1. (6 pts) What is the oxidation state (number) for
   a) N in NH₄Cl
   b) I in IO₃⁻
   c) Cr in K₂Cr₂O₇

2. (8 pts) Indicate which of the following are oxidation-reduction reactions. Circle yes or no for each reaction.
   a) PCl₃ + Cl₂ → PCl₅  yes no
   b) Cu + 2 AgNO₃ → Cu(NO₃)₂ + 2 Ag  yes no
   c) CO₂ + 2 LiOH → Li₂CO₃ + H₂O  yes no
   d) FeCl₂ + 2 NaOH → Fe(OH)₂ + 2 NaCl  yes no

3. (6 pts) Consider the following oxidation-reduction reaction.
   \[ 2 \text{Fe}^{3+} + 2 \text{I}^{-} \rightarrow 2 \text{Fe}^{2+} + \text{I}_2 \]
   Write the balanced oxidation and reduction half-reactions for this reaction.
   Oxidation half-reaction:
   Reduction half-reaction:

4. (5 pts) How many moles of electrons are transferred in the following oxidation-reduction reaction?
   \[ \text{CH}_4 + 2 \text{O}_2 \rightarrow \text{CO}_2 + 2 \text{H}_2\text{O} \]

5. (8 pts) Balance the following oxidation-reduction reaction in acidic solution, using the half-reaction method.
   \[ \text{Cr}_2\text{O}_7^{2-} + \text{I}^- \rightarrow \text{Cr}^{3+} + \text{IO}_3^- \]
6. Suppose the following data is obtained for the reaction \( \text{CO} + \text{Cl}_2 \rightarrow \text{COCl} + \text{Cl} \)

<table>
<thead>
<tr>
<th>([\text{CO}]_0) (mol/L)</th>
<th>([\text{Cl}_2]_0) (mol/L)</th>
<th>Rate (mol L(^{-1}) s(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.00 x 10(^2)</td>
<td>1.00 x 10(^2)</td>
<td>6.60 x 10(^3)</td>
</tr>
<tr>
<td>2.00 x 10(^2)</td>
<td>1.00 x 10(^2)</td>
<td>1.32 x 10(^4)</td>
</tr>
<tr>
<td>3.00 x 10(^2)</td>
<td>1.00 x 10(^2)</td>
<td>1.98 x 10(^4)</td>
</tr>
<tr>
<td>1.00 x 10(^2)</td>
<td>2.00 x 10(^2)</td>
<td>2.64 x 10(^4)</td>
</tr>
<tr>
<td>2.00 x 10(^2)</td>
<td>3.00 x 10(^2)</td>
<td>1.19 x 10(^5)</td>
</tr>
</tbody>
</table>

a) (6 pts) Write the rate law for this reaction.

b) (6 pts) Calculate the rate constant (be sure to include the units!!)

7. Given the following reaction mechanism, \( \text{Mechanisms will NOT be on this exam.} \)

\[
\begin{align*}
2 \text{NO}_2\text{Cl} & \rightleftharpoons \text{ClO}_2 + \text{N}_2\text{O} + \text{ClO} \quad \text{(fast equilibrium)} \\
\text{N}_2\text{O} + \text{ClO}_2 & \rightleftharpoons \text{NO}_2 + \text{NOCl} \quad \text{(fast equilibrium)} \\
\text{NOCl} + \text{ClO} & \rightarrow \text{NO}_2 + \text{Cl}_2 \quad \text{(slow)}
\end{align*}
\]

a) (2 pts) What is the overall reaction?

b) (2 pts) List the intermediate(s) in the reaction.

c) (6 pts) What is the order of reaction with respect to NO\(_2\)?
8. (9 pts) Nitryl chloride decomposes to nitrogen dioxide and chlorine, according to the following reaction.

\[ 2 \text{NO}_2\text{Cl} \longrightarrow 2 \text{NO}_2 + \text{Cl}_2 \]

The experimental rate law for this reaction is

\[ \text{Rate} = k [\text{NO}_2\text{Cl}] \]

Mechanisms will NOT be on this exam.

Which, if any, of the following mechanisms are consistent with the observed rate law? More than one answer is possible. Cross out the mechanisms, if any, which are not consistent with the observed rate law.

a) \[ \text{NO}_2\text{Cl} \longrightarrow \text{NO}_2 + \text{Cl} \] (slow)
   \[ \text{Cl} + \text{NO}_2\text{Cl} \longrightarrow \text{NO}_2 + \text{Cl}_2 \] (fast)

b) \[ 2 \text{NO}_2\text{Cl} \rightleftharpoons \text{N}_2\text{O}_4 + \text{Cl}_2 \] (fast equilibrium)
   \[ \text{N}_2\text{O}_4 \longrightarrow 2 \text{NO}_2 \] (slow)

c) \[ 2 \text{NO}_2\text{Cl} \rightleftharpoons \text{ClO}_2 + \text{N}_2\text{O} + \text{ClO} \] (fast equilibrium)
   \[ \text{N}_2\text{O} + \text{ClO}_2 \rightleftharpoons \text{NO}_2 + \text{NOCl} \] (fast equilibrium)
   \[ \text{NOCl} + \text{ClO} \longrightarrow \text{NO}_2 + \text{Cl}_2 \] (slow)

9. (8 pts) The decomposition of nitrogen dioxide, \[ 2\text{NO}_2 \longrightarrow 2\text{NO} + \text{O}_2 \] obeys the rate law:

\[ \text{Rate} = k[\text{NO}_2]^2 \]

For this reaction the rate constant, \( k = 1.4 \times 10^{-2} \text{ L mol}^{-1} \text{s}^{-1} \) at 500 K. If the initial concentration is 1.00 mol/L, how long will it take for the [NO\textsubscript{2}] to decrease to 25.0 %?

10. (6 pts) Consider the reaction of nitrogen dioxide with oxygen, \[ \text{NO}_2 + \text{O}_2 \longrightarrow \text{NO} + \text{O}_3 \] This reaction is endothermic with \( \Delta H^\circ = +199 \text{ kJ/mol} \) and the forward activation energy, \( E_a \), is 209 kJ/mol. Draw a potential energy profile for this reaction. Your diagram should show the reactants, products, transition state \([X]^\dagger\), \( E_a \) and \( \Delta H^\circ \).

\[ \text{NOT be on this exam.} \]
11. Answer the questions using the following half reactions:

\[
\begin{array}{ccc}
\text{Reaction} & \varepsilon^0 (\text{V}) \\
\text{Cl}_2 + 2e^- & \rightarrow & 2 \text{Cl}^- \\
\text{Cr}_2\text{O}_7^{2-} + 14 \text{H}^+ + 6 e^- & \rightarrow & 2 \text{Cr}^{3+} + 7 \text{H}_2\text{O} \\
\text{O}_2 + 4 \text{H}^+ + 4 e^- & \rightarrow & 2 \text{H}_2\text{O} \\
\text{ClO}_2^- + e^- & \rightarrow & \text{ClO}_2^- \\
\text{Ag}^+ + e^- & \rightarrow & \text{Ag} (s) \\
\text{Cu}^{2+} + 2 e^- & \rightarrow & \text{Cu} (s) \\
2 \text{H}^+ + 2 e^- & \rightarrow & \text{H}_2 \\
\text{Co}^{2+} + 2 e^- & \rightarrow & \text{Co} (s) \\
\text{Cd}^{2+} + 2 e^- & \rightarrow & \text{Cd} (s) \\
\text{Cr}^{3+} + 3 e^- & \rightarrow & \text{Cr} (s)
\end{array}
\]

a) (2 pts) Which is the strongest reducing agent?

b) (2 pts) Is \text{Cr}^{3+} capable of oxidizing \text{Ag} (s)?

c) (2 pts) Is the reaction \text{Cd} (s) + 2 \text{H}^+ \rightarrow \text{H}_2 + \text{Cd}^{2+} spontaneous?

e) (2 pts) Does \text{Cu} (s) dissolve in hydrochloric acid?

f) (6 pts) Calculate \(\Delta G^0\) for the following reaction at 25°C.

\[
2 \text{NaClO}_2 (aq) + \text{Cl}_2 (g) \rightarrow 2 \text{ClO}_2 (g) + 2 \text{NaCl(aq)}
\]

g) (8 pts) An antique automobile bumper is to be chrome plated. The bumper is dipped into an acidic \text{Cr}_2\text{O}_7^{2-} solution where it serves as the cathode of an electrolytic cell. If oxidation of \text{H}_2\text{O} occurs at the anode, how many moles of oxygen gas will evolve for every 100 g of \text{Cr} (s) deposited? The atomic mass of \text{Cr} is 52 g/mol.