Nuclear Chemistry Test ; Study Guide - Answers

2. a)

Nuclide	Nuclear Charge	Mass Number	Symbol
Alpha particle	+2	4	α or ${}^{4}_{2}He$
β^- particle	−1	0	β^- or ${}^{0}_{-1}e$
Positron	+1	0	${}^{0}_{+1}e$
Gamma Ray	0	0	${}^{0}_{0}\gamma$
Neutron	0	1	${}^{1}_{0}n$

b)

Reaction	General Equation
Alpha Decay	${}^{A}_{Z}X \rightarrow {}^{A-4}_{Z-2}Y + {}^{4}_{2}He$
β^- Decay	${}^{A}_{Z}X \rightarrow {}^{A}_{Z+1}Y + {}^{0}_{-1}e$
Positron Emission	${}^{A}_{Z}X \rightarrow {}^{A}_{Z-1}Y + {}^{0}_{+1}e$
Electron Capture	${}^{A}_{Z}X + {}^{0}_{-1}e \rightarrow {}^{A}_{Z-1}Y$

3. $C = C_0 e^{-kt} = C_0 e^{-\frac{\ln 2}{t_{1/2}} t}$

At $t = 24.6$ years, $C = 0.25\, C_0$ (75% has decayed)

$$C = C_0 e^{-\frac{\ln 2}{t_{1/2}} t}$$

$$0.25\, C_0 = C_0 e^{\frac{-\ln 2}{t_{1/2}}(24.6)}$$

$$\ln(0.25) = -\frac{\ln 2}{t_{1/2}}(24.6)$$

$$t_{1/2} = 12.3 \text{ years}$$

4. $t_{1/2} = 8.05$ days ; $C_0 = 2.4$ mL ; $C(t) = 1.0$ mL ; $t = ?$

$$C(t) = C = C_0 e^{-\frac{\ln 2}{t_{1/2}} t}$$

$$1 = 2.4\, e^{-\frac{\ln 2}{8.05} t}$$

$$\ln\left(\frac{1}{2.4}\right) = -\frac{\ln 2}{8.05} t$$

$t = 10.167$ days

= 10 days, 4 hours, 1 minute, 5.7 seconds

M T W Th F S Su

Thursday at 7:01 pm and 5.7 seconds

5. **Cr-60** Cr-45 Cr-44 Cr-52

	$^{60}_{24}Cr$	$^{45}_{24}Cr$	$^{44}_{24}Cr$	$^{52}_{24}Cr$
$\frac{N}{Z} =$	$\frac{60-24}{24} = \frac{36}{24} = 1.5$	$\frac{45-24}{24} = \frac{21}{24} = 0.875$	$\frac{44-24}{24} = \frac{20}{24} = 0.833$	$\frac{52-24}{24} = \frac{28}{24} = 1.167$

Stable nuclei tend to have N/Z between 1 + 1.5.

β^- decay increases Z and decreases N.

Since, Cr-60 has the highest N/Z ratio, it is most likely to decay by β^- decay.

6. Oxygen-14 ⇒ $^{14}_{8}O$ ⇒ $\frac{N}{Z} = \frac{14-8}{8} = \frac{6}{8} = 0.75$

$\frac{N}{Z}$ too low. Most likely to decay by a process that increases N, decreases Z, or both: [illegible] (prove to yourself that α-decay won't work)

$^{0}_{+1}e$ emission

7. $^{240}_{94}Pu \rightarrow ^{4}_{2}He + ^{236}_{92}U$

$m(^{240}P) = 240.0538$ amu

$m(^{4}He) = 4.0026$ amu

$m(^{236}U) = 236.0456$ amu

$\Delta m = [4.0026 + 236.0456] - [240.0538]$

$= -0.0056$ amu

$= -9.299 \times 10^{-30}$ kg

$\Delta E = \Delta mc^2 = (-9.299 \times 10^{-30}\ J)(3 \times 10^8)^2 = -8.3689 \times 10^{-13}\ J/rxn$

$= (-8.3689 \times 10^{-13})(6.022 \times 10^{23}) \times 10^{-3} = -5.0398 \times 10^{8}\ kJ/mol\ rxn$

$= (-5.0398 \times 10^{8})/240.0538 = -2.0994 \times 10^{6}\ kJ/g\ ^{240}Pu$

8. $^{40}K \rightarrow ^{0}_{-1}e + ^{40}Ca$

$m(^{40}Ca) = 39.9626$

$m(^{40}K) = 39.9640$

$m(^{0}_{-1}e) = 5.4858 \times 10^{-4}$

$\Delta m = [5.4858 \times 10^{-4} + 39.9626] - [39.9640]$

$= -0.0008514$ amu

$= -1.4138 \times 10^{-30}$ kg

$\Delta E = \Delta mc^2 = -1.2724 \times 10^{-13}\ J/rxn$

$= -7.6624 \times 10^{7}\ kJ/mol\ rxn$

$= -1.9173 \times 10^{6}\ kJ/g\ ^{40}K$

$50\ kg\ ^{40}K \times \frac{1000\ g\ ^{40}K}{1\ kg\ ^{40}K} \times \frac{-1.9173 \times 10^{6}\ kJ}{1\ g\ ^{40}K} = -9.5865 \times 10^{10}\ kJ$

9. Factors Determining Toxicity of Radioactive Particles (Products of Nuclear Reactions)

1. Ionizing Ability: the relative ability of a particle to ionize other molecules

strongest IA $^{4}_{2}He$, $^{0}_{+1}e$ / $^{0}_{-1}e$, $^{0}_{0}\gamma$ weakest IA

higher mass
higher charge

lower mass
lower charge

2. Penetrating Ability: the relative ability of a particle to penetrate a material

strongest PA $^{0}_{0}\gamma$, $^{0}_{+1}e$ / $^{0}_{-1}e$, $^{4}_{2}He$ weakest PA

3. Biocompatability: the similarity of a radioactive, unstable nucleus to other elements in the human body; also related to half-life of nucleus, life-cycle of nucleus in body, organ/tissue which it affects

10. $^{211}_{82}Pb \rightarrow {}^{0}_{-1}e + {}^{211}_{83}Bi$; $^{238}_{94}Pu \rightarrow {}^{4}_{2}He + {}^{234}_{92}U$

	^{211}Pb	^{238}Pu
Time in body:	10 years	40 years
Location in body:	Bones	Liver
Particles Emitted:	$^{0}_{-1}e$	$^{4}_{2}He$
Half-Life:	36 minutes	88 years

Convincing arguments could be made for the relative toxicity of either nuclide. Good arguments will be specific, comparing each nuclide based on the four categories listed above. One sentence in a good argument might be:

"Though the half-life of ^{238}Pu is much longer than that of ^{211}Pb, the significantly higher ionization activity of $^{4}_{2}He$ compared to $^{0}_{-1}e$ makes ^{238}Pu the more toxic radioactive nucleus."