SCH4U1

Hess's Law and the Additivity of Heats

Hess's Law: The value of ΔH for any reaction that can be written in steps equals the sum of the values of ΔH for the individual steps.

Method 1: Additivity of Heats

1. Identify the target equation and balanced it (if not given).

2. Identify the individual step equations. These are provided or are found on a Table of Heats of Formation.

3. Reverse any step equations so that the position of reactants/products matches that of the target equation. If an equation is reversed, also reverse the sign of ΔH for the step equation.

4. Multiply the step equations by the appropriate coefficient to match those in the target equation. Also multiply the ΔH by the same coefficient.

5. Add up the modified step equations and their ΔH values. The sum of the modified individual step equation should be identical to the target equation.

Heats (Enthalpy Change) of Formation

Elements	Formula	Name	ΔH (kJ/mol)
H_2 (g) + ½ O_2 (g)	→ H_2O (g)	water vapour	- 241.8
H_2 (g) + ½ O_2 (g)	→ H_2O (l)	water	- 285.8
S (s) + ½ O_2 (g)	→ SO_2 (g)	sulfur dioxide	- 296.8
S (s) + ⅔ O_2 (g)	→ SO_3 (g)	sulfur trioxide	-395.7
H_2(g) + S(s) + $2O_2$(g)	→ H_2SO_4 (l)	sulfuric acid	- 811.7
½ N_2 (g) + ½ O_2 (g)	→ NO (g)	nitric oxide	+ 90.25
½ N_2 (g) + O_2 (g)	→ NO_2 (g)	nitrogen dioxide	+ 33.18
½ N_2 (g) + ⅔ H_2 (g)	→ NH_3 (g)	ammonia	- 46.11
C (s) + ½ O_2 (g)	→ CO (g)	carbon monoxide	- 110.5
C (s) + O_2 (g)	→ CO_2 (g)	carbon dioxide	- 393.5
C (s) + $2H_2$ (g)	→ CH_4 (g)	methane	- 74.81
2C (s) + $3H_2$ (g)	→ C_2H_6 (g)	ethane	- 84.68
3C (s) + $4H_2$ (g)	→ C_3H_8 (g)	propane	- 103.8
½ H_2 (g) + ½ I_2 (g)	→ HI (g)	hydrogen iodide	+ 25.9
4C(s) + $4H_2$ (g) + O_2 (g)	→ C_3H_7COOH (l)	butyric acid	- 522.1
2C(s) + $2H_2$ (g) + O_2 (g)	→ CH_3COOH (l)	acetic acid	- 486.6

Method 1: Additivity of Heats (continued)

Example: Determine ΔH for the following reaction:

methane (g) + oxygen (g) $\longrightarrow$ carbon dioxide (g) + water (g)

Method 2: Summation of Heats

Identify the $\Delta H_{\text{formation}}$ for each product and reactant and solve using the equation:

$$\Delta H = \sum\left(n\Delta H_{form}(products)\right) - \sum\left(n\Delta H_{form}(reactants)\right)$$

Example: Determine ΔH for the following reaction:

ammonia (g) + oxygen (g) $\longrightarrow$ nitrogen dioxide (g) + water (g)

$$NH_3\,(g) + \tfrac{7}{4}\,O_2 \longrightarrow NO_2\,(g) + \tfrac{3}{2}\,H_2O\,(g)$$

SCH4U1

Hess's Law and Additivity of Heats

Complete these questions using the Additivity of Heats method. Refer to the Table of Heats of Formation for the individual step equations.

1. Calculate ΔH for each of the following:

   a) $H_2O\ (l) \longrightarrow H_2O\ (g)$

   b) $C_3H_7COOH\ (l) + 5\ O_2\ (g) \longrightarrow 4\ CO_2\ (g) + 4\ H_2O\ (l)$

   c) $3\ CH_3COOH\ (l) + {}^{11}\!/_{2}\ O_2\ (g) \longrightarrow 5\ CO_2\ (g) + CO\ (g) + 6\ H_2O\ (l)$

2. a) Write a balanced equation for the combustion of propane gas (C_3H_8) to produce carbon dioxide and water vapour.
   b) Add equations and heats of formation to calculate the ΔH for the combustion of 1.00 mol of propane.

Answers: 1 a) 44.0 kJ/mol
b) -2195 kJ/mol
c) -2333 kJ/mol
2 -2044 kJ

Do the following problems using the Summation of Heats method.

1. Predict the heat of reaction for:

   $CH_4\ (g) + 2\ O_2\ (g) \longrightarrow CO_2\ (g) + 2\ H_2O\ (g)$

2. Given that ΔH_{form} for SiO_2 (s) is – 856.9 kJ/mol, what is the ΔH for:

   $SiO_2\ (s) + C\ (s) \longrightarrow CO_2\ (g) + Si\ (s)$

3. What is the heat of formation of H_2SO_4 (l) from H_2O (l) and SO_3 (g)?

4. Given: ΔH_{form} for P_4O_{10} (s) = -3009.5 kJ/mol
   ΔH_{form} for H_3PO_4 (s) = -1266.5 kJ/mol

   Calculate the heat of reaction for: $P_4O_{10}\ (s) + 6H_2O\ (l) \longrightarrow 4H_3PO_4\ (s)$

Answers: 1. - 802.3 kJ/mol
2. + 463.4 kJ/mol
3. - 130.2 kJ/mol
4. – 342 kJ/mol