Section 5.3
Representing Enthalpy Changes

Energy changes obtained from empirical studies (calorimetric experiments) can be communicated in **four** ways.

- By including an energy value as a term in a thermochemical equation
- By writing a chemical and stating the enthalpy change in terms of ΔH notation
- By stating the molar enthalpy
- By drawing a chemical potential energy diagram

Method 1: Thermochemical equations with energy terms.

Example 1:
Write a thermochemical equation for the burning of 2 moles of butane, C_4H_8, in an excess of oxygen gas. The molar enthalpy for the combustion of butane is -2871 kJ/mol.

1. Write the balanced equation for the reaction.

$$\mathbf{2C_4H_{8(g)} + 13O_{2(g)} \rightarrow 8CO_{2(g)} + 10H_2O_{(l)}}$$

2. Then obtain the number of moles of butane from the balanced equation and use this to calculate the ΔH for the reaction.

$n = 2$ moles C_4H_8

$\Delta H = n\,\Delta H_{comb.}$

$=2$ mol x -2871 J/mol

$= -5742$ kJ

3. Report the energy change for the reaction by writing the appropriate thermochemical equation.

$$\mathbf{2C_4H_{8(g)} + 13O_{2(g)} \rightarrow 8CO_{2(g)} + 10H_2O_{(l)} + 5742\ kJ.}$$

Method 2: Thermochemical Equations with ΔH Values
A second method is to write a balanced chemical equation for the enthalpy change and then write the ΔH value beside it, making sure it has the correct sign.
Example: Write a thermochemical equation for the reaction between sulfur dioxide and oxygen in the formation of sulfur trioxide. The molar enthalpy is -98.9 kJ/ mol SO_2.

1. Write the balanced chemical equation:

$$\mathbf{2SO_{2(g)} + O_{2(g)} \rightarrow 2SO_{3(g)}}$$

2. The $\Delta H_{comb.}$ in this reaction is -98.9 kJ/mol SO_2.

3. Obtain the amount of sulfur dioxide, n, from the balanced equation.

$n = 2$ mol

4. Calculate ΔH for the reaction

$\Delta H = n\Delta H_{comb.}$

$n = 2$ mol and $\Delta H_{comb.} = -98.9\ kJ \cdot mol^{-1}$

$$\Delta H = 2\ mol \times \frac{-98.9 kJ}{1 mol}$$
$$= -197.8\ kJ$$

5. Write the reaction for the enthalpy change with the appropriate energy term.

$2SO_{2(g)} + O_{2(g)} \rightarrow 2SO_{3(g)}$ $\Delta H = -197.8\ kJ$

Note that the units for the enthalpy change are in kJ, kilojoules, because enthalpy change applies to the reaction as written.

If the balanced equation for the reaction is written differently, the enthalpy change should be reported differently. For the equation above

$SO_{2(g)} + \frac{1}{2}O_{2(g)} \rightarrow SO_{3(g)}$ $\Delta H = -98.9\ kJ \cdot mol^{-1}$

The enthalpy changes for reactions must be accompanied by a balanced chemical equation that includes the state of matter of each reaction.

Method 3: Molar Enthalpies of Reaction

Molar enthalpies are convenient ways of describing the energy changes involved in a variety of physical and chemical changes.

Some molar enthalpies are listed in the table below

Type of Molar Enthalpy	**Example of Change**
Heat of solution, ΔH_{sol}	$NaCl_{(s)} \rightarrow Na^+_{(aq)} + Cl^-_{(aq)}$
Heat of combustion, ΔH_{comb}	$CH_{4(g)} + 2O_{2(g)} \rightarrow CO_{2(g)} + H_2O_{(l)}$
Heat of vapourization, ΔH_{vap}	$H_2O_{(l)} \rightarrow H_2O_{(g)}$

Molar enthalpies that are determined when the initial and final conditions are at SATP are called **Standard Molar Enthalpies of Reaction**.

The symbol ΔH^{o}_{x} distinguishes standard molar enthalpies from molar enthalpies, ΔH_x, where x represents the type of molar enthalpy change.

Standard molar enthalpies are listed in tables that allow us to compare enthalpy values.

For an exothermic reaction the standard molar enthalpy is measured by taking into account all the energy required to change the reaction from SATP, in order to initiate the reaction, and all the energy released following the reaction, as the products are cooled to SATP.

Example: for the combustion of methanol

$$\mathbf{2CH_3OH_{(l)} + 3O_{2(g)} \rightarrow 2CO_{2(g)} + 4H_2O_{(l)}}$$

Now take the equation and rewrite it for one mole of CH_3OH.

$$\mathbf{CH_3OH_{(l)} + \tfrac{3}{2}\,O_{2(g)} \rightarrow CO_{2(g)} + 2H_2O_{(l)}}$$

The standard molar enthalpy of the combustion of methanol is $\Delta H^{o}_{comb} = -726\ kJ \cdot mol^{-1}$.

<u>Method 4: Potential Energy Diagrams</u>

Observed energy changes in chemical reactions can be explained in terms of chemical potential energy. This stored energy is related to the relative position of the particles and the their bond strengths.

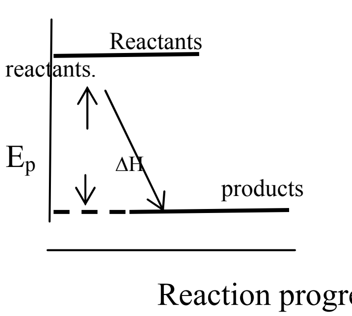
Potential energy is stored or released as the position of the particles changes due to the breaking and re-formation of bonds as reactants are changed to products.

The potential energy change in the system is equivalent to the heat transferred to or from the surroundings.

Potential energy diagrams visually communicate the energy transferred during a change, when bonds are broken or formed.

The vertical axis represents the potential energy of the system.

The horizontal axis represents the change from reactants to products and is thus called the reaction coordinate or reaction progress.

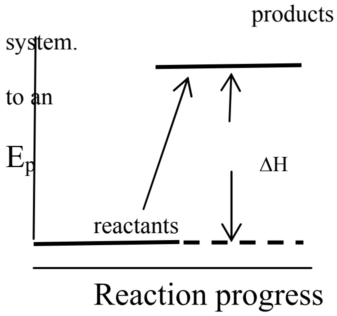


Exothermic Reaction: the products have less potential energy than the reactants.

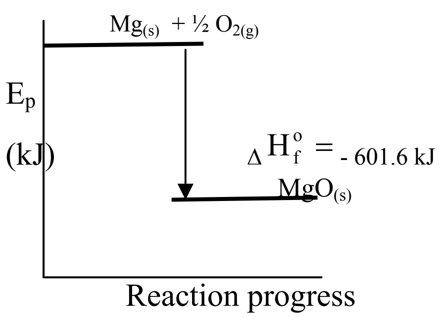
Energy is released to the surroundings as the product is formed, this is by a temperature increase of the surroundings.

Endothermic Reaction: the products have more potential energy than the reactants. Energy is absorbed from the surroundings into the chemical system.

We observe a temperature decrease in the surroundings. This corresponds to an increase in the enthalpy of the chemical system.

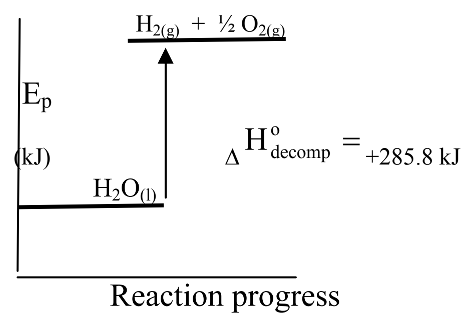


Exothermic Chemical Change



The reaction in which one mole of magnesium oxide is formed from its elements is exothermic, so the reactants must have a higher potential energy than the products.

Endothermic Chemical Change



The reaction in which water decomposes to form hydrogen ad oxygen gases is endothermic, so the reactant, water, must have a lower potential energy than the products, hydrogen and oxygen.

$$\mathbf{Mg_{(s)} + ½O_{2(g)} \rightarrow MgO_{(s)}} \quad \Delta H^o_f = -601.6\ kJ \cdot mol^{-1}$$

$$\mathbf{H_2O_{(l)} \rightarrow H_{2(g)} + ½O_{2(g)}} \quad \Delta H^o_{decomp} = +285.8\ kJ \cdot mol^{-1}$$