CH 223 Practice Problem Set #5

*This is a **practice problem set** and not the actual graded problem set that you will turn in for credit. Answers to each problem can be found at the end of this assignment.*

Covering: **Chapter Sixteen** *and* **Chapter Guide Five**
Important Tables and/or Constants: **F = 96485 C/mol e^-**, **R = 8.3145 J mol^{-1} K^{-1}**, "**Redox Reactions**" *(Handout),* **Table of Redox Potentials** *at the end of problem set #5*

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1. Write balanced equations for the following half-reactions. Specify whether each is an oxidation or reduction.
   a. $Cr(s) \rightarrow Cr^{3+}(aq)$ (in acid)
   b. $AsH_3(g) \rightarrow As(s)$ (in acid)
   c. $VO_3^{-1}(aq) \rightarrow V^{2+}(aq)$ (in acid)
   d. $Ag(s) \rightarrow Ag_2O(s)$ (in base)
2. Balance the following redox equations. All occur in acid solution.
   a. $Ag(s) + NO_3^{-1}(aq) \rightarrow NO_2(g) + Ag^+(aq)$
   b. $MnO_4^{-1}(aq) + HSO_3^{-1}(aq) \rightarrow Mn^{2+}(aq) + SO_4^{2-}(aq)$
   c. $Zn(s) + NO_3^{-1}(aq) \rightarrow Zn^{2+}(aq) + N_2O(g)$
   d. $Cr(s) + NO_3^{-1}(aq) \rightarrow Cr^{3+}(aq) + NO(g)$
3. Balance the following redox equations. All occur in basic solution.
   a. $Al(s) + OH^{-1}(aq) \rightarrow Al(OH)_4^{-1}(aq) + H_2(g)$
   b. $CrO_4^{2-}(aq) + SO_3^{2-}(aq) \rightarrow Cr(OH)_3(s) + SO_4^{2-}(aq)$
   c. $Zn(s) + Cu(OH)_2(s) \rightarrow [Zn(OH)_4]^{2-}(aq) + Cu(s)$
   d. $HS^{-1}(aq) + ClO_3^{-1}(aq) \rightarrow S(s) + Cl^{-1}(aq)$
4. A voltaic cell is constructed using the reaction of chromium metal and iron(II) ion.

   $$2\ Cr(s) + 3\ Fe^{2+}(aq) \rightarrow 2\ Cr^{3+}(aq) + 3\ Fe(s)$$

   Complete the following sentences: Electrons in the external circuit flow from the ___ electrode to the ___ electrode. Negative ions move in the salt bridge from the ___ half-cell to the ___ half-cell. The half-reaction at the anode is ___ and that at the cathode is ___.
5. The half-cells $Fe(s) \mid Fe^{2+}(aq) \parallel O_2(g, 1\ atm) \mid H_2O(l, pH = 1.0)$ are linked to create a voltaic cell.
   a. Write equations for the oxidation and reduction half-reactions and for the overall (cell) reaction.
   b. Which half-reaction occurs in the anode compartment and which occurs in the cathode compartment?
   c. Complete the following sentences: Electrons in the external circuit flow from the ___ electrode to the ___ electrode. Negative ions move in the salt bridge from the ___ half-cell to the ___ half-cell.
6. Balance each of the following *unbalanced* equations, then calculate the standard redox potential, $E°$, and decide whether each is product-favored as written. All reactions occur in acid solution.
   a. $Sn^{2+}(aq) + Ag(s) \rightarrow Sn(s) + Ag^{+1}(aq)$
   b. $Al(s) + Sn^{4+}(aq) \rightarrow Sn^{2+}(aq) + Al^{3+}(aq)$ *continued*

c. $ClO_3^{-1}(aq) + Ce^{3+}(aq) \rightarrow Cl^{-1}(aq) + Ce^{4+}(aq)$ *Look these cell potentials up online*

d. $Cu(s) + NO_3^{-1}(aq) \rightarrow Cu^{2+}(aq) + NO(g)$

7. Calculate the voltage delivered by a voltaic cell using the following reaction if all dissolved species are 2.5×10^{-2} M. *Use the OpenStax text to find the cell potentials.*

$$Zn(s) + 2\ H_2O(l) + 2\ OH^{-1}(aq) \rightarrow [Zn(OH)_4]^{2-}(aq) + H_2(g)$$

8. Calculate $\Delta G°$ and the equilibrium constant for the following reactions.

a. $2\ Fe^{3+}(aq) + 2\ I^{-1}(aq) \rightarrow 2\ Fe^{2+}(aq) + I_2(aq)$

b. $I_2(aq) + 2\ Br^{-1}(aq) \rightarrow 2\ I^{-1}(aq) + Br_2(aq)$

9. A potential of +0.146 V is recorded (under standard conditions) for a voltaic cell constructed using the following half-reactions:

Anode: $Ag(s) \rightarrow Ag^{+1}(aq) + e^-$

Cathode: $Ag_2SO_4(s) + 2\ e^- \rightarrow 2\ Ag(s) + SO_4^{2-}(aq)$

a. What is the standard reduction potential for the cathode reaction?

b. Calculate the solubility product, K_{sp}, for Ag_2SO_4.

10. In the electrolysis of a solution containing $Ni^{2+}(aq)$, metallic Ni(s) deposits on the cathode. Using a current of 0.150 A for 12.2 min, what mass of nickel will form?

11. Electrolysis of molten NaCl is done in cells operating at 7.0 V and 4.0×10^4 A. What mass of Na(s) and $Cl_2(g)$ can be produced in one day in such a cell? What is the energy consumption in kilowatt-hours? (1 kWh = 3.6×10^6 J and 1 J = 1 C • V)

Answers to the Practice Problem Set: ***Please note*** *that all thermodynamic and electrochemical answers will vary slightly depending on the source of values used to solve the problems. The answers should be close, however.*

1. *Answers:*
   a. $Cr(s) \rightarrow Cr^{3+}(aq) + 3\ e^-$ oxidation
   b. $AsH_3(g) \rightarrow As(s) + 3\ H^+(aq) + 3\ e^-$ oxidation
   c. $VO_3^-(aq) + 6\ H^+(aq) + 3\ e^- \rightarrow V^{2+}(aq) + 3\ H_2O(\ell)$ reduction
   d. $2\ Ag(s) + 2\ OH^-(aq) \rightarrow Ag_2O(s) + H_2O(\ell) + 2\ e^-$ oxidation
2. *Answers:*
   a. $Ag(s) + NO_3^-(aq) + 2\ H^+(aq) \rightarrow Ag^+(aq) + NO_2(g) + H_2O(\ell)$
   b. $2\ MnO_4^-(aq) + H^+(aq) + 5\ HSO_3^-(aq) \rightarrow 2\ Mn^{2+}(aq) + 3\ H_2O(\ell) + 5\ SO_4^{2-}(aq)$
   c. $4\ Zn(s) + 2\ NO_3^-(aq) + 10\ H^+(aq) \rightarrow 5\ H_2O(\ell) + 4\ Zn^{2+}(aq) + N_2O(g)$
   d. $Cr(s) + NO_3^-(aq) + 4\ H^+(aq) \rightarrow Cr^{3+}(aq) + NO(g) + 2\ H_2O(\ell)$
3. *Answers:*
   a. $2\ Al(s) + 6\ H_2O(\ell) + 2\ OH^-(aq) \rightarrow 2\ Al(OH)_4^-(aq) + 3\ H_2(g)$
   b. $2\ CrO_4^-(aq) + 5\ H_2O(\ell) + 3\ SO_3^{2-}(aq) \rightarrow 2\ Cr(OH)_3(s) + 4\ OH^-(aq) + 3\ SO_4^{2-}(aq)$
   c. $Zn(s) + 2\ OH^-(aq) + Cu(OH)_2(s) \rightarrow Zn(OH)_4^{2-}(aq) + Cu(s)$
   d. $3\ HS^-(aq) + ClO_3^-(aq) \rightarrow 3\ S(s) + Cl^-(aq) + 3\ OH^-(aq)$
4. Electrons in the external circuit flow from the Cr electrode to the Fe electrode. Negative ions move in the salt bridge from the Fe/Fe^{2+} half-cell to the Cr/Cr^{3+} half-cell. The half-reaction at the anode is $Cr(s) \rightarrow Cr^{3+}(aq) + 3\ e^-$ and that at the cathode is $Fe^{2+}(aq) + 2\ e^- \rightarrow Fe(s)$.
5. *Answers:*
   a. Oxidation: $Fe(s) \rightarrow Fe^{2+}(aq) + 2\ e^-$
   Reduction: $O_2(g) + 4\ H^+(aq) + 4\ e^- \rightarrow 2\ H_2O(\ell)$
   Overall: $2\ Fe(s) + O_2(g) + 4\ H^+(aq) \rightarrow 2\ H_2O(\ell) + 2\ Fe^{2+}(aq)$
   b. Oxidation occurs in the anode compartment and reduction occurs in the cathode compartment.
   c. Electrons in the external circuit flow from the Fe electrode to the positive (site of O_2 reduction) electrode. Negative ions move in the salt bridge from the O_2/H_2O half-cell to the Fe/Fe^{2+} half-cell.
6. *Answers:*
   a. $Sn^{2+}(aq) + 2\ Ag(s) \rightarrow Sn(s) + 2\ Ag^+(aq)$
   $E^\circ_{cell} = E^\circ_{cathode} - E^\circ_{anode} = (-0.14\ V) - (+0.799\ V) = -0.94\ V$ not product-favored
   b. $2\ Al(s) + 3\ Sn^{4+}(aq) \rightarrow 2\ Al^{3+}(aq) + 3\ Sn^{2+}(aq)$
   $E^\circ_{cell} = E^\circ_{cathode} - E^\circ_{anode} = (+0.15\ V) - (-1.66\ V) = +1.81\ V$ product-favored
   c. $ClO_3^-(aq) + 6\ H^+(aq) + 6\ Ce^{3+}(aq) \rightarrow Cl^-(aq) + 3\ H_2O(\ell) + 6\ Ce^{4+}(aq)$
   $E^\circ_{cell} = E^\circ_{cathode} - E^\circ_{anode} = (+0.62\ V) - (+1.61\ V) = -0.99\ V$ not product-favored
   d. $3\ Cu(s) + 2\ NO_3^-(aq) + 8\ H^+(aq) \rightarrow 2\ NO(g) + 3\ Cu^{2+}(aq) + 4\ H_2O(\ell)$
   $E^\circ_{cell} = E^\circ_{cathode} - E^\circ_{anode} = (+0.96\ V) - (+0.337\ V) = +0.62\ V$ product-favored

7. 0.32 V
8. a. $\Delta G^o = -45.5$ kJ, $K = 9 \times 10^7$ b. $\Delta G^o = 110$ kJ, $K = 4 \times 10^{-19}$
9. a. 0.653 V b. $K_{sp} = 1 \times 10^{-5}$
10. 0.0334 g
11. 8.2×10^5 g Na, 1.3×10^6 g Cl_2, 6700 kwh