



PRAYAS

JEE 2025

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Lecture - 06

Physics

Modern Physics

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Topics *to be covered*

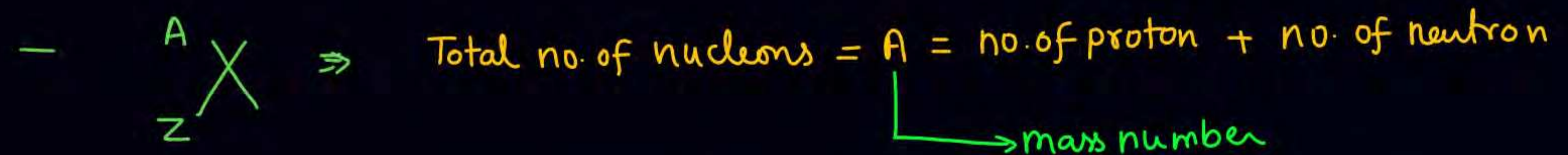
1 Nuclear Force

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2 Mass Defect

3 Binding Energy

4 Q Value

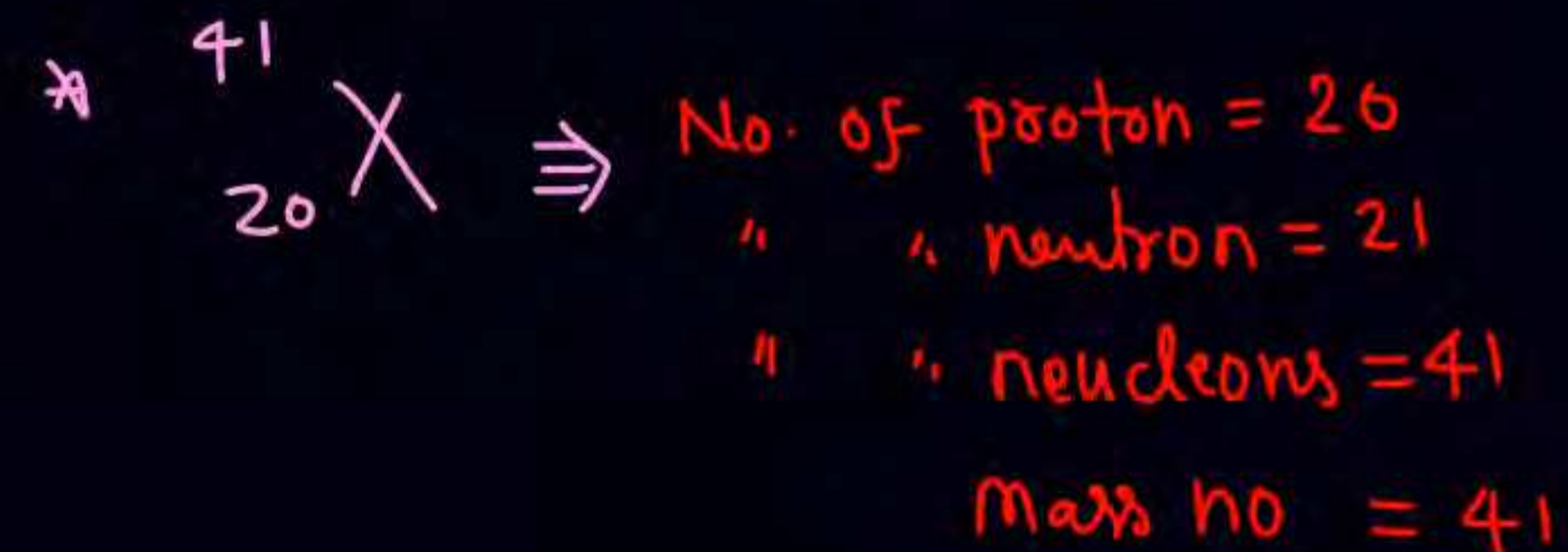


$Z \rightarrow$ Atomic no

\swarrow Total No. of proton

$A-Z \rightarrow$ Total no. of neutron

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- shape of the nucleus is approx. spherical & its radius is approx.

$$R = R_0 A^{1/3} \quad R_0 \approx 1.2 \times 10^{-15} \text{ m}$$

A
Z

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

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

$$m_p \approx m_n = m (\text{let})$$

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

\equiv Independent on A



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

$$V_{oi} \hat{=} \frac{4}{3} \pi (r_0 A^{1/3})^3 = \frac{4}{3} \pi r_0^3 A$$

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$$J = \frac{m \cdot V}{V} = \frac{A m}{\frac{4}{3} \pi r_0^3 A} = \underline{A^0}$$

proton
neutrons

$$m_p \approx m_n \approx m$$



Chemistry

Isotopes \longrightarrow Same Z , diff. neutron ${}^{12}_6\text{C}$, ${}^{14}_6\text{C}$

Isobar \longrightarrow Same mass number ${}^{14}_6\text{C}$, ${}^{14}_7\text{N}$

Isotone \longrightarrow Same neutron ${}^{14}_6\text{C}$, ${}^{16}_8\text{O}$

$\begin{matrix} A \\ Z \end{matrix} X$

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Nuclear force



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

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

→ Stronger than gravitational & Coulombic force.

→ Nuclear force on average are attractive as the compensate for repulsive Coulombic force

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→ When distance between nucleon become less than $.7 \text{ fm}$ 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 (0.8 - 2.5) fm
- Independent on charge.

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

$$E = mc^2$$

Rest mass energy

rest mass

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Atomic mass Unit (Amu)

$$m_p \approx m_n \approx m$$

$$\rightarrow 1 \text{ amu} = \frac{1}{12} \left(\text{mass of } C_{12} \text{ at rest in ground state} \right)$$

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

$$\rightarrow \Delta E = \Delta mc^2 = \frac{1.67 \times 10^{-27} \times (3 \times 10^8)^2}{1.6 \times 10^{-19}} \text{ J} = 931.5 \text{ MeV} \Rightarrow 1 \text{ amu mass is equivalent to } 931.5 \text{ MeV.}$$

(Approx)

$$\begin{aligned} * \text{ If } 5 \text{ amu mass is converted into energy} \\ = 931.5 \times 5 \text{ MeV} \end{aligned}$$



Binding Energy

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



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$$* \quad B.E = \left(Z m_p + (A - Z) m_n - \underset{\substack{\downarrow \\ \text{mass of} \\ \text{nucleus}}}{M} \right) c^2 = \Delta m c^2$$

└──────────┬──────────> mass defect.

* $\Delta m = \text{mass defect} = \text{Difference in mass of independent nucleons \& mass of nucleus.}$



- or



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

Binding energy.

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Q Find B.E. of α particle

$$\text{mass of } {}^1_1\text{H atom} = 1.007825 \text{ u}$$

$$\text{" " neutron} = 1.008665 \text{ u}$$

$$\text{" " } {}^4_2\text{He atom} = 4.00260 \text{ u}$$

Solⁿ

$$\text{B.E.} =$$

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Q Find B.E. of α particle ${}^4_2\text{He}$

mass of ${}^1_1\text{H}$ atom = 1.007825 u

" " neutron = 1.008665 u

" " ${}^4_2\text{He}$ atom = 4.00260 u



Solⁿ

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

$$\Delta m = \left[(2 \times 1.007825 + 2 \times 1.008665) - (4.00260) \right] \text{ u}$$

$$\begin{aligned} \text{Energy release} &= \Delta m \times 931.5 \text{ MeV} = 0.03038 \times 931.5 \text{ MeV} \quad (\text{check}) \\ &= \text{BE} \end{aligned}$$

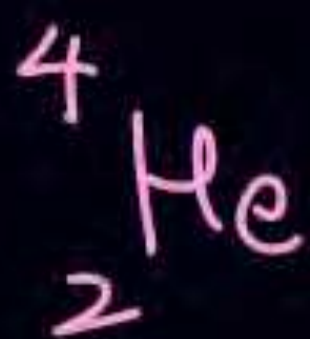


Q Find B.E. of α particle

$$\text{mass of } {}^1_1\text{H atom} = 1.007825 \text{ u}$$

$$\text{" " neutron} = 1.008665 \text{ u}$$

$$\text{" " } {}^4_2\text{He atom} = 4.00260 \text{ u}$$



Solⁿ

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

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

Atomic mass of ${}_{26}^{56}\text{Fe} = 55.9349\text{u}$

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

mass of neutron is 1.00867u

Solⁿ

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

Atomic mass of ${}_{26}^{56}\text{Fe} = 55.9349\text{u}$

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

mass of neutron is 1.00867u

Solⁿ

$$\text{B.E} = \left[(26 \times 1.00783 + 30 \times 1.00867) - (55.9349) \right] \times 931.5 \text{ MeV}$$

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

Given
mass of proton (m_p) = 1.007825 amu
" " neutron (m_n) = 1.008665 amu

Solⁿ

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7



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

Given mass of proton (m_p) = 1.007825 amu
 " " neutron (m_n) = 1.008665 amu

Solⁿ

$$9315) 29800(.319 \\ \underline{27945}$$

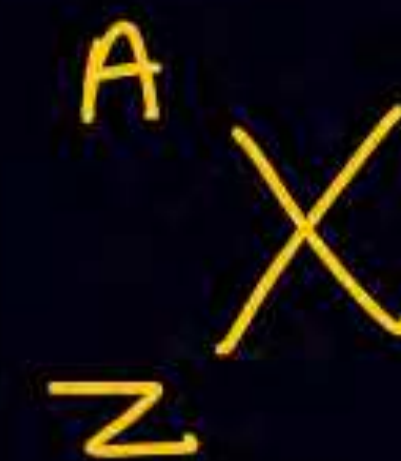
$$[17 \times 1.007825 + 18 \times 1.008665 - M] \times 931.5 = 298$$

$$\left(17 \cdot 133025 + 18 \cdot 155970 \right) - 319 = m$$

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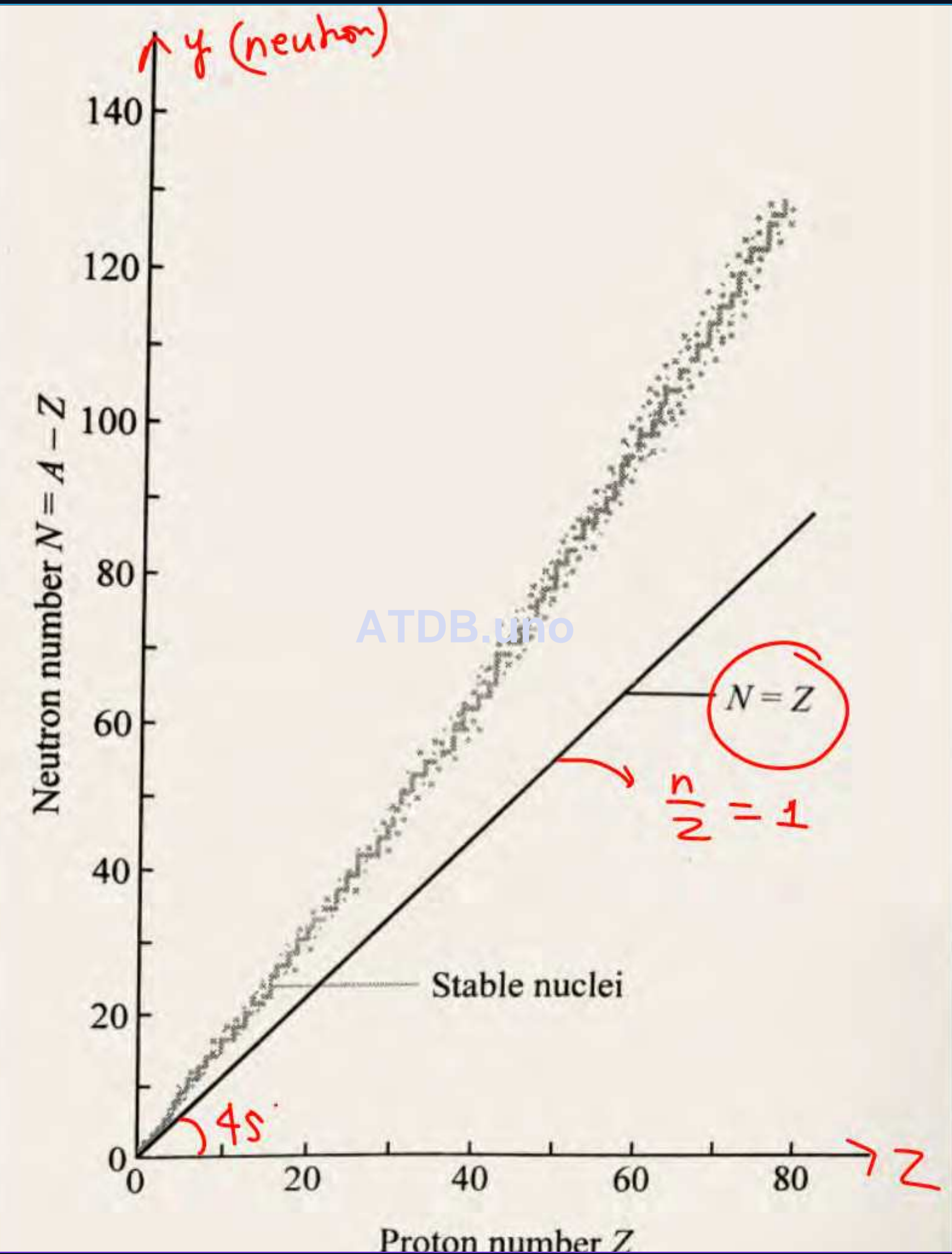
$$35 \cdot 288995 - 319$$

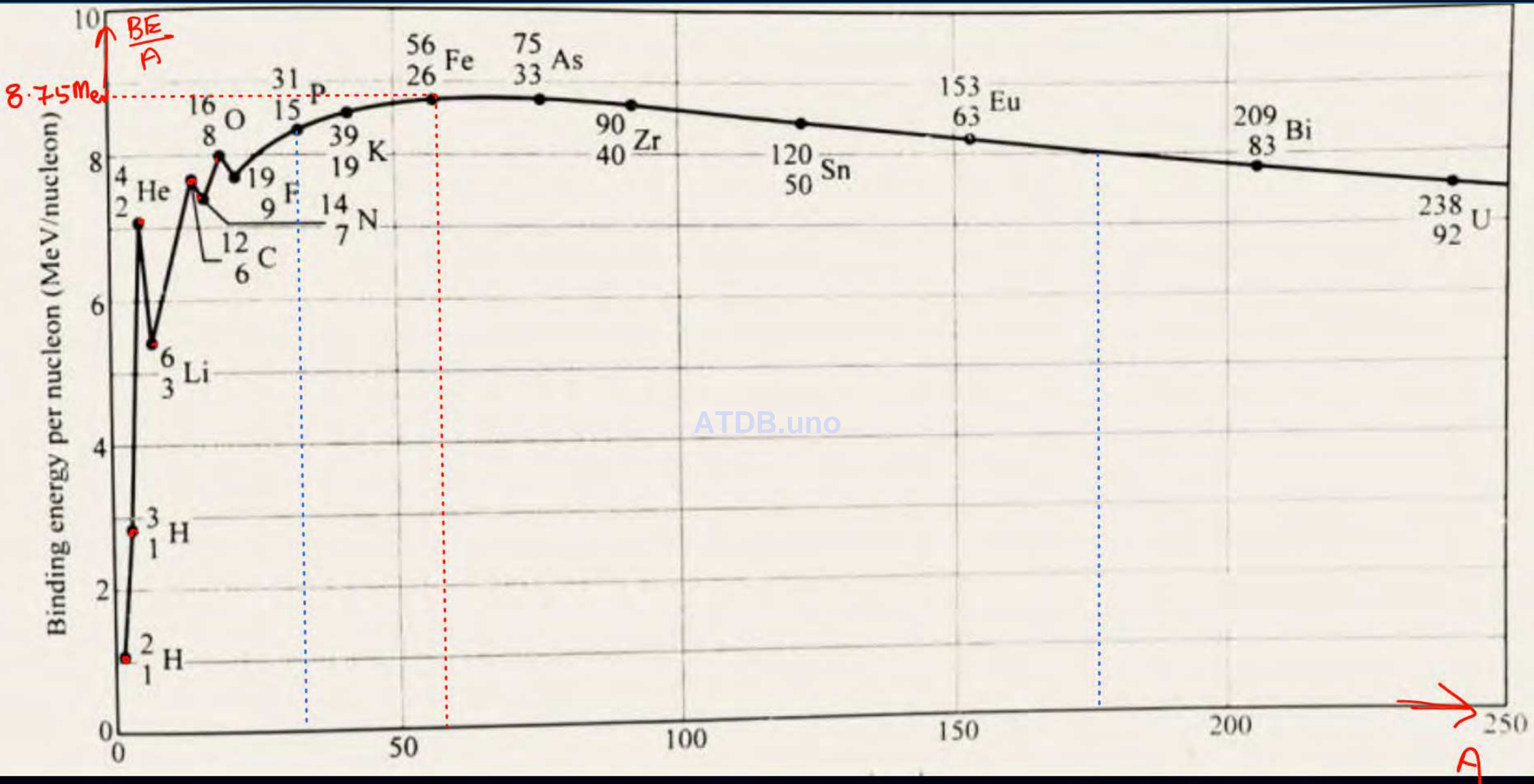
$$35 \cdot 289 - 319 = \underline{34.97}$$



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

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

- $\left(\frac{B \cdot E}{A}\right)_{\text{max}}$ for Fe $\approx 8.75 \text{ MeV}$

- Heavy nucleus decay into lighter nuclei energy would be release in this process
Nuclear fission



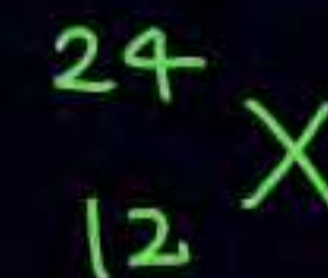
- Two light nuclei want to join ^{to} form a heavier nucleus, $\frac{B \cdot E}{A}$ of fused heavier nuclei is more than binding energy per nucleon of lighter nuclei, this means that the final system is more tightly bound than initial. (Nuclear fusion)





which is more stable.

Q



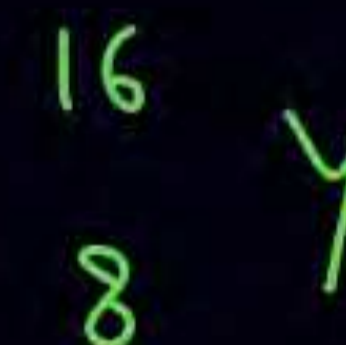
B.E.

24 MeV

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

$$\frac{24}{24} = 1 \text{ MeV}$$

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



18 MeV

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$$\frac{18}{16} = 1.12 \text{ MeV}$$



Q value of nuclear reaction



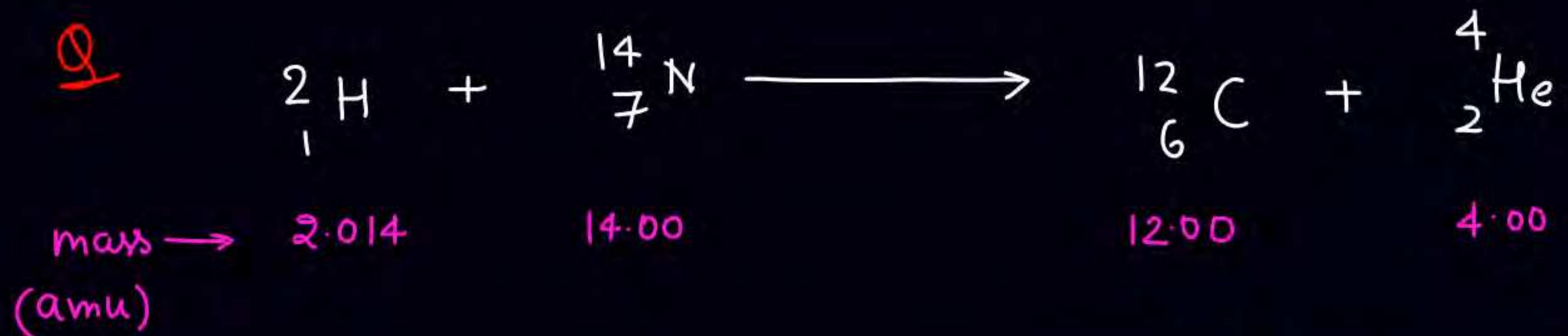
$$* \quad Q = (m_R - m_P) c^2 = (m_A + m_B - m_C - m_D) c^2 \quad \equiv \text{Total energy released in nuclear Rxn.}$$

* If $Q > 0 \Rightarrow$ Exothermic

* If $Q < 0 \Rightarrow$ Endothermic.

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

↓
Amu



Solⁿ

$$Q_{\text{value}} = (2.014 + 14.00 - 12.00 - 4.00) \times 931.5 \text{ MeV}$$

$$= 0.014 \times 931.5 \text{ MeV} \quad (\text{Exothermic})$$



* In nuclear reaction

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

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$$*** Q = (m_R - m_P) \times 931.5 \text{ MeV}$$

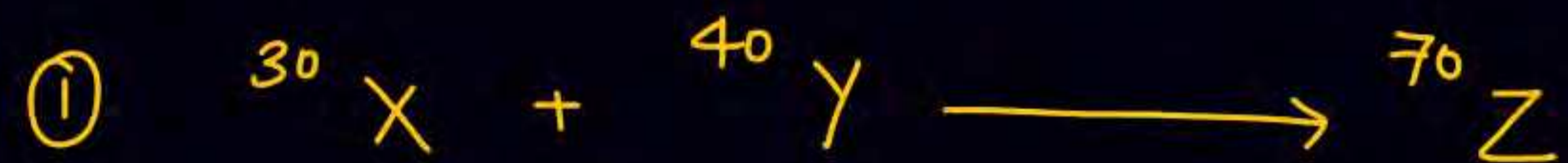
$$**** Q = (B.E.)_f - (B.E.)_R$$

$$Q = (K.E.)_f - (K.E.)_i$$

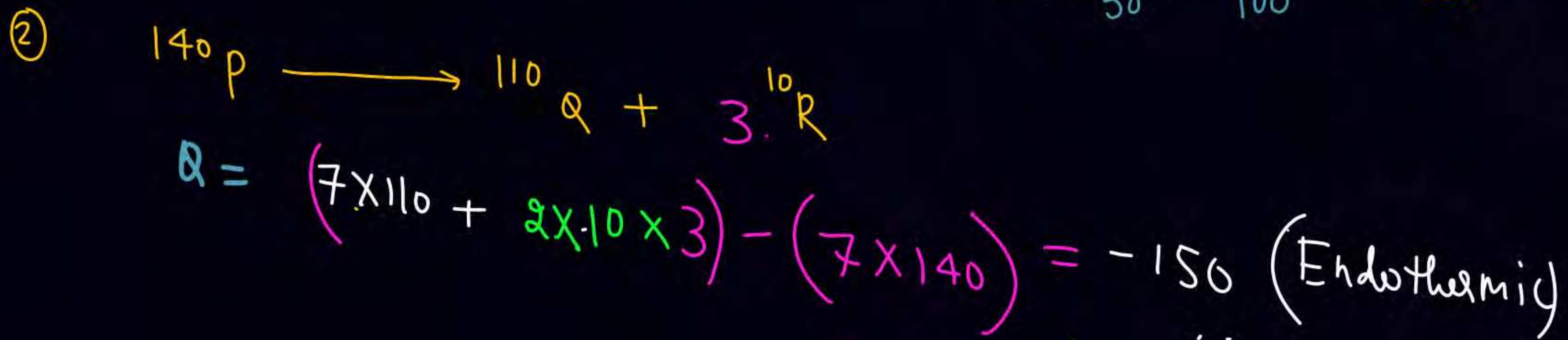
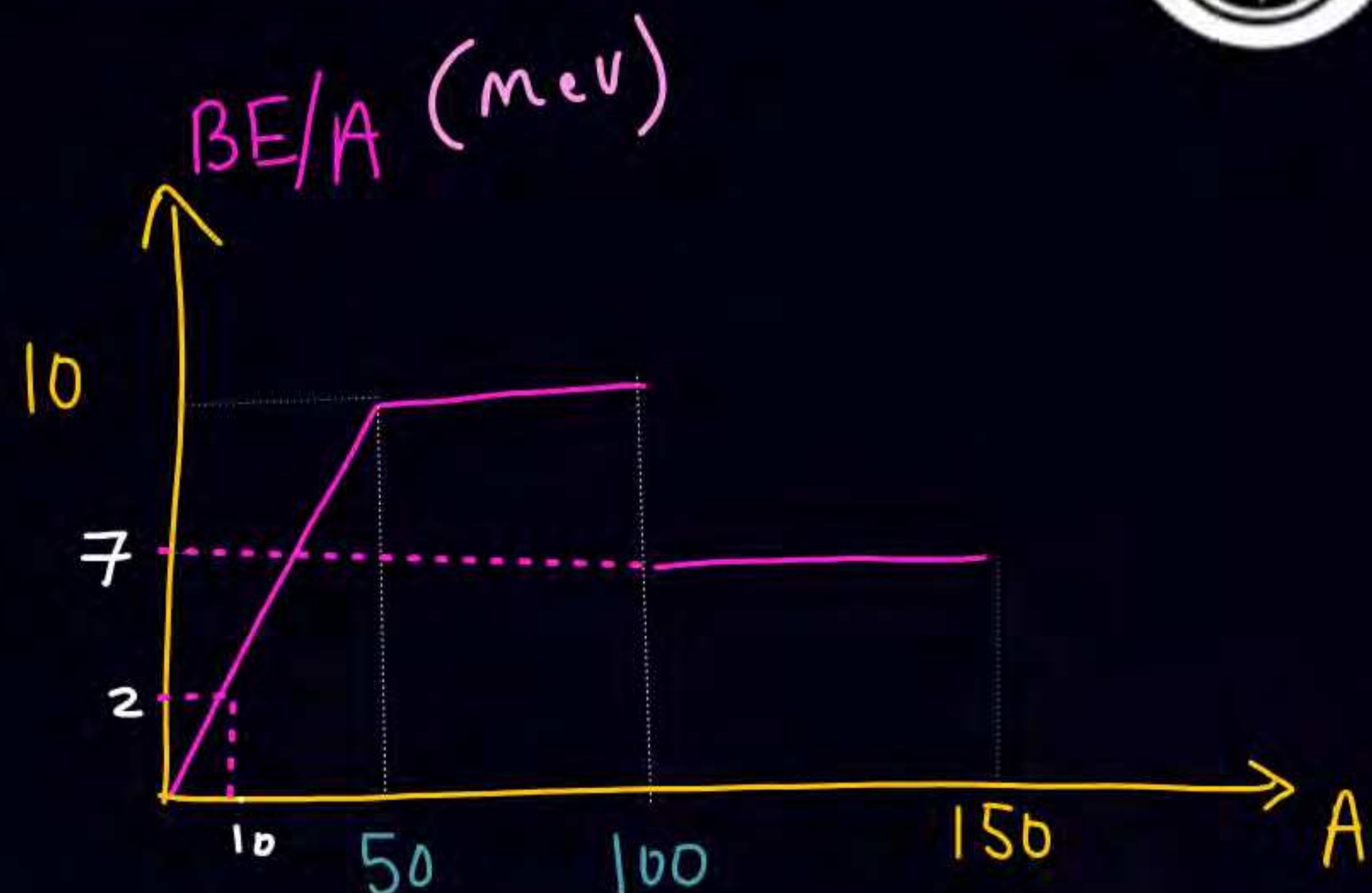
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Q In following rxn find energy released or absorbed



$$\begin{aligned} Q_{\text{value}} &= (BE)_P - (BE)_R \\ &= (70 \times 10) - (30 \times 6 + 8 \times 40) \\ &= 700 - 180 - 320 = 200 \text{ MeV} \\ &\quad \text{(Exothermic)} \end{aligned}$$



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

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Ans. (2)

QUESTION



The ratio of the density of oxygen nucleus (${}^{16}_8\text{O}$) and helium nucleus (${}^4_2\text{He}$) is ____.

[25 January 2023 - Shift 1]

1 4 : 1

2 8 : 1

3 1 : 1

4 2 : 1

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

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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

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Ans. (4)

QUESTION



A nucleus with mass number 242 and binding energy per nucleon as 7.6 MeV breaks into two fragments 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]



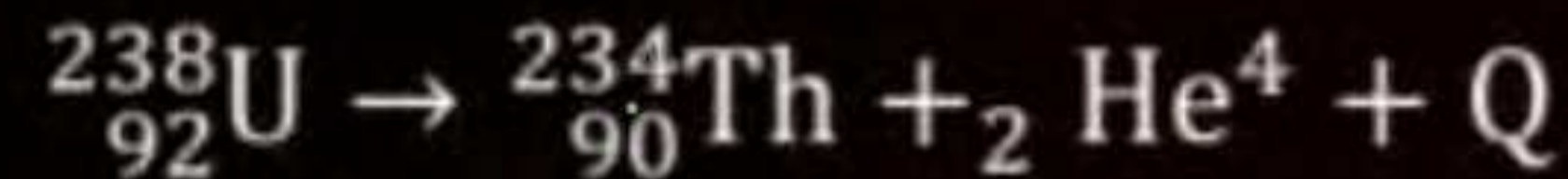
$$\begin{aligned} (BE)_f &= (121 \times 8.1) \times 2 \\ (BE)_i &= 242 \times 7.6 \end{aligned}$$

Ans. (121)

QUESTION



A common example of alpha decay is



Given:

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

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

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

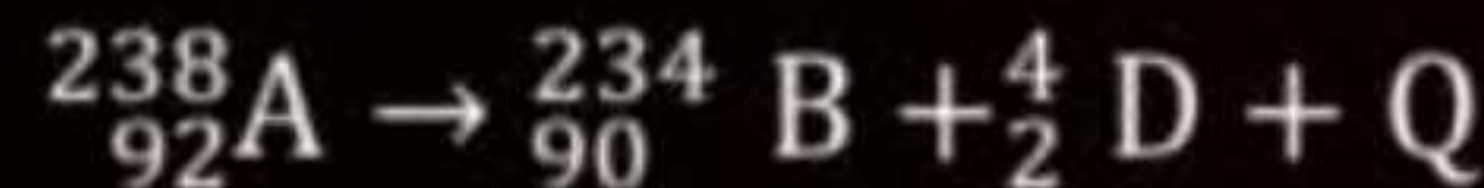
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$${}_2\text{He} = 4.00260\text{u} \text{ and } 1\text{u} = 931.5 \frac{\text{MeV}}{c^2}$$

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

[12 April 2023 - Shift 1]

Ans. (4)

QUESTION

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

[Given, mass of ${}_{92}^{238}\text{A} = 238.05079 \times 931.5\text{MeVc}^{-2}$, mass of

${}_{90}^{234}\text{B} = 234.04363 \times 931.5\text{MeVc}^{-2}$, mass of ${}_2^4\text{D} = 4.00260 \times 931.5\text{MeVc}^{-2}$]

[13 April 2023 - Shift 1]

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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.

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[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]

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

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

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

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Ans : (27)

QUESTION



In a nuclear fission process, a high mass nuclide ($A \approx 236$) with binding energy 7.6 MeV/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]



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

Ans : (236)

QUESTION



The atomic mass of ${}_6\text{C}^{12}$ is 12.000000 u and that of ${}_6\text{C}^{13}$ is 13.003354 u. The required energy to remove a neutron from ${}_6\text{C}^{13}$, 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~~



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

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

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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]

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

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

$$R^3 = R_0 A$$

Ans : (4)

QUESTION

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

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

Value of $c^2 = \underline{931\text{MeV/u}}$

[04 Apr. 2024 - Shift 2]

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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 $1u = 931\text{MeV}/c^2$, atomic mass of helium = $4.002603u$)

[05 Apr. 2024 - Shift 1]

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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 $10 \mu\text{g}$
- 2 $20 \mu\text{g}$
- 3 $0.2 \mu\text{g}$
- 4 $2 \mu\text{g}$

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

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

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

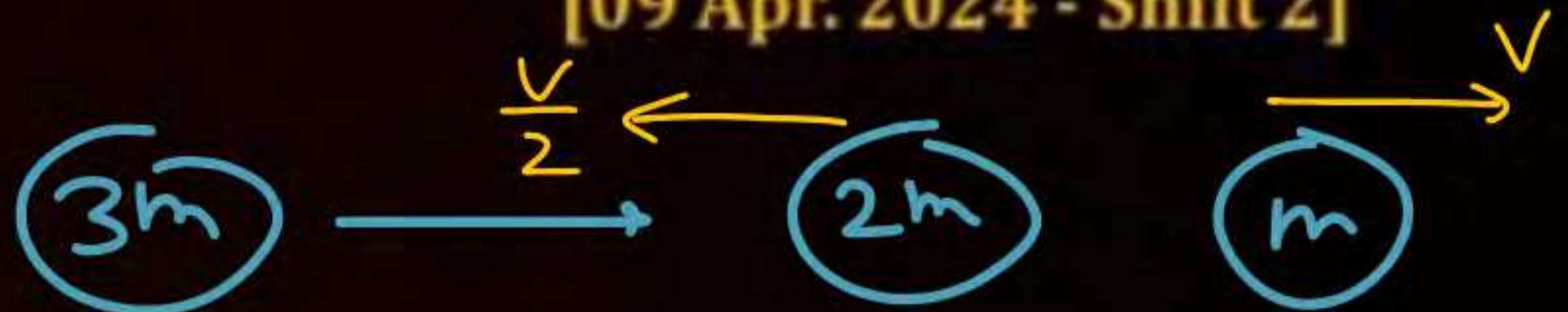
Ans : (2)

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.

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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 ($M_{\text{prot}} \cong M_{\text{neut}} \simeq 1.67 \times 10^{-27} \text{ kg}$).

(JEE Main-2020)

- 1 $10^{24} \text{ kg m}^{-3}$
- 2 10^3 kg m^{-3}
- 3 $10^{17} \text{ kg m}^{-3}$
- 4 $10^{10} \text{ kg m}^{-3}$

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Ans : (3)

QUESTION



From the given data, the amount of energy required to break the nucleus of aluminium ${}_{13}^{27}\text{Al}$ is $\underline{\hspace{1cm}} \times 10^{-3}$ J.

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)

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(JEE Main-2021)

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

Ans : (27)

QUESTION



Two lighter nuclei combine to form a comparative heavier nucleus by the relation given below: ${}^2_1X + {}^2_1X = {}^4_2Y$,

The binding energies per nucleon 2_1X and 4_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)



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

Ans : (4)



Home Work

— Ques attached solve all 2-3 times.

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THANK YOU

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