MULTIPLE CHOICE (3 points each)

1) The molar solubility of aluminum hydroxide in a 0.0182 M KOH solution is __________ M. The $K_{sp}$ of aluminum hydroxide ($\text{Al(OH)}_3$) is $1.9 \times 10^{-33}$.
   \[A) 3.2 \times 10^{-28} \quad B) 2.9 \times 10^{-9} \quad C) 3.1 \times 10^{-12} \quad D) 1.9 \times 10^{-33} \quad E) 1.2 \times 10^{-11}\]

2) What is the maximum concentration (in M) of chloride ions in a solution that contains 0.100 M Pb$^{2+}$. The $K_{sp}$ for lead (II) chloride is $1.0 \times 10^{-4}$.
   \[A) 0.032 \quad B) 1.0 \times 10^{-4} \quad C) 0.029 \quad D) 0.058 \quad E) 0.0.0010\]

3) The $K_{sp}$ for Zn(OH)$_2$ is $5.0 \times 10^{-17}$. Determine the molar solubility of Zn(OH)$_2$ in a buffer solution with a pH of 11.50.
   \[A) 5.0 \times 10^6 \quad B) 1.2 \times 10^{-12} \quad C) 1.6 \times 10^{-14} \quad D) 5.0 \times 10^{-17} \quad E) 5.0 \times 10^{-12}\]

4) The first law of thermodynamics can be given as ________.
   \[A) \text{the entropy of a pure crystalline substance at absolute zero is zero} \]
   \[B) \Delta E = q + w \]
   \[C) \Delta H^{\text{f,rxn}} = \Sigma (n\Delta H^o_f \text{(products)}) - \Sigma (m\Delta H^o_f \text{(reactants)}) \]
   \[D) \text{for any spontaneous process, the entropy of the universe increases} \]
   \[E) \Delta S = q_{\text{rev}}/T \text{ at constant temperature} \]

5) Of the following, only __________ is not a state function.
   \[A) E \quad B) H \quad C) S \quad D) q \quad E) T\]

6) The thermodynamic quantity that expresses the degree of disorder in a system is __________.
   \[A) \text{heat flow} \quad B) \text{enthalpy} \quad C) \text{entropy} \quad D) \text{internal energy} \quad E) \text{bond energy}\]

7) The second law of thermodynamics can be given as __________.
   \[A) \Delta S = q_{\text{rev}}/T \text{ at constant temperature} \]
   \[B) \Delta E = q + w \]
   \[C) \text{for any spontaneous process, the entropy of the universe increases} \]
   \[D) \Delta H^{\text{f,rxn}} = \Sigma (n\Delta H^o_f \text{(products)}) - \Sigma (m\Delta H^o_f \text{(reactants)}) \]
   \[E) \text{the entropy of a pure crystalline substance is zero at absolute zero}\]

8) $\Delta S$ is be positive for the reaction __________.
   \[A) \text{CO}_2 (g) \rightarrow \text{CO}_2 (s) \quad B) 2\text{H}_2 (g) + \text{O}_2 (g) \rightarrow 2\text{H}_2\text{O} (g) \]
   \[C) \text{BaF}_2 (s) \rightarrow \text{Ba}^{2+} (aq) + 2\text{F}^- (aq) \quad D) 2\text{Hg} (l) + \text{O}_2 (g) \rightarrow 2\text{HgO} (s) \]
   \[E) 2\text{NO}_2 (g) \rightarrow \text{N}_2\text{O}_4 (g) \]

9) The third law of thermodynamics can be given as __________.
   \[A) \Delta S = q_{\text{rev}}/T \text{ at constant temperature} \]
   \[B) \text{the entropy of a pure crystalline substance at absolute zero is zero} \]
   \[C) \Delta H^{\text{f,rxn}} = \Sigma (n\Delta H^o_f \text{(products)}) - \Sigma (m\Delta H^o_f \text{(reactants)}) \]
   \[D) \text{for any spontaneous process, the entropy of the universe increases} \]
   \[E) \Delta E = q + w \]
10) The value of $\Delta S^0$ for the oxidation of solid elemental sulfur to gaseous sulfur trioxide,

$$2S \text{ (s, rhombic)} + 3O_2 \text{ (g)} \rightarrow 2SO_3 \text{ (g)}$$

is $-$166.4 J/K.
A) -166.4 B) +19.3 C) -19.3 D) +493.1 E) -493.1

11) The value of $\Delta S^0$ for the formation of POCl₃ from its constituent elements,

$$P_2 \text{ (g)} + O_2 \text{ (g)} + 3Cl_2 \text{ (g)} \rightarrow 2POCl_3 \text{ (g)}$$

is -442 J/K.
A) +321 B) +771 C) -442 D) -771 E) -321

12) The value of $\Delta G^0$ at 25°C for the decomposition of gaseous sulfur dioxide to solid elemental sulfur and gaseous oxygen,

$$SO_2 \text{ (g)} \rightarrow S \text{ (s, rhombic)} + O_2 \text{ (g)}$$

is +300.4 kJ/mol.
A) +269.9 B) -300.4 C) -269.9 D) +300.4 E) +395.2

13) The equilibrium constant for the following reaction is $5.0 \times 10^8$ at 25°C.

$$N_2 \text{ (g)} + 3H_2 \text{ (g)} \rightleftharpoons 2NH_3 \text{ (g)}$$

The value of $\Delta G^0$ for this reaction is -50 kJ/mol.
A) 22 B) -4.2 C) -22 D) -25 E) -50

14) Consider the reaction:

$$Ag^+ \text{ (aq)} + Cl^- \text{ (aq)} \rightarrow AgCl \text{ (s)}$$

Given the following table of thermodynamic data at 298K:

<table>
<thead>
<tr>
<th>Substance</th>
<th>$\Delta H^{o}_f \text{ (kJ/mol)}$</th>
<th>$S^{o} \text{(J/K(mol))}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ag⁺ (aq)</td>
<td>105.9</td>
<td>73.93</td>
</tr>
<tr>
<td>Cl⁻ (aq)</td>
<td>-167.2</td>
<td>56.5</td>
</tr>
<tr>
<td>AgCl (s)</td>
<td>-127.0</td>
<td>96.11</td>
</tr>
</tbody>
</table>

The value of K for the reaction at 25°C is $5.4 \times 10^9$.
A) $1.8 \times 10^3$ B) 810 C) $1.9 \times 10^{-10}$ D) $3.7 \times 10^{10}$ E) $5.4 \times 10^9$

15) The gain of electrons by an element is called ________.
A) reduction B) sublimation C) disproportionation D) fractionation E) oxidation

16) ________ is the oxidizing agent in the reaction below.

$$Cr_{2}O_{7}^{2-} + 6 S_2O_3^{2-} + 14 H^+ \rightarrow 2 Cr^{3+} + 3 S_4O_6^{2-} + 7 H_2O$$
A) $Cr_{2}O_{7}^{2-}$ B) $S_4O_6^{2-}$ C) $S_2O_3^{2-}$ D) $H^+$ E) $Cr^{3+}$

17) Which of the following reactions is a redox reaction?
   (a) K₂CrO₄ + BaCl₂ $\rightarrow$ BaCrO₄ + 2KCl
   (b) Pb₂⁺ + 2Br⁻ $\rightarrow$ PbBr₂
   (c) Cu + S $\rightarrow$ CuS

A) (a) only B) (b) only C) (c) only D) (a) and (c) E) (b) and (c)

18) What is the oxidation number of chromium in the dichromate ion ($Cr_2O_7^{2-}$)?
A) +14 B) +6 C) +12 D) +7 E) +3
19) What is the oxidation number of manganese in manganese dioxide?
   A) +4  B) +2  C) +3  D) +7  E) +1

20) What is the coefficient of the permanganate ion when the following equation is balanced?
    \[ \text{MnO}_4^- + \text{Br}^- \rightarrow \text{Mn}^{2+} + \text{Br}_2 \]  (acidic solution)
    A) 2  B) 5  C) 3  D) 1  E) 4

21) What is the coefficient of \( \text{Fe}^{3+} \) when the following equation is balanced?
    \[ \text{CN}^- + \text{Fe}^{3+} \rightarrow \text{CNO}^- + \text{Fe}^{2+} \]  (basic solution)
    A) 1  B) 2  C) 3  D) 4  E) 5

22) What is the oxidation number of potassium in potassium permanganate?
    A) +2  B) -1  C) +1  D) +3  E) 0

23) A reaction that is spontaneous as written __________.
    A) will proceed without outside intervention
    B) is very slow
    C) has an equilibrium position that lies far to the left
    D) is very rapid
    E) is also spontaneous in the reverse direction

24) A reversible process is one that __________.
    A) must be carried out at high temperature
    B) can be reversed with no net change in either system or surroundings
    C) happens spontaneously
    D) must be carried out at low temperature
    E) is spontaneous in both directions

25) Which of the following is a reversible process?
    A) freezing of water at -10°C and 1 atm
    B) melting of ice at 0°C and 1 atm
    C) freezing of water at -25°C and 1 atm
    D) melting of ice at 25°C and 1 atm
    E) evaporation of water at 25°C and 1 atm
Problems

(5 points) For a given reaction, $\Delta H = 35.5 \text{ kJ/mol}$ and $\Delta S = 83.6 \text{ J/K-mol}$. Determine the minimum temperature at which the reaction is spontaneous. Assume that $\Delta H$ and $\Delta S$ do not vary with temperature.

$$
\Delta G = \Delta H - T(\Delta S)
= 35.5 \text{ kJ/mol} - T(0.0836 \text{ kJ/K})
$$

$$
T = \frac{35.5 \text{ kJ/mol}}{0.0836 \text{ kJ/K}}
= 425 \text{ K or } 152^\circ \text{C}
$$

The temperature must be greater than $152^\circ \text{C}$ for the reaction to be spontaneous.

(10 points) A 1.00L solution saturated at 25°C with lead(II) iodide contains 0.54g of PbI$_2$. Calculate the solubility-product constant for this salt at 25°C.

$$
\begin{align*}
s &= [\text{PbI}_2] \\
&= [\text{Pb}^{2+}] \cdot \frac{1}{2} [\text{I}^-] \\
&= \left( \frac{0.54 \text{ g}}{461 \text{ g/mol}} \right) \cdot \frac{1}{2} \left( \frac{1.00 \text{ L}}{} \right) \\
&= 0.00117 \text{ M}
\end{align*}
$$

$$
\begin{align*}
[\text{Pb}^{2+}] &= 0.00117 \text{ M} \\
[\text{I}^-] &= 0.00234 \text{ M} \\
K_{sp} &= [\text{Pb}^{2+}] \cdot [\text{I}^-]^2 \\
&= [0.00117 \cdot 0.00234]^2 \\
&= 6.4 \times 10^{-9}
\end{align*}
$$
(10 points) Complete and balance the following equations, and identify the oxidizing and reducing agents.

\[
\text{NO}_2^-(aq) + \text{Cr}_2\text{O}_7^{2-}(aq) \rightarrow \text{Cr}^{3+}(aq) + \text{NO}_3^-(aq) \quad \text{(acid)}
\]

\[
\begin{align*}
3 \text{H}_2\text{O} + 3 \text{NO}_2^- & \rightarrow 3 \text{NO}_3^- + 6 \text{H}^+ + 6 e^- \\
6 e^- + 14\text{H}^+ + \text{Cr}_2\text{O}_7^{2-} & \rightarrow 2 \text{Cr}^{3+} + 7 \text{H}_2\text{O} \\
8 \text{H}^+ + 3 \text{NO}_2^- + \text{Cr}_2\text{O}_7^{2-} & \rightarrow 2 \text{Cr}^{3+} + 3 \text{NO}_3^- + 4 \text{H}_2\text{O}
\end{align*}
\]

\[
\text{CN}^-(aq) + \text{MnO}_4^-(aq) \rightarrow \text{CNO}^-(aq) + \text{MnO}_2(aq) \quad \text{(basic)}
\]

\[
\begin{align*}
6(\text{OH})^- + 3 \text{CN}^- & \rightarrow 3 \text{CNO}^- + 3 \text{H}_2\text{O} + 6 e^- \\
6 e^- + 4 \text{H}_2\text{O} + 2 \text{MnO}_4^- & \rightarrow 2 \text{MnO}_2 + 8 (\text{OH})^- \\
\text{H}_2\text{O} + 3 \text{CN}^- + 2 \text{MnO}_4^- & \rightarrow 2 \text{MnO}_2 + 3 \text{CNO}^- + 2 (\text{OH})^-
\end{align*}
\]