PRAYAS

JEE 2025

Lecture - 06 | **Physics**

Modern Physics

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Topics *to be covered*

1. Nuclear Force
2. Mass Defect
3. Binding Energy
4. Q Value

- $^{A}_{Z}X$ ⇒ Total no. of nucleons = A = no. of proton + no. of neutron
  - A → mass number

Z → Atomic no
Z → Total No. of proton

A−Z → Total no. of neutron

* $^{41}_{20}X$ ⇒ No. of proton = 20
  " " neutron = 21
  " " neucleons = 41
  Mass no = 41

- Shape of the nucleus is approxim. spherical & its radius is approx.

$$R = R_0 A^{1/3} \qquad R_0 \simeq 1.2 \times 10^{-15}\, m$$

$${}^{A}_{Z}X$$

- Volume of nucleus $= \frac{4}{3}\pi R^3 = \frac{4}{3}\pi R_0^3 \cdot A$

- Density of nucleus $= \frac{\text{mass}}{\text{Vol}^n} = \frac{mA}{\frac{4}{3}\pi R_0^3 A} = \frac{m}{\frac{4}{3}\pi R_0^3}$

$$m_p \simeq m_n \simeq m \text{ (let)}$$

$$\simeq \frac{1.6 \times 10^{-27}}{\frac{4}{3} \times \frac{22}{7} \times (1.2 \times 10^{-15})^3} \simeq 2.3 \times 10^{17}\, kg/m^3$$

= Independent on A

$r = r_0 A^{1/3}$

$vol^n = \frac{4}{3}\pi (r_0 A^{1/3})^3 = \frac{4}{3}\pi r_0^3 \cdot A$

$\rho = \frac{m}{V} = \frac{A m}{\frac{4}{3}\pi r_0^3 A} = A^0$

proton

neutrons

$m_p \simeq m_n \simeq m$

Chemistry

Isotopes ⟶ same Z, diff. neutron $^{12}_{6}C$, $^{14}_{6}C$

$^{A}_{Z}X$

Isobar ⟶ same mass number $^{14}_{6}C$, $^{14}_{7}N$

Isoton ⟶ Same neutron

$^{14}_{6}C$, $^{16}_{8}O$

Nuclear force

- → Short range force comes into picture when distance between nucleon's become order of fermi

  1 fermi $= 10^{-15}$ m

- → Stronger than gravitational & Coulombic force.
- → Nuclear force on average are attractive as the compansate for repulsive Coulombic force
- → When distance between nucleon become less than .7 fm nuclear forces are repulsive.
- → They are not central force & their value also depends on spin.

- They act equally between neutron-neutron, proton-proton, neutron-proton.
- Short range force.
- Their value decrease rapidly to insignificant value at a distance beyond 2.5 fm. approx.

- Attractive in range of (.8 - 2.5) fm
- Independent on charge.

- According to einstien, mass is another form of energy and one can convert mass energy into another form of energy & vice versa by the relation

$$E = mc^2$$

- E → Rest mass energy
- m → rest mass

Atomic mass Unit (Amu)

$m_p \approx m_n \approx m$

* → $1\,amu = \frac{1}{12}$ (mass of C_{12} at rest in ground state)

$= \frac{1}{12}(6m_p + 6m_n) \approx m_p = 1.67 \times 10^{-27}\,kg = 1\,amu = 1\,u$

* → $\Delta E = \Delta m c^2 = \frac{1.67 \times 10^{-27} \times (3 \times 10^8)^2}{1.6 \times 10^{-19}} = 931.5\ MeV$ (Approx) ⇛ 1 amu mass is equivalent to 931.5 MeV.

* If 5 amu mass is converted into energy

$= 931.5 \times 5\ MeV$

Binding Energy

- Energy required to break the nucleus into nucleons. or energy release during formation of nucleus.

* $B.E = \left(Zm_p + (A-Z)m_n - M\right)c^2 = \Delta m c^2$

  M ↓ mass of nucleus

  Δm → mass defect.

* Δm = mass defect = Difference in mass of independent nucleons & mass of nucleus.

(A − Z) neutron

p p p p p   n n n n n

(Z − proton)

freely $\longrightarrow$ ${}^{A}_{Z}X$ + energy

$$\Delta m = [Zm_p - (A-Z)m_n - M_x] = \text{mass defect}$$

$$\text{Energy} = (\Delta m)c^2 = [Zm_p - (A-Z)m_n - M_x]\,c^2 = \text{B.E.}$$

- or

$$Zm_p + (A-Z)m_n \longrightarrow M_x + \text{energy}$$

energy → ?

By Einstien mass energy relationship some amount of mass is converted into energy & released when nucleons bounded with each other to form a stable nucleus. ⇒ This energy which holds the neucleons is called Binding energy.

Q Find B.E. of α particle

mass of ^1_1H atom $= 1.007825\ u$

" " neutron $= 1.008665\ u$

" " ^4_2He atom $= 4.00260\ u$

Sol^n B.E $=$

Q Find B.E. of α particle ^4_2He

mass of ^1_1H atom = 1.007825 u

" " neutron = 1.008665 u

" " ^4_2He atom = 4.00260 u

$^4_2He \longrightarrow$ 2 proton, 2 neutron

p p n n free $\longrightarrow$ ^4_2He + energy

Sol^n

$$\Delta m = (2m_p + 2m_n - M_{He})$$

$$\Delta m = [(2 \times 1.007825 + 2 \times 1.008665) - (4.00260)]\ u$$

Energy release = $\Delta m \times 931.5$ MeV = $.03038 \times 931.5$ MeV (check)

= BE

Q Find B.E. of α particle $\quad {}^{4}_{2}He$

mass of ${}^{1}_{1}H$ atom = 1.007825 u

" " neutron = 1.008665 u

" " ${}^{4}_{2}He$ atom = 4.00260 u

Sol^n

$$B.E = [2 \times 1.007825 + 2 \times 1.008665 - 4.00260] \times 931.5 \text{ MeV}$$

Q Find B.E of $^{56}_{26}Fe$

Atomic mass of ^{56}Fe = 55.9349 u

& that of $^{1}_{1}H$ is 1.00783 u

mass of neutron is 1.00867 u

Sol^n

Q Find B.E of $^{56}_{26}Fe$

Atomic mass of ^{56}Fe = 55.9349 u

& that of $^{1}_{1}H$ is 1.00783 u

mass of neutron is 1.00867 u

Solⁿ

$$BE = [(26 \times 1.00783 + 30 \times 1.00867) - (55.9349)] \times 931.5 \text{ MeV}$$

Q. B.E. of $^{35}_{17}Cl$ nucleus is 298 MeV. Find its atomic mass

Given mass of proton $(m_p) = 1.007825$ amu

" " neutron $(m_n) = 1.008665$ amu

Sol^n

Q. B.E. of $^{35}_{17}Cl$ nucleus is 298 MeV. Find its atomic mass

Given mass of proton $(m_p) = 1.007825$ amu

" " neutron $(m_n) = 1.008665$ amu

Sol^n

$931.5 \overline{)\,29800\,}(.319$
27945

$$[17 \times 1.007825 + 18 \times 1.008665 - M] \times 931.5 = 298$$

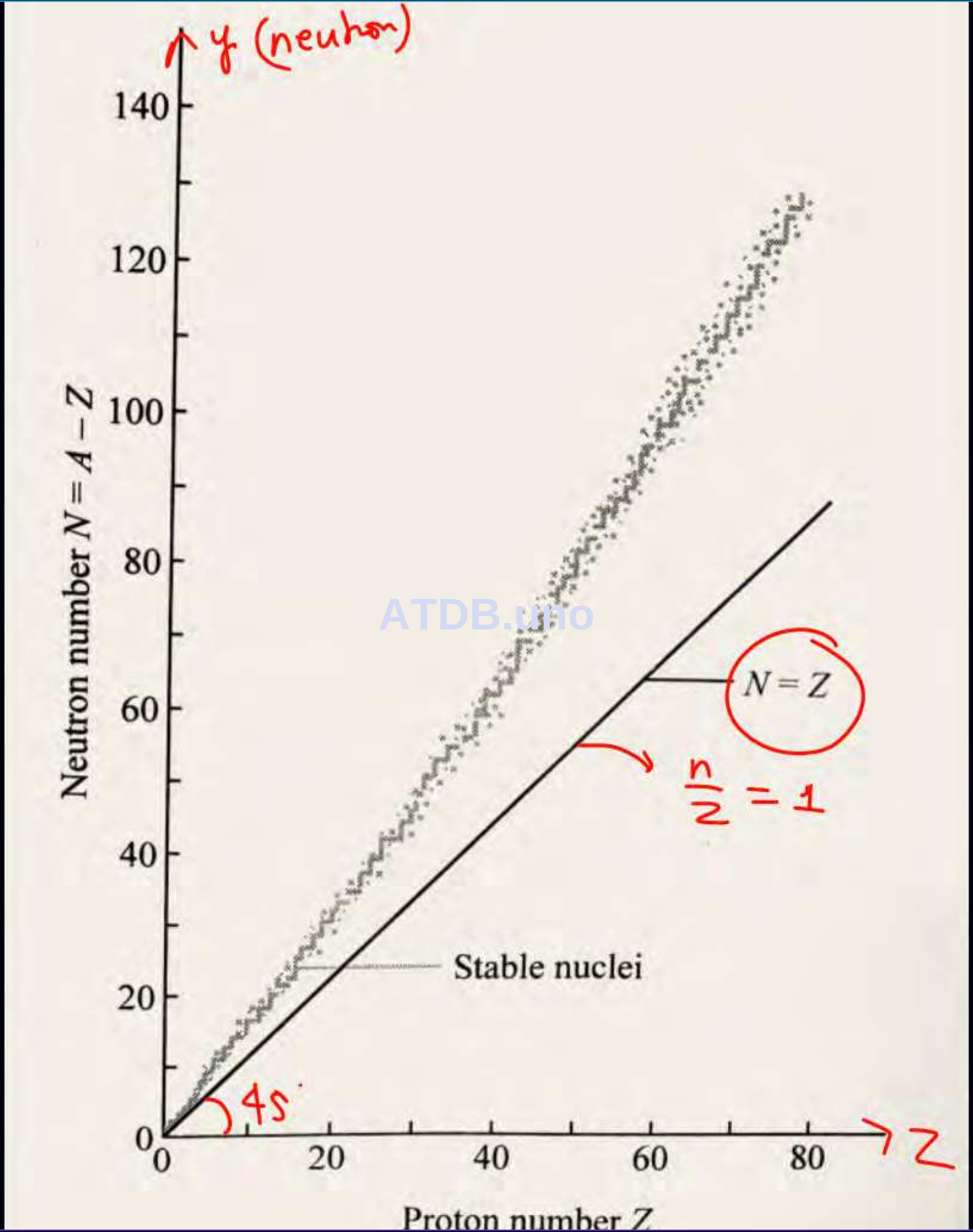
$$(17.133025 + 18.155970) - .319 = m$$

$$35.288995 - .319$$

$$35.289 - .319 = 34.97$$

$$^{A}_{Z}X$$

$$\text{Binding energy} = \left(Zm_p + (A-Z)m_n - M_X\right) \times 931.5 \text{ MeV}$$


y (neutron)
Neutron number N = A − Z
140
120
100
80
60
40
20
0
N = Z
n/z = 1
Stable nuclei
45°
0
20
40
60
80
Z
Proton number Z

BE/A
8.75MeV
Binding energy per nucleon (MeV/nucleon)
10
8
6
4
2
0
0
50
100
150
200
250
A
2 1 H
3 1 H
4 2 He
6 3 Li
12 6 C
14 7 N
16 8 O
19 9 F
31 15 P
39 19 K
56 26 Fe
75 33 As
90 40 Zr
120 50 Sn
153 63 Eu
209 83 Bi
238 92 U

- Criteria for stability of nucleus $\Rightarrow \frac{B.E}{Nucleons} = \frac{BE}{A}$ ✓

- $\left(\frac{B.E}{A}\right)_{max}$ for Fe $\simeq$ 8.75 MeV

- Heavy nucleus decay into lighter nuclie energy would be release in this process

  $C \longrightarrow A + B$ Nuclear fission

- Two light nuclie want to join to form a heavior nucleus, $\frac{B.E}{A}$ of fused heavior nuclie is more than binding energy per nucleon of lighter nuclie, this means that the final system is more tightly bound than initial. (Nuclear fusion) $X + Y \longrightarrow Z$

which is more stable.

$B.E/\text{nucleons} = \frac{BE}{A}$

Q

	B.E.	
$^{24}_{12}X$	24 MeV	$\frac{24}{24} = 1$ MeV
$^{16}_{8}Y$	18 MeV	$\frac{18}{16} = 1.12$ MeV

$(\text{Stable})_Y > (\text{Stable})_X$

Q value of nuclear reaction

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

* $Q = (m_R - m_P)c^2 = (m_A + m_B - m_C - m_D)c^2$ = Total energy released in nuclear Rxn.

* If $Q > 0 \Rightarrow$ Exothermic
* If $Q < 0 \Rightarrow$ Endothermic.

$Q = (m_R - m_P) \times 931.5$ MeV

($m_R - m_P$ in) Amu

Q

$$ {}^{2}_{1}H + {}^{14}_{7}N \longrightarrow {}^{12}_{6}C + {}^{4}_{2}He $$

mass → (amu) 2.014 14.00 12.00 4.00

Sol^n

$$ Q_{value} = (2.014 + 14.00 - 12.00 - 4.06) \times 931.5 \text{ MeV} $$

$$ = .014 \times 931.5 \text{ MeV} \quad \text{(Exothermic)} $$

* In nuclear reaction

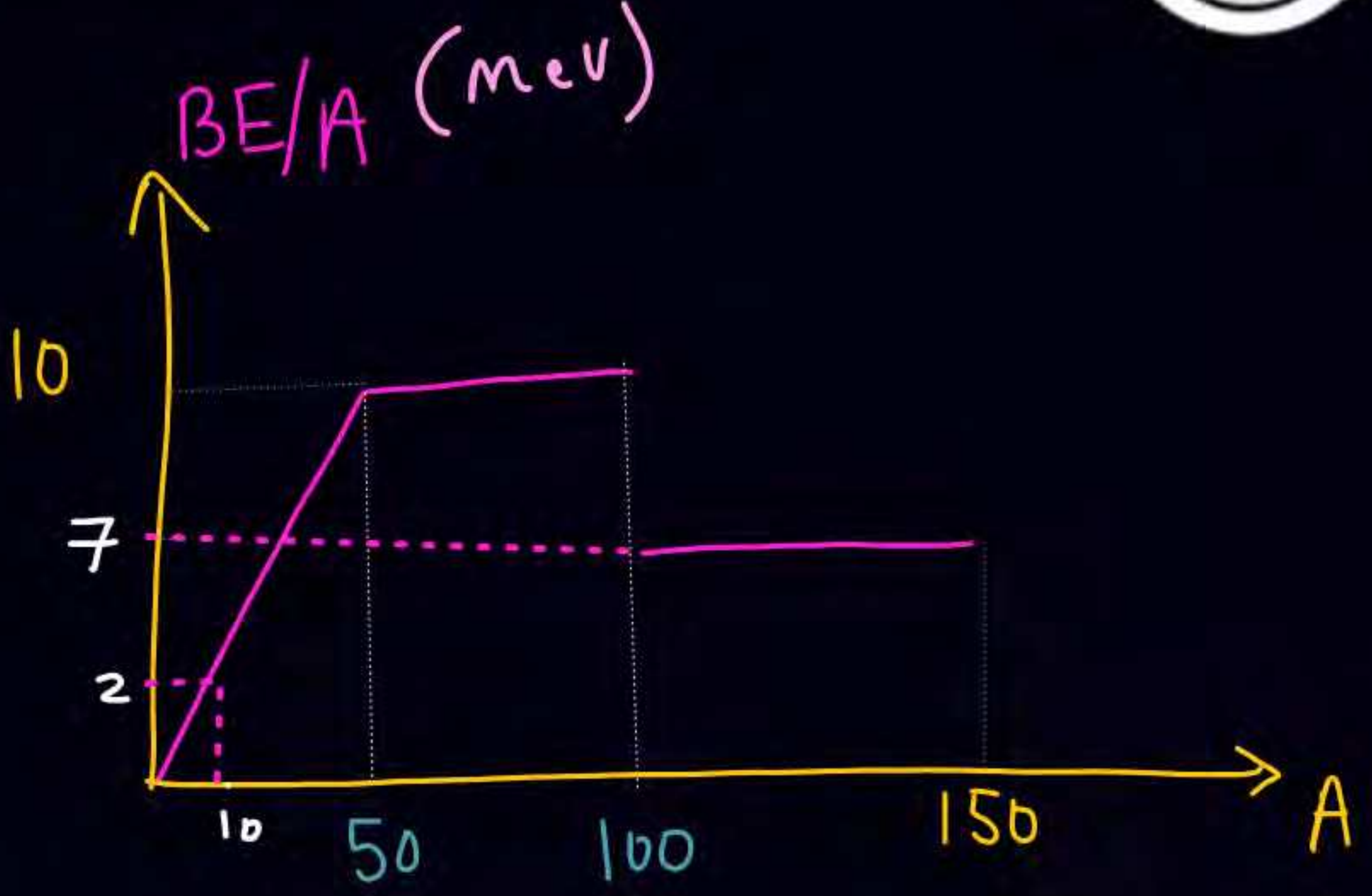
- If $F_{net} = 0 \Rightarrow$ Total momentum of system conserve.
- If $\tau_{ext} = 0 \Rightarrow$ Total angular momentum " "
- Total charge is conserve.
- No. of nucleons are conserve
- (mass + Energy) is conserve.

*** $Q = (M_R - M_P) \times 931.5$ MeV

**** $Q = (B.E.)_P - (B.E.)_R$

$Q = (KE)_f - (KE)_i$

Q In following rxn find energy released or absorbed



① $^{30}X + {}^{40}Y \longrightarrow {}^{70}Z$

$Q_{value} = (BE)_P - (BE)_R$

$= (70 \times 10) - (30 \times 6 + 8 \times 40)$

$= 700 - 180 - 320 = 200$ MeV

(Exothermic)

② $^{140}P \longrightarrow {}^{110}Q + 3 \cdot {}^{10}R$

$Q = (7 \times 110 + 2 \times 10 \times 3) - (7 \times 140) = -150$ (Endothermic)

QUESTION

The mass of proton, neutron and helium nucleus are respectively 1.0073 u, 1.0087 u and 4.0015 u. The binding energy of helium nucleus is ______.

[01 February 2023 - Shift 1]

(1) 14.2 MeV

(2) 28.4 MeV

(3) 56.8 MeV

(4) 7.1 MeV

Ans. (2)

QUESTION

The ratio of the density of oxygen nucleus ($^{16}_{8}O$) and helium nucleus ($^{4}_{2}He$) is ____.

[25 January 2023 - Shift 1]

(1) 4 : 1

(2) 8 : 1

(3) 1 : 1

(4) 2 : 1

Ans. (3)

QUESTION

Mass numbers of two nuclei are in the ratio of 4 : 3. Their nuclear densities will be the ratio of: (JEE Main-2022)

(1) $4 : 3$

(2) $\left(\frac{3}{4}\right)^{\frac{1}{3}}$

(3) $1 : 1$

(4) $\left(\frac{4}{3}\right)^{\frac{1}{3}}$

Ans : (3)

QUESTION

A free neutron decays into a proton but a free proton does not decay into neutron. This is because [31 January 2023 - Shift 1]

(1) neutron is an uncharged particle

(2) proton is a charged particle

(3) neutron is a composite particle made of a proton and an electron

(4) neutron has larger rest mass than proton

Ans. (4)

QUESTION

A nucleus with mass number 242 and binding energy per nucleon as 7.6 MeV breaks into two fragment each with mass number 121. If each fragment nucleus has binding energy per nucleon as 8.1 MeV, the total gain in binding energy is ______MeV.

[08 April 2023 - Shift 1]

$$^{242}A \longrightarrow {}^{121}B + {}^{121}C$$

$$(BE)_f = (121 \times 8.1) \times 2$$

$$(BE)_i = 242 \times 7.6$$

Ans. (121)

QUESTION

A common example of alpha decay is

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

Given:

$(238.05060 - 234.04360 - 4.00260) \times 931.5$

$^{238}{}_{92}U = 238.05060u$

$^{234}{}_{90}Th = 234.04360u$

$^{2}{}_{2}He = 4.00260$ u and $1u = 931.5 \dfrac{MeV}{c^2}$

The energy released (Q) during the alpha decay of $^{238}{}_{92}U$ is _____ MeV.

[12 April 2023 - Shift 1]

Ans. (4)

QUESTION

$${}^{238}_{92}A \rightarrow {}^{234}_{90}B + {}^{4}_{2}D + Q$$

In the given nuclear reaction, the approximate amount of energy released will be:

[Given, mass of ${}^{238}_{92}A = 238.05079 \times 931.5 MeVc^{-2}$, mass of ${}^{234}_{90}B = 234.04363 \times 931.5 MeVc^{-2}$, mass of ${}^{4}_{2}D = 4.00260 \times 931.5 MeVc^{-2}$]

[13 April 2023 - Shift 1]

(1) 3.82MeV

(2) 5.9MeV

(3) 2.12MeV

(4) 4.25MeV

Ans. (4)

QUESTION

Given below are two statements: one is labelled as Assertion A and the other is labelled as Reason R

Assertion A: The binding energy per nucleon is practically independent of the atomic number for nuclei of mass number in the range 30 to 170.

Reason R: Nuclear force is short ranged.

In the light of the above statements, choose the correct answer from the options given below. **[13 April 2023 - Shift 2]**

1. A is false but R is true
2. Both A and R are true and R is the correct explanation of A
3. Both A and R are true but R is NOT the correct explanation of A
4. A is true but R is false.

Ans. (2)

QUESTION

The radius of a nucleus of mass number 64 is 4.8 fermi. Then the mass number of another nucleus having radius of 4 fermi is 1000/x, where x is ____.

[01 Feb. 2024 - Shift 1]

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

$$4.8 = R_0 (64)^{\frac{1}{3}}$$

$$4 = R_0 A^{1/3}$$

Ans : (27)

QUESTION

In a nuclear fission process, a high mass nuclide ($A \approx 236$) with binding energy 7.6MeV/Nucleon dissociated into middle mass nuclides ($A \approx 118$), having binding energy of 8.6 MeV/Nucleon. The energy released in the process would be ____ MeV.

[27 Jan. 2024 - Shift 1]

$$A \longrightarrow 2B$$

$$\Delta E = (118 \times 8.6 \times 2) - (236 \times 7.6)$$

Ans : (236)

QUESTION

The atomic mass of ${}_6C^{12}$ is 12.000000 u and that of ${}_6C^{13}$ is 13.003354 u. The required energy to remove a neutron from ${}_6C^{13}$, if mass of neutron is 1.008665 u, will be:

[27 Jan. 2024 - Shift 2]

(1) 62.5 MeV

(2) 6.25 MeV

(3) 4.95 MeV

(4) 49.5 MeV

$${}_6^{13}C \longrightarrow {}_6^{12}C + {}_0^1n$$

$$(13.003354 - 12 - 1.008665) \times 931.5$$

Ans : (3)

QUESTION

The mass number of nucleus having radius equal to half of the radius of nucleus with mass number 192 is: [31 Jan. 2024 - Shift 2]

(1) 24

(2) 32

(3) 40

(4) 20

Ans : (1)

QUESTION

A nucleus has mass number A_1 and volume V_1. Another nucleus has mass number A_2 and volume V_2. If relation between mass number is $A_2 = 4A_1$, then $\frac{V_2}{V_1} =$ $\left(\frac{R_2}{R_1}\right)^3 = \frac{A_2}{A_1}$

[31 Jan. 2024 - Shift 2]

$V = \frac{4}{3}\pi R^3$

$=$

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

$R^3 = R_0 A$

Ans : (4)

QUESTION

The disintegration energy Q for the nuclear fission of $^{235}U \rightarrow {}^{140}Ce + {}^{94}Zr + n$ is ______ MeV .

Given atomic masses of ^{235}U: $235.0439u$; ^{140}Ce: $139.9054u$, ^{94}Zr: $93.9063u$; n: $1.0086u$,

Value of $c^2 = 931 MeV/u$

[04 Apr. 2024 - Shift 2]

Ans : (208)

QUESTION

If three helium nuclei combine to form a carbon nucleus then the energy released in this reaction is ______ $\times 10^{-2}$ MeV. (Given $1u = 931 MeV/c^2$, atomic mass of helium $= 4.002603u$)

[05 Apr. 2024 - Shift 1]

Ans : (727)

QUESTION

Binding energy of a certain nucleus is 18×10^8 J. How much is the difference between total mass of all the nucleons and nuclear mass of the given nucleus:

[08 Apr. 2024 - Shift 1]

(1) 10μg

(2) 20μg

(3) 0.2μg

(4) 2μg

$\Delta E = \Delta m c^2$

$18 \times 10^8 = \Delta m \times (3 \times 10^8)^2$

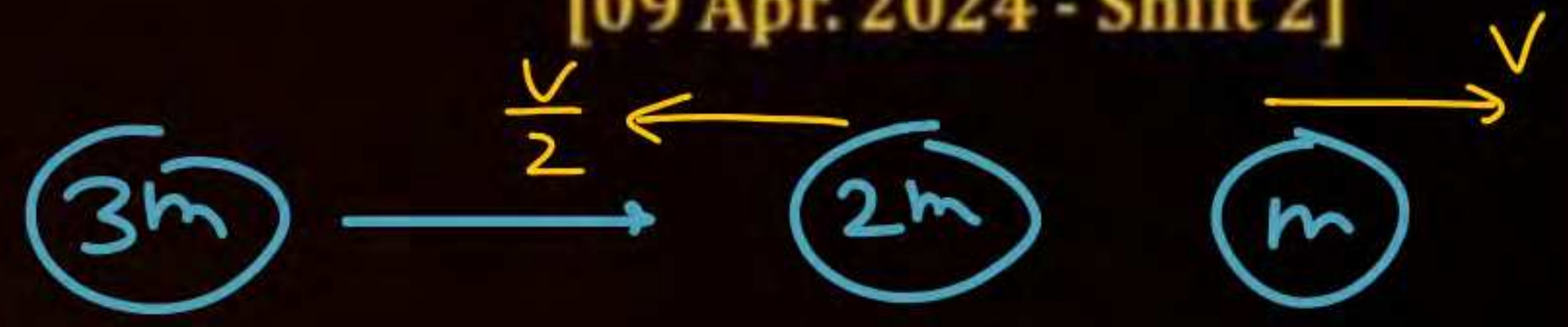
2×10^{-8} kg $= 2000 \times 10^{-8}$ gm

Ans : (2)

QUESTION

A nucleus at rest disintegrates into two smaller nuclei with their masses in the ratio 2 : 1 of. After disintegration they will move:

[09 Apr. 2024 - Shift 2]



(1) in the same direction with same speed.

(2) in opposite directions with the same speed.

(3) in opposite directions with speed in the ratio of 2 : 1 respectively.

(4) in opposite directions with speed in the ratio of 1 : 2 respectively.

Ans : (4)

QUESTION

The radius of R of a nucleus of mass number A can be estimated by the formula $R = (1.3 \times 10^{-15})A^{1/3}\ m$. It follows that the mass density of a nucleus is of the order $(M_{prot} \cong M_{neut} \simeq 1.67 \times 10^{-27}\ kg)$. (JEE Main-2020)

(1) $10^{24}\ kg\ m^{-3}$

(2) $10^{3}\ kg\ m^{-3}$

(3) $10^{17}\ kg\ m^{-3}$

(4) $10^{10}\ kg\ m^{-3}$

Ans : (3)

QUESTION

From the given data, the amount of energy required to break the nucleus of aluminium $^{27}_{13}Al$ is ____ $x \times 10^{-3}$ J.

$$B.E = (13m_p + 14m_n - m_{Al}) \times 931.5$$

Mass of neutron = 1.00866 u

Mass of proton = 1.00726 u

Mass of Aluminium nucleus = 27.18846 u

(Assume 1 u corresponds to x *J* of energy)

(Round off to the nearest integer) (JEE Main-2021)

Ans : (27)

QUESTION

Two lighter nuclei combine to form a comparative heavier nucleus by the relation given below: ${}_1^2X + {}_1^2X = {}_2^4Y$.
The binding energies per nucleon ${}_1^2X$ and ${}_1^2Y$ are 1.1 MeV and 7.6 MeV respectively. The energy released in this process is ______ MeV (JEE Main-2022)

$(7.6 \times 4) - (1.1 \times 2 \times 2)$

26

Ans : (26)

QUESTION

Nucleus A is having mass number 220 and its binding energy per nucleon is 5.6 MeV. It splits in two fragments 'B' and 'C' of mass numbers 105 and 115. The binding energy of nucleons in 'B' is 6.4 MeV per nucleon. The energy Q released per fission will be:

(JEE Main-2022)

$$^{220}A \longrightarrow {}^{105}B + {}^{115}C$$

1. 0.8 MeV
2. 275 MeV
3. 220 MeV
4. 176 MeV

Ans : (4)

Home Work

- Ques attached solve all 2-3 times.


THANK
YOU