This exam has four (4) questions. Please check before beginning to make sure no questions are missing. All scratch work must be done on the attached blank pages, which will be collected. Please sign BOTH cover pages.
Periodic Table of the Elements

<table>
<thead>
<tr>
<th>Group I</th>
<th>II</th>
<th>III</th>
<th>IV</th>
<th>V</th>
<th>VI</th>
<th>VII</th>
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<tbody>
<tr>
<td>Period</td>
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<td>2. 20</td>
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<td>B</td>
<td>C</td>
<td>N</td>
<td>O</td>
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<tr>
<td>3. 30</td>
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<td>Mg</td>
<td>Al</td>
<td>Si</td>
<td>P</td>
<td>S</td>
<td>Cl</td>
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<td>4. 10</td>
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<td>Ca</td>
<td>Ti</td>
<td>V</td>
<td>Cr</td>
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<td>5. Rb</td>
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<td>Zr</td>
<td>Nb</td>
<td>Mo</td>
<td>Tc</td>
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<td>La</td>
<td>Hf</td>
<td>Ta</td>
<td>W</td>
<td>Re</td>
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<td>7. Fr</td>
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<td>Ac</td>
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Lanthanide Series

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<th>Sm</th>
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<th>Gd</th>
<th>Tb</th>
<th>Dy</th>
<th>Ho</th>
<th>Er</th>
<th>Tm</th>
<th>Yb</th>
<th>Lu</th>
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Actinide Series

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<th>U</th>
<th>Np</th>
<th>Pu</th>
<th>Am</th>
<th>Cm</th>
<th>Bk</th>
<th>Cf</th>
<th>Es</th>
<th>Fm</th>
<th>Md</th>
<th>No</th>
<th>Lw</th>
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<td>101</td>
<td>102</td>
<td>103</td>
</tr>
</tbody>
</table>

ADVICE: A picture is worth a thousand words!
1. For the reactions below, fill in the missing starting materials, reagents or products as appropriate. Be certain to show stereochemistry where applicable with an accurate drawing. You must draw your answer neatly in the box to receive credit. (50 pts).

(a) 
\[
\begin{align*}
    &\text{1. } O_3 \\
    &\text{2. Zn/HOAc} \\
\end{align*}
\]

(b) 
\[
\begin{align*}
    &\text{Br}_2 \\
    &\text{H}_2\text{O} \\
\end{align*}
\]

(c) 
\[
\begin{align*}
    &\text{1. } \text{Hg(OAc)}_2 \\
    &\text{2. NaBH}_4 \\
\end{align*}
\]

(d) 
\[
\begin{align*}
    &\text{1. } \text{Hg(OAc)}_2 / \text{CH}_3\text{OH} \\
    &\text{2. NaBH}_4 \\
\end{align*}
\]

(e) 
\[
\begin{align*}
    &\text{1. } \text{Br}_2 \text{ (or Cl}_2\text{) } \\
    &\text{2. } x's \text{ KOH} / \Delta \\
\end{align*}
\]
(f)\[\text{Br}_2\text{ excess LiCl} \rightarrow \text{Br}\text{Cl}\]

(g)\[\text{CH}_3\text{CH}_2\text{H} \xrightarrow{1. \text{BH}_3} \text{CH}_3\text{CH}_2\text{CH}_2\text{CO}_2\text{H} \xrightarrow{2. \text{HOOH/KOH}} \]

(h)\[\text{H}_2\text{O} \xrightarrow{\text{HIO}_4} \text{NO REACTION} \]

(i)\[\text{CH}_3 \xrightarrow{\text{KMnO}_4} \text{CH}_3\text{CO}_2\text{H} \]

(j)\[\text{Me} \xrightarrow{1. \text{OsO}_4, 2. \text{NaHSO}_3, 3. \text{HIO}_4} \]


2. (a) Provide a detailed mechanistic analysis for the reaction shown below. Label all intermediate structures (a, b, c etc.), and show all electron flow using the curved arrow convention. (15 pts).

(b) Draw a qualitative reaction energy diagram for this reaction in the template provided below, indicating the relative energy of all reactants, intermediates and products. You need not re-draw structures which are clearly labeled above - use the labels. (5 pts).

3. Provide the most efficient synthesis possible for each of the compounds below using organic building blocks containing no more than four carbons. (30 pts).
4. Caryophyllene (C_{15}H_{24}) is a naturally occurring hydrocarbon isolated from cloves. Determine the structure of this compound from the information provided below. (10 pts).

1. Caryophyllene + H_2 \xrightarrow{Pd/C} A compound of formula C_{15}H_{28}

2. Caryophyllene + 1. O_3, 2. Zn/HOAc

3. Caryophyllene + 1. 1 equiv BH_3, 2. HOOH, KOH → C_{15}H_{26}O + 1. O_3, 2. Zn/HOAc

Caryophyllene (either structure correct) Isocaryophyllene