Ch. 17: Reaction Energy and Reaction Kinetics

Heat of Reaction
Heat of Formation
Hess’ Law

Heat of Reaction

- amount of energy released or absorbed during a chemical reaction
- the difference between the stored energy of reactants and products
- energy can be a reactant or product
- same as the change in enthalpy ($\Delta H$)

\[ \Delta H = H_{\text{products}} - H_{\text{reactants}} \]

- endo: $+\Delta H$
- exo: $-\Delta H$

Heat of Formation

- change in enthalpy that accompanies the formation of one mole of a compound from its elements in standard states
- means that the process happened under standard conditions so we can compare values more easily
- room temperature (298 K) and 1 atm
- values given p. 902

Writing Formation Equations

- always write equation where 1 mole of compound is formed (even if you must use non-integer coefficients)

**NO**$_2$(g):

\[ \frac{1}{2}N_2(g) + O_2(g) \rightarrow NO_2(g) \]

$\Delta H_f^\circ = 34$ kJ/mol

**CH**$_3$OH(l):

\[ C(s) + H_2(g) + \frac{1}{2}O_2(g) \rightarrow CH_3OH(l) \]

$\Delta H_f^\circ = -239$ kJ/mol

Stability

- Would a large negative value, like $\Delta H_f^\circ = -239$ kJ/mol, indicate a very stable or unstable compound?
- If the compound is very stable, lots of energy will be released when it is formed so it will have a large negative value.
- If the compound is unstable, it will have a positive value and will most likely decompose into its elements
Hess’ Law

- Thermochemical equations can be rearranged and added together to give enthalpy changes for reactions not given in the Appendix.
- Hess’ Law: the overall enthalpy change is equal to the sum of the enthalpy changes for individual steps in a reaction.
- Start by making sure each species is on the correct side of the equation.
- Then worry about getting the right number of each species.

Example 1

- Using the enthalpies of combustion for graphite (-394 kJ/mol) and diamond (-396 kJ/mol), find the ΔH for the conversion of graphite to diamond.

\[
\text{C}_{\text{graphite}}(s) \rightarrow \text{C}_{\text{diamond}}(s) \quad \Delta H=?
\]

Example 2

- Find the enthalpy change for the following reaction.

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

- Given:

1. \(\text{NH}_3(g) \rightarrow \frac{1}{2}\text{N}_2(g) + \frac{3}{2}\text{H}_2(g) \quad \Delta H=46 \text{ kJ}\)
2. \(\text{2H}_2(g) + \text{O}_2(g) \rightarrow 2\text{H}_2\text{O}(g) \quad \Delta H=-484 \text{ kJ}\)

Example 1

- Goal: \(\text{C}_{\text{graphite}}(s) \rightarrow \text{C}_{\text{diamond}}(s) \quad \Delta H=?\)

1. \(\text{C}_{\text{graphite}}(s) + \text{O}_2(g) \rightarrow \text{CO}_2(g) \quad \Delta H=-394 \text{kJ/mol}\)
2. \(\text{C}_{\text{diamond}}(s) + \text{O}_2(g) \rightarrow \text{CO}_2(g) \quad \Delta H=-396 \text{kJ/mol}\)

- To get the desired equation, we must reverse the 2nd equation:

\[
\begin{align*}
\text{C}_{\text{graphite}}(s) + \text{O}_2(g) &\rightarrow \text{CO}_2(g) \quad \Delta H=-394 \text{kJ/mol} \\
\text{C}_{\text{diamond}}(s) + \text{O}_2(g) &\rightarrow \text{CO}_2(g) \quad \Delta H=-396 \text{kJ/mol}
\end{align*}
\]

Example 2

- \(\text{NH}_3; (1)\) must be reversed and multiplied by 4
- \(\text{H}_2\text{O}; (2)\) must be reversed and multiplied by 3

\[
\begin{align*}
(1) \quad 2\text{N}_2(g) + 6\text{H}_2\text{O}(g) &\rightarrow 4\text{NH}_3(g) \quad \Delta H=-4\times(46 \text{ kJ}) \\
(2) \quad 6\text{H}_2\text{O}(g) + 3\text{O}_2(g) &\rightarrow 4\text{NH}_3(g) + 3\text{O}_2(g) \quad \Delta H=-3\times(484 \text{ kJ})
\end{align*}
\]

\[
2\text{N}_2(g) + 6\text{H}_2\text{O}(g) \rightarrow 3\text{O}_2(g) + 4\text{NH}_3(g) \quad \Delta H=1268 \text{ kJ}
\]
Example 3

- **Calculate the change in enthalpy for the following reaction:**
  \[ 2N_2(g) + 5O_2(g) \rightarrow 2N_2O_5(g) \]

- **Given**
  1. \( H_2(g) + \frac{1}{2}O_2(g) \rightarrow H_2O(l) \) \( \Delta H = -285.8 \text{kJ/mol} \)
  2. \( N_2O_5(g) + H_2O(l) \rightarrow 2HNO_3(l) \) \( \Delta H = -76.6 \text{kJ/mol} \)
  3. \( \frac{1}{2}H_2(g) + \frac{1}{2}N_2(g) + \frac{3}{2}O_2(g) \rightarrow HNO_3(l) \) \( \Delta H = -174.1 \text{kJ/mol} \)

Example 4

- **Find \( \Delta H \) for the synthesis of \( B_2H_6 \), diborane:**
  \[ 2B(s) + 3H_2(g) \rightarrow B_2H_6(g) \]

- **Given:**
  1. \( 2B(s) + 3/2O_2(g) \rightarrow B_2O_3(s) \) \( \Delta H_1 = -1273 \text{kJ} \)
  2. \( B_2H_6(g) + 3O_2(g) \rightarrow B_2O_3(s) + 3H_2O(g) \) \( \Delta H_2 = -2035 \text{kJ} \)
  3. \( H_2(g) + \frac{1}{2}O_2(g) \rightarrow H_2O(l) \) \( \Delta H_3 = -286 \text{kJ} \)
  4. \( H_2O(l) \rightarrow 3H_2O(g) \) \( \Delta H_4 = 44 \text{kJ} \)

Example 4

- **Underline what you want to keep—those that will help you figure out how to cancel everything else:**
  1. \( 2B(s) + 3/2O_2(g) \rightarrow B_2O_3(s) \) \( \Delta H_1 = -1273 \text{kJ} \)
  2. \( B_2O_3(s) + 3H_2O(g) \rightarrow B_2H_6(g) + 3O_2(g) \) \( \Delta H_2 = 2035 \text{kJ} \)
  3. \( H_2(g) + \frac{1}{2}O_2(g) \rightarrow H_2O(l) \) \( \Delta H_3 = -286 \text{kJ} \)
  4. \( H_2O(l) \rightarrow 3H_2O(g) \) \( \Delta H_4 = 44 \text{kJ} \)

Example 4

- **Start by paying attention to what needs to be on reactants and products side:**
  1. \( 2B(s) + 3/2O_2(g) \rightarrow B_2O_3(s) \) \( \Delta H_1 = -1273 \text{kJ} \)
  2. \( B_2O_3(s) + 3H_2O(g) \rightarrow B_2H_6(g) + 3O_2(g) \) \( \Delta H_2 = 2035 \text{kJ} \)
  3. \( H_2(g) + \frac{1}{2}O_2(g) \rightarrow H_2O(l) \) \( \Delta H_3 = -286 \text{kJ} \)
  4. \( H_2O(l) \rightarrow 3H_2O(g) \) \( \Delta H_4 = 44 \text{kJ} \)

Example 4

- **Need 3 \( H_2 \) (g) so 3 x (3)
- Need 3 \( H_2O \) to cancel so 3 x (4)

\[
\begin{align*}
(1) & \quad 2B(s) + 3/2O_2(g) \rightarrow B_2O_3(s) \quad \Delta H_1 = -1273 \text{kJ} \\
(2) & \quad B_2O_3(s) + 3H_2O(g) \rightarrow B_2H_6(g) + 3O_2(g) \quad \Delta H_2 = 2035 \text{kJ} \\
(3) & \quad H_2(g) + \frac{1}{2}O_2(g) \rightarrow H_2O(l) \quad \Delta H_3 = -286 \text{kJ} \\
(4) & \quad H_2O(l) \rightarrow 3H_2O(g) \quad \Delta H_4 = 44 \text{kJ} \\
2B(s) + 3H_2(g) \rightarrow B_2H_6(g) & \quad \Delta H = -1273 + (2035) + (-286) + (44) = 36 \text{kJ}
\end{align*}
\]