Nuclear Physics

1.NUCLEAR FORCES

POINTS TO REMEMBER

1. Theoretical assumption of the nucleus was made by Rutherford
2. Experimental existence of the nucleus was made by Geiger & Mansden.
3. The size of the nucleus is of the order of 10^{-15}m (Fermi)
4. The size of the atom is of the order of 10^{-10}m.
5. The radius of the nucleus is given by $r = r_0 A^{1/3}$
   where r_0= constant, which varies from 1.2 Fermi to 1.5 Fermi $r_0 = 1.4\times10^{-15}$m
6. Density of the nucleus is of the order of 10^{17} kg/m^3 or 10^{14}gm/cc or 10^8tonne/cc.
7. Density of the nucleus does not depend on mass number (A)
8. Density of the nucleus is maximum at its centre and falls to zero as one moves radially outwards
9. The nuclear radius is the distance from the centre of the nucleus to a point where the density of the nucleus becomes half of the value at the centre.
10. Nuclear density is much more than the matter in bulk due to its small size.
11. Same Z and different A – isotope
12. Same A different Z – isobar
13. Same (A-Z) – isotones
14. Same A and same Z but different radioactive properties - isomer
15. Same (A – 2Z) – isodiaphere
16. **Mass defect and binding energy of nucleus :**
   a) The actual mass of a nucleus is always found to be less than the sum of the masses of the nucleons present in it. The mass difference is known as the “mass defect” and is denoted by Δm.
   b) $\Delta m = \lfloor Zm_p + (A-Z)m_n \rfloor - M$ where m_p and m_n are the masses of proton and neutron respectively and M is the actual mass of the nucleus.
   c) The mass defect per nucleon of the nucleus is defined as “Packing fraction”.
   Packing fraction= $\dfrac{\text{mass defect}}{\text{Mass number}} = \dfrac{\Delta m}{A}$
   d) **Binding energy**: The energy equivalent of the mass defect is the binding energy of the nucleus. Binding energy is also defined as the minimum energy required to split the nucleus into its constituent nucleons. More the binding energy, more the stability
   e) The ratio of binding energy of nucleus and the total number of nucleons in the nucleus is called the binding energy per nucleon. It is also called as “binding fraction” or average binding energy or specific binding energy.
   Binding fraction= $\dfrac{\text{Binding energy of the nucleus}}{A}$
   f) Binding energy of the nucleus= Δm x 931.5 MeV
   g) The binding energy ranges from 2.23MeV for $_1H^2$ and 1649MeV for bismuth $\left({}_{83}Bi^{209}\right)$.
   h) The binding energy per nucleon rises sharply to a maximum of about 8.8MeV in the neighborhood of A = 56, attains a 8.4MeV at about A = 140 and decreases to 7.6MeV for uranium.

17. **Nuclear Forces**

a) The force that holds the nucleons together in the nucleus is an attractive forces and it is called nuclear force.
b) Nuclear force is the strongest force of all the basic forces.
c) $F_{gravitational} : F_{electrostatic} : F_{Nuclear} = 1:10^{36}:10^{38}$
d) Nuclear forces are the short range forces.
e) Nuclear forces are more effective if the separation between the nucleons is of order of 1Fermi or less.
f) If the distance between the nucleons is less, about 0.4Fermi, the nuclear forces become repulsive.
g) These are charge independent.
h) The magnitude of these forces between two protons or two neutrons or between a proton and neutron are same.
i) Nuclear forces are spin dependent
j) When the spins of the nucleons are parallel, the forces between them are strong and when the spins are anti-parallel, the forces are weak.
k) Nuclear forces are non-central, i.e., the nuclear forces do not depend only on their separation.
l) These also depend on their orientation.
m) Due to the spin motion of the nucleons, they acquire magnetic moment and the force between them is similar to the force between two magnets.
n) These are called tensor forces.
o) Nuclear forces have saturation property, i.e., each nucleon interacts with its immediate neighbor only.
p) The force between the nucleons arises from the exchange of particles called π mesons.

18. Yukawa theory of Nuclear Forces

a) According to this theory a nucleon consists of a core surrounded by a cloud of mesons which may be charged or neutral.
b) The mesons constantly get exchanged between two neighboring nucleons.
c) The force between two protons is due to the exchange of π^0 (neutral) meson between them. $_1H^1 \rightarrow {_1H^1} + \pi^0$
d) The force between two neutrons is also due to the exchange of π^0 between them.

$$_0n^1 \rightarrow {_0n^1} + \pi^0$$

e) The force between proton and neutron is due to the exchange of π^+ or π^- mesons.

19 The existence of neutron was first predicted by Rutherford and it was discovered by Chadwick. ${}^9_4Be + {}^4_2He \rightarrow [{}^{13}_6C] \rightarrow {}^{12}_6C + {_0n^1}$.

Long Answer Questions

1. Define binding energy. How does binding energy per nucleon vary with mass number? What is its significance? (Or)

Define binding energy of nucleus. Draw a curve between mass number and average binding energy. Give the salient features of the curve.

Ans. **Binding energy:** Binding energy is defined as the minimum amount of energy required to split the nucleus into its constituent nucleons.

The actual mass of a nucleus is always found to be less than the sum of the masses of the nucleons present in it. This mass difference is known as the "mass defect" and is denoted by Δm.

$\Delta m = \lfloor Zm_p + (A - Z)m_n \rfloor - M$ where m_p and m_n are the masses of proton and neutron respectively and M is the actual mass of the nucleus.

Number of protons in the nucleus is Z

Number of neutrons N = A – Z

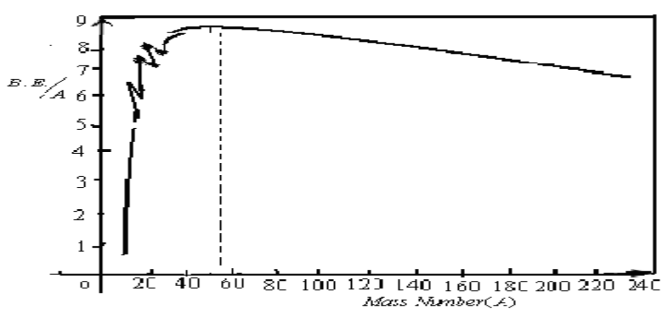
i) The energy equivalent of the mass defect is the binding energy of the nucleus

The ratio of binding energy of nucleus and the total number of nucleons in the nucleus is called the binding energy per nucleon. It is also called as "binding fraction" or average binding energy or specific binding energy.

$$\text{Binding fraction} = \frac{\text{Binding energy of the nucleus}}{A} = \frac{\Delta mc^2}{A}$$

Binding energy of the nucleus= Δm x 931.5 MeV

The graph of binding energy per nucleon as a function of mass number is shown in the figure.



More the binding energy, more the stabilityThe binding energy ranges from 2.23MeV for $_1H^2$ and 1649MeV for bismuth $\left({}_{83}Bi^{209}\right)$.The binding energy per nucleon rises sharply to a maximum of about 8.8MeV in the neighborhood of A = 56, attains a 8.4MeV at about A = 140 and decreases to 7.6MeV for uranium.A large amount of energy can be liberated if heavier nuclei can be split into lighter nuclei. (This is what happens when $_{92}U^{235}$ undergoes fission). A large amount of energy can be liberated if lighter nuclei can be made to fuse to form heavier nuclei (This is what happens when hydrogen nuclei combine to form heavier nucleus $_2He^4$ in nuclear fusion).

2. What are nuclear forces? Discuss their important properties. If nuclear forces are strong attractive forces between nucleons, then why the nucleus does not collapse?

Ans: **Nuclear Forces:** The force that holds the nucleons together in the nucleus is an attractive force and is called nuclear forces.

Properties of Nuclear forces:

1. The nuclear force is attractive in nature and is the strongest of all the basic forces.

Nuclear forces are strong attractive forces between proton and neutron, proton and proton and neutron and neutron. The relative strength of gravitational, coulombs and nuclear force are in ratio $F_g : F_e : F_n = 1 : 10^{36} : 10^{38}$.

2. Nuclear force is a short range force:

The nuclear force is more pronounced when the separation between the nucleons is of the order of 1fm or less. When two nucleons are within a distance of about 0.4 fm, the nuclear forces become repulsive.

3. The nuclear force is independent of electric charge of nucleons.

The nuclear force between two protons, between two neutrons or between a proton and a neutron are all same. Hence the nuclear force is charge independent.

4. Nuclear force is spin dependent:

Force between nucleons is strong when spin are parallel and weak when spins are anti-parallel.

5. Nuclear force is not completely central.

The force that depends only on the magnitude of separation of particles is known as central force. Nuclear force depends on distance and also nuclear spins relative to line joining two nucleons. Hence nuclear force is not completely central. It is tensor force.

- When two nucleons are within a distance of about 0.4 fm, the nuclear force becomes repulsive. Hence nucleons do not collapse.

SHORT ANSWER QUESTIONS

1. Why is the density of the nucleus more than that of the atom? Show that the density of nuclear matter is same for all the nuclei.

Ans: Atom is mostly hollow. The Entire mass is concentrated at the centre of atom i.e. nucleus. Thus, mass per unit volume (density) of the nucleus is more than that of the atom.

Density of the nucleus

Volume of the nucleus = $\frac{4}{3}\pi r^3 = \frac{4}{3}\pi\left(r_0 A^{1/3}\right)^3 = \frac{4}{3}\pi r_0^3 A$

Mass of each proton = 1.670020×10^{-27} kg

Mass of the nucleus = 1.670020×10^{-13} A

Density = $\frac{\text{mass}}{\text{volume}} = \frac{1.67 \times 10^{-27} \times A}{\frac{4}{3}\pi r_0 \times A} \approx 10^{17}$ kg/m^3

19. Density of the nucleus is of the order of
10^{17} kg/m^3 or 10^{14}gm/cc or 10^8tonne/cc.

20. Density of the nucleus does not depend on mass number (A)
Hence the density of nuclear matter is same for all nuclei.

2. What is meant by mass defect and binding energy? How do you account for the mass defect of a nucleus?

Ans: **Mass defect :** The actual mass of a nucleus is always found to be less than the sum of the masses of the nucleons present in it. This mass difference is known as the "mass defect" and is denoted by Δm.

$\Delta m = \lfloor Zm_p + (A-Z)m_n \rfloor - M$ where m_p and m_n are the masses of proton and neutron respectively and M is the actual mass of the nucleus.

Binding energy : The energy equivalent of the mass defect is the binding energy of the nucleus. Binding energy is also defined as the minimum energy required to split the nucleus into its constituent nucleons.

Relation between mass defect and binding energy is

$$\Delta mc^2 = \left\{[Zm_p + (A-Z)m_n] - M\right\}c^2$$

The energy equivalent to mass defect is responsible to hold all the nucleons together in the nucleons

Binding energy = mass defect x 931.5MeV.

3. For greater stability, a nucleus should have greater value of binding energy per nucleon. why?

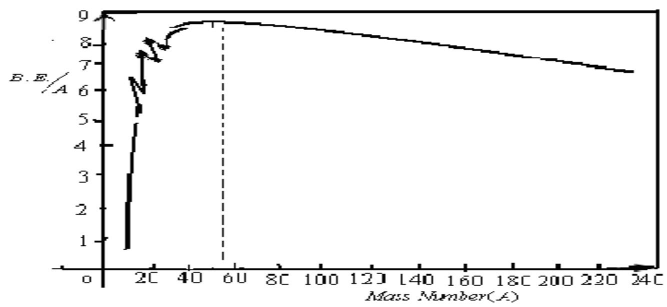
Ans: The ratio of binding energy of nucleus and the total number of nucleons in the nucleus is called the binding energy per nucleon. It is also called as "binding fraction" or average binding energy or specific binding energy.

$$\text{Binding fraction} = \frac{\text{Binding energy of the nucleus}}{A}$$

The increase in the binding fraction that the fusion of light nuclei results a stable nucleus with higher binding fractions. These results in a phenomenon called fusion.

4. Draw a diagram to show the variation of binding energy per nucleon with mass number for different nuclei. State the reason why light nuclei usually undergo fusion and heavy nuclei usually undergo fission.

Ans: Uranium has a relatively low binding energy per nucleon as 7MeV. To attain greater stability. Uranium break up into intermediate mass nuclei resulting in a phenomenon called fission.



While the light nuclei such as hydrogen combine to form heavy nucleus to form helium for greater stability, resulting in a phenomenon called fusion.

5. M_1 **and** M_2 **represent the masses** ${}^{20}_{10}Ne$ **and** ${}^{40}_{20}Cu$ **nucleus respectively. Show that** $M_2 > 2M_1$

Ans: Mass of 1st nuclei M_1 = mass of 10 protons + Mass of 20 neutrons.

Mass of 2nd nuclei M_2 = mass of 20 protons +Mass of 40 neutrons.

Thus $(M_2 > 2M_1)$

VERY SHORT ANSWER QUESTIONS

1. What are isotopes and isobars?

Ans: **Isotopes:** Nuclei which have the same atomic number but different mass numbers are called isotopes.

Ex : Hydrogen : ${}_1H^1; {}_1H^2; {}_1H^3$

Oxygen : ${}_8O^{16}; {}_8O^{17}; {}_8O^{18}$

Isobars : Nuclei which have same mass number but different atomic numbers are called isobars.

Ex: ${}_1H^3$ and ${}_2He^3$ l ${}_3Li^7$ and ${}_4Be^7$

2. What are isotones and isomers?

Ans: **Isotones :** Nuclei which have same number of neutrons are called isotones.

Ex: ${}_{20}Ca^{40}$ and ${}_{19}K^{39}$ l ${}_{29}Cu^{63}$ and ${}_{30}Zn^{64}$

Isomers : Nuclei with same number of protons and neutrons, but the nuclei exist in different energy states for a measurable time are known as isomers.

Ex : Uranium X_2 i.e., ${}_{92}UX_2$; Uranium Z i.e., l ${}_{92}UZ^{234}$

3. What will be the ratio of the radii of two nuclei of mass numbers A_1 and A_2 ?

Ans: Radius of the nucleus of an atom of mass number A is given by , $R = R_0 A^{\frac{1}{3}}$

Where $r_0 = 1.4\times10^{-15}$m

$\therefore\ R \propto A^{\frac{1}{3}}$

The ratio of radii of two nuclei of mass numbers A_1 and A_2 is $\frac{R_1}{R_2} = \left[\frac{A_1}{A_2}\right]^{\frac{1}{3}}$

4. Why is the mass of a nucleus less than the sum of the masses of the individual nucleons in it?

Ans: Every stable nucleus has a mass which is less than the total mass of its constituents (protons and neutrons) and the mass defect accounts for the binding of the nucleons in the nucleus.

The magnitude of mass defect is a measure of stability of the nucleus.

5. The isotope $^{16}_{8}O$ has 8 protons, 8 neutrons and 8 electrons, while $^{8}_{4}B$ has a 4 protons , 4 neutrons and 4 electrons. Yet the ratio of their atomic masses is not exactly equal to one. Why?

Ans: $_8O^{16}$ has 16 nucleons. While $_4Be^8$ has 8 nucleons. Atomic mass ratio of these nucleons 16:8 or 2:1. Hence the ratio is not equal to one.

6. Give two important characteristics to nuclear forces?(June2010)

Ans: Nuclear forces are the strongest of all the basic forces. They are of attractive nature. They are charge independent and spin dependent. They are short-range forces.

7. What do you mean by the charge independent nature of nuclear forces?

Ans: It is observed that the nuclear forces acting between two protons or between two neutrons or between a proton and a neutron are all same. Hence they are charge independent.

SOLVED PROBLEMS

1. Show that the density of a nucleus does not depend upon its mass number.

Sol: Radius of the nucleus $r = r_0 A^{\frac{1}{3}}$

Volume of the nucleus = $\frac{4}{3}\pi r^3 = \frac{4}{3}\pi\left(r_0 A^{1/3}\right)^3 = \frac{4}{3}\pi r_0^3 A$

Mass of each proton = 1.670020×10^{-27} kg

Mass of the nucleus = 1.670020×10^{-13} A

Density = $\frac{\text{mass}}{\text{volume}} = \frac{1.67\times10^{-27}\times A}{\frac{4}{3}\pi r_0^{\,3}\times A} \approx 10^{17}$ kg/m³

Hence the density of the nucleus is independent of the mass number A and is the same for all the nuclei.

2. Calculate the density of a nucleus taking the mass of a nucleon as $m=1.67\times10^{-27}\,kg$ and $R_0=1.4\times10^{-15}\,m$

Sol: Mass of proton = mass of neutron = m = $1.67\times10^{-27}\,kg$; $R_0=1.4\times10^{-15}\,m$.

Density of the nucleus = $\frac{1.67\times10^{-27}\times A}{\frac{4}{3}\pi r_0^{\,3}\times A} = \frac{3(1.67\times10^{-27})}{4\times\pi\times(1.4\times10^{-15})^3} = 1.453\times10^{17}\,kg/m^3$.

3. Compare the radii of the nuclei of mass numbers 27 and 64.

Sol: $R=R_0A^{1/3}$

$$\therefore \frac{R_1}{R_2}=\left(\frac{A_1}{A_2}\right)^{\frac{1}{3}}=\left(\frac{27}{64}\right)^{\frac{1}{3}}=\frac{3}{4}$$

4. Calculate the mass defect, binding energy and binding energy per nucleon of an alpha particle.

Sol: An α-particle $\left({}^4_2He\right)$ contains 2 protons, 2 neutrons with a mass number 4.

Mass of hydrogen atom $m_H=1.007825u$, Mass of neutron $m_n=1.008665u$;

Atomic number of helium Z = 2; Mass number of helium A = 4;

Mass of helium atom $M=4.00260u$.

Mass defect $\Delta m=Zm_H+(A-Z)m_n-M$ = [(2) (1.007825) + (4 – 2) (1.008665) – 4.00260]u

$$\Delta m=0.0308u.$$

$\therefore$ Binding energy of the nucleus $=(\Delta m)c^2$ $=(0.03038)u\times c^2$ = 0.03038 x 931.5MeV

= 28.3MeV

Binding energy per nucleon $=\frac{28.3}{4}MeV$ = 7.075MeV.

5. Find the binding energy of ${}^{56}_{26}Fe$. Atomic mass of Fe is 55.9349u and that of hydrogen is 1.00783u. Mass of neutron is 1.00876u.

Sol: Mass of the hydrogen atom $m_H=1.00783u$; Mass of neutron $m_n=1.00867u$

Atomic number of iron = Z = 26 ; Mass number of iron A = 56

Mass of iron atom $M = 55.9349u$

Mass defect $\Delta m = Zm_H + (A - Z)m_n - M$

= (26 x 1.00783 + (56 – 20) 1.00867 – 55.93493) u = 0.528 u

$\therefore$ Binding energy $= (\Delta m)c^2 = (0.52878)u \times c^2$ = (0.52878) (931.5MeV) = 492.55MeV

$\therefore$ Binding energy per nucleon of iron $= \frac{492.55}{56}$ = 8.79MeV.

6. **Calculate the binding energy per nucleon of Uranium? Given that Atomic mass of uranium $M = 238.0508u$; Mass of hydrogen atom $m_H = 1.0078u$; mass of neutron $m_n = 1.0087u$, Atomic number uranium Z = 92 mass of number of uranium A = 238.**

Sol: Mass defect $\Delta m = Zm_H + (A - Z)m_n - M$

= [(92) 1.0078 + (238 – 92) 1.0087 – 238.0508)] u = 1.9370 u

Mass defect = 1.9370 u

$\therefore$ Binding energy $= (\Delta m)(c^2)$ = $= (1.9370)u\,(c^2)$ = (1.9370) 931.5MeV

Binding energy of the nucleus = 1804MeV

Binding energy per nucleon $= \frac{1804}{238} = 7.580\,MeV$

7. **Compare the radii of the nuclei of $^{27}_{13}Al$ and $^{125}_{52}Te$.**

Sol: $A_1 = 27; A_2 = 125$

Radius of a nucleus $R = R_0 A^{1/3} \Rightarrow \frac{R_1}{R_2} = \left(\frac{A_1}{A_2}\right)^{1/3} = \left(\frac{27}{125}\right)^{1/3} = \frac{3}{5}$

8. **Find the average binding energy per nucleon of $^{14}_{7}N$ and $^{16}_{8}O$. Their atomic masses are 14.008u and 16.000 u respectively. The mass of $^{1}_{1}H$ atom is 1.007825 u and the mass of neutron is 1.008665 u. Which is more stable?**

Sol: The average binding energy per nucleon $= \frac{[Zm_H + (A - Z)m_n - M]}{A}$

For $^{14}_{7}N = \frac{[7 \times 1.007825 + 7 \times 1.008665 - 14.008]u \times c^2}{A}$

$$=\frac{[14.115430-14.008]931.5}{14}MeV \ =7.148\,MeV$$

For $^{16}_{8}O=\frac{[8\times1.007825+8\times1.008665-16.000]u\times c^2}{A}$

$$=\frac{0.131920\times931.5}{16}MeV=7.680\,MeV$$

Hence $^{16}_{8}O$ is more stable than $^{14}_{7}N$.

UNSOLVED PROBLEM

1. **The radius of the oxygen nucleus** $\left(^{16}_{8}O\right)$ is 2.8×10^{-15} m. Find the radius of the lead nucleus $\left(^{205}_{82}Pb\right)$.

Sol: **R**adius of O^{16} nucleus $R_1=2.8\times10^{-15}m$

Mass number of O^{16} nucleus A_1 = 16

Mass number of Pb^{205} nucleus A_2 = 205

$$R\,\alpha\,A^{1/3}\Rightarrow\frac{R_2}{R_1}=\left(\frac{A_2}{A_1}\right)^{1/3}=\left(\frac{205}{16}\right)^{1/3}\ \Rightarrow R_2=\left(\frac{205}{16}\right)^{1/3}\times2.8\times10^{-1}J\ =6.55\times10^{-15}m$$

2. **Find the ratio of the radii of** $\left(^{197}_{79}Au\right)$ and $\left(^{107}_{92}Ag\right)$.

Sol: $A_1\ =197,\ A_2\ =107$

$$R\,\alpha\,A^{1/3}\Rightarrow\frac{R_1}{R_2}=\left(\frac{A_1}{A_2}\right)^{1/3}=\left(\frac{197}{107}\right)^{1/3}\ =1.226$$

3. **Compare the radii of two nuclei with mass numbers 8 and 64. Also compare their densities.**

Sol: $A_1=8,\ A_2=64$

$$R\alpha\ A^{1/3}\Rightarrow\frac{R_1}{R_2}=\left(\frac{A_1}{A_2}\right)^{1/3}=\left(\frac{84}{64}\right)^{1/3}=1:2$$

Since density of all nuclei are same. $\frac{d_1}{d_2}=\frac{1}{1}=1:1$

4. **How much energy is required to separate the typical middle mass nucleus $^{120}_{50}Sn$ into its constituent nucleons? Mass of proton** $_1H^1 = 1.007825\,amu$ **; mass of neutron** $m_n = 1.008665$ **amu; mass of** $_{50}Sn^{120} = 119.902199$ **.**

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

= (50 x 1.007825) + (70 x 1.008665) – 119.902199= 1.095601 amu.

Binding energy = 1.095601 x 931.50 = 1021 MeV.

5. **Calculate the binding energy of an α-particle. Given that mass of proton = 1.0073u, mass of neutron = 1.0087u, and mass of α-particle = 4.0015 u.**

Sol: For $_2He^4$, Z = 2, A = 4

$m_p = 1.0073\,amu$; $m_n = 1.0087\,amu$; $M_{He} = 4.0015\,amu$

Mass defect $\Delta m = (Zm_p + (A-Z)m_n) - M_{He}$ = [2 (1.0073) + 2 (1.0087)] – 4.0015

= 4.0320 – 4.0015 = 0.0305 amu

$B.E = \Delta m \times 931\ MeV$ = 0.0305 x 93.1 = 28.4 MeV

6. **Find the energy required to spilt $^{16}_{8}O$ nucleus into four α-particles. The mass of an α-particle is 4.0026.03u and that of oxygen is 15.994915u.**

Sol: $_8O^{16} \rightarrow 2H_e^4$

Mass of each α-particle , $2H_e^4 = 4.002603\,amu$

Mass of $4\alpha-$ particles = 4 x 4.00603 = 16.010412 amu

Mass of $_8O^{16} = 15.994915\,amu$

Mass defect $\Delta m =$ 16.010412 – 15.994915 = 0.015497 amu

Energy required $= \Delta m \times 931 MeV$ = 0.015497 x 931 = 14.43 MeV

7. **Calculate the binding energy per nucleon of $^{35}_{17}Cl$ nucleus. Given that mass of $^{35}_{17}Cl$ nucleus = 34.98000u, mass of proton = 1.007825u, mass of neutron = 1.006000 u and 1 u is equivalent to 931MeV.**

Sol: For $_{17}Cl^{35}$, Z = 17, A= 35

$m_p = 1.007825\,amu$, $m_n = 1.008665\,amu$, $m_{cl} = 34.98000\,amu$

Mass defect = $\Delta m = (Zm_p + (A-Z)m_n) - M_{cl}$

$$\Delta m = [17\ (1.007825) + 18(1.008665)] - 34.98000 = 0.30899\text{amu}$$

B.E = 931 x $\Delta m = 931 \times 0.30899$ = 287.6743MeV

$$\frac{B.E}{A} = \frac{287.6743}{35} = 8.2MeV$$

8. Calculate the binding energy per nucleon of $^{40}_{20}Ca$. Given that mass of $^{40}_{20}Ca$ nucleus = 39.962589u, mass of a protons = 1.007825u, mass of neutron = 1.008665u and 1u is equivalent to 931MeV.

Sol: For $_{20}Ca^{40}$, Z = 20, A = 40

$m_n = 1.008665\,amu$, $m_p = 1.007825\,amu$, $m_{Ca} = 39.962589\,amu$

$\Delta m = (Zm_p + (A-Z)m_n) - M_{Ca}$

] [20 (1.007825) + 20 (1.008665)] – 39.962589 = 0.3673amu

$BE = \Delta m \times 931 = 0.3673 \times 931 = 341.9563\,MeV$

B.E per nucleon $= \frac{BE}{A} = \frac{341.9563}{40}$ = 8.55MeV.

9. Calculate the i) mass defect, (ii) binding energy and (iii) the binding energy per nucleon $^{12}_{6}C$ nucleus. Nuclear mass of $^{12}_{6}C = 12.000000\,u$; mass of proton = 1.007825 u and mss of neutron = 1.008665 u.

Sol: For $_6C^{12}$, Z = 6, A = 12

$m_p = 1.007825\,amu$, $m_n = 1.008665\,amu$, $m_c = 12.00000\,amu$

$\Delta m = (Zm_p + (A-Z)m_n) - M_c$ = [6 (1.007825) + 6 (1.008665)] – 12.00000 = 0.09894amu

$B.E = \Delta m \times 931 = 0.09894 \times 931 = 92.1\,MeV$

B.E. per nucleon $= \frac{BE}{A} = \frac{92.131}{12} = 7.675\,MeV$

10. The binding energies per nucleon for deuterium and helium are 1.1MeV and 7.0MeV respectively. What energy in joules will be liberated when 10^6 deuterons take part in the reaction $^2_1H + ^2_1H \rightarrow ^4_2He$?

Sol: mass of ^2_1H = 1.1 x 2 = 2.2MeV

Mass of two deuteron = 2.2 x 2 = 4.4MeV

Mass of $^{4}_{2}He = 7.0 MeV$ = 7 x 4 = 28MeV

Energy liberated = 28 - 4.4

Energy released when 10^6 deuterons take part in reaction $= \frac{23.6\times10^6}{2} = 11.8\times10^6 MeV$

$= 18.88\times10^{-7} J$

11. Bombardment of lithium with protons gives rise to the following reaction. $_3Li^7 +_1 H^1 \rightarrow 2\ _2He^4 + Q$. The atomic masses of lithium, proton and helium are 7.016amu, 1.008amu and 4.004amu respectively. Find the initial energy. Given 1amu = 931.5MeV.

Sol: $Q = \Delta MC^2 = [7.016 + 1.008 - 2(4.004)]931.5 MeV$ = (7.016 + 1.008 – 8.008) 931.5MeV

$\therefore Q = 14.904 MeV$

ASSESS YOUR SELF

1. Mention the symbols for a proton, neutron and an electron.

A. $^{1}_{1}p, ^{1}_{0}n, ^{0}_{-1}e$.

2. How many neutrons and protons do the nucleus of the element $^{196}_{79}Au$ possess?

A. Number of neutrons is 117 and number of protons is 79.

3. Why do different isotopes an element have same chemical properties?

A. Because different isotopes have same number of electrons on which chemical properties depend.

4. Consider gaseous oxygen and solid lead. Whose nuclear density will be greater?

A. Their nuclear densities are the same.

5. Why doesn’t do the nucleus collapse despite the strong attractive forces between the nucleons?

A. Because when two nucleons are within a distance of about 0.4 fm, the nuclear force becomes repulsive.