R = 0.08206 L atm/mol K = 8.314 J/mol K
F = 96,485 J/V(C/mol e⁻)
c = 2.99792 x 10⁸ m/s

1. Hydrogen reacts with nitric oxide to form nitrous oxide (laughing gas) according to the equation

$$2\text{NO} (g) + \text{H}_2 (g) \rightarrow \text{N}_2\text{O} (g) + \text{H}_2\text{O}(g)$$

The following initial rates of reaction have been observed for certain reactant concentrations:

<table>
<thead>
<tr>
<th>NO, mol L⁻¹</th>
<th>H₂ mol L⁻¹</th>
<th>Rate, mol L⁻¹ h⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.30</td>
<td>0.35</td>
<td>2.835 x 10⁻³</td>
</tr>
<tr>
<td>0.60</td>
<td>0.35</td>
<td>1.134 x 10⁻²</td>
</tr>
<tr>
<td>0.60</td>
<td>0.70</td>
<td>2.268 x 10⁻²</td>
</tr>
</tbody>
</table>

a. What is the rate equation for the reaction? (5 pt)

Rate = \( k [\text{NO}]^x [\text{H}_2]^y \)

Hold \([\text{H}_2]\) constant, double \([\text{NO}]\), rate quadruples. \(x = 2\)

Hold \([\text{NO}]\) constant, double \([\text{H}_2]\), rate doubles. \(y = 1\)

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

b. What is the value of the rate constant? (3 pt)

\(k = \frac{\text{Rate}}{[\text{NO}]^2 [\text{H}_2]} = \frac{2.835 \times 10^{-3}}{(0.30)^2(0.35)} = 0.09\)

c. What is the order of the reaction in each reactant and the overall order of the reaction? (3 pt)

2nd order in \(\text{NO}\)
1st order in \(\text{H}_2\)

3rd order overall
2. Use the following diagram for questions a-e, (10 pt)

![Reaction pathway diagram](image)

- a. Which is the transition state? A B C D E
- b. Which is the activation energy? A B C D E
- c. Is the activation energy positive or negative? positive negative
- d. Which is the energy of reaction? A B C D E
- e. Is the reaction exothermic or endothermic? exothermic endothermic

3. For the following reaction between gases at equilibrium, determine the effect on the equilibrium (circle one of the following: shift left, no change, shift right) when the following changes take place. (10 pt)

\[
\text{CO(g)} + 2 \text{H}_2(\text{g}) \rightarrow \text{CH}_3\text{OH(g)} \quad \Delta H = -90.7 \text{ kJ}
\]

- a. Decrease the temperature shift left no change shift right
- b. Increase the volume shift left no change shift right
- c. Increase the pressure shift left no change shift right
- d. Remove H₂(g) from the reaction shift left no change shift right
- e. Add a catalyst shift left no change shift right
4. Circle the \textbf{acid} in each of the following pairs that is \textbf{stronger}. (10 pt)

a. \( \text{H}_2\text{O} \) and \( \text{H}_2\text{S} \)

b. \( \text{HBrO}_4 \) and \( \text{HIO}_4 \)

c. \( \text{HBrO}_4 \) and \( \text{HBrO} \)

d. \( \text{HCl} \) and \( \text{HI} \)

e. \( \text{HCNO} \ (K_a = 3.5 \times 10^{-4}) \) and \( \text{HCN} \ (K_a = 4.9 \times 10^{-10}) \)

5. Consider a 1.00-L buffer made by adding 0.20 mol benzoic acid, \( \text{HC}_7\text{H}_5\text{O}_2 \), and 0.10 mol sodium benzoate, \( \text{NaC}_7\text{H}_5\text{O}_2 \), to sufficient water. Calculate the pH of the buffer.

For benzoic acid, \( K_a = 6.3 \times 10^{-5} \). (6 pt)

\[
\text{HA} \rightleftharpoons \text{H}^+ + \text{A}^-
\]

\[
K_a = \frac{[\text{H}^+][\text{A}^-]}{[\text{HA}]} = 6.3 \times 10^{-5}
\]

\[
\text{pH} = -\log \left( K_a \cdot \frac{[\text{HA}]}{[\text{A}^-]} \right) = -\log \left( 6.3 \times 10^{-5} \cdot \frac{0.20}{0.10} \right) = 3.90
\]
6. In the following reaction, identify the **acid** (A), **conjugate acid** (CA), **base** (B), and **conjugate base** (CB). (4 pt)

\[
\text{F}^- + \text{H}_2\text{O} \rightarrow \text{HF} + \text{OH}^- \\
\begin{array}{cccc}
B & A & CA & CB
\end{array}
\]

7. Identify the **Lewis acid** (LA) and **Lewis base** (LB) in each of the reactions below. (4 pt)

a. \( \text{Ni}^{2+} + 6\text{H}_2\text{O} \rightarrow [\text{Ni(H}_2\text{O})_6]^{2+} \)

\( \text{LA} \quad \text{LB} \)

b. \( \text{CaO} + \text{SO}_2 \rightarrow \text{CaSO}_3 \)

\( \text{LB} \quad \text{LA} \)

8. What is the pH of a 0.33 M solution of NH\(_3\)? For NH\(_3\), \( K_b = 1.8 \times 10^{-5} \). (5 pt)

\[
\text{B} + \text{H}_2\text{O} \rightleftharpoons \text{BH}^+ + \text{OH}^- \\
\text{weak base}
\]

\[
K_b = \frac{[\text{BH}^+][\text{OH}^-]}{[\text{B}]} \\
x^2 = K_b [\text{B}] \\
x = \sqrt{K_b [\text{B}]} = 2.4 \times 10^{-3} = [\text{OH}^-]
\]

\[
\text{pOH} = -\log [\text{OH}^-] = 2.62 \\
\text{pH} = 14 - \text{pOH} = 11.38
\]
9. Calculate the molar solubility of barium fluoride, BaF₂, given that the solubility product constant, $K_{sp}$, of barium fluoride is $1.7 \times 10^{-6}$. (5 pt)

$$
\text{BaF}_2(s) \rightleftharpoons \text{Ba}^{2+}(aq) + 2\text{F}^-(aq)
$$

$$
K_{sp} = [\text{Ba}^{2+}][\text{F}^-]^2 = 1.7 \times 10^{-6}
$$

$$
\left(x\right)\left(2x\right)^2 = 1.7 \times 10^{-6}
$$

$$
4x^3 = 1.7 \times 10^{-6}
$$

$$
x^3 = 4.25 \times 10^{-7}
$$

$$
x = 7.5 \times 10^{-3} \text{ M}
$$

10. The half life of cesium-137 is 30 years. What percentage will remain after 200 years? (5 pt)

**Skip**
11. For titanium tetrachloride, TiCl₄, (a) write the equilibrium equation for the boiling point, (b) calculate $\Delta G^\circ$, and (c) estimate the boiling temperature, $T_{bp}$. (10 pt)

for TiCl₄ (l) $\Delta H_f^\circ = -804.2$ kJ, $S^\circ = 221.9$ J/K ;

TiCl₄ (g) $\Delta H_f^\circ = -763.2$ kJ, $S^\circ = 354.9$ J/K

a) $TiCl_4 (l) \rightleftharpoons TiCl_4 (g)$

b) At boiling point, $P = 1 \text{ atm}$

$K = P_{TiCl_4} = 1 \text{ atm}$

$\Delta G^\circ = -RT \ln K = 0$

c) $0 = \Delta H^\circ - T \Delta S^\circ$

$$T_{bp} = \frac{\Delta H^\circ}{\Delta S^\circ} = \frac{(-763.2 \text{ kJ} - (-804.2 \text{ kJ}))}{(354.9 \frac{\text{J}}{\text{K}} - 221.9 \frac{\text{J}}{\text{K}}) \left(\frac{1000 \text{ J}}{\text{kJ}}\right)}$$

$$= 308.3 \text{ K}$$
12. What is the hybridization and geometry about the indicated carbon atoms in each of the following (6 pt)

\[
\begin{align*}
\text{HC\equiv CH} & & \text{H}_3\text{C} - \text{CH}_3 & & \text{H}_2\text{C} = \text{O} \\
& & \uparrow & & \uparrow
\end{align*}
\]

Hybridization:
\[\text{SKP}\]

Geometry:

13. Given the following two half-reactions and their potentials, write the balanced equation for the reaction that is spontaneous and give the \(E^\circ\) of the cell. (4 pt)

\[
\begin{align*}
\text{Sn}^{2+}(aq) + 2e^- & \rightarrow \text{Sn}(s) & E^\circ = -0.136 \text{ V} \\
\text{Al}^{3+}(aq) + 3e^- & \rightarrow \text{Al}(s) & E^\circ = -1.66 \text{ V}
\end{align*}
\]

\[
2(\text{Al} \rightarrow \text{Al}^{3+} + 3e^-) \quad E^\circ_{\text{ox}} = +1.66 \text{ V}
\]

\[
3(\text{Sn}^{2+} + 2e^- \rightarrow \text{Sn}) \quad E^\circ_{\text{red}} = -0.136 \text{ V}
\]

\[
\frac{2\text{Al} + 3\text{Sn}^{4+} \rightarrow 2\text{Al}^{3+} + 3\text{Sn}}{E^\circ_{\text{cell}} = 1.52 \text{ V}}
\]

14. Calculate \(\Delta G^\circ\) for the cell in problem 13. (3 pt)

\[
\Delta G^\circ = -nFE^\circ = -(6)(96485 \text{ J/mol})(1.52 \text{ V}) = -880 \text{ kJ}
\]