8.5 Enthalpies of Formation

YOU ARE EXPECTED TO BE ABLE TO:

• Relate $\Delta H$ to enthalpies of formation.
Enthalpies of Formation

- Heats of Formation, or Enthalpies of Formation, are used to provide a concise collection of thermochemical data.
- For consistency, enthalpy of formation data are recorded for reactions that take place under standard conditions.
- Standard conditions are:
  - Constant pressure of 1 atmosphere
  - Fixed temperature of 25°C
Standard Molar Enthalpy of Formation

• The enthalpy change when one mole of a compound is formed from its elements at 1 atm and 25°C
• The elements must be in their stable states at this pressure and temperature

\[
\frac{1}{2} \text{N}_2(g) + \frac{3}{2} \text{H}_2(g) \rightarrow \text{NH}_3(g); \Delta H^\circ_f = -46.1 \text{kJ}
\]
Notes About $\Delta H^o_f$

- Enthalpies of formation are listed in most data books and are shown in Table 8.3 of the text (page 221)
- Most enthalpies of formation are negative. This means that the formation of a compound from its elements is exothermic
- There are no entries in a table of enthalpies of formation for elemental species such as $\text{Br}_2$, $\text{O}_2$, $\text{N}_2$, etc. $\Delta H^o_f$ for an element is zero
Using Heats of Formation

- Enthalpies of formation can be used to determine the Standard Enthalpy Change for a reaction, $\Delta H^\circ$.
- One way is to apply Hess’ Law.
- Use $\Delta H^\circ_f$ for CaCO$_3$, CaO and CO$_2$ to determine the standard heat of reaction for the reaction:

$$\text{CaCO}_3(s) \rightarrow \text{CaO}_2(s) + \text{CO}_2(g)$$
• \[ \text{Ca}_\text{(s)} + \text{C}_\text{(s)} + \frac{3}{2}\text{O}_2\text{(g)} \rightarrow \text{CaCO}_3\text{(s)} ; \Delta H = -1206.9\text{kJ} \]
• \[ \text{Ca}_\text{(s)} + \frac{1}{2}\text{O}_2\text{(g)} \rightarrow \text{CaO}_\text{(s)} ; \Delta H = -635.1\text{kJ} \]
• \[ \text{C}_\text{(s)} + \text{O}_2\text{(g)} \rightarrow \text{CO}_2\text{(g)} ; \Delta H = -393.5\text{kJ} \]
  – Reverse equation 1
  – Add equation 2
  – Add equation 3
\[ \text{CaCO}_3\text{(s)} \rightarrow \text{Ca}_\text{(s)} + \text{C}_\text{(s)} + \frac{3}{2}\text{O}_2\text{(g)} ; \Delta H = +1206.9\text{kJ} \]
\[ \text{Ca}_\text{(s)} + \frac{1}{2}\text{O}_2\text{(g)} \rightarrow \text{CaO}_\text{(s)} ; \Delta H = -635.1\text{kJ} \]
\[ \text{C}_\text{(s)} + \text{O}_2\text{(g)} \rightarrow \text{CO}_2\text{(g)} ; \Delta H = -393.5\text{kJ} \]

\[ \text{CaCO}_3\text{(s)} \rightarrow \text{CaO}_\text{(s)} + \text{CO}_2\text{(g)} ; \Delta H = +178.3\text{kJ} \]
An Alternative Process

- The standard enthalpy change for a reaction is equal to the sum of the standard enthalpies of formation of the products minus the sum of the standard enthalpies of formation of the reactants

\[ \Delta H^o = \Sigma \Delta H^o_f \text{ products} - \Sigma \Delta H^o_f \text{ reactants} \]

- Coefficients of reactants and products in the balanced equation for the reaction must be taken into account
Textbook Example 8.8

• Calculate $\Delta H^o$ for the combustion of one mole of propane, $C_3H_8$

$$C_3H_8(g) + 5O_2(g) \rightarrow 3CO_2(g) + 4H_2O(l)$$

$$\Delta H^o = [3 \Delta H^o_{f CO_2(g)} + 4 \Delta H^o_{f H_2O(l)}] - [\Delta H^o_{f C_3H_8(g)} + 5 \Delta H^o_{f O_2(g)}]$$

$$\Delta H^o = [3 \times -393.5 + 4 \times -285.8] - [1 \times -103.8 + 5 \times 0]$$

$$\Delta H^o = -2219.9 \text{kJ}$$
Enthalpies of Formation of Ions in Solution

• It is possible to construct a table to show the heats of formation of ions in solution.

• However, all ionic solution processes involve both a + and a – ion.

\[
\text{HCl}_\text{(g)} \rightarrow \text{H}^+\text{(aq)} + \text{Cl}^-\text{(aq)}
\]

• To get around this problem, \( \Delta H^o_f \) for the \( \text{H}^+\text{(aq)} \) ion is set at zero.
Determining Enthalpies of Formation of Ions in Solution

• When HCl\(_{(g)}\) is added to water

\[ \text{HCl}_{(g)} \rightarrow \text{H}^+_{(aq)} + \text{Cl}^-_{(aq)}; \Delta H^o = -74.9 \text{kJ} \]

• Using the summation method:

\[-74.9 \text{kJ} = [\Delta H^o_f \text{H}^+_{(aq)} + \Delta H^o_f \text{Cl}^-_{(aq)}] - [\Delta H^o_f \text{HCl}_{(g)}] \]

\[-74.9 \text{kJ} = 0 + \Delta H^o_f \text{Cl}^-_{(aq)} + 92.3 \text{kJ} \text{ (from Table 8.3)} \]

\[ \Delta H^o_f \text{Cl}^-_{(aq)} = -74.9 \text{kJ} - 92.3 \text{kJ} = -167.2 \text{kJ} \]
Using Enthalpies of Formation of Ions in Solution

• Example 8.10
• Calculate $\Delta H^o$ for the reaction:

$$2H^+_{(aq)} + CO_3^{2-}_{(aq)} \rightarrow CO_2_{(g)} + H_2O_{(l)}$$

• Use the summation method