Molar Enthalpy Change and Calculating Enthalpy Changes

- Recall that enthalpy change depends on the amount/moles of reactants that are available to undergo a reaction
  - Therefore the value of ΔH will change depending on the amount of reactants used
- Sometimes it is useful to record the *molar enthalpy change* for a reaction instead of the enthalpy change
- **Molar enthalpy change (Δ_rH)** is a measurement that indicates the potential energy change for *only one mole* of a specific chemical undergoing a particular reaction
  - * The molar enthalpy change for a chemical involved in a specific reaction will never change because it is always referenced for 1 mole of chemical
  - Enthalpy change is usually given the symbol ΔH and is measured in units of joules (J) or kilojoules (kJ) look for units!
  - Molar enthalpy change is usually given the symbol Δ_rH and is measured in units of joules/mole (J/mol) or kilojoules/mole (kJ/mol)
  - The subscript letter just represents a type of reaction (*r* is for any generic reaction, *c* is for combustion reaction, *f* is formation reaction, *sol* is for a dissolving/solution reaction, etc.)
- When a molar enthalpy is recorded, the type of chemical has to be indicated because molar enthalpy change is for one mole of a *specific chemical*
- The enthalpy change and the molar enthalpy change for a reaction are closely related as shown in the following equation.

$$\Delta H = n\Delta_r H$$

memorize!

where ΔH is the enthalpy change (J of kJ)

n is the amount of moles for a specific chemical species (mol)

Δ_rH is the molar enthalpy for a specific chemical species (J/mol or kJ/mol)

units of J or kJ need to be consistent

- Sometime enthalpy change or molar enthalpy change for a reaction can also be referred to as the "*heat of a reaction*" or "*molar heat of a reaction*". For example, the enthalpy of combustion may also be referred to as the heat of combustion.
- Remember that the enthalpy change (ΔH) appears in a thermochemical equation, **NOT** the molar enthalpy change (Δ_rH)
- Last note, **standard enthalpy change** (ΔH^o) or **standard molar enthalpy change** (Δ_rH^o) for a reaction simply means the chemical reaction occurred at SATP (25°C and 100kPa). The superscript "°" indicates at SATP conditions.

EXAMPLES

1. Consider the following equation:

combustion must be in open system!

$C_3H_{8(g)} + 5O_{2(g)} \rightarrow 3CO_{2(g)} + 4H_2O_{\underline{(g)}}$ ✓ $\Delta_cH = -2043.9\text{kJ/mol } C_3H_{8(g)}$

Write the thermochemical equation when 3 mols of $C_3H_{8(g)}$ is burned.

$\Delta_rH = -2043.9 \text{ kJ/mol}$

$n = 3 \text{ mols}$

$\Delta H = ?$

$\Delta H = n\Delta_rH$

$\Delta H = (3 \text{ mol})(-2043.9 \text{ kJ/mol})$

$\Delta H = -6131.7 \text{ kJ}$

$$3C_3H_{8(g)} + 15O_{2(g)} \rightarrow 9CO_{2(g)} + 12H_2O_{(g)} + 6131.7\text{kJ}$$

but $\Delta_cH = -2043.9\text{kJ/mol } C_3H_{8(g)}$ still stays the same

2. Consider the combustion reaction that methane undergoes in an open system.

$CH_{4(g)} + 2O_{2(g)} \rightarrow CO_{2(g)} + 2H_2O_{\underline{(g)}}$ ✓ $\Delta_cH = -802.5 \text{ kJ/mol } CH_{4(g)}$

What is the enthalpy change when 50.00g of methane gas is burned?

$\Delta_rH = -802.5 \text{ kJ/mol}$

$m = 50.00\text{g}$

$\Delta H = ?$

$\Delta H = n\Delta_rH$ ②

$\downarrow$

$m = Mn$ ①

aside

$M_{CH_4} = 12.01 \text{ g/mol} + (1.01 \text{ g/mol})4$

$= 16.05 \text{ g/mol}$

① $n = \dfrac{m}{M} = \dfrac{50.00\text{g}}{16.05\text{g/mol}} = 3.115... \text{mol}$

② $\Delta H = n\Delta_rH = (3.115... \text{mol})(-802.5 \text{ kJ/mol})$

$\Delta H = -2500 \text{ kJ}$

$$\boxed{\Delta H = -2.50\times10^3 \text{ kJ}}$$

3. Consider the following equation:

$C_6H_{12}O_{6(s)} + 6O_{2(g)} \rightarrow 6CO_{2(g)} + 6H_2O_{(g)}$ $\Delta_cH = -2802.5$ kJ/mol $C_6H_{12}O_{6(s)}$

What is the molar enthalpy for $CO_{2(g)}$?

$\underline{C_6H_{12}O_6}$		$\underline{CO_2}$
$\Delta_cH = -2802.5$ kJ/mol		$\Delta_rH = ?$
$n = 1$ mol	← from balanced rxn →	$n = 6$ mol

② $\Delta H = n\Delta_rH$ for CO_2

↙

① $\Delta H = n\Delta_rH$ for $C_6H_{12}O_6$

* ΔH will be the same for the whole rxn!

① $\Delta H = n\Delta_rH = (1\text{mol})(-2802.5 \text{ kJ/mol})$

$\Delta H = -2802.5$ kJ

② $\Delta H = n\Delta_rH \longrightarrow \Delta_rH = \dfrac{\Delta H}{n}$

$$\Delta_rH = \frac{-2802.5\text{ kJ}}{6\text{ mol}} = -467.08\bar{3}\text{ kJ/mol}$$

$$\boxed{\Delta_rH_{CO_2} = -467.08\text{ kJ/mol}}$$

*****Now try pg. 349 # 3a (need to use table on pg. 347), 5 (has a typo; should be -725.9 <u>kJ/mol</u>), 6 & pg. 350 #4*****

- If ΔH for a specific reaction or the thermochemical equation is given, it is possible to calculate the enthalpy change for that same reaction, but when different amounts of reactants are used

* I call these problems "specific amount" problems!

EXAMPLES

1. Sulphur dioxide reacts with oxygen to produce sulphur trioxide, as shown in the thermochemical equation. Determine what mass of sulphur dioxide is consumed if 750kJ of energy is released by the reaction.

specific amount problem

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

aside

$$M_{SO_2} = 32.07\text{ g/mol} + (16.00\text{ g/mol}) \times 2 = 64.07\text{ g/mol}$$

specific amount	balanced rxn
$\Delta H = -750\text{kJ}$	$\Delta H = -197.8\text{kJ}$
$n = ?$	$n = 2\text{ mol}$

② ↖ $\Delta_r H_{SO_2}$ ↙ ①

① $\Delta H = n\Delta_r H \longrightarrow \Delta_r H = \dfrac{\Delta H}{n} = \dfrac{-197.8\text{kJ}}{2} = -98.9\text{kJ/mol}$

② $\Delta H = n\Delta_r H \longrightarrow n = \dfrac{\Delta H}{\Delta_r H} = \dfrac{-750\text{ kJ}}{-98.9\text{kJ/mol}} = 7.583\ldots\text{ mol}$

③ $m = Mn = (64.07\text{ g/mol})(7.583\ldots\text{ mol})$

$m = 485.869\ldots\text{g}$

$\boxed{m = 486\text{g}}$

2. Liquid hydrogen peroxide is an oxidizing agent in many rocket fuel mixtures because it releases oxygen gas on decomposition. The following reaction is shown below.

$$2H_2O_{2(l)} \rightarrow 2H_2O_{(l)} + O_{2(g)} + 196.1\text{ kJ}$$

How much heat is released when 6.50g of $H_2O_{2(l)}$ decomposes?

* specific amount problem! *

specific amount	balanced rxn
$\Delta H = ?$	$n = 2$ mol
$n = 0.19106\ldots$ mol	$\Delta H = -196.1$ kJ

② ↖ $\Delta_r H$ H_2O_2 ↙ ①

① $\Delta H = n\Delta_r H \rightarrow \Delta_r H = \frac{\Delta H}{n}$

$$\Delta_r H = \frac{-196.1\text{kJ}}{2\text{mol}} = -98.05\text{ kJ/mol}$$

② $\Delta H = n\Delta_r H$

$\Delta H = (0.19106\ldots\text{mol})(-98.05\text{ kJ/mol})$

$\Delta H = -18.7338\ldots$ kJ

$$\boxed{\Delta H = -18.7\text{ kJ}}$$

aside

$$M_{H_2O_2} = (1.01\text{g/mol})2 + (16.00\text{g/mol})2 = 34.02\text{g/mol}$$

$m = Mn$

$$n = \frac{m}{M} = \frac{6.50\text{g}}{34.02\text{g/mol}}$$

$n = 0.19106\ldots$ mol

*****Now try Practice Problems*****

Practice Problems

1. Consider the following thermochemical equation:

   $2\ ZnS_{(s)} + 3\ O_{2(g)} \rightarrow 2\ ZnO_{(s)} + 2\ SO_{2(g)}$ $\Delta H^\circ = -878.2\ kJ$

   a. What is the enthalpy change when 223.9g of $ZnS_{(s)}$ react with excess oxygen?

   b. What mass of oxygen is required to produce 505 kJ of energy from the reaction above?

2. Slaked lime ($Ca(OH)_{2(s)}$) is produced when lime (calcium oxide, $CaO_{(s)}$) reacts with liquid water. For each mole of $Ca(OH)_{2(s)}$ produced, 65.2kJ of heat is released.

   a. Write the thermochemical equation for the reaction.

   b. What is the enthalpy change when 523.3kg of lime reacts with excess water?

3. The following reaction represents the complete combustion of hexane, $C_6H_{14(l)}$.

   $C_6H_{14(l)} + \frac{19}{2} O_{2(g)} \rightarrow 6\ CO_{2(g)} + 7\ H_2O_{(l)}$ $\Delta H^\circ = -4163\ kJ$

   a. If 25.0kg of hexane is burned in sufficient oxygen, how much heat will be released?

   b. What mass of hexane is required to produce $1.00\text{x}10^5$ J of heat by complete combustion?

Answers

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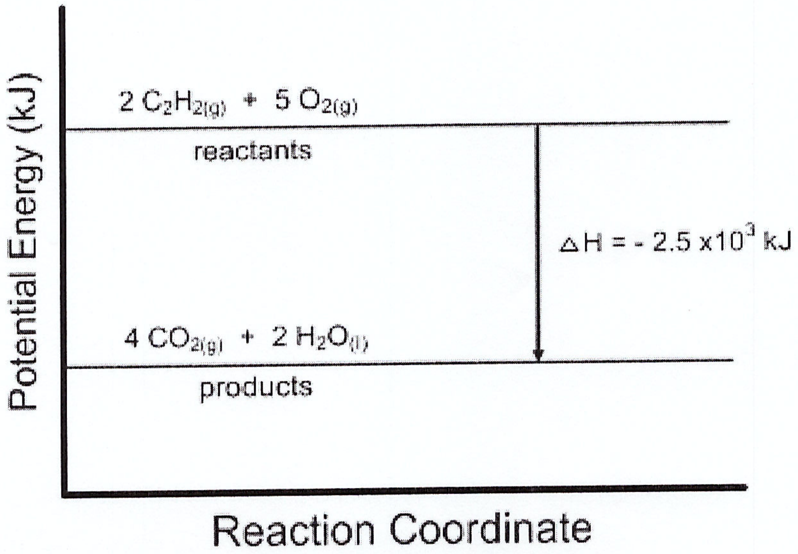
4.

a. $2\ C_2H_{2(g)}\ +\ 5\ O_{2(g)}\ \rightarrow\ 4\ CO_{2(g)}\ +\ 2\ H_2O_{(l)}\ +\ 2.50\times10^3\ kJ$



b.

c. $\Delta H = -\ 104\ kJ$

PRACTICE PROBLEMS

1.

a. $\Delta H = -\ 1009\ kJ$

b. 55.2 g

2.

a. $CaO_{(s)}\ +\ H_2O_{(l)}\ \rightarrow\ Ca(OH)_{2(s)}\ +\ 65.2\ kJ$

b. $\Delta H = -\ 6.08\times10^5\ kJ$

3.

a. $1.21\times10^6\ kJ$

b. 2.07 g

Molar Enthalpy Review

1. Identify the false statement about the following equation:

   $2H_{2(g)} + O_{2(g)} \rightarrow 2H_2O_{(g)}$ $\Delta H = -483.6\text{ kJ}$

   a) the reaction is exothermic
   b) 483.6 kJ of heat are evolved per mole of O_2 used
   c) the heat of formation of water vapor is -241.8 kJ/mol
   [✓ d)] 483.6 kJ of heat are evolved per mole of water produced

2. Given the following reaction, $C_8H_{16(l)} + 12O_{2(g)} \rightarrow 8CO_{2(g)} + 8H_2O_{(g)} + 4902.4\text{ kJ}$, the enthalpy change that occurs when 26.1g of carbon dioxide ($CO_{2(g)}$) is produced is is 363 kJ.

specific	balanced
$n = 0.593...\text{ mol}$	$n = 8\text{ mol}$
$\Delta H = ?$	$\Delta H = -4902.4\text{ kJ}$

② ↖ $\Delta_r H_{CO_2}$ ↙ ①

aside

$$n = \frac{m}{M} = \frac{26.1\text{ g}}{44.01\text{ g/mol}}$$

$n = 0.593...\text{ mol}$

① $$\Delta_r H = \frac{\Delta H}{n} = -\frac{4902.4\text{ kJ}}{8\text{ mol}}$$

$\Delta_r H = -612.8\text{ kJ/mol}$

② $\Delta H = n\Delta_r H = (0.593...\text{ mol})(-612.8\text{ kJ/mol})$

$$\boxed{\Delta H = -363\text{ kJ}}$$