CHEM1612 Worksheet 2: Enthalpy Change of formation

Model 1: Forming a Compound from its Elements

If a compound is formed from the elements it contains in their naturally occurring forms, the enthalpy change is called the **enthalpy change of formation** (**$\Delta_f H$**). The naturally occurring forms of the elements at room temperature and pressure are called the **standard states** of the elements and include, for example, graphite for carbon and O_2(g) for oxygen. CO_2 contains carbon and oxygen and so $\Delta_f H$ for CO_2 is for the reaction in which it is formed from graphite and O_2(g):

$$C(s) + O_2(g) \rightarrow CO_2(g) \qquad \Delta_{rxn}H = \Delta_f H\,(CO_2(g)) = -393.5 \text{ kJ mol}^{-1}$$

The enthalpies of formation for many compounds are tabulated in databooks and on websites. One reason for this is that they can be combined to predict the enthalpies of reactions which involve these compounds.

Critical thinking questions

1. Write down the reactions that correspond to the enthalpies of formation of (a) CH_4(g) and (b) H_2O(l).

   (a) (b)

2. Why are $\Delta_f H°$ (O_2(g)) and $\Delta_f H°$ (H_2(g)) both equal to 0 kJ? (*Hint*: what is the reaction in each case?)

Model 2: Calculating the Enthalpy of Reaction using $\Delta_f H$

To determine the overall value of ΔH for a reaction, we can *imagine* the reaction taking place in two steps:

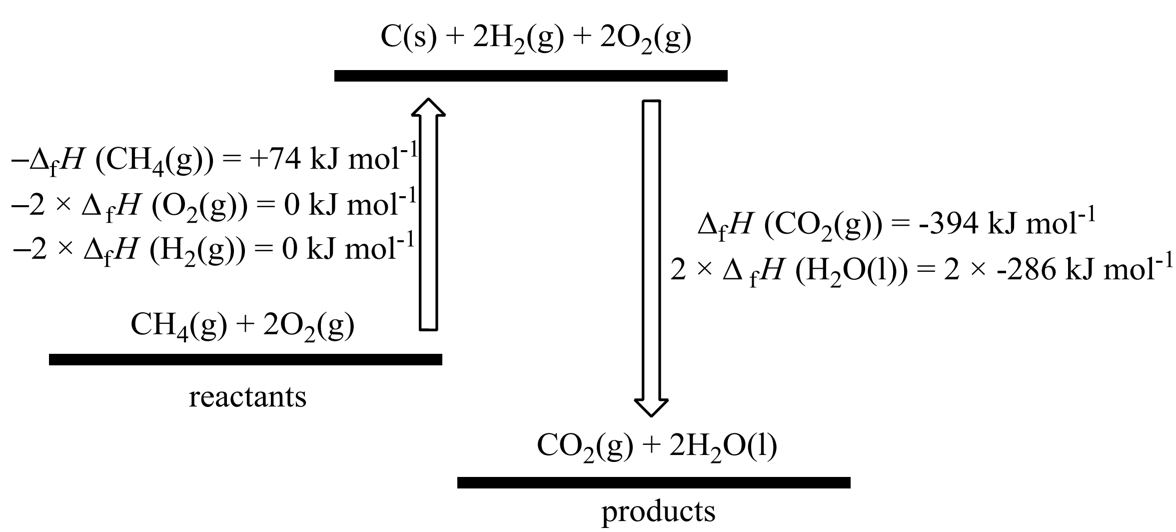
(i) The reactant molecules are broken apart into the corresponding elements in their naturally occurring forms. This is the *opposite* process to the formation of the reactant molecules from their elements and requires an enthalpy change equal to $-\Delta_f H$ (reactants)

(ii) These elements are then reassembled to make the product molecules. The enthalpy change for this process is *equal* to $+\Delta_f H$ (products)

Using this method, the equation for the enthalpy of reaction becomes:

$$\Delta_{rxn}H° = \Delta_f H° \text{ (products)} - \Delta_f H° \text{ (reactants)} \qquad (1)$$

The enthalpy change for the combustion of methane is represented on the energy level diagram below. On the left, CH_4(g) and O_2(g) are broken up into their elements in the standard states, graphite (C(s)), H_2(g) and O_2(g). This is the *reverse* of their formation so the energy required is $-\Delta_f H°$ (reactants). On the right, CO_2(g) and H_2O(g) are formed from the same elements in the same states so the energy change is + $\Delta_f H°$ (products).



Critical thinking questions

1. What is $\Delta_{rxn}H°$ for the reaction $CH_4(g) + 2O_2(g) \rightarrow CO_2(g) + 2H_2O(l)$?

2. Use equation (1) and the data below to calculate $\Delta_{rxn}H°$ for the reaction $MgO(s) + CO_2(g) \rightarrow MgCO_3(s)$.
$\Delta_f H°$: $MgO(s) = -602$ kJ mol^{-1}, $CO_2(g) = -394$ kJ mol^{-1} and $MgCO_3(s) = -1096$ kJ mol^{-1}

Nitrogen dioxide, NO_2, is a prominent air pollutant. At low temperatures, it is in equilibrium with its dimer, N_2O_4. Starting from NO_2, the formation of the dimer can be studied using one of the two equations below:

$2NO_2(g) \rightarrow N_2O_4(g)$ (A)

$NO_2(g) \rightarrow ½\, N_2O_4(g)$ (B)

Starting from the dimer, the formation of NO_2 can be studied using one of the two equations below:

$N_2O_4(g) \rightarrow 2NO_2(g)$ (C)

$½\, N_2O_4(g) \rightarrow NO_2(g)$ (D)

3. Use equation (1) to calculate $\Delta_{rxn}H°$ for reaction A. $\Delta_f H°$: $NO_2(g)$, 33 kJ mol^{-1}, $N_2O_4(g)$ 9 kJ mol^{-1}.

4. Explain in *words* the origin of the *sign* of $\Delta_{rxn}H°$ in terms of the chemical changes in the reaction.

5. Use equation (1) to calculate $\Delta_{rxn}H°$ for reaction B. How is the value related to your answer to Q3?

6. Use equation (1) to calculate $\Delta_{rxn}H°$ for reaction C. How is the value related to your answers to Q3 and Q5?

7. Explain in *words* the origin of the *sign* of $\Delta_{rxn}H°$ and in terms of the chemical changes in the reaction.

8. Without doing any calculations, work out the value of $\Delta_{rxn}H°$ for reaction D.

Marks
4

- Nitroglycerine, $C_3H_5(NO_3)_3$, decomposes to form N_2, O_2, CO_2 and H_2O according to the following equation.

$$4C_3H_5(NO_3)_3(l) \rightarrow 6N_2(g) + O_2(g) + 12CO_2(g) + 10H_2O(g)$$

If 15.6 kJ of energy is evolved by the decomposition of 2.50 g of nitroglycerine at 1 atm and 25 °C, calculate the enthalpy change, $\Delta H°$, for the decomposition of 1.00 mol of this compound under standard conditions.

Answer:

Hence calculate the enthalpy of formation of nitroglycerine under standard conditions.

Data:

	$\Delta_f H°$ (kJ mol^{-1})
$H_2O(g)$	–242
$CO_2(g)$	–394

Answer:

Marks 3

- Ammonium perchlorate mixed with powdered aluminium powers the space shuttle booster rockets:

$$2NH_4ClO_4(s) + 2Al(s) \rightarrow Al_2O_3(s) + 2HCl(g) + 2NO(g) + 3H_2O(g)$$

Given the following thermochemical data, how much heat would be released per gram of Al(s)?

ΔH_f^o ($H_2O(l)$) = –285.1 kJ mol^{-1} ΔH_f^o ($Al_2O_3(s)$) = –1669.8 kJ mol^{-1}

ΔH_f^o ($NO(g)$) = 90.4 kJ mol^{-1} ΔH_f^o ($NH_4ClO_4(s)$) = –290.6 kJ mol^{-1}

ΔH_f^o ($HCl(g)$) = –92.3 kJ mol^{-1} ΔH_{vap}^o (H_2O) = 44.1 kJ mol^{-1}

Answer:

Marks 6

- The thermite reaction is written below. Show that the heat released in this reaction is sufficient for the iron to be produced as molten metal.

$$2Al(s) + Fe_2O_3(s) \rightarrow Al_2O_3(s) + 2Fe(l)$$

Assume that the values in the table are independent of temperature.

Substance	Enthalpy of formation, $\Delta_f H^o$ kJ mol^{-1}	Molar heat capacity, C_p J K^{-1} mol^{-1}	Melting point °C	Enthalpy of fusion kJ mol^{-1}
Al	0	24	660	11
Al_2O_3	–1676	79	2054	109
Fe	0	25	1535	14
Fe_2O_3	–824	104	1565	138