5. Chemical energetics

5.1 Enthalpy change

Paper 2

Question Paper

1 **(a)** Define enthalpy change of formation.

.....

.....

..... [2]

(b) Iron is made when iron(III) oxide is heated with carbon monoxide, as shown by reaction 2.

reaction 2 $Fe_2O_3 + 3CO \rightarrow 2Fe + 3CO_2$

Table 4.1 shows enthalpy change of formation data measured at 298 K and 101 kPa.

Table 4.1

substance	equation	value for $\Delta H_f^{\ominus}$ / kJ mol^{-1}
Fe_2O_3		–824.2
CO		–110.5
CO_2	$C(s) + O_2(g) \rightarrow CO_2(g)$	–393.5

(i) Complete Table 4.1 by adding equations with relevant state symbols to represent:

- standard enthalpy change of formation for Fe_2O_3
- standard enthalpy change of formation for CO.

[2]

(ii) Use the data in Table 4.1 to calculate the enthalpy change of reaction, ΔH_r, in kJ mol^{-1}, for reaction 2.

Show your working.

ΔH_r = ... kJ mol^{-1} [2]

2 Separate samples of Na_2CO_3 and $NaHCO_3$ react with $HCl(aq)$ to produce the same products, as shown in Table 2.1.

Table 2.1

reaction	equation	ΔH / kJ mol^{-1}
1	$Na_2CO_3 + 2HCl \rightarrow 2NaCl + H_2O + CO_2$	ΔH_1
2	$NaHCO_3 + HCl \rightarrow NaCl + H_2O + CO_2$	$\Delta H_2 = +27.2$

(a) Complete the reaction pathway diagram in Fig. 2.1 for reaction 2.

Label the diagram to show the enthalpy change, ΔH_2, and the activation energy, E_A.

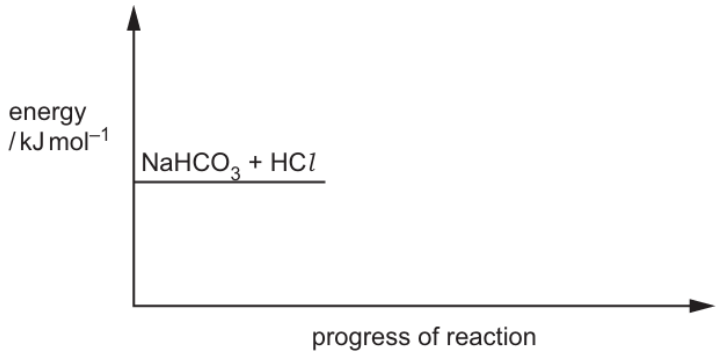


Fig. 2.1

[2]

(b) The value for ΔH_1 is determined by experiment using the following method.

- 50.0 cm^3 of 2.00 mol dm^{-3} $HCl(aq)$ is added to a polystyrene cup.
- The initial temperature of the acid is recorded as 19.6 °C.
- 0.0400 mol of Na_2CO_3 is added and the mixture is stirred.
- All the solid Na_2CO_3 disappears and a colourless solution is produced.

The maximum temperature recorded during the reaction is 26.2 °C.

(i) Describe **one** other observation that shows the reaction is complete.

..... [1]

(ii) Calculate the value of ΔH_1 in kJ mol^{-1}.

Assume the specific heat capacity of the reaction mixture is the same as for water and no heat is lost to the surroundings.

Show your working.

ΔH_1 = ... kJ mol^{-1} [3]

(iii) Thermal decomposition occurs when $NaHCO_3$ is heated.

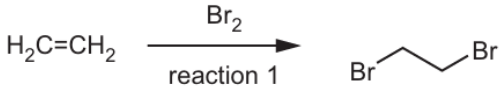
reaction 3 $2NaHCO_3 \rightarrow Na_2CO_3 + H_2O + CO_2$

Calculate the enthalpy change for reaction 3, ΔH_r, using the data in Table 2.1 and the value of ΔH_1 calculated in **(b)(ii)**.

(If you were unable to calculate a value for ΔH_1 in **(b)(ii)**, assume the enthalpy change is –38.4 kJ mol^{-1}. This is **not** the correct value.)

ΔH_r = ... kJ mol^{-1} [2]

3 **(b)** The enthalpy change of reaction 1, $\Delta H_r = -90.0\,kJ\,mol^{-1}$.



The enthalpy change of formation of ethene, $\Delta H_f = +52.2\,kJ\,mol^{-1}$.

Calculate the enthalpy change of formation of 1,2-dibromoethane.

ΔH_f of 1,2-dibromoethane = ... $kJ\,mol^{-1}$ [1]

4 A neutralisation reaction occurs when NaOH(aq) is added to H_2SO_4(aq).

equation 1 $2NaOH(aq) + H_2SO_4(aq) \rightarrow Na_2SO_4(aq) + 2H_2O(l)$

(a) Define enthalpy change of neutralisation, ΔH_{neut}.

.....

.....

..... [2]

(b) An experiment is carried out to calculate ΔH_{neut} for the reaction between NaOH(aq) and H_2SO_4(aq).

100 cm^3 of 1.00 mol dm^{-3} NaOH(aq) is added to 75 cm^3 of 1.00 mol dm^{-3} H_2SO_4(aq) in a polystyrene cup and stirred. Results from the experiment are shown in Table 2.1.

Table 2.1

initial temperature of NaOH(aq) / °C	20.0
initial temperature of H_2SO_4(aq) / °C	20.0
maximum temperature of mixture / °C	27.8

(i) Use equation 1 to calculate the amount, in mol, of H_2SO_4(aq) that is neutralised in the experiment.

amount of H_2SO_4(aq) neutralised = ... mol [1]

(ii) Calculate ΔH_{neut} using the results in Table 2.1. Include units in your answer.

Assume that:
- the specific heat capacity of the final solution is 4.18 J g^{-1} K^{-1}
- 1.00 cm^3 of the final solution has a mass of 1.00 g
- there is no heat loss to the surroundings
- full dissociation of H_2SO_4(aq) occurs
- the experiment takes place at constant pressure.

Show your working.

ΔH_{neut} = ... units .....
[3]

(c) (i) Complete the equation for the reaction that occurs when a solution of $Ba(OH)_2$ is added to aqueous sulfuric acid. Include state symbols.

..... $H_2SO_4(aq)$ + ...$Ba(OH)_2(aq) \rightarrow$ .....
[2]

(ii) Suggest why the enthalpy change of neutralisation cannot be determined using the addition of dilute sulfuric acid to aqueous barium hydroxide.

.....

..... [1]

5 In industry, ethanol is made by reacting ethene with steam in the presence of H_3PO_4.

reaction 1 $C_2H_4(g) + H_2O(g) \rightleftharpoons C_2H_5OH(g)$

(a) Use the bond energy values in Table 4.1 to calculate the enthalpy change, ΔH_r, for reaction 1.

Table 4.1

bond	bond energy / kJ mol^{-1}
C–C	350
C=C	610
C≡C	840
C–H	410
C–O	360
C=O	740
O–H	460

ΔH_r = ... kJ mol^{-1} [2]

(e) $POCl_3(g)$ forms when $PCl_3(g)$ reacts with $O_2(g)$.

$$2PCl_3(g) + O_2(g) \longrightarrow 2POCl_3(g)$$

Table 1.3 gives some relevant data.

Table 1.3

process	value / kJ mol^{-1}
enthalpy change of formation of $PCl_3(g)$	–289
enthalpy change of formation of $POCl_3(g)$	–592
$O_2(g) \longrightarrow 2O(g)$	+496

(i) Define enthalpy change of formation, ΔH_f.

.....

.....

..... [2]

(ii) Calculate the bond energy of P=O in $POCl_3$ using the data in Table 1.3.

Show your working.

bond energy of P=O = ... kJ mol^{-1}
[2]

6 Phosphoric(V) acid, H_3PO_4, is used in both inorganic and organic reactions.

(b) H_3PO_4 is also formed in the process shown in reaction 1.

reaction 1 $4H_3PO_3 \rightarrow 3H_3PO_4 + PH_3$

Table 3.1 shows some relevant thermodynamic data.

Table 3.1

compound	enthalpy change of formation, ΔH_f / kJ mol^{-1}
H_3PO_3	–972
H_3PO_4	–1281
PH_3	+9

(i) Define enthalpy change of formation.

.....

.....

..... [2]

(ii) Use the data in Table 3.1 to calculate the enthalpy change, ΔH_r, of reaction 1.

ΔH_r = ... kJ mol^{-1}
[2]

(iii) Explain why reaction 1 is a disproportionation reaction.

Explain your reasoning with reference to relevant oxidation numbers.

.....

.....

..... [2]

7 Radium, Ra, is an element found in Group 2 of the Periodic Table. It is a crystalline solid at room temperature and conducts electricity.

Radium chloride, $RaCl_2$, has a melting point of 900 °C and is soluble in water.

(b) Use equation **1** and the bond energy values in Table 3.1 to calculate the change in enthalpy, ΔH, for the thermal decomposition of 1 mole of HI(g). Show your working.

Table 3.1

bond	bond energy / kJ mol^{-1}
H–H	436
I–I	151
H–I	299

ΔH = ... kJ mol^{-1} [2]

8 Sulfides are compounds that contain sulfur but not oxygen.

(b) The enthalpy change of combustion of $CS_2(l)$ is represented by the following equation.

$$CS_2(l) + 3O_2(g) \xrightarrow{\Delta H_c} CO_2(g) + 2SO_2(g)$$

(i) Define *enthalpy change of combustion*.

.....

.....

..... [2]

(ii) The table shows the enthalpy changes of formation of $CS_2(l)$, $CO_2(g)$ and $SO_2(g)$.

compound	enthalpy change of formation, ΔH_f / kJ mol^{-1}
$CS_2(l)$	+89.7
$CO_2(g)$	–394
$SO_2(g)$	–297

Use the data in the table to calculate the enthalpy change of combustion, ΔH_c, of $CS_2(l)$, in kJ mol^{-1}.

Show your working.

ΔH_c of $CS_2(l)$ = ... kJ mol^{-1}
[2]

9 Phosphorus is a reactive Period 3 element.

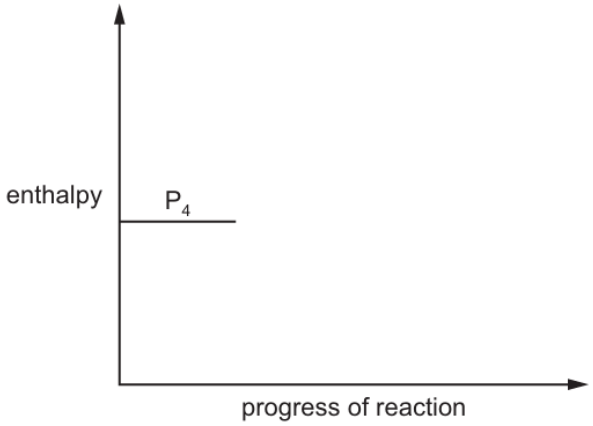
(a) Phosphorus has several allotropes. Details of two allotropes are given.

allotrope of phosphorus	formula	melting point / °C
white	P_4	44
red	P	590

(ii) Red phosphorus (P) forms when white phosphorus (P_4) is exposed to sunlight.

$$\underset{\text{white}}{\tfrac{1}{4}P_4(s)} \rightarrow \underset{\text{red}}{P(s)} \qquad \Delta H = -17.6\,\text{kJ mol}^{-1}$$

Use this information to draw a reaction pathway diagram to show the formation of red phosphorus (P) from white phosphorus (P_4).



[1]

10 Hydrogen iodide, HI, is a colourless gas at room temperature.

(b) The standard enthalpy change of formation, $\Delta H_f^{\ominus}$, of HI(g) is +26.5 kJ mol^{-1}.

Define the term *standard enthalpy change of formation*.

.....

.....

..... [2]

11 Nitric acid, HNO_3, can be made by reacting nitrogen dioxide with water.

The enthalpy change for the reaction can be measured indirectly using a Hess' cycle.

$$3NO_2(g) + H_2O(l) \xrightarrow{\Delta H_r} 2HNO_3(l) + NO(g)$$

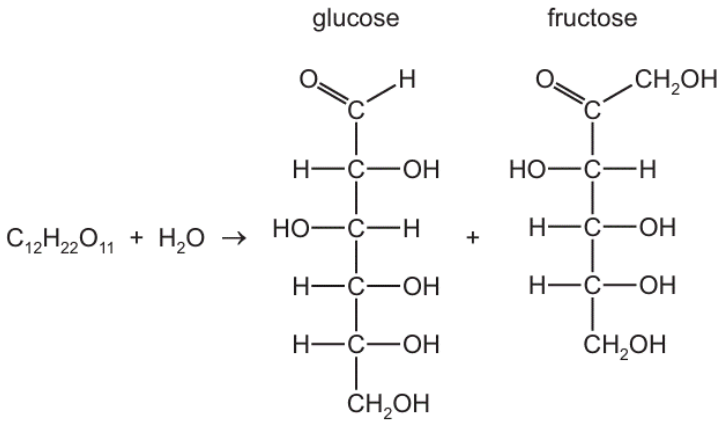
(a) Explain what is meant by the term *enthalpy change of formation*.

.....

.....

..... [2]

12 Sucrose, $C_{12}H_{22}O_{11}$, reacts with water to form glucose and fructose in reaction **A**.



reaction **A**

(d) 1.00 g of sucrose, $C_{12}H_{22}O_{11}$, is completely combusted. The heat energy produced is used to increase the temperature of 250 g of water inside a calorimeter from 25.0 °C to 40.7 °C.

These data can be used to calculate the enthalpy change of combustion of sucrose.

(i) Explain what is meant by the term *enthalpy change of combustion of sucrose*.

.....

.....

..... [2]

(ii) Use the *Data Booklet* to calculate the enthalpy change, in kJ mol^{-1}, for the combustion of sucrose.
Assume that all of the heat energy produced is transferred to the water.

Show your working.

enthalpy change of combustion of sucrose = ... kJ mol^{-1}
[3]

13 Magnesium silicide, Mg_2Si, is a compound made by heating magnesium with sand.

(e) SiH_4 reacts in air without heating but CH_4 must be ignited before combustion occurs.

$$SiH_4 + 2O_2 \rightarrow SiO_2 + 2H_2O$$

$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$$

Suggest, with reference to bond energies from the *Data Booklet*, why SiH_4 reacts in air without heating but CH_4 must be ignited.

.....

.....

..... [2]

14 **(b)** Thiophene, $C_4H_4S(l)$, is an organic compound that is found as a contaminant in crude oil.

(i) Construct the equation for the complete combustion of thiophene, $C_4H_4S(l)$.

Include state symbols in your answer.

..... [2]

(ii) A student carries out an experiment to determine the enthalpy change of combustion of $C_4H_4S(l)$.

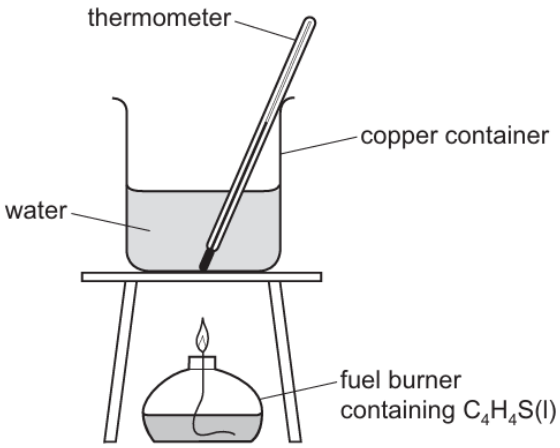
Explain the meaning of the term *enthalpy change of combustion*.

.....

.....

..... [2]

(iii) The student uses the following apparatus in the experiment.



mass of water in copper container / g	200
initial temperature of water / °C	18.5
highest temperature of water / °C	37.5

Calculate the heat energy released, in J, by the reaction.

Assume that 4.18 J of heat energy changes the temperature of 1.0 cm^3 of water by 1.0 °C.

Assume no heat is lost to the surroundings.

heat energy released = ... J
[2]

(iv) The student used 0.63 g of $C_4H_4S(l)$ in the experiment.

Calculate the enthalpy change of combustion of thiophene, $\Delta H_c(C_4H_4S(l))$. Include a sign in your answer.

$\Delta H_c(C_4H_4S(l))$ = ... $kJ\,mol^{-1}$
[2]

15 Sulfuric acid is manufactured by the Contact process.

One stage in this process is the conversion of sulfur dioxide into sulfur trioxide in the presence of a heterogeneous catalyst of vanadium(V) oxide, V_2O_5.

$$2\,O{=}S{=}O(g) + O{=}O(g) \rightleftharpoons 2\,O{=}\overset{\overset{O}{\|}}{S}{=}O(g) \qquad \Delta H = -196\,kJ\,mol^{-1}$$

(b) Some bond energies are given.

bond	bond energy / kJ mol^{-1}
S=O (in SO_2)	534
O=O	496

Use the data, and the enthalpy change for the conversion of sulfur dioxide into sulfur trioxide, to calculate a value for the S=O bond energy in SO_3.

S=O bond energy in SO_3 = ... kJ mol^{-1} [2]