Communicating Enthalpy Changes - pgs 495-501

Most information about energy changes comes from the experimental method of calorimetry. These studies give us molar enthalpies that can be communicated in at least four ways:

1. by stating the molar enthalpy of a **specific reactant** in a reaction

2. by stating the **enthalpy change** for a balanced reaction equation

3. by including an energy value **as a term** in a balanced reaction equation

4. by drawing a **chemical potential energy diagram**

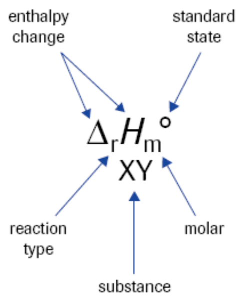
All four of these methods of expressing energy changes are equivalent.

- The first three are closer to empirical descriptions

- The fourth method is a theoretical description.

Method 1: Molar Enthalpies of Reaction, $\Delta_r H_m$

To communicate a molar enthalpy, both the **substance** and the **reaction** must be specified. The substance is conveniently specified by its chemical formula.



Standard enthalpy values are expressed with a ° superscript, as in $\Delta_f H_m°$. The reactants and products are in their standard state:

- a pressure of 100 kPa,

- an aqueous concentration of 1 mol/L

- liquid and solid elements the pure state must be at 25 °C.

- Liquid and solid compounds must only have the same initial and final temperature

Example:

$$\underset{CH_3OH}{\Delta_f H_m°} = -239.2 \text{ kJ/mol}$$

This means that 239.2 kJ of energy is released to the surroundings when 1 mol of methanol is formed from its elements when they are in their standard states at SATP

The following chemical equation communicates the formation reaction assumed to occur:

$$C(s) + 2\,H_2(g) + \tfrac{1}{2}\,O_2(g) \rightarrow CH_3OH(l)$$

Method 2: Enthalpy Changes, $\Delta_r H$

A second method for communicating an energy change is to write an enthalpy change ($\Delta_r H$) beside the chemical equations.

$$CO(g) + 2\,H_2(g) \rightarrow CH_3OH(l) \qquad \Delta_r H^\circ = -128\ \text{kJ}$$

Molar enthalpies of reaction can be used to calculate the enthalpy change during a chemical reaction; a molar enthalpy and a balanced chemical equation are required for the calculation

$$\Delta_r H^\circ = n\,\Delta_r H_m^\circ$$

Example

Sulfur dioxide and oxygen react to form sulfur trioxide (**Figure 3**). The standard molar enthalpy of combustion of sulfur dioxide, in this reaction, is −98.9 kJ/mol. What is the enthalpy change for this reaction? First write the balanced chemical equation.

$\Delta_c H_{m\,SO_2} = -98.9\ \text{kJ/mol}$

$\Delta_r H = n\,\Delta_r H_m$
$= (2\ \text{mol})(-98.9\ \frac{\text{kJ}}{\text{mol}})$
$=$

$2\,SO_{2(g)} + 1\,O_{2(g)} \rightarrow 2\,SO_{3(g)} \qquad \Delta_c H = -197.8\ \text{kJ}$

The enthalpy change depends on the actual chemical amount of reactants and products in the chemical reaction.

Therefore, if the balanced equation for the reaction is written differently, the enthalpy change should be reported differently.

$$SO_2(g) + \tfrac{1}{2}\,O_2(g) \rightarrow SO_3(g) \qquad \Delta_c H^\circ = -98.9\ \text{kJ}$$

$$2\,SO_2(g) + O_2(g) \rightarrow 2\,SO_3(g) \qquad \Delta_c H^\circ = -197.8\ \text{kJ}$$

Method 3: Energy Terms in Balanced Equations

Another way to report the enthalpy change in a chemical reaction is to include it as a term in a balanced equation

$$H_2O(l) + 285.8\ kJ \rightarrow H_2(g) + \tfrac{1}{2}O_2(g)$$

$$Mg(s) + \tfrac{1}{2}O_2(g) \rightarrow MgO(s) + 601.6\ kJ$$

If a reaction is **endothermic**, it requires a certain quantity of additional energy for the reactants to continuously react.

- This energy (like the reactants) is transformed as the reaction progresses and is listed along with the **reactants**

If a reaction is **exothermic**, energy is released as the reaction proceeds and is listed along with the **products**

Ethane is cracked into ethene in world-scale quantities in Alberta. Communicate the enthalpy of reaction as a term in the equation representing the cracking reaction.

$$C_2H_6(g) \rightarrow C_2H_4(g) + H_2(g) \qquad \Delta_{cr}H = +136.4\ kJ$$

$$C_2H_6(g) + 136.4\ kJ \rightarrow C_2H_4(g) + H_2(g)$$

Method 4: Chemical Potential Energy Diagrams

Chemists use the law of conservation of energy to describe what happens during a chemical reaction.

They explain their observations theoretically: observed energy changes are due to changes in chemical potential energy that occur during a reaction.

- This energy is a stored form of energy that is related to the relative positions of particles and the strengths of the bonds between them

- As bonds break and re-form and the positions of atoms are altered, changes in potential energy occur.

Evidence of a change in enthalpy of a chemical system is provided by a temperature change of its surroundings

A chemical potential energy diagram shows the potential energy of both the reactants and the products of a chemical reaction (**Figures 5** and **6**).

The difference between the initial and final energies in a chemical potential energy diagram is the enthalpy change ($\Delta_r H$), obtained from calorimetry.

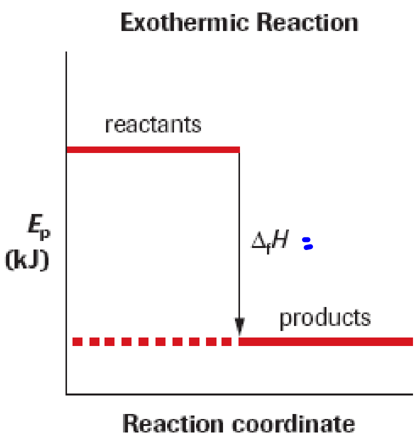


Figure 5
During an exothermic reaction, the enthalpy of the system decreases and heat flows into the surroundings. We observe a temperature increase in the surroundings.

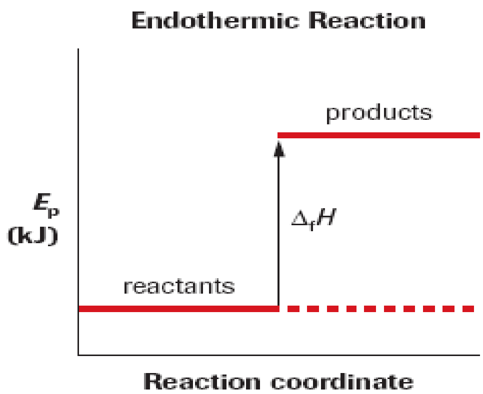


Figure 6
During an endothermic reaction, heat flows from the surroundings into the chemical system. We observe a temperature decrease in the surroundings.

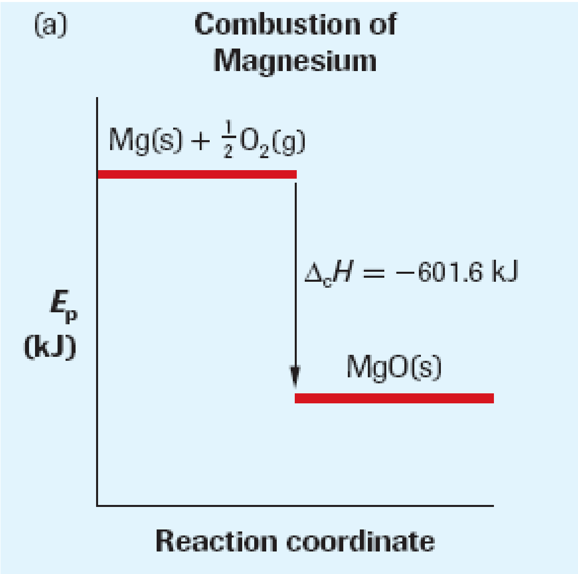
Example

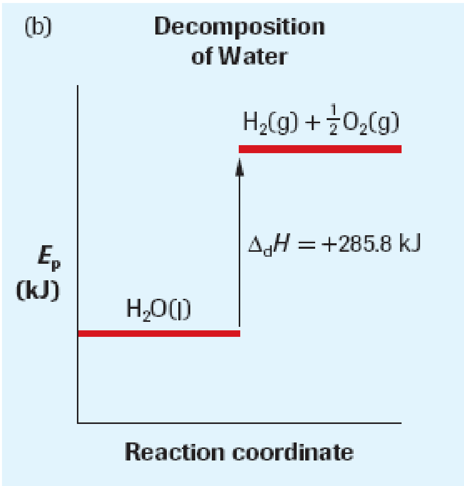
Communicate the following enthalpies of reaction as chemical potential energy diagrams.
(a) The burning of magnesium to produce a very bright emergency flare.

$Mg(s) + \frac{1}{2}O_2(g) \rightarrow MgO(s)$ $\Delta_c H = -601.6$ kJ

(b) The decomposition of water by electrical energy from a solar cell.

$\Delta_d H_m = +285.8$ kJ/mol
H_2O





Example:

Energy is transformed in cellular respiration and in photosynthesis (**Figure 8**). Cellular respiration, a series of exothermic reactions, is the breakdown of foodstuffs, such as glucose, that takes place within cells. Photosynthesis, a series of endothermic reactions, is the process by which green plants use light energy to make glucose from carbon dioxide and water.

Express the standard enthalpy changes for cellular respiration and for photosynthesis by using the four different methods of communication.

(a) One mole of glucose is consumed, during cellular respiration, to release 2802.5 kJ of energy.

(b) Glucose is produced during photosynthesis.

(a) 1 The standard molar enthalpy for cellular respiration of glucose:

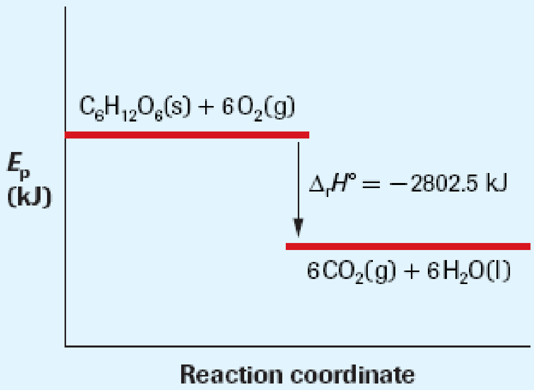
$\Delta_r H_m°_{C_6H_{12}O_6} = -2802.5$ kJ/mol

2 $C_6H_{12}O_6(g) + 6O_2(g) \rightarrow 6CO_2(g) + 6H_2O(l) \quad \Delta_r H° = -2802.5$ kJ

3 $C_6H_{12}O_6(s) + 6O_2(g) \rightarrow 6CO_2(g) + 6H_2O(l) + 2802.5$ kJ

4 Potential energy diagram for cellular respiration:

Cellular Respiration



(b) 1 The standard molar enthalpy for photosynthesis of glucose:

$\Delta_r H°_{m\,C_6H_{12}O_6} = +2802.5$ kJ/mol

2 $6CO_2(g) + 6H_2O(l) \rightarrow C_6H_{12}O_6(s) + 6O_2(g) \quad \Delta_r H° = +2802.5$ kJ

3 $6CO_2(g) + 6H_2O(l) + 2802.5 \text{ kJ} \rightarrow C_6H_{12}O_6(s) + 6O_2(g)$

4 Potential energy diagram for photosynthesis:

Photosynthesis