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CHM 102
Exam III

1. The neptunium-237 decay series is one of the four natural radioactive series through which unstable isotopes decay to eventual stability. The members of this series are no longer found in nature because the half-life of the slowest decay is small compared to the age of the earth.

$$^{237}_{93}\mathrm{Np} \xrightarrow{\alpha} \xrightarrow{\beta} \xrightarrow{\alpha} \xrightarrow{\alpha} \xrightarrow{\beta} \xrightarrow{\alpha} \xrightarrow{\alpha} \xrightarrow{\alpha} \xrightarrow{\beta} \xrightarrow{\alpha} \xrightarrow{\beta} {}^{209}_{83}\mathrm{Bi}$$

a) Write balanced nuclear equations for each decay in this series.

$$^{237}_{93}\mathrm{Np} \rightarrow {}^{4}_{2}\mathrm{He} + \boxed{^{233}_{91}\mathrm{Pa}} \rightarrow {}^{0}_{-1}e + \boxed{^{233}_{92}\mathrm{U}} \rightarrow {}^{4}_{2}\mathrm{He} + \boxed{^{229}_{90}\mathrm{Th}}$$

$$^{229}_{90}\mathrm{Th} \rightarrow {}^{4}_{2}\mathrm{He} + \boxed{^{225}_{88}\mathrm{Ra}} \rightarrow {}^{0}_{-1}e + \boxed{^{225}_{89}\mathrm{Ac}} \rightarrow {}^{4}_{2}\mathrm{He} + \boxed{^{221}_{87}\mathrm{Fr}}$$

$$^{221}_{87}\mathrm{Fr} \rightarrow {}^{4}_{2}\mathrm{He} + \boxed{^{217}_{85}\mathrm{At}} \rightarrow {}^{4}_{2}\mathrm{He} + \boxed{^{213}_{83}\mathrm{Bi}} \rightarrow {}^{0}_{-1}e + \boxed{^{213}_{84}\mathrm{Po}}$$

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$$^{213}_{84}\mathrm{Po} \rightarrow {}^{4}_{2}\mathrm{He} + \boxed{^{209}_{82}\mathrm{Pb}} \rightarrow {}^{0}_{-1} + {}^{209}_{83}\mathrm{Bi}$$

b) The half-life of ^{221}Fr, one of the isotopes within this series, is 4.8 minutes. How long does it take for 99% of a 1.0 mg sample of francium-221 to decay?

If 99% decays, 1% is left, so $N/N_0 = 1/100$.

$$\ln\left(\frac{N}{N_0}\right) = -(\ln 2)\frac{t}{t_{1/2}}$$

$$\ln\left(\frac{1}{100}\right) = -(\ln 2)\frac{t}{4.8}$$

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$$\boxed{t = 32 \text{ minutes}}$$

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2. Fluorine reacts with water to form oxygen and hydrogen fluoride:

$$F_2(g) + H_2O(l) \rightarrow O_2(g) + HF(aq)$$

a) Assign oxidation states to all atoms in this reaction. Red

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$$\underset{0}{F_2} + \underset{+1\ \ -2}{H_2O} \rightarrow \underset{0}{O_2} + \underset{+1\ \ -1}{HF}$$

ox

b) Identify which species reacts as an oxidizing agent and which species reacts as a reducing agent.

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F_2: oxidizing Agent H_2O: reducing Agent

c) Using the method of half-reactions, balance this chemical equation.

$$2 \times (2e^- + 2H^+ + F_2 \rightarrow 2HF)$$

$$2H_2O \rightarrow O_2 + 4H^+ + 4e^-$$

$$\cancel{4e^-} + \cancel{4H^+} + 2F_2 + 2H_2O \rightarrow 4HF + O_2 + \cancel{4H^+} \cancel{+4e^-}$$

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$$\boxed{2F_2 + 2H_2O \rightarrow 4HF + O_2}$$

d) How many liters of $F_2(g)$ are required to produce 1.0 L of 0.1 M $HF(aq)$? Under standard conditions, 1 mol of $F_2(g)$ occupies 22.4 L.

$$1.0L\ HF \cdot \frac{0.1 mol\ HF}{1 L\ HF} \cdot \frac{2 mol\ F_2}{4 mol\ HF} \cdot \frac{22.4 L F_2}{1 mol\ F_2} = \boxed{1.1 L\ F_2}$$

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3. Balance the following nuclear equations, each of which produce neutrons.

a) Uranium-235 reacts with a neutron to produce xenon-134 and strontium-100.

$$^{235}_{92}U + {}^{1}_{0}n \longrightarrow {}^{134}_{54}Xe + {}^{100}_{38}Sr + 2\,{}^{1}_{0}n$$

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b) Hydrogen-2 reacts with hydrogen-3 to form helium-4.

$$^{2}_{1}H + {}^{3}_{1}H \longrightarrow {}^{4}_{2}He + {}^{1}_{0}n$$

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c) What kind of nuclear process does the reaction in part (a) illustrate? What kind of nuclear process does the reaction in part (b) illustrate?

(a): FISSION

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(b): FUSION

d) Which, if any, of the above reactions could form an uncontrolled chain reaction? Explain.

(a) CAN BECOME AN UNCONTROLLED CHAIN REACTION BECAUSE

3 IT PRODUCES MORE NEUTRONS THAN IT CONSUMES.

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4. The last step of the Ostwald process for nitric acid production is the reaction of nitrogen dioxide with water to form nitric acid and nitrogen oxide:

$$NO_2(g) + H_2O(l) \rightarrow HNO_3(l) + NO(g)$$

a) Assign oxidation states to all atoms in this reaction.

Red

$$\underset{+4\ -2}{NO_2} + \underset{+1\ -2}{H_2O} \longrightarrow \underset{+1\ +5\ -2}{HNO_3} + \underset{+2\ -2}{NO}$$

Ox

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b) Identify which atom is being oxidized and which atom is being reduced.

1 N in NO_2 is both oxidized and reduced.

c) Using the method of half-reactions, balance this chemical reaction.

$$2\times(H_2O + NO_2 \rightarrow HNO_3 + H^+ + e^-)$$

$$2e^- + 2H^+ + NO_2 \rightarrow NO + H_2O$$

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$$\overset{1}{\cancel{2}}H_2O + \overset{3}{\cancel{2}}NO_2 + \cancel{2e^-} + \cancel{2H^+} + \cancel{NO_2} \rightarrow 2HNO_3 + \cancel{2H^+} + \cancel{2e^-} + NO + \cancel{H_2O}$$

$$\boxed{H_2O + 3NO_2 \rightarrow 2HNO_3 + NO}$$

d) The pure nitric acid produced has a density of 1.51 g / mL. How many moles of $NO_2(g)$ are necessary to produce 1.0 L of pure nitric acid? mw: 63.01 g/mol

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$$1000\,mL\ HNO_3 \cdot \frac{1.51\,g\ HNO_3}{1\,mL\ HNO_3} \cdot \frac{1\,mol\ HNO_3}{63.01\,g\ HNO_3} \cdot \frac{3\,mol\ NO_2}{2\,mol\ HNO_3} = \boxed{35.9\,mol\ NO_2}$$

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5. Explain the following phenomena.

a) Gamma rays can penetrate much farther into matter than alpha particles.

ALPHA PARTICLES ARE LARGE, CHARGED PARTICLES, WHILE GAMMA RAYS ARE NEUTRAL, MASSLESS PHOTONS, SO THE α- PARTICLES INTERACT MORE STRONGLY WITH MATTER AND CANNOT PENETRATE AS FAR AS γ-RAYS.

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b) Sodium hydride (NaH) is a very strong reducing agent, but none of the atoms in sodium hydride undergo reduction in its reactions.

A REDUCING AGENT FORCES OTHER COMPOUNDS TO UNDERGO REDUCTION, WHICH MEANS THAT IT DONATES ELECTRONS TO THEM AND MUST BE ITSELF OXIDIZED.

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c) An electrolysis cell reducing $Pb(SO_4)_2$ to lead metal will produce half as much lead as an electrolysis cell reducing $Pb(NO_3)_2$ to lead metal per mol of electrons passed through the cell.

$4e^- + Pb^{4+} \rightarrow Pb$

$2e^- + Pb^{2+} \rightarrow Pb$

THE LEAD (IV) SULFATE REQUIRES TWICE AS MANY ELECTRONS TO REDUCE AS LEAD (II) NITRATE, SO IT WILL PRODUCE HALF AS MANY MOL Pb PER MOL e^-.

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For the remaining questions, circle the letter that corresponds to the best answer.

6. What is the reducing agent in the reaction below?

red

$$As_4O_6(s) + Cl_2(g) + H_2O(l) \rightarrow H_3AsO_4(aq) + HCl(aq)$$

+3 -2   0   +1 -2   +1 +5 -2   +1 -1

ox

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[✓ (A)] $As_4O_6(s)$
(B) $Cl_2(g)$
(C) $H_2O(l)$
(D) $H_3AsO_4(aq)$
(E) $HCl(aq)$

7. An artifact contains 12.5% of the amount of ^{14}C present in living things. The half-life of ^{14}C is 5,730 years. How old is the artifact?

5730   5730   5730

100% → 50% → 25% → 12.5%

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(A) 1,432 years
(B) 2,865 years
(C) 11,460 years
[✓ (D)] 17,190 years
(E) 22,920 years

$t = 3t_{1/2} = 3(5730)$

8. The radioactive decay of silver-110 to cadmium-110 is an example of:

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(A) nuclear fusion
(B) nuclear fission
(C) α particle emission
[✓ (D)] β particle emission
(E) γ ray emission

$^{110}_{47}Ag \rightarrow ^{110}_{48}Cd + ^{0}_{-1}e$

9. In the following reaction, what is oxidized and what is reduced?

red

+2 +6 -2   +1 -1   +1 +5 -2   +1 -2   +2 -2 +1   +1 +6 -2   0

$$3\ CoSO_4(aq) + 5\ KI(aq) + KIO_3(aq) + 3\ H_2O(l) \rightarrow 3\ Co(OH)_2(s) + 3\ K_2SO_4(aq) + 3\ I_2(aq)$$

ox

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(A) Co^{2+} is oxidized and the I in IO_3^- is reduced.
[✓ (B)] I^- is oxidized and the I in IO_3^- is reduced.
(C) I in IO_3^- is oxidized and H_2O is reduced.
(D) I^- is oxidized and Co^{2+} is reduced.
(E) None of these are correct.

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For problems 10 and 11, refer to the activity series at the right.

The Activity Series

$Li(s) \rightarrow Li^+(aq) + e^-$
$K(s) \rightarrow K^+(aq) + e^-$
$Ca(s) \rightarrow Ca^{2+}(aq) + 2\ e^-$
$Na(s) \rightarrow Na^+(aq) + e^-$
$Mg(s) \rightarrow Mg^{2+}(aq) + 2\ e^-$
$Al(s) \rightarrow Al^{3+}(aq) + 3\ e^-$
$Mn(s) \rightarrow Mn^{2+}(aq) + 2\ e^-$
$Zn(s) \rightarrow Zn^{2+}(aq) + 2\ e^-$
$Cr(s) \rightarrow Cr^{3+}(aq) + 3\ e^-$
$Fe(s) \rightarrow Fe^{2+}(aq) + 2\ e^-$
$Ni(s) \rightarrow Ni^{2+}(aq) + 2\ e^-$
$Sn(s) \rightarrow Sn^{2+}(aq) + 2\ e^-$
$Pb(s) \rightarrow Pb^{2+}(aq) + 2\ e^-$
$\mathbf{H_2(g) \rightarrow 2\ H^+(aq) + 2\ e^-}$
$Cu(s) \rightarrow Cu^{2+}(aq) + 2\ e^-$
$Ag(s) \rightarrow Ag^+(aq) + e^-$
$Au(s) \rightarrow Au^{3+}(aq) + 3\ e^-$

10. Which of the following reactions are spontaneous?

I. ✓ $2\ Al(s) + 3\ Ni^{2+}(aq) \rightarrow 2\ Al^{3+}(aq) + 3\ Ni(s)$
II. ✗ $Li^+(aq) + Ag(s) \rightarrow Li(s) + Ag^+(aq)$
III. ✓ $Pb^{2+}(aq) + Sn(s) \rightarrow Pb(s) + Sn^{2+}(aq)$
IV. ✓ $3\ Na(s) + Au^{3+}(aq) \rightarrow 3\ Na^+(aq) + Au(s)$
V. ✗ $Ca^{2+}(aq) + Cu(s) \rightarrow Ca(s) + Cu^{2+}(aq)$

(A) 2 **I and III**
(B) 2 **I and IV**
(C) **II and IV**
5 [✓ (D)] **I, III, and IV**
(E) **II, III, and V**

11. Which of the following set of metals will dissolve in acid?

(A) Ag, Au, and Cu
(B) Ag, Li, and Na
(C) Al, Au, and Cr
5 [✓ (D)] Ca, Mg, and Zn
(E) Cu, Pb, and Zn

12. Which of the following are oxidation-reduction reactions?

I. ✓ $SF_4(g) + F_2(g) \rightarrow SF_6(g)$
II. ✗ $6\ H_2O(l) + P_4O_{10}(s) \rightarrow 4\ H_3PO_4(aq)$
III. ✓ $K(s) + O_2(g) \rightarrow KO_2(s)$
IV. ✓ $Sn(s) + 2\ AgNO_3(aq) \rightarrow Sn(NO_3)_2(aq) + 2\ Ag(s)$
V. ✗ $Na_2O(s) + H_2O(l) \rightarrow 2\ NaOH(aq)$

(A) **II and III**
5 (B) **II and V**
(C) **I, II, and IV**
(D) **I, III, and V**
[✓ (E)] **I, III, and IV**

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13. How many neutrons, protons, and electrons are in lead-206?

$^{206}_{82}Pb$

(A) 82 neutrons, 82 protons, 124 electrons
(B) 206 neutrons, 82 protons, 82 electrons
(C) 124 neutrons, 82 protons, 124 electrons
[✓ (D)] 124 neutrons, 82 protons, 82 electrons
(E) 82 neutrons, 206 protons, 206 electrons

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14. Technetium-99 has a half-life of 2.12x10^5 years. If a sample originally contains 30.0 mg of ^{99}Tc, how much will be left after one million years?

[✓ (A)] 1.14 mg
(B) 21.6 mg
(C) 25.9 mg
(D) 34.7 mg
(E) 789 mg

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$N = N_0 e^{-(\ln 2) t/t_{1/2}}$

$-(\ln 2) \frac{1\times10^6}{2.12\times10^5}$

$= 30.0mg\ e$

$= 1.14mg$

15. One process that forms fermium-250 is the following reaction:

$$^{238}_{92}U + ^{16}_{8}O \rightarrow ^{250}_{100}Fm + 4\,^{1}_{0}n$$

What is this process an example of?

[✓ (A)] nuclear fusion
(B) nuclear fission
(C) α particle emission
(D) β particle emission
(E) γ ray emission

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Equations for radioactive decay

$$N = N_0\, e^{-(\ln 2)\cdot\frac{t}{t_{1/2}}}$$

$$\ln\left(\frac{N}{N_0}\right) = -(\ln 2)\frac{t}{t_{1/2}}$$

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