

## Hess's Law and the Additivity of Heats

**Hess's Law:** The value of  $\Delta H$  for any reaction that can be written in steps equals the sum of the values of  $\Delta H$  for the individual steps.

### Method 1: Additivity of Heats

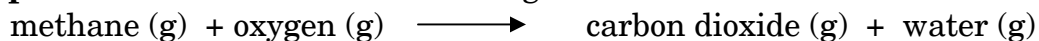
1. Identify the target equation and balanced it (if not given).
2. Identify the individual step equations. These are provided or are found on a Table of Heats of Formation.
3. Reverse any step equations so that the position of reactants/products matches that of the target equation. If an equation is reversed, also reverse the sign of  $\Delta H$  for the step equation.
4. Multiply the step equations by the appropriate coefficient to match those in the target equation. Also multiply the  $\Delta H$  by the same coefficient.
5. Add up the modified step equations and their  $\Delta H$  values. The sum of the modified individual step equation should be identical to the target equation.

#### Heats (Enthalpy Change) of Formation

Elements	Formula	Name	$\Delta H$ (kJ/mol)
$\text{H}_2(\text{g}) + \frac{1}{2} \text{O}_2(\text{g})$	$\rightarrow \text{H}_2\text{O}(\text{g})$	water vapour	- 241.8
$\text{H}_2(\text{g}) + \frac{1}{2} \text{O}_2(\text{g})$	$\rightarrow \text{H}_2\text{O}(\text{l})$	water	- 285.8
$\text{S}(\text{s}) + \frac{1}{2} \text{O}_2(\text{g})$	$\rightarrow \text{SO}_2(\text{g})$	sulfur dioxide	- 296.8
$\text{S}(\text{s}) + \frac{3}{2} \text{O}_2(\text{g})$	$\rightarrow \text{SO}_3(\text{g})$	sulfur trioxide	-395.7
$\text{H}_2(\text{g}) + \text{S}(\text{s}) + 2\text{O}_2(\text{g})$	$\rightarrow \text{H}_2\text{SO}_4(\text{l})$	sulfuric acid	- 811.7
$\frac{1}{2} \text{N}_2(\text{g}) + \frac{1}{2} \text{O}_2(\text{g})$	$\rightarrow \text{NO}(\text{g})$	nitric oxide	+ 90.25
$\frac{1}{2} \text{N}_2(\text{g}) + \text{O}_2(\text{g})$	$\rightarrow \text{NO}_2(\text{g})$	nitrogen dioxide	+ 33.18
$\frac{1}{2} \text{N}_2(\text{g}) + \frac{3}{2} \text{H}_2(\text{g})$	$\rightarrow \text{NH}_3(\text{g})$	ammonia	- 46.11
$\text{C}(\text{s}) + \frac{1}{2} \text{O}_2(\text{g})$	$\rightarrow \text{CO}(\text{g})$	carbon monoxide	- 110.5
$\text{C}(\text{s}) + \text{O}_2(\text{g})$	$\rightarrow \text{CO}_2(\text{g})$	carbon dioxide	- 393.5
$\text{C}(\text{s}) + 2\text{H}_2(\text{g})$	$\rightarrow \text{CH}_4(\text{g})$	methane	- 74.81
$2\text{C}(\text{s}) + 3\text{H}_2(\text{g})$	$\rightarrow \text{C}_2\text{H}_6(\text{g})$	ethane	- 84.68
$3\text{C}(\text{s}) + 4\text{H}_2(\text{g})$	$\rightarrow \text{C}_3\text{H}_8(\text{g})$	propane	- 103.8
$\frac{1}{2} \text{H}_2(\text{g}) + \frac{1}{2} \text{I}_2(\text{g})$	$\rightarrow \text{HI}(\text{g})$	hydrogen iodide	+ 25.9
$4\text{C}(\text{s}) + 4\text{H}_2(\text{g}) + \text{O}_2(\text{g})$	$\rightarrow \text{C}_3\text{H}_7\text{COOH}(\text{l})$	butyric acid	- 522.1
$2\text{C}(\text{s}) + 2\text{H}_2(\text{g}) + \text{O}_2(\text{g})$	$\rightarrow \text{CH}_3\text{COOH}(\text{l})$	acetic acid	- 486.6

## Method 1: Additivity of Heats (continued)

**Example:** Determine  $\Delta H$  for the following reaction:

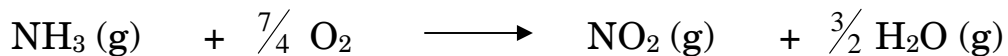


## Method 2: Summation of Heats

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

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

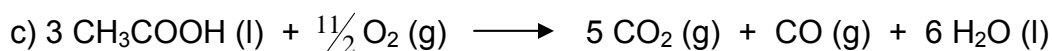
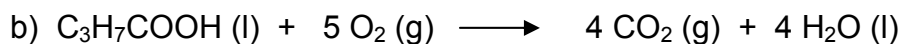
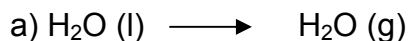
**Example:** Determine  $\Delta H$  for the following reaction:



### 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  $\Delta H$  for each of the following:



2. a) Write a balanced equation for the combustion of propane gas ( $\text{C}_3\text{H}_8$ ) to produce carbon dioxide and water vapour.

b) Add equations and heats of formation to calculate the  $\Delta H$  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:

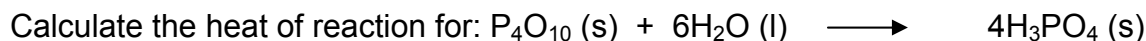


2. Given that  $\Delta H_{\text{form}}$  for  $\text{SiO}_2 (\text{s})$  is  $-856.9 \text{ kJ/mol}$ , what is the  $\Delta H$  for:



3. What is the heat of formation of  $\text{H}_2\text{SO}_4 (\text{l})$  from  $\text{H}_2\text{O} (\text{l})$  and  $\text{SO}_3 (\text{g})$ ?

4. Given:  $\Delta H_{\text{form}}$  for  $\text{P}_4\text{O}_{10} (\text{s}) = -3009.5 \text{ kJ/mol}$   
 $\Delta H_{\text{form}}$  for  $\text{H}_3\text{PO}_4 (\text{s}) = -1266.5 \text{ kJ/mol}$



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