There are a total of four pages (9 problems) in the exam. All work must be shown on the exam. Show your method of calculation clearly. Correct answers not showing the work will not receive credit. Include the **UNITS** of all answers.

Notes written on one 8.5 X 11 inch page may be used. All other notes and books are not allowed.

### EQUATIONS:

\[
\begin{align*}
\Delta E &= q + w \\
W &= -P_{\text{ext}}AV \\
W_{\text{rev}} &= -nRT\ln(V_2/V_1) \\
\Delta H &= nC_p\Delta T \\
\Delta E &= nC_v\Delta T \\
q &= Mc\Delta T \\
q_p &= nC_p\Delta T \\
q_v &= nC_v\Delta T \\
C_p &= C_v + R \\
C_v &= (3/2) R \\
\Delta S &= Q_{\text{rev}}/T \\
\Delta S_{\text{vap}} &= \Delta H_{\text{vap}}/T_b \\
\Delta S_{\text{fus}} &= \Delta H_{\text{fus}}/T_m \\
\Delta G^0 &= \Delta H^0 - T\Delta S^0 \\
\Delta G &= \Delta G^0 + RT\ln Q \\
\Delta G^0 &= -RT\ln K \\
\Delta G &= \Delta H - T\Delta S \\
PV &= nRT
\end{align*}
\]

### CONSTANTS:

\[
\begin{align*}
R &= 8.3145 \text{ J mol}^{-1}\text{K}^{-1} \\
N_A &= 6.022 \times 10^{23} \\
R &= 0.08206 \text{ L atm mol}^{-1}\text{K}^{-1} \\
1 \text{ L atm} &= 101.3 \text{ J}
\end{align*}
\]
1. (9 pts) At room pressure and temperature, a balloon, on a bottle containing liquid nitrogen, was observed to expand as liquid nitrogen vaporized to produce nitrogen gas.

\[ \text{N}_2 \text{(l)} \rightarrow \text{N}_2 \text{(g)} \]

Circle the correct answer for this process for each of the following quantities: \( q \), \( w \), and \( \Delta E \).

\[
\begin{array}{ccc}
q < 0 & q > 0 & q = 0 \\
w < 0 & w > 0 & w = 0 \\
\Delta E < 0 & \Delta E > 0 & \Delta E = 0 \\
\end{array}
\]

2. (9 pts) A sample of ethane gas is heated from 25°C to 75°C under conditions of constant pressure.

Circle the correct answer for this process for each of the following quantities: \( q \), \( w \), and \( \Delta E \).

\[
\begin{array}{ccc}
q < 0 & q > 0 & q = 0 \\
w < 0 & w > 0 & w = 0 \\
\Delta E < 0 & \Delta E > 0 & \Delta E = 0 \\
\end{array}
\]

\[ w = -P_{\text{ext}} \frac{\Delta V}{V} \]

\[ \Delta E = nC_v \frac{\Delta T}{T} \]

3. (10 pts) Given the following data at 25°C:

\[
\begin{align*}
\text{C (graphite)} + \text{O}_2 \text{(g)} & \rightarrow \text{CO}_2 \text{(g)} & \Delta H^\circ &= -393.5 \text{ kJ} \\
2 \text{H}_2 \text{(g)} + \text{O}_2 \text{(g)} & \rightarrow 2 \text{H}_2\text{O (l)} & \Delta H^\circ &= -571.6 \text{ kJ} \\
2 \text{C}_2\text{H}_2 \text{(g)} + 5 \text{O}_2 \text{(g)} & \rightarrow 4 \text{CO}_2 \text{(g)} + 2 \text{H}_2\text{O (l)} & \Delta H^\circ &= -2598.8 \text{ kJ} \\
\end{align*}
\]

Calculate the standard heat of formation, \( \Delta H_f^\circ \), for \( \text{C}_2\text{H}_2 \text{(g)} \).

\[
\begin{align*}
2 \text{ C (graphite)} + \text{H}_2 \text{(g)} & \rightarrow \text{C}_2\text{H}_2 \text{(g)} & \Delta H &= +2598.8 \text{ kJ} \\
2 \text{H}_2 \text{(g)} + \text{O}_2 & \rightarrow 2 \text{H}_2\text{O} & \Delta H &= -571.6 \text{ kJ} \\
4 \text{(C + O}_2 \rightarrow \text{CO}_2) & \rightarrow 2 \text{C}_2\text{H}_2 \text{(g)} & \Delta H &= 4(-393.5) = -1574 \\
\frac{1}{2} (4 \text{ C + 2H}_2 \rightarrow \text{C}_2\text{H}_2) & \rightarrow \frac{1}{2} \text{C}_2\text{H}_2 \text{(g)} & \Delta H &= (453.2)^{1/2} \\
2 \text{ C + H}_2 & \rightarrow \text{C}_2\text{H}_2 & \Delta H &= 226.6 \text{ kJ} \\
\end{align*}
\]
4. (10 pts) Consider the following reaction:

\[ 2 \text{ Al (s)} + 3 \text{ Cl}_2 (g) \rightarrow 2 \text{ AlCl}_3 (s) \quad \Delta H^\circ = -1390.81 \text{ kJ} \]

How many grams of Al are required to produce 1.00 kJ of heat?

\[
1.00 \text{ kJ} \left( \frac{2 \text{ mol Al}}{-1390.81 \text{ kJ}} \right) \left( \frac{26.98 \text{ g}}{\text{ mol}} \right) = \boxed{0.0399 \text{ g Al}}
\]

5. (12 pts) The combustion of acetylene gas, C\textsubscript{2}H\textsubscript{2} (g), with O\textsubscript{2} (g) produces CO\textsubscript{2} (g) and H\textsubscript{2}O (g). Given the following standard heats of formation, calculate the change in enthalpy for the combustion of 1 mole of acetylene at 298 K and 1 atm.

<table>
<thead>
<tr>
<th>Compound</th>
<th>(\Delta H^\circ) (kJ/mol)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C\textsubscript{2}H\textsubscript{2} (g)</td>
<td>+226.7</td>
</tr>
<tr>
<td>CO\textsubscript{2} (g)</td>
<td>-393.5</td>
</tr>
<tr>
<td>H\textsubscript{2}O (g)</td>
<td>-241.8</td>
</tr>
</tbody>
</table>

\[
\text{C}_2\text{H}_2 + \frac{5}{2}\text{O}_2 \rightarrow 2\text{CO}_2 + \text{H}_2\text{O} \quad +226.7 + 0 -393.5 -241.8
\]

\[
\Delta H^\circ = \left[ 2(-393.5) + (-241.8) \right] - \left[ 226.7 + \frac{5}{2}(0) \right] = -1255.5 \text{ kJ}
\]
6. (6 pts) In which case must a reaction be spontaneous at all temperatures?
   
   a) ΔH is positive, ΔS is positive  
   b) ΔH = 0, ΔS is negative  
   c) ΔH is negative, ΔS is negative  
   d) ΔH is negative, ΔS is positive  
   e) None of these  

7. One mole of liquid is vaporized at its boiling point, 80.0°C, and 1.00 atm. ΔH_{vap} for the liquid is 30.7 kJ/mol at 80°C.

   a) (10 pts) Calculate w

   \[
   \text{liquid} \rightarrow \text{gas} \quad 1 \text{ mol} \\
   w = -P_{\text{ext}} \Delta V = -N_{\text{gas}} RT \\
   w = -(1)(8.3145 \text{ J mol}^{-1} \text{ K}^{-1})(353 \text{ K})(1000 \text{ J}) \\
   w = -2935 \text{ J} \quad \text{or} \quad 2935 \text{ J} 
   \]

   b) (10 pts) Calculate ΔE

   \[ \Delta E = q + w \]

   \[ q_p = \Delta H_{vap} = (30.7 \text{ kJ/mol})1 \text{ mol} \]

   \[ \Delta E = 30.7 \text{ kJ} - 2.94 \text{ kJ} \]

   \[ \Delta E = 27.8 \text{ kJ} \]

8. (12 pts) An ideal gas is compressed isothermally.

   Circle the correct answer for each of the following quantities: w, q, ΔH, ΔE, ΔS and ΔG.

   \[
   \begin{array}{ccc}
   w < 0 & \frac{w > 0}{q > 0} & w = 0 \\
   q < 0 & q > 0 & q = 0 \\
   \Delta H < 0 & \Delta H > 0 & \Delta H = 0 \\
   \Delta E < 0 & \Delta E > 0 & \Delta E = 0 \\
   \Delta S < 0 & \Delta S > 0 & \Delta S = 0 \\
   \Delta G < 0 & \Delta G > 0 & \Delta G = 0 \\
   \end{array}
   \]

   \[ \Delta T = 0 \]

   \[ \Delta G = \Delta H - T \Delta S \]

   \[ \Delta G > 0 \]
9. (12 pts) In a coffee cup calorimeter, 200.0 mL of 0.862 M HCl is mixed with 200.0 mL of 0.431 M Ba(OH)\(_2\). The heat capacity of the calorimeter is 453 J/°C. The initial temperature of both the HCl and Ba(OH)\(_2\) solution is 20.48°C. Assume all solutions have a density of 1.00 g/mL and a specific heat capacity of 4.18 J °C\(^{-1}\) g\(^{-1}\). For the reaction,
\[
\text{H}^+ (aq) + \text{OH}^- (aq) \rightarrow \text{H}_2\text{O (l)}
\]
the heat of neutralization is −56.2 kJ. What is the final temperature of the mixed solution? Circle the correct answer. Show your work. NO WORK = NO CREDIT

a) 46.9 °C  

b) 25.0 °C  

c) 15.9 °C  

d) 20.5 °C  

e) 28.0 °C  

f) 22.8 °C  

g) 64.1 °C  

h) none of these

\[-q_{rxn} = m_{soln} C_{soln} \Delta T + C_{cal} \Delta T\]

\[
\text{H}^+ + \text{OH}^- \rightarrow \text{H}_2\text{O}
\]

\[
0.2 \text{ L} (0.862 \frac{\text{mol H}^+}{\text{L}}) = 0.172 \text{ mol H}^+
\]

\[
0.2 \text{ L} (0.862 \frac{\text{mol OH}^-}{\text{L}}) = 0.172 \text{ mol OH}^-
\]

\[
q_{rxn} = 0.172 \text{ mol} \left(\frac{-56.2 \text{ kJ}}{1 \text{ mol}}\right) = -9.69 \text{ kJ}
\]

\[
[Ba(OH)_2] = 0.431 \text{ M}
\rightarrow [OH^-] = 0.862 \text{ M}
\]

\[-q_{rxn} = m_{soln} C_{soln} \Delta T + C_{cal} \Delta T\]

\[-(-9.69 \text{ kJ}) = (400 \text{ g})(4.18 \frac{\text{J}}{\text{g} \cdot \text{°C}})(\frac{1.11 \text{ kJ}}{1000 \text{ J}}) \Delta T + (0.455 \frac{\text{kJ}}{\text{°C}}) \Delta T\]

\[
\Delta T = 45.6 \text{ °C}
\]

\[
\Delta T = T_f - 20.48 \text{ °C}
\]

\[
T_f = 25.0 \text{ °C}
\]