

**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 =  $m_{\text{nucleus}} = 3.016049\text{u}$

Charge number of tritium =  $Z = 1$

Mass number of tritium =  $A = 3$

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

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

**$\Delta m = 0.00855\text{u}$**

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

We know that  $1 \text{ u} = 931 \text{ MeV}$

B.E. =  $(0.00855) (931 \text{ MeV})$

**B.E. = 7.97 MeV**

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

**Solution:-** Half-life =  $T_{1/2} = 9.70 \text{ hours} = 9.70 \times 3600 \text{ s} = 3.492 \times 10^4 \text{ s}$

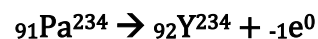
Decay constant =  $\lambda = 0.693 / T_{1/2} = 0.693 / (3.492 \times 10^4)$

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

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

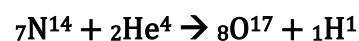
**Question 21.3:- The element  ${}_{91}\text{Pa}^{234}$  is unstable and decays by  $\beta$ -emission with a half-life 6.66 hours. State the nuclear reaction and the daughter nuclei.**

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



**Daughter nuclide =  ${}_{92}\text{U}^{234}$**

**Question 21.4:- Find the energy associated with the following reaction: (Mass of  ${}_{1}\text{H}^1 = 1.00784\text{u}$ )**



**What does negative sign indicate?**

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

$\Delta m = [(\text{Mass of } {}_{7}\text{N}^{14} + \text{Mass of } {}_{2}\text{He}^4)] - [(\text{Mass of } {}_{8}\text{O}^{17}) + (\text{Mass of } {}_{1}\text{H}^1)]$

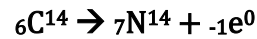
$\Delta m = [14.0031\text{u} + 4.00264\text{u}] - [16.991\text{u} + 1.00784\text{u}] = -0.0012\text{u}$

$Q = \Delta m c^2 = (-0.0012)(931 \text{ MeV})$

**$Q = -1.12 \text{ MeV}$**

**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  ${}^{14}_6\text{C} = 14.0077\text{u}$ )



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

$$\Delta m = [(\text{Mass of } {}^{14}_6\text{C})] - [(\text{Mass of } {}^{14}_7\text{N}) + (\text{Mass of } {}^0_{-1}\text{e})]$$

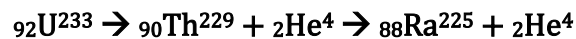
$$\Delta m = [14.0077\text{u}] - [14.0031\text{u} + 0.00055\text{u}] = 0.00405\text{u}$$

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

$$Q = 3.77 \text{ MeV}$$

**Question 21.6:-** If  ${}^{233}_{92}\text{U}$  decays twice by  $\alpha$ -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  $\alpha$ -emission. The decay of  ${}^{233}_{92}\text{U}$  by alpha emission twice is shown in the following:-



**Resulting isotope =  ${}^{225}_{88}\text{Ra}$**

$\therefore$  The answer in book  ${}^{225}_{88}\text{Rn}$  is wrong

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



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

$$\Delta m = [(\text{Mass of } {}^1_1\text{H}^2 + \text{Mass of } {}^1_1\text{H}^3)] - [(\text{Mass of } {}^2_2\text{He}^4) + (\text{Mass of } {}^1_0\text{n})]$$

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

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

$$Q = 17.6 \text{ MeV}$$

**Question 21.8:-** A sheet of lead 5.0 mm thick reduces the intensity of a beam of  $\gamma$ -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 =  $x_1 = 5 \text{ mm} = 0.005 \text{ m}$

$$\text{Intensity reduction factor} = \frac{I}{I_0} = 0.4$$

We know that intensity of radiation decreases in a solid as  $I = I_0 e^{-\mu x}$  which can be rearranged

$$\text{as } \frac{I}{I_0} = e^{-\mu x}$$

$$\text{At } x = x_1, \frac{I}{I_0} = 0.4$$

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

Take natural logarithm on both sides

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

$$-0.916 = -\mu x_1$$

$$\mu = 0.916/0.005$$

$$\mu = 183.2 \text{ m}^{-1}$$

Now, we want find the depth (value of  $x$ ) for which intensity reduction factor is 0.5 i.e.  $\frac{I}{I_0} = 0.5$

We will use the relation  $\frac{I}{I_0} = e^{-\mu x}$

Put value of  $\frac{I}{I_0} = 0.5$  and  $\mu = 183.2 \text{ m}^{-1}$

$$0.5 = e^{-183.2x}$$

Take natural logarithm on both sides

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

$$-0.693 = -183.2x$$

$$x = 0.693/183.2 = 0.00378 \text{ m}$$

$$\mathbf{x = 3.78 \text{ mm}}$$

**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 =  $r_1 = 1.0 \text{ m}$

Initial count rate =  $R_1 = 360$  counts per minute

Final distance =  $r_2 = 3.0 \text{ m}$

Final count rate =  $R_2$

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

So we can say that

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

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

$$\mathbf{R_2 = 40 \text{ counts per minute}}$$

**Question 21.10:-** A 75 kg person receives a whole body radiation dose of 24 m-rad, delivered by  $\alpha$ -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 =  $m = 75 \text{ kg}$

Absorbed dose =  $D = 24 \text{ m-rad} = 24 \times 10^{-3} \text{ rad}$

We know that  $1 \text{ rad} = 0.01 \text{ Gy}$

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

$$\text{RBE} = 12$$

$$\mathbf{(a) D = E/m}$$

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

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

$$\underline{E = 18 \text{ mJ}}$$

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

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

We know that  $1 \text{ Sv} = 100 \text{ rem}$

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

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

$$\underline{D_e = 0.29 \text{ rem}}$$

**For Your Information**

**Some atomic masses**

Particle	Mass (u)
e	0.00055
n	1.008665
$^1\text{H}$	1.007276
$^2\text{H}$	2.014102
$^3\text{H}$	3.01605
$^3\text{He}$	3.01603
$^4\text{He}$	4.002603
$^7\text{Li}$	7.016004
$^{10}\text{Be}$	10.013534
$^{14}\text{N}$	14.0031
$^{16}\text{O}$	16.9991