CHEM 2
Problem Set Ch.20 **Key Begins on Page 3.**

1. Write the complete nuclear equation for the following processes:
   a) tritium, ${}^{3}_{1}H$, undergoes β decay.

   b) Plutonium-242 (^{242}Pu) undergoes α particle emission.

2. Why is it impossible for the isotope ${}^{2}_{2}He$ to exist?

3. For each pair of isotopes listed, indicate the nuclide that is radioactive:
   a) ${}^{95}_{42}Mo$ or ${}^{92}_{43}Tc$ b) ${}^{22}_{11}Na$ or ${}^{25}_{11}Na$ c) ${}^{40}_{20}Ca$ or ${}^{45}_{20}Ca$

4. The radioactive decay of Tl-206 to Pb-206 has a half-life of 4.20 min. Starting with 5.00 x 10^{22} atoms of Tl-206, calculate the number of such atoms left after 42.0 min.

5. The radioactive potassium-40 isotope decays to argon-40 with a half-life of 1.2 x 10^{9} yr.
   a) Write a balanced equation for the reaction

   b) A sample of moon rock is found to contain 18 percent potassium-40 and 82 percent argon by mass. Calculate the age of the rock in years

6. Write balanced nuclear equations for the following reactions
   a) ${}^{14}_{7}N\left(p,\alpha\right){}^{12}_{6}C$ b) ${}^{9}_{4}Be\left(d,2p\right){}^{9}_{3}Li$

7. Complete the following nuclear equations and identify X in each case.

a) ${}^{26}_{12}Mg + {}^{1}_{1}p \rightarrow {}^{4}_{2}He + X$

b) ${}^{40}_{19}K \rightarrow {}^{0}_{-1}\beta + X$

c) ${}^{235}_{92}U + {}^{1}_{0}n \rightarrow {}^{99}_{40}Sr + {}^{135}_{52}Te + 2X$

8. Define a tracer and describe three applications of isotopes in chemistry and medicine.

9. A laboratory rat weighs 265 g and receives 1.77×10^{10} β particles, each with an energy of 2.20×10^{-13} J.

a) How many rads does the animal receive?

b) If the RBE is 0.75, how many mrem is this?

10. The ^{80}Br nuclide decays by either b decay or electron capture.

a) What is the product of each process?

b) Which process releases more energy? (Masses of atoms: ^{80}Br = 79.918528 amu; ^{80}Kr = 79.916380 amu; ^{80}Se = 79.961520 amu; neglect the mass of the electron involved.)

11. Nuclear disarmament could be accomplished if weapons were not "replenished." The tritium in nuclear warhead decays with a half-life of 12.26 yr to helium, and must be periodically replaced or the weapon is useless. What fraction of the tritium is lost in 5 years?

1. Write the complete nuclear equation for the following processes.

   a) tritium, $^{3}_{1}H$, undergoes β decay.

   $^{3}_{1}H \rightarrow ^{3}_{2}He + ^{0}_{-1}e$

   b) Plutonium-242 (^{242}Pu) undergoes α particle emission.

   $^{242}_{94}Pu \rightarrow ^{238}_{92}U + ^{4}_{2}He$

2. Why is it impossible for the isotope $^{2}_{2}He$ to exist?

   Two opposing forces help stabilize the nucleus: ① repulsive force between protons and ② strong force - the attractive force between proton and neutron nucleons. If one of these forces is missing, the isotope will not exist.

   $^{2}_{2}He$ nucleus consists of 2 protons and 0 neutrons. This nucleus is unstable because the repulsive force between 2 protons is not countered by the strong force.

3. For each pair of isotopes listed, indicate the nuclide that is radioactive:

   a) $^{95}_{42}Mo$ or **$^{92}_{43}Tc$** — contains odd number of protons + neutrons, which is very unstable

   b) **$^{22}_{11}Na$** or $^{25}_{11}Na$ — contains an odd number of protons + neutrons, which is unstable.

   c) $^{40}_{20}Ca$ or **$^{45}_{20}Ca$** — $^{40}_{20}Ca$: contains a magic number of protons + neutrons, very stable; $^{45}_{20}Ca$: has a odd number of neutrons + a magic number of protons, less stable than $^{40}_{20}Ca$

4. The radioactive decay of Tl-206 to Pb-206 has a half-life of 4.20 min. Starting with 5.00 x 10^{22} atoms of Tl-206, calculate the number of such atoms left after 42.0 min.

   $k = \frac{0.693}{t_{1/2}} = \frac{0.693}{4.20 min} = 0.165/min$

   $\ln \frac{N_t}{N_0} = -kt$

   $\frac{N_t}{N_0} = e^{-kt}$

   $\frac{N_t}{N_0} = e^{-(0.165/min)(42.0 min)} = 9.78 \times 10^{-4}$

   $N_t = (9.78 \times 10^{-4}) N_0 = (9.78 \times 10^{-4})(5.00 \times 10^{22}$ atoms$)$

   $N_t = 4.89 \times 10^{19}$ nuclides remain

5. The radioactive potassium-40 isotope decays to argon-40 with a half-life of 1.2 x 10^9 yr.

   a) Write a balanced equation for the reaction

   $^{40}_{19}K \longrightarrow ^{40}_{18}Ar + ^{0}_{1}e$

   b) A sample of moon rock is found to contain 18 percent potassium-40 and 82 percent argon by mass. Calculate the age of the rock in years

   $k = \frac{0.693}{t_{1/2}} = \frac{0.693}{1.2 \times 10^{9} yr}$

   $k = 5.78 \times 10^{-10}/yr$

   $\ln \frac{N_t}{N_0} = -kt$

   $t = -\frac{1}{k} \ln \frac{N_t}{N_0}$

   $t = -\frac{1}{5.78 \times 10^{-10}/yr} \ln\left(\frac{18}{100}\right)$

   $t = 3.0 \times 10^{9} yr$

6. Write balanced nuclear equations for the following reactions

   a) $^{15}_{7}N(p,\alpha)^{12}_{6}C$

   $^{15}_{7}N + ^{1}_{1}H \rightarrow ^{12}_{6}C + ^{4}_{2}He$

   b) $^{9}_{4}Be(d,2p)^{9}_{3}Li$

   $^{9}_{4}Be + ^{2}_{1}H \rightarrow ^{9}_{3}Li + 2\,^{1}_{1}H$

7. Complete the following nuclear equations and identify X in each case.

a) $^{26}_{12}Mg + ^{1}_{1}p \rightarrow ^{4}_{2}He + X$ $X = ^{23}_{11}Na$

b) $^{40}_{19}K \rightarrow ^{0}_{-1}\beta + X$ $X = ^{40}_{20}Ca$

c) $^{235}_{92}U + ^{1}_{0}n \rightarrow ^{99}_{40}Sr + ^{135}_{52}Te + 2X$ $X = ^{1}_{0}n$

8. Define a tracer and describe three applications of isotopes in chemistry and medicine.

A tracer is a very small amount of radioactive isotope added to a chemical, biological, or physical system to study the system.

3 applications out of several

① Follow a reaction mechanism ③ verify dynamic equilibrium

② trace a metabolic pathway

9. A laboratory rat weighs 265 g and receives 1.77×10^{10} β particles, each with an energy of 2.20×10^{-13} J.

a) How many rads does the animal receive?

$$\frac{(1.77\times10^{10}\ \beta\ \text{particles})(2.20\times10^{-13}\ \text{J/particle})}{0.265\ \text{kg}} = 1.47\times10^{-2}\ \frac{\text{J}}{\text{kg}} = 1.47\times10^{-2}\ \text{rad}$$

b) If the RBE is 0.75, how many mrem is this?

rem = RBE x rad

$$0.75 \times (1.47\times10^{-2}\ \text{rad}) = 1.10\times10^{-2}\ \text{rem}\left(\frac{1\ \text{mrem}}{10^{-3}\ \text{rem}}\right) = \boxed{11.0\ \text{mrem}}$$

10. The ^{80}Br nuclide decays by either β decay or electron capture.

a) What is the product of each process?

① $^{80}_{35}Br \longrightarrow ^{0}_{-1}e + ^{80}_{36}Kr$

② $^{80}_{35}Br + ^{0}_{-1}e \longrightarrow ^{80}_{34}Se$

b) Which process releases more energy? (Masses of atoms: ^{80}Br = 79.918528 amu; ^{80}Kr = 79.916380 amu; ^{80}Se = 79.961520 amu; neglect the mass of the electron involved.)

Δm = mass of products − mass of reactants $\Delta E = (\Delta m)c^2$

① $\Delta m = 79.916380 - 79.918528 = -0.002148\ \text{amu}$ $\Delta E = (2.148\times10^{-6}\ \text{kg})(2.998\times10^{8}\ \text{m/s})^2$ $\Delta E = -1.93\times10^{11}\ \text{J}$ energy is released

② $\Delta m = 79.961520 - 79.918528 = 0.042992\ \text{amu}$ $\Delta E = (4.292\times10^{-5}\ \text{kg})(2.998\times10^{8}\ \text{m/s})^2$ $\Delta E = 3.86\times10^{12}\ \text{J}$ energy is absorbed

11. Nuclear disarmament could be accomplished if weapons were not "replenished." The tritium in nuclear warhead decays with a half-life of 12.26 yr to helium, and must be periodically replaced or the weapon is useless. What fraction of the tritium is lost in 5 years?

$k = \frac{0.693}{t_{1/2}} = \frac{0.693}{12.26\ \text{yr}}$

$k = 5.65\times10^{-2}/\text{yr}$

$\ln\frac{N_t}{N_0} = -kt$

$\frac{N_t}{N_0} = e^{-kt} = e^{-(5.65\times10^{-2}/\text{yr})(5\ \text{yr})}$

$\frac{N_t}{N_0} = 0.753$

75.3% tritium remains after 5 years

and

24.6% of tritium is lost in 5 years