Curriculum:

Organizers
1. Reaction Kinetics
2. Dynamic Equilibrium
3. Solubility Equilibria
4. Acids, Bases, and Salts
5. Oxidation – Reduction

Sub-Organizers
A, B, C
D, E, F
G, H, I
J, K, L, M, N, O, P, Q, R
S, T, U, V, W

Part A: Multiple Choice

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Multiple Choice = 60 marks (48 questions)
### Part B: Written Response

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**Written Response** = 40 marks

**Multiple Choice** = 60 (48 questions)

**Written Response** = 40 (12 questions)

**EXAMINATION TOTAL** = 100 marks

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**LEGEND:**
- **Q** = Question Number
- **K** = Keyed Response
- **C** = Cognitive Level
- **B** = Score Box Number
- **S** = Score
- **CO** = Curriculum Organizer
- **PLO** = Prescribed Learning Outcome
1. Using the axes below, sketch a PE diagram for the reacting system where: \( \Delta H = -30 \text{ kJ/mol} \) and \( E_a = 50 \text{ kJ/mol} \) \((3 \text{ marks})\)

Solution:

For Example:

See graph above.
2. Consider the following reaction mechanism:

<table>
<thead>
<tr>
<th>Step</th>
<th>Reaction</th>
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<tbody>
<tr>
<td>Step 1</td>
<td>$2\text{NO} \rightarrow \text{N}_2\text{O}_2$</td>
</tr>
<tr>
<td>Step 2</td>
<td>$\text{N}_2\text{O}_2 + \text{H}_2 \rightarrow \text{N}_2\text{O} + \text{H}_2\text{O}$</td>
</tr>
<tr>
<td>Step 3</td>
<td>$\text{N}_2\text{O} + \text{H}_2 \rightarrow \text{N}_2 + \text{H}_2\text{O}$</td>
</tr>
</tbody>
</table>

a) Determine the overall reaction. (2 marks)

Solution:

Overall Reaction: $2\text{NO} + 2\text{H}_2 \rightarrow \text{N}_2 + 2\text{H}_2\text{O}$ ← \{ 1 mark for reactants, 1 mark for products \}

b) Identify a reaction intermediate. (1 mark)

Solution:

$\text{N}_2\text{O}_2 \text{ OR } \text{N}_2\text{O}$ ← 1 mark
3. Consider the following equilibrium:

\[ \text{CH}_4(g) + \text{H}_2\text{O}(g) \rightleftharpoons \text{CO}(g) + 3\text{H}_2(g) \]

<table>
<thead>
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<th>(K_{eq})</th>
<th>Temperature</th>
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<td>(1.78 \times 10^{-3})</td>
<td>800(^\circ)C</td>
</tr>
<tr>
<td>(4.68 \times 10^{-2})</td>
<td>1000(^\circ)C</td>
</tr>
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</table>

Is the forward reaction in this equilibrium exothermic or endothermic? Explain your answer. (3 marks)

Solution:

*For Example:*

This equilibrium is endothermic. \(\leftarrow 1\) mark

Since \(K_{eq}\) increases as a result of a temperature increase, equilibrium has shifted to the right. \(\leftarrow 2\) marks
4. Consider the following equilibrium:

\[ \text{CO}_{(g)} + \text{Cl}_2(g) \rightleftharpoons \text{COCl}_2(g) \]

At equilibrium, the system contains 2.00 mol CO, 1.00 mol Cl₂ and 0.200 mol COCl₂ in a 2.0 L container. Calculate the value of \( K_{eq} \). (3 marks)

**Solution:**

*For Example:*

\[ K_{eq} = \frac{[\text{COCl}_2]}{[\text{CO}][\text{Cl}_2]} \]

\[ = \frac{(0.200 \text{ mol/2.0 L})}{(2.00 \text{ mol/2.0 L})(1.00 \text{ mol/2.0 L})} \]

\[ = \frac{(0.100)}{(1.00)(0.500)} \]

\[ = 0.20 \]

(Deduct \( \frac{1}{2} \) mark for incorrect significant figures.)
5. Calculate the mass of NaI necessary to begin precipitation of Cu⁺ from a 250.0 mL sample of 0.010 M Cu(NO₃)₂.

Solution:

For Example:

\[
\text{CuI}_\text{(s)} \rightleftharpoons \text{Cu}^+\text{(aq)} + \text{I}^-\text{(aq)}
\]

\[
K_{sp} = [\text{Cu}^+][\text{I}^-] = 1.3 \times 10^{-12}
\]

\[
[\text{I}^-] = \frac{K_{sp}}{[\text{Cu}^+]} = \frac{1.3 \times 10^{-12}}{0.010} = 1.3 \times 10^{-10} \text{ M}
\]

\[
[\text{NaI}] = [\text{I}^-] = 1.3 \times 10^{-10} \text{ M}
\]

mass of NaI = \(1.3 \times 10^{-1} \text{ mol/L} \times \frac{149.9 \text{ g}}{\text{mole}} \times 0.250 \text{ L}
\]

\[
= 4.9 \times 10^{-9} \text{ g}
\]

\(\leftarrow 2 \text{ marks}\)

\(\leftarrow 2 \text{ marks}\)
6. When a solution of \( \text{Na}_2\text{CO}_3(\text{aq}) \) is mixed with a solution of \( \text{Ca(NO}_3\text{)}_2(\text{aq}) \), a precipitate forms.

   a) Write the net ionic equation for the precipitation reaction.  
   
   **Solution:**

   **For Example:**

   \[
   \text{Ca}^{2+}(\text{aq}) + \text{CO}_3^{2-}(\text{aq}) \rightarrow \text{CaCO}_3(\text{s}) \quad \leftarrow 1 \text{ mark}
   \]

   b) Explain what happens to the precipitate when HCl is added.  
   
   **Solution:**

   **For Example:**

   Addition of HCl provides \( \text{H}^+(\text{aq}) \) which reacts with the \( \text{CO}_3^{2-}(\text{aq}) \):  

   \[
   \text{H}^+(\text{aq}) + \text{CO}_3^{2-}(\text{aq}) \rightarrow \text{HCO}_3^-(\text{aq}) \quad \leftarrow 3 \text{ marks}
   \]

   This reduces the \( [\text{CO}_3^{2-}(\text{aq})] \) in the solubility equilibrium,  

   \[
   \text{CaCO}_3(\text{s}) \rightleftharpoons \text{Ca}^{2+}(\text{aq}) + \text{CO}_3^{2-}(\text{aq})
   \]

   causing more solid to dissolve to offset the stress caused by the reduction in concentration.
7. Write a chemical reaction showing an amphiprotic anion reacting as a base in water. (2 marks)

Solution:

*For Example:*

\[
\text{HPO}_4^{2-} + \text{H}_2\text{O} \rightleftharpoons \text{H}_2\text{PO}_4^- + \text{OH}^- 
\]

← 2 marks
8. Calculate the pOH of 0.25 M Sr(OH)$_2$. (2 marks)

Solution:

*For Example:*

\[
\left[ \text{OH}^- \right] = 2(0.25 \text{ M}) = 0.50 \text{ M} \quad \leftarrow 1 \text{ mark}
\]

\[
\text{pOH} = -\log(0.50)
\]

\[
= 0.30 \quad \leftarrow 1 \text{ mark}
\]

(Deduct $\frac{1}{2}$ mark for incorrect significant figures.)
9. A 2.00 M diprotic acid has a pH of 0.50. Calculate its $K_a$ value. \hfill (5 marks)

Solution:

*For Example:*

\[
\begin{array}{c|ccc}
[I] & H_2X & + & H_2O \\ 
[C] & -0.316 & + & 0.316 \\ 
[E] & 1.684 & & 0.316
\end{array}
\]

\[
\begin{align*}
\text{pH} = 0.50; \quad \left[ H_3O^+ \right] &= 10^{-0.50} = 0.316 \text{ M} \\
K_a &= \frac{\left[ H_3O^+ \right] \left[ HX^- \right]}{\left[ H_2X \right]} = \frac{(0.316)^2}{1.684} = 5.9 \times 10^{-2}
\end{align*}
\]

$\leftarrow 2$ marks $\quad \leftarrow 1$ mark $\quad \leftarrow 2$ marks
10. The following two experiments were conducted:

    Titration A: A strong acid was titrated with a strong base.
    Titration B: A weak acid was titrated with a strong base.

a) How does the pH at the equivalence point of Titration B compare with the pH at
   the equivalence point of Titration A? 
   (1 mark)

Solution:

For Example:

The pH at the equivalence point of Titration A = 7.0.
The pH at the equivalence point of Titration B > 7.0. \[ \rightarrow 1 \text{ mark} \]

b) Explain your answer to a). 
   (2 marks)

Solution:

For Example:

Neutral salt formed in titration A, a basic salt is formed in
titration B. \[ \rightarrow 2 \text{ marks} \]
11. Balance the following redox reaction.  

\[ \text{Sb} + \text{NO}_3^- \rightarrow \text{Sb}_2\text{O}_5 + \text{NO} \]  (acidic)  

**Solution:**

*For Example:*

\[
\begin{align*}
\left( 5\text{H}_2\text{O} + 2\text{Sb} \rightarrow \text{Sb}_2\text{O}_5 + 10\text{H}^+ + 10\text{e}^- \right) \times 3 \\
\left( 3\text{e}^- + 4\text{H}^+ + \text{NO}_3^- \rightarrow \text{NO} + 2\text{H}_2\text{O} \right) \times 10 \\
15\text{H}_2\text{O} + 6\text{Sb} + 40\text{H}^+ + 10\text{NO}_3^- \rightarrow 3\text{Sb}_2\text{O}_5 + 30\text{H}^+ + 10\text{NO} + 20\text{H}_2\text{O} \\
10\text{H}^+ + 6\text{Sb} + 10\text{NO}_3^- \rightarrow 3\text{Sb}_2\text{O}_5 + 10\text{NO} + 5\text{H}_2\text{O}
\end{align*}
\]

2 marks  
(1 mark for each half-reaction)  
1 mark for electron balance  
1 mark for overall reaction
12. A 1.0 M HCl solution is electrolyzed using a copper anode and an inert carbon cathode. Predict the half-reactions that will occur and describe what you would observe at each electrode. (4 marks)

Solution:

*For Example:*

Anode half-reaction:  \( \text{Cu}(s) \rightarrow \text{Cu}^{2+} + 2e^- \)

Anode observations:
Electrode is eaten away and solution turns blue. \( \leftarrow 2 \text{ marks} \)

Cathode half-reaction:  \( 2\text{H}^+ + 2e^- \rightarrow \text{H}_2(g) \)

Cathode observations:
Bubbles form, but no change to electrode. \( \leftarrow 2 \text{ marks} \)