Chapter 11 – Old quiz and exam questions

\[
\begin{align*}
\text{Cu}^{2+} + 2e^- & \rightarrow \text{Cu}(s) \quad 0.34 \\
\text{Pb}^{2+} + 2e^- & \rightarrow \text{Pb}(s) \quad -0.13 \\
\text{Ni}^{2+} + 2e^- & \rightarrow \text{Ni}(s) \quad -0.23 \\
\text{Fe}^{2+} + 2e^- & \rightarrow \text{Fe}(s) \quad -0.40 \\
\text{Zn}^{2+} + 2e^- & \rightarrow \text{Zn}(s) \quad -0.76 \\
\text{Al}^{3+} + 3e^- & \rightarrow \text{Al}(s) \quad -1.66 \\
\end{align*}
\]

\[E = E^\circ - \frac{RT}{nF} \ln Q\]

\[E = E^\circ - \frac{0.0592}{n} \log Q \text{ at } 25^\circ C\]

\[\Delta G^\circ = -nFE^\circ\]

\[1 = \frac{nF}{t}\]

1. You want to plate out nickel from a nickel (II) nitrate solution onto a piece of metal inserted into the solution. Should you use copper or zinc or can you use either of these metals?
   a) copper
   b) zinc
   c) can use either copper or zinc

   ANSWERS are given at the end of the quiz.

2. Consider the galvanic cell shown below (the contents of each half-cell are written beneath each compartment).

   0.50 M \(\text{Br}_2\) (aq) 0.20 M \(\text{Cr}^{2+}\) (aq)

   0.10 M \(\text{Br}^-\) (aq)

   The standard reduction potentials are as follows:

   \[
   \begin{align*}
   \text{Cr}^{3+} + 3e^- & \rightarrow \text{Cr}(s) \quad E^\circ = -0.73 \text{ V} \\
   \text{Br}_2(aq) + 2e^- & \rightarrow 2\text{Br}^- \quad E^\circ = +1.09 \text{ V} \\
   \end{align*}
   \]

   What is the value of \(E\) for this cell at 25°C?
   a) 1.88 V
   b) 1.76 V
   c) 2.12 V
   d) 1.82 V
   e) 2.21 V

3. (4 pts) An aqueous solution of an unknown salt of ruthenium is electrolyzed by a current of 2.50 A passing for 50.0 minutes. If 2.618 g of Ru is produced at the cathode, what is the charge on the ruthenium ions in solution? The molar mass of Ru is 101.07 g/mol. \(1A = 1\ \text{C/sec} \quad 1 = \text{nF/t} \quad F = 96,485\ \text{C/mol e's}\)

   A) +3
   B) +4
   C) +2
   D) +1
   E) +5
4. (3 pts) Using the above half reactions, which of the following species can be reduced by Fe(II)?

A) Al^{3+}
B) Ni
C) I_2
D) Cu
E) I^-

Questions 5 – 6: A galvanic cell is described as follows

Pt|H_2 (1.0 atm)|H^+ (0.1 M)||Fe^{3+} (1.0 M), Fe^{2+} (1.0 M)|Pt

5. (3 pts) The half reaction that occurs at the cathode of this cell is written as

A) H_2 → 2 H^+ + 2e^-
B) 2 H^+ + 2e^- → H_2
C) Pt + Fe^{3+} → Pt^{2+} + Fe^{2+}
D) Fe^{3+} → Fe^{2+} + e^-
E) Fe^{2+} + e^- → Fe^{3+}

6. (3 pts) What is the potential of this galvanic cell at 25 °C.

\[ E = E^0 - \left( \frac{0.0257}{n} \right) \ln Q \] at 25 °C

A) 0.77 V
B) greater than 0.77 V
C) less than 0.77 V
D) negative
E) 0 V

5. (3 pts) A galvanic cell is described as follows. Cu(s) | Cu^{2+} (1 M) || Fe^{3+} (1 M), Fe^{2+} (1 M) | Pt

Which of the following will increase the cell voltage the most?

A) halve [Cu^{2+}]
B) halve [Fe^{3+}]
C) double [Cu^{2+}]
D) double [Fe^{3+}]
E) cut the Cu electrode in half
7. (2 pts) In the reaction below, which substance is the oxidizing agent?

\[
Pb (s) + PbO_2 (s) + 2 H^+ (aq) + 2 HSO_4^- (g) \rightarrow 2 PbSO_4 (s) + 2 H_2O (l)
\]

A) Pb  
B) PbO_2  
C) H^+  
D) HSO_4^-  
E) PbSO_4

8. (3 pts) A galvanic cell is constructed with a copper electrode in a CuSO_4 (aq) solution and the lead electrode in a Pb(NO_3)_2 (aq) solution at 25 °C. The standard reduction potentials are:

\[
Pb^{2+} + 2 e^- \rightarrow Pb (s) \quad E^\circ = -0.13 \text{ V}
\]

\[
Cu^{2+} + 2 e^- \rightarrow Cu (s) \quad E^\circ = +0.34 \text{ V}
\]

When sulfuric acid is added to the Pb(NO_3)_2(aq) solution, a PbSO_4 (s) precipitate is formed. This will cause the cell potential to

A) increase  
B) decrease  
C) remain unchanged  
D) more information is needed to determine the effect

1. How many electrons are transferred in the following reaction?

\[
Cr_2O_7^{2-} + 14H^+ + 6Cl^- \rightarrow 2Cr^{3+} + 3Cl_2 + 7H_2O
\]

A) 2  
B) 4  
C) 6  
D) 8  
E) none of these

2. Which of the following is the strongest oxidizing agent?

\[
\begin{align*}
MnO_4^- + 4H^+ + 3e^- & \rightarrow MnO_2 + 2H_2O \quad E^\circ = 1.68 \text{ V} \\
I_2 + 2e^- & \rightarrow 2I^- \quad E^\circ = 0.54 \text{ V} \\
Zn^{2+} + 2e^- & \rightarrow Zn \quad E^\circ = -0.76 \text{ V}
\end{align*}
\]

A) MnO_4^-  
B) I_2  
C) Zn^{2+}  
D) Zn  
E) MnO_2
Use the following to answer question 3:

<table>
<thead>
<tr>
<th>Reaction</th>
<th>$E^\circ$ (volts)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$F_2 + 2e^- \rightarrow 2F^-$</td>
<td>2.87</td>
</tr>
<tr>
<td>$Cl_2 + 2e^- \rightarrow 2Cl^-$</td>
<td>1.36</td>
</tr>
<tr>
<td>$Ag^+ + e^- \rightarrow Ag$</td>
<td>0.80</td>
</tr>
<tr>
<td>$Cu^{2+} + 2e^- \rightarrow Cu$</td>
<td>0.34</td>
</tr>
<tr>
<td>$Co^{2+} + 2e^- \rightarrow Co$</td>
<td>-0.28</td>
</tr>
<tr>
<td>$Fe^{3+} + 2e^- \rightarrow Fe$</td>
<td>-0.44</td>
</tr>
<tr>
<td>$Al^{3+} + 3e^- \rightarrow Al$</td>
<td>-1.66</td>
</tr>
</tbody>
</table>

3. Silver, Ag, will spontaneously reduce which of the following?

A) Fe
B) $Co^{3+}$
C) $Al^{3+}$
D) $Cl^-$
E) none of these

5. Given the standard reduction potentials,

$Cu^{2+} + 2e^- \rightarrow Cu$ $E^\circ = 0.34$ V
$Ag^+ + e^- \rightarrow Ag$ $E^\circ = 0.80$ V

calculate the cell potential, $E_c$, for a Galvanic cell when $[Cu^{2+}]_0$ is 0.0034 M and $[Ag^+]_0$ is 0.34 M at 25 °C.

A) 0.52 V
B) 0.59 V
C) 0.51 V
D) 0.41 V
E) 0.40 V

1) (3 pts) Will Pb (s) dissolve in a 1.0 M solution of $NiCl_2$?

$Cl_2 + 2e^- \rightarrow 2Cl^-$ $E^\circ = 1.36$ V
$Pb^{2+} + 2e^- \rightarrow Pb$ (s) $E^\circ = -0.13$ V
$Ni^{2+} + 2e^- \rightarrow Ni$ (s) $E^\circ = -0.23$ V

a) Yes
b) No

3) (3 pts) A Galvanic cell is constructed based on the following two half reactions:

$Ag^+ + e^- \rightarrow Ag$ (s) $E^\circ = 0.80$ V
$Co^{2+} + 2e^- \rightarrow Co$ (s) $E^\circ = -0.28$ V

After the reaction has run for a certain amount of time, the mass of the Ag (s) electrode has changed by 2.32 grams. Which of the following best describes the change in the mass of the Co (s) electrode?

a) The mass of the Co (s) electrode increased by 0.634 grams
b) The mass of the Co (s) electrode decreased by 0.634 grams
c) The mass of the Co (s) electrode increased by 1.23 grams
d) The mass of the Co (s) electrode decreased by 1.23 grams
e) The mass of the Co (s) electrode did not change
4) (4 pts) A solution of NaCl is electrolyzed to produce Cl₂ gas. What volume of Cl₂ at 25°C and 1 atm is generated when a solution of NaCl is electrolyzed using a current of 54 A for 13 minutes? (1 minute = 60 seconds)

a) 11 L  
b) 320 L  
c) 641 L  
d) 541 L  
e) 5.3 L

5) (3 pts) A concentration cell is constructed using two zinc electrodes each immersed in solutions of Zn²⁺. In the anode compartment, [Zn²⁺] = 0.56 M. What must be the [Zn²⁺] in the other compartment in order to attain a cell potential of 0.023 V at 298 K?

\[ \text{Zn}^{2+} + 2 \text{e}^- \rightarrow \text{Zn} \ (s) \quad \quad E^\circ = -0.76 \text{ V} \]

a) 0.093 M  
b) 1.37 M  
c) 0.23 M  
d) 3.4 M  
e) 5.7 M

6) (4 pts) Consider a cell at 25°C described as follows: X|X²⁺|\text{Y}^3⁺|Y

Where X and Y are unknown metals. Given that the equilibrium constant K for the reaction takes place in this electrochemical cell is 4.9x10⁷ and the standard reduction potential for X²⁺ is

\[ \text{X}^{2+} + 2 \text{e}^- \rightarrow \text{X} \quad \quad E^\circ = 0.57 \text{ V} \]

What is the standard reduction potential of Y³⁺?

a) 0.65 V  
b) -0.49 V  
c) 1.02 V  
d) 0.57 V  
e) 0.49 V
Questions 1-2  Consider a Galvanic cell which uses the following two half reactions:

\[
\begin{align*}
\text{Br}_2 (l) + 2 \text{ e}^- & \rightarrow 2 \text{ Br}^- (a q) & E^0 &= 1.06 \\
\text{Cu}^{2+} (a q) + 2 \text{ e}^- & \rightarrow \text{Cu} (s) & E^0 &= 0.34
\end{align*}
\]

1)  (3 pts) What is the reaction that takes place at the cathode?

a) \( \text{Cu}^{2+} (a q) + 2 \text{ e}^- \rightarrow \text{Cu} (s) \)

b) \( \text{Br}_2 (l) + 2 \text{ e}^- \rightarrow 2 \text{ Br}^- (a q) \)

c) \( 2 \text{ Br}^- (a q) \rightarrow \text{Br}_2 (l) + 2 \text{ e}^- \)

d) \( \text{Cu} (s) \rightarrow \text{Cu}^{2+} (a q) + 2 \text{ e}^- \)

e) no reaction takes place at the cathode

2)  (3 pts) Assuming standard concentrations for all species in solution and a temperature of 298K, what is the equilibrium constant \( K \) for the overall reaction that occurs in this cell?

a) \( 6.7 \times 10^{-11} \)

b) \( 2.3 \times 10^{24} \)

c) \( 1.5 \times 10^{12} \)

d) \( 4.4 \times 10^{-25} \)

e) 1

4)  (3 pts) Based on the information given below, which of the following can reduce \( \text{Ni}^{2+} \) but not \( \text{Al}^{3+} \) ?

\[
\begin{align*}
\text{Cu}^{2+} + 2 \text{ e}^- & \rightarrow \text{Cu} (s) & E^0 &= 0.34 \text{ V} \\
\text{Ni}^{2+} + 2 \text{ e}^- & \rightarrow \text{Ni} (s) & E^0 &= -0.28 \text{ V} \\
\text{Fe}^{2+} + 2 \text{ e}^- & \rightarrow \text{Fe} (s) & E^0 &= -0.44 \text{ V} \\
2 \text{ H}_2\text{O} (l) + 2 \text{ e}^- & \rightarrow \text{H}_2 (g) + 2 \text{ OH}^- & E^0 &= -0.83 \text{ V} \\
\text{Al}^{3+} + 3 \text{ e}^- & \rightarrow \text{Al} (s) & E^0 &= -1.66 \text{ V} \\
\text{Na}^+ + \text{ e}^- & \rightarrow \text{Na} (s) & E^0 &= -2.71 \text{ V}
\end{align*}
\]

a) \( \text{H}_2\text{O} (l) \)

b) \( \text{Na} (s) \)

c) \( \text{Cu}^{2+} \)

d) \( \text{Fe} (s) \)

e) More than one of these

5)  (4 pts) Consider an electrochemical cell described as follows: \( \text{Mg} | \text{Mg}^{2+} \parallel \text{Cr}^{3+} | \text{Cr} \)

Calculate \( \Delta G \) at 298K if \([\text{Mg}^{2+}] = 2.3 \text{ M} \) and \([\text{Cr}^{3+}] = 0.16 \text{ M} \). Choose the response closest to your answer.

\[
\begin{align*}
\text{Cr}^{3+} + 3 \text{ e}^- & \rightarrow \text{Cr} & E^0 &= -0.73 \text{ V} \\
\text{Mg}^{2+} + 2 \text{ e}^- & \rightarrow \text{Mg} & E^0 &= -2.37 \text{ V}
\end{align*}
\]

a) \(-934 \text{ kJ} \)

b) \(-943 \text{ kJ} \)

c) \(-156 \text{ kJ} \)

d) \(-949 \text{ kJ} \)

e) \(-926 \text{ kJ} \)
5) (4 pts) To determine the molar mass of an unknown metal M, the metal is plated out from a solution containing $M^{n+}$ ions. If 61.8 grams of M is plated out after electrolyzing the solution with a current of 25.1 A for 85 minutes, what is the molar mass of M?

a) 46.6 g/mol  
b) 15.5 g/mol  
c) 182 g/mol  
d) 60.6 g/mol  
e) 140 g/mol

1) (3 pts) Consider the following information:

\[ \begin{align*}
F_2 (g) + 2 e^- & \rightarrow 2 F^- & E^0 = 2.87 \text{ V} \\
2 \text{H}^+ + 2 e^- & \rightarrow \text{H}_2 (g) & E^0 = 0.00 \text{ V} \\
Pb^{2+} + 2 e^- & \rightarrow \text{Pb} (s) & E^0 = -0.13 \text{ V} \\
\text{Zn}^{2+} + 2 e^- & \rightarrow \text{Zn} (s) & E^0 = -0.76 \text{ V}
\end{align*} \]

Which of the following is the strongest reducing agent?

a) Pb (s)  
b) F^-  
c) Zn^{2+}  
d) F_2 (g)

2) (3 pts) How many electrons are transferred in the following reaction:

\[ \text{CH}_4 (g) + 4 \text{S} (s) \rightarrow \text{CS}_2 (l) + 2 \text{H}_2\text{S} (g) \]

a) 0  
b) 2  
c) 4  
d) 6  
e) 8

3) (4 pts) NaCl is electrolyzed to produce Cl\textsubscript{2} gas. What volume of Cl\textsubscript{2} at 25°C and 1 atm is generated when NaCl is electrolyzed using a current of 32 A for 32 minutes?

a) 7.8 L  
b) 16 L  
c) 467 L  
d) 934 L  
e) 789 L
Questions 5 and 6: A concentration cell is constructed in which one half cell contains a Cr (s) electrode immersed in a 0.21 M Cr^{3+} solution and the other half cell contains a Cr (s) electrode immersed in a 1.8 M Cr^{2+} solution.

\[ \text{Cr}^{2+} + 3 \text{e}^- \rightarrow \text{Cr} (s) \quad E^o = -0.73 \text{ V} \]

5) (3 pts) Consider the information above. A KNO_3 salt bridge is used for this cell. Into which half cell do K^+ ions flow?

a) K^+ ions flow into the half cell containing 0.21 M Cr^{3+}
b) K^+ ions flow into the half cell containing 1.8 M Cr^{2+}
c) K^+ ions flow back and forth between the two half cells

6) (4 pts) Consider the information above. What is the cell potential (E_{cell}) for this concentration cell before any reactions take place? Assume T = 298K.

a) 0.055 V  
b) 0.00 V  
c) -0.73 V  
d) 0.73 V  
e) 0.018 V  

2) (3 pts) Consider a Galvanic cell constructed using an Ag (s) electrode immersed in a 1.0 M Ag^+ solution and a Ni (s) electrode immersed in a 1.0 M Ni^{2+} solution. Which direction will electrons flow?

\[ \text{Ag}^+ + \text{e}^- \rightarrow \text{Ag} (s) \quad E^o = 0.80 \text{ V} \]
\[ \text{Ni}^{2+} + 2 \text{e}^- \rightarrow \text{Ni} (s) \quad E^o = -0.26 \text{ V} \]

a) Electrons flow from the compartment containing Ag (s) and Ag^+ to the compartment containing Ni (s) and Ni^{2+}
b) Electrons flow from the compartment containing Ni (s) and Ni^{2+} to the compartment containing Ag (s) and Ag^+

3) (3 pts) An aqueous solution of KI is electrolyzed to produce I_2 (s). Calculate the mass of I_2 produced in 1.5 hours using a constant current of 11 A. Note: 1 hour = 3600 seconds.

a) 156 g  
b) 312 g  
c) 78 g  
d) 48 g  
e) 127 g
4) (3 pts) A Galvanic concentration cell is created using copper electrodes and aqueous Cu²⁺ solutions. The standard reduction potential of Cu²⁺ is:

\[ \text{Cu}^{2+} + 2 \text{e}^- \rightarrow \text{Cu} \ (s) \quad E^\circ = 0.34 \text{V} \]

In the cathode compartment, [Cu²⁺] = 1.0 M. To achieve a positive cell potential (E_{cell}), which of the following statements must be true?

a) The concentration of Cu²⁺ at the anode must be less than 1.0 M
b) The concentration of Cu²⁺ at the anode must be greater than 1.0 M
c) The concentration of Cu²⁺ at the anode must be equal to 1.0 M
d) The cell potential will always be zero, regardless of the concentration of Cu²⁺ at the anode
e) The cell potential will always be positive, regardless of the concentration of Cu²⁺ at the anode

5) (4 pts) Consider an electrochemical cell at 25°C described as follows: \[ \text{X} \mid \text{X}^{2+} (1.0 \text{M}) \mid \mid \text{Y}^{2+} (1.0 \text{M}) \mid \text{Y} \]

The standard reduction potential of X²⁺ is –1.3 V. Calculate the standard reduction potential of Y²⁺, given that \( \Delta G^\circ \) for the reaction occurring in this Galvanic cell is –430.1 kJ.

a) –0.34 V  
b) 3.2 V  
c) –0.56 V  
d) 2.0 V  
e) 0.34 V

6) (4 pts) Consider the following reaction: \[ 2 \text{Al} (s) + 3 \text{Sn}^{4+} (aq) \rightarrow 2 \text{Al}^{3+} (aq) + 3 \text{Sn}^{2+} (aq) \]

Calculate the cell potential at 298 K when [Sn⁴⁺] = 1.7 M, [Sn²⁺] = 0.0073 M, and [Al³⁺] = 0.025 M.

\[
\begin{align*}
\text{Sn}^{4+} + 2 \text{e}^- & \rightarrow \text{Sn}^{2+} \quad E^\circ = 0.15 \text{V} \\
\text{Al}^{3+} + 3 \text{e}^- & \rightarrow \text{Al} (s) \quad E^\circ = -1.66 \text{V}
\end{align*}
\]

a) 1.85 V  
b) 1.81 V  
c) –1.41 V  
d) 1.61 V  
e) 1.91 V

1) (3 pts) Predict what will happen when a piece of Sn (s) is placed in a solution of FeCl₂ (aq).

\[
\begin{align*}
\text{Cl}_2 (g) + 2 \text{e}^- & \rightarrow 2 \text{Cl}^- \quad E^\circ = 1.36 \text{V} \\
\text{Sn}^{2+} + 2 \text{e}^- & \rightarrow \text{Sn} (s) \quad E^\circ = -0.14 \text{V} \\
\text{Fe}^{2+} + 2 \text{e}^- & \rightarrow \text{Fe} (s) \quad E^\circ = -0.44 \text{V}
\end{align*}
\]

a) Sn²⁺ (aq) will be produced  
b) Cl₂ (g) will be produced  
c) Fe (s) will be produced  
d) No reaction will occur  
e) More than one of these will happen
2) (3 pts) Consider an electrochemical cell described as follows: \( \text{Zn} \mid \text{Zn}^{2+} (1.0 \text{M}) \parallel \text{Fe}^{2+} (1.0 \text{M}) \mid \text{Fe} \)

Which of the following will increase the cell potential?

a) Cut the Fe (s) electrode in half
b) Increase [Zn\(^{2+}\)]
c) Increase [Fe\(^{2+}\)]
d) Add NaOH to the compartment containing Fe\(^{2+}\), forming the insoluble compound Fe(OH)\(_2\)
e) More than one of these will increase the cell potential

4) (3 pts) How long will it take to plate out 54 grams of Al (s) from an Al\(^{3+}\) solution using a current of 71 A? Note: 1 hour = 3600 seconds.

a) 2.3 hours
b) 0.44 hours
c) 1.1 hours
d) 3.4 hours
e) 0.76 hours

5) (3 pts) Consider the following reaction and standard cell potential:

\[
\text{N}_2\text{H}_4 (aq) + \text{O}_2 (g) \rightarrow \text{N}_2 (g) + 2 \text{H}_2\text{O} (l) \quad E^\circ_{\text{cell}} = 1.56 \text{ V}
\]

Under standard conditions, what is the change in Gibbs free energy (\(\Delta G^\circ\)) for this reaction?

a) –602 kJ
b) –301 kJ
c) –151 kJ
d) –903 kJ
e) –450 kJ

6) (4 pts) Consider a Galvanic cell based on the following half reactions:

\[
\begin{align*}
\text{Ag}^+ + e^- &\rightarrow \text{Ag} (s) \quad E^\circ = 0.80 \text{ V} \\
\text{Cu}^{2+} + 2e^- &\rightarrow \text{Cu} (s) \quad E^\circ = 0.34 \text{ V}
\end{align*}
\]

Initially, [Ag\(^+\)] = 1.00 M and [Cu\(^{2+}\)] = 1.00 M. Calculate the cell potential at 298K after the reaction has operated long enough for [Cu\(^{2+}\)] to have changed by 0.48 M. Assume the volumes of each solution in each half-cell are 1.00 L and do not change during the reaction.

a) 0.41 V
b) 0.30 V
c) 0.46 V
d) 0.44 V
e) 0.37 V

1) (3 pts) Consider an electrochemical cell described by the following line notation: \( \text{Pb} | \text{Pb}^{2+} | \mid \text{Cu}^{2+} | \text{Cu} \)

Will the cell potential increase, decrease, or remain the same if Cu(NO\(_3\))\(_2\) is added to the Cu\(^{2+}\) | Cu half cell? Note: Cu(NO\(_3\))\(_2\) is a soluble compound. Assume the volume of added Cu(NO\(_3\))\(_2\) is negligible.

a) Cell potential will increase
b) Cell potential will decrease
c) Cell potential will remain the same
2) (3 pts) Consider a Galvanic cell at 298K that consists of a Sn (s) electrode immersed in a 1.0 M Sn²⁺ solution and a Fe (s) electrode immersed in a 1.0 M Fe²⁺ solution. A KNO₃ salt bridge is used. Into which half-cell will the K⁺ ions flow?

Sn²⁺ + 2 e⁻ → Sn (s) \[ E^0 = -0.14 \text{ V} \]
Fe²⁺ + 2 e⁻ → Fe (s) \[ E^0 = -0.44 \text{ V} \]

a) K⁺ ions flow into the half-cell containing Fe²⁺ and Fe (s)
b) K⁺ ions flow into the half-cell containing Sn²⁺ and Sn (s)
c) K⁺ ions flow into both half-cells
d) K⁺ ions do not flow into either half-cell

3) (3 pts) A piece of solid Cu is added to a 1.0 M MgBr₂ solution. Will solid Mg plate out on the Cu?

Br₂ (l) + 2 e⁻ → 2 Br⁻ \[ E^0 = 1.09 \text{ V} \]
Cu²⁺ + 2 e⁻ → Cu (s) \[ E^0 = 0.34 \text{ V} \]
Mg²⁺ + 2 e⁻ → Mg (s) \[ E^0 = -2.37 \text{ V} \]

a) Yes
b) No

4) (4 pts) Consider the following reaction at 298K: 2 Ag⁺ + Fe (s) → Fe²⁺ + 2 Ag (s) \[ \Delta G^0 = -239 \text{ kJ} \]

Initially, [Ag⁺] = 0.84 M and [Fe²⁺] = 1.32 M. Calculate the cell potential after the reaction has operated for long enough that [Fe²⁺] has changed by 0.40 M.

a) 1.24 V
b) 1.33 V
c) 1.05 V
d) 1.15 V
e) 1.19 V

5) (3 pts) A solution containing Cu²⁺ ions is electrolyzed to plate out solid Cu. What mass of solid Cu will be produced if this solution is electrolyzed for 7.1 hours with a current of 11 A? Note: 1 hour = 3600 sec

a) 185 g
b) 370 g
c) 93 g
d) 31 g
e) 0.026 g

1) (3 pts) Consider an electrochemical cell described by the following line notation: \[ \text{Ag} | \text{Ag}^+ | [\text{Ni}^{2+}] | \text{Ni} \]

Which of the following will decrease the cell potential?

a) Decrease [Ag⁺]
b) Use a larger Ni (s) electrode
c) Increase [Ni²⁺]
d) Increase [Ag⁺]
e) More than one of these will decrease the cell potential
2) (3 pts) Will Mn (s) dissolve in a 1.0 M HCl solution?

\[
\begin{align*}
\text{Cl}_2 (g) + 2 \text{e}^- & \rightarrow 2 \text{Cl}^- & E^\circ &= 1.36 \text{ V} \\
2 \text{H}^+ + 2 \text{e}^- & \rightarrow \text{H}_2 (g) & E^\circ &= 0.00 \text{ V} \\
\text{Mn}^{2+} + 2 \text{e}^- & \rightarrow \text{Mn} (s) & E^\circ &= -1.18 \text{ V}
\end{align*}
\]

a) Yes 

b) No

3) (3 pts) Consider a Galvanic cell at 298K that consists of a Cd (s) electrode immersed in a 1.0 M Cd\(^{2+}\) solution and a Zn (s) electrode immersed in a 1.0 M Zn\(^{2+}\) solution. Which half-cell is the anode?

\[
\begin{align*}
\text{Cd}^{2+} + 2 \text{e}^- & \rightarrow \text{Cd} (s) & E^\circ &= -0.40 \text{ V} \\
\text{Zn}^{2+} + 2 \text{e}^- & \rightarrow \text{Zn} (s) & E^\circ &= -0.76 \text{ V}
\end{align*}
\]

a) The Cd (s) electrode immersed in a 1.0 M Cd\(^{2+}\) solution 

b) The Zn (s) electrode immersed in a 1.0 M Zn\(^{2+}\) solution 

c) Neither half-cell is an anode 

d) Both half-cells are anodes 

4) (3 pts) The molar mass of element X was determined by electrolyzing a solution of X\(^{3+}\) ions. It took 39 minutes and a current of 15 A to plate out 25 grams of solid X. What is the molar mass of X? Note: 1 minute = 60 seconds.

a) 69 g/mol 

b) 140 g/mol 

c) 106 g/mol 

d) 96 g/mol 

e) 206 g/mol

5) (4 pts) A Galvanic concentration cell is constructed in which one half cell contains a Fe (s) electrode immersed in a 0.084 M Fe\(^{3+}\) solution and the other half cell contains a Fe (s) electrode immersed in a 1.4 M Fe\(^{2+}\) solution. What is the cell potential \((E_{cell})\)? Assume T = 298K. The standard reduction potential of Fe\(^{3+}\) is −0.056 V.

a) −0.060 V 

b) 0.024 V 

c) 0.060 V 

d) 0.00 V 

e) −0.024 V

6) (3 pts) Will solid nickel dissolve in a solution of 1.0 M CrBr\(_3\)?

\[
\begin{align*}
\text{Br}_2 (l) + 2 \text{e}^- & \rightarrow 2 \text{Br}^- & E^\circ &= 1.09 \text{ V} \\
\text{Ni}^{2+} + 2 \text{e}^- & \rightarrow \text{Ni} (s) & E^\circ &= -0.23 \text{ V} \\
\text{Cr}^{3+} + 3 \text{e}^- & \rightarrow \text{Cr} (s) & E^\circ &= -0.73 \text{ V}
\end{align*}
\]

a) Yes 

b) No
2) (3 pts) Consider a Galvanic cell based on the following two half reactions:

\[ Ag^+ + e^- \rightarrow Ag (s) \quad E^0 = 0.80 \, V \]
\[ Sn^{2+} + 2 e^- \rightarrow Sn (s) \quad E^0 = -0.14 \, V \]

Which of the following statements is true?

a) Sn (s) is produced at the anode
b) Ag\(^+\) is produced at the anode
c) Sn\(^{2+}\) is produced at the anode
d) Ag (s) is produced at the anode
e) More than one of these statements is true

3) (4 pts) Consider the following reaction:

\[ 4 \, P + 5 \, O_2 \rightarrow 2 \, P_2O_5 \quad \Delta G^0 = -2698 \, kJ \]

If the energy released by this reaction could be harnessed as a Galvanic cell, what would be the standard cell potential \(E_{cell}^0\) for the reaction at 298K?

a) 2.8 V
b) 0.0028 V
c) 0.7 V
d) 5.6 V
e) 1.4 V

4) (4 pts) In an electrolysis experiment, a student passes the same current through two electrolytic cells for the same amount of time. One cell contains Ag\(^+\), and the other contains Mn\(^{2+}\), where x is unknown. In the experiment, 7.6 grams of Ag and 0.77 grams of Mn were plated out. What is the value of x in Mn\(^{2+}\)?

a) 1
b) 4
c) 2
d) 5
e) 3

5) (3 pts) A concentration cell is constructed such that one half-cell contains a Cd (s) electrode immersed in a 0.26 M Cd\(^{2+}\) solution and the other half-cell contains a Cd (s) electrode immersed in a 2.1 M Cd\(^{2+}\) solution. What is the cell potential \(E_{cell}\) at 298K?

\[ Cd^{2+} + 2 \, e^- \rightarrow Cd (s) \quad E^0 = -0.40 \, V \]

a) 0.027 V
b) 0.00 V
c) 0.054 V
d) 0.40 V
e) -0.40 V

6) (3 pts) Which metal, Al or Ni, could reduce Zn\(^{2+}\) to Zn (s) if placed in a 1.0 M Zn\(^{2+}\) solution?

\[ Ni^{2+} + 2 \, e^- \rightarrow Ni (s) \quad E^0 = -0.23 \, V \]
\[ Zn^{2+} + 2 \, e^- \rightarrow Zn (s) \quad E^0 = -0.76 \, V \]
\[ Al^{3+} + 3 \, e^- \rightarrow Al (s) \quad E^0 = -1.66 \, V \]

a) Al
b) Ni
c) Both Al and Ni could reduce Zn\(^{2+}\) to Zn (s)
d) Neither Al nor Ni could reduce Zn\(^{2+}\) to Zn (s)
2) (3 pts) A concentration cell is constructed using Cu (s) electrodes immersed in Cu\(^{2+}\) solutions. In one half-cell, [Cu\(^{2+}\)] = 2.0 M. In the other half-cell, [Cu\(^{2+}\)] = 1.2 M. Which half-cell will be the cathode?

a) The half-cell containing 2.0 M Cu\(^{2+}\)
b) The half-cell containing 1.2 M Cu\(^{2+}\)

3) (3 pts) Consider a Galvanic cell described by the following half reactions:

\[
\begin{align*}
\text{Hg}^{2+} + 2 \text{e}^- &\rightarrow \text{Hg} \quad E^\circ = 0.86 \text{ V} \\
\text{Ag}^+ + \text{e}^- &\rightarrow \text{Ag} \quad E^\circ = 0.80 \text{ V}
\end{align*}
\]

Which of the following will increase the cell potential by the largest amount?

a) Double [Hg\(^{2+}\)]
b) Double [Ag\(^+\)]
c) Halve [Hg\(^{2+}\)]
d) Halve [Ag\(^+\)]
e) More than one of these will increase the cell potential by the largest amount

4) (4 pts) Consider the following reaction for the oxidation of ammonia:

\[4 \text{NH}_3 + 3 \text{O}_2 \rightarrow 2 \text{N}_2 + 6 \text{H}_2\text{O}\]

The standard cell potential for this reaction is 1.17 V. Calculate AG\(^\circ\) for this reaction at 298K.

a) −113 kJ
b) −677 kJ
c) −337 kJ
d) −1863 kJ
e) −1355 kJ

6) (4 pts) Consider an electrochemical cell described as follows: Mg|Mg\(^{2+}\)||Al\(^{3+}\)|Al

Initially, [Mg\(^{2+}\)] = [Al\(^{3+}\)] = 0.85 M. Each solution has a volume of 1.0 L. What is [Al\(^{3+}\)] after the cell delivers 0.22 A of current for 31.6 hr? Note: 1 hr = 3600 sec.

a) 0.81 M
b) 0.76 M
c) 0.94 M
d) 0.087 M
e) 1.02 M

1) (3 pts) A Galvanic cell is constructed based on the following two half reactions:

\[
\begin{align*}
\text{Cu}^{2+} + 2 \text{e}^- &\rightarrow \text{Cu} \quad E^\circ = 0.34 \text{ V} \\
\text{Fe}^{2+} + 2 \text{e}^- &\rightarrow \text{Fe} \quad E^\circ = -0.44 \text{ V}
\end{align*}
\]

Which of the following statements is correct:

a) Electrons flow from the half cell containing Fe\(^{2+}\) and Fe (s) into the half cell containing Cu\(^{2+}\) and Cu (s)
b) Electrons flow from the half cell containing Cu\(^{2+}\) and Cu (s) into the half cell containing Fe\(^{2+}\) and Fe (s)
2) (3 pts) Which of the following metals, Pt (s) or Cu (s), will dissolve in a 1.0 M solution of HNO₃?

\[
\begin{align*}
\text{Pt}^{2+} + 2 \text{e}^- & \rightarrow \text{Pt} \ (s) & \mathcal{E}^0 &= 1.20 \, \text{V} \\
\text{NO}_3^- + 4 \text{H}^+ + 3 \text{e}^- & \rightarrow \text{NO} \ (g) + 6 \text{H}_2\text{O} \ (l) & \mathcal{E}^0 &= 0.96 \, \text{V} \\
\text{Cu}^{2+} + 2 \text{e}^- & \rightarrow \text{Cu} \ (s) & \mathcal{E}^0 &= 0.34 \, \text{V}
\end{align*}
\]

a) Pt (s) only  

b) Cu (s) only  

c) Both Pt (s) and Cu (s)  

d) Neither Pt (s) nor Cu (s)

4) (4 pts) Consider a cell at 298 K described as follows: \( \text{Fe|Fe}^{3+} | \text{Cu}^+ | \text{Cu} \)

Initially, \([\text{Fe}^{3+}] = 1.65 \, \text{M}\) and \([\text{Cu}^+] = 1.65 \, \text{M}\). Calculate the cell potential after the reaction has operated long enough for \([\text{Fe}^{3+}]\) to change by 0.54 M.

\[
\begin{align*}
\text{Cu}^+ + \text{e}^- & \rightarrow \text{Cu} \ (s) & \mathcal{E}^0 &= 0.52 \, \text{V} \\
\text{Fe}^{3+} + 3 \text{e}^- & \rightarrow \text{Fe} \ (s) & \mathcal{E}^0 &= -0.036 \, \text{V}
\end{align*}
\]

a) 0.65 V  

b) 0.55 V  

c) 0.27 V  

d) 0.52 V  

e) 0.46 V

5) (4 pts) You were given two solutions: one containing \(\text{Ag}^+\) and the other containing \(\text{Cu}^{2+}\). These two solutions were electrolyzed using the same current for the same amount of time to produce \(\text{Ag} \ (s)\) and \(\text{Cu} \ (s)\). After electrolysis, 3.00 grams of \(\text{Ag} \ (s)\) were produced. What is the mass of \(\text{Cu} \ (s)\) produced?

a) 1.77 g  

b) 0.589 g  

c) 3.00 g  

d) 0.883 g  

e) 6.23 g

6) (3 pts) Determine \(K\) at 25°C for the reaction: \(3 \text{ In}^- \ (aq) \rightarrow 2 \text{ In} \ (s) + \text{ In}^{3+} \ (aq)\)

Given the following standard reduction potentials:

\[
\begin{align*}
\text{In}^- \ (aq) + \text{e}^- & \rightarrow \text{In} \ (s) & \mathcal{E}^0 &= -0.21 \, \text{V} \\
\text{In}^{3+} \ (aq) + 2 \text{e}^- & \rightarrow \text{In}^- \ (aq) & \mathcal{E}^0 &= -0.40 \, \text{V}
\end{align*}
\]

a) \(3.7 \times 10^{-7}\)  

b) \(4.4 \times 10^9\)  

c) \(2.7 \times 10^5\)  

d) \(1.9 \times 10^{19}\)  

e) \(2.3 \times 10^{-10}\)
1. (2 points) The following two half-reactions take place in a galvanic cell. At standard conditions, what species are produced at each electrode?

\[
\begin{align*}
\text{Sn}^{2+} + 2e^- & \rightarrow \text{Sn} & E^o &= -0.14 \text{ V} \\
\text{Cu}^{2+} + 2e^- & \rightarrow \text{Cu} & E^o &= 0.34 \text{ V}
\end{align*}
\]

- a. Sn is produced at the anode, and Cu^{2+} is produced at the cathode.
- b. Cu is produced at the cathode, and Sn^{2+} is produced at the anode.
- c. Cu is produced at the anode, and Sn^{2+} is produced at the cathode.
- d. Sn is produced at the anode, and Cu is produced at the cathode.
- e. Sn is produced at the cathode, and Cu^{2+} is produced at the anode.

2. (4 points) The following electrochemical cell has a potential of +0.217 V at 25 °C.

\[
\text{Pt} \mid \text{H}_2(g, 1.00 \text{ atm}) \mid \text{H}^+(\text{aq}, 1.00 \text{ M}) \mid \text{Cu}^{2+}(\text{aq}) \mid \text{Cu}
\]

The standard reduction potential, \(E^o\), of Cu^{2+} = +0.337 V. What is the Cu^{2+}(aq) concentration?

- a. \(1.9 \times 10^{-19} \text{ M}\)
- b. \(8.8 \times 10^{-5} \text{ M}\)
- c. \(4.6 \times 10^{-10} \text{ M}\)
- d. 0.12 M
- e. 0.65 M

3. (2 points) For a reaction in a voltaic cell, both \(\Delta H^o\) and \(\Delta S^o\) are positive. Which of the following statements is true?

- a. \(E^o_{\text{cell}}\) will not change when the temperature increases.
- b. \(E^o_{\text{cell}}\) will increase with an increase in temperature.
- c. \(\Delta G^o > 0\) for all temperatures.
- d. \(E^o_{\text{cell}}\) will decrease with an increase in temperature.
- e. None of the above statements is true.

4. (3 points) Cu^{2+} is reduced to Cu(s) at an electrode. If a current of 1.25 ampere is passed for 72 hours, what mass of copper is deposited at the electrode? Assume 100% current efficiency. The atomic weight of Cu is 63.546 g/mol.

- a. \(1.1 \times 10^2 \text{ g}\)
- b. \(3.0 \times 10^{-2} \text{ g}\)
- c. \(2.90 \times 10^2 \text{ g}\)
- d. \(2.1 \times 10^2 \text{ g}\)
- e. \(4.3 \times 10^3 \text{ g}\)

7. (2 points) Consider the following half-reactions:

\[
\begin{align*}
\text{Cu}^{2+}(\text{aq}) + 2e^- & \rightarrow \text{Cu}(s) & E^o &= +0.34 \text{ V} \\
\text{Sn}^{2+}(\text{aq}) + 2e^- & \rightarrow \text{Sn}(s) & E^o &= -0.14 \text{ V} \\
\text{Fe}^{2+}(\text{aq}) + 2e^- & \rightarrow \text{Fe}(s) & E^o &= -0.44 \text{ V} \\
\text{Al}^{3+}(\text{aq}) + 3e^- & \rightarrow \text{Al}(s) & E^o &= -1.66 \text{ V} \\
\text{Mg}^{2+}(\text{aq}) + 2e^- & \rightarrow \text{Mg}(s) & E^o &= -2.37 \text{ V}
\end{align*}
\]

Which of the above metals or metal ions will oxidize Fe(s)?

- a. Cu^{2+}(aq) and Sn^{2+}(aq)
- b. Sn(s) and Al^{3+}(aq)
- c. Al^{3+}(aq) and Mg^{2+}(aq)
- d. Cu(s) and Sn(s)
- e. Al(s) and Mg(s)
1. (3 points) For a reaction in a voltaic cell, both $\Delta f^{\circ}$ and $\Delta S^{\circ}$ are negative. Which of the following statements is true?
   a. $E^{\circ}_{\text{cell}}$ will not change when the temperature increases.
   b. $E^{\circ}_{\text{cell}}$ will decrease with an increase in temperature.
   c. $E^{\circ}_{\text{cell}}$ will increase with an increase in temperature.
   d. $\Delta G^{\circ} > 0$ for all temperatures.
   e. None of the above statements is true.

2. (3 points) Calculate $E_{\text{cell}}$ for the following electrochemical cell at 25 °C
   Pt(s) | Fe$^{3+}$ (aq, 0.25 M), Fe$^{2+}$ (aq, 0.25 M) || Cl$^{-}$ (aq, 0.20 M) | AgCl(s) | Ag(s)
   given the following standard reduction potentials.
   \[
   \begin{align*}
   \text{AgCl(s) + e}^- & \rightarrow \text{Ag(s) + Cl}^- \quad (aq) \quad E^{\circ} = +0.222 \text{ V} \\
   \text{Fe}^{3+} (aq) + e^- & \rightarrow \text{Fe}^{2+} (aq) \quad E^{\circ} = +0.771 \text{ V}
   \end{align*}
   \]
   a. +0.590 V
   b. +0.135 V
   c. +0.549 V
   d. +0.508 V
   e. -0.549 V

3. (3 points) In a common car battery, six identical cells each carry out the following reaction:
   Pb + PbO$_2$ + 2HSO$_4^-$ + 2H$^+$ $\rightarrow$ 2PbSO$_4$ + 2H$_2$O
   Suppose that to start a car on a cold morning, 137 amperes is drawn for 18.0 seconds from such a cell. How many grams of Pb are consumed? (Pb has an atomic mass of 207.2 g/mol)
   a. 2.65 g
   b. 10.59 g
   c. 0.378 g
   d. 0.00817 g
   e. 5.30 g
4. (2 points) Use the standard reduction potentials below to determine which element or ion is the best reducing agent.

\[
\begin{align*}
Pd^{2+}(aq) + 2e^- & \rightarrow Pd(s) & E^o &= +0.90 \text{ V} \\
2H^+(aq) + 2e^- & \rightarrow H_2(g) & E^o &= 0.00 \text{ V} \\
Mn^{2+}(aq) + 2e^- & \rightarrow Mn(s) & E^o &= -1.18 \text{ V}
\end{align*}
\]

a. Pd(s) 

b. Mn(s) 

c. H^+(aq) 

d. Mn^{2+}(aq) 

e. Pd^{2+}(aq)

5. (2 points) In a typical lithium-ion battery, an ammonium chloride paste is used as a salt bridge to transfer negative ions.

a. True 

b. False

6. (2 points) Based on \(E^o\), manganese would be a good sacrificial material to mix in with iron in order to prevent iron oxidation from air, similar to zinc in galvanized iron.

\[
\begin{align*}
Fe & \rightarrow Fe^{2+} + 2e^- & E^o &= +0.44 \text{ V} \\
Mn & \rightarrow Mn^{2+} + 2e^- & E^o &= +1.18 \text{ V}
\end{align*}
\]

a. True 

b. False

2. (3 points) The nickel-cadmium battery cell has a standard potential of +1.20 V. The cell reaction is

\[
2 \text{NiO(OH)}(s) + \text{Cd}(s) + 2 \text{H}_2\text{O}(l) \rightarrow 2 \text{Ni(OH)}_2(s) + \text{Cd(OH)}_2(s)
\]

What is the standard free energy change for this reaction?

a. -463 kJ 

b. -232 kJ 

c. -38.7 kJ 

d. -116 kJ

3. (2 points) Consider the following standard reduction potentials,

\[
\begin{align*}
\text{Al}^{3+}(aq) + 3e^- & \rightarrow \text{Al}(s) & E^o &= -1.66 \text{ V} \\
I_2(s) + 2e^- & \rightarrow 2 I^-(aq) & E^o &= +0.54 \text{ V}
\end{align*}
\]

Under standard conditions,

a. I^-(aq) is a stronger oxidizing agent than Al(s), and I_2(s) is a stronger reducing agent than Al^{3+}(aq).

b. Al(s) is a stronger oxidizing agent than I^-(aq), and Al^{3+}(aq) is a stronger reducing agent than I_2(s).

c. Al^{3+}(aq) is a stronger oxidizing agent than I_2(s), and I^-(aq) is a stronger reducing agent than Al(s).

d. I_2(s) is a stronger oxidizing agent than Al^{3+}(aq), and Al(s) is a stronger reducing agent than I^-(aq).
5. (3 points) Calculate the cell potential at 25°C for the cell
\[ \text{Fe}(s) | \text{Fe}^{2+}(0.100 \text{ M}) || \text{Pd}^{2+}(1.0 \times 10^{-5} \text{ M}) | \text{Pd}(s) \]
given that the standard reduction potential for \( \text{Fe}^{2+}/\text{Fe} \) is \(-0.45 \text{ V} \) and for \( \text{Pd}^{2+}/\text{Pd} \) is \(+0.95 \text{ V} \).
   a. +1.16 V
   b. +1.52 V
   c. +1.68 V
   d. +1.28 V
   e. +2.16 V

7. (3 points) If a current of 5.4 ampere is passed through a solution of \( \text{Fe}^{3+} \) for 2.9 hours, how many grams of \( \text{Fe} \) will plate out? (\( \text{Fe} \) is 55.845 g/mol)
   a. 1.61 g
   b. 10.9 g
   c. 32.2 g
   d. 0.18 g
   e. 97.7 g

8. (2 points) What species is oxidized in the reaction: \( \text{CuSO}_4(aq) + \text{Mg}(s) \rightarrow \text{MgSO}_4(aq) + \text{Cu}(s) \)?
   a. \( \text{Mg}(s) \)
   b. \( \text{CuSO}_4(aq) \)
   c. \( \text{MgSO}_4(aq) \)
   d. \( \text{Cu}(s) \)

\[
\begin{array}{lccc}
\text{Au}^{3+} + 3 e^- & \rightarrow & \text{Au}(s) & 1.50 \\
\text{Cl}_2 & \rightarrow & 2 \text{Cl}^- & 1.36 \\
\text{O}_2 + 4\text{H}^+ + 2e^- & \rightarrow & 2 \text{H}_2\text{O} & 1.23 \\
\text{Fe}^{3+} + e^- & \rightarrow & \text{Fe}^{2+} & 0.77 \\
\text{I}_2 + 2 e^- & \rightarrow & 2 \text{I}^- & 0.54 \\
\end{array}
\]

\[
\begin{array}{lccc}
\text{Cu}^{2+} + 2 e^- & \rightarrow & \text{Cu}(s) & 0.34 \\
2 \text{H}^+ + 2 e^- & \rightarrow & \text{H}_2 & 0.00 \\
\text{Fe}^{3+} + 3 e^- & \rightarrow & \text{Fe}(s) & -0.036 \\
\text{Ni}^{2+} + 2 e^- & \rightarrow & \text{Ni}(s) & -0.23 \\
\text{Al}^{3+} + 3 e^- & \rightarrow & \text{Al}(s) & -1.66 \\
\end{array}
\]

2. (6 pts) Using the above half reactions, which of the following species can be reduced by \( \text{Fe}(s) \)?
   a) \( \text{Al}^{3+} \)
   b) \( \text{Ni} \)
   c) \( \text{I}_2 \)
   d) \( \text{Cu} \)
   e) \( \text{I}^- \)
Questions 3 – 5: A galvanic cell is described by the following shorthand line notation

\[
P|H_2(g, 1.0 \text{ atm})|0.1 \text{ M } \text{H}^+ (aq)|\text{Fe}^{3+} (1 \text{ M}), \text{Fe}^{2+} (1 \text{ M})|\text{Pt}
\]

3. (6 pts) The half reaction that occurs at the cathode of this cell is written as

a) \( \text{H}_2 (g, 1 \text{ atm}) \rightarrow 2 \text{H}^+ (0.1 \text{ M}) + 2\text{e}^- \)

b) \( 2 \text{H}^+ (0.1 \text{ M}) + 2\text{e}^- \rightarrow \text{H}_2 (g, 1 \text{ atm}) \)

c) \( \text{Pt} (s) + \text{Fe}^{3+} (1 \text{ M}) \rightarrow \text{Pt}^+(aq) + \text{Fe}^{2+} (1 \text{ M}) \)

d) \( \text{Fe}^{3+} (1 \text{ M}) \rightarrow \text{Fe}^{2+} (1 \text{ M}) + e^- \)

e) \( \text{Fe}^{2+} (1 \text{ M}) + e^- \rightarrow \text{Fe}^{3+} (1 \text{ M}) \)

4. (6 pts) The potential of this galvanic cell at 25 \(^\circ\)C is

a) 0.77 V

b) greater than 0.77 V

c) less than 0.77 V

d) negative

e) 0 V

5. (6 pts) When this cell is connected to an external circuit and its output is used to drive a fan motor, which of the following will occur?

a) Platinum will be reduced

b) Hydrogen gas will be formed

c) Platinum will be oxidized

d) Iron metal will plate out at the cathode

e) None of the above

Questions 6 – 7: An acidified solution was electrolyzed using copper electrodes. A constant current of 1.18 A caused the anode to lose 0.584 g after \(1.52 \times 10^3\) sec. Hydrogen gas was produced at the cathode.

6. (6 pts) Calculate the value of Faraday’s constant from the experimental data given.

a) \( F > 96,485 \text{ C/mol} \)

b) \( F < 96,485 \text{ C/mol} \)

c) \( F = 96,485 \text{ C/mol} \)

d) Faraday’s constant cannot be determined from the data given.

7. (6 pts) Use the data given above to determine the volume of hydrogen gas produced at 23 \(^\circ\)C and 1 atm.

a) 0.446 L

b) 0.223 L

c) 0.893 L

d) 22.3 L

e) none of the above
8. (6 pts) For the following galvanic cell, the standard free energy is \( \Delta G^o = -89.3 \text{ kJ} \).

\[
\text{M(s) | M}^{2+} \text{(aq) || Ag}^+ \text{(aq) | Ag (s)}
\]

Calculate the standard cell potential \( E^o \).

a) + 0.463 V
b) - 0.926 V
c) - 0.463 V
d) + 0.926 V
e) + 0.231 V

9. (6 pts) The following two half-reactions take place in a galvanic cell. At standard conditions, what species are produced at each electrode?

\[
\begin{align*}
\text{Au}^{3+} + 3 e^- & \rightarrow \text{Au (s)} & 1.60 \\
\text{Ag}^+ + e^- & \rightarrow \text{Ag (s)} & 0.70
\end{align*}
\]

a) \( \text{Ag}\) is produced at the anode and \( \text{Au}^{3+}\) is produced at the cathode.
b) \( \text{Au}\) is produced at the cathode and \( \text{Ag}^+\) is produced at the anode.
c) \( \text{Au}\) is produced at the anode and \( \text{Ag}^+\) is produced at the cathode.
d) \( \text{Ag}\) is produced at the anode and \( \text{Au}\) is produced at the cathode.
e) \( \text{Ag}\) is produced at the cathode and \( \text{Au}^{3+}\) is produced at the anode.

Questions 8 – 10: (6 pts each) Consider the following galvanic cell.

\[
\begin{array}{c}
\text{Cd}^{2+} + 2 e^- \rightarrow \text{Cd (s)} \quad E^o = -0.40 \text{ V} \\
\text{VO}_2^+ + 2H^+ + e^- \rightarrow \text{VO}^{2+} + \text{H}_2\text{O} \quad E^o = 1.00 \text{ V}
\end{array}
\]

8. (6 pts) What is the oxidizing agent for the spontaneous reaction that occurs when this is used as a galvanic cell?

A) \( \text{Cd}^{2+}\)  
B) \( \text{Cd (s)}\)  
C) \( \text{VO}_2^+\)  
D) \( \text{VO}^{2+}\)  
E) \( \text{H}^+\)

9. (6 pts) What is the value of the standard cell potential for the galvanic cell?

A) +0.60 V  
B) +1.40 V  
C) -1.40 V  
D) -0.60 V  
E) +2.40 V
10. (6 pts) If the concentration of \( \text{Cd}^{2+} \) is reduced from 1.0 M to 0.01 M, and all other concentrations remain at their standard values, what happens to the potential of the cell?

A) The cell potential increases

B) The cell potential decreases

C) The cell potential remains the same

D) The cell potential will be negative

E) None of the above

11. (6 pts) A galvanic cell is described as follows: \( \text{Cu(s)} | \text{Cu}^{2+} (1 \ \text{M}) \ || \text{Fe}^{3+} (1 \ \text{M}), \text{Fe}^{2+} (1 \ \text{M}) | \text{Pt} \)

Which of the following will increase the cell voltage the most?

A) halve \([\text{Cu}^{2+}]\)

B) halve \([\text{Fe}^{3+}]\)

C) double \([\text{Cu}^{2+}]\)

D) double \([\text{Fe}^{2+}]\)

E) cut the Cu electrode in half

12. (6 pts) A galvanic cell is constructed with a copper electrode in a \( \text{CuSO}_4 \) (aq) solution and the lead electrode in a \( \text{Pb(NO}_3)_2 \) (aq) solution at 25 °C. The standard reduction potentials are:

\[
\begin{align*}
\text{Pb}^{2+} + 2 \text{e}^- & \rightarrow \text{Pb} (s) \quad E^0 = -0.13 \ \text{V} \\
\text{Cu}^{2+} + 2 \text{e}^- & \rightarrow \text{Cu} (s) \quad E^0 = +0.34 \ \text{V}
\end{align*}
\]

When sulfuric acid is added to the \( \text{Pb(NO}_3)_2 \) (aq) solution, a \( \text{PbSO}_4 \) (s) precipitate is formed. This will cause the cell potential to

A) increase

B) decrease

C) remain unchanged

D) more information is needed to determine the effect

19. (6 pts) In a common car battery, six identical cells each carry out the following reaction:

\[
\text{Pb} + \text{PbO}_2 + 2\text{HSO}_4^- + 2\text{H}^+ \rightarrow 2\text{PbSO}_4 + 2\text{H}_2\text{O}
\]

Suppose that to start a car on a cold morning, 136 amperes is drawn for 16.0 seconds from such a cell. How many grams of \( \text{Pb} \) are consumed? (The atomic mass of \( \text{Pb} \) is 207.19 g/mol.)

A) 9.35 g

B) 2.34 g

C) 4.67 g

D) 0.00913 g

E) 0.428 g
1. (4 pts) Given the standard reduction potentials,

\[
\begin{align*}
\text{Cu}^{2+} + 2 \text{e}^- & \rightarrow \text{Cu} \quad \quad \quad \text{E}^\circ = 0.34 \text{ V} \\
\text{IO}_3^- + 6 \text{H}^+ + 5 \text{e}^- & \rightarrow \frac{3}{2} \text{I}_2 + 3 \text{H}_2\text{O} \quad \text{E}^\circ = 1.20 \text{ V}
\end{align*}
\]

Calculate the standard free energy for the following reaction.

\[
2 \text{IO}_3^- + 12 \text{H}^+ + 5 \text{Cu} \rightarrow \text{I}_2 + 6 \text{H}_2\text{O} + 5 \text{Cu}^{2+}
\]

A) \(-414.9 \text{ kJ}\)
B) \(-675.4 \text{ kJ}\)
C) \(-829.8 \text{ kJ}\)
D) \(+675.4 \text{ kJ}\)
E) \(+829.8 \text{ kJ}\)

2. (4 pts) The following two half reactions take place in a galvanic cell. At standard conditions, what species are produced at each electrode?

\[
\begin{align*}
\text{Ag}^+ + \text{e}^- & \rightarrow \text{Ag} \quad \text{E}^\circ = +0.80 \text{V} \\
\text{Ni}^{2+} + 2\text{e}^- & \rightarrow \text{Ni} \quad \text{E}^\circ = -0.23 \text{V}
\end{align*}
\]

A) Ag\(^+\) is produced at the cathode and Ni\(^{2+}\) at the anode
B) Ag is produced at the cathode and Ni at the anode
C) Ag is produced at the cathode and Ni\(^{2+}\) at the anode
D) Ag\(^+\) is produced at the cathode and Ni at the anode
E) None of the above

3. (4 pts) For a reaction in a voltaic cell, both \(\Delta H^\circ\) and \(\Delta S^\circ\) are positive. Which of the following statements is true?

A) \(E^\circ_{\text{cell}}\) will not change with an increase in temperature.
B) \(E^\circ_{\text{cell}}\) will decrease with an increase in temperature.
C) \(E^\circ_{\text{cell}}\) will increase when the temperature increases.
D) \(\Delta G^\circ\) > 0 for all temperatures.
E) None of the above statements is true.
Questions 4 and 5: Consider the following galvanic cell.

\[
\begin{align*}
\text{Zn}^{2+} + 2e^- &\rightarrow \text{Zn} \text{ (s)} \quad E^\circ = -0.76 \text{ V} \\
\text{VO}_2^+ + 2\text{H}^+ + e^- &\rightarrow \text{VO}^{2+} + \text{H}_2\text{O} \quad E^\circ = 1.00 \text{ V}
\end{align*}
\]

4. (4 pts) What is the reducing agent for the spontaneous reaction that occurs when this is used as a galvanic cell?
   A) Zn^{2+}
   B) VO_2^+
   C) H^+
   D) Zn (s)
   E) VO^{2+}

5. (6 pts) What is the value of the cell potential, E, at 25 °C, given the concentrations indicated above?
   A) 1.78 V
   B) 1.76 V
   C) 1.85 V
   D) 1.89 V
   E) 1.63 V

6. (6 pts) Nickel is electroplated from a NiSO_4 solution. A constant current of 5.00 A is applied by an external power supply. How long will it take to deposit 100. g of Ni metal? The atomic mass of Ni is 58.69 g/mol.
   A) 18.3 hours
   B) 1.20 hours
   C) 63.1 minutes
   D) 56.7 seconds
   E) 9.1 hours
Questions 5 – 8: Consider the following galvanic cell at 25 °C.

The standard reduction potentials are as follows:

\[
\begin{align*}
\text{MnO}_4^- + 8\text{H}^+ + 5\text{e}^- & \rightarrow \text{Mn}^{2+} + 4\text{H}_2\text{O} & E^0 = 1.51 \text{ V} \\
\text{Cr}_2\text{O}_7^{2-} + 14\text{H}^+ + 6\text{e}^- & \rightarrow 2 \text{Cr}^{3+} + 7\text{H}_2\text{O} & E^0 = 1.33 \text{ V}
\end{align*}
\]

5. When current is allowed to flow, which species is oxidized?
   A) \text{Cr}_2\text{O}_7^{2-}
   B) \text{Cr}^{3+}
   C) \text{MnO}_4^-
   D) \text{Mn}^{2+}
   E) \text{H}^+

6. When current is allowed to flow, which species is reduced?
   A) \text{Cr}_2\text{O}_7^{2-}
   B) \text{Cr}^{3+}
   C) \text{MnO}_4^-
   D) \text{Mn}^{2+}
   E) \text{H}^+

7. What is the value of the cell potential, \(E\), at 25 °C, given the concentrations indicated?
   \([\text{Mn}^{2+}] = 0.20 \text{ M}, \ [\text{MnO}_4^-] = 0.10 \text{ M}, \ [\text{H}^+] = 1.0 \text{ M}, \ [\text{Cr}^{3+}] = 0.40 \text{ M}, \ [\text{Cr}_2\text{O}_7^{2-}] = 0.30 \text{ M}
   \[\begin{align*}
   \text{A)} & \ 0.174 \text{ V} \\
   \text{B)} & \ 0.186 \text{ V} \\
   \text{C)} & \ 0.143 \text{ V} \\
   \text{D)} & \ 0.180 \text{ V} \\
   \text{E)} & \ 0.149 \text{ V}
\end{align*}\]

8. In which direction do electrons flow in the external circuit?
   A) left to right
   B) right to left
   C) No current flows; the cell is at equilibrium.
9. A concentration cell is constructed using two Ni electrodes with Ni\(^{2+}\) concentrations of 1.64 M and 2.85 \times 10^{-4} M in the two half-cells.

Given the standard reduction potential: \( \text{Ni}^{2+} + 2\text{e}^- \rightarrow \text{Ni} \quad E^\circ = -0.23 \text{ V} \)

Calculate the cell potential, E, at 25°C.

A) +0.341 V  
B) −0.222 V  
C) −0.256 V  
D) +0.111 V  
E) −0.0078 V

10. Copper is electroplated from an aqueous CuSO₄ solution. A constant current of 5.10 amps is applied by an external power supply. How long will it take to deposit 408 g of Cu? The atomic mass of copper is 63.546 g/mol.

A) 67.5 hr  
B) 33.7 hr  
C) 2.44 hr  
D) 135.0 hr  
E) 101.2 hr

4. (5 pts) An electrochemical cell is described by the following line notation: \( \text{Al}|\text{Al}^{3+}|\text{Zn}^{2+}|\text{Zn} \)

Into which half-cell do electrons flow?

a) Into the half-cell containing Zn and Zn\(^{2+}\)  
b) Into the half-cell containing Al and Al\(^{3+}\)

5. (5 pts) Consider the reaction \( 2 \text{Cu}^+ + \text{Cd} \rightarrow \text{Cd}^{2+} + 2 \text{Cu} \)

Which of the following will decrease the cell potential by the largest amount?

a) Double [Cu\(^+\)]  
b) Double [Cd\(^{2+}\)]  
c) Halve [Cd\(^{2+}\)]  
d) Halve [Cu\(^+\)]  
e) More than one of these will decrease cell potential by the largest amount
Questions 8-9. Consider the following information:

\[ E^\circ (V) \]

- \( \text{Au}^{3+} + 3 \text{e}^- \rightarrow \text{Au} \quad 1.50 \)
- \( \text{Ag}^+ + \text{e}^- \rightarrow \text{Ag} \quad 0.80 \)
- \( \text{I}_2 + 2 \text{e}^- \rightarrow 2 \Gamma \quad 0.53 \)
- \( \text{Cu}^{2+} + 2 \text{e}^- \rightarrow \text{Cu} \quad 0.34 \)
- \( \text{Pb}^{2+} + 2 \text{e}^- \rightarrow \text{Pb} \quad -0.13 \)
- \( \text{Zn}^{2+} + 2 \text{e}^- \rightarrow \text{Zn} \quad -0.76 \)

8. (5 pts) Use the information above to determine which of the following statements is true.

a) Ag is capable of reducing \( \text{I}_2 \) to \( \Gamma \) but not capable of reducing \( \text{Au}^{3+} \) to \( \text{Au} \)

b) Ag is capable of both reducing \( \text{Au}^{3+} \) to \( \text{Au} \) and reducing \( \text{I}_2 \) to \( \Gamma \)

c) Ag is capable of reducing \( \text{Au}^{3+} \) to \( \text{Au} \) but not capable of reducing \( \text{I}_2 \) to \( \Gamma \)

d) None of these statements is true

9. (6 pts) Use the information above to answer the following question: At 298 K, a galvanic cell is constructed using a \( \text{Cu} \) (s) electrode immersed in a 0.16 M solution of \( \text{Cu}^{2+} \) and an \( \text{Au} \) (s) electrode immersed in a 1.3 M solution of \( \text{Au}^{3+} \). Calculate \( \Delta G \) for the reaction under these conditions.

a) \(-672 \text{ kJ}\)

b) \(-686 \text{ kJ}\)

c) \(-677 \text{ kJ}\)

d) \(-657 \text{ kJ}\)

e) \(-698 \text{ kJ}\)

16. (6 pts) An aqueous solution of \( \text{Cr}^{3+} \), where \( \text{X} \) is unknown, is electrolyzed to plate out solid \( \text{Cr} \). If 36.4 grams of solid \( \text{Cr} \) is plated out using a constant current of 37 A for 122 minutes, what is the value of \( \text{X} \)?

a) 1

b) 2

c) 3

d) 4

e) 6
Questions 5-6. Consider the following information:

$$E^o (V)$$

- $\text{Cl}_2 + 2e^- \rightarrow 2 \text{Cl}^- \quad 1.36$
- $\text{Br}_2 + 2e^- \rightarrow 2 \text{Br}^- \quad 1.09$
- $\text{Ag}^+ + e^- \rightarrow \text{Ag} \quad 0.80$
- $\text{Cd}^{2+} + 2e^- \rightarrow \text{Cd} \quad -0.40$
- $\text{Cr}^{3+} + 3e^- \rightarrow \text{Cr} \quad -0.73$
- $\text{Al}^{3+} + 3e^- \rightarrow \text{Al} \quad -1.66$

5. (5 pts) Use the information above to determine which of the following is capable of oxidizing Cr but not Br?  
   a) Cd  
   b) $\text{Cl}_2$  
   c) $\text{Ag}^+$  
   d) $\text{Al}^{3+}$  
   e) More than one of these

6. (5 pts) Use the information above to answer the following question: At 298K, a galvanic cell is constructed using a Cd (s) electrode immersed in a 1.0 M solution of Cd$^{2+}$ and an Al (s) electrode immersed in a 1.0 M solution of Al$^{3+}$. Predict the change in cell potential if NaOH is added to the half-cell containing Al and Al$^{3+}$, causing solid Al(OH)$_3$ to precipitate out.
   a) cell potential will decrease  
   b) cell potential will increase  
   c) cell potential will not change

7. (5 pts) How many electrons are transferred in the following reaction?  $\text{N}_2 + 2 \text{O}_2 \rightarrow 2 \text{NO}_2$
   a) 4  
   b) 6  
   c) 2  
   d) 16  
   e) 8

8. (5 pts) A concentration cell is constructed using an Ag (s) electrode immersed in a 1.0 M Ag$^+$ solution and an Ag (s) electrode immersed in a 2.0 M Ag$^+$ solution. A KNO$_3$ salt bridge is used. Into which half-cell do NO$_3^-$ ions flow?
   a) Into the half-cell containing 1.0 M Ag$^+$  
   b) Into the half-cell containing 2.0 M Ag$^+$

10. (6 pts) A solution of Cu$^{2+}$ is electrolyzed to plate out solid Cu (molar mass = 63.55 g/mol). If 11 grams of solid Cu was plated out in 15 minutes, how many amps of current were used? Note 1 minute = 60 seconds.
   a) 19 A  
   b) 2227 A  
   c) 37 A  
   d) 74 A  
   e) 9.3 A
18. (6 pts) Consider the following reaction at 298K: \[ \text{PbS (s)} \rightleftharpoons \text{Pb}^{2+} + \text{S}^{2-} \quad K = 8.0 \times 10^{-28} \]

Using this information, determine the standard reduction potential for the following reaction:

\[ \text{PbS (s)} + 2 \text{ e}^- \rightarrow \text{Pb (s)} + \text{S}^{2-} \quad E^\circ = ??? \]

Note: You may find the following standard reduction potential useful:

\[ \text{Pb}^{2+} + 2 \text{ e}^- \rightarrow \text{Pb (s)} \quad E^\circ = -0.13 \text{ V} \]

a) -0.80 V  
b) -0.67 V  
c) 0.67 V  
d) -0.93 V  
e) 0.48 V

6. (5 pts) Consider the following standard reduction potentials:

\[
\begin{align*}
\text{Cl}_2 (l) + 2 \text{ e}^- & \rightarrow 2 \text{ Cl}^- & E^\circ = 1.36 \text{ V} \\
\text{Pb}^{2+} + 2 \text{ e}^- & \rightarrow \text{Pb (s)} & E^\circ = -0.14 \text{ V} \\
2\text{n}^{2+} + 2 \text{ e}^- & \rightarrow 2\text{n (s)} & E^\circ = -0.76 \text{ V} \\
\text{Al}^{3+} + 3 \text{ e}^- & \rightarrow \text{Al (s)} & E^\circ = -1.66 \text{ V}
\end{align*}
\]

Which of the following is the strongest oxidizing agent?

a) Zn (s)  
b) Pb^{2+}  
c) Al^{3+}  
d) Cl^-  
e) Al (s)

11. (6 pts) 530 mL of a 2.1 M Fe_{2}(SO_{4})_{3} solution is electrolyzed using a current of 35 A. How long will it take to plate out all of the Fe^{3+} ions from this solution?

a) 5.1 hour  
b) 2.6 hour  
c) 1.7 hour  
d) 0.85 hour  
e) 2600 hour
**Questions 12-13** (4 pts each) Consider a Galvanic cell based on the following half reactions:

\[
\begin{align*}
\text{Pb}^{2+} + 2\text{e}^- &\rightarrow \text{Pb} \quad \text{E}^\circ = -0.13 \text{ V} \\
\text{Cr}^{3+} + 3\text{e}^- &\rightarrow \text{Cr} \quad \text{E}^\circ = -0.73 \text{ V}
\end{align*}
\]

Initially, \([\text{Pb}^{2+}] = 1.0 \text{ M}\) and \([\text{Cr}^{3+}] = 1.0 \text{ M}\). Will the cell potential (E) increase, decrease, or stay the same under the following conditions:

12. (4 pts) Water is added to both half-cell compartments until the volume of each solution is doubled.
   a) increase
   b) decrease
   c) stay the same

13. (4 pts) Sodium hydroxide is added to the chromium half-cell compartment. Note: \(\text{OH}^-\) ions react with \(\text{Cr}^{3+}\) to produce the insoluble compound \(\text{Cr(OH)}_3\).
   a) increase
   b) decrease
   c) stay the same

14. (7 pts) A concentration cell is constructed using two copper electrodes each immersed in solutions of \(\text{Cu}^{2+}\). In the cathode compartment, \([\text{Cu}^{2+}] = 0.84 \text{ M}\). What must be the \([\text{Cu}^{2+}]\) in the other compartment in order to achieve a cell potential of 22 mV at 298 K?
   a) 4.66 M
   b) 0.15 M
   c) 0.36 M
   d) 1.98 M
   e) 0.27 M

17. (7 pts) Calculate the equilibrium constant \((K)\) for the following reaction at 298K: 3 \(\text{Fe}^{2+}\) \(\rightarrow\) \(\text{Fe}\) (s) + 2 \(\text{Fe}^{3+}\)

   **NOTE:** You may not need to use all of the reduction potentials listed below.

   \[
   \begin{align*}
   \text{Fe}^{3+} + \text{e}^- &\rightarrow \text{Fe}^{2+} \quad \text{E}^\circ = 0.77 \text{ V} \\
   \text{Fe}^{3+} + 3\text{e}^- &\rightarrow \text{Fe} \quad \text{E}^\circ = -0.036\text{V} \\
   \text{Fe}^{2+} + 2\text{e}^- &\rightarrow \text{Fe} \quad \text{E}^\circ = -0.44 \text{ V}
   \end{align*}
   \]

   a) 3.4x10^{-25}
   b) 4.0x10^{-46}
   c) 5.5x10^{-78}
   d) 1.6x10^{-123}
   e) 1.2x10^{-83}
2. (5 pts) How many electrons are transferred in the following reaction:

\[ 2\text{CO (g)} \rightarrow \text{C (s)} + \text{CO}_2 (g) \]

a) 2  
b) 0  
c) 4  
d) 8  
e) 1

Questions 5 & 6

Consider the following reaction in an electrochemical cell:

\[ \text{Cu}^{2+} + 2\text{Fe}^{3+} \rightarrow 2\text{Fe}^{2+} + \text{Cu (s)} \quad E^\circ_{\text{cell}} = 0.43 \text{ V} \]

Initially [Cu^{2+}] = 1.0 M, [Fe^{3+}] = 1.0 M, and [Fe^{2+}] = 1.0 M. Predict how the cell potential will change under the following conditions:

5. (4 pts) The Cu (s) electrode is doubled in size

a) cell potential increases  
b) cell potential decreases  
c) cell potential stays the same

6. (4 pts) Water is added to the half cell containing Fe^{3+} and Fe^{2+} until [Fe^{3+}] = 0.5 M and [Fe^{2+}] = 0.5 M

a) cell potential increases  
b) cell potential decreases  
c) cell potential stays the same

7. (6 pts) Which of the following aqueous solutions is capable of oxidizing Bi (s) to Bi^{3+} (aq)?

\[
\begin{align*}
\text{Cl}_2 + 2\text{e}^- \rightarrow 2\text{Cl}^- & \quad E^\circ = 1.36 \text{ V} \\
\text{Br}_2 + 2\text{e}^- \rightarrow 2\text{Br}^- & \quad E^\circ = 1.09 \text{ V} \\
\text{NO}_3^- + 4\text{H}^+ + 3\text{e}^- \rightarrow \text{NO} + 2\text{H}_2\text{O} & \quad E^\circ = 0.96 \text{ V} \\
\text{Bi}^{3+} + 3\text{e}^- \rightarrow \text{Bi} (s) & \quad E^\circ = 0.31 \text{ V} \\
2\text{H}^+ + 2\text{e}^- \rightarrow \text{H}_2 & \quad E^\circ = 0.00 \text{ V}
\end{align*}
\]

a) HCl only  
b) HBr only  
c) HNO_3 only  
d) HCl, HBr, and HNO_3  
e) None of these

13. (6 pts) The molar mass of element X was determined by electrolyzing a solution of X^{2+} ions. It took 64 minutes for a current of 15 A to plate out 27 grams of solid X. What is the molar mass of X? Note: 1 minute = 60 seconds.

a) 47 g/mol  
b) 23 g/mol  
c) 138 g/mol  
d) 91 g/mol  
e) 125 g/mol
17. (7 pts) Consider the following electrochemical cell:

\[
\text{Al} \mid \text{Al}^{3+} (0.74 \text{ M}) \parallel \parallel \text{Cu}^{2+} (2.10 \text{ M}) \mid \text{Cu}
\]

Calculate the cell potential after 5.8 A of current has flowed through the cell for 19 hours (note 1 hour = 3600 seconds). Assume each half cell contains 1.00 L of solution.

\[
\begin{align*}
\text{Cu}^{2+} + 2e^- &\rightarrow \text{Cu} (s) \quad E^\circ = 0.34 \text{ V} \\
\text{Al}^{3+} + 3e^- &\rightarrow \text{Al} (s) \quad E^\circ = -1.66 \text{ V}
\end{align*}
\]

a) 2.00 V  
b) 1.95 V  
c) 1.98 V  
d) 0.71 V  
e) 1.86 V

1. (5 pts) Consider a Galvanic cell described by the following half reactions:

\[
\begin{align*}
\text{Ag}^+ + e^- &\rightarrow \text{Ag} (s) \quad E^\circ = 0.80 \text{ V} \\
\text{Zn}^{2+} + 2e^- &\rightarrow \text{Zn} (s) \quad E^\circ = -0.76 \text{ V}
\end{align*}
\]

Which of the following occurs at the anode?

a) Ag is oxidized to Ag$^+$  
b) Ag$^+$ is reduced to Ag  
c) Zn is oxidized to Zn$^{2+}$  
d) Zn$^{2+}$ is reduced to Zn

14. (6 pts) Consider the Galvanic cell at 298K that uses the following two half reactions:

\[
\begin{align*}
\text{Cu}^+ + e^- &\rightarrow \text{Cu} (s) \quad E^\circ = 0.52 \text{ V} \\
\text{Fe}^{3+} + 3e^- &\rightarrow \text{Fe} (s) \quad E^\circ = -0.036 \text{ V}
\end{align*}
\]

Initially, [Fe$^{3+}$] = 1.27 M and [Cu$^+$] = 1.27 M. Calculate the cell potential after the reaction has operated long enough for [Fe$^{3+}$] to change by 0.41 M.

a) 0.65 V  
b) 0.56 V  
c) 0.29 V  
d) 0.52 V  
e) 0.47 V

2. (4 pts) In a Galvanic cell, a salt bridge balances charge by supplying positive ions to the anode.

a) True  
b) False
7. (5 pts) A galvanic concentration cell is constructed using Ag(s) electrodes and Ag⁺ solutions. In one half-cell, \([\text{Ag}^+]=0.5\ \text{M}\). In the other half-cell, \([\text{Ag}^+]=0.1\ \text{M}\). Write the line notation for this cell.

   a) \(\text{Ag} | \text{Ag}^+(0.1 \text{ M}) \parallel | \text{Ag}^+(0.5 \text{ M}) | \text{Ag}\)
   b) \(\text{Ag}^+(0.1 \text{ M}) | \text{Ag} | \text{Ag} | \text{Ag}^+(0.5 \text{ M})\)
   c) \(\text{Ag} | \text{Ag}^+(0.5 \text{ M}) | | \text{Ag}^+(0.1 \text{ M}) | \text{Ag}\)
   d) \(\text{Ag}^+(0.5 \text{ M}) | \text{Ag} | | \text{Ag} | \text{Ag}^+(0.1 \text{ M})\)
   e) \(\text{Ag}^+(0.1 \text{ M}) | \text{Ag} | | \text{Ag} | \text{Ag}^+(0.5 \text{ M}) | \text{Ag}\)

13. (6 pts) We have three separate solutions: one contains Mo²⁺, one contains Sr²⁺, and one contains K⁺. These solutions are electrolyzed to plate out solid metals. If the solutions are electrolyzed using the same current for the same amount of time, which solid metal will be produced in the largest amount (by mass)?

   a) Mo
   b) Sr
   c) K
   d) Equal masses of all three solid metals will be produced

14. (6 pts) We have three separate solutions: one contains Al³⁺, one contains Ca²⁺, and one contains Rb⁺. These solutions are electrolyzed using the same current to plate out solid metals. Which of the following will take the longest amount of time?

   a) Plating 5 grams of solid Al from an Al³⁺ solution
   b) Plating 15 grams of solid Ca from a Ca²⁺ solution
   c) Plating 40 grams of solid Rb from a Rb⁺ solution
   d) All three processes take the same amount of time

17. (6 pts) Consider the galvanic cell shown below:

   ![Galvanic Cell Diagram]

Initially, the mass of the Al(s) electrode = 116 g, and the mass of the Zn(s) electrode = 150 g. Assuming the reaction goes to completion, calculate the final mass of the Al(s) electrode.

   \[
   \begin{align*}
   \text{Zn}^{2+} + 2 \text{e}^- & \rightarrow \text{Zn (s)} \quad E^o = -0.76 \text{V} \\
   \text{Al}^{3+} + 3 \text{e}^- & \rightarrow \text{Al (s)} \quad E^o = -1.66 \text{V}
   \end{align*}
   \]

   a) 125 g
   b) 103 g
   c) 8.8 g
   d) 107 g
   e) 13 g
10. (5 points) Which cell involves a nonspontaneous redox reaction?
   a. electrolytic cell
   b. fuel cell
   c. galvanic cell
   d. concentration cell

16. (4 points) Which of the following statements is/are CORRECT?
    1. A lithium ion battery is an example of a rechargeable battery, often used in
       portable devices.
    2. Hydrogen-oxygen fuel cells use the heat of combustion of hydrogen to
       recharge lead storage batteries.
    3. Concentration cells create voltages that are typically very large.

   a. 1 only
   b. 2 only
   c. 1 and 2
   d. 1 and 3
   e. 1, 2, and 3

3. (4 points) In a typical lithium-ion battery, an ammonium chloride paste is used as a salt bridge to transfer
   negative ions.

   a. True
   b. False

4. (4 points) Concentration cells create voltages that are typically very large.

   a. True
   b. False