IMPORTANT: On the scantron (answer sheet), you MUST clearly fill your name, your student number, section number, and test form (white cover = test form A; yellow cover = test form B). Use a #2 pencil.

There are 25 questions on this exam. Check that you have done all of the problems and filled in the first 25 bubbles on the scantron. Your score will be reported in percent (max 100%).

Exam policy

- Calculators with text-programmable memory are not allowed.
- Relevant data and formulas, including the periodic table, are attached at the end of this exam.
- Your grade will be based only on what is on the scantron form.
- The answer key will be posted on the web after the exam (on the Exam Schedule page).
- You must turn in your cover sheet with your scantron answer form.

Hints

- As you read the question, underline or circle key words to highlight them for yourself. Avoid errors from "mis-reading" the question.
- Pay attention to units and magnitudes (decimal places) of numbers obtained from calculations. There is no penalty for guessing.

1. Consider the following reaction:

   \[ A + B \rightarrow C + D \]

   The reaction will never be spontaneous when \( \Delta H \) is __ and \( \Delta S \) is __.

   A. +, +
   B. −, −
   C. −, +
   D. +, −
   E. The reaction will always be spontaneous.

2. The value of the equilibrium constant for a particular chemical reaction is 0.48 at 25°C. What is the value of \( \Delta G^\circ \) for this reaction at 25°C?

   A. 1.8 kJ/mol
   B. −4.2 kJ/mol
   C. 1.5 x 10^2 kJ/mol
   D. 4.2 kJ/mol
   E. 1.5 x 10^2 kJ/mol

3. Which one of the following substances will decrease the solubility of CuCO\(_3\) when added to an aqueous solution of CuCO\(_3\)? (\( K_{sp} = 2.3 \times 10^{-10} \))

   A. HNO\(_3\)
   B. Na\(_2\)CO\(_3\)
   C. NH\(_3\)
   D. NaNO\(_3\)
   E. NaCl
4. How many Faradays will be required to reduce 1 mole of Cr$_2$O$_7^{2-}$ to Cr$^{3+}$?
   A. 8
   B. 6
   C. 4
   D. 3
   E. 2

5. Which of the following is true regarding a spontaneous electrochemical reaction?
   A. $\Delta G = 0$, $E = 0$, and $K > 1$
   B. $\Delta G < 0$, $E > 0$, and $K > 1$
   C. $\Delta G > 0$, $E < 0$, and $K < 1$
   D. $\Delta G > 0$, $E < 0$, and $K > 1$
   E. $\Delta G < 0$, $E = 0$, and $K < -1$

6. The following reaction is important in the smelting of iron:
   $\text{Fe}_3\text{O}_4 (s) + 4 \text{ CO}(g) \rightarrow 3 \text{ Fe}(l) + 4 \text{ CO}_2(g)$

   What is the reducing agent in the reaction?
   A. $\text{Fe}_3\text{O}_4 (s)$
   B. $\text{CO} (g)$
   C. $\text{Fe} (l)$
   D. $\text{CO}_2 (g)$
   E. This is not a redox reaction.

7. Calculate the $\Delta G^\circ$ for the following reaction at 500K.
   $\text{Cu} (s) + \text{H}_2\text{O} (g) \rightarrow \text{CuO} (g) + \text{H}_2 (g)$

<table>
<thead>
<tr>
<th></th>
<th>$\Delta H^\circ$ (kJ/mol)</th>
<th>$S^\circ$ (J/K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cu (s)</td>
<td>0</td>
<td>33.3</td>
</tr>
<tr>
<td>H$_2$O (g)</td>
<td>$-241.8$</td>
<td>188.7</td>
</tr>
<tr>
<td>CuO (g)</td>
<td>$-155.2$</td>
<td>43.5</td>
</tr>
<tr>
<td>H$_2$ (g)</td>
<td>0</td>
<td>130.6</td>
</tr>
</tbody>
</table>

   A. +110.6 kJ/mol
   B. $-86.6$ kJ/mol
   C. +23.9 kJ/mol
   D. $-62.6$ kJ/mol
   E. +301 kJ/mol

8. When excess Ni(OH)$_2$ ($K_{sp} = 1.6 \times 10^{-14}$) is added to pure water to make a saturated solution, what will be the pH at equilibrium?
   A. 9.2
   B. 14.0
   C. 9.5
   D. 7.0
   E. 4.4
9. What is the coefficient of the hypochlorite ion when the following reaction is balanced?

\[ \text{ClO}^- + \text{S}_2\text{O}_3^{2-} \rightarrow \text{Cl}^- + \text{SO}_4^{2-} \]

A. 1  
B. 2  
C. 3  
D. 4  
E. 5

10. A voltaic cell is made from Pb and Co electrodes, immersed respectively in 1.0 M solutions of Pb(NO_3)_2 and Co(NO_3)_2, respectively. Which statement is true concerning the following reaction?

\[ \text{Pb}^{2+} (aq) + \text{Co(s)} \rightarrow \text{Pb(s)} + \text{Co}^{2+} (aq) \]

A. \( E^{\circ}_{\text{cell}} = 0.41 \text{ V} \)  
B. \( \Delta G^{\circ} > 0 \)  
C. The voltage will increase as the mass of the Pb electrode is increased.  
D. The reaction is non-spontaneous as written.  
E. The cell voltage will decrease as more Co^{2+} is formed.

11. Which of the following reactions will occur spontaneously under standard conditions?

1. \( \text{Cl}_2 (g) + 2 \text{ Br}^- (aq) \rightarrow 2 \text{ Cl}^- (aq) + \text{ Br}_2 (l) \)
2. \( \text{Cl}_2 (g) + 2 \text{ I}^- (aq) \rightarrow 2 \text{ Cl}^- (aq) + \text{ I}_2 (s) \)
3. \( \text{I}_2 (s) + 2 \text{ Br}^- (aq) \rightarrow 2 \text{ I}^- (aq) + \text{ Br}_2 (l) \)

A. 1 only  
B. 2 only  
C. 3 only  
D. 1 and 2 only  
E. 1, 2 and 3

12. Iron objects such as storage tanks and underground pipelines can be protected from corrosion by connecting them through a wire to a piece of which metal?

A. Pb  
B. Ag  
C. Sn  
D. Mg  
E. Cu

13. For the voltaic cell shown below, which way will the electrons flow through the external circuit, and what will be the standard cell potential, \( E^{\circ}_{\text{cell}} \)?

A. Electrons flow from Cu(s) to Mn(s), 1.52 V  
B. Electrons flow from Cu(s) to Mn(s), 0.84 V  
C. Electrons flow from Mn(s) to Cu(s), 1.52 V  
D. Electrons flow from Mn(s) to Cu(s), 0.84 V  
E. Electrons flow from Mn(s) to the KCl salt bridge, 0.84 V
14. How many seconds will be required to produce 1.0 g of silver metal by the electrolysis of an aqueous AgNO₃ solution using a current of 30 amps?
   A. $2.7 \times 10^4$ s
   B. $3.2 \times 10^3$ s
   C. 60 s
   D. 30 s
   E. 524 s

15. The entropy of vaporization ($\Delta S_{vap}^\circ$) for benzene is 96.4 J/K·mol. The enthalpy of vaporization ($\Delta H_{vap}^\circ$) is 33.9 kJ/mol. What is the boiling point of benzene in degrees Celsius?
   A. 2.8°C
   B. 0.35°C
   C. 93°C
   D. 54°C
   E. 79°C

16. Which of the following substances will be more soluble in acidic solutions than in neutral water?
   A. CaF₂
   B. AgCl
   C. PbBr₂
   D. AgI
   E. None of the above

17. Calculate the concentration of free Ni²⁺(aq) ions in 1 L of a solution that contains a total of 1x10⁻³ moles of Ni atoms (including both free ions and complexed ions), and that is 0.20 M in NH₃ at equilibrium. ($K_f [Ni(NH₃)₆]^{2+} = 1.2 \times 10^9$)
   A. $1.2 \times 10^8$ M
   B. $1 \times 10^{-3}$ M
   C. $1 \times 10^{-3}$ M
   D. $2 \times 10^{-3}$ M
   E. $5 \times 10^{-3}$ M

18. What are the elemental products initially formed at the cathode and anode of an electrolytic cell when an aqueous solution containing a mixture of 1M of HCl, CuCl₂ and CoBr₂ is electrolyzed?
   A. Co(s) and Cl₂ (g)
   B. Cu(s) and Br₂ (l)
   C. H₂ (g) and Cl₂ (g)
   D. Co(s) and Br₂ (l)
   E. H₂ (g) and Br₂ (l)

19. Which of the following is the best oxidizing agent?
   A. Fe³⁺
   B. Fe²⁺
   C. Cu²⁺
   D. Al³⁺
   E. H⁺
20. What is the equilibrium constant for the following reaction at 25°C?

\[ 2 \text{Cu}^{2+} (aq) + \text{Sn}(s) \rightarrow 2 \text{Cu}^+ (aq) + \text{Sn}^{2+} (aq) \]

A. \(3 \times 10^2\)  
B. \(2 \times 10^3\)  
C. \(8 \times 10^4\)  
D. \(9 \times 10^5\)  
E. \(6 \times 10^6\)

21. The first step in a commercial process in which magnesium is obtained from seawater involves precipitating \(\text{Mg}^{2+}\) as \(\text{Mg(OH)}_2(s)\). The magnesium ion concentration \([\text{Mg}^{2+}]\) in seawater is about 0.059 M. If a seawater sample is treated so that the \([\text{OH}^-]\) is maintained at \(2.0 \times 10^{-3}\) M, what will be the approximate magnesium ion concentration \([\text{Mg}^{2+}]\) in the treated sample? (\(K_{sp}\) of \(\text{Mg(OH)}_2\) is \(1.8 \times 10^{-11}\))

A. \(8.8 \times 10^{-7}\) M  
B. \(4.5 \times 10^{-8}\) M  
C. \(2.5 \times 10^{-2}\) M  
D. \(1.0 \times 10^{-9}\) M  
E. \(1.2 \times 10^{-6}\) M

22. A solution contains a mixture of three anions with the following concentrations: 0.20 M \(\text{CrO}_4^{2-}\), 0.10 M \(\text{CO}_3^{2-}\), and 0.010 M \(\text{Cl}^-\). If a dilute \(\text{AgNO}_3\) solution is slowly added to the solution, which solid compound will be the first to precipitate?

A. \(\text{AgNO}_3\)  
B. \(\text{Ag}_2\text{CrO}_4\) (\(K_{sp} = 1.2 \times 10^{-12}\))  
C. \(\text{Ag}_2\text{CO}_3\) (\(K_{sp} = 8.1 \times 10^{-12}\))  
D. \(\text{AgCl}\) (\(K_{sp} = 1.8 \times 10^{-10}\))  
E. \(\text{Ag}_2\text{CrO}_4\), \(\text{Ag}_2\text{CO}_3\) and \(\text{AgCl}\) will all precipitate at exactly the same time.

23. The solubility of \(\text{LaF}_3\) is \(1.8 \times 10^{-3}\) g/L. Given that the molecular weight of \(\text{LaF}_3\) is 196 g/mol, what is the value of \(K_{sp}\)?

A. \(4 \times 10^{-15}\)  
B. \(8 \times 10^{-16}\)  
C. \(2 \times 10^{-19}\)  
D. \(7 \times 10^{-21}\)  
E. \(3 \times 10^{-27}\)

24. What is the concentration of \(\text{Zn}^{2+}\) (aq) when the cell based on the following reaction has a potential of 1.30 V at 25°C and the concentration of \(\text{Cu}^{2+}\) is \(1.0 \times 10^{-5}\) M?

\[ \text{Zn}(s) + \text{Cu}^{2+} (aq) \rightarrow \text{Zn}^{2+} (aq) + \text{Cu}(s) \]

A. 1.0 M  
B. \(1.8 \times 10^{-12}\) M  
C. \(4.4 \times 10^{-9}\) M  
D. \(4.1 \times 10^{-9}\) M  
E. 60.2 M
25. The following standard reduction potentials apply for a nickel-cadmium (nicad) rechargeable battery:

\[
\begin{align*}
\text{Cd(OH)}_2(s) + 2 \text{e}^- & \rightarrow \text{Cd}(s) + 2 \text{OH}^- \text{(aq)} & E_{\text{red}}^\circ &= -0.76 \text{ V} \\
2 \text{NiO(OH)}(s) + 2 \text{H}_2\text{O}(l) + 2 \text{e}^- & \rightarrow 2 \text{Ni(OH)}_2(s) + 2 \text{OH}^- \text{(aq)} & E_{\text{red}}^\circ &= +0.49 \text{ V}
\end{align*}
\]

Which of the following statements is true?

A. During discharge the electrode with cadmium species acts as the cathode.
B. The cell potential is $-0.27 \text{ V}$.
C. During recharge the electrode with nickel species acts as the cathode.
D. The free energy change during battery discharge is positive.
E. During recharge the cell potential is $-1.25 \text{ V}$.