WS 28.1 Radioactive Dating!

| | # of protons | # of neutrons | Mode of radioactive decay | Half-Life, $t_{1/2}$ |
|---|---|---|---|---|
| C-11 | 6 | 5 | β+ decay (positron emission) | 20.3 minutes |
| C-12 | 6 | 6 | none (stable isotope) | N/A |
| C-13 | 6 | 7 | none (stable isotope) | N/A |
| C-14 | 6 | 8 | β- decay (beta emission) | 5730 years |
| Pb-210 | 82 | 128 | β- decay (beta emission) | 22.3 years |
| U-238 | 92 | 146 | α decay (alpha emission) | 4.47 x $10^9$ years |
| Rf-261 | 104 | 157 | α decay (alpha emission) | 62 seconds |

**1.** Complete the chart, above.

**2.** Carbon-14 forms in the upper atmosphere when nitrogen nuclei are struck from neutrons (from cosmic radiation).

**a.** Complete the equation that shows the formation of C-14:

$^{14}_{7}N + ^{1}_{0}n \text{ ------> } ^{14}_{6}C + ^{1}_{1}H$ (or $^{1}_{1}p$) p=proton

**b.** Write an equation for the beta-decay of Carbon-14. $^{14}_{6}C \longrightarrow ^{0}_{-1}\beta + ^{14}_{7}N$

**c.** After we die, how long will it take for half of our carbon-14 atoms to undergo radioactive decay? 5730 yrs (the half-life of carbon)

**3.** $X_f = X_i(0.5)^N$

**a.** Define: $X_f$ final amount of radioactive substance $X_i$ initial amount of radioactive substance N number of half-lives that have passed.

**b.** If a sample contained 12.00 grams of C-14 17,190 years ago, how many grams of Carbon-14 would it contain now?

$N = \frac{17190 \text{ yr}}{5730 \text{ yr}} = 3.000$

$X_f = X_i(0.5)^N = (12.00g)(0.5)^3 = 12.00g(.125) = 1.50 \text{ grams}$

$12.00g \xrightarrow{1} 6.00g \xrightarrow{2} 3.00g \xrightarrow{3} 1.50g$

**c.** How many grams of a 100.0 gram sample of C-14 would remain after 20,000 years?

$X_f = (100.0g)(0.5)^{3.4904} = 100.0g(0.088978) = 8.9 \text{ grams}$

$N = \frac{20000 \text{yr}}{5730 \text{yr}} = 3.4904$

**d.** If an organic sample only contains 12.5% of its original C-14, how old is it?

$X_f = X_i(0.5)^N$

$12.5 = 100(0.5)^N$

$0.125 = (0.5)^N$

$\ln(.125) = N \ln(.5)$

$N = \ln(.125)/\ln(.5)$

$N = 3.00$ half-lives

$3.00(5730 \text{ yr}) = 17190 \text{ yr}$ or $17200 \text{ yr}$

**e.** How old is an organic sample if it only contains 10.0% of its original C-14?

$X_f = X_i(0.5)^N$

$10.0 = 100(.5)^N$

$0.100 = (0.5)^N$

$\ln(.100) = N\ln(.5)$

$N = \frac{\ln(.100)}{\ln(.5)} = \frac{-2.3026}{-.69315} = 3.3219$ half-lives

$(3.3219)(5730 \text{ yr}) = 19035 \rightarrow 1.90 \times 10^4 \text{ yr}$

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**4.** Rutherfordium-261 undergoes alpha decay with a half-life of 62 seconds (look it up in the chart!)

**a.** Write an equation for the alpha decay of Rf-261.

$$^{261}_{104}Rf \rightarrow ^{257}_{102}No + ^{4}_{2}\alpha$$

**b.** If you start with a 1.0 mg sample of Rf, how many milligrams of Rf would remain after 160 seconds?

$$X_f = X_i(0.5)^N = (1.0\,mg)(0.5)^{2.5806} = 0.16717\,mg \rightarrow 0.17\,mg$$

$$N = \frac{160s}{62s} = 2.5806$$

**c.** How long would it take for a sample of Rf to decay so that only 20.0% of the Rf atoms remained?

$$20.0 = 100(0.5)^N$$

$$0.200 = (0.5)^N$$

$$\ln(.200) = N \ln(.5)$$

$$N = \frac{\ln(.200)}{\ln(.5)} = \frac{-1.60944}{-.693147} = 2.3219 \text{ half lives}$$

$$(2.3219)(62s) = 143.95$$

140 seconds

**5.** Lead-210 beta decays with a half-life of 22.3 years.

**a.** Write an equation for the Beta-decay of lead-210.

$$^{210}_{82}Pb \rightarrow ^{0}_{-1}\beta + ^{210}_{83}Bi$$

**b.** If a sample contains 50.0 mg of lead-210, how many milligrams will remain, as lead-210, after 100. years?

$$N = \frac{100.\,yr}{22.3\,yr} = 4.4843 \text{ half lives}$$

$$X_f = (50.0\,mg)(0.5)^{4.4843} = (50.0\,mg)(.04468) = 2.23\,mg$$

**6.** Uranium-238 is one of many radioactive isotopes found in the "spent fuel" of a nuclear reactor. U-238 alpha decays with a half-life of $4.47 \times 10^9$ years.

a. How long would it take for a 20.0 kg sample of U-238 to decay so that only 18.0 kg remained as U-238?

$$X_f = X_i(0.5)^N$$

$$18.0\,kg = 20.0\,kg(0.5)^N$$

$$0.900 = (0.5)^N$$

$$\ln(.900) = N \ln(.5)$$

$$N = \frac{\ln(.900)}{\ln(.5)} = \frac{-.10536}{-.693147} = 0.15200 \text{ half lives}$$

$$(0.15200)(4.47 \times 10^9\,yr) = 6.79 \times 10^8\,yr$$

$6.7945 \times 10^8$

(679 million yrs)

b. Write an equation for the alpha decay of uranium.

$$^{238}_{92}U \rightarrow ^{4}_{2}\alpha + ^{234}_{90}Th$$

c. Explain why samples of uranium ore often contain trapped helium gas. Refer to your equation, above.

an alpha particle is 2 protons and 2 neutrons, the same as a He nucleus. If alphas are trapped in the U, they gain 2e- to form He (gas).

d. Based on the half lives given in #4 and #6 for Uranium and Rutherfordium, which would you rather stand next to: a 1.00 gram sample of Rf-261, or a 1.00 g sample of U-238? ________

Explain: $t_{1/2} = 62s$ $t_{1/2} = 4.47 \times 10^9\,yr$

Ummm... I'll choose the uranium. It has a longer half-life, so undergoes alpha decay at a lower rate. Uranium will eject much fewer alpha particles per unit time than the Rf.