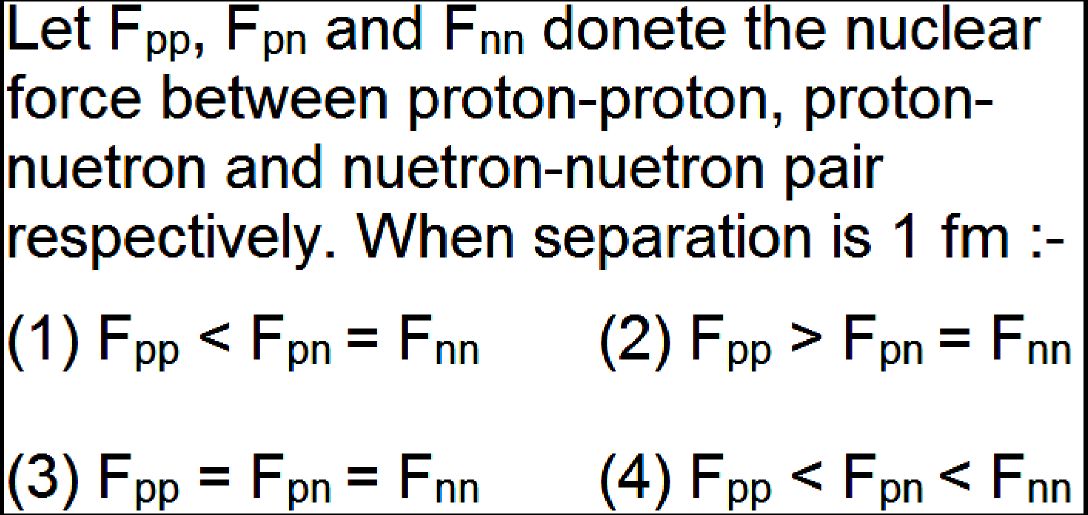
38th Session: Modern Physics III
Nuclear Fusion & Exponential RA Decay

- Sunday Test
- Recap: Nuclear Fission (nuclear fuel, chain reaction, critical size)
- Nuclear fission
    - Nuclear reactor & breeder reactors
    - Fast breeder reaction
- Nuclear fusion
- Exponential Radioactive Decay
    - Units of radioactivity
    - Rutherford-Soddy theory of Radioactivity
    - Half life, mean life
    - RA equilibrium, rate of accumulation, simultaneous decay

Q. 1).



Let F_{pp}, F_{pn} and F_{nn} donete the nuclear force between proton-proton, proton-nuetron and nuetron-nuetron pair respectively. When separation is 1 fm :-

(1) $F_{pp} < F_{pn} = F_{nn}$

(2) $F_{pp} > F_{pn} = F_{nn}$

(3) $F_{pp} = F_{pn} = F_{nn}$

(4) $F_{pp} < F_{pn} < F_{nn}$

Q. 2). A nuclear fission is given below

$A^{240} \rightarrow B^{100} + C^{140} + Q(\text{energy})$

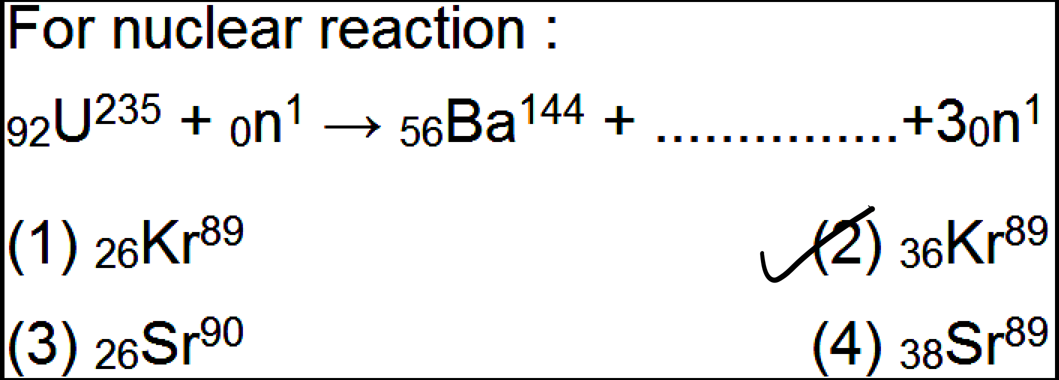
Let binding energy per nucleon of nucleus A, B and C is 7.6 MeV, 8.1 MeV and 8.1 MeV respectively. Value of Q is :- (Approximately)

(1) 20 MeV
(2) 220 MeV
✓ (3) 120 MeV
(4) 240 MeV

$Q = [(8.1 \times 140 + 8.1 \times 100) - (7.6) \times 240]\,\text{MeV}$

$= 120\,\text{MeV}$

Q. 3).



For nuclear reaction :

$$_{92}U^{235} + {}_{0}n^{1} \longrightarrow {}_{56}Ba^{144} + \ldots\ldots\ldots\ldots\ldots + 3\,{}_{0}n^{1}$$

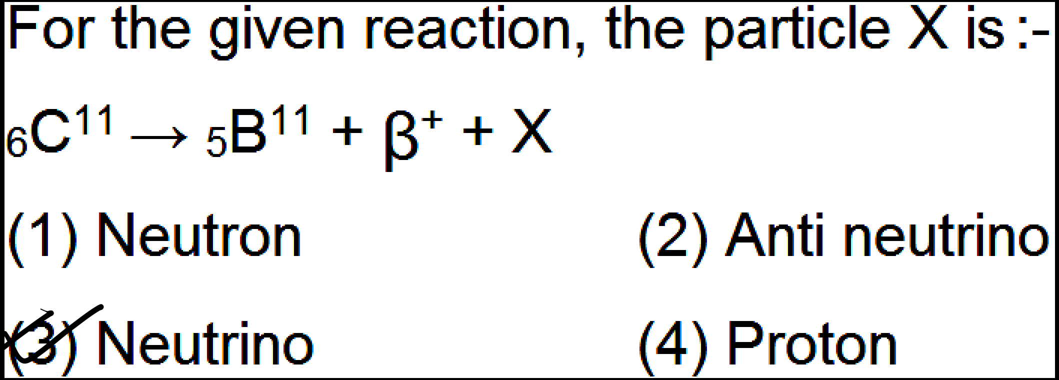
(1) $_{26}Kr^{89}$

[✓ (2) $_{36}Kr^{89}$]

(3) $_{26}Sr^{90}$

(4) $_{38}Sr^{89}$

Q. 4).



For the given reaction, the particle X is :-

$_6C^{11} \rightarrow {}_5B^{11} + \beta^+ + X$

(1) Neutron

(2) Anti neutrino

[✓ (3) Neutrino]

(4) Proton

Q. 5). M_n and M_p represet the mass of neutron and proton respectively. An element having nuclear mass M has N neutron and Z-protons, then the correct relation will be :-

[✓ (1) $M<\{N.M_n+Z.M_p\}$]

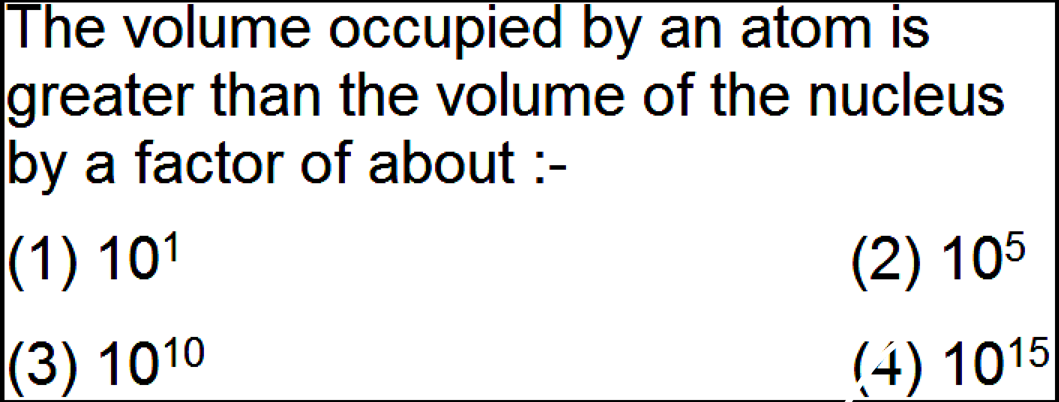
(2) $M>\{N.M_n+Z.M_p\}$

(3) $M=\{N.M_n+Z.M_p\}$

(4) $M=N\{M_n + M_p\}$

$$M < \underline{\left(N\cdot M_n + ZM_p\right)}$$

Q. 6).



The volume occupied by an atom is greater than the volume of the nucleus by a factor of about :-

(1) 10^1 (2) 10^5

(3) 10^{10} (4) 10^{15} ✓

$$\frac{V_a}{V_n} = \cancel{\propto} (10^5)^3$$

$$= 10^{15}$$

Q. 7). The mass of proton is 1.0073 u and that of neutron is 1.0087 u (u = atomic mass unit). The binding energy of ${}^{4}_{2}He$ is :-

(1) 0.0305 J | (2) 0.0305 erg
✓(3) 28.4 MeV | (4) 0.061 u

(Given :- mass of helium nucleus ≈ 4.0015 u)

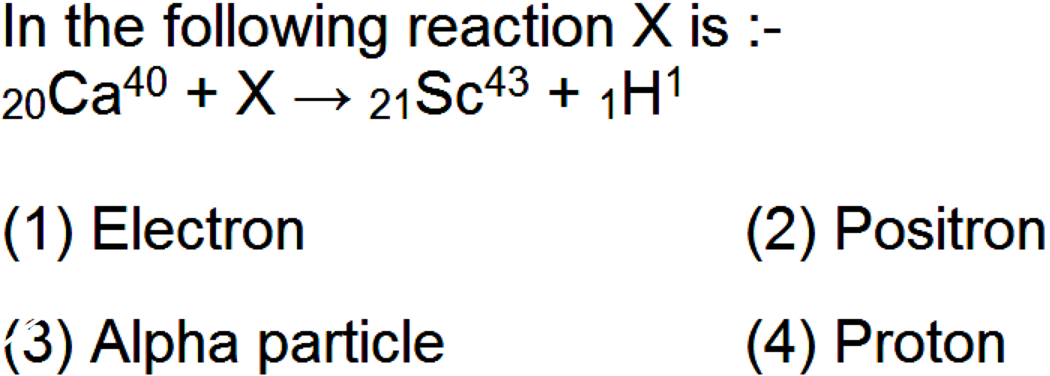
$$B.E = \Delta m c^2 = \left[(2\times 1.0073\,u + 2\times 1.0087\,u) - 4.0015\,u\right] c^2$$

$$\boxed{1\,J = 10^{7}\,ergs}$$

$$= (\qquad)\, u \times c^2$$

931.5 MeV

$$MeV \rightarrow 10^{6}\times 1.6\times 10^{-19}\,J$$

Q. 8). 
In the following reaction X is :-

$_{20}Ca^{40} + X \rightarrow {}_{21}Sc^{43} + {}_{1}H^{1}$

(1) Electron
(2) Positron
[✓ (3) Alpha particle]
(4) Proton

Q. 9). Which one of the following is a possible nuclear reaction :-

(1) ${}^{10}_{5}B + {}^{4}_{2}He \rightarrow {}^{13}_{7}N + {}^{1}_{1}H$

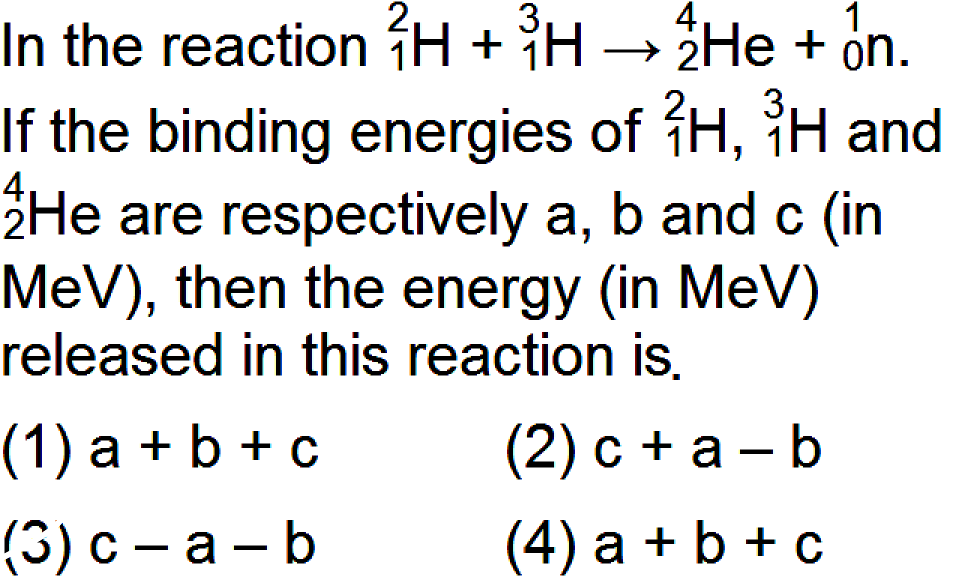
(2) ${}^{23}_{11}Na + {}^{1}_{1}H \rightarrow {}^{22}_{10}Ne + {}^{4}_{2}He$

✓ (3) ${}^{239}_{93}Np \rightarrow {}^{239}_{94}Pu + \beta^{-} + \bar{v}$

(4) ${}^{11}_{7}N + {}^{1}_{1}H \rightarrow {}^{12}_{6}C + \beta^{-} + v$

β^{+} β^{-} $\boxed{{}^{-1}_{0}\beta}$ ${}^{0}_{-1}\beta$ ${}^{0}_{+1}\beta$

Q. 10).

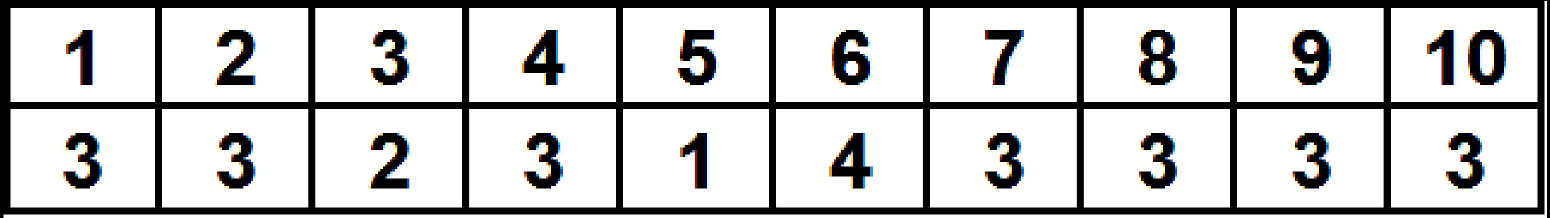


In the reaction ${}^{2}_{1}H + {}^{3}_{1}H \rightarrow {}^{4}_{2}He + {}^{1}_{0}n$. If the binding energies of ${}^{2}_{1}H$, ${}^{3}_{1}H$ and ${}^{4}_{2}He$ are respectively a, b and c (in MeV), then the energy (in MeV) released in this reaction is.

(1) a + b + c
(2) c + a – b
[✓ (3) c – a – b]
(4) a + b + c

$$Q = (B.E.)_{He} - B.E._{{}^{2}_{1}H} - B.E._{{}^{3}_{1}H}$$

$$= c - (a+b)$$



1	2	3	4	5	6	7	8	9	10
3	3	2	3	1	4	3	3	3	3

Nuclear Fission → Splitting of an unstable (heavy) nucleus into lighter fragments, when struck by neutrons.

→ There exists an energy barrier to cross to form stable nuclei. To cross that energy barrier, neutrons are ~~strike~~ struck to parent nucleus.

Nuclear fuel → Criteria for using a nuclear fuel is its abundance. Uranium → most abundant nuclear fuel.
(U^{238})

→ On an average, only two ppm concentration of ^{238}U is available.

Nuclear Fuel

Nuclear Fuel → $^{238}U \longrightarrow {}^{238}U + {}^{235}U$

^{238}U: 99.3% → this is stable nucleus.

^{235}U: (0.5-0.7%) → this is radioactive

Enrichment → ^{235}U percentage is increased to 3%. Rest is ^{238}U.

$$A + n \longrightarrow B + C + Q$$

Q: (energy)

A → heavy nucleus

B, C → comparable mass nos.

Nuclear fission Reaction →

$$\underset{(\text{Slow moving})\ (0.04\ [illegible]\text{eV})}{{}^{235}_{92}U + {}^{1}_{0}n} \rightarrow \underset{\downarrow\ (\text{not found in nature})}{{}^{236}_{92}U} \rightarrow {}^{140}_{56}Ba + {}^{\cancel{94}\,93}_{36}Kr + \overset{3}{\cancel{2}}\,{}^{1}_{0}n + 200\,MeV$$

$${}^{236}_{92}U \rightarrow {}^{137}_{53}I + {}^{97}_{39}Y + 2\,{}^{1}_{0}n + 200\,MeV$$

→ Energy generated in each fission event → 200 MeV

→ Out of this ~ 15-20 MeV taken by $^{1}_{0}n$

Further decays →

$${}^{97}Y \xrightarrow{\beta^-} {}^{97}Zr \xrightarrow{\beta^-} {}^{97}Nb \xrightarrow{\beta^-} {}^{97}Mo$$

$${}^{137}I \xrightarrow{\beta^-} {}^{137}Xe \longrightarrow {}^{136}Xe + {}^{1}_{0}n$$

Radiation types → β-rays, neutrons, γ rays, α-rays, ν, $\bar{\nu}$

Chain Reaction → Secondary neutrons can start 2 to 3 more nuclear reactions. And these reaction may further generate upto 9 neutrons & a lot of energy. This is called as an uncontrolled chain reaction.

How can a chain reaction be controlled → If neutrons can be removed or absorbed then it can be controlled.

$$k,\ \text{reprod}^{n}\ \text{factor} = \frac{\text{rate of prod}^{n}\ \text{of neutrons}}{\text{rate of loss/absorption of neutrons}}$$

if $k > 1 \Rightarrow$ uncontrolled chain rxn, if $k < 1 \Rightarrow$ stoppage of fission.

Nuclear Reactor

→ U^{238} can absorb fast moving neutrom

→ k, reprod^n factor depends upon the size of Uranium fuel.

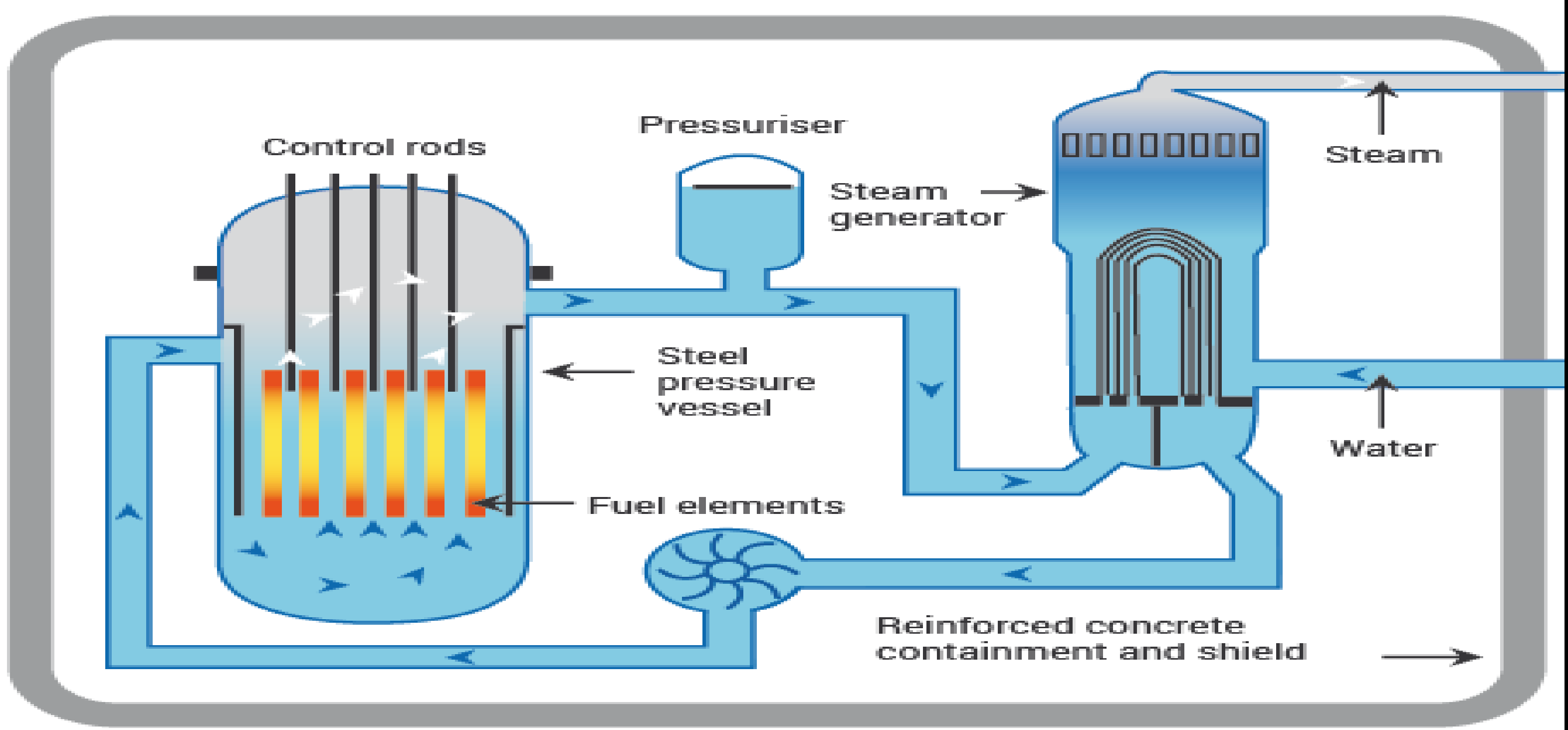
→ for $k = 1$, there is a critical size of Uranium fuel.

if size < critical size $\Rightarrow k > 1 \Rightarrow$ chain r^{xn} ↑

size > -ll- $\Rightarrow k < 1 \Rightarrow r^{xn}$ will stop

size = -ll- $\Rightarrow \boxed{k = 1} \rightarrow$ controlled r^{xn}

Nuclear Reactor



Fast Breeder Reactor

Nuclear reactor – 4 imp. elements

① Nuclear fuel → ^{238}U, ^{235}U → designed to match a critical size.
- ↳ this also absorbs the neutrons.

② Control Rods → Boron & Cadmium rods
- ↳ they absorb the neutrons
- ↳ they can control the rate of r^{xn} @ any stage.

③ Moderator → Heavy water, D_2O
- ↳ It slows down the neutron for ^{235}U fission to happen
- ↳ It shouldn't absorb the neutrons.

④ Coolant → It absorbs the heat generated & transfers to water.
- ↳ (Sodium metal)

What is fast breeder Reactor?

Reactor in which fresh fissionable fuel is generated along with the energy.

$$^{238}_{92}U + ^{1}_{0}n \longrightarrow ^{239}_{92}U \xrightarrow{2\beta^-} \boxed{^{239}_{94}Pu} \longrightarrow \boxed{fuel}$$

it is not available naturally

this is radioactive & quite stable

its half life 2400 yrs.

Nuclear fusion

$$A + B \rightarrow C + Q$$

when two lighter nuclei fuse together, they form a heavier stable nucleus & generate a lot of energy. This rxn requires a very high temp & pressure & hence not practically possible on earth.

$$4\,{}^{1}_{1}H \longrightarrow {}^{4}_{2}He + 2\,{}^{0}_{+1}\beta + 2\nu + 26\,MeV$$

$$\underset{(200\,MeV)}{\text{Energy generated per fission}} > \underset{(26\,MeV)}{\text{Energy generated per fusion}}$$

$$\underset{(200/235)}{\text{Energy generated per nucleon in fission}} << \underset{(26/4)}{\text{Energy gen. per nucleon in fusion}}$$

Radioactive Statistical Decay Law

Radioactivity was discovered by H. Becquerel in 1896 & Curie discovered → Radium

- 3 Units of radioactivity
  - → dps

$1\ Bq = 1\ dps$, $1\ Ci = 3.7 \times 10^{7}\ dps$

$1\ Ru = 10^{6}\ dps$

- Rutherford – Soddy Theory of Radioactive Decay
  - Nuclear phenomena
    - → ē configuration is immaterial
  - RA properties v/s chemical properties → independent properties.
    - → Chemical rxns depend upon T & P & env. condn.
    - → Nuclear phenomena don't T & P.
  - Random process

$$\underset{(RA)}{X} + \underset{(Not\ RA)}{y} \longrightarrow \underset{(RA)}{\cancel{X}}\ \underset{(Not\ RA)}{\cancel{y}}$$