus, mass of fission products < mass of parent nucleus.
$\Rightarrow$ Mass of fission products/Mass of parent nucleus < 1