

Name: Josh WhiteheadUID: U1069343

Homework #1 – Due on September 17, 2021

1. Answer the following short-answer questions (1 point)

Question	Answer
a. How many neutrons are in $^{244}\text{Pu}$	There are 150 neutrons in $^{244}\text{Pu}$
b. True/False: Most stable nuclei exist with an even pairing of neutrons and protons	True
c. True/False: All odd-odd nuclei are radioactive.	False
d. What force holds the nucleus together?	The Strong Force
e. What daughter is produced from the alpha decay of $^{239}\text{Pu}$ ?	$^{235}\text{U}$
f. Based on the ratio of protons to neutrons and the atomic mass of the nuclide, what is the most likely mode of decay of $^{47}\text{Ca}$ ?	$^{20}\text{P}$ $^{27}\text{N}$ Negatron Decay
g. What is parent nuclide that could positron decay to form $^{169}\text{Yb}$ ?	$^{70}\text{P}$ $^{169}\text{N}$ $^{169}\text{Lu}$
h. If a proton rich nuclide has a total radioactive decay energy of 0.5 MeV, then it will decay by positron emission.	True
i. True/False: Because total mass must always be conserved, the mass of the bound nucleons in a nucleus will always equal the mass of the unbound nucleons.	False
j. True/False: If we take two lighter nuclei, which have lower binding energies per nucleons, then we can fuse them together to form a nucleus that has greater stability.	True

2. What is the mass in kg of a molecule of uranyl sulfate ( $\text{UO}_2\text{SO}_4$ )? (1 point)

$$M_{\text{U}} = 238.0289 \frac{\text{g}}{\text{mol}}$$

$$M_{\text{O}} = 15.9994 \frac{\text{g}}{\text{mol}}$$

$$M_{\text{S}} = 32.065 \frac{\text{g}}{\text{mol}}$$

$$M_{\text{UO}_2\text{SO}_4} = [238.0289 + 6(15.9994) + 32.065] \frac{\text{g}}{\text{mol}} = 366.0903 \frac{\text{g}}{\text{mol}}$$

$$N_{\text{A}} = 6.022 \times 10^{23} \frac{\text{molecule}}{\text{molecule}}$$

$$m = 366.0903 \frac{\text{g}}{\text{mol}} \cdot \frac{1 \cancel{\text{mol}}}{6.022 \times 10^{23} \text{ molecules}} = 6.0792145 \times 10^{-22} \frac{\text{g}}{\text{molecules}}$$

$$= 6.079214547 \times 10^{-25} \text{ kg}$$

Answer:  $6.079214547 \times 10^{-25} \text{ kg}$



3. How many atoms of  $^{234}\text{U}$  are there in 1 kg of natural uranium? (1 point)

in U,  $\begin{cases} 99.2742\% & ^{238}\text{U} \\ 0.7204\% & ^{235}\text{U} \\ 0.0054\% & ^{234}\text{U} \end{cases}$

$$\therefore 1 \text{ kg U} \Rightarrow 0.000054 \text{ kg } ^{234}\text{U}$$

$$M_{\text{molar}} = 0.23404095 \frac{\text{kg}}{\text{mol}}$$

$$\Rightarrow 0.000054 \text{ kg} \cdot \frac{1 \text{ mol}}{0.23404095 \text{ kg}} = 2.30729 \times 10^{-4} \text{ mol} \cdot 6.022 \times 10^{23} \frac{\text{atoms}}{\text{mol}}$$

$$= 1.38945 \times 10^{20}$$

Answer:  $1.38945 \times 10^{20}$  atoms

4. A crystal of  $^{22}\text{Na}^{127}\text{I}$  has a density of  $2.17 \text{ g/cm}^3$ . What is the atom density of sodium in the crystal? (1 point)

$$N = \frac{\rho}{A} N_A$$

$$N_A = 6.022 \times 10^{23}$$

$$\rho = 2.17 \text{ g/cm}^3$$

$$A = 21.99443755 \frac{\text{g}}{\text{mol}} + 126.904473 \frac{\text{g}}{\text{mol}}$$

$$= 148.8989106 \frac{\text{g}}{\text{mol}}$$

$$\therefore N = \frac{2.17 \frac{\text{g}}{\text{cm}^3}}{148.8989106 \frac{\text{g}}{\text{mol}}} \cdot 6.022 \times 10^{23} \frac{\text{atom}}{\text{mol}} = 8.77625 \times 10^{21} \frac{\text{atom}}{\text{cm}^3}$$

Answer:  $8.77625 \times 10^{21} \frac{\text{atom}}{\text{cm}^3}$

5. What is the mass defect of  $^{142}\text{La}$ ? (1 point)

$$\Delta M_A = M_A - ZM_H - NM_N$$

$$M_A = 141.914091 \frac{\text{g}}{\text{mol}}$$

$$Z = 57$$

$$M_H = 1.007825$$

$$N = 85$$

$$M_N = 1.008665$$

$$\therefore \Delta M_A = 141.914091 - 57(1.007825) - 85(1.008665)$$

$$= -1.268459 \text{ amu}$$

Answer: -1.268459 amu



6. What is the binding energy of  $^{144}\text{Nd}$ ? (1 point)

$$BE = -931.5 \Delta M_A$$

$$\Delta M_A = M_A - Z M_H - N M_N$$

$$= 143.9100928 - 60(1.007825) - 84(1.008665)$$

$$= -1.2872672 \text{ amu}$$

$$BE = -931.5 \cdot -1.2872672$$

Answer: 1199.089397 MeV

7. What is the activity of 0.1000 micro grams of  $^{235}\text{Np}$ ? (1 point)

$$A = \lambda N$$

$$t_{1/2} = 396.1 \text{ d} = 3.42 \times 10^7 \text{ sec}$$

$$\lambda = \frac{\ln(2)}{t_{1/2}}$$

$$\therefore \lambda = \frac{\ln(2)}{3.42 \times 10^7 \text{ sec}} = 2.02675 \times 10^{-8} \frac{1}{\text{sec}}$$

$$N = 1 \times 10^{-7} \text{ g} \cdot \frac{1 \text{ mol}}{235.0440615 \text{ g}} \cdot 6.022 \times 10^{23} \frac{\text{atoms}}{\text{mol}} = 2.56 \times 10^{14} \text{ atoms}$$

$$A = 2.02675 \times 10^{-8} \cdot 2.56 \times 10^{14} = 5.19 \times 10^6 \text{ Bq} \cdot \frac{1 \text{ Ci}}{3.7 \times 10^{10} \text{ Bq}}$$

$$= 1.40 \times 10^{-4} \text{ Ci}$$

Answer:  $1.40 \times 10^{-4} \text{ Ci}$

8. How many grams of  $^{232}\text{Th}$  are in a 100 mCi source? (1 point)

$$A = \lambda N \rightarrow N = \frac{A}{\lambda}$$

$$A = 100 \text{ mCi} = 0.1 \text{ Ci} \cdot \frac{3.7 \times 10^{10} \text{ Bq}}{1 \text{ Ci}}$$

$$A = 3.7 \times 10^9 \frac{\text{atom}}{\text{sec}}$$

$$\lambda = \frac{\ln(2)}{t_{1/2}} = \frac{\ln(2)}{4.42 \times 10^{17} \text{ sec}} = 1.56821 \times 10^{-18} \frac{1}{\text{sec}}$$

$$A = \frac{3.7 \times 10^9 \frac{\text{atom}}{\text{sec}}}{1.56821 \times 10^{-18} \frac{1}{\text{sec}}} = 2.35938 \times 10^{27} \text{ atoms} \cdot \frac{1 \text{ mol}}{6.022 \times 10^{23} \text{ atoms}}$$

$$= 3917.940003 \text{ mol} \cdot \frac{232.0380536 \text{ g}}{1 \text{ mol}} = 909111.1724$$

Answer:  $9.091111724 \times 10^5 \text{ g}$



9. A sample of radioactive Iodine (I-131), has been decaying for 65 days. The current activity of the sample is 12,345 dps. What was the initial activity of the sample in DPS? (1 point)

$$A = A_0 e^{-\lambda t} \rightarrow A_0 = \frac{A}{e^{-\lambda t}}$$

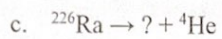
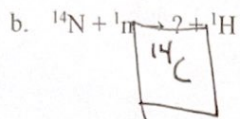
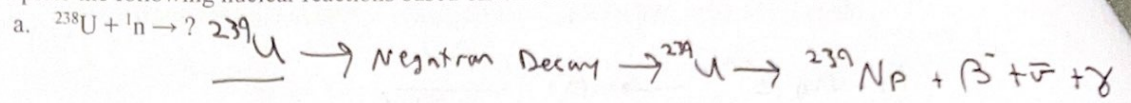
~~XXXXXXXXXX~~ 
$$\lambda = \frac{\ln(2)}{t_{1/2}} = \frac{\ln(2)}{6.93 \times 10^5 \text{ sec}} = 1.00021 \times 10^{-6} \frac{1}{\text{sec}} \cdot \frac{60 \text{ sec}}{1 \text{ min}} \cdot \frac{60 \text{ min}}{1 \text{ hr}} \cdot \frac{24 \text{ hr}}{1 \text{ day}}$$

$$\lambda = 0.08641835 \frac{1}{\text{day}}$$

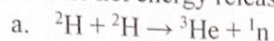
$$\therefore A_0 = \frac{12345 \text{ dps}}{e^{-(0.08641835 \cdot 65)}} = 3396306.711 \text{ dps}$$

Answer: 3.396306711  $\times 10^6$  dps

10. Complete the following nuclear reactions based on the conservation of nucleons. (1 point)



11. What is the net energy released for the following fusion reactions? (1 point)



$$E = mc^2$$

$$c = 2.99792458 \times 10^8 \frac{\text{m}}{\text{sec}}$$

$$m = \Delta M_A$$

$$M_{{}^2\text{H}} = 2.01410177784$$

$$M_{{}^3\text{He}} = 3.01602932197$$

$$M_{{}^1_0\text{n}} = 1.008665$$

$$\therefore m = M_{{}^3\text{He}} + M_{{}^1_0\text{n}} - 2M_{{}^2\text{H}} = 3.01602932197 + 1.008665 - 2(2.01410177784)$$

$$m = -3.50923 \times 10^{-3} \frac{\text{g}}{\text{mol}} = -3.50923 \times 10^{-6} \frac{\text{kg}}{\text{mol}} \cdot 1 \text{ mol}$$

~~$$E = -3.50923 \times 10^{-3} \frac{\text{g}}{\text{mol}} c^2 = -3.50923 \times 10^{-3} \frac{\text{g}}{\text{mol}} (2.99792458 \times 10^8 \frac{\text{m}}{\text{sec}})^2$$~~

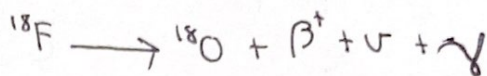
$$E = mc^2 = -3.15394 \times 10^8 \text{ J}$$

Answer:  $-3.15394 \times 10^8 \text{ J}$



12. Write the full radioactive decay equation then calculate the Q-value for the radioactive decay of the following radionuclides. (1.5 points)

a. Positron Decay of  $^{18}\text{F}$



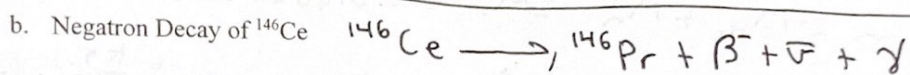
$$Q_{\beta^+} = -931.5 (M_{\text{O}} + 2M_e - M_{\text{F}})$$

$$= -931.5 (17.9991596121 + 2(5.45 \times 10^{-4}) - 18.0009373)$$

$$= 0.640581279$$

Answer (Q-Value): 0.640581279 MeV

b. Negatron Decay of  $^{146}\text{Ce}$

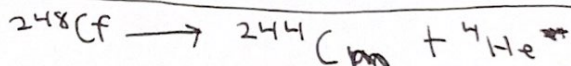


$$Q_{\beta^-} = -931.5 (M_{\text{Pr}} - M_{\text{Ce}})$$

$$= -931.5 (145.91769 - 145.918812) = 1.045143$$

Answer (Q-Value): 1.045143 MeV

c. Alphas Decay of  $^{248}\text{Cf}$



$$Q_{\alpha} = -931.5 (M_{\text{Cm}} + M_{\text{He}} - M_{\text{Cf}})$$

$$= -931.5 (244.0627506 + 4.00260325413 - 248.072183)$$

$$= 6.361349378$$

Answer (Q-Value): 6.361349378 MeV

13. A 40 mg sample of pure  $^{226}\text{Ra}$  is encapsulated. How long will it take for the activity of  $^{222}\text{Rn}$  to build up to 10 mCi? (1.5 points)

~~$$\frac{dN_B}{dt} = \lambda_A N_A - \lambda_B N_B$$~~

~~$$\lambda_B N_B = \lambda_A N_A$$~~

~~$$N_B = \frac{\lambda_A}{\lambda_B - \lambda_A} N_A^0 (e^{-\lambda_A t} - e^{-\lambda_B t}) + N_B^0 e^{-\lambda_B t}$$~~

$$N_{B0} = 0$$

$$N_B = \frac{\lambda_A}{\lambda_B - \lambda_A} N_A^0 (e^{-\lambda_A t} - e^{-\lambda_B t})$$

$$A_B = \lambda_B N_B = \frac{\lambda_A \lambda_B}{\lambda_B - \lambda_A} N_A^0 (e^{-\lambda_A t} - e^{-\lambda_B t})$$

$$A_B = 0.01 \text{ Ci} = \frac{3.7 \times 10^{10} \text{ Ba}}{1 \text{ Ci}} = 3.7 \times 10^5 \frac{\text{atom}}{\text{sec}}$$

$$\lambda_A = \frac{\ln(2)}{5.05 \times 10^{10}} = 1.37257 \times 10^{-11} \frac{1}{\text{sec}}$$

$$\lambda_B = \frac{\ln(2)}{3.3 \times 10^5} = 2.10045 \times 10^{-6} \frac{1}{\text{sec}}$$

$$N_A^0 = 0.04 \text{ g} = \frac{1 \text{ mol}}{226.02541082 \text{ g}} \cdot \frac{6.022 \times 10^{23} \text{ atom}}{\text{mol}} = 1.06572 \times 10^{20} \text{ atom}$$

$$3.7 \times 10^5 = \frac{1.37257 \times 10^{-11} \cdot 2.10045 \times 10^{-6}}{2.10045 \times 10^{-6} - 1.37257 \times 10^{-11}} \cdot 1.06572 \times 10^{20} (e^{-1.37257 \times 10^{-11} t} - e^{-2.10045 \times 10^{-6} t})$$

$$t = 120.4391195 \text{ sec}$$

Answer: 120.4391195 sec



14. The average mass of potassium in the human body is about 140 grams. From the abundance and the half-life of  $^{40}\text{K}$ , estimate the average activity (Bq) of  $^{40}\text{K}$  in the body. (1 point)

$$A = \lambda N \quad \lambda = \frac{\ln(2)}{t_{1/2}} = \frac{\ln(2)}{3.94 \times 10^{16} \text{ sec}} = 1.75926 \times 10^{-17} \frac{1}{\text{sec}}$$

$$N = 140 \text{ g} \cdot \frac{1 \text{ mol}}{39.96399817 \text{ g}} \cdot \frac{6.022 \times 10^{23} \text{ atoms}}{\text{mol}} = 2.1096 \times 10^{24} \text{ atoms}$$

$$A = 1.75926 \times 10^{-17} \frac{1}{\text{sec}} \cdot 2.1096 \times 10^{24} \text{ atoms} = 37113259.28 \frac{\text{atoms}}{\text{sec}}$$

Answer:  $3.711325928 \times 10^7 \text{ Bq}$