CHAPTER NO. 21(NUCLEAR PHYSICS)

Question 21.1:- Find the mass defect and binding energy of the tritium, if the atomic mass of the tritium is 3.016049u.

Solution:- Mass of tritium nucleus = $m_{nucleus}$ = 3.016049u

Charge number of tritium = Z = 1

Mass number of tritium = A = 3

Mass defect = $\Delta m = Z\, m_P + (A - Z)\, m_n - m_{nucleus}$

$\Delta m = m_p + 2\, m_n - m_{nucleus} = (1.007276u) + 2(1.008665u) - 3.016049u$

$\Delta m = 0.00855u$

Binding energy = B.E. = $\Delta m\, c^2$

We know that 1 u = 931 MeV

B.E. = (0.00855) (931 MeV)

B.E. = 7.97 MeV

Question 21.2:- The half-life of $_{38}Sr^{91}$ is 9.70 hours. Find its decay constant.

Solution:- Half-life = $T_{1/2}$ = 9.70 hours = 9.70 x 3600 s = 3.492×10^4 s

Decay constant = $\lambda = 0.693/ T_{1/2} = 0.693/(3.492 \times 10^4)$

$\lambda = 0.199 \times 10^{-4}\ s^{-1}$

$\lambda = 1.99 \times 10^{-5}\ s^{-1}$

Question 21.3:- The element $_{91}Pa^{234}$ is unstable and decays by β-emission with a half-life 6.66 hours. State the nuclear reaction and the daughter nuclei.

Solution:- We know that charge number is increased by one and mass number remains the same in beta decay.

$$_{91}Pa^{234} \rightarrow {}_{92}Y^{234} + {}_{-1}e^{0}$$

Daughter nuclide = $_{92}U^{234}$

Question 21.4:- Find the energy associated with the following reaction: (Mass of $_1H^1$ = 1.00784u)

$$_{7}N^{14} + {}_{2}He^{4} \rightarrow {}_{8}O^{17} + {}_{1}H^{1}$$

What does negative sign indicate?

Solution:- Mass difference = Mass of reactants – Mass of products

Δm = [(Mass of $_7N^{14}$ + Mass of $_2He^4$)] – [(Mass of $_8O^{17}$) + (Mass of $_1H^1$)]

Δm = [14.0031u + 4.00264u] – [16.991u + 1.00784u] = - 0.0012u

$Q = \Delta m\, c^2$ = (-0.0012)(931 MeV)

Q = - 1.12 MeV

The negative sign indicates that 1.12 MeV energy is required to initiate this reaction.

Question 21.5:- Find the energy associated with the following reaction: (Mass of C^{14} = 14.0077u)

$$_{6}C^{14} \rightarrow {}_{7}N^{14} + {}_{-1}e^{0}$$

Solution:- Mass difference = Mass of reactants – Mass of products

$\Delta m = [(\text{Mass of } {}_{6}C^{14})] - [(\text{Mass of } {}_{7}N^{14}) + (\text{Mass of } {}_{-1}e^{0})]$

$\Delta m = [14.0077u] - [14.0031u + 0.00055u] = 0.00405u$

$Q = \Delta m\, c^2 = (0.00405)(931 \text{ MeV})$

Q = 3.77 MeV

Question 21.6:- If $_{92}U^{233}$ decays twice by α-emission, what is the resulting isotope?

Solution:- We know that mass number decreases by 4 and charge number decreases by 2 as a result of α-emission. The decay of $_{92}U^{233}$ by alpha emission twice is shown in the following:-

$$_{92}U^{233} \rightarrow {}_{90}Th^{229} + {}_{2}He^{4} \rightarrow {}_{88}Ra^{225} + {}_{2}He^{4}$$

Resulting isotope = $_{88}Ra^{225}$ ∴The answer in book $_{88}Rn^{225}$ is wrong

Question 21.7:- Calculate the energy (in MeV) released in the following fusion reaction:

$$_{1}H^{2} + {}_{1}H^{3} \rightarrow {}_{2}He^{4} + {}_{0}n^{1}$$

Solution:- Mass difference = Mass of reactants – Mass of products

$\Delta m = [(\text{Mass of } {}_{1}H^{2} + \text{Mass of } {}_{1}H^{3})] - [(\text{Mass of } {}_{2}He^{4}) + (\text{Mass of } {}_{0}n^{1})]$

$\Delta m = [2.014102u + 3.01605u] - [4.002603u + 1.008665u] = 0.018884u$

$Q = \Delta m\, c^2 = (0.018884)(931 \text{ MeV})$

Q = 17.6 MeV

Question 21.8:- A sheet of lead 5.0 mm thick reduces the intensity of a beam of γ-rays by a factor 0.4. Find half value thickness of lead sheet which will reduce the intensity to the half of its initial value.

Solution:- Thickness of lead sheet = x_1 = 5 mm = 0.005 m

Intensity reduction factor = $\frac{I}{I_o} = 0.4$

We know that intensity of radiation decreases in a solid as $\mathbf{I = I_o e^{-\mu x}}$ which can be rearranged as $\frac{I}{I_o} = e^{-\mu x}$

At $x = x_1$, $\frac{I}{I_o} = 0.4$

$0.4 = e^{-\mu x_1}$

Take natural logarithm on both sides

$\ln(0.4) = \ln(e^{-\mu x_1})$

$-0.916 = -\mu x_1$

$\mu = 0.916/0.005$

<u>$\mu = 183.2\ m^{-1}$</u>

Now, we want find the depth (value of x) for which intensity reduction factor is 0.5 i.e. $\frac{I}{I_o} = 0.5$

We will use the relation $\frac{I}{I_o} = e^{-\mu x}$

Put value of $\frac{I}{I_o} = 0.5$ and $\mu = 183.2\ m^{-1}$

$0.5 = e^{-183.2x}$

Take natural logarithm on both sides

$\ln(0.5) = \ln(e^{-183.2x})$

$-0.693 = -183.2\ x$

$x = 0.693/183.2 = 0.00378\ m$

<u>**x = 3.78 mm**</u>

Question 21.9:- Radiation from a point source obeys inverse square law. If the count rate at a distance of 1.0 m from Geiger counter is 360 counts per minute, what will be its count rate at 3.0 m from the source?

Solution:- Initial distance = r_1 = 1.0 m

Initial count rate = R_1 = 360 counts per minute

Final distance = r_2 = 3.0 m

Final count rate = R_2

Inverse square law states that $R \propto \frac{1}{r^2}$

So we can say that

$$\frac{R_2}{R_1} = \frac{r_1^2}{r_2^2}$$

$R_2 = R_1\left(\frac{r_1^2}{r_2^2}\right) = (360)\left(\frac{1^2}{3^2}\right) = (360)(1/9)$

<u>**R_2 = 40 counts per minute**</u>

Question 21.10:- A 75 kg person receives a whole body radiation dose of 24 m-rad, delivered by α-particles for which RBE factor is 12. Calculate (a) the absorbed energy in joules, and (b) the equivalent does in rem.

Solution:- Mass of the person = m = 75 kg

Absorbed dose = D = 24 m-rad = 24×10^{-3} rad

We know that 1 rad = 0.01 Gy

$D = 24 \times 10^{-3} \times 10^{-2}\ Gy = 24 \times 10^{-5}\ Gy$

RBE = 12

(a) D = E/m

$E = D \times m = 24 \times 10^{-5} \times 75$

$E = 1800 \times 10^{-5}$ J

<u>E = 18 mJ</u>

(b) $D_e = D \times RBE = 24 \times 10^{-5} \times 12$

$D_e = 288 \times 10^{-5}$ Sv

We know that 1 Sv = 100 rem

$D_e = 288 \times 10^{-5} \times 100$ rem

$D_e = 288 \times 10^{-3}$ rem = 0.288 rem

<u>D_e = 0.29 rem</u>

For Your Information

Some atomic masses

Particle	Mass (u)
e	0.00055
n	1.008665
^{1}H	1.007276
^{2}H	2.014102
^{3}H	3.01605
^{3}He	3.01603
^{4}He	4.002603
^{7}Li	7.016004
^{10}Be	10.013534
^{14}N	14.0031
^{17}O	16.9991