1. The fusion of water corresponds to the following phase change. \( \text{H}_2\text{O} \text{ (s)} \rightarrow \text{H}_2\text{O} \text{ (l)} \)
   a) (4 pts) Is the fusion of water endothermic or exothermic?

   **endothermic**

   b) (4 pts) For water, is \( \Delta H_{\text{fusion}} \) less than, equal to or greater than \( \Delta H_{\text{vap}} \)? Circle the correct answer.
   \[ \Delta H_{\text{fus}} < \Delta H_{\text{vap}} \quad \Delta H_{\text{fus}} = \Delta H_{\text{vap}} \quad \Delta H_{\text{fus}} > \Delta H_{\text{vap}} \]

2. (4 pts) Dissolving of ammonium chloride in water lowers the temperature of the system. Circle the correct answer for the change in enthalpy for the dissolving of ammonium chloride.

   \[ \Delta H < 0 \quad \boxed{\Delta H > 0} \quad \Delta H = 0 \]

3. a) (4 pts) Write the balanced reaction that corresponds to the heat of formation, \( \Delta H_f \), of ethanol, \( \text{C}_2\text{H}_5\text{OH} \text{ (l)} \).
   \[
   2 \text{C} \text{ (s)} + 3 \text{H}_2 \text{ (g)} + \frac{1}{2} \text{O}_2 \text{ (g)} \rightarrow \text{C}_2\text{H}_5\text{OH} \text{ (l)}
   \]

   b) (4 pts) Write the balanced reaction that corresponds to the heat of formation, \( \Delta H_f \), of aluminum oxide.
   \[
   2 \text{Al} \text{ (s)} + \frac{3}{2} \text{O}_2 \text{ (g)} \rightarrow \text{Al}_2\text{O}_3 \text{ (s)}
   \]

4. (10 pts) \( \text{SO}_2 \) reacts with \( \text{Cl}_2 \) according to the following equation.
   \[
   \text{SO}_2 \text{ (g)} + \text{Cl}_2 \text{ (g)} \rightarrow \text{SO}_2\text{Cl}_2 \text{ (g)}
   \]
   Given the following data, calculate how much heat (in kJ) is released when 7.5 g of \( \text{SO}_2 \) reacts.
   \( \Delta H_f \) (kJ/mol)
   \[
   \begin{align*}
   \text{SO}_2 \text{ (g)} & \quad -297 \\
   \text{SO}_2\text{Cl}_2 \text{ (g)} & \quad -364
   \end{align*}
   \]
   \[
   \begin{align*}
   \text{SO}_2 + \text{Cl}_2 & \rightarrow \text{SO}_2\text{Cl}_2 \\
   \Delta H & = -364 - (-297) \text{ kJ} \\
   \Delta H & = -67 \text{ kJ}
   \end{align*}
   \]
   \[
   7.5 \text{ g} \left( \frac{1 \text{ mol}}{64.1 \text{ g}} \right) = 0.117 \text{ mol} \text{SO}_2 \left( \frac{67 \text{ kJ}}{1 \text{ mol} \text{SO}_2} \right) = 7.8 \text{ kJ of heat released}
   \]
5. Consider the following reaction. \[ 2O(g) \rightarrow O_2(g) + \text{heat} \]

a) (4 pts) Predict the sign for \( \Delta H \) and \( \Delta S \).

\[
\begin{array}{ccc}
\Delta H < 0 & \Delta H > 0 & \Delta H = 0 \\
\Delta S < 0 & \Delta S > 0 & \Delta S = 0
\end{array}
\]

b) (4 pts) Would the reaction be more spontaneous at high or low temperatures?

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

low temperatures

6. (6 pts) Consider the following reaction at 25°C and 1 atm.

\[ \text{C(s)} + \text{H}_2\text{O (g)} \rightarrow \text{CO (g)} + \text{H}_2 \text{(g)} \]

For this reaction \( \Delta H^\circ = 131 \text{ kJ/mol} \) and \( \Delta S^\circ = 135 \text{ J/mol·K} \). Is this reaction spontaneous at 25°C?

Show your work. **NO WORK = NO CREDIT**

\[ \Delta G = \Delta H - T\Delta S \\
= 131 \text{ kJ/mol} - (298 \text{ K})(135 \text{ J/mol·K})(\frac{1 \text{ kJ}}{1000 \text{ J}}) \\
\Delta G = +90.8 \text{ kJ/mol} \\
\Delta G > 0 \text{ not spontaneous} \]

7. (8 pts) Given the following data at 25°C:

\[ 2 \text{H}_2(g) + \text{O}_2(g) \rightarrow 2 \text{H}_2\text{O (g)} \quad \Delta H = -484 \text{ kJ} \]

\[ 2 \text{NH}_3(g) \rightarrow \text{N}_2 (g) + 3 \text{H}_2(g) \quad \Delta H = 92 \text{ kJ} \]

Calculate the \( \Delta H \) for the following reaction.

\[ 2 \text{N}_2(g) + 6 \text{H}_2\text{O (g)} \rightarrow 3 \text{O}_2(g) + 4 \text{NH}_3(g) \]

\[ 6 \text{H}_2\text{O} \rightarrow 6 \text{H}_2 + 3 \text{O}_2 \quad (+484)3 = 1452 \text{ kJ} \]

\[ 2 \text{N}_2 + 3 \text{H}_2 \rightarrow 4 \text{NH}_3 \quad (-92)2 = -184 \]

\[ \frac{1268}{1268} \]

\[ \Delta H = 1268 \text{ kJ} \]
8. (12 pts) Consider the following exothermic reaction at 25°C and 1 atm.

\[ 2 \text{Na} (s) + 2 \text{H}_2\text{O} (l) \rightarrow 2 \text{NaOH} (aq) + \text{H}_2 (g) \]

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

\[
\begin{align*}
w < 0 & \quad w > 0 \quad w = 0
\end{align*}
\]

\[
\begin{align*}
q < 0 & \quad q > 0 \quad q = 0
\end{align*}
\]

\[
\begin{align*}
\Delta H < 0 & \quad \Delta H > 0 \quad \Delta H = 0
\end{align*}
\]

\[
\begin{align*}
\Delta E < 0 & \quad \Delta E > 0 \quad \Delta E = 0
\end{align*}
\]

\[
\begin{align*}
\Delta S < 0 & \quad \Delta S > 0 \quad \Delta S = 0
\end{align*}
\]

\[
\begin{align*}
\Delta G < 0 & \quad \Delta G > 0 \quad \Delta G = 0
\end{align*}
\]

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

\[ q < 0 \text{ exothermic} \]

\[ \Delta E = q + w \]

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

9. (4 pts) Which one of the following substances would have the largest absolute entropy, \(S^o\), at 25°C.
Circle the correct answer.

a) NO (g)  

b) \(\text{H}_2\text{O} (s)\)  

c) He (g)  

d) \(\text{C}_2\text{H}_6 (g)\)

10. Nitrogen reacts with oxygen to produce nitrogen dioxide according to the following equation.

\[ \text{N}_2 (g) + 2 \text{O}_2 (g) \rightarrow 2 \text{NO}_2 (g) \]

For this reaction, 67.7 kJ of heat is released, when 1.0 mole of \(\text{N}_2\) reacts with 2 moles \(\text{O}_2\) at 25°C and 1 atm.

a) (5 pts) Determine \(\Delta H\) for this reaction at 25°C.

\[ \Delta H = -67.7 \text{ kJ} \]

b) (5 pts) Determine \(\Delta E\) for this reaction at 25°C.

\[ \Delta E = -65.2 \text{ kJ} \]

\[ \Delta E = q + w \]

\[ q = q_p = \Delta H = -67.7 \text{ kJ} \]

\[ w = - P_{\text{ext}} \Delta V = -\Delta n_{\text{gas}} \frac{RT}{\Delta n_{\text{gao}}} \]

\[ \Delta n_{\text{gao}} = 2 - 3 = -1 \]

\[ \Delta E = -67.7 \text{ kJ} + (1)(8.3145 \frac{J}{\text{mol} \cdot \text{K}})(298 \text{ K}) \left( \frac{-1700}{1000} \right) \]

\[ \Delta E = -67.7 + 2.48 \text{ kJ} \]
11. (8 pts) In a coffee cup calorimeter, 50.0 g of water at 69°C is added to an unknown amount of water at 22.0°C. The final temperature is 31.0°C. How many grams of water were there initially at 22.0°C? The heat capacity of water is 4.18 J °C⁻¹ g⁻¹. Assume no heat is lost to the calorimeter.

\[-m_1 \cdot \Delta T_1 = m_2 \cdot \Delta T_2\]

\[-50.0 \, \text{g} \cdot (31 - 69) = m_2 \cdot (31 - 22)\]

\[m_2 = 21.1 \, \text{g}\]

12. (4 pts) Which of the following is always positive when a spontaneous process occurs? Circle the correct answer.

a) \(\Delta S_{\text{system}}\)  

b) \(\Delta S_{\text{surroundings}}\)  

c) \(\Delta S_{\text{universe}}\)  

d) \(\Delta G_{\text{system}}\)

13. (10 pts) Calculate the entropy change when 45.0 g of ethanol (C₂H₅OH) vaporizes at its normal boiling point of 78.5°C. The heat of vaporization of ethanol is 38.6 kJ/mol.

\[\Delta S = \frac{q_{\text{rev}}}{T} = \frac{\Delta H_{\text{vap}}}{T_B}\]

\[45.0 \, \text{g} \cdot \frac{C_2H_5OH}{46 \, \text{g}} = 0.98 \, \text{mol}\]

\[\Delta H_{\text{vap}} = (38.6 \, \frac{kJ}{mol})(0.98 \, \text{mol})\]

\[\Delta H_{\text{vap}} = 37.8 \, \text{kJ}\]

\[\Delta S = \frac{37.8 \, \text{kJ}}{351.5 \, \text{K}} = 0.107 \, \text{kJ/K}\]

\[\Delta S = 107 \, \text{J/K}\]

\[\Delta S = 107 \, \text{J/K}\]