Name: Josh whitehead UID: 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}Pu	There are 150 neutrons in ^{244}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}Pu?	^{235}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}Ca?	20 P 27 N Negatron Decay
g. What is parent nuclide that could positron decay to form ^{169}Yb?	70 P 169 N ^{169}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 (UO_2SO_4)? (1 point)

$M_U = 238.0289 \ \frac{g}{mol}$

$M_O = 15.9994 \ \frac{g}{mol}$

$M_S = 32.065 \ \frac{g}{mol}$

$M_{UO_2SO_4} = \left[238.0289 + 6(15.9994) + 32.065\right]\frac{g}{mol} = 366.0903 \ \frac{g}{mol}$

$N_A = 6.022 \times 10^{23} \ \frac{molecule}{mole}$

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

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

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

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

in U, 99.2742% ^{238}U

0.7204% ^{235}U

0.0054% ^{234}U

$\therefore$ 1 kg U => 0.000054 kg ^{234}U

$M_{w}^{234}U = 0.23404095 \frac{kg}{mol}$

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

$= 1.38945 \times 10^{20}$

Answer: 1.38945×10^{20} atoms

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

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

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

$\rho = 2.17\ g/cm^3$

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

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

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

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

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

$\Delta M_A = M_A - ZM_H - NM_N$

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

$Z = 57$ $M_H = 1.007825$

$N = 85$ $M_N = 1.008665$

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

$= -1.268459$ amu

Answer: -1.268459 amu

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

$BE = -931.5 \Delta M_A$

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

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

$= -1.2872672$ amu

$BE = -931.5 \cdot -1.2872672$

Answer: 1199.089397 MeV

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

$A = \lambda N$ $\qquad t_{1/2} = 396.1\,d = 3.42 \times 10^{7}\ sec$

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

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

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

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

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

Answer: 1.40×10^{-4} Ci

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

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

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

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

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

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

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

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

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)

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

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

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

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

Answer: 3.396306711×10^6 dps

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

a. $^{238}U + {}^{1}n \rightarrow$? $^{239}U \rightarrow$ Negatron Decay $\rightarrow {}^{239}U \rightarrow {}^{239}Np + \beta^{-} + \bar{\nu} + \gamma$

b. $^{14}N + {}^{1}n \rightarrow$? $+ {}^{1}H$

$\boxed{^{14}C}$

c. $^{226}Ra \rightarrow$? $+ {}^{4}He$

$\boxed{^{222}Rn}$

d. ? $\rightarrow {}^{230}Th + {}^{4}He$

$\boxed{^{234}U}$

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

a. $^{2}H + ^{2}H \rightarrow ^{3}He + ^{1}n$

$E = mc^2$ $\qquad c = 2.99792458 \times 10^{8} \ \frac{m}{sec}$

$m = \Delta M_A$

$M_{^2H} = 2.01410177784$

$M_{^3He} = 3.01602932197$

$M_{^1n} = 1.008665$

$\therefore m = M_{He} + M_n - 2M_H = 3.01602932197 + 1.008665 - 2(2.01410177784)$

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

$\cancel{E = -3.50923 \times 10^{-3} \ \frac{g}{mol} \cdot c^2 =}$ [illegible]

$E = mc^2 = -3.15394 \times 10^{11} \ J$

Answer: -3.15394×10^{11} 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}F $\quad ^{18}F \longrightarrow {}^{18}O + \beta^{+} + \nu + \gamma$

$$Q\beta^{+} = -931.5\left(M_O + 2M_e - M_F\right)$$

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

$$= 0.640581279$$

Answer (Q-Value): 0.640581279 MeV

b. Negatron Decay of ^{146}Ce $\quad ^{146}Ce \longrightarrow {}^{146}Pr + \beta^{-} + \bar{\nu} + \gamma$

$$Q\beta^{-} = -931.5\left(M_{Pr} - M_{Ce}\right)$$

$$= -931.5\left(145.91769 - 145.918812\right) = 1.045143$$

Answer (Q-Value): 1.045143 MeV

c. Alphas Decay of ^{248}Cf

$$^{248}Cf \longrightarrow {}^{244}Cm + {}^{4}He$$

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

$$= -931.5\left(244.0627506 + 4.0026032 5413 - 248.072183\right)$$

$$= 6.361349378$$

Answer (Q-Value): 6.361349378 MeV

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

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

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

$N_{B_0} = 0$

$\therefore$

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

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

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

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

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

$$N_A^0 = 0.04\ g \cdot \frac{1\ mol}{226.0254082\ g} \cdot \frac{6.022 \times 10^{23}\ atom}{mol} = 1.06572 \times 10^{20}\ atom$$

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

$t = 120.4391195$ 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}K, estimate the average activity (Bq) of ^{40}K in the body. (1 point)

$$A = \lambda N \qquad \lambda = \frac{\ln(2)}{t_{1/2}} = \frac{\ln(2)}{3.94\times10^{16}\ \text{sec}} = 1.75926\times10^{-17}\ \frac{1}{\text{sec}}$$

$$N = 140\ \cancel{g} \cdot \frac{1\ \cancel{mol}}{39.96399817\ \cancel{g}} \cdot \frac{6.022\times10^{23}\ \text{atom}}{\cancel{mol}} = 2.1096\times10^{24}\ \text{atom}$$

$$A = 1.75926\times10^{-17}\ \frac{1}{\text{sec}} \cdot 2.1096\times10^{24}\ \text{atoms} = 37113259.28\ \frac{\text{atom}}{\text{sec}}$$

Answer: 3.711325928×10^{7} Bq