Hess's Law

Read from **Lesson 2b:** [Hess's Law] in the **Chemistry Tutorial Section, Chapter 12** of **The Physics Classroom**

Hess's Law is a fundamental principle in thermochemistry that states: *The total enthalpy change for a chemical reaction is the same, no matter how many steps the reaction takes*. In other words, if a reaction can be expressed as the sum of two or more steps, the overall enthalpy change (ΔH) is equal to the sum of the enthalpy changes of the individual steps.

This law is based on the fact that enthalpy is a **state function**, meaning it depends only on the initial and final states of a system, not the path taken to get there. Hess's Law allows chemists to calculate the enthalpy changes of reactions that are difficult or impossible to measure directly, by using known enthalpy values from related reactions.

A Hess's Law Problem Involves:

1. **Manipulating the Given Equations.**
   - **Multiplying through by a coefficient.**
   - **Reversing the equation.**
2. **Adding the Manipulated Versions of the Given Equation**
3. **Cancelling and Grouping Formulae … … in the hope of generating the target equation.**

Steps 1 - 3 involve a trial-and-error process. If successful, you can then …

4. **Use Hess's Law to Calculate the ΔH of the Target Equation.**

For example, if given the thermochemical equations:

Equation 1: $S + \frac{3}{2} O_2 \rightarrow SO_3$ $\Delta H = -395$ kJ

Equation 2: $2\ SO_2 + O_2 \rightarrow 2\ SO_3$ $\Delta H = -198$ kJ

Determine the ΔH of the *Target Equation*:

Target Equation: $\mathbf{S + O_2 \rightarrow SO_2}$

Step 1: Manipulate the Given Equations

Equation 1(stays the same): $S + \frac{3}{2} O_2 \rightarrow SO_3$ $\Delta H = -395$ kJ

Equation 2 (first reversed): $2\ SO_3 \rightarrow 2\ SO_2 + O_2$ $\Delta H = +198$ kJ

Equation 2 (then halved): $SO_3 \rightarrow SO_2 + \frac{1}{2} O_2$ $\Delta H = +99$ kJ

Step 2: Add the Manipulated Versions of the Given Equations

Equation 3: $S + \frac{3}{2} O_2 + SO_3 \rightarrow SO_3 + SO_2 + \frac{1}{2} O_2$

Step 3: Cancel and Group Formulae

Equation 3: $S + \cancel{\frac{3}{2} O_2} + \cancel{SO_3} \rightarrow \cancel{SO_3} + SO_2 + \cancel{\frac{1}{2} O_2}$

Equation 3: $S + O_2 \rightarrow SO_2$

Step 4: Use Hess's Law to Calculate the ΔH

$\Delta H_{\text{Target Equation}} = \Delta H_{\text{Equation 1}} + \Delta H_{\text{Equation 2 (reversed and halved)}}$

$\Delta H_{\text{Target Equation}} = -395\text{ kJ} + 99\text{ kJ} = -296\text{ kJ}$

Questions

1. How would you manipulate these two equations to get the target equation?
   Equation 1: $N_2\ (g) + O_2\ (g) \rightarrow 2\ NO\ (g)$
   Equation 2: : $N_2\ (g) + 2O_2\ (g) \rightarrow 2\ NO_2\ (g)$
   Target Equation: $2NO\ (g) + O_2\ (g) \rightarrow 2NO_2\ (g)$

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2. Determine the ΔH of the *target equation* from the previous question.
   Equation 1: N_2 (g) + O_2 (g) → 2 NO (g) ΔH = 180 kJ
   Equation 2: N_2 (g) + 2O_2 (g) → 2 NO_2 (g) ΔH = 68 kJ

   Target Equation: 2NO (g) + O_2 (g) → 2NO_2 (g) ΔH = ???

3. Given these thermochemical equations, determine the ΔH of the *target equation.*
   Equation 1: H_2 (g) + ½ O_2 (g) → H_2O (g) $\Delta H = -242$ kJ
   Equation 2: 3 O_2 (g)→ 2 O_3 (g) ΔH = 285 kJ

   Target Equation: 3 H_2 (g) + O_3 (g) → 3 H_2O (g) ΔH = ???

4. Given these thermochemical equations, determine the ΔH of the *target equation.*
   Equation 1: C (s) + O_2(g) → CO_2(g) $\Delta H = -393$ kJ
   Equation 2: H_2 (g) + ½ O_2 (g) → H_2O (l) $\Delta H = -286$ kJ
   Equation 3: 2 C (s) + H_2 (g) → C_2H_2 (g) $\Delta H = +227$ kJ

   Target Equation: C_2H_2 (g) + $\frac{5}{2}$ O_2(g) → 2 CO_2(g) + H_2O(l) ΔH = ???

5. Given these thermochemical equations, determine the ΔH of the *target equation.*
   Equation 1: N_2(g) + 3H_2(g) → 2NH_3(g) $\Delta H = -91.8$ kJ
   Equation 2: N_2(g) + 4H_2(g) + Cl_2(g) → 2NH_4Cl(s) $\Delta H = -628.8$ kJ
   Equation 3: NH_3(g) + HCl(g) → NH_4Cl(s) $\Delta H = -176.2$ kJ

   Target Equation: H_2(g) + Cl_2(g) → 2HCl(g) ΔH = ???