Chapter: Nuclear Physics

Numerical with Hints:

1) Calculate the binding energy per nucleon of $_{26}Fe^{56}$. {Atomic mass of $_{26}Fe^{56}$ is 55.9349u and that of $_{1}H^{1}$ is 1.00783u and mass of $_{0}n^{1}$= 1.00867u and 1u=931MeV}.[2076,2070]

Solution:

Mass defect = sum of masses of the constituent nucleon - Rest mass of nucleus

i.e. $\Delta \mathbf{m} = (Zm_p+Nm_n) - M$ .....(1)

Where, Z = atomic number,

m_p = mass of proton ,

m_n = mass of neutron

N=number of neutron

BINDING ENERGY: $E_B=(\Delta m) \times 931$ Mev.....(2)

BINDING ENERGY PER NUCLEON: $\overline{B.E.} = \frac{E_B}{A}$ ....(3)

Here given,

Z= 26, A=56 and so N=A-Z=56-26=30

m_p = 1.00783u, m_n = 1.00867u and M=55.9349u

From (1): $\Delta \mathbf{m} = (Zm_p+Nm_n) - M$

$= (26 \times 1.00783 + 30 \times 1.00867) - 55.9349$

$= 0.52878$ u

From (2): $E_B=(\Delta m) \times 931$ Mev = 0.52878 X 931MeV=492.29418MeV

From (3): $\overline{B.E.} = \frac{E_B}{A} = \frac{492.29418 MeV}{56}$ = 8.791 MeV/Nucleon

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2) Calculate the binding energy per nucleon of calcium nucleus ($_{20}Ca^{40}$). { mass of $_{20}Ca^{40}$ is 39.962589u and that of proton($_1H^1$)is 1.007825u and mass of neutron($_0n^1$)= 1.008665u and 1u=931MeV.}[2076,]

Solution:

Mass defect = sum of masses of the constituent nucleon - Rest mass of nucleus

i.e. $\Delta \mathbf{m} = \{Zm_p+(A-Z)m_n\} - M$ ......(1)

where, Z = atomic number,

m_p = mass of proton ,

m_n = mass of neutron

BINDING ENERGY: $E_B=(\Delta m\ ) \times 931$ Mev..........(2)

BINDING ENERGY PER NUCLEON: $\overline{B.E.} = \frac{E_B}{A}$ ....(3)

Here given,

Z= 2o, A=40 and so N=A-Z=40-20=20

m_p = 1.007825u, m_n = 1.008665u and M=39.962589u

From (1): $\Delta \mathbf{m} = (Zm_p+Nm_n) - M$

$= (20 \times 1.007825 + 20 \times 1.008665) - 39.962589$

$= 0.367211$ u

From (2): $E_B=(\Delta m\ ) \times 931$ Mev = 0.367211X 931MeV=341.873441MeV

From (3): $\overline{B.E.} = \frac{E_B}{A} = \frac{341.873441 \text{ MeV}}{20}$ = 8.54 MeV/Nucleon

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3) A city requires 10^7Watts of electrical power on the average. If this is to be supplied by a nuclear reactor of efficiency 20%. Using ${}_{92}U^{235}$ as the fuel source, calculate the amount of fuel required per day.(Energy released per fission ${}_{92}U^{235}$=200MeV)[2075]

Solution:

$\eta = \frac{P_{out}}{P_{in}}$ ....(1)

Again, Power (P_{in}) = $\frac{\text{total Energy released(E)}}{\text{time taken(t)}}$

Or, $P_{in} = \frac{\text{Number of atoms(N)X liberated energy(Q)}}{\text{time taken}}$

Or, N X Q= P_{in} X t

Or, $N=\frac{P_{in} \text{ X } t}{Q}$ ....(2)

Here given,

Efficiency (η%)=20%

Output Power (P_{out})= 10^7 W

Then from (1): $P_{in} = \frac{P_{out}}{\eta} = \frac{10^7}{(\frac{20}{100})} = 5 \text{ X } 10^7$W

Time (t)=1 day = 86400 seconds

Energy liberated (Q)= 200MeV=200X(10^6)X(1.6X10^{-19}J)=3.2X10^{-11}J

From (2): $N=\frac{P_{in} \text{ X } t}{Q} = \frac{(5 \text{ X } 10^7)\text{X } 86400}{3.2\text{X}10^{-11}}$ = 1.35X10^{23} atoms

Now, 6.023X10^{23} atoms have mass of Uranium= 235gram

So, 1 atom has mass of Uranium = $\frac{235}{6.023 \text{ X } 10^{23}}$ gram

∴ 1.35X10^{23} atoms have mass of Uranium=$\frac{235}{6.023 \text{ X } 10^{23}}$ X 1.35X10^{23}

= 52.67 gram

=0.05267 kg

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4) A nucleus of $_{92}U^{238}$ disintegrates according to $_{92}U^{238} \rightarrow {}_{90}Th^{234} + {}_2He^4$

Calculate

a) The total energy released in the disintegration process

b) The KE of the α-Particle, the nucleus at rest before disintegration.

(Mass of $_{92}U^{238}$ =3.859X10^{-25}Kg, Mass of $_{90}Th^{234}$ =3.787X10^{-25}Kg, Mass of $_2He^4$ =6.648X10^{-27}Kg) [2075,2067]

Solution: 1 amu (1 u) =1.66X10^{-27} Kg

Here given,

Mass of $_{92}U^{238}$ =3.859X10^{-25}Kg= 232.469879 u

Mass of $_{90}Th^{234}$ =3.787X10^{-25}Kg=228.132530 u

Mass of $_2He^4$ =6.648X10^{-27}Kg)=4.004819 u

Mass defect (Δm) = Decrease of mass in reaction

= mass of reactant – mass of product

= mass of $_{92}U^{238}$ – (mass of $_{90}Th^{234}$ +mass of $_2He^4$)

=232.469879 – { 228.132530 + 4.004819 }

=232.469879 – 232.137349

= 0.33253 u

Total energy: $E_B = \Delta m$ X 931MeV

= 0.33253 X931MeV

= 309.59MeV

b)K.E of the α-Particle=$\left[\frac{m_{Th}}{m_{Th}+m_\alpha}\right]$X E_B

$= \left[\frac{228.132530}{228.132530+4.004819}\right]$ X 309.59MeV

= 304.24MeV

(Since, α-particle is Helium).

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5) The Mass of $_{17}Cl^{35}$ is 34.9800amu. Calculate its binding energy and binding energy per nucleon. Mass of proton($_1H^1$)is 1.007825amu and mass of neutron($_0n^1$)= 1.008665amu and 1u=931MeV.[2074]

Solution:

Mass defect = sum of masses of the constituent nucleon - Rest mass of nucleus

i.e. $\Delta \mathbf{m} = \{Zm_p+(A-Z)m_n\} - M$……(1)

where, Z = atomic number,

m_p = mass of proton ,

m_n = mass of neutron

BINDING ENERGY: $E_B=(\Delta m)$ X 931 Mev……..(2)

BINDING ENERGY PER NUCLEON: $\overline{B.E.} = \frac{E_B}{A}$ ……(3)

Here given,

Z= 17, A=35 and so N=A-Z=35-17=18

m_p = 1.007825amu, m_n = 1.008665amu and M=34.9800amu

From (1): $\Delta \mathbf{m} = (Zm_p+Nm_n) - M$

= (17X1.007825 +18X1.008665)- 34.9800

=0.308995 amu

From (2): $E_B=(\Delta m)$ X 931 Mev = 0.308995 X 931MeV=287.674MeV

From (3): $\overline{B.E.} = \frac{E_B}{A} = \frac{287.674MeV}{35}$ = 8.219 MeV/Nucleon

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6) What will be the amount of energy released in the fusion of three alpha particles into a C^{12} nucleus if the mass of He^4 and C^{12} nuclei are respectively 4.00263amu and 12amu.[2073]

Solution:

Given reaction $3 \times {}_2He^4 \rightarrow C^{12} + Q$

Mass of He^4 = 4.00263 amu

And mass of C^{12} = 12 amu

Mass defect (Δm)= Decrease of mass in reaction

=mass of reactant – mass of product

= mass of $3\ {}_2He^4$ – mass of C^{12}

= 3 X 4.00263 - 12

= 0.00789amu

Energy released: $E_B = (\Delta m) \times 931$ Mev

= 0.00789 X 931 MeV

= 7.37 MeV

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7) The Mass of the nucleus of the isotope Lithium ($_3Li^7$) is 7.014351u. Find its binding energy and binding energy per nucleon. (. Mass of proton($_1H^1$)is 1.007275u and mass of neutron($_0n^1$)= 1.008665u and 1u=931MeV.[2072supp,2069]

Solution:

Mass defect = sum of masses of the constituent nucleon - Rest mass of nucleus

i.e. $\Delta \mathbf{m}$ =$\{Zm_p+(A-Z)m_n\}$ - M ....(1)

where, Z = atomic number,

m_p = mass of proton ,

m_n = mass of neutron

BINDING ENERGY: $E_B=(\Delta m\ )$ X 931 Mev........(2)

BINDING ENERGY PER NUCLEON: $\overline{B.E.}\ =\frac{E_B}{A}$ ....(3)

Here given,

Z= 3, A=7 and so N=A-Z=7-3=4

m_p = 1.007275amu, m_n = 1.008665amu and M=7.01435amu

From (1): $\Delta \mathbf{m}$ =(Zm_p+Nm_n) - M

= (3X1.007275 +4X1.008665)- 7.01435

=0.042135 amu

From (2): $E_B=(\Delta m\ )$ X 931 Mev = 0.042135 X 931MeV=39.22MeV

From (3): $\overline{B.E.}\ =\frac{E_B}{A} = \frac{39.22\text{MeV}}{7}$ = 5.60 MeV/Nucleon

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8) $_{28}Ni^{62}$ may be described as the most strongly bound nucleus because it has the highest BE per nucleon. Its neutral atomic mass is 61.928349amu. Find its mass defect, its total binding energy and binding energy per nucleon. Mass of proton($_1H^1$)is 1.007825amu and mass of neutron($_0n^1$)= 1.008665amu and 1u=931.5MeV.[2072]

Solution:

Mass defect = sum of masses of the constituent nucleon - Rest mass of nucleus

i.e. $\Delta\mathbf{m} = \{Zm_p+(A-Z)m_n\} - M$............(1)

where, Z = atomic number,

m_p = mass of proton ,

m_n = mass of neutron

BINDING ENERGY: $E_B=(\Delta m) \times 931$ Mev ......(2)

BINDING ENERGY PER NUCLEON: $\overline{\mathrm{B.E.}} = \frac{E_B}{A}$ ....(3)

Here given,

Z= 28, A=62 and so N=A-Z=62-28=34

m_p = 1.007825amu, m_n = 1.008665amu and M=61.928349amu

From (1): $\Delta\mathbf{m} = (Zm_p+Nm_n) - M$

$= (28 \times 1.007825 + 34 \times 1.008665) - 61.928349$

$= 0.585361$ amu

From (2): $E_B=(\Delta m) \times 931.5$ Mev = 0.585361 X 931.5MeV=545.26MeV

From (3): $\overline{\mathrm{B.E.}} = \frac{E_B}{A} = \frac{545.26\mathrm{MeV}}{62}$ = 8.80 MeV/Nucleon

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9) Calculate the binding energy per nucleon for a helium nucleus. Mass of Helium nucleus=4.001509amu, Mass of proton($_1H^1$)is 1.007825amu and mass of neutron($_0n^1$)= 1.008665amu and 1u=931MeV.[2071]

Solution:

Mass defect = sum of masses of the constituent nucleon - Rest mass of nucleus

i.e. $\Delta \mathbf{m} = \{Zm_p+(N)m_n\} - M$............(1)

where, Z = atomic number,

m_p = mass of proton ,

m_n = mass of neutron

BINDING ENERGY: $E_B=(\Delta m) \times 931$ Mev ....(2)

BINDING ENERGY PER NUCLEON: $\overline{B.E.} = \frac{E_B}{A}$ ....(3)

Here given,

Z= 2, A=4 and so N=A-Z=4-2=2

m_p = 1.007825amu, m_n = 1.008665amu and M=4.001509amu

From (1): $\Delta \mathbf{m} = (Zm_p+Nm_n) - M$

$= (2 \times 1.007825 + 2 \times 1.008665) - 4.001509$

$= 0.031471$ amu

From (2): $E_B=(\Delta m) \times 931$ Mev = 0.031471 X 931MeV=29.2995MeV

From (3): $\overline{B.E.} = \frac{E_B}{A} = \frac{29.2995\text{MeV}}{4}$ = 7.32 MeV/Nucleon

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10) The most common isotope of Uranium $_{92}U^{238}$ has atomic mass 238.050783u. Calculate the mass defect, binding energy and binding energy per nucleon. Mass of proton($_1H^1$)is 1.007825amu and mass of neutron($_0n^1$)= 1.008665amu and 1u=931.5MeV.[2070supp]

Solution:

Mass defect = sum of masses of the constituent nucleon - Rest mass of nucleus

i.e. $\Delta\mathbf{m} = \{Zm_p+Nm_n\} - M$............(1)

where, Z = atomic number,

m_p = mass of proton ,

m_n = mass of neutron

BINDING ENERGY: $E_B=(\Delta m\ ) \times 931$ Mev..........(2)

BINDING ENERGY PER NUCLEON: $\overline{\mathrm{B.E.}} = \frac{E_B}{A}$ ....(3)

Here given,

Z= 92, A=238 and so N=A-Z=238-92=146

m_p = 1.007825amu, m_n = 1.008665amu and M=238.050783amu

From (1): $\Delta\mathbf{m} = (Zm_p+Nm_n) - M$

= (92X1.007825 +146X1.008665)- 238.050783

=1.934207 amu

From (2): $E_B=(\Delta m\ ) \times 931$ Mev = 1.934207 X 931MeV=1800.75MeV

From (3): $\overline{\mathrm{B.E.}} = \frac{E_B}{A} = \frac{1800.75\mathrm{MeV}}{238}$ = 7.57 MeV/Nucleon

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11) Assuming that about 200MeV energy is released per fission of $_{92}U^{235}$ nuclei. What would be the mass of U^{235} consumed per day in the fission reactor of power 1MW approximately?[2068old]

Solution:

Power produced = $\frac{\text{total Energy released(E)}}{\text{time taken(t)}}$

Or, $P = \frac{\text{Number of atoms(N)X liberated energy(Q)}}{\text{time taken}}$

Or, N X Q= P X t

Or, $N=\frac{P\,X\,t}{Q}$ ....(1)

Here given

P=1MW =1 X 10^6W = 1000000 W

Time (t)= 1 day =86400 seconds

Energy liberated (Q)= 200MeV = $3.2X10^{-11}$J

From(1): $N = \frac{P\,X\,t}{Q}$

$= \frac{(1000000W)X\,(86400sec)}{3.2 \times 10^{-11}J}$

$= 2.7 \times 10^{21}$ atoms

Now, $6.023X10^{23}$ atoms have mass of Uranium= 235gram

So, 1 atoms have mass of Uranium = $\frac{235}{6.023\,X\,10^{23}}$ gram

∴ $2.7\,X\,10^{21}$ atoms have mass of Uranium=$\frac{235}{6.023\,X\,10^{23}}$ X $2.7\,X\,10^{21}$

= 1.05 gram

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12) The energy liberated in the fission of a single Uranium -235 atom is $3.2X10^{-11}$J. Calculate the power production corresponding to the fission of 1.5Kg of Uranium per day.[2064]

Solution:

Here, 235 gm of Uranium contains= $6.023X10^{23}$atoms

So 1 gm of Uranium contains=$\frac{6.023 \text{ X } 10^{23}}{235}$ atoms

∴1.5Kg (i.e.1500gm) Uranium contains = $\frac{6.023 \text{ X } 10^{23}}{235}$ X 1500 atoms

= $3.844 \text{ X } 10^{24}$ atoms

i.e. N= $3.844 \text{ X } 10^{24}$ atoms

Given, Q= energy liberated by fission of U^{235} atom= $3.2X10^{-11}$J

Time(t)= 1 day = 86400 seconds

Again, Power produced = $\frac{\text{total Energy released}}{\text{time taken}}$

$$= \frac{\text{Number of atoms(N)X liberated energy(Q)}}{\text{time taken(t)}}$$

$$= \frac{3.844X10^{24}\ 3.2X10^{-11}}{86400}$$

= $1.42X10^{9}$ W

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13) The energy liberated in the fission of a single Uranium -235 atom is $3.2X10^{-11}$J. Calculate the power production corresponding to the fission of 1Kg of Uranium per day. Assume Avogadro constant as $6.02x10^{23}mole^{-1}$. [2054]

Solution:

Here, 235 gm of Uranium contains= $6.023X10^{23}$atoms

So, 1 gm of Uranium contains=$\frac{6.023 \text{ X } 10^{23}}{235}$ atoms

∴ 1Kg(i.e.1000gm) Uranium contains = $\frac{6.023 \text{ X } 10^{23}}{235}$ X 1000 atoms

= $2.55X10^{24}$ atoms

i.e. N= $2.55X10^{24}$ atoms

Given, Q= energy liberated by fission of U^{235} atom= $3.2X10^{-11}$J

Time(t)= 1 day = 86400 seconds

Now,

$$\text{Power produced} = \frac{\text{total Energy released}}{\text{time taken}}$$

$$= \frac{\text{Number of atoms(N)X liberated energy(Q)}}{\text{time taken}}$$

$$= \frac{2.55X10^{24}\ \ 3.2X10^{-11}}{86400}$$

= $9.4 \text{ X}10^{8}$ W

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14) The energy liberated in the fission of single uranium-235 atom is 3.2×10^{-11}J. Calculate the power production corresponding to the fission of 1g of uranium per day. Assume Avogadro constant as 6.02×10^{23}mole^{-1}.[2073supp,2072,2070supp,2068]

Solution:

Here, 235 gm of Uranium contains= 6.023×10^{23}atoms

So, 1 gm of Uranium contains $= \frac{6.023 \text{ X } 10^{23}}{235}$ atoms

$= 2.56 \times 10^{21}$ atoms

i.e. N= 2.56×10^{21} atoms

Given, Q= energy liberated by fission of U^{235} atom= 3.2×10^{-11}J

Time (t)= 1 day = 86400 seconds

Now,

$$\text{Power produced} = \frac{\text{total Energy released}}{\text{time taken}}$$

$$= \frac{\text{Number of atoms(N)X liberated energy(Q)}}{\text{time taken(t)}}$$

$$= \frac{2.56\text{X}10^{21}\ \ 3.2\text{X}10^{-11}}{86400}$$

$= 9.47 \times 10^{5}$ W

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15) The energy released by fission of one U^{235} atom is 200MeV. Calculate the energy released in KWH, when one gram of uranium undergoes fission.[2071]

Solution:

Here, 235 gm of Uranium contains= $6.023X10^{23}$atoms

So 1 gm of Uranium contains=$\frac{6.023 \text{ X } 10^{23}}{235}$ atoms

= $2.56X10^{21}$ atoms

i.e. N= $2.56X10^{21}$ atoms

Given,

Q= energy liberated by fission of U^{235} atom=200MeV= $3.2X10^{-11}$J

Now, Total energy released (E)= N X Q

= $2.56X10^{21}$ X $3.2X10^{-11}$

= 8.19 X 10^{10} J

As we Know, 1KWh= 3.6 X 10^{6} J

So, E= 8.19 X 10^{10} J

= $\frac{8.19X10^{10}}{3.6X10^{6}}$ KWh

= 2.275 X 10^{4} KWh

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16) Calculate the speed of a particle if the mass of it is equal to 5 times its rest mass.[2052]

Solution:

From the relativistic formula for the variation of mass with velocity is given as

$$m=\frac{m_0}{\sqrt{1-\frac{v^2}{c^2}}} \quad ....(1)$$

Here given,

Speed of light in vacuum(c)= 3 X10^8m/s

And m = 5m_0 where m_0 is rest mass of particle

From(1): $m=\frac{m_0}{\sqrt{1-\frac{v^2}{c^2}}}$

Or, $\sqrt{1-\frac{v^2}{c^2}}=\frac{m_0}{m} = \frac{m_0}{5m_0} = \frac{1}{5}$

Squaring on both sides,

$1-\frac{v^2}{c^2}=\frac{1}{25}$

Or, $1-\frac{1}{25}=\frac{v^2}{c^2}$

Or, $v^2=\frac{24}{25}c^2=\frac{24}{25}X(3 X10^8)^2$

Or, v={ $\sqrt{\frac{24}{25}}$ } X 3 X10^8 = 2.94X10^8 m/s

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17) Calculate the Q-value of the reaction and mention the type of reaction(endothermic or exothermic) Mass of proton($_1H^1$)is 1.00814amu and mass of Helium($_2He^4$)= 4.00377amu, Mass of Nitrogen ($_7N^{14}$)is 14.00783amu and mass of Oxygen ($_8O^{16}$)= 17.00450amu [2052]

Solution:

Given reaction $_7N^{14} + {_2He^4} \rightarrow {_8O^{17}} + {_1H^1} + Q$

Given,

Mass of proton($_1H^1$)= 1.00814amu

mass of Helium($_2He^4$)= 4.00377amu,

Mass of Nitrogen($_7N^{14}$)= 14.00783amu

mass of Oxygen($_8O^{16}$)= 17.00450amu

Now, from reaction

Mass of reactant = mass of N^{14} + mass of He^4

=14.00783amu + 4.00377amu

= 18.0116amu

Mass of Product= mass of O^{16} + mass of H^1

=17.00450amu + 1.00814amu

= 18.01264 amu

Then,

Mass defect (Δm)= Decrease of mass in reaction=

=mass of reactant – mass of product

= 18.0116amu - 18.01264 amu

= -0.00104 amu

Here, Q-value of reaction: $E_B=(\Delta m)$ X 931 Mev

= -0.00104 X 931 MeV

= - 0.96824 MeV

Here, Q-value is negative, so the reaction is endothermic.

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SHORT QUESTIONS

1) Define Mass defect, Packing fraction, binding Energy and Binding Energy per Nucleon of a nucleus.
2) Write the significance of Binding energy per nucleon.
3) All nuclei have nearly the same density. Why?
4) Does nucleus contain the electrons? Explain.
5) Does the nucleus contain the protons? Explain.
6) Neutron is considered the most effective bombarding particle in a nuclear reaction. Why?
7) A nucleus consists of positively charged particle protons and electrically neutral neutrons in a small volume. How can this be possible as the like charges repel each other?
8) Why is the mass of a nucleus slightly less than the mass of constituent nucleons?
9) Define Atomic mass unit (amu). Hence convert the mass of a neutron, (1840 MeV),into amu where M_e is the mass of an electron.
10) By what factor must the mass number of a nucleus increase to double its volume?
11) Diameter of Al^{27} nucleus is D_{Al}. How can one express the diameter of Cu^{64}in terms of D_{Cu}? Explain.
12) What does the energy balance (Q-value) of a nuclear reaction signify? Explain.
13) Why does a mountain of Uranium not explode as a bomb?
14) Write difference between nuclear fission and nuclear fusion.
15) Distinguish between isotopes and isobar?
16) Explain Binding energy in terms of Packing fraction.
17) What is meant by Chain reaction?
18) Write down the representative nuclear fission and fusion reactions.

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LONG QUESTIONS:

1) Define mass Defect, Binding Energy and Binding Energy per Nucleon. Explain the Binding energy curve with neat and clean Diagram and write its significance?
2) Write the differences between Nuclear Fusion & Nuclear Fission? Explain the Production of energy in the Sun.
3) What is nuclear fusion? How energy is released in nuclear fusion reaction? Explain with examples
4) What is nuclear fission? How energy is released in nuclear fission reaction? Explain with examples.
5) State and explain Einstein's mass energy relation with example. Write its significance.
6) Discuss the important properties (size, charge, mass and density) of Nuclei.

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