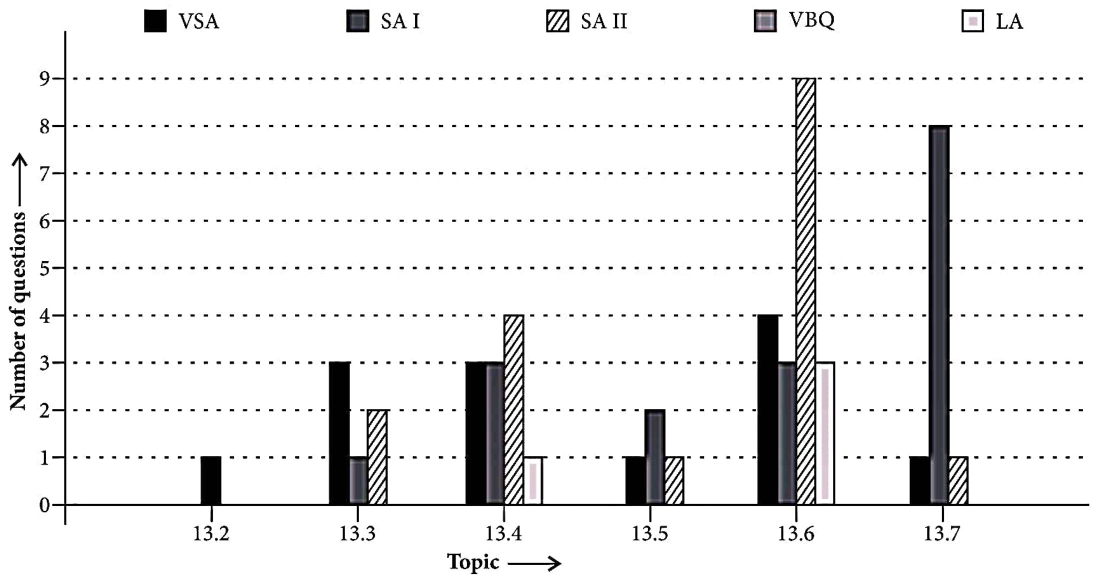
13 Nuclei

Topicwise Analysis of Last 10 Years' CBSE Board Questions



- Maximum weightage is of *Radioactivity.*
- Maximum VSA, SA II and LA type questions were asked from *Radioactivity.*
- Maximum SA I type questions were asked from *Nuclear Energy.*
- No VBQ type questions were asked till now.

QUICK RECAP

Composition of the Nucleus

- The nucleus of an atom contains protons and neutrons which are collectively known as nucleons. The number of protons in a nucleus is called its atomic number and is denoted by Z. The total number of protons and neutrons in a nucleus is called its mass number and is denoted by A.
  - Number of protons in an atom = Z
  - Number of electrons in an atom = Z
  - Number of nucleons in an atom = A
  - Number of neutrons in an atom = $N = A - Z$.

- **Nuclide :** It is a specific nucleus of an atom which is characterised by its atomic number Z and mass number A. It is represented by $_ZX^A$ where X is the chemical symbol of the element.
- **Nuclear Radius :** Nuclear radius $R = R_0 A^{1/3}$ where R_0 is a constant and A is the mass number.
  Nuclear radius is measured in fermi.
  $1 \text{ fm} = 10^{-15} \text{ m}$
- **Nuclear Density :**

$$\text{Nuclear density } \rho = \frac{\text{mass of nucleus}}{\text{volume of nucleus}}$$

  Nuclear density is independent of A and is in order of the 10^{17} kg m^{-3}.

Isotopes : Isotopes of an element are the atoms of the element which have the same atomic number but different mass numbers. *e.g.* $_1H^1$, $_1H^2$, $_1H^3$, are the three isotopes of hydrogen.

Isobars : Isobars are the atoms of different elements which have the same mass number but different atomic numbers. *e.g.* $_{11}Na^{22}$ and $_{10}Ne^{22}$.

Isotones : Isotones are the nuclides which contain the same number of neutrons. *e.g.* $_{17}Cl^{37}$ and $_{19}K^{39}$.

Nuclear forces : Nuclear forces are the strong forces of attraction which hold together the nucleons (neutrons and protons) in the tiny nucleus of an atom, inspite of strong electrostatic forces of repulsion between protons.

- Nuclear forces are strongest forces in nature.
- Nuclear forces are short range forces.
- Nuclear forces do not obey inverse square law.
- Nuclear forces are charge independent.

Mass defect : The difference in mass of a nucleus and its constituents is known as the mass defect and is given by

$$\Delta m = [Zm_p + (A - Z)m_n - m_N]$$

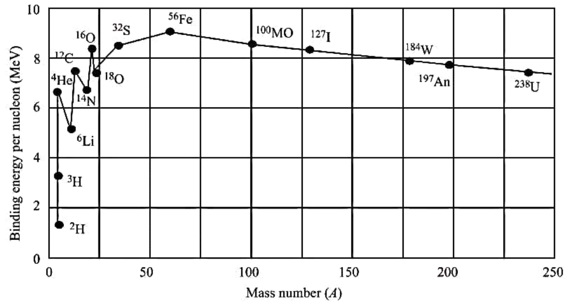
where m_p is the mass of the proton and m_n is the mass of the neutron and m_N is the mass of the nucleus.

Binding Energy : The binding energy of nucleus is given by

$$E_b = \Delta mc^2 = [Zm_p + (A - Z)m_n - m_N]c^2$$
$$= [Zm_p + (A - Z)m_n - m_N] \times 931.49 \text{ MeV/u.}$$

The binding energy per nucleon of a nucleus $= E_b/A$
The greater the binding energy per nucleon, the more stable is the nucleus.

- **Binding Energy Curve**
  It is curve drawn between binding energy per nucleon and mass number as shown in the figure.



- The main features of the curve as follows :
  - The binding energy per nucleon is practically constant, *i.e.*, practically independent of the atomic number for nuclei of middle mass number ($30 < A < 170$). The curve has a maximum of about 8.75 MeV for $A = 56$ and has a value of 7.6 MeV for $A = 238$.
  - The binding energy per nucleon is lower for both light nuclei ($A < 30$) and heavy nuclei ($A > 170$).

Radioactivity : Radioactivity was discovered in 1896 by Antoine Henri Becquerel.
Radioactivity is the spontaneous disintegration of nuclei of some nuclides (called radio nuclides) with the emission of alpha particles or beta particles, some accompanied by a gamma ray emission.

- **Law of Radioactive Decay**

$$\frac{dN}{dt} = -\lambda N(t) \quad \text{or} \quad N(t) = N_0 e^{-\lambda t}$$

  where λ is the decay constant or disintegration constant, N is the number of nuclei left undecayed at the time t, N_0 is the number of radioactive nuclei at $t = 0$.
  - Half-life of a radioactive substance is given by

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

  - Mean life or average life of a radioactive substance is given by

$$\tau = \frac{1}{\lambda} = \frac{T_{1/2}}{0.693} = 1.44T_{1/2}$$

- **Activity :** The number of disintegrations occurring in a radioactive substance per second and it is given by $R = -dN/dt$.
  - The SI unit of activity is becquerel.
    1 becquerel = 1 Bq = 1 decay/sec.
  - The traditional unit of activity is the curie.
    1 curie = 1 Ci = 3.70×10^{10} decays/s
    = 37 GBq.
- The other unit of radioactivity is rutherford.
  1 rutherford = 10^6 disintegrations/s.
- Activity law, $R(t) = R_0 e^{-\lambda t}$
  where $R_0 = \lambda N_0$ is the decay rate at $t = 0$ and $R = N\lambda$.
- Fraction of nuclei left undecayed after n half lives is

$$\frac{N}{N_0} = \left(\frac{1}{2}\right)^n = \left(\frac{1}{2}\right)^{t/T_{1/2}} \quad \text{or} \quad t = nT_{1/2}$$

Radioactive decay : The various radioactive decays are shown in the table.

Decay	Transformation	Example
Alpha decay	${}^A_Z X \rightarrow {}^{A-4}_{Z-2}Y + {}^4_2\text{He}$	${}^{238}_{92}\text{U} \rightarrow {}^{234}_{90}\text{Th} + {}^4_2\text{He}$
Beta decay	${}^A_Z X \rightarrow {}_{Z+1}^{A}Y + e^- + \bar{\nu}$	${}^{14}_6\text{C} \rightarrow {}^{14}_7\text{N} + e^- + \bar{\nu}$
Positron emission	${}^A_Z X \rightarrow {}_{Z-1}^{A}Y + e^+ + \nu$	${}^{64}_{29}\text{Cu} \rightarrow {}^{64}_{28}\text{Ni} + e^+ + \nu$
Electron capture	${}^A_Z X + e^- \rightarrow {}_{Z-1}^{A}Y$	${}^{64}_{29}\text{Cu} + e^- \rightarrow {}^{64}_{28}\text{Ni}$
Gamma decay	${}^A_Z X^* \rightarrow {}^A_Z X + \gamma$	${}^{87}_{38}\text{Sr}^* \rightarrow {}^{87}_{38}\text{Sr} + \gamma$

[*de notes an excited nuclear state.]

- **Alpha decay :** A nucleus that decays spontaneously by emitting an alpha particle (a helium nucleus ${}^4_2\text{He}$) is said to undergo alpha decay. The alpha decay is represented by

$${}^A_Z X \rightarrow {}^{A-4}_{Z-2}Y + {}^4_2\text{He}$$

where ${}^A_Z X$ is the parent nucleus and ${}^{A-4}_{Z-2}Y$ is the daughter nucleus.
  - In a alpha decay disintegration energy Q is given by
    $Q = (m_X - m_Y - m_{\text{He}})c^2$
  - Kinetic energy of alpha particles is given by

$$KE_\alpha = \frac{A-4}{A}Q$$

where A is the mass number of parent nucleus.

- **Beta decay :** A nucleus that decays spontaneously by emitting an electron or a positron is said to undergo beta decay.
  - In beta minus decay (β^-), a neutron is transformed into a proton and an electron and antineutrino is emitted.

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

    where n is the neutron, p is the proton, e^- is the electron and $\bar{\nu}$ is the antineutrino.
  - The beta minus decay is represented by

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

  - In beta minus decay, disintegration energy Q is given by
    $Q = [m_X - m_Y]c^2$
  - In beta plus decay (β^+) or positron emission, a proton is transformed into neutron and positron and neutrino is emitted.
    $p \rightarrow n + e^+ + \nu$
    where e^+ is the positron and ν is the neutrino.
  - The beta plus decay is represented by

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

  - In beta plus decay, the disintegration energy is given by
    $Q = [m_X - m_Y - 2m_e]c^2$
    where m_e is the mass of the electron.
  - The kinetic energy of an electron or a positron in the beta decay vary continuously from zero to a certain maximum value $K.E._{\text{max}}$. The maximum kinetic energy $K.E._{\text{max}}$ of an electron or positron must equal the disintegration energy Q.
- **Gamma decay :** When a nucleus in an excited state makes a transition to state of lower energy, electromagnetic radiation of very short wavelength is emitted.
  - The gamma decay is represented by

$${}^A_Z X^* \rightarrow {}^A_Z X + \gamma$$

    [* denotes the excited nuclear state.]

Nuclear reaction : A nuclear reaction is represented by

$$A + a \rightarrow B + b + Q$$

where A is the target nucleus, a is the impinging particle, B and b are the products, Q is the energy released in the process.

The nuclear reaction is represented by notation $A(a, b)B$.

Q value of nuclear reaction,

$$Q = (m_A + m_a - m_B - m_b)c^2$$

- If Q is positive, the reaction is exothermic and if Q is negative the reaction is endothermic.
- Conservation laws obeyed by every nuclear reaction are
  - Conservation of charge number
  - Conservation of mass number
  - Conservation of linear momentum
  - Conservation of energy
- **Nuclear fission :** It is the phenomenon of splitting a heavy nucleus into two or more smaller nuclei.
  - The nuclear fission of $_{92}U^{235}$ is represented as
    $$_{92}U^{235} + {}_0n^1 \rightarrow {}_{56}Ba^{141} + {}_{36}Kr^{92} + 3\,{}_0n^1 + Q$$

  The value of the Q is 200 MeV per fission reaction.
- **Nuclear chain reaction :** Under suitable conditions, the three secondary neutrons may cause further fission of U^{235} nuclei and start what is known as nuclear chain reaction. The nuclear chain reaction is controlled by

  Neutron reproduction factor (K)
  $$= \frac{\text{rate of production of neutrons}}{\text{rate of loss of neutrons}}$$
- Uncontrolled nuclear chain reaction is the basis of an atom bomb. Controlled nuclear chain reaction is the basis of a nuclear reactor.
- **Nuclear reactor :** Nuclear reactor uses nuclear energy for peaceful purposes. It is based on the phenomenon of controlled nuclear chain reaction. Moderators like heavy water, graphite, paraffin and deuterium slow down neutrons. Rods of cadmium and boron serv as control rods. Ordinary water and heavy water serve as coolants.
- **Nuclear fusion :** It is the phenomenon of fusing two or more lighter nuclei to form a single heavy nucleus.
  - The nuclear fusion reaction of two deutrons is represented as
    $_1H^2 + {}_1H^2 \rightarrow {}_2He^4 + 24$ MeV
  - Temperature $\approx 10^7$ K are required for fusion to take place.
  - Nuclear fusion is a basis of hydrogen bomb.
- **Stellar energy :** It is the energy obtained from the sun and stars. The source of stellar energy is nuclear fusion.

Previous Years' CBSE Board Questions

13.2 Atomic Masses and Composition of Nucleus

VSA (1 mark)

1. The radioactive isotope D decays according to the sequence.

   $D \xrightarrow{\beta^-} D_1 \xrightarrow{\alpha\text{-particle}} D_2$

   If the mass number and atomic number of D_2 are 176 and 71 respectively, what is (*i*) the mass number (*ii*) atomic number of D? *(Delhi 2007)*

13.3 Size of the Nucleus

VSA (1 mark)

2. How is the radius of a nucleus related to its mass number A? *(AI 2013C, 2011C)*
3. A nucleus undergoes β^--dacay. How does its (i) mass number (ii) atomic number change? *(Delhi 2011C)*
4. Two nuclei have mass numbers in the ratio 1: 2. What is the ratio of their nuclear densities? *(Delhi 2009)*

SA I (2 marks)

5. How is the size of a nucleus experimentally determined? Write the relation between the radius and mass number of the nucleus. Show that the density of nucleus is independent of its mass number. *(Delhi 2012, 2011 C)*

SA II (3 marks)

6. In the study of Geiger-Marsden experiment on scattering of α particles by a thin foil of gold, draw the trajectory of α-particles in the coulomb field of target nucleus. Explain briefly how one gets the information on the size of the nucleus from this study.
   From the relation $R = R_0 A^{1/3}$, where R_0 is constant and A is the mass number of the nucleus, show that nuclear matter density is independent of A. *(Delhi 2015)*
7. In a Geiger-Marsden experiment, calculate the distance of closest approach to the nucleus of $Z = 80$, when an α-particle of 8 MeV energy impinges on it before it comes momentarily to rest and reverses its direction. How will the distance of closest approach be affected when the kinetic energy of the α-particle is doubled? *(AI 2012)*

13.4 Mass-Energy and Nuclear Binding Energy

SA I (2 marks)

8. If both the number of protons and neutrons in a nuclear reaction is conserved, in what way is mass converted into energy (or vice versa)? Explain giving one example. *(Delhi 2015C)*
9. Draw a plot of the binding energy per nucleon as a function of mass number for a large number of nuclei, $2 < A < 240$. How do you explain the constancy of binding energy per nucleon in the range $30 < A < 170$ using the property that nuclear force is short-ranged? *(AI 2010)*
10. A nucleus $^{23}_{10}\text{Ne}$ undergoes β–decay and becomes $^{23}_{11}$ Na. Calculate the maximum kinetic energy of emitted electrons assuming that the daughter nucleus and anti-neutrino carry negligible kinetic energy.

$$\begin{bmatrix} \text{mass of } ^{23}_{10}\text{Ne} = 22.994466 \text{ u} \\ \text{mass of } ^{23}_{11}\text{Na} = 22.989770 \text{ u} \\ 1\text{u} = 931\,\text{MeV/c}^2 \end{bmatrix}$$

(Delhi 2008)

SA II (3 marks)

11. Draw a plot of $B.E./A$ versus mass number A for $2 < A < 170$. Use this graph to explain the release of energy in the process of nuclear fusion of two light nuclei. *(Delhi 2014C)*
12. Distinguish between the phenomena of nuclear fission and fusion.

Explain, using the graph for the *B.E./A* versus mass number (*A*), how the release in energy can be accounted for in the two processes. *(AI 2014C, 2012C)*

13. Answer the following points :
(i) Why is the binding energy per nucleon found to be constant for nuclei in the range of mass number (*A*) lying between 30 and 170?
(ii) When a heavy nucleus with mass number $A = 240$ breaks into two nuclei, $A = 120$ energy is released in the process. *(AI 2012C)*

14. Draw the graph to show variation of binding energy per nucleon with mass number of different atomic nuclei. Calculate binding energy per nucleon of $^{40}_{20}Ca$ nucleus.
Actual mass of Ca = 39.962589 u
$m_p = 1.007825u$ $m_n = 1.008665$ u *(AI 2007)*

LA (5 marks)

15. (a) Draw the plot of binding energy per nucleon (B.E./*A*) as a function of mass number *A*. Write two important conclusions that can be drawn regarding the nature of nuclear force.
(b) Use this graph to explain the release of energy in both the processes of nuclear fusion and fission. *(AI 2013)*

13.5 Nuclear force

VSA (1 mark)

16. Write any two characteristic properties of nuclear force. *(AI 2008, 2011)*

SA I (2 marks)

17. Draw a plot of potential energy of a pair of nucleons as a function of their separation. Write two important conclusions which you can draw regarding the nature of nuclear forces. *(AI 2015, 2010)*

18. 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. *(AI 2012, 2007)*

SA II (3 marks)

19. Write three characteristic properties of nuclear force. *(AI 2015)*

13.6 Radioactivity

VSA (1 mark)

20. Why is it found experimentally difficult to detect neutrinos in nuclear β-decay? *(Foreign 2015, AI 2014)*

21. In both β^- and β^+ decay processes, the mass number of a nucleus remains same whereas the atomic number *Z* increases by one in β^- decay and decreases by one in β^+ decay. Explain giving reason. *(Foreign 2014)*

22. Define the activity of a given radioactive substance. Write its S.I. unit *(AI-2013, 2007)*

23. What is the relationship between the half-life and mean life of a radioactive nucleus? *(AI 2012C, Foreign 2011)*

SA I (2 marks)

24. Derive the expression for the law of radioactive decay of a given sample having initially N_0 decaying to the number *N* present at any subsequent time *t*.
Plot a graph showing the variation of the number of nuclei versus the time lapsed. Mark a point on the plot in terms of $T_{1/2}$ value the number present $N = N_0/16$. *(Foreign 2013)*

25. In a given sample two radioisotopes *A* and *B* are initially present in the ratio of 1:4. The half lives of *A* and *B* are respectively 100 years and 50 years. Find the time after which the amounts of *A* and *B* become equal. *(Foreign 2012)*

26. A radioactive nucleus '*A*' undergoes a series of decays according to the following scheme.

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

The mass number and atomic number of A are 180 and 72 respectively. What are these numbers for A_4? *(Delhi 2009)*

SA II (3 marks)

27. (i) Write the basic nuclear process involved in the emission of β^+ in a symbolic form, by a radioactive nucleus.
(ii) In the reactions given below :
(a) $^{11}_{6}C \rightarrow ^{z}_{y}B + x + \nu$

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

Find the values of x, y and z and a, b and c. *(AI 2016)*

28. (a) Complete the following nuclear reactions:

(i) ${}^{208}_{84}Po \rightarrow {}^{204}_{82}Pb + ...$

(ii) ${}^{32}_{15}P \rightarrow {}^{32}_{16}S + ...$

(b) Write the basic process involved in nuclei responsible for (i) β^- and (ii) β^+ decay.

(c) Why is it found experimentally difficult to detect neutrinos? *(AI 2015C)*

29. (a) Deduce the expression, $N = N_0\, e^{-\lambda\tau}$, for the law of radioactive decay.

(b) (i) Write symbolically the process expressing the β^+ decay of ${}^{22}_{11}Na$. Also write the basic nuclear process underlying this decay.

(ii) Is the nucleus formed in the decay of the nucleus ${}^{22}_{11}Na$, an isotope or isobar? *(Delhi 2014)*

30. (a) Define the term 'activity' of a sample of a radioactive nucleus. Write its S.I. unit.

(b) The half life of ${}^{238}_{92}U$ undergoing α-decay is 4.5×10^9 years. Determine the activity of 10 g sample of ${}^{238}_{92}U$. Given that 1 g of ${}^{238}_{92}U$ contains 25.3×10^{20} atoms. *(AI 2014 C)*

31. (a) The number of nuclei of a given radioactive sample at time $t = 0$ and $t = T$ are N_0 and N_0/n respectively. Obtain an expression for the half life ($T_{1/2}$) of the nucleus in terms of n and T.

(b) Write the basic nuclear process underlying β^- decay of a given radioactive nucleus. *(Delhi 2013C)*

32. In β-decay, the experimental detection of neutrinos (or antinetrinos) is found to be extremely difficult. *(1/3, AI 2012C)*

33. State the law of radioactive decay.

Plot a graph showing the number (N) of undecayed nuclei as a function of time (t) for a given radioactive sample having half life $T_{1/2}$.

Depict in the plot the number of undecayed nuclei at (i) $t = 3T_{1/2}$ and (ii) $t = 5T_{1/2}$. *(Delhi 2011)*

34. (i) Define 'activity' of a radioactive material and write its S.I. unit.

(ii) Plot a graph showing variation of activity of a given radioactive sample with time.

(iii) The sequence of stepwise decay of a radioactive nucleus is

$$D \xrightarrow{\alpha} D_1 \xrightarrow{\beta^-} D_2$$

If the atomic number and mass number of D_2 are 71 and 176 respectively, what are their corresponding values for D? *(Delhi 2010)*

35. Write symbolically the β^- decay process of ${}^{32}_{15}P$. *(1/3 AI 2010)*

36. What is the basic mechanism for the emission of β^- or β^+ particles in a nucleide? Give an example by writing explicitly a decay process for β^- emission. Is (a) the energy of the emitted β-particles continuous or discrete; (b) the daughter nucleus obtained through β-decay, an isotope or an isobar of the parent nucleus.

LA (5 marks)

37. (a) Define the terms (i) half-life ($T_{1/2}$) and (ii) average life (τ). Find out their relationship with the decay constant (λ).

(b) A radioactive nucleus has a decay constant $\lambda = 0.3465\ (\text{day})^{-1}$. How long would it take the nucleus to decay to 75% of its initial amount? *(Foreign 2014)*

38. Write the basic nuclear process of neutron undergoing β-decay. Why is the detection of neutrinos found very difficult? *(2/5, AI 2013)*

39. (a) Define the term 'activity' of a given sample of radionuclide. Write the expression for the law of radioactive decay in terms of the activity of a given sample.

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

(c) When a nucleus (X) undergoes β-decay, the transforms to the nucleus (Y), does the pair (X, Y) form isotopes, isobars or isotones? Justify your answer. *(Delhi 2012C)*

40. (a) Derive the law of radioactive decay, viz. $N = N_0 e^{-\lambda t}$.

(b) Explain, giving necessary reactions, how energy is released during (i) fission and (ii) fusion. *(AI 2011 C)*

13.7 Nuclear Energy

VSA (1 mark)

41. State the reason, why heavy water is generally used as a moderator in a nuclear reactor. *(Delhi 2008)*

SA I (2 marks)

42. A nucleus with mass number $A = 240$ and $B.E./A = 7.6$ MeV breaks into two fragments each of $A = 120$ with $B.E./A = 8.5$ MeV. Calculate the released energy. *(Delhi 2016)*

43. Calculate the energy in fusion reaction : ${}_1^2H + {}_1^2H \rightarrow {}_2^3He + n$, where B.E. of ${}_1^2H = 2.23$ MeV and of ${}_2^3He = 7.73$ MeV. *(Delhi 2016)*

44. Complete the following nuclear reactions.

(a) ${}_5^{10}B + {}_0^1n \rightarrow {}_2^4He + ...$

(b) ${}_{42}^{94}Mo + {}_1^2H \rightarrow {}_{43}^{95}Te + ...$ *(Delhi 2015C)*

45. Using the curve for the binding energy per nucleon as a function of mass number A, state clearly how the release in energy in the processes of nuclear fission and nuclear fusion can be explained. *(AI 2011)*

46. 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 neutrons) Given:

(i) Mass of ${}_1^1H = 1.007825$ u

(ii) mass of helium nucleus = 4.002603 u, $1u = 931$ MeV/c^2 *(Foreign 2011)*

47. 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 of two nucleons, is 8.5. Calculate the energy Q released per fission in MeV. *(Delhi 2010)*

48. If both the number of protons and the number of neutrons are conserved in a nuclear reaction like ${}_6^{12}C + {}_6^{12}C \longrightarrow {}_{10}^{20}Ne + {}_2^4He$

In what way is mass converted into energy? Explain. *(Foreign 2010)*

49. Calculate the energy released in MeV in the following nuclear reaction:

${}_{92}^{238}U \rightarrow {}_{90}^{234}Th + {}_2^4He + Q$

[Mass of ${}_{92}^{238}U = 238.05079$ u

Mass of ${}_{90}^{234}Th = 234.043630$ u

Mass of ${}_2^4He = 4.002600$ u

$1\ u = 931.5$ MeV/c^2.] *(AI 2008, Delhi 2007)*

SA II (3 marks)

50. In a typical nuclear reaction, *e.g.*

${}_1^2H + {}_1^2H \rightarrow {}_2^3He + {}_0^1n + 3.27$ MeV,

although number of nucleons is conserved, yet energy is released. How? Explain. *(1/3, Delhi 2016, 2013)*

Detailed Solutions

1. $^{180}_{72}D \xrightarrow{\beta^-} {}^{180}_{73}D_1 \xrightarrow{\alpha} {}^{176}_{71}D_2$

(i) Mass number of D = 180, (ii) Atomic number of $D = 72$

2. The volume of the nucleus is directly proportional to the number of nucleons (mass number) constituting the nucleus.

$\frac{4}{3}\pi R^3 \propto A$ Where $R \to$ radius

$R \propto A^{1/3}$ $A \to$ Mass number

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

3. When β-decay takes place, (i) mass number remains unchanged and (ii) atomic number increases by one unit.

4. Nuclear density is independent of mass number.

5. Nucleus was first discovered in 1911 by Lord Rutherford and his associates by experiments on scattering of α-particle by atoms. He found that the scattering result could be explained, if atoms consists of a small, central, massive and positive core surrounded by orbiting electron. The experiment results indicated that the size of the nucleus is of the order of 10^{-14} metres and it thus 10,000 times smaller than the size of atom.

Relation between the radius and mass number of the nucleus $R = R_0 A^{1/3}$

If m is the average mass of a nucleon and R is the nuclear radius, then mass of nucleus = mA, where A is the mass number of the element.

Volume of the nucleus, $V = \frac{4}{3}\pi R^3$

$$\therefore \quad V = \frac{4}{3}\pi \left(R_0 A^{1/3}\right)^3$$

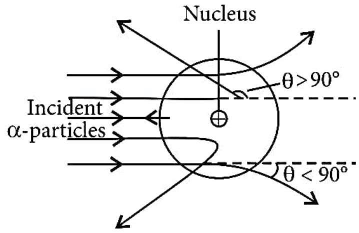
$$\Rightarrow \quad V = \frac{4}{3}\pi R_0^3 A$$

Density of nuclear matter, $\rho = \frac{mA}{V}$

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

This shows that the nuclear density is independent of A.

6. Trajectory of α-particles in coulomb field of target nucleus shows that only a small fraction of the number of incident α-particles (1 in 8000) rebound back.



This shows that the number of α-particles undergoing head-on collision is small. This implies that the entire positive charge of the atom is concentrated in a small volume. So, this experiment is an important way to determine an upper limit on the size of nucleus.

$$\text{Density of nucleus} = \frac{\text{mass of nucleus}}{\text{volume}}$$

$$\rho = \frac{A \times 1\,\text{amu}}{\frac{4}{3}\pi R^3}$$

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

$$\text{Density } \rho = \frac{A \times 1\,\text{amu}}{\frac{4}{3}\pi R_0^3 A} = \frac{1\,\text{amu}}{\frac{4}{3}\pi R_0^3}$$

$\rho = 2.97 \times 10^{17}\ \text{kg m}^{-3}$

so, nuclear density is constant irrespective of mass number or size.

7. $\frac{(Ze)(2e)}{4\pi\varepsilon_0 (r_0)} = K.E.$

$$\therefore \quad r_0 = \frac{2Ze^2}{4\pi\varepsilon_0 (K.E.)} \qquad (\because Z = 80, K.E. = 8\text{ MeV})$$

$$r_0 = \frac{9\times10^9 \times 2\times 80 \times (1.6\times10^{-19})^2}{8\times10^6 \times (1.6\times10^{-19})}\text{m}$$

$$r_0 = \frac{18\times1.6\times10^{-10}\times 80}{8\times10^6} = 2.88 \times 10^{-14}\text{ m}$$

$$\because \ r_0 \ \alpha \frac{1}{K.E.}$$

If $K.E.$ becomes twice then $r_0' = \frac{r_0}{2}$

i.e. distance of closest approach becomes half.

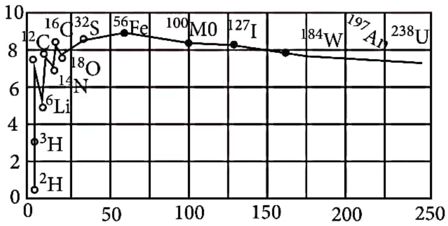
8. A certain number of neutrons and protons are brought together to form a nucleus of a certain charge and mass, an energy ΔE_b will be released in this process.

The energy ΔE_b is called the binding energy of the nucleus. If we separate a nucleus into its nucleons we would have to transfer a total energy equal to ΔE_b, to the nucleons.

Example : ${}_{92}U^{235} + {}_0n^1 \rightarrow {}^{141}_{56}Ba + {}^{92}_{36}Kr + 3^1_0n + Q$

The energy (Q) released was estimated to be 200 MeV per fission (or about 0.9 MeV per nucleon and is equivalent to the difference in masses of the nuclei before and after the fission.

9.



The constancy of binding energy in the range $30 < A < 170$ is a consequence of the fact that the nuclear force is short ranged. Consider a particular nucleon inside a sufficiently large nucleus. It will be under the influence of only some of its neighbours, which come within the range of the nuclear force. If any other nucleon is at a distance more than the range of the nuclear force from the particular nucleon it will have no influence on the binding energy of the nucleon under consideration. If a nucleon can have a maximum of p neighbours within the range of nuclear force, its binding energy would be proportional to p. Let the binding energy of the nucleus be pk, where k is a constant having the dimensions of energy. If we increase A by adding nucleons they will not change the binding energy of a nucleon inside. Since most of the nucleons in a large nucleus reside inside it and not on the surface, the change in binding energy per nucleon would be small. The binding energy per nucleon is a constant and is approximately equal to pk.

10. The equation representing β– decay of ${}^{23}_{10}Ne$ is

${}^{23}_{10}Ne \rightarrow {}^{23}_{11}Na + \beta^- + \bar{\nu} + Q$

where Q is the kinetic energy shared by ${}^{23}_{10}Ne$ and ${}^{23}_{11}Na$. Ignoring the rest mass of antineutrino ($\bar{\nu}$) and electron.

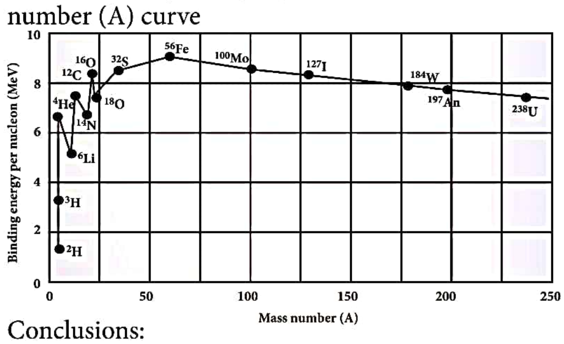
Mass defect $\Delta m = m\left({}^{23}_{10}Ne\right) - m\left({}^{23}_{11}Na\right) - m(\beta^-)$

= (22.994466 – 22.989770) = 0.004696 u

$\therefore$ $Q = 0.004696 \times 931$ MeV = 4.372 MeV

$\therefore$ Maximum K.E. of β^- = 4.372 MeV, when energy carried by ($\bar{\nu}$) is zero.

11. (a) Binding energy per nucleon versus mass number (A) curve



Conclusions:

(i) Nuclear forces are strong and attractive in nature

(ii) Nuclear force is a short ranged force.

Explanation of fusion : When two very light nuclei ($A < 10$) fuse to form a heavy nucleus, the BE/A of fused heavier nucleus is more than the binding energy per nucleon of lighter nuclei. This implies release of energy.

Energy released in nuclear fission : A Very heavy nucleus, say $A = 240$, has lower binding energy per nucleon as compared to a nucleus with $A = 120$. Thus, if somehow a nucleus having $A = 240$ breaks into two nuclei, each having mass number $A = 120$. Then energy would be released in the process.

12.

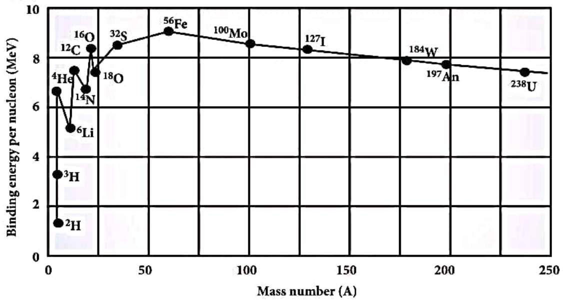
	Nuclear Fission		Nuclear Fusion
1.	The process of splitting of a heavy nucleus into two nuclei of nearly comparable masses with liberation of energy is called nuclear fission. Example: ${}^{235}_{92}U + {}^1_0n \rightarrow {}^{141}_{56}Ba + {}^{92}_{36}Kr + 3^1_0n + Q$	1.	When two or more than two light nuclei fuse together to form heavy nucleus with the liberation of energy, the process is called nuclear fusion. Example: ${}^2_1H + {}^2_1H \rightarrow {}^4_2He + 24\ MeV$
2.	A suitable bullet or projectile like neutron is needed.	2.	The lighter nuclei have to be brought very close to each other against electrostatic repulsion.
3.	The product of nuclear fission reaction are radioactive.	3.	The products of nuclear fusion are not radioactive.

Refer to answer 11.

13. (i) *Refer to answer 9.*

(ii) A very heavy nucleus with $A = 240$, has lower binding energy per nucleon compared to that of a nucleus with $A = 120$. When a heavy nucleus with mass number $A = 240$ breaks into two nuclei, $A = 120$, energy is released in this process.

14.



Number of protons = 20

Number of neutrons = 40 – 20 = 20

Expected mass of the nucleus

$m = 20\,(m_p + m_n)$

= 20 (1.007825 + 1.008665) u = 40.3298u

Actual mass is $m' = 39.962589$ u

Mass defect, $\Delta m = m - m'$

= 40.3298 – 39.962589 = 0.367211

Total $B.E.$ = 0.367211 × 931 MeV = 341.873441 MeV

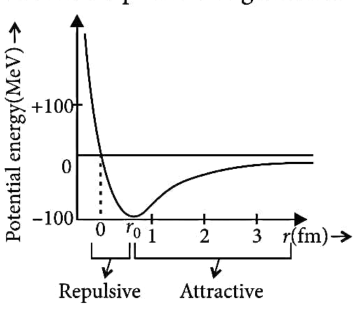
$$B.E./\text{nucleon} = \frac{341.873441}{40} = 8.547 \text{ MeV/nucleon}$$

15. *Refer to answer 11.*

16. Nuclear forces are strongest forces in nature: Magnitude of nuclear forces is 100 times that of electrostatic force and 10^{38} times the gravitational forces.

Nuclear forces are charge independent: Nuclear forces between a pair of protons, a pair of neutrons or a pair of neutron and proton act with same strength.

17. Plot of potential energy of a pair of nucleons as a function of their separation is given in the figure.



Conclusions: (i) The nuclear force is much stronger than the coulomb force acting between charges or the gravitational forces between masses.

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

(iii) For a separation greater than r_0, the force is attractive and for separation less than r_0, the force is strongly repulsive.

18. *Refer to answer17.*

19. Properties of nuclear force are :

(i) Nuclear forces are short range forces and are strongly attractive within a range of 1 fermi to 4.2 fermi.

(ii) Nuclear forces above 4.2 Fermi are negligible, whereas below 1 Fermi, they become repulsive in nature. It is this repulsive nature below 1 fermi, which prevents the nucleus from collapsing under strong attractive force.

(iii) Nuclear forces are charge independent. The same magnitude of nuclear force act between a pair of protons, pair of proton and neutron and pair of neutrons. The attractive nuclear force is due to exchange of π mesons (π^0, π^+, π^-) between them.

20. Neutrinos are neutral (chargeless), almost massless particles that hardly interact with matter.

21. In β^- decay, *a* β particle of zero mass and –1 charge is emitted. The decay process is shown below.

$${}^{A}_{Z}X \to {}^{A}_{Z+1}Y + {}^{0}_{-1}\beta + \bar{\nu}$$

Since the mass of β^-particle is negligibly small, the mass number of the nucleus remains the same and the atomic number increases by 1 due to the loss of 1 negative charge.

Similarly for *a* β^+ decay, a β particle of negligibly small and +1 charge is emitted. The decay process is shown below ${}^{A}_{Z}X \to {}^{A}_{Z-1}Y + {}^{0}_{+1}\beta + \nu$

The mass number remains the same, but here, the atomic number decreases by 1 due to the loss of 1 positive charge.

22. The rate of decay of a radioactive substance is called the activity of that substance.

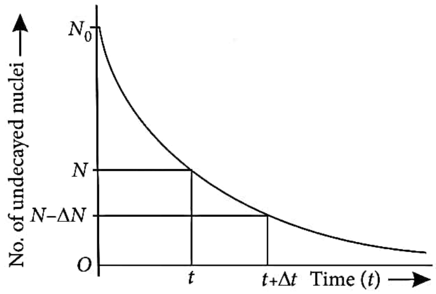
$$R = -\frac{dN}{dt}$$

S.I. unit : becquerel (Bq) or disintegrations/s

23. $T_{1/2} = \frac{ln2}{\lambda} = \tau\, ln2$

Where $T_{1/2}$ is half life and τ is mean life.

24. Let N be the number of undecayed nuclei in the sample at time t and ΔN nuclei undergo decay in time Δt. Then, $\frac{-\Delta N}{\Delta t} \propto N, \frac{-\Delta N}{\Delta t} = \lambda N$



Where λ is disintegration constant.

The rate of change in N in time $\Delta t \to 0$, can be expressed as $\frac{dN}{N} = -\lambda dt$

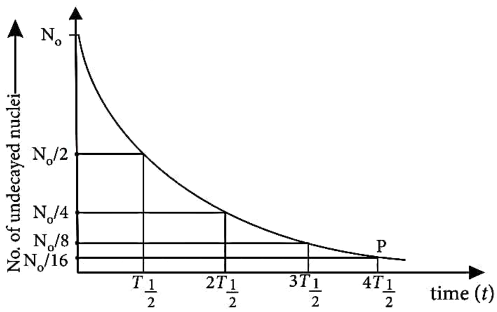
On integrating both sides $\int_{N_0}^{N} \frac{dN}{N} = -\int_0^t \lambda dt$

Where N_0 is in initial undecayed nuclei.

$ln\frac{N}{N_0} = -\lambda t$

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

Mark of $N = \frac{N_0}{16}$ in terms of $T_{1/2}$ is shown in the figure



25. We have $N = N_0\, e^{-\lambda t}$

For radio isotopes A and B, we can write

$N_A = N_0 e^{-\lambda_A t_A}$

$N_B = 4N_0 e^{-\lambda_B t_B}$

Let t be the time after which $N_A = N_B$

$\therefore \quad N_0 e^{-\lambda_A t} = 4N_0 e^{-\lambda_B t} \Rightarrow \quad 4 = e^{\lambda_B t - \lambda_A t}$

$\Rightarrow \log_e 4 = (\lambda_B t - \lambda_A t) \log_e e$

$\Rightarrow \quad 2\log_e 2 = \left[\frac{\log_e 2}{T_{B_{1/2}}} - \frac{\log_e 2}{T_{A_{1/2}}}\right] t \quad \left[\because \lambda = \frac{\log_e 2}{T_{1/2}}\right]$

$\Rightarrow \quad 2 = \left(\frac{1}{50} - \frac{1}{100}\right) t \quad \Rightarrow 2 = \left(\frac{2-1}{100}\right) t$

$\Rightarrow \quad t = 200$ years

26. ${}^{180}_{72}A \xrightarrow{\alpha = {}^4_2\text{He}} {}^{176}_{70}A_1 \xrightarrow{\beta = {}^{0}_{-1}e} {}^{176}_{71}A_2$

$\xrightarrow{\alpha = {}^4_2\text{He}} {}^{172}_{69}A_3 \xrightarrow{\gamma} {}^{172}_{69}A_4$

$\therefore$ The mass number of $A_4 = 172$

and the atomic number of $A_4 = 69$

27. (i) Basic nuclear reaction

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

(ii) (a) ${}^{11}_{6}\text{C} \to {}^{11}_{5}\text{B} + {}_{+1}e^0 + \nu$, $\therefore x = {}_{+1}e^0, y = 5, z = 11$

(b) ${}^{12}_{6}\text{C} + {}^{12}_{6}\text{C} \to {}^{20}_{10}\text{Ne} + {}^{4}_{2}\text{He}$

$\therefore \quad a = 10, b = 2, c = 4$

28. (a) (i) ${}^{208}_{84}\text{Po} \to {}^{204}_{82}\text{Pb} + {}^{4}_{2}\text{He}$

$208 = 204 + A$

$A = 208 - 204 = 4$

$84 = 82 + Z; Z = 84 - 82 = 2$

(ii) ${}^{32}_{15}P \to {}^{32}_{16}S + {}_{-1}e^0 + \nu$

$$\left.\begin{aligned} 32 &= 32 + A \\ A &= 32 - 32 = 0 \\ 15 &= 16 + Z \\ Z &= 15 - 16 = -1 \end{aligned}\right\} \begin{aligned} A &= 0 \\ Z &= -1 \end{aligned} \Rightarrow {}_{-1}e^0$$

(b) In both processes the conversion of neutron to proton and proton to neutron inside the nucleus.

${}^{A}_{Z}X \to \beta^- + {}^{A}_{Z+1}Y + \bar{\nu}$ (β^- decay)

${}^{A}_{Z}X \to \beta^+ + {}^{A}_{Z-1}Y + \nu$ (β^+ decay)

(c) Nutrinos are chargeless (neutral) and almost massless particles that hardly interact with matter.

29. (a) Radioactivity is a spontaneous phenomenon and one cannot predict, when a particular nucleus in a given radioactive sample will undergo disintegration. When a radioactive nucleus disintegrates, either an α-particle or a β-particle is emitted, generally followed by emission of γ-ray photon.

The number of radioactive nuclei disintegrating per second of a radioactive sample at any time is directly proportional to the number of active nuclei (undecayed) present at that time.

i.e. $\frac{dN}{dt} \propto N$

or $\frac{dN}{dt} = -\lambda N$ ...(i)

where N is number of active nuclei in a radioactive sample at time t and λ is called "disintegration constant" or "decay constant" of radioactive substance. The –ve sign indicates that the rate of disintegration $\frac{dN}{dt}$ decreases with time.

From equation (i)

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

Integrating above equation on both sides, using the limits that initially at time $t = 0$, number of active nuclei are N_0, and at time t, number of active nuclei are N,

$\int_{N_0}^{N} \frac{dN}{N} = -\lambda \int_0^t dt$ or $[\log_e N]_{N_0}^{N} = -\lambda[t]_0^t$

or $\log_e N - \log_e N_0 = -\lambda[t - 0]$

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

or $N = N_0 e^{-\lambda t}$ ...(ii)

(b) (i) The β^+ decay of ${}^{22}_{11}\text{Na}$ is given by

${}^{22}_{11}\text{Na} \longrightarrow {}^{22}_{10}\text{Ne} + e^+ + \nu$

If the unstable nucleus has excess protons than needed for stability, a proton converts into a neutron.

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

where e^+ is a positron and ν is a neutrino created during the process.

(ii) A nucleus ${}^{22}_{10}\text{Na}$ is formed in the decay of the nucleus ${}^{22}_{11}\text{Na}$. Both the nuclei are isobar because they have same mass number.

30. (a) *Refer to answer 22.*

(b) $T_{1/2} = 4.5 \times 10^9$ years

$= 4.5 \times 10^9 \times 3.15 \times 10^7$ seconds

Number of atoms in 10 g sample of ${}^{238}_{92}\text{U}$ is

$N = 6.023 \times 10^{23} \times \frac{10}{238} = 253 \times 10^{20}$ atoms

Activity of Sample $A = \lambda N = \frac{\ln 2}{T_{1/2}} \times N$

$= \left[\frac{0.6931}{4.5 \times 10^9 \times 3.15 \times 10^7}\right] \times 253 \times 10^{20}$

$= 1.237 \times 10^5$ becquerel

31. In one half life, $N = \frac{N_0}{2}$

$N = N_0/2$

In another half life (*i.e.*, 2 half lives)

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

Another half life (i.e., 3 half lives)

$N = \frac{1}{2}\left(\frac{N_0}{4}\right) = \frac{N_0}{8} = N_0\left(\frac{1}{2}\right)^3$ and so on

Hence, after n half lives,

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

Where $t = n \times T$ = total time of n half lives.

or $\frac{N}{N_0} = \left(\frac{1}{2}\right)^n = \left(\frac{1}{2}\right)^{t/T}$

(b) *Refer to answer 21.*

32. In β-decay, the experimental detection of neutrinos (or antineutrinos) is found to be extemely difficult. Neutrinos do not carry electric charge, which means that they are not affected by the electronmagnetic forces.

33. The rate of decay of atoms is proportional to the number of undecayed radioactive atoms present at any instant. If N is the number of undecayed atoms in a radioactive substance at any time t, dN the number of atoms disintegrating in time dt, the rate of decay is $\frac{dN}{dt}$ so that

$-\frac{dN}{dt} \propto N$ or $\frac{dN}{dt} = -\lambda N$ ...(i)

where λ is a constant of proportionality called the decay (or disintegration) constant, equation (i) results

$N = N_0 e^{-\lambda t}$ ...(ii)

where N_0 = Initial number of undecayed radioactive atoms.

If N_0 is the initial number of radioactive atoms present then in a half life time $T_{1/2}$, the number of undecayed radioactive atoms will be $N_0/2$ and in next half $N_0/4$ and so on.

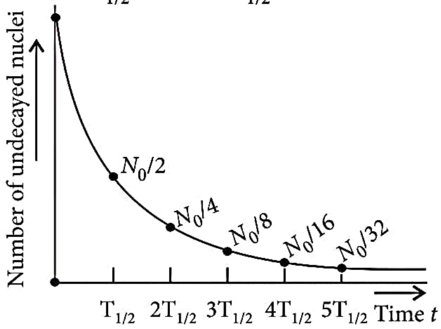
Using, $\frac{N}{N_0}=\left(\frac{1}{2}\right)^{t/T_{1/2}}$

According to problem form for $t=3T_{1/2}$

$\therefore\ N=N_0\left(\frac{1}{2}\right)^3=\frac{N_0}{8}$

and for $t=5T_{1/2}$; $N=\frac{N_0}{32}$

The graph shown for the number of undecayed nuclei at $t=3T_{1/2}$ and $t=5T_{1/2}$.



34. (i) *Refer to answer 22.*

(ii) *Refer to answer 33.*

(iii) ${}^{180}_{72}D \xrightarrow[{}^{4}_{2}He]{\alpha} {}^{176}_{70}D_1 \xrightarrow[{}^{0}_{-1}e]{\beta^-} {}^{176}_{71}D_2$

$\therefore$ Atomic number of $D=72$,

Mass number of $D=180$

35. In beta minus (β^-) decay, an electron is emitted by the nucleus and in beta plus (β^+) decay, a positron is emitted by the nucleus.

For example, in the decay of ${}^{32}_{15}P$

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

36. *Refer to answer 28 (b).*

(a) The energy emitted by β-particles is continuous.

(b) The daughter nucleus obtained through b-decay is an isobar of the parent nucleus.

37. (a) (i) Half life ($T_{1/2}$): It is the time in which half the number of nuclei of the given radionuclide decay.

$t=t_{1/2}$; $N=\frac{1}{2}N_0$

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

(ii) Average life (τ) : The Average life of a radioactive substance is defined as the average time for which the nuclei of the atoms of the radioactive substance exist.

Average life or mean-life $(\tau)=\dfrac{\lambda N_0\int_0^\infty te^{-\lambda t}dt}{N_0}$

$\tau=\lambda\int_0^\infty te^{-\lambda t}dt=\frac{1}{\lambda}$

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

(b) According to the decay law, we have:

$R=R_0e^{-\lambda t}$

$\Rightarrow\ \frac{R_0\times 75}{100}=R_0e^{-0.3465t}$

$\Rightarrow\ \frac{4}{3}=e^{0.3465t}$

$\therefore\ t=0.823$ day

38. ${}^{1}_{0}n\rightarrow{}^{1}_{1}p+{}^{0}_{-1}\beta+\bar{\nu}$

Refer to answer 20.

39. (a) *Refer to answer 22.*

(b) $\frac{R}{R_0}=\left(\frac{1}{2}\right)^n$ ...(i)

$\frac{R}{R_0}=\frac{3.125}{100}=\frac{1}{32}=\left(\frac{1}{2}\right)^5$

From (i)

$\left(\frac{1}{2}\right)^5=\left(\frac{1}{2}\right)^n$, $n=5$ half lives,

or $\frac{t}{T}=5\Rightarrow t=5T$

(c) *Refer to answer 36(b).*

40. *(a) Refer to answer 29(a).*

(b) (i) The fission reaction of ${}_{92}U^{235}$ may be represented as given below :

${}_{92}U^{235}+{}_0n^1\rightarrow{}_{92}U^{236}\rightarrow{}_{56}Ba^{141}+{}_{36}Kr^{92}+3{}_0n^1+Q$

The energy (Q) released was estimated to be 200 MeV per fission (or about 0.9 MeV per nucleon) and is equivalent to the difference in masses of the nuclei before and after the fission.

(ii) When two or more than two light nuclei fuse together to form heavy nucleus with the liberation of energy, the process is called nuclear fusion. *For* example, two deutrons can fuse together to form a helium nucleus releasing 24 MeV of energy. The fusion reaction may be expressed as follow:

${}_1H^2+{}_1H^2\rightarrow{}_2He^4+24\text{ MeV}$

This above nuclear fusion reaction is energetically possible, only if the mass of the $_2He^4$ nucleus is less than the sum of the masses of the two deutron nuclei.

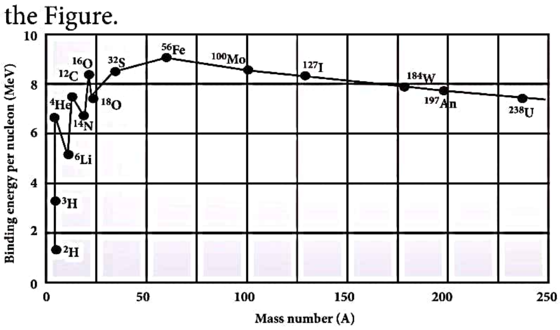
41. Heavy water is used to slow down fast moving neutrons.

42. For a big nucleus, $A = 240$, $BE/A = 7.6$ MeV
Initial binding energy = 240 × 7.6 = 1824 MeV
For two small nuclei, $A = 120$, $BE/A = 8.5$ MeV
Final binding energy = 2 × 120 × 8.5 = 2040 MeV
Energy released during fission
= (final *B.E.*) – (Initial *B.E.*)
= 2040 – 1824 = 216 MeV

43. Fusion reaction,
$${}_1^2H + {}_1^2H \longrightarrow {}_2^3He + n$$
Energy released = final *B.E.* – initial *B.E.*
= 7.73 – (2.23 + 2.23) = 3.27 MeV.

44. (a) ${}_5^{10}B + {}_0^1n \rightarrow {}_2^4He + {}_3^7Li$
$$10 + 1 = 4 + A$$
$$A = 11 - 4 = 7$$
$$5 + 0 = 2 + Z$$
$$Z = 5 - 2 = 3$$
$$\therefore A = 7, Z = 3$$
(b) ${}_{42}^{94}M_0 + {}_1^2H \rightarrow {}_{43}^{95}Te + {}_0n^1$
$$94 + 2 = 95 + A$$
$$A = 96 - 95 = 1$$
$$42 + 1 = 43 + Z$$
$$Z = 43 - 43 = 0$$

45. Binding Energy Curve: The variation of average B.E. per nucleon with mass number *A* is shown in the Figure.



The binding energy curve can be used to explain the phenomena of nuclear fission and nuclear fusion as follows :

Nuclear fission : Binding energy per nucleon is smaller for heavier nuclei than the middle ones, *i.e.*, heavier nuclei are less stable. When an heavier nucleus splits into the lighter nuclei, the *B.E./* nucleon changes from about 7.6 MeV to 8.4 MeV. Greater binding energy of the product nuclei results in the liberation of energy. This is what happens in nuclear fission which is the basis of the atom bomb.

Nuclear fusion : The binding energy per nucleon is small for light nuclei, *i.e.*, they are less stable. So when two light nuclei combine to form a heavier nucleus, the higher binding energy per nucleon of the latter results in the release of energy. This is what happens in a nuclear fussion which is the basis of the hydrogen bomb.

46. Energy released = $\Delta m \times 931$ MeV
$$\Delta m = 4m\,({}_1^1H) - m\,({}_2^4He)$$
Energy released
$$Q = [4.m\,({}_1^1H) - m\,({}_2^4He)] \times 931\,\text{MeV}$$
= [4 × 1.007825 – 4.002603] × 931 MeV
= 26.72 MeV.

47. We have $^{240}X = {}^{110}Y + {}^{130}Z$
Binding energy for $X = 7.6$ MeV
Binding energy of two fragments Y and $Z = 8.5$ MeV.
Energy released, $Q = 240\,(8.5 - 7.6)$ MeV = 216 MeV

48. 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 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.

49. Given nuclear reaction is
$${}_{92}^{238}U \rightarrow {}_{90}^{234}Th + {}_2^4He + Q$$
Mass defect = $M_U - M_{Th} - M_{He}$
= 238.05079 – 234.043630 – 4.002600 = 0.00456 u
Energy released = (0.00456 u) × (931.5 MeV/c^2)
= 4.25 M eV.

50. In a nuclear reaction, the sum of the masses of the target nucleus (21H) and the bombarding particle (21H) may be greater than the product nucleus $\left({}_2^3He\right)$ and the outgoing neutron ${}_0^1n$. So from the law of conservation of mass-energy some energy (3.27 MeV) is evolved due to mass defect in the nuclear reaction. This energy is called Q-value of the nuclear reaction.