Enthalpy, Entropy & Free Energy AS & A Level

Question Paper 1

Level,	A Level
Subject	Chemistry
Exam Board	OCR
Module	Physical Chemistry & Transition Elements
Topic	Enthalpy, Entropy & Free Energy
Paper	AS & A Level
Booklet	Question Paper 1

Time allowed: **77 minutes**

Score: **/57**

Percentage: **/100**

Grade Boundaries:

A*	A	B	C	D	E
>85%	73%	60%	47%	34%	21%

Chemists use three energy terms, enthalpy, entropy and free energy, to help them make predictions about whether reactions may take place.

(a) The table below shows five processes. Each process has either an increase in entropy or a decrease in entropy.

For each process, tick (✓) the appropriate box.

process		increase in entropy	decrease in entropy
A	$C_2H_5OH(l) \longrightarrow C_2H_5OH(g)$		
B	$C_2H_2(g) + 2H_2(g) \longrightarrow C_2H_6(g)$		
C	$NH_4Cl(s) + aq \longrightarrow NH_4Cl(aq)$		
D	$4Na(s) + O_2(g) \longrightarrow 2Na_2O(s)$		
E	$2CH_3OH(l) + 3O_2(g) \longrightarrow 2CO_2(g) + 4H_2O(l)$		

[2]

(b) At 1 atm (101 kPa) pressure, ice melts into water at 0 °C.

Complete the table below using the symbols '+', '–' or '0' to show the sign of ΔH and ΔS for the melting of ice at 0 °C and 1 atm.

For each sign, explain your reasoning.

energy change	sign +, – or 0	reasoning
ΔH		
ΔS		

[2]

(c) Much of the hydrogen required by industry is produced by reacting natural gas with steam:

$$CH_4(g) + H_2O(g) \rightarrow 3H_2(g) + CO(g)$$

Standard entropies are given in the table below.

substance	$CH_4(g)$	$H_2O(g)$	$H_2(g)$	$CO(g)$
$S^{\ominus}$ **/ J K^{-1} mol^{-1}**	186	189	131	198

(i) Calculate the standard entropy change, in J K^{-1} mol^{-1}, for this reaction of natural gas with steam. [2]

(ii) State **two** large-scale uses for the hydrogen produced. [1]

(d) Ammonium chloride, NH_4Cl, can dissociate to form ammonia, NH_3, and hydrogen chloride, HCl.

$$NH_4Cl(s) \longrightarrow NH_3(g) + HCl(g)$$

At 298 K, $\Delta H = +176\,kJ\,mol^{-1}$ and $\Delta G = +91.2\,kJ\,mol^{-1}$.

- Calculate ΔG for this reaction at 1000 K.
- Hence show whether this reaction takes place spontaneously at 1000 K.

Show **all** your working. [4]

[Total 11 Marks]

Free energy changes can be used to predict the feasibility of processes.

(a) Write down the equation that links the free energy change with the enthalpy change and temperature. [1]

(b) You are provided with equations for five processes.

For each process, predict the sign of ΔS

process	sign of ΔS
$2CO(g) + O_2(g) \rightarrow 2CO_2(g)$	
$NaCl(s) + (aq) \rightarrow NaCl(aq)$	
$H_2O(l) \rightarrow H_2O(s)$	
$Mg(s) + H_2SO_4(aq) \rightarrow MgSO_4(aq) + H_2(g)$	
$CuSO_4(s) + 5H_2O(l) \rightarrow CuSO_4 \cdot 5H_2O(s)$	

[2]

(c) Ammonia can be oxidised as shown in the equation below.

$$4NH_3(g) + 5O_2(g) \rightarrow 4NO(g) + 6H_2O(g)$$

Standard entropies are given in the table below.

substance	$NH_3(g)$	$O_2(g)$	$NO(g)$	$H_2O(g)$
$S^{\ominus}$ / **J K^{-1} mol^{-1}**	192	205	211	189

Calculate the standard entropy change, in J K^{-1} mol^{-1}, for this oxidation of ammonia. [2]

(d) The exothermic reaction below occurs spontaneously at low temperatures but does **not** occur at very high temperatures.

$$2SO_2(g) + O_2(g) \rightarrow 2SO_3(g)$$

Explain why. [2]

(e) An ore of iron contains iron(III) oxide, Fe_2O_3.
Iron is extracted from this ore by heating with carbon.
The equation below shows one of the reactions which takes place.

$$Fe_2O_3(s) + 3C(s) \rightarrow 2Fe(s) + 3CO(g)$$

ΔS = +543 J K^{-1} mol^{-1} and ΔH = +493 kJ mol^{-1}

Calculate the minimum temperature at which this reaction becomes feasible.

Show **all** your working. [3]

[Total 10 Marks]

This question is about free energy changes, ΔG, enthalpy changes, ΔH, and temperature, T.

(a) The Gibbs' equation is shown below.

$$\Delta G = \Delta H - T\Delta S$$

A chemist investigates a reaction to determine how ΔG varies with T.
The results are shown in **Fig. 18.1**.

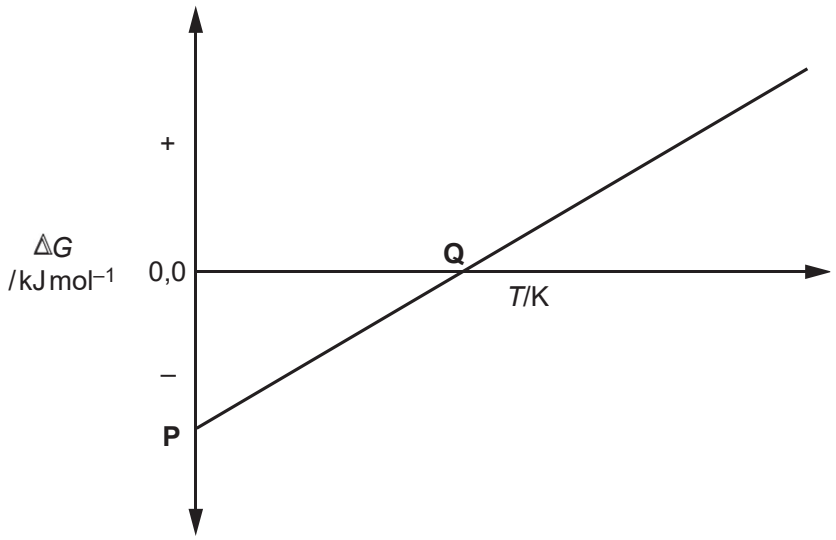


Fig. 18.1

What is significant about the gradient of the line and the values **P** and **Q** shown in **Fig. 18.1**? Explain your reasoning.

[4]

(b) Iron can be extracted from its ore Fe_3O_4 using carbon.
Several equilibria are involved including **equilibrium 18.1**, shown below.

equilibrium 18.1 $Fe_3O_4(s) + 4C(s) \rightleftharpoons 3Fe(s) + 4CO(g)$ $\Delta H = +676.4\,kJ\,mol^{-1}$ $\Delta S = +703.1\,JK^{-1}\,mol^{-1}$

(i) Why is **equilibrium 18.1** a *heterogeneous* equilibrium? **[1]**

(ii) Write the expression for K_p for **equilibrium 18.1**. **[1]**

(iii) The forward reaction in **equilibrium 18.1** is only feasible at high temperatures.

- Show that the forward reaction is **not** feasible at 25 °C.
- Calculate the minimum temperature, in K, for the forward reaction to be feasible.

[3]

(iv) Another equilibrium involved in the extraction of iron from Fe_3O_4 is shown below.

$$Fe_3O_4(s) + 4CO(g) \rightleftharpoons 3Fe(s) + 4CO_2(g) \qquad \Delta H = -13.5\,kJ\,mol^{-1}$$

Enthalpy changes of formation, $\Delta_f H$, for $Fe_3O_4(s)$ and $CO_2(g)$ are shown in the table.

Compound	$\Delta_f H$ / kJ mol^{-1}
$Fe_3O_4(s)$	–1118.5
$CO_2(g)$	–393.5

Calculate the enthalpy change of formation, $\Delta_f H$, for CO(g). **[3]**

(Total 12 marks)

Entropy changes and free energy changes can be used to predict the feasibility of processes.

(a) Three processes are given below.

For each process, predict and explain whether the entropy change, ΔS, would be positive or negative.

- The melting of iron.

  ΔS: positive or negative

  Explanation

- The reaction of magnesium with dilute sulfuric acid.

  ΔS: positive or negative .

  Explanation

- The complete combustion of ethane:

  $$2C_2H_6(g) + 7O_2(g) \rightarrow 4CO_2(g) + 6H_2O(l)$$

  ΔS: positive or negative

  explanation [3]

(b) Ammonia can be oxidised as shown in the equation below.

$$4NH_3(g) + 5O_2(g) \rightleftharpoons 4NO(g) + 6H_2O(g)$$

At 450 °C, $\Delta H = -907\,kJ\,mol^{-1}$ and $\Delta G = -1041\,kJ\,mol^{-1}$.

Calculate the standard entropy change, ΔS, in $J\,K^{-1}\,mol^{-1}$, for this reaction.

Show all your working. [2]

(c) A reaction is **not** feasible at low temperatures but is feasible at high temperatures.

Deduce the signs of ΔH and ΔS for the reaction and explain why the feasibility changes with temperature. [3]

[Total: 8 Marks]

Energy changes take place when water dissolves compounds and when water changes its physical state.

(a) You are provided with the following information.

Ion	$\Delta H_{hydration}$ /kJ mol^{-1}
Na^+	–405
Mg^{2+}	–1926
OH^-	–460

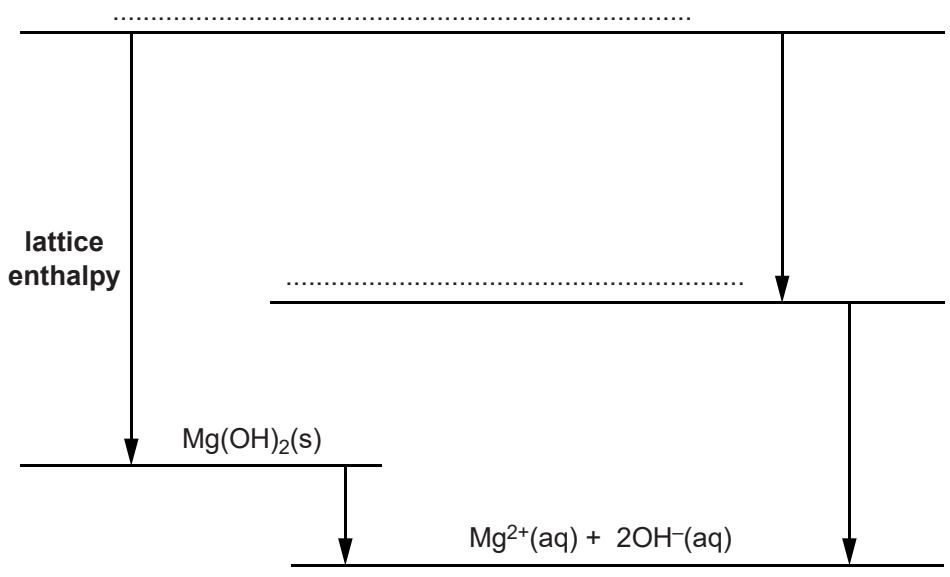
The enthalpy change of solution of $Mg(OH)_2$ is –152 kJmol^{-1}.

(i) Define, in words, the terms *enthalpy change of solution* and *enthalpy change of hydration*. [3]

(ii) Explain the difference between the $\Delta H_{hydration}$ values for Na^+ and Mg^{2+}. [3]

(iii) A Born–Haber cycle can be drawn to link the lattice enthalpy and enthalpy change of solution of $Mg(OH)_2$ with hydration enthalpies.

On the two dotted lines, add the species present, including state symbols.



[2]

(iv) Calculate the lattice enthalpy of $Mg(OH)_2$. [2]

(b) Energy changes for the melting and boiling of H_2O are shown below.

$H_2O(s) \longrightarrow H_2O(l)$ $\quad \Delta H = +6.01\,kJ\,mol^{-1}$
$H_2O(l) \longrightarrow H_2O(g)$ $\quad \Delta H = +40.7\,kJ\,mol^{-1}$

Standard entropies of H_2O in its three physical states are given in the table below.

	$H_2O(s)$	$H_2O(l)$	$H_2O(g)$
$S^{\ominus}$ / J K^{-1} mol^{-1}	+48.0	+70.0	+188.7

(i) Explain the following:

- When water melts or boils, ΔH is positive
- When water melts or boils, $S^{\ominus}$ increases.

In your answer, you should explain why the increase in $S^{\ominus}$ is much greater when water boils than when water melts. [3]

(ii) Using the data in the table above, show that ice melts at 0 °C (at standard pressure). [3]

[Total 16 Marks]