

AQA A-LEVEL CHEMISTRY • 7405

CHEMISTRY



EXAM QUESTION PACK

3.1.8 THERMODYNAMICS

SCORE

/581

PERCENTAGE

%

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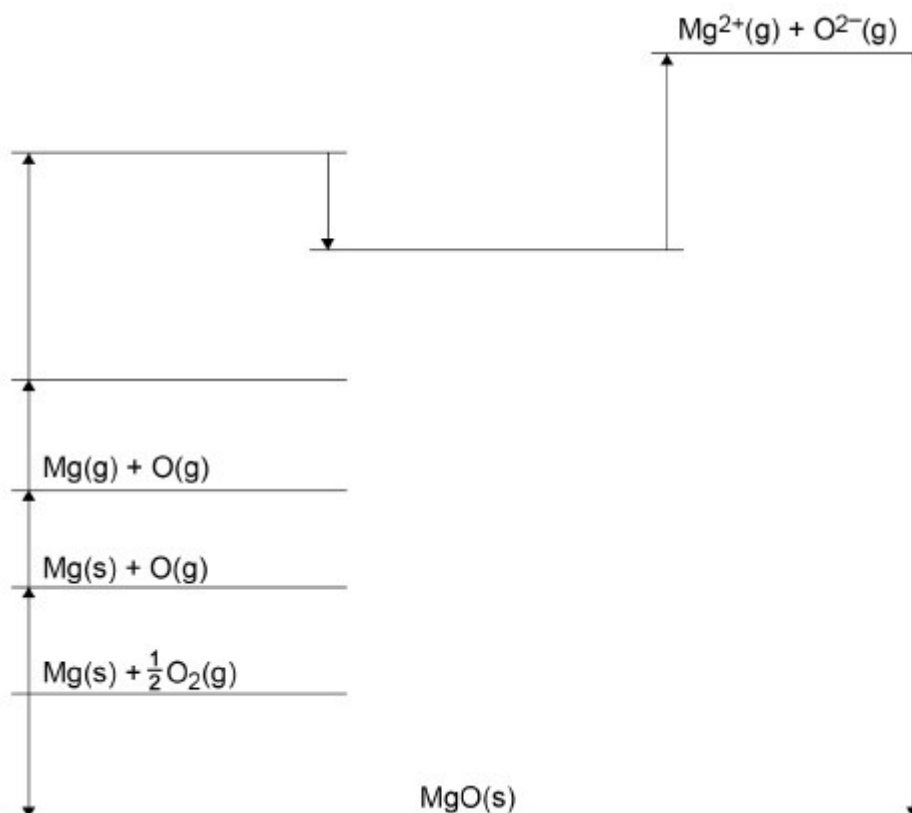
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Q1.

This question is about lattice enthalpies.

- (a) The diagram shows a Born–Haber cycle for the formation of magnesium oxide.

Complete the diagram by writing the missing symbols on the appropriate energy levels.



(3)

- (b) The table contains some thermodynamic data.

	Enthalpy change / kJ mol^{-1}
Enthalpy of formation for magnesium oxide	−602
Enthalpy of atomisation for magnesium	+150
First ionisation energy for magnesium	+736
Second ionisation energy for magnesium	+1450
Bond dissociation enthalpy for oxygen	+496
First electron affinity for oxygen	−142
Second electron affinity for oxygen	+844

Calculate a value for the enthalpy of lattice formation for magnesium oxide.

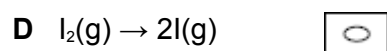
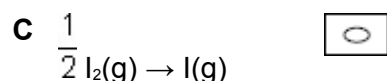
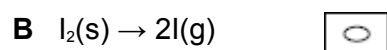
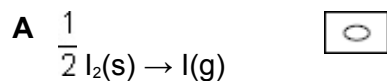
Enthalpy of lattice formation _____ kJ mol⁻¹

(3)

(Total 6 marks)

Q2.

Which equation represents the process that occurs when the standard enthalpy of atomisation of iodine is measured?



(Total 1 mark)

Q3.

Lattice enthalpy values can be obtained from Born–Haber cycles and by calculations based on a perfect ionic model.

Which compound shows the greatest percentage difference between these two values?



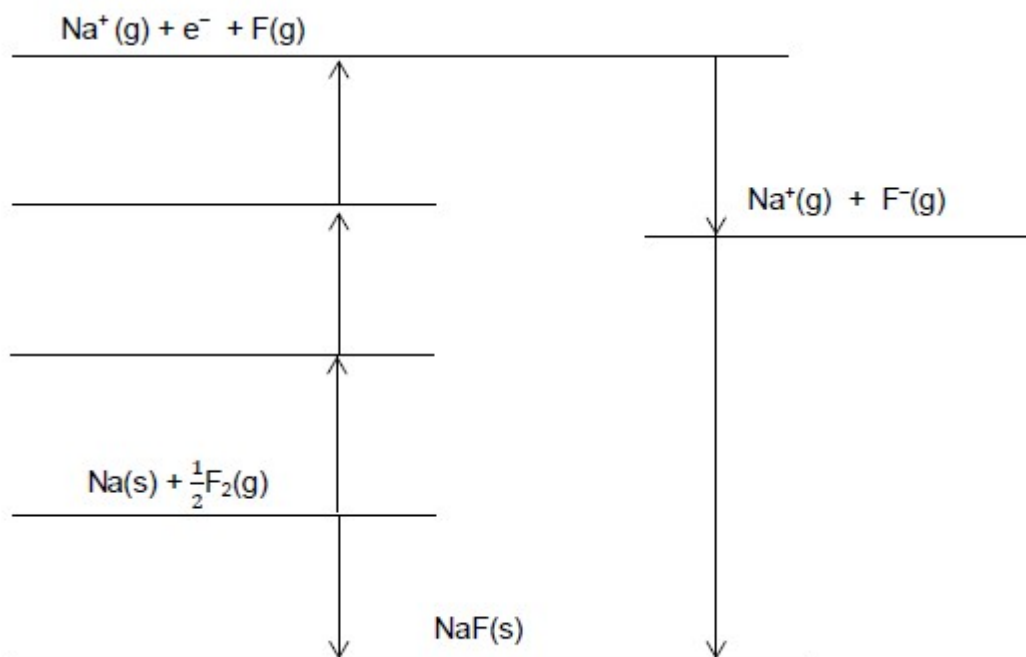
- C LiF ☐
- D LiI ☐

(Total 1 mark)

Q4.

This question is about sodium fluoride.

- (a) Complete the Born–Haber cycle for sodium fluoride by adding the missing species on the lines.



(2)

- (b) Use the data in the table and your completed Born–Haber cycle from part (a) to calculate the enthalpy of lattice formation of sodium fluoride.

	$\Delta H^\circ / \text{kJ mol}^{-1}$
$\text{Na(s)} \rightarrow \text{Na(g)}$	+109
$\text{Na(g)} \rightarrow \text{Na}^+(\text{g}) + \text{e}^-$	+494
$\text{F}_2(\text{g}) \rightarrow 2\text{F(g)}$	+158
$\text{F(g)} + \text{e}^- \rightarrow \text{F}^-(\text{g})$	-348
$\text{Na(s)} + \frac{1}{2}\text{F}_2(\text{g}) \rightarrow \text{NaF(s)}$	-569

Enthalpy of lattice formation _____ kJ mol^{-1}

(2)

- (c) Suggest how the enthalpy of lattice formation of NaCl compares with that of NaF

Justify your answer.

How enthalpies of formation compare _____

Justification _____

(3)

- (d) Calculate the volume, in cm^3 , of fluorine gas at 298 K and 100 kPa required to produce 1.00 g of sodium fluoride by reaction with an excess of sodium.

The gas constant $R = 8.31 \text{ J } ^{-1} \text{ mol}^{-1}$

Volume _____ cm^3

(4)

(Total 11 marks)

Q5.

A 5.00 g sample of potassium chloride was added to 50.0 g of water initially at 20.0 °C. The mixture was stirred and as the potassium chloride dissolved, the temperature of the solution decreased.

- (a) Describe the steps you would take to determine an accurate minimum temperature that is **not** influenced by heat from the surroundings.

(4)

- (b) The temperature of the water decreased to 14.6 °C.

Calculate a value, in kJ mol^{-1} , for the enthalpy of solution of potassium chloride.

You should assume that only the 50.0 g of water changes in temperature and that

the specific heat capacity of water is $4.18 \text{ J K}^{-1} \text{ g}^{-1}$.
Give your answer to the appropriate number of significant figures.

Enthalpy of solution = _____ kJ mol^{-1}

(4)

- (c) The enthalpy of solution of calcium chloride is $-82.9 \text{ kJ mol}^{-1}$.
The enthalpies of hydration for calcium ions and chloride ions are -1650 and -364 kJ mol^{-1} , respectively.

Use these values to calculate a value for the lattice enthalpy of dissociation of calcium chloride.

Lattice enthalpy of dissociation = _____ kJ mol^{-1}

(2)

- (d) Explain why your answer to part (c) is different from the lattice enthalpy of dissociation for magnesium chloride.

(2)

(Total 12 marks)

Q6.

This question is about silver iodide.

- (a) Define the term enthalpy of lattice formation.

(2)

- (b) Some enthalpy change data are shown in the table.

	Enthalpy change / kJ mol^{-1}
$\text{AgI(s)} \rightarrow \text{Ag}^+(\text{aq}) + \text{I}^-(\text{aq})$	+112
$\text{Ag}^+(\text{g}) \rightarrow \text{Ag}^+(\text{aq})$	-464
$\text{I}^-(\text{g}) \rightarrow \text{I}^-(\text{aq})$	-293

Use the data in the table to calculate the enthalpy of lattice formation of silver iodide.

Enthalpy of lattice formation = _____ kJ mol^{-1}

(2)

- (c) A calculation of the enthalpy of lattice formation of silver iodide based on a perfect ionic model gives a smaller numerical value than the value calculated in part (b)

Explain this difference.

(2)

- (d) Identify a reagent that could be used to indicate the presence of iodide ions in an aqueous solution and describe the observation made.

Reagent _____

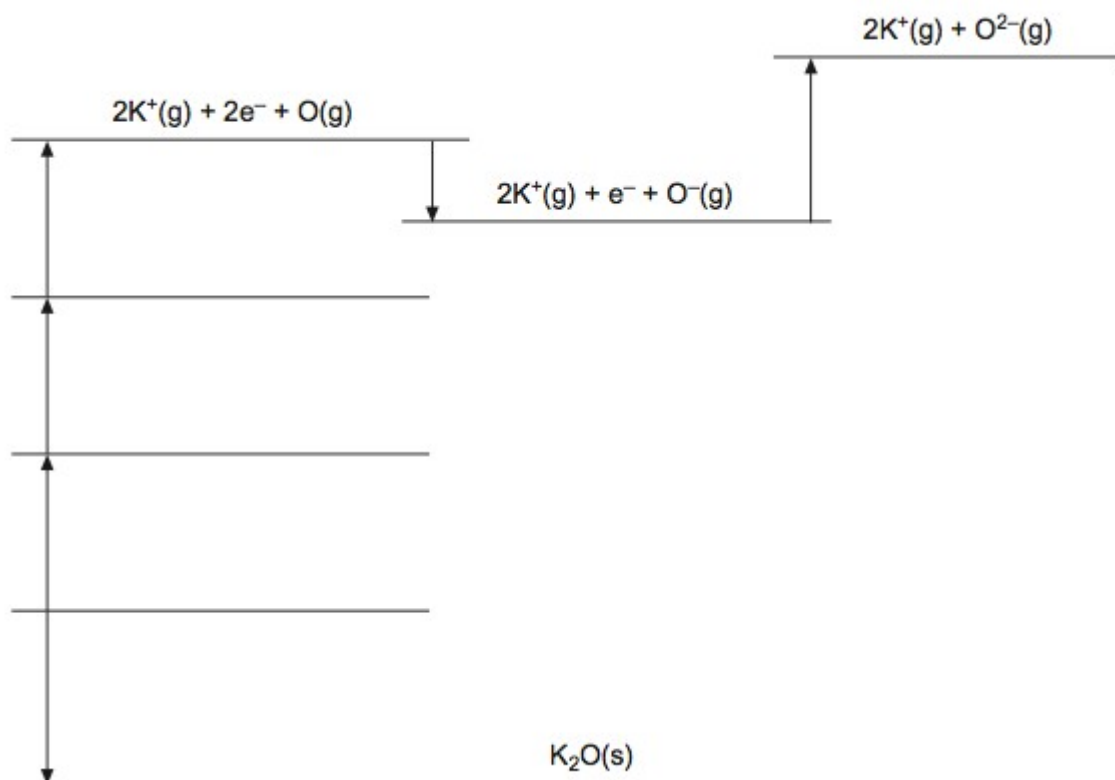
Observation _____

(2)

(Total 8 marks)

Q7.

- (a) The diagram is a Born–Haber cycle for potassium oxide, K_2O . The diagram is not to scale and not fully labelled.
- (i) Complete the diagram by writing the formulae, including state symbols, of the appropriate species on each of the three blank lines.



(3)

- (ii) The table shows some enthalpy data.

Enthalpy change	$\Delta H^\circ/\text{kJ mol}^{-1}$
Enthalpy of atomisation of potassium	+90
First ionisation enthalpy of potassium	+418
Enthalpy of atomisation of oxygen	+248
First electron affinity of oxygen	-142
Second electron affinity of oxygen	+844
Enthalpy of formation of potassium	-362

oxide	
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Use the data in the table to calculate the enthalpy of lattice dissociation of potassium oxide, K_2O .

(3)

- (b) Explain why the enthalpy of lattice dissociation of potassium oxide is less endothermic than that of sodium oxide.

(2)

(Total 8 marks)

Q8.

This question is about magnesium chloride.

- (a) Write the equation, including state symbols, for the process corresponding to the enthalpy of solution of magnesium chloride.

(1)

- (b) Use these data to calculate the standard enthalpy of solution of magnesium chloride.

Enthalpy of lattice dissociation of $MgCl_2$ = +2493 kJ mol⁻¹

Enthalpy of hydration of magnesium ions = -1920 kJ mol⁻¹

Enthalpy of hydration of chloride ions = -364 kJ mol⁻¹

(2)

- (c) Solubility is the measure of how much of a substance can be dissolved in water to make a saturated solution. A salt solution is saturated when an undissolved solid is in equilibrium with its aqueous ions.

Use your answer to part (b) to deduce how the solubility of MgCl_2 changes as the temperature is increased.

Explain your answer.

(3)

(Total 6 marks)

Q9.

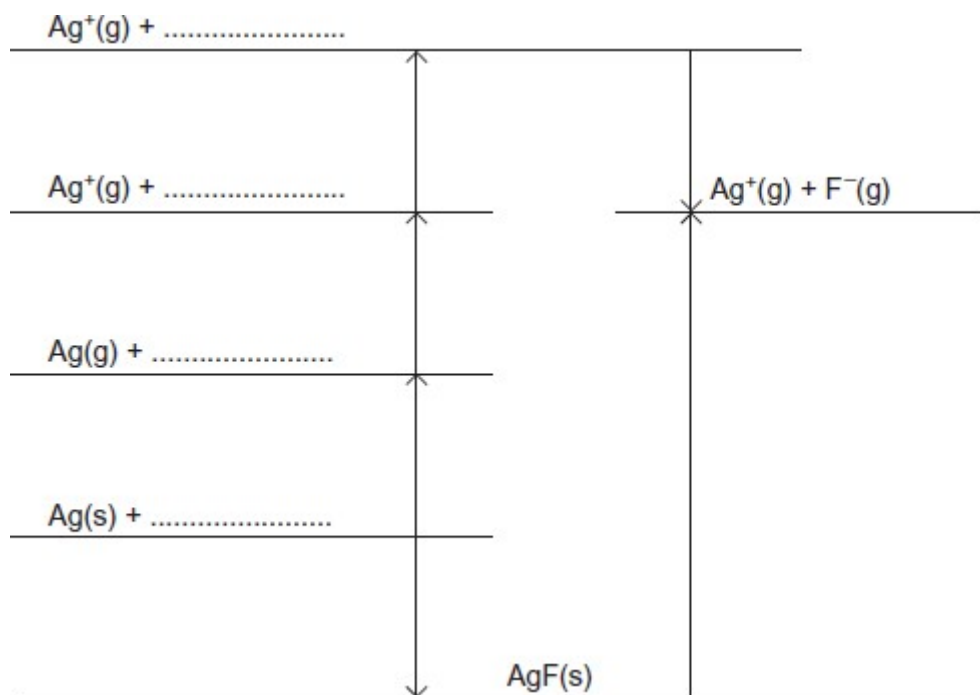
- (a) Write an equation for the process that has an enthalpy change equal to the electron affinity of chlorine.

(1)

- (b) In terms of electrostatic forces, suggest why the electron affinity of fluorine has a negative value.

(2)

- (c) (i) Complete the Born–Haber cycle for silver fluoride by adding the missing species on the dotted lines.



(3)

- (ii) Use the cycle in part (i) and the data in the table to calculate a value, in kJ mol^{-1} , for the bond enthalpy of the fluorine–fluorine bond.

Enthalpy change	Value / kJ mol^{-1}
Enthalpy of atomisation for silver	+298
First ionisation energy for silver	+732
Electron affinity for fluorine	–348
Experimental enthalpy of lattice dissociation for silver fluoride	+955
Enthalpy of formation for silver fluoride	–203

(2)

- (d) A theoretical value for enthalpy of lattice dissociation can be calculated using a perfect ionic model.

The theoretical enthalpy of lattice dissociation for silver fluoride is $+870 \text{ kJ mol}^{-1}$.

- (i) Explain why the theoretical enthalpy of lattice dissociation for silver fluoride is different from the experimental value that can be calculated using a Born–

Haber cycle.

(2)

- (ii) The theoretical enthalpy of lattice dissociation for silver chloride is $+770 \text{ kJ mol}^{-1}$.

Explain why this value is less than the value for silver fluoride.

(2)

(Total 12 marks)

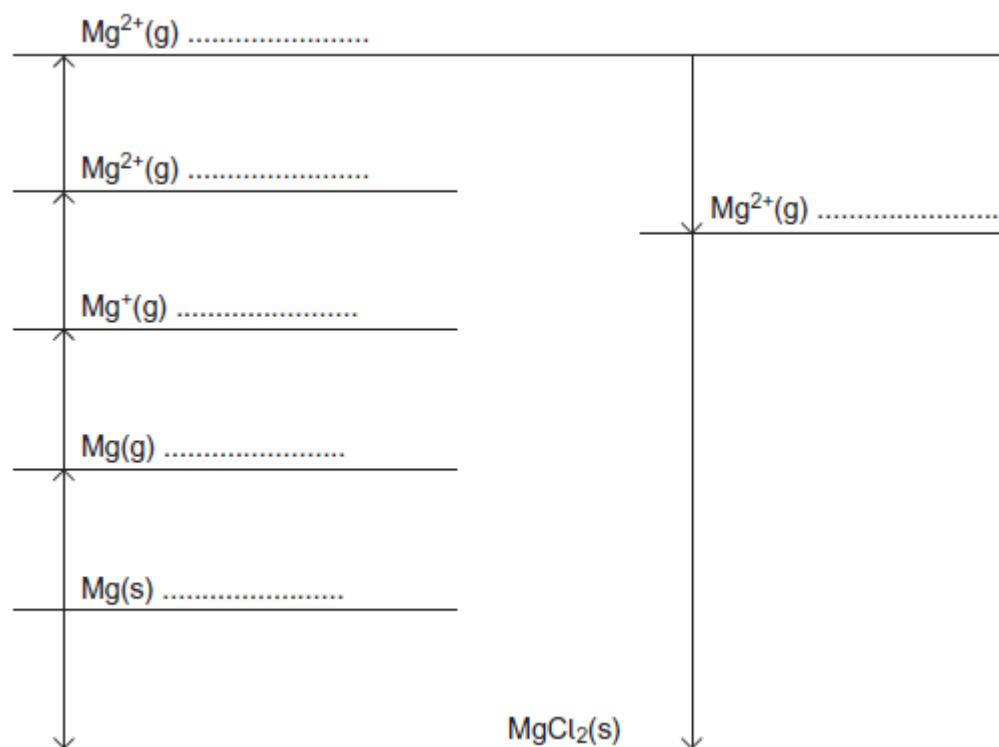
Q10.

- (a) Define the term **electron affinity** for chlorine.

(2)

- (b) Complete this Born–Haber cycle for magnesium chloride by giving the missing species on the dotted lines. Include state symbols where appropriate.

The energy levels are **not** drawn to scale.



(6)

(c) **Table 1** contains some enthalpy data.

Table 1

	Enthalpy change / kJ mol ⁻¹
Enthalpy of atomisation of magnesium	+150
Enthalpy of atomisation of chlorine	+121
First ionisation energy of magnesium	+736
Second ionisation energy of magnesium	+1450
Enthalpy of formation of magnesium chloride	-642
Lattice enthalpy of formation of magnesium chloride	-2493

Use your Born-Haber cycle from part (b) and data from **Table 1** to calculate a value for the electron affinity of chlorine.

(3)

- (d) **Table 2** contains some more enthalpy data.

Table 2

	Enthalpy change / kJ mol ⁻¹
Enthalpy of hydration of Mg ²⁺ ions	-1920
Enthalpy of hydration of Na ⁺ ions	-406
Enthalpy of hydration of Cl ⁻ ions	-364

- (i) Explain why there is a difference between the hydration enthalpies of the magnesium and sodium ions.

(2)

- (ii) Use data from **Table 1** and **Table 2** to calculate a value for the enthalpy change when one mole of magnesium chloride dissolves in water.

(2)

(Total 15 marks)

Q11.

The following table shows some enthalpy change and entropy change data.

	ΔH / kJ mol ⁻¹	ΔS / J K ⁻¹ mol ⁻¹
AgCl(s) $\longrightarrow$ Ag ⁺ (g) + Cl ⁻ (g)	+905	
AgCl(s) $\longrightarrow$ Ag ⁺ (aq) + Cl ⁻ (aq)	+77	+33

$\text{AgF(s)} \longrightarrow \text{Ag}^+(\text{aq}) + \text{F}^-(\text{aq})$	-15	to be calculated
$\text{Ag}^+(\text{g}) \longrightarrow \text{Ag}^+(\text{aq})$	-464	

- (a) Define the term **enthalpy of hydration** of an ion.

(2)

- (b) Use data from the table to calculate a value for the enthalpy of hydration of the chloride ion.

(2)

- (c) Suggest why hydration of the chloride ion is an exothermic process.

(2)

- (d) Silver chloride is insoluble in water at room temperature.

Use data from the table to calculate the temperature at which the dissolving of silver chloride in water becomes feasible.
Comment on the significance of this temperature value.

Calculation of temperature _____

Significance of temperature value _____

(4)

- (e) When silver fluoride dissolves in water at 25 °C, the free-energy change is – 9 kJ mol⁻¹.

Use this information and data from the table to calculate a value, with units, for the entropy change when silver fluoride dissolves in water at 25 °C.

(3)

(Total 13 marks)

Q12.

- (a) Define the term *lattice enthalpy of dissociation*.

(2)

- (b) Lattice enthalpy can be calculated theoretically using a **perfect ionic model**.

Explain the meaning of the term *perfect ionic model*.

(1)

- (c) Suggest **two** properties of ions that influence the value of a lattice enthalpy calculated using a perfect ionic model.

Property 1 _____

Property 2 _____

(2)

- (d) Use the data in the table to calculate a value for the lattice enthalpy of dissociation for silver chloride.

Enthalpy change	Value / kJ mol^{-1}
Enthalpy of atomisation for silver	+289
First ionisation energy for silver	+732
Enthalpy of atomisation for chlorine	+121
Electron affinity for chlorine	-364
Enthalpy of formation for silver chloride	-127

(3)

- (e) Predict whether the magnitude of the lattice enthalpy of dissociation that you have calculated in part (d) will be less than, equal to or greater than the value that is obtained from a perfect ionic model. Explain your answer.

Prediction compared with ionic model _____

Explanation _____

Q13.

The enthalpy of hydration for the chloride ion is -364 kJ mol^{-1} and that for the bromide ion is -335 kJ mol^{-1} .

- (a) By describing the nature of the attractive forces involved, explain why the value for the enthalpy of hydration for the chloride ion is more negative than that for the bromide ion.

(3)

- (b) The enthalpy of hydration for the potassium ion is -322 kJ mol^{-1} . The lattice enthalpy of dissociation for potassium bromide is $+670 \text{ kJ mol}^{-1}$.

Calculate the enthalpy of solution for potassium bromide.

(2)

- (c) The enthalpy of solution for potassium chloride is $+17.2 \text{ kJ mol}^{-1}$.

- (i) Explain why the free-energy change for the dissolving of potassium chloride in water is negative, even though the enthalpy change is positive.

(3)

- In your calculation, assume that only the 20.0 g of water changes in temperature and that the specific heat capacity of water is $4.18 \text{ J K}^{-1} \text{ g}^{-1}$.

(5)

Q14.

	Fluorine	Chlorine
Electronegativity	4.0	3.0
Electron affinity / kJ mol ⁻¹	−348	−364
Enthalpy of atomisation / kJ mol ⁻¹	+79	+121
Enthalpy of hydration of X ⁻ (g) / kJ mol ⁻¹	−506	−364

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- (a) Explain the meaning of the term *electron affinity*.

(2)

- (b) Explain why the electronegativity of fluorine is greater than the electronegativity of chlorine.

(2)

- (c) Explain why the hydration enthalpy of the fluoride ion is more negative than the hydration enthalpy of the chloride ion.

(2)

- (d) The enthalpy of solution for silver fluoride in water is -20 kJ mol^{-1} .

The hydration enthalpy for silver ions is -464 kJ mol^{-1} .

- (i) Use these data and data from the table to calculate a value for the lattice enthalpy of dissociation of silver fluoride.

-
- (3)
- (ii) Suggest why the entropy change for dissolving silver fluoride in water has a positive value.
-
-
-
- (1)
- (iii) Explain why the dissolving of silver fluoride in water is always a spontaneous process.
-
-
-
-
-
- (2)
- (Total 12 marks)

Q15.

This question is about magnesium oxide. Use data from the table below, where appropriate, to answer the following questions.

	$\Delta H^\ominus / \text{kJ mol}^{-1}$
First electron affinity of oxygen (formation of $\text{O}^-(\text{g})$ from $\text{O}(\text{g})$)	-142
Second electron affinity of oxygen (formation of $\text{O}^{2-}(\text{g})$ from $\text{O}^-(\text{g})$)	+844
Atomisation enthalpy of oxygen	+248

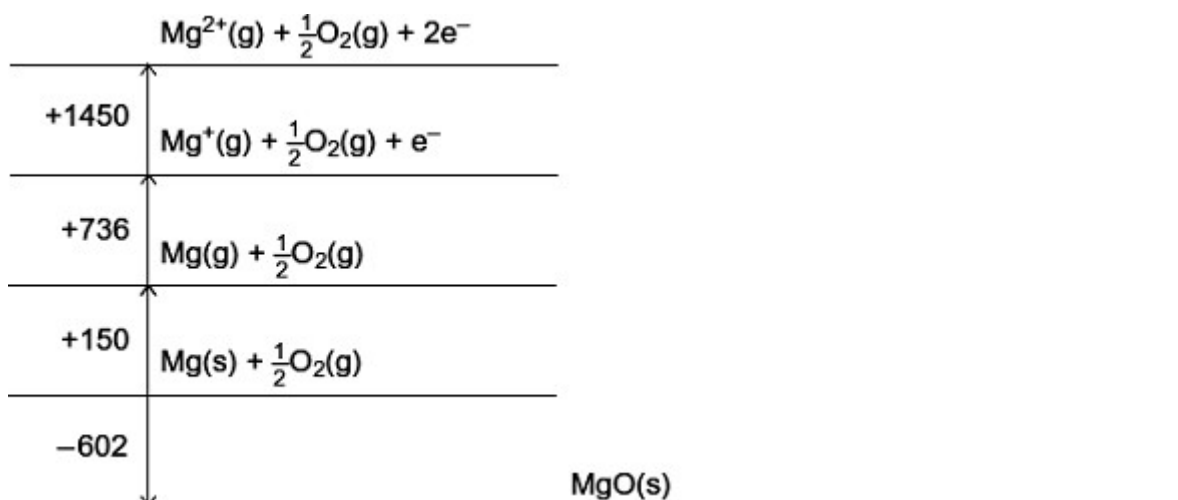
- (a) Define the term *enthalpy of lattice dissociation*.

(3)

- (b) In terms of the forces acting on particles, suggest **one** reason why the first electron affinity of oxygen is an exothermic process.

(1)

- (c) Complete the Born–Haber cycle for magnesium oxide by drawing the missing energy levels, symbols and arrows.
The standard enthalpy change values are given in kJ mol^{-1} .



(4)

- (d) Use your Born–Haber cycle from part (c) to calculate a value for the enthalpy of lattice dissociation for magnesium oxide.

(2)

- (e) The standard free-energy change for the formation of magnesium oxide from magnesium and oxygen, $\Delta G_f^\ominus = -570 \text{ kJ mol}^{-1}$.
Suggest **one** reason why a sample of magnesium appears to be stable in air at room temperature, despite this negative value for $\Delta G_f^\ominus$.

(1)

- (f) Use the value of $\Delta G_f^\ominus$ given in part (e) and the value of $\Delta H_f^\ominus$ from part (c) to calculate a value for the entropy change $\Delta S^\ominus$ when one mole of magnesium oxide is formed from magnesium and oxygen at 298 K. Give the units of $\Delta S^\ominus$.

(3)

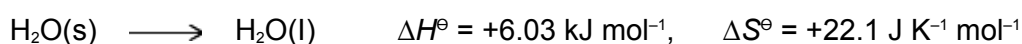
- (g) In terms of the reactants and products and their physical states, account for the sign of the entropy change that you calculated in part (f).

(2)

(Total 16 marks)

Q16.

Consider the following process that represents the melting of ice.



- (a) State the meaning of the symbol $^\ominus$ in $\Delta H^\ominus$.

(1)

- (b) Use your knowledge of bonding to explain why $\Delta H^\ominus$ is positive for this process.

(2)

- (c) Calculate the temperature at which $\Delta G^\ominus = 0$ for this process. Show your working.

(3)

- (d) The freezing of water is an exothermic process. Give **one** reason why the temperature of a sample of water can stay at a constant value of 0 °C when it freezes.

(1)

- (e) Pure ice can look pale blue when illuminated by white light. Suggest an explanation for this observation.

(2)

(Total 9 marks)

Q17.

This table contains some values of lattice dissociation enthalpies.

Compound	MgCl ₂	CaCl ₂	MgO
Lattice dissociation enthalpy / kJ mol ⁻¹	2493	2237	3889

- (a) Write an equation, including state symbols, for the reaction that has an enthalpy change equal to the lattice dissociation enthalpy of magnesium chloride.

(1)

- (b) Explain why the lattice dissociation enthalpy of magnesium chloride is greater than that of calcium chloride.

(2)

- (c) Explain why the lattice dissociation enthalpy of magnesium oxide is greater than that of magnesium chloride.

(2)

- (d) When magnesium chloride dissolves in water, the enthalpy of solution is -155 kJ mol^{-1} .

The enthalpy of hydration of chloride ions is -364 kJ mol^{-1} .

Calculate the enthalpy of hydration of magnesium ions.

(3)

- (e) Energy is released when a magnesium ion is hydrated because magnesium ions attract water molecules.

Explain why magnesium ions attract water molecules.

You may use a labelled diagram to illustrate your answer.

(2)

- (f) Suggest why a value for the enthalpy of solution of magnesium oxide is **not** found in any data books.
-

(1)
(Total 11 marks)

Q18.

Thermodynamics can be used to investigate the changes that occur when substances such as calcium fluoride dissolve in water.

(a) Give the meaning of each of the following terms.

(i) enthalpy of lattice formation for calcium fluoride

(2)

(ii) enthalpy of hydration for fluoride ions

(1)

(b) Explain the interactions between water molecules and fluoride ions when the fluoride ions become hydrated.

(2)

(c) Consider the following data.

	$\Delta H^\ominus / \text{kJ mol}^{-1}$
Enthalpy of lattice formation for CaF_2	–2611
Enthalpy of hydration for Ca^{2+} ions	–1650
Enthalpy of hydration for F^- ions	–506

Use these data to calculate a value for the enthalpy of solution for CaF_2

(2)

(Total 7 marks)

Q19.

Comparison of lattice enthalpies from Born-Haber cycles with lattice enthalpies from calculations based on a perfect ionic model are used to provide information about bonding in crystals.

- (a) Define the terms *enthalpy of atomisation* and *lattice dissociation enthalpy*.

Enthalpy of atomisation _____

Lattice dissociation enthalpy _____

(4)

- (b) Use the following data to calculate a value for the lattice dissociation enthalpy of sodium chloride.

	$\Delta H^\ominus / \text{kJ mol}^{-1}$
$\text{Na(s)} \longrightarrow \text{Na(g)}$	+109
$\text{Na(g)} \longrightarrow \text{Na}^+(\text{g}) + \text{e}^-$	+494
$\text{Cl}_2(\text{g}) \longrightarrow 2\text{Cl(g)}$	+242
$\text{Cl(g)} + \text{e}^- \longrightarrow \text{Cl}^-(\text{g})$	-364
$\text{Na(s)} + \frac{1}{2}\text{Cl}_2(\text{g}) \longrightarrow \text{NaCl(s)}$	-411

(3)

- (c) Consider the following lattice dissociation enthalpy (ΔH_L°) data.

	NaBr	AgBr
$\Delta H_L^\circ(\text{experimental})/\text{kJ mol}^{-1}$	+733	+890
$\Delta H_L^\circ(\text{theoretical})/\text{kJ mol}^{-1}$	+732	+758

The values of ΔH_L° (experimental) have been determined from Born–Haber cycles.

The values of ΔH_L° (theoretical) have been determined by calculation using a perfect ionic model.

- (i) Explain the meaning of the term *perfect ionic model*.

(2)

- (ii) State what you can deduce about the bonding in NaBr from the data in the table.

(1)

- (iii) State what you can deduce about the bonding in AgBr from the data in the table.

(1)

(Total 11 marks)

Q20.

The table below gives some values of standard enthalpy changes. Use these values to answer the questions.

Name of enthalpy change	$\Delta H^\circ / \text{kJ mol}^{-1}$
Enthalpy of atomisation of chlorine	+121
Electron affinity of chlorine	−364
Enthalpy of atomisation of silver	+289
First ionisation enthalpy of silver	+732

Enthalpy of formation of silver chloride	-127
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- (a) Calculate the bond enthalpy of a Cl–Cl bond.

(1)

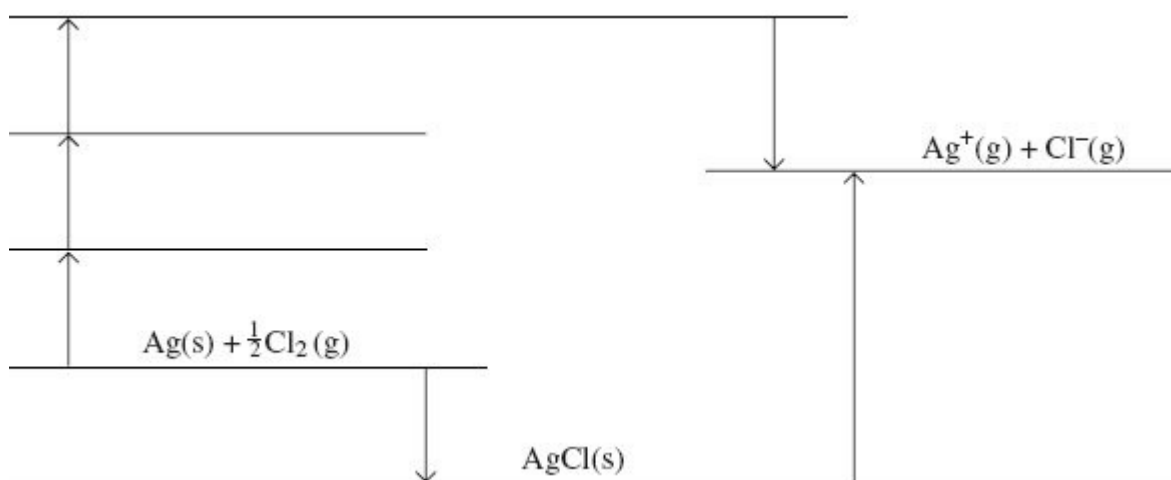
- (b) Explain why the bond enthalpy of a Cl–Cl bond is greater than that of a Br–Br bond.

(2)

- (c) Suggest why the electron affinity of chlorine is an exothermic change.

(1)

- (d) The diagram below is an incomplete Born–Haber cycle for the formation of silver chloride. The diagram is not to scale.



- (i) Complete the diagram by writing the appropriate chemical symbols, with state symbols, on each of the three blank lines.

(3)

- (ii) Calculate a value for the enthalpy of lattice dissociation for silver chloride.

(2)

- (e) The enthalpy of lattice dissociation for silver chloride can also be calculated theoretically assuming a perfect ionic model.

- (i) Explain the meaning of the term *perfect ionic model*.

(1)

- (ii) State whether you would expect the value of the theoretical enthalpy of lattice dissociation for silver chloride to be greater than, equal to or less than that for silver bromide. Explain your answer.

Theoretical lattice enthalpy for silver chloride _____

Explanation _____

(3)

- (iii) Suggest why your answer to part (d) (ii) is greater than the theoretical value for the enthalpy of lattice dissociation for silver chloride.

(2)

(Total 15 marks)

Q21.

Calcium fluoride occurs naturally as the mineral fluorite, a very hard crystalline solid that is almost insoluble in water and is used as a gemstone.

Tables 1 and 2 contain thermodynamic data.

Table 1

Process	$\Delta H^\circ / \text{kJ mol}^{-1}$
$\text{Ca(s)} \rightarrow \text{Ca(g)}$	+193
$\text{Ca(g)} \rightarrow \text{Ca}^+(\text{g}) + \text{e}^-$	+590
$\text{Ca}^+(\text{g}) \rightarrow \text{Ca}^{2+}(\text{g}) + \text{e}^-$	+1150
$\text{F}_2(\text{g}) \rightarrow 2\text{F(g)}$	+158
$\text{F(g)} + \text{e}^- \rightarrow \text{F}^-(\text{g})$	-348

Table 2

Name of enthalpy change	$\Delta H^\circ / \text{kJ mol}^{-1}$
Enthalpy of lattice dissociation for calcium fluoride	+2602
Enthalpy of lattice dissociation for calcium chloride	+2237
Enthalpy of hydration for F^- ions	–506
Enthalpy of hydration for Cl^- ions	–364
Enthalpy of hydration for Ca^{2+} ions	–1650

- (a) Write an equation, including state symbols, for the process that occurs when the calcium fluoride lattice dissociates and for which the enthalpy change is equal to the lattice enthalpy.

_____ (1)

- (b) (i) Define the term *standard enthalpy of formation*.

 _____ (3)

- (ii) Write an equation, including state symbols, for the process that has an enthalpy change equal to the standard enthalpy of formation of calcium fluoride.

_____ (1)

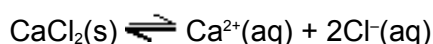
- (iii) Use data from the **Tables 1** and **2** to calculate the standard enthalpy of formation for calcium fluoride.

 _____ (3)

- (c) Explain why the enthalpy of lattice dissociation for calcium fluoride is greater than that for calcium chloride.

(2)

- (d) Calcium chloride dissolves in water. After a certain amount has dissolved, a saturated solution is formed and the following equilibrium is established.



- (i) Using data from **Table 2**, calculate the enthalpy change for this reaction.

(2)

- (ii) Predict whether raising the temperature will increase, decrease or have no effect on the amount of solid calcium chloride that can dissolve in a fixed mass of water.

Explain your prediction.

(If you have been unable to obtain an answer to part (d) (i), you may assume that the enthalpy change = -60 kJ mol^{-1} . This is **not** the correct answer.)

Effect on amount of solid that can dissolve _____

Explanation _____

(3)

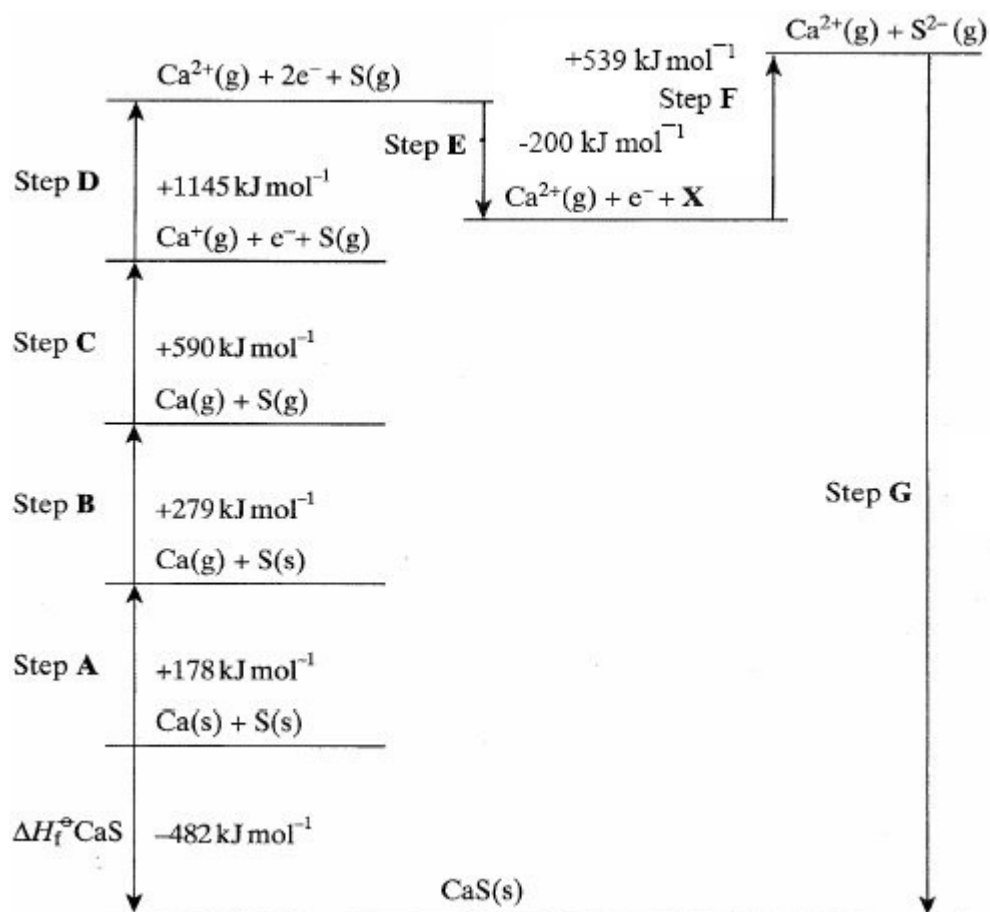
- (e) Calcium fluoride crystals absorb ultra-violet light. Some of the energy gained is given out as visible light. The name of this process, fluorescence, comes from the name of the mineral, fluorite.

Use your knowledge of the equation $\Delta E = h\nu$ to suggest what happens to the electrons in fluorite when ultra-violet light is absorbed and when visible light is given out.

(2)
(Total 17 marks)

Q22.

- (a) A Born–Haber cycle for the formation of calcium sulphide is shown below. The cycle includes enthalpy changes for all steps except step **G**. (The cycle is not drawn to scale.)



- (i) Give the full electronic configuration of the ion S^{2-}

- (ii) Suggest why step **F** is an endothermic process.

- (iii) Name the enthalpy changes in steps **B** and **D**.

Step **B** _____

Step **D** _____

- (iv) Explain why the enthalpy change for step **D** is larger than that for step **C**.

- (v) Use the data shown in the cycle to calculate a value for the enthalpy change for step **G**.

(9)

- (b) Using a Born–Haber cycle, a value of -905 kJ mol^{-1} was determined for the lattice enthalpy of silver chloride. A value for the lattice enthalpy of silver chloride using the ionic model was -833 kJ mol^{-1} .

Explain what a scientist would be able to deduce from a comparison of these values.

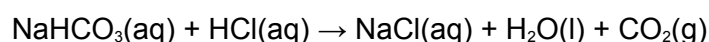
(3)

- (c) Some endothermic reactions occur spontaneously at room temperature. Some exothermic reactions do not occur if the reactants are heated together to a very high temperature.

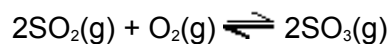
In order to explain the following observations, another factor, the entropy change, ΔS , must be considered. The equation which relates ΔS to ΔH is given below.

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

- (i) Explain why the following reaction occurs at room temperature even though the reaction is endothermic.



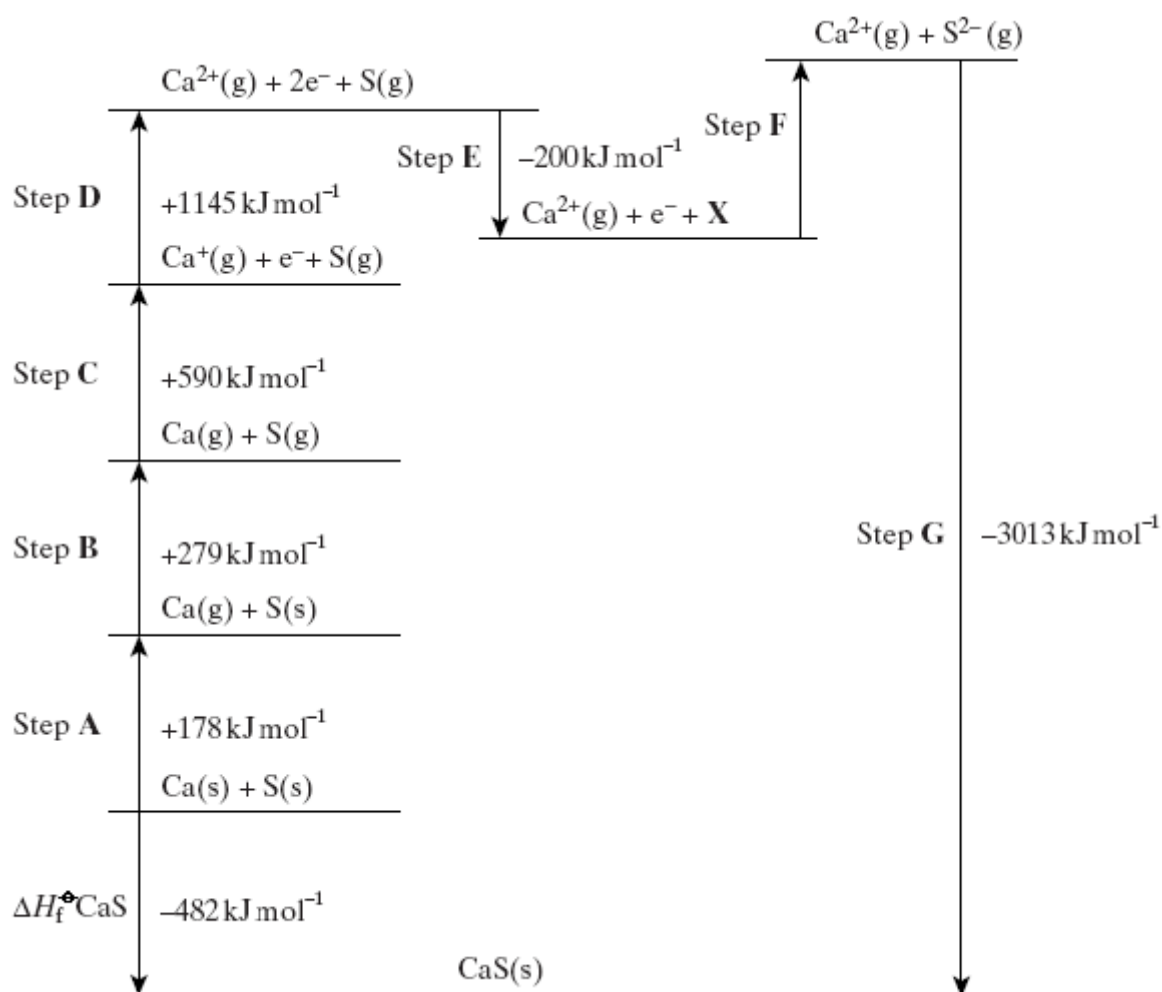
- (ii) Explain why the following reaction does not occur at very high temperatures even though the reaction is exothermic.



(6)
(Total 18 marks)

Q23.

A Born–Haber cycle for the formation of calcium sulphide is shown below. The cycle includes enthalpy changes for all Steps except Step F. (The cycle is not drawn to scale.)



- (a) Give the full electronic arrangement of the ion S^{2-}

(1)

- (b) Identify the species **X** formed in Step E.

(1)

- (c) Suggest why Step **F** is an endothermic process.

(2)

- (d) Name the enthalpy change for each of the following steps.

(i) Step **B** _____

(ii) Step **D** _____

(iii) Step **F** _____

(3)

- (e) Explain why the enthalpy change for Step **D** is larger than that for Step **C**.

(2)

- (f) Use the data shown in the cycle to calculate a value for the enthalpy change for Step **F**.

(2)

(Total 11 marks)

Q24.

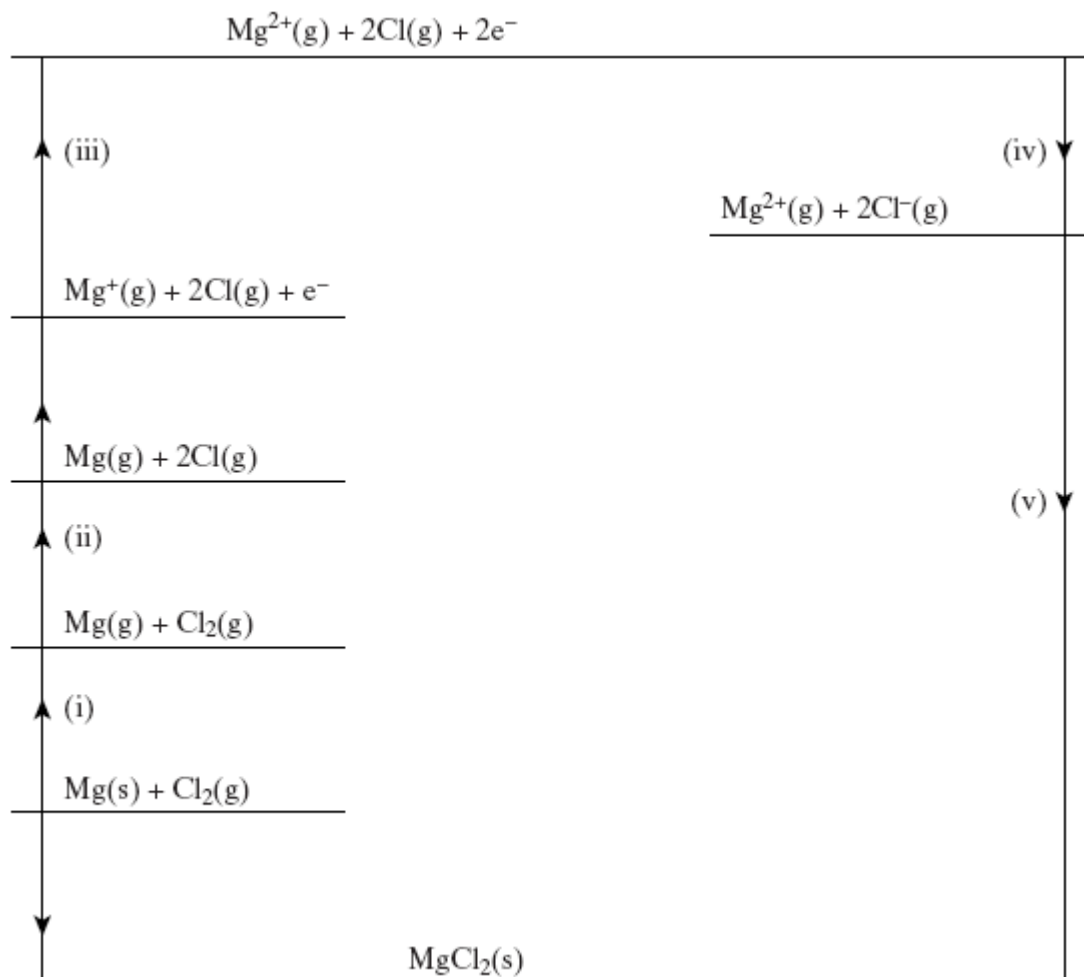
Which one of the following statements is **not** correct?

- A** The first ionisation energy of iron is greater than its second ionisation energy.
- B** The magnitude of the lattice enthalpy of magnesium oxide is greater than that of barium oxide.
- C** The oxidation state of iron in $[\text{Fe}(\text{CN})_6]^{3-}$ is greater than the oxidation state of copper in $[\text{CuCl}_2]^-$
- D** The boiling point of C_3H_8 is lower than that of $\text{CH}_3\text{CH}_2\text{OH}$

(Total 1 mark)

Q25.

- (a) A Born–Haber cycle for the formation of magnesium(II) chloride is shown below.



Taking care to note the direction of the indicated enthalpy change and the number of moles of species involved, give each of the enthalpy changes (i) to (v) above.

Enthalpy change (i) _____

Enthalpy change (ii) _____

Enthalpy change (iii) _____

Enthalpy change (iv) _____

Enthalpy change (v) _____

(5)

- (b) Write an equation for the decomposition of MgCl(s) into $\text{MgCl}_2\text{(s)}$ and Mg(s) and use the following data to calculate a value for the enthalpy change of this reaction.

$$\Delta H_f^\ominus \text{MgCl(s)} = -113 \text{ kJ mol}^{-1}$$

$$\Delta H_f^\ominus \text{MgCl}_2\text{(s)} = -653 \text{ kJ mol}^{-1}$$

Equation _____

Calculation _____

(4)

- (c) Use the data below to calculate a value for the molar enthalpy of a solution of $\text{MgCl}_2(\text{s})$.

Lattice formation enthalpy of $\text{MgCl}_2(\text{s})$ = $-2502 \text{ kJ mol}^{-1}$

$\Delta H_{\text{hydration}}^{\oplus}$ of $\text{Mg}^{2+}(\text{g})$ = $-1920 \text{ kJ mol}^{-1}$

$\Delta H_{\text{hydration}}^{\oplus}$ of $\text{Cl}^{-}(\text{g})$ = -364 kJ mol^{-1}

(3)

(Total 12 marks)

Q26.

- (a) (i) Draw a fully-labelled Born–Haber cycle for the formation of solid barium chloride, BaCl_2 , from its elements. Include state symbols for all species involved.

- (ii) Use your Born–Haber cycle and the standard enthalpy data given below to calculate a value for the electron affinity of chlorine.

Enthalpy of atomisation of barium	$+180 \text{ kJ mol}^{-1}$
Enthalpy of atomisation of chlorine	$+122 \text{ kJ mol}^{-1}$
Enthalpy of formation of barium chloride	-859 kJ mol^{-1}

First ionisation enthalpy of barium	+503 kJ mol ⁻¹
Second ionisation enthalpy of barium	+965 kJ mol ⁻¹
Lattice formation enthalpy of barium chloride	-2056 kJ mol ⁻¹

(9)

- (b) Use data from part (a)(ii) and the entropy data given below to calculate the lowest temperature at which the following reaction becomes feasible.



	BaCl ₂ (s)	Ba(s)	Cl ₂ (g)
$S^\ominus / \text{J K}^{-1} \text{mol}^{-1}$	124	63	223

(4)

(Total 13 marks)

Q27.

Which one of the following has the most covalent character?

- A MgF₂
- B MgBr₂
- C AlF₃
- D AlBr₃

(Total 1 mark)

Q28.

Which one of the following has the most covalent character?

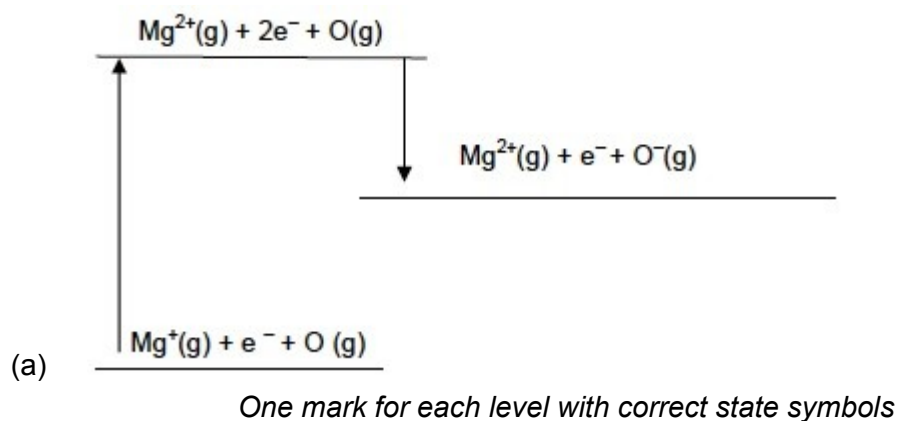
- A MgF₂
- B MgBr₂
- C AlF₃

D AlBr_3

(Total 1 mark)

Mark schemes

Q1.



1
1
1

(b) $\Delta_f H = \Delta_a H (\text{Mg}) + \frac{1}{2} \Delta_{\text{BD}} H (\text{O}_2) + \Delta_{1\text{st IE}} H (\text{Mg}) + \Delta_{2\text{nd IE}} H (\text{Mg}) +$

1

$\Delta_{1\text{st EA}} H (\text{O}) + \Delta_{2\text{nd EA}} H (\text{O}) + \Delta_{\text{LE}} H (\text{MgO})$

$-602 = 150 + (\frac{1}{2} \times 496) + 736 + 1450 - 142 + 844 + \Delta_{\text{LE}} H (\text{MgO})$

1

$\Delta_{\text{LE}} H (\text{MgO}) = -3888 / -3890 \text{ (kJ mol}^{-1}\text{)}$

Allow answers to 2sf or more

1 mark for +3888 or +3890

1 mark for -4136 or -4140 (not $496 \times \frac{1}{2}$)

1

[6]

Q2.

A

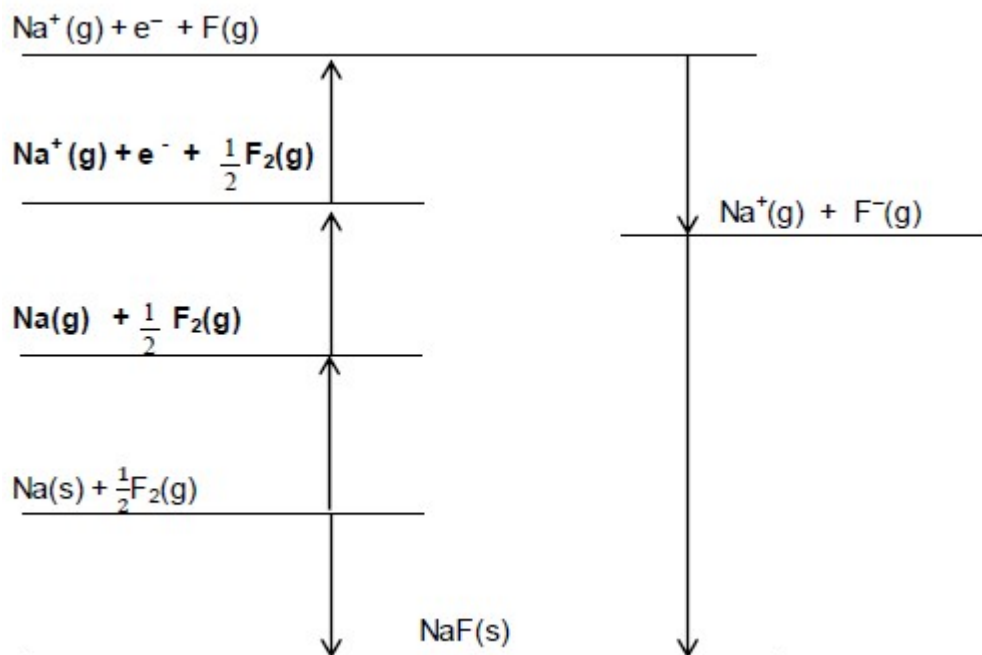
[1]

Q3.

D

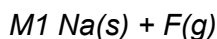
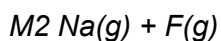
[1]

Q4.

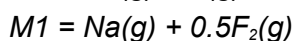
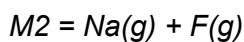


(a)

or



or



2

(b) $LE = -109 - 494 - 158/2 + 348 - 569$

1

$$= -903 \text{ (kJ mol}^{-1}\text{)}$$

1

(c) NaCl enthalpy of lattice formation will be less negative **OR** less exothermic

1

Cl^- ion bigger (than F^-)

1

So attraction of halide ion to Na^+ is weaker

Allow so ionic bonding is stronger

1

(d) Amount of NaF = $1/42 = 2.38 \times 10^{-2}$ mol

1

$$\text{Amount of } F_2 = (2.38 \times 10^{-2})/2 = 1.19 \times 10^{-2} \text{ mol}$$

1

$$V = nRT/p = (1.19 \times 10^{-2} \times 8.31 \times 298)/100000$$

1

$$V = 2.95 \times 10^{-4} \text{ m}^3$$

$$= 295 \text{ cm}^3$$

Q5.

- (a) Start a clock when KCl is added to water

1

Record the temperature every subsequent minute for about 5 minutes

*Allow record the temperature at regular time intervals until
some time after all the solid has dissolved for M2*

1

Plot a graph of temperature vs time

1

Extrapolate back to time of mixing = 0 and determine the temperature

1

- (b) Heat taken in = $m \times c \times \Delta T = 50 \times 4.18 \times 5.4 = 1128.6 \text{ J}$

Max 2 if 14.6 °C used as ΔT

1

Moles of KCl = $5.00 / 74.6 = 0.0670$

1

Enthalpy change per mole = $+1128.6 / 0.0670 = 16\,839 \text{ J mol}^{-1}$

1

= $+16.8 \text{ (kJ mol}^{-1}\text{)}$

Answer must be given to this precision

1

- (c) $\Delta H_{\text{solution}} = \Delta H_{\text{lattice}} + \Delta H(\text{hydration of calcium ions}) + 2 \times \Delta H(\text{hydration of chloride ions})$

$\Delta H_{\text{lattice}} = \Delta H_{\text{solution}} - \Delta H(\text{hydration of calcium ions}) - 2 \times \Delta H(\text{hydration of chloride ions})$

1

$\Delta H_{\text{lattice}} = -82 - 9 - (-1650 + 2 \times -364) = +2295 \text{ (kJ mol}^{-1}\text{)}$

1

- (d) Magnesium ion is smaller than the calcium ion

1

Therefore, it attracts the chloride ion more strongly / stronger ionic bonding

1

[12]

Q6.

- (a) Enthalpy change or heat energy change when 1 mol of solid ionic compound/substance or 1 mol of ionic lattice

1

is formed from its gaseous ions.

1

Allow: enthalpy change for:

$M^+(g) + X^-(g) \rightarrow MX(s)$ or $Ag^+(g) + I^-(g) \rightarrow AgI(s)$
CE=0/2 if describing wrong process (e.g. ΔH of lattice dissociation or ΔH of formation / or heat energy required)
Ignore heat energy released

- (b) lattice dissociation energy = $(112 + 464 + 293) = +869 \text{ (kJ mol}^{-1}\text{)}$

1

lattice formation energy = $-869 \text{ (kJ mol}^{-1}\text{)}$

$(+869 = 1 \text{ mark})$

1

- (c) AgI contains covalent character

CE=0/2 if atoms/molecules

For M1, allow the following:

*not completely ionic / ions not spherical / ions distorted /
 some covalent bonding*

1

Forces / bonds (holding the lattice together) are stronger

Ignore covalent bonds stronger (than ionic bonds)

Ignore electronegativity

Ignore references to energy

1

- (d) $AgNO_3$
yellow ppt

Ignore ammonia/acidified/nitric acid/sulfuric acid

1

or

Cl_2 or Br_2

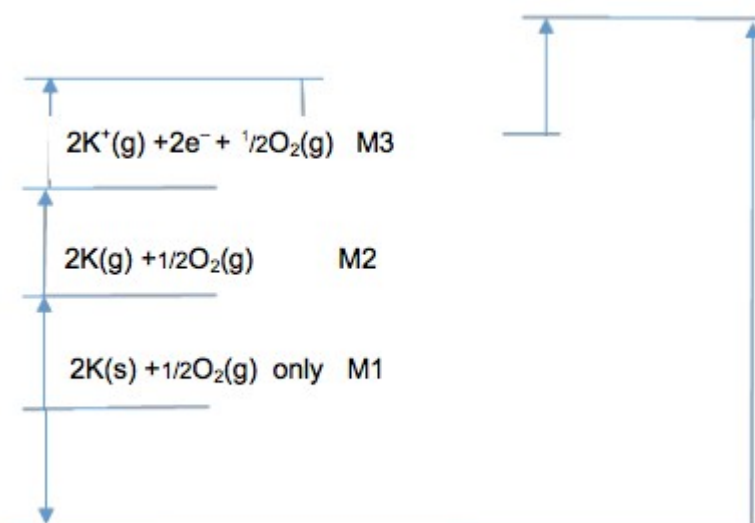
brown solution/black ppt

M2 dependent on correct M1 but mark on from Ag^+ or Tollens

1

[8]

Q7.



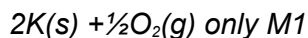
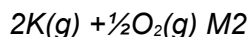
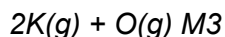
- (a) (i)

Mark each line independently, but follow one route only

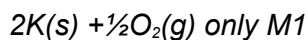
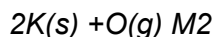
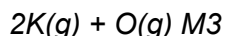
Must have state symbols, but ignore s.s. on electrons

Penalise lack of state symbols each time

Alternative answers



or



1
1
1

- (ii) $(2 \times 90) + 248 + (2 \times 418) - 142 + 844 = -362$ + Lattice enthalpy of dissociation

Enthalpy of lattice dissociation = (+) 2328 (kJmol⁻¹)

M1 for (2×90) and (2×418)

M2 for a correct expression (either in numbers or with words/formulae)

M3 for answer

2328 kJmol⁻¹ scores 3 marks

Allow answers given to 3sf

Answer of 1820, scores zero marks as two errors in calculation.

Answers of 2238, 1910, 2204 max = 1 mark only since one chemical error in calculation (incorrect/missing factor of 2)

Allow 1 mark for answer of -2328 (kJmol⁻¹)

Penalise incorrect units by one mark

3

- (b) K⁺ (ion)/K ion is bigger (than Na⁺ ion)

K⁺ has lower charge density / Na⁺ has higher charge density

Ignore K atom is bigger

1

(Electrostatic) attraction between (oppositely charged) ions is weaker

If attraction is between incorrect ions, then lose M2

Attraction between molecules/atoms or mention of intermolecular forces CE=0/2

Allow converse for Na₂O if explicit

1

[8]

Q8.

- (a) $MgCl_2(s) \rightarrow Mg^{2+}(aq) + 2Cl^-(aq)$

State symbols essential

Do not allow this equation with H₂O on the LHS

Ignore + aq on the LHS

Allow H₂O written over the arrow / allow equation written as an equilibrium

Allow correct equations to form [Mg(H₂O)₆]²⁺ ions

1

(b) $\Delta H_{\text{soln}} \text{MgCl}_2 = \text{LE} + (\Delta H_{\text{hyd}} \text{Mg}^{2+}) + 2(\Delta H_{\text{hyd}} \text{Cl}^-)$

$\Delta H_{\text{soln}} \text{MgCl}_2 = 2493 - 1920 + (2 \times -364)$

$= -155 \text{ (kJ mol}^{-1}\text{)}$

M1 for expression in words or with correct numbers

Ignore units, but penalise incorrect units

1

1

(c) M1: Solubility decreases (as temp increases)

M2: the enthalpy of solution is exothermic / reaction is exothermic / backwards reaction is endothermic

M3: (According to Le Chatelier) the equilibrium moves to absorb heat/reduce temperature/oppose the increase in temperature (in the endothermic direction)

If M1 is incorrect then CE=0/3

If answer to (b) is a +ve value, allow:

M1: Solubility increases (as temp increases)

M2: Enthalpy of solution is endothermic etc

M3: (According to Le Chatelier) the equilibrium moves to absorb heat/reduce the temperature/oppose the increase in temperature (in the endothermic direction)

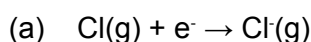
1

1

1

[6]

Q9.



State symbols essential

Allow e with no charge

This and all subsequent equations must be balanced

1

(b) There is an attraction between the nucleus / protons and (the added) electron(s)

1

Energy is released (when the electron is gained)

Allow product more stable / product has lower energy

Allow reaction exothermic / heat released

Allow reference to chlorine rather than fluorine

Wrong process eg ionisation, boiling CE = 0

1

(c) (i) Top line: $+\text{e}^- + \text{F(g)}$

Penalise missing / wrong state symbols one mark only

Penalise FI or CI one mark only

1

Second line from top : $+ e^- + \frac{1}{2}F_2(g)$

Mark independently

Allow e with no charge

1

Bottom two lines: $+ \frac{1}{2}F_2(g)$

Penalise each lack of an electron in M1 and M2 each time

1

(ii) $\frac{1}{2}E(F-F) + 732 + 289 + +203 = 348 + 955$

$\frac{1}{2}E(F-F) = 79$

1

$E(F-F) = 158 \text{ (kJ mol}^{-1}\text{)}$

Award one mark (M2) if M1 wrong but answer = $M1 \times 2$

Ignore no units, penalise wrong units but allow kJ mol⁻¹

Any negative answer, CE = 0

1

- (d) (i) Experimental lattice enthalpy value allows for / includes covalent interaction / non-spherical ions / distorted ions / polarisation

OR AgF has covalent character

Allow discussion of AgCl instead of AgF

CE = 0 for mention of molecules, atoms, macromolecular, mean bond enthalpy, intermolecular forces (imf), electronegativity

1

Theoretical lattice enthalpy value assumes only ionic interaction / point charges / no covalent / perfect spheres / perfectly ionic

OR AgF is not perfectly ionic

1

- (ii) Chloride ion larger (than fluoride ion) / fluoride ion smaller (than chloride ion)

Penalise chlorine ion once only

Allow Cl⁻ and F⁻ instead of names of ions

Allow chloride ion has smaller charge density / smaller charge to size ratio but penalise mass to charge ratio

1

Attraction between Ag⁺ and Cl⁻ weaker / attraction between Ag⁺ and F⁻ stronger

For M2 Cl⁻ and F⁻ can be implied from an answer to M1

Mark M1 and M2 independently provided no contradiction

CE = 0 for mention of chlorine not chloride ion, molecules, atoms, macromolecular, mean bond enthalpy, intermolecular forces (imf), electronegativity

1

[12]

Q10.

- (a) The enthalpy change / heat energy change / ΔH for the formation of one mole of (chloride) ions from (chlorine) atoms

Allow enthalpy change for $\text{Cl} + \text{e}^- \rightarrow \text{Cl}^-$

Do not allow energy change

ionisation energy description is CE=0

Allow enthalpy change for the addition of 1 mol of electrons to Chlorine atoms

penalise Cl_2 and chlorine molecules CE = 0

allow chlorine ions

1

Atoms and ions in the gaseous state

Or state symbols in equation

Cannot score M2 unless M1 scored

except allow M2 if energy change rather than enthalpy change

ignore standard conditions

1

- (b) $\text{Mg}^{2+}(\text{g}) + 2\text{e}^- + 2\text{Cl}(\text{g})$ (1)
(M5)

$\text{Mg}^{2+}(\text{g}) + 2\text{e}^- + \text{Cl}_2(\text{g})$ (1) (M4)	
	$\text{Mg}^{2+}(\text{g}) + 2\text{Cl}^-(\text{g})$ (1) (M6)
$\text{Mg}^+(\text{g}) + \text{e}^- + \text{Cl}_2(\text{g})$ (1) (M3)	
$\text{Mg}(\text{g}) + \text{Cl}_2(\text{g})$ (1) (M2)	
$\text{Mg}(\text{s}) + \text{Cl}_2(\text{g})$ (1) (M1)	
	$\text{MgCl}_2(\text{s})$

Allow e for electrons (i.e. no charge)

State symbols essential

If no electrons allow M5 but not M3,M4

If incorrect 1 / 2 Cl_2 used allow M3 and M4 for correct electrons (scores 2 / 6)

6

- (c) $-\Delta H_f(\text{MgCl}_2) + \Delta H_a(\text{Mg}) + 1^{\text{st}} \text{IE}(\text{Mg}) + 2^{\text{nd}} \text{IE}(\text{Mg}) + 2\Delta H_a(\text{Cl}) = -2\text{EA}(\text{Cl}) - \text{LE}(\text{MgCl}_2)$

Allow Enthalpy of Formation = sum of other enthalpy changes (incl lattice formation)

1

$$-2EA(\text{Cl}) = 642 + 150 + 736 + 1450 + 242 - 2493 = 727$$

1

$$EA(\text{Cl}) = -364 \text{ (kJ mol}^{-1}\text{)}$$

Allow -363 to -364

Allow M1 and M2 for -727

Allow 1 (1 out of 3) for +364 or +363 but award 2 if due to arithmetic error after correct M2

Also allow 1 for -303

Units not essential but penalise incorrect units

Look for a transcription error and mark as AE-1

1

- (d) (i) Magnesium (ion) is smaller **and** more charged (than the sodium ion)
OR

magnesium (ion) has higher charge to size ratio / charge density

Do not allow wrong charge on ion if given

Do not allow similar size for M1

Do not allow mass / charge ratio

1

(magnesium ion) attracts water more strongly

Mark independently

Mention of intermolecular forces, (magnesium) atoms or atomic radius CE = 0

1

- (ii) Enthalpy change = $-LE(\text{MgCl}_2) + \Sigma(\Delta H_{\text{hyd}}\text{ions})$

$$= 2493 + (-1920 + 2 \times -364)$$

1

$$= -155 \text{ (kJ mol}^{-1}\text{)}$$

Units not essential but penalise incorrect units

1

[15]

Q11.

- (a) Enthalpy change / ΔH when 1 mol of a gaseous ion

Enthalpy change for $X^{+/-}(\text{g}) \rightarrow X^{+/-}(\text{aq})$ scores M1 and M2

1

forms aqueous ions

Allow heat energy change instead of enthalpy change

Allow 1 mol applied to aqueous or gaseous ions

If substance / atoms in M1 CE = 0

If wrong process (eg boiling) CE = 0

1

(b) $\Delta H(\text{solution}) = \Delta H(\text{lattice}) + \sum(\Delta H_{\text{hydration}})$

OR $+77 = +905 - 464 + \Delta H(\text{hydration, Cl}^-)$

OR $\Delta H(\text{hydration, Cl}^-) = +77 - 905 + 464$

Allow any one of these three for M1 even if one is incorrect

1

$= -364 \text{ (kJ mol}^{-1}\text{)}$

Allow no units, penalise incorrect units, allow kJ mol⁻¹

Allow lower case j for J (Joules)

+364 does not score M2 but look back for correct M1

1

(c) Water is polar / water has $\text{H}\delta^+$

1

(Chloride ion) attracts (the H in) water molecules

(note chloride ion can be implied from the question stem)

Idea that there is a force of attraction between the chloride ion and water

Do not allow H bonds / dipole–dipole / vdW / intermolecular but ignore loose mention of bonding

Do not allow just chlorine or chlorine atoms / ion

Mark independently

1

(d) $\Delta G = \Delta H - T\Delta S$

Look for this equation in part (d) and / or (e); equation can be stated or implied by correct use. Record the mark in part (d)

1

$(\Delta G = 0 \text{ so}) T = \Delta H / \Delta S$

1

$T = 77 \times 1000 / 33 = 2333 \text{ K}$ (allow range 2300 to 2333.3)

Units essential, allow lower case k for K (Kelvin)

Correct answer with units scores M1, M2 and M3

2.3 (K) scores M1 and M2 but not M3

1

Above the boiling point of water (therefore too high to be sensible) / water would evaporate

Can only score this mark if M3 > 373 K

1

(e) $\Delta S = (\Delta H - \Delta G) / T$ OR $\Delta S = (\Delta G - \Delta H) / -T$

1

$= ((-15 + 9) \times 1000) / 298$ OR $(-15 + 9) / 298$

1

$= -20 \text{ J K}^{-1} \text{ mol}^{-1}$ OR $-0.020 \text{ kJ K}^{-1} \text{ mol}^{-1}$

(allow -20 to -20.2) (allow -0.020 to -0.0202)

Answer with units must be linked to correct M2

For M3, units must be correct

Correct answer with appropriate units scores M1, M2 and M3 and possibly M1 in part (d) if not already given

Correct answer without units scores M1 and M2 and possibly M1 in part (d) if not already given

Answer of $-240 / -0.24$ means temperature of 25 used instead of 298 so scores M1 only

If ans = $+20 / +0.020$ assume AE and look back to see if M1 and possibly M2 are scored

1

[13]

Q12.

- (a) Enthalpy change (to separate) 1 mol of an (ionic) substance into its ions

If ionisation or hydration / solution, CE = 0

If atoms / molecules / elements mentioned, CE = 0

Allow heat energy change but not energy change alone.

If forms 1 mol ions, lose M1

1

Forms ions in the gaseous state

If lattice formation not dissociation, allow M2 only.

Ignore conditions.

Allow enthalpy change for

$MX(s) \rightarrow M^+(g) + X^-(g)$ (or similar) for M1 and M2

1

- (b) Any **one** of:

- Ions are point charges
- Ions are perfect spheres
- Only electrostatic attraction / bonds (between ions)
- No covalent interaction / character
- Only ionic bonding / no polarisation of ions

If atoms / molecules mentioned, CE = 0

1 max

- (c) (Ionic) radius / distance between ions / size

Allow in any order.

Do not allow charge / mass or mass / charge.

1

(Ionic) charge / charge density

Do not allow 'atomic radius'.

1

- (d) $\Delta H_L = \Delta H_a(\text{chlorine}) + \Delta H_a(\text{Ag}) + \text{I.E}(\text{Ag}) + \text{EA}(\text{Cl}) - \Delta H_f^\ominus$

Or cycle

If AgCl_2 , CE=0 / 3

1

$$= 121 + 289 + 732 - 364 + 127$$

1

$$= (+) 905 \text{ (kJ mol}^{-1}\text{)}$$

Allow 1 for -905

Allow 1 for (+)844.5 (use of 121 / 2)

Ignore units even if incorrect.

1

(e) M1 Greater

Do not penalise AgCl₂

1

M2 (Born-Haber cycle method allows for additional) covalent interaction

Allow AgCl has covalent character.

Only score M2 if M1 is correct

OR

M1 Equal

M2 AgCl is perfectly ionic / no covalent character

1

[10]

Q13.

(a) Chloride (ions) are smaller (than bromide ions)

Must state or imply ions.

Allow chloride has greater charge density (than bromide).

Penalise chlorine ions once only (max 2 / 3).

1

So the force of attraction between chloride ions and water is stronger

This can be implied from M1 and M3 but do not allow intermolecular forces.

1

Chloride ions attract the δ^+ on H of water / electron deficient H on water

Allow attraction between ions and polar / dipole water.

*Penalise H⁺ (ions) and mention of hydrogen bonding for **M3***

Ignore any reference to electronegativity.

Note: If water not mentioned can score M1 only.

1

(b) $\Delta H_{\text{solution}} = \Delta H_{\text{L}} + \Delta H_{\text{hyd}} \text{ K}^+ \text{ ions} + \Delta H_{\text{hyd}} \text{ Br}^- \text{ ions} / = 670 - 322 - 335$

$$\text{Allow } \Delta H_{\text{solution}} = \Delta H_{\text{L}} + \Sigma \Delta H_{\text{hyd}}$$

1

$$= (+)13 \text{ (kJ mol}^{-1}\text{)}$$

Ignore units even if incorrect.

+13 scores M1 and M2

-13 scores 0
 -16 scores M2 only (transcription error).

1

- (c) (i) The entropy change is positive / entropy increases
 ΔS is negative loses M1 and M3

1

Because 1 mol (solid) $\rightarrow$ 2 mol (aqueous ions) / no of particles increases
 Allow the aqueous ions are more disordered (than the solid).
 Mention of atoms / molecules loses M2

1

Therefore $T\Delta S > \Delta H$

1

- (ii) Amount of KCl = $5/M_r = 5/74.6 = 0.067(0)$ mol
 If moles of KCl not worked out can score M3, M4 only
 (answer to M4 likely to be 205.7 K)

1

Heat absorbed = $17.2 \times 0.0670 = 1.153$ kJ
 Process mark for M1 $\times 17.2$

1

Heat absorbed = mass $\times$ sp ht $\times \Delta T$

$(1.153 \times 1000) = 20 \times 4.18 \times \Delta T$
 If calculation uses 25 g not 20, lose M3 only (M4 = 11.04, M5 = 287)

1

$\Delta T = 1.153 \times 1000 / (20 \times 4.18) = 13.8$ K
 If 1000 not used, can only score M1, M2, M3
 M4 is for a correct ΔT
 Note that 311.8 K scores 4 (M1, M2, M3, M4).

1

$T = 298 - 13.8 = 284(.2)$ K
 If final temperature is negative, M5 = 0
 Allow no units for final temp, penalise wrong units.

1

[13]

Q14.

- (a) Enthalpy change/heat energy change when one mole of gaseous atoms
 Allow explanation with an equation that includes state symbols

1

Form (one mole of) gaseous negative ions (with a single charge)
 If ionisation/ionisation energy implied, CE=0 for both marks
 Ignore conditions

1

- (b) Fluorine (atom) is smaller than chlorine/shielding is less/ outer electrons closer to nucleus

Fluorine molecules/ions/charge density CE=0 for both marks

1

(Bond pair of) electrons attracted more strongly to the nucleus/protons

1

- (c) Fluoride (ions) smaller (than chloride) / have larger charge density

Any reference to electronegativity CE=0

1

So (negative charge) attracts (δ^+ hydrogen on) water more strongly

Allow H on water, do not allow O on water

Allow F^- hydrogen bonds to water, chloride ion does not

Mark independently

1

- (d) (i) $\Delta H(\text{solution}) = LE + \Sigma(\text{hydration enthalpies})$ / correct cycle

AgF_2 or other wrong formula CE = 0

Ignore state symbols in cycle

1

$$LE = -20 - (-464 + -506)$$

1

$$= (+) 950 \text{ kJ mol}^{-1}$$

Ignore no units, penalise M3 for wrong units

-950 scores max 1 mark out of 3

990 loses M3 but M1 and M2 may be correct

808 is transfer error (AE) scores 2 marks

848 max 1 if M1 correct

1456 CE=0 (results from AgF_2)

1

- (ii) There is an increase in the number of particles / more disorder / less order

Allow incorrect formulae and numbers provided number increases

Do not penalise reference to atoms/molecules

Ignore incorrect reference to liquid rather than solution

1

- (iii) Entropy change is positive/entropy increases and enthalpy change negative/exothermic

1

So ΔG is (always) negative

1

[12]

Q15.

- (a) Enthalpy change when 1 mol of an (ionic) compound/lattice (under standard conditions)

- Allow heat energy change* 1
- Is dissociated/broken/separated into its (component) ions 1
- The ions being in the gaseous state (at infinite separation)
Mark independently. Ignore any conditions. 1
- (b) There is an attractive force between the nucleus of an O atom and an external electron.
Allow any statement that implies attraction between the nucleus and an electron 1
- (c) $\text{Mg}^{2+}(\text{g}) + \text{O}(\text{g}) + 2\text{e}^{-}$
Ignore lack of state symbols
Penalise incorrect state symbols 1
- $\text{Mg}^{2+}(\text{g}) + \text{O}^{-}(\text{g}) + \text{e}^{-}$ 1
- $\text{Mg}^{2+}(\text{g}) + \text{O}^{2-}(\text{g})$ 1
- First new level for Mg^{2+} and O above last on L
If levels are not correct allow if steps are in correct order with arrows in the correct direction and correct ΔH values 1
- Next level for Mg^{2+} and O^{-} below that
- Next level for Mg^{2+} and O^{2-} above that and also above that for Mg^{2+} and O
Allow +124
Allow M4 with incorrect number of electrons
- (d) $\text{LE MgO} = 602 + 150 + 736 + 1450 + 248 - 142 + 844$
Note use of 124 instead of 248 CE=0 1
- $= +3888 \text{ kJ mol}^{-1}$
Allow 1 for -3888
Allow no units
Penalise wrong units 1
- (e) Forms a protective layer/barrier of MgO / MgO prevents oxygen attacking Mg
Allow activation energy is (very) high
Allow reaction (very) slow 1
- (f) $\Delta G = \Delta H - T\Delta S$

$$\Delta S = \frac{(\Delta H - \Delta G)}{T}$$

1

$$\Delta S = (-602 - (-570)) \times 1000 / 298$$

1

$$= -107 \text{ J K}^{-1} \text{ mol}^{-1} / -0.107 \text{ kJ K}^{-1} \text{ mol}^{-1}$$

If units not correct or missing, lose mark

Allow -107 to -108

+107 with correct units scores max 1/3

1

- (g) 1 mol of solid and 0.5 mol of gas reactants form 1 mol solid products

Decrease in number of moles (of gas/species)

Allow gas converted into solid

Numbers of moles/species, if given, must be correct

1

System becomes more ordered

Allow consequential provided ΔS is -ve in 1(f)

If ΔS is +ve in 1(f) can only score M1

1

[16]

Q16.

- (a) Standard pressure (100 kPa) (and a stated temperature)

Allow standard conditions. Do not allow standard states

Allow any temperature

Allow 1 bar but not 1atm

Apply list principle if extra wrong conditions given

Penalise reference to concentrations

1

- (b) Hydrogen bonds between water molecules

1

Energy must be supplied in order to break (or loosen) them

Allow M2 if intermolecular forces mentioned

Otherwise cannot score M2

CE = 0/2 if covalent or ionic bonds broken

1

- (c) $T = \Delta H / \Delta S$

1

$$= (6.03 \times 1000) / 22.1$$

1

$$= 273 \text{ K}$$

Allow 272 to 273; units K must be given

Allow 0°C if units given

0.273 (with or without units) scores 1/3 only

Must score M2 in order to score M3
Negative temperature can score M1 only

1

- (d) The heat given out escapes

1

- (e) (Red end of white) light (in visible spectrum) absorbed by ice
Allow complementary colour to blue absorbed

1

Blue light / observed light is reflected / transmitted / left
Penalise emission of blue light

1

[9]

Q17.

- (a) $\text{MgCl}_2(\text{s}) \rightarrow \text{Mg}^{2+}(\text{g}) + 2\text{Cl}^-(\text{g})$

1

- (b) The magnesium ion is smaller / has a smaller radius / greater charge density (than the calcium ion)

If not ionic or if molecules / IMF / metallic / covalent / bond pair / electronegativity mentioned, CE = 0

1

Attraction between ions / to the chloride ion stronger

Allow ionic bonds stronger

Do not allow any reference to polarisation or covalent character

Mark independently

1

- (c) The oxide ion has a greater charge / charge density than the chloride ion

If not ionic or if molecules / IMF / metallic / covalent / bond pair mentioned, CE = 0

Allow oxide ion smaller than chloride ion

1

So it attracts the magnesium ion more strongly

Allow ionic bonds stronger

Mark independently

1

- (d) $\Delta H_{\text{solution}} = \Delta H_{\text{L}} + \Sigma \Delta H_{\text{hyd}} \text{Mg}^{2+} \text{ ions} + \Sigma \Delta H_{\text{hyd}} \text{Cl}^- \text{ ions}$

Allow correct cycle

1

$$-155 = 2493 + \Delta H_{\text{hyd}} \text{Mg}^{2+} \text{ ions} - 2 \times 364$$

$$\Delta H_{\text{hyd}} \text{Mg}^{2+} \text{ ions} = -155 - 2493 + 728$$

1

$$= -1920 \text{ (kJ mol}^{-1}\text{)}$$

Ignore units

Allow max 1 for +1920
 Answer of + or -1610, CE = 0
 Answer of -2284, CE = 0

1

- (e) Water is polar / O on water has a delta negative charge
 Allow O (not water) has lone pairs (can score on diagram)

1

Mg²⁺ ion / +ve ion / + charge attracts (negative) O on a water molecule
 Allow Mg²⁺ attracts lone pair(s)
 M2 must be stated in words (QoL)
 Ignore mention of co-ordinate bonds
 CE = 0 if O²⁻ or water ionic or H bonding

1

- (f) Magnesium oxide reacts with water / forms Mg(OH)₂
 Allow MgO does not dissolve in water / sparingly soluble / insoluble

1

[11]

Q18.

- (a) (i) (Enthalpy change for formation of) 1 mol (of CaF₂) from its ions
 allow heat energy change
 do not allow energy or wrong formula for CaF₂
 penalise 1 mol of ions
 CE=0 if atoms or elements or molecules mentioned
 ignore conditions

1

ions in the gaseous state
 ions can be mentioned in M1 to score in M2
 allow fluorine ions
 Ca²⁺(g) + 2F⁻(g) → CaF₂ scores M1 and M2

1

- (ii) (enthalpy change when) 1 mol of gaseous (fluoride) ions (is converted) into aqueous ions / an aqueous solution
 allow F⁻(g) → F⁻(aq) (ignore + aq)
 do not penalise energy instead of enthalpy
 allow fluorine ions
 do not allow F⁻ ions surrounded by water

1

- (b) water is polar / H on water is δ^+ / is electron deficient / is unshielded
 penalise H⁺ on water 1 mark

1

(F⁻ ions) attract water / δ^+ on H / hydrogen
 allow H on water forms H-bonds with F⁻
 allow fluorine ions

penalise co-ordinate bonds for M2
penalise attraction to O for M2

1

(c) $\Delta H = -(-2611) - 1650 + 2x - 506$

ignore cycles

M1 is for numbers and signs correct in expression

1

$= -51 \text{ (kJ mol}^{-1}\text{)}$

correct answer scores 2

ignore units even if incorrect

1

[7]

Q19.

(a) Enthalpy change for the formation of 1 mol of gaseous atoms

allow heat energy change for enthalpy change

1

From the element (in its standard state)

ignore reference to conditions

1

Enthalpy change to separate 1 mol of an ionic lattice/solid/compound

enthalpy change not required but penalise energy

1

Into (its component) gaseous ions

mark all points independently

1

(b) $\Delta H_L = -\Delta H_f + \Delta H_a + \text{I.E.} + 1/2E(\text{Cl-Cl}) + \text{EA}$

Or correct Born-Haber cycle drawn out

1

$= +411 + 109 + 494 + 121 - 364$

1

$= +771 \text{ (kJ mol}^{-1}\text{)}$

-771 scores 2/3

+892 scores 1/3

-51 scores 1/3

-892 scores zero

+51 scores zero *ignore units*

1

(c) (i) Ions are perfect spheres (or point charges)

1

Only electrostatic attraction/no covalent interaction

mention of molecules/intermolecular forces/covalent bonds

CE = 0

allow ionic bonding only

If mention of atoms CE = 0 for M2

1

(ii) Ionic

Allow no covalent character/bonding

1

(iii) Ionic with additional covalent bonding

Or has covalent character/partially covalent

Allow mention of polarisation of ions or description of polarisation

1

[11]

Q20.

(a) 242

Units not essential

1

(b) Bond is shorter or bonding pair closer to nucleus

Allow Cl is a smaller atom

Allow fewer electron shells

do not allow smaller molecules

1

So attraction (between nucleus and) (to) bond pair is stronger

Allow shared pair (or bonding electrons) held more tightly

Mention of Cl⁻ loses M2

1

(c) Net attraction between the chlorine nucleus and the extra electron

Allow Cl⁻ ion more stable than Cl

1

(d) (i) step 1 $\text{Ag(s)} \rightarrow \text{Ag(g)}$ only change

1

step 2 $\text{Ag(s)} \rightarrow \text{Ag}^{\text{+}}(\text{g}) + \text{e}^{-}$ only change

1

step 3 $\frac{1}{2}\text{Cl}_2(\text{g}) \rightarrow \text{Cl(g)}$ only change

This step can be first, second or third

1

(ii) $127 + 289 + 732 + 121 - 364$

1

$= 905 \text{ kJ mol}^{-1}$

–905 scores 1 mark only

1

(e) (i) Ions can be regarded as point charges (or perfect spheres)

Allow no polarisation

OR *only bonding is ionic*

OR *no covalent character*

1

- (ii) Greater
Electronegativity argument or mention of intermolecular, CE = 0
 1
- Chloride ions are smaller than bromide
Mark independently but see above
 1
- They are attracted more strongly to the silver ions
Mark independently
 1
- (iii) AgCl has covalent character
Ignore reference to molecules
 1
- Forces in the lattice are stronger than pure ionic attractions
Allow stronger bonding OR additional/extra bonding
 1

[15]

Q21.

- (a) $\text{CaF}_2(\text{s}) \rightarrow \text{Ca}^{2+}(\text{g}) + 2\text{F}^{-}(\text{g})$
 1
- (b) (i) Enthalpy change for formation of 1 mol of substance
Allow heat energy change, NOT energy
 1
- From its elements
 1
- Reactants and products/all substances in their standard states
Or normal states at 298 K, 1 bar (100 kPa)
 1
- (ii) $\text{Ca}(\text{s}) + \text{F}_2(\text{g}) \rightarrow \text{CaF}_2(\text{s})$
 1
- (iii) $\Delta H_f(\text{CaF}_2) = \Delta H_a(\text{Ca}) + 1\text{st IE}(\text{Ca}) + 2^{\text{nd}} \text{IE}(\text{Ca}) + \text{BE}(\text{F}_2) + 2 \times \text{EA}(\text{F}) - \Delta H_L(\text{CaF}_2)$
Or labelled diagram
 1
- $= 193 + 590 + 1150 + 158 + (2 \times -348) - 2602$
 1
- $= -1207 \text{ kJ mol}^{-1}$
 1
- Correct answer scores 3*
-842 scores 2 (transfer error)
-859 scores 1 only (using one E.A.)
Units not required, wrong units lose 1 mark
 1
- (c) Electrostatic attraction stronger/ionic bonding stronger/attraction

between ions stronger/more energy to separate ions

Molecular attraction/atoms/intermolecular forces CE=0

1

Because fluoride (ion) smaller than chloride

Do not allow F or fluorine

1

(d) (i) $\Delta H = \Delta H_L + \Sigma \Delta H_{\text{hyd}} = 2237 - 1650 + (2 \times -364)$

Can be on cycle/diagram

1

$= -141 \text{ kJ mol}^{-1}$

Correct answer scores 2

Units not required, wrong units lose 1 mark

1

(ii) Decreases

If ans to (d)(i) positive allow increases

1

Reaction exothermic/ ΔH –ve

If (d)(i) +ve allow endothermic/ ΔH + ve

1

(Equilibrium) shifts to left/backwards

(as temperature rises)/equilibrium

opposes the change

If (d) (i) +ve allow shifts to right/forwards/equilibrium opposes the change

If no answer to (d) (i) assume –ve ΔH used

If effect deduced incorrectly from any ΔH CE = 0 for these 3 marks

1

(e) u.v. absorbed: electrons/they move to higher energy (levels)/electrons excited

1

visible light given out: electrons/they fall back down/move to lower energy (levels)

Must refer to absorbing u.v. NOT visible light or this must be implied.

1

[17]

Q22.

(a) (i) $1s^2 2s^2 2p^6 3s^2 3p^6$

1

(ii) The negative S^- ion

1

repels the added electron

1

(iii)	Step B is the atomisation enthalpy of sulphur	1
	Step D is the second ionisation enthalpy of calcium	1
(iv)	Electrons nearer to the nucleus	1
	Electrons removed from a positive species or more strongly attracted	1
(v)	$+178 + 279 + 590 + 1145 - 200 + 539 + G + 482 = 0$	1
	$G + 3013 = 0$ hence $G = -3013$	1
(b)	The model used assumes the ions are spherical and in a lattice	1
	The calculated value is smaller than the cycle value or stronger attraction	1
	Indicating some covalent character or ions are polarised	1
(c)	(i) For a reaction to occur $\Delta G < 0$	1
	ΔS is positive and large as a gas is evolved	1
	$T\Delta S$ is larger than ΔH and ΔG is negative	1
	(ii) ΔS is negative	1
	Four moles gaseous reactant forming or more moles of gaseous product	1
	At high temperature $T\Delta S$ is larger than ΔH and ΔG is positive	1

[18]

Q23.

(a)	$1s^2 2s^2 2p^6 3s^2 3p^6$	1
(b)	$S^-(g)$	1
(c)	The negative S^- ion	1
	repels the electron being added	

- | | |
|---|---|
| | 1 |
| (d) (i) Enthalpy of atomisation of sulphur | 1 |
| (ii) Second ionisation enthalpy of calcium | 1 |
| (iii) Second electron affinity of sulphur | 1 |
| (e) Electron more strongly attracted | 1 |
| nearer to the nucleus or attracted by Ca^+ ion | 1 |
| (f) Correct cycle | |
| e.g. $+178 + 279 + 590 + 1145 - 200 + E - 3013 + 482 = 0$ | 1 |
| $= 539$ | 1 |
| Allow one mark for -539 | |

[11]

Q24.

A

[1]

Q25.

- | | |
|---|---|
| (a) (i) ΔH atomisation/sublimation of magnesium | 1 |
| (ii) Bond/dissociation enthalpy of Cl-Cl | |
| OR $2 \times H$ atomisation of chlorine | 1 |
| (iii) Second ionisation enthalpy of magnesium | 1 |
| (iv) $2 \times$ electron affinity of chlorine | 1 |
| (v) Lattice formation enthalpy of MgCl_2 | 1 |
| (b) Equation $2\text{MgCl(s)} \rightarrow \text{MgCl}_2\text{(s)} + \text{Mg(s)}$ | |
| <i>State symbols not required but penalise if incorrect</i> | 1 |
| Calculation $\Delta H_{\text{reaction}} = \Sigma \Delta H_f \text{ products} - \Sigma \Delta H_f \text{ reactants}$ | 1 |
| $= -653 - (2 \times -133)$ | |

1

$$= -427 \text{ (kJmol}^{-1}\text{)}$$

Allow +427 to score (1) mark

Other answers; award (1) for a correct ΔH reaction expression

1

(c) $\Delta H \text{ soln MgCl}_2 = -\Delta H \text{ Lat.form.} + \Delta H \text{ hyd.Mg}^{2+} + 2\Delta H \text{ hyd.Cl}^-$

1

or cycle

$$= 2502 - 1920 - (2 \times 364)$$

1

$$= -146 \text{ (kJmol}^{-1}\text{)}$$

Allow +146 to score (1) mark

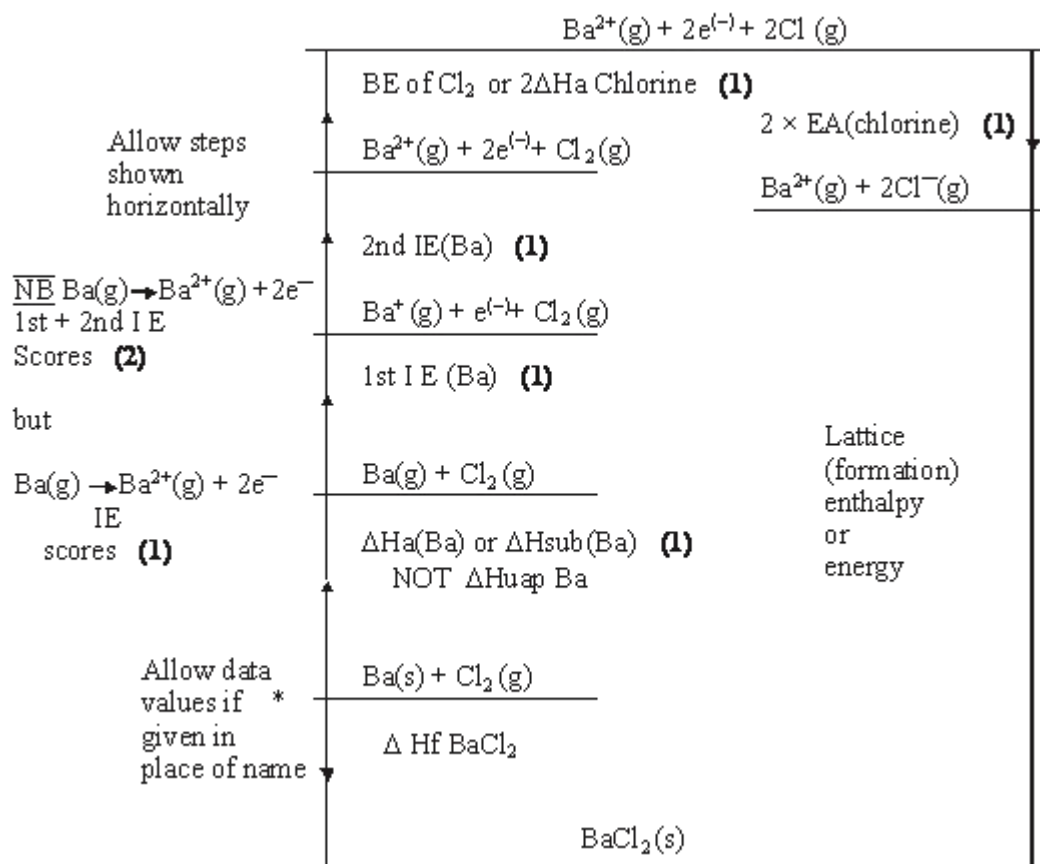
Other answers; award (1) for a correct $\Delta H \text{ soln MgCl}_2$ expression/cycle

1

[12]

Q26.

(a) (i)



ONLY consider species involved in the step marked

(ii) Cycling clockwise about (*)

CE if step missing

$$\Delta H_a \text{Ba} + 1^{\text{st}} \text{IEBa} + 2^{\text{nd}} \text{IE Ba} + 2\Delta H_a \text{Cl} + 2\text{EACl} + \text{LE} - \Delta H_f \text{BaCl}_2 = 0 \text{ (1)}$$
$$+180 + 503 + 965 + 2 \times 122 + 2\text{EA} - 2056 + 859 = 0 \text{ (1)}$$
$$\text{EA} = -695/2 = - (347 \text{ to } 348) \text{ (1)}$$

Ignore units

Calculation –1 for each error

Mark conseq.

Notes: –695 scores (2)

+(347 to 348) scores (2)

–(286 to 287) scores (2)

+(286 to 287) scores (1)

–573 scores (1)

+573 scores (0)

9

(b) $\Delta S = \Sigma S \text{ products} - \Sigma S \text{ reactants}$
 $= (63 + 223) - 124 = 162 \text{ (1)}$

$$\Delta G = \Delta H - T\Delta S \quad \text{or} \quad \Delta H = T\Delta S \text{ or } T = \Delta H/\Delta S \text{ (1)}$$

or used correctly

$$\Delta H = 859 \times 10^3 \text{ (1)} = T \times 162$$

$$T = (5\,300 \text{ to } 5304) \text{ K (1)}$$

Penalise if units °C

–1 for each error + mark conseq.

4

[13]

Q27.

D

[1]

Q28.

D

[1]

Examiner reports

Q1.

- (a) Over 50% of students answered this part correctly, but some failed to gain maximum marks by omitting state symbols or electrons in the equations.
- (b) This was answered less well with many students failing to divide the bond dissociation energy for oxygen by two. Some calculated the enthalpy of lattice dissociation rather than formation. Just over a third of students scored zero here.

Q2.

On this question with a 47% success rate, C, followed by B, were the commonest incorrect responses. Students choosing C either failed to remember that the standard enthalpy change refers to starting from the element in its standard state, or thought that iodine is a gas. Those choosing B presumably thought that the molar reference in the definition is to the starting element rather than to a mole of atoms being formed.

Q3.

The correct response was only the third most 'popular' choice for this question, suggesting that this concept is not well known. Poor agreement between theoretical and experimental lattice energy values suggests that the ionic compound has covalent character. This is due to anion polarisation and is most likely when the cation is small with a high charge density and the anion is large (D, chosen by only 23.1% of students). A and C were chosen more often than the correct answer, but the fluoride ion is very resistant to polarisation due to its small size, so fluorides usually match the ionic model and have good agreement between theoretical and experimental values.

Q6.

- (a) The definition was only given by the best students. Some students gave definitions of other enthalpy changes, particularly the enthalpy of formation of a substance. Many students missed the idea that a solid was being formed and some thought that the solid ionic lattice was formed from one mole of gaseous ions.
- (b) Many students were uncertain about the sign of the enthalpy change for lattice formation and $+869 \text{ kJ mol}^{-1}$ was a common wrong answer.
- (c) Many students understood that the lattice was not perfectly ionic and had some covalent character. Linking the covalent character with stronger bonding eluded all but the strongest students.
- (d) The reagent silver nitrate was well known, and this was generally followed by the correct colour of the precipitate. Some students used a more reactive halogen as the reagent and this was given full credit; however, observations for this were less well known.

Q7.

The Born Haber cycle in part (a)(i) was completed well by the majority of students; common errors included use of the symbol K_2 for elemental potassium, missing state symbols and missing electrons. The calculation in part (a)(ii) was not straightforward; many students failed to multiply the enthalpy changes for potassium by 2 and some

included a $\times 2$ factor for the atomisation of oxygen. The explanation in part (b) was quite a challenge for many students. Many commented on the relative size of the atoms rather than the ions and a common incorrect explanation referred to attraction between the nucleus and the electrons.

Q8.

The equation in part (a) was generally well known but common errors included the formation of Mg^+ , the formation of one mole of chloride ions and the inclusion of water as a reagent. The calculation in part (b) was well done by many students; a common error was a failure to use $2\times$ the enthalpy of hydration of the chloride ion. Students generally used their answer to part (b) to give a good explanation in part (c).

Q9.

Students found this question difficult. In part (a), answers omitting or giving incorrect state symbols were common. In part (b), weaker students often mixed up electron affinity with ionisation or with electronegativity. Many correct answers to part (c) were seen but too often students omitted to include a half before F_2 on the bottom two lines and also omitted to show an electron on the top two lines. The calculation in part (c)(ii) was often correct but many answers stopped at the value of 79 kJ mol^{-1} , therefore giving the atomisation enthalpy of fluorine rather than the bond enthalpy. Answers to part (d)(i) were usually correct but not succinct. In part (d)(ii), many students lost marks due to a lack of precision in their use of language. Silver chloride does not contain atoms, molecules or intermolecular forces and electronegativity is not relevant to ionic solids.

Q10.

Many students failed to score 2 marks in part (a) for the definition of electron affinity. Common mistakes were to refer to energy rather than enthalpy change, to omit one mole of atoms or ions and to refer to chlorine molecules rather than atoms. Part (b) was usually answered well but some state symbols and electrons were common omissions. Good students scored full marks for part (c) but a very common error amongst others was to use the value of 121 kJ mol^{-1} for the atomisation of chlorine instead of doubling that value to allow for 2 mol of chlorine atoms. In part (d)(i) a common omission was a failure to mention that magnesium ions are smaller than those of sodium and a common error was to suggest that the ions would be attracted to O^{2-} ions in water. Answers to part (d)(ii) were usually correct.

Q11.

Answers to part (a) usually gained both marks but some students lost a mark because they gave imprecise answers. Most students calculated the enthalpy of hydration correctly for part (b) but part (c) was found to be more challenging and only the highest-scoring students were able to describe the interaction between a chloride ion and a polar water molecule. In part (d), the calculation of temperature was usually correct but most students did not mention that, at this temperature, water would no longer be a liquid. The value for the entropy change in part (e) was usually correct but the units were sometimes missing or incorrect. A number of students omitted the negative sign for this entropy change possibly in the mistaken belief that entropy would always increase when a solid dissolves.

Q12.

Most students answered part (a) well but weaker students sometimes confused lattice enthalpy with enthalpy of formation or with enthalpy of solution. Parts (b) and (c) were also answered well although in part (c), some students incorrectly suggested mass to charge

ratio. Parts (d) and (e) were answered less well; the main errors in part (d) were either to use an incorrect formula of AgCl_2 for silver chloride or to use 60.5 instead of 121 for the enthalpy of atomisation for chlorine.

Q13.

This question proved to be difficult. In part (a), most students scored one mark for mentioning that the ionic radius of the chloride ion is less than that for the bromide ion. However, many weaker students lost this mark because they did not make reference to a chloride ion; often, just chlorine was mentioned. Only the best students went on to discuss how a chloride ion is attracted to the partially positive hydrogen atom in a water molecule. Others referred incorrectly to intermolecular forces or to hydrogen bonding. About 60% of students gained both marks for the calculation in part (b). In part (c)(i), most students stated that the entropy would increase but many did not clearly explain why and also that the $T\Delta S$ term would outweigh the positive enthalpy change. Although about a quarter of all students scored at least 4 marks in part (c)(ii), less than 10% went on to score full marks by subtracting the temperature change from 298 K. Marks were generally low because many students did not recognise that the heat absorbed could be calculated by multiplying the enthalpy of solution by the amount in moles of potassium chloride. Weak students also used a wrong value for the mass of water heated – usually 25 g or 5.00 g.

Q14.

In part (a), it was disappointing to find that students continue to be unable to give precise definitions of thermodynamic terms. Many students failed to score full marks for recalling the meaning of the term electron affinity. Common errors were to mention energy instead of enthalpy change, a failure to mention one mole and omitting to state that the atoms and then the ions formed must be in the gaseous state. In part (b), mention of molecules or ions rather than atoms spoiled some answers and only the best students mentioned attraction of a bonding pair of electrons to the fluorine nucleus. Answers to part (c) were often disappointing with only about 22% of students scoring both marks. Students at this level should appreciate that electronegativity is a property of atoms in molecules and has no place in an explanation of the hydration enthalpy of an ion. Students also lost marks for referring to fluorine rather than to the fluoride ion. The most common error in part (d)(i) was to use the wrong sign for the enthalpy of solution. Students may have been more likely to obtain a correct answer if they had drawn out a cycle but few did. Another fairly common error was to use the incorrect formula of AgF_2 for silver fluoride. It is pleasing to report that parts (d)(ii) and (iii) were answered well by most students.

Q15.

Most answers to part (a) were correct and scored all three marks. The most common error was to confuse enthalpy of lattice dissociation with enthalpy of formation. Part (b) was not answered so well. Weak students often confused electron affinity with ionisation. Part (c) was answered well and many correct answers were seen. Answers to part (d) were less good. The most common error was to confuse atomisation enthalpy for oxygen with bond enthalpy and therefore to use a value of 124 kJ mol^{-1} in the calculation instead of 248 kJ mol^{-1} . Another common error was to give a negative value for the answer – presumably due to confusion of the enthalpy of lattice formation with the required enthalpy of lattice dissociation. About half of all students gave a correct answer to part (e). Answers to part (f) were often wrong. The usual error was a failure to use a factor of 1000 in order to make enthalpy and entropy have the same units. Part (g) was answered well and those students who calculated a negative entropy change in part (f) usually scored full marks.

Q16.

In part (a), about half of all students knew the meaning of the symbol. Answers to part (b) were very disappointing. Answers were characterised by a lack of precise language and a lack of understanding that hydrogen bonds between water molecules must be broken when ice melts. Students are expected to understand that the bonds broken are between the molecules. It is pleasing to report that answers to part (c) were almost always correct. However, in part (d) this 'how science works' question was not understood and only 11% of students gained a mark. Part (e), however, was answered correctly by the great majority of students and it is pleasing to report that the concept of colour was understood well, despite the context being unfamiliar.

Q17.

Part (a) was usually correct. In parts (b) and (c), however, marks were often low. Too often students referred to molecules or atoms or intermolecular forces of various kinds. Even when students recognised that magnesium chloride and magnesium oxide are purely ionic, most were still unable to answer the questions. It seems that the students who answered this paper did not appreciate that they could assume a perfect ionic crystal in which the force of attraction between ions depends only on their charge and distance apart and that the distance apart is the sum of the ionic radii of the positive and the negative ions. In part (d), many students did not understand how to draw a cycle or create a formula that combined the lattice enthalpy, hydration enthalpy and enthalpy of solution using the correct + and/or – signs. Another common error was a failure to recognise that two moles of chloride ions were involved. Higher-scoring students answered part (e) well but weaker students showed a lack of understanding by suggesting that water was ionised or that the magnesium ions could hydrogen bond with water.

Q18.

The scores for this question were generally very low. It was disappointing to find that many candidates could not give correct meanings for thermodynamic terms. In part (a)(i) common errors were to state energy instead of enthalpy, to omit to mention that ions must be in the gaseous state and to state incorrectly formation from elements rather than from gaseous ions. It is clear that some candidates confused enthalpy of lattice formation with enthalpy of formation. In part (a)(ii) only the best candidates mentioned formation of aqueous ions from gaseous ions. Answers to part (b) were also very often disappointing and confused. The polar nature of water was confused with ions and a significant number of candidates described incorrectly an attraction between fluorine and an oxide (O^{2-}) ion or between fluoride and an H^+ ion. Answers to part (c) were also often incorrect. The usual mistakes were to calculate an endothermic value or to fail to recognise that the formula of calcium fluoride indicates that one mole of calcium fluoride contains two moles of fluoride ions.

Q19.

Answers to part (a) were disappointing. Very few candidates scored all four marks and the average score was less than half marks. Typical errors were a failure to mention the formation of one mole of atoms and also to omit to state that the atoms and ions formed should be gaseous. In part (b), only the best candidates gained full marks. Most candidates either failed to use the correct enthalpy change for the formation of one mole of chlorine atoms, using the bond enthalpy without halving it, or incorrectly doubled the electron affinity of chlorine. In part (c)(i), very few candidates were able to give a full explanation of the term perfect ionic model but answers to parts (c)(ii) and (c)(iii) were usually correct.

Q20.

This question also proved to be very testing. In part 4(a) the majority of candidates did not realise that the chlorine-chlorine bond enthalpy is twice the enthalpy of atomisation. In part (b) only 20% of candidates could suggest correctly why the chlorine-chlorine bond is stronger than that in bromine. Many answers confused bond enthalpy with ionisation energy. Answers to parts (d)(i) and (d)(ii) were reasonable but answers to the new Specification material in parts (e)(ii) and (e)(iii) were rarely good enough to gain full marks. Candidates did not recognise that additional covalent interactions in an ionic lattice will result in a requirement for more energy to separate the particles in the lattice.

Q21.

It was surprising that only about half of candidates answered part (a) correctly. In many cases, either state symbols were incorrect or the products were not ions. In part (b)(i) the majority of candidates lost a mark because they failed to mention that all substances must be in their standard states. Answers to part (b)(ii) were also disappointing. Again state symbols were often wrong and also fluorine was not shown as F_2 . Good candidates were successful with part (b)(iii) but weaker candidates often scored zero. The most common mistakes were a failure to multiply the electron affinity by 2 and incorrectly using twice the bond enthalpy of fluorine, presumably because it was confused with enthalpy of atomisation. Only the very best candidates gave sensible explanations in part (c). Other candidates often referred to intermolecular forces showing a lack of ability to use Unit 1 material. Answers to parts (d)(i) and (ii) were of a higher standard. Most candidates made progress with part (e) but weaker candidates often incorrectly offered an explanation for the colour of a compound caused by transmission of some visible light rather than suggesting that visible light is emitted after the UV light has been absorbed.

Q23.

Almost all candidates gave a correct electronic arrangement for the ion S^{2-} in part (a) and, in part (b), identified species **X** as S^- (g). Many, however, failed to state in part (c) that repulsion between the negative S^- ion and the added electron would result in Step **F** being an endothermic process. Part (d) was generally well answered but 'enthalpy of sublimation' was not accepted for Step **B** as gaseous sulphur does not consist of single sulphur atoms. There were relatively few fully correct answers to part (e). Candidates who stated that 'more energy is needed' were merely repeating the question and not giving an explanation. Part (f) was well answered with many candidates scoring full marks.

Q25.

Although candidates were specifically told in part (a) to note the direction of the indicated enthalpy change and the number of moles of species involved in the Born-Haber cycle, a significant number of candidates lost marks by failing to take this advice. Almost all candidates gave a correct equation for the disproportionation of $MgCl$ in part (b) and many candidates scored full marks for the calculations required in parts (b) and (c). Sadly it was often impossible to award part scores to candidates who did not complete these calculations correctly as they did not give the necessary steps. Candidates must be encouraged to always show their working.

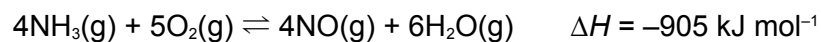
Q26.

All of the required enthalpy changes involved in the Born-Haber cycle for the formation of $BaCl_2$ were given in section (ii) of part (a) and the question specifically stated that a full labelled cycle was required with symbols for all species. Nevertheless, many candidates lost marks when they omitted state symbols, electrons and steps and gave incorrect species.

Consequential marks were awarded in (a)(ii) and only candidates who made three errors failed to score in this section. Part (b) was well answered. Candidates who failed to convert the values of the enthalpy and entropy changes into the same units lost one mark as did those who chose the wrong value for the enthalpy of the reaction from the data given.

Q1.

The equation for the reaction between ammonia and oxygen is shown.



Some standard entropies are given in the table.

Gas	$S^\circ / \text{J K}^{-1} \text{ mol}^{-1}$
$\text{NH}_3(\text{g})$	193
$\text{O}_2(\text{g})$	205
$\text{NO}(\text{g})$	211
$\text{H}_2\text{O}(\text{g})$	189

- (a) Calculate the entropy change for the reaction between ammonia and oxygen.

Entropy change _____ $\text{J K}^{-1} \text{ mol}^{-1}$

(2)

- (b) Calculate a value for the Gibbs free-energy change (ΔG), in kJ mol^{-1} , for the reaction between ammonia and oxygen at 600°C

(If you were unable to obtain an answer to part (a), you should assume that the entropy change is $211 \text{ J K}^{-1} \text{ mol}^{-1}$. This is not the correct answer.)

ΔG _____ kJ mol^{-1}

(2)

- (c) The reaction between ammonia and oxygen was carried out at a higher temperature.

Explain how this change affects the value of ΔG for the reaction.

(2)

- (d) Platinum acts as a heterogeneous catalyst in the reaction between ammonia and oxygen. It provides an alternative reaction route with a lower activation energy.

Describe the stages of this alternative route.

(3)

- (e) Deduce the change in oxidation state of nitrogen, when NH_3 is oxidised to NO

(1)

- (f) When ammonia reacts with oxygen, nitrous oxide (N₂O) can be produced instead of NO

Give an equation for this reaction.

(1)

(Total 11 marks)

Q2.

Titanium(IV) chloride can be made from titanium(IV) oxide as shown in the equation.



Some entropy data are shown in the table.

Substance	TiO ₂ (s)	C(s)	Cl ₂ (g)	CO(g)	TiCl ₄ (l)
S° / J K ⁻¹ mol ⁻¹	50.2	5.70	223	198	253

Use the equation and the data in the table to calculate the Gibbs free-energy change for this reaction at 989 °C

Give your answer to the appropriate number of significant figures.

Use your answer to explain whether this reaction is feasible.

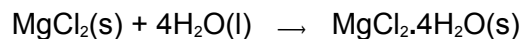
Gibbs free-energy change _____ kJ mol⁻¹

Explanation _____

(Total 6 marks)

Q3.

Anhydrous magnesium chloride, MgCl_2 , can absorb water to form the hydrated salt $\text{MgCl}_2 \cdot 4\text{H}_2\text{O}$



- (a) Suggest **one** reason why the enthalpy change for this reaction cannot be determined directly by calorimetry.

(1)

- (b) Some enthalpies of solution are shown in Table 1.

Table 1

Salt	Enthalpy of solution / kJ mol^{-1}
$\text{MgCl}_2(\text{s})$	-155
$\text{MgCl}_2 \cdot 4\text{H}_2\text{O}(\text{s})$	-39

Calculate the enthalpy change for the absorption of water by $\text{MgCl}_2(\text{s})$ to form $\text{MgCl}_2 \cdot 4\text{H}_2\text{O}(\text{s})$.

Enthalpy change _____ kJ mol^{-1}

(2)

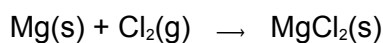
- (c) Describe how you would carry out an experiment to determine the enthalpy of solution of anhydrous magnesium chloride.

You should use about 0.8 g of anhydrous magnesium chloride.

Explain how your results could be used to calculate the enthalpy of solution.

(6)

- (d) Anhydrous magnesium chloride can be formed by direct reaction between its elements.



The free-energy change, ΔG , for this reaction varies with temperature as shown in **Table 2**.

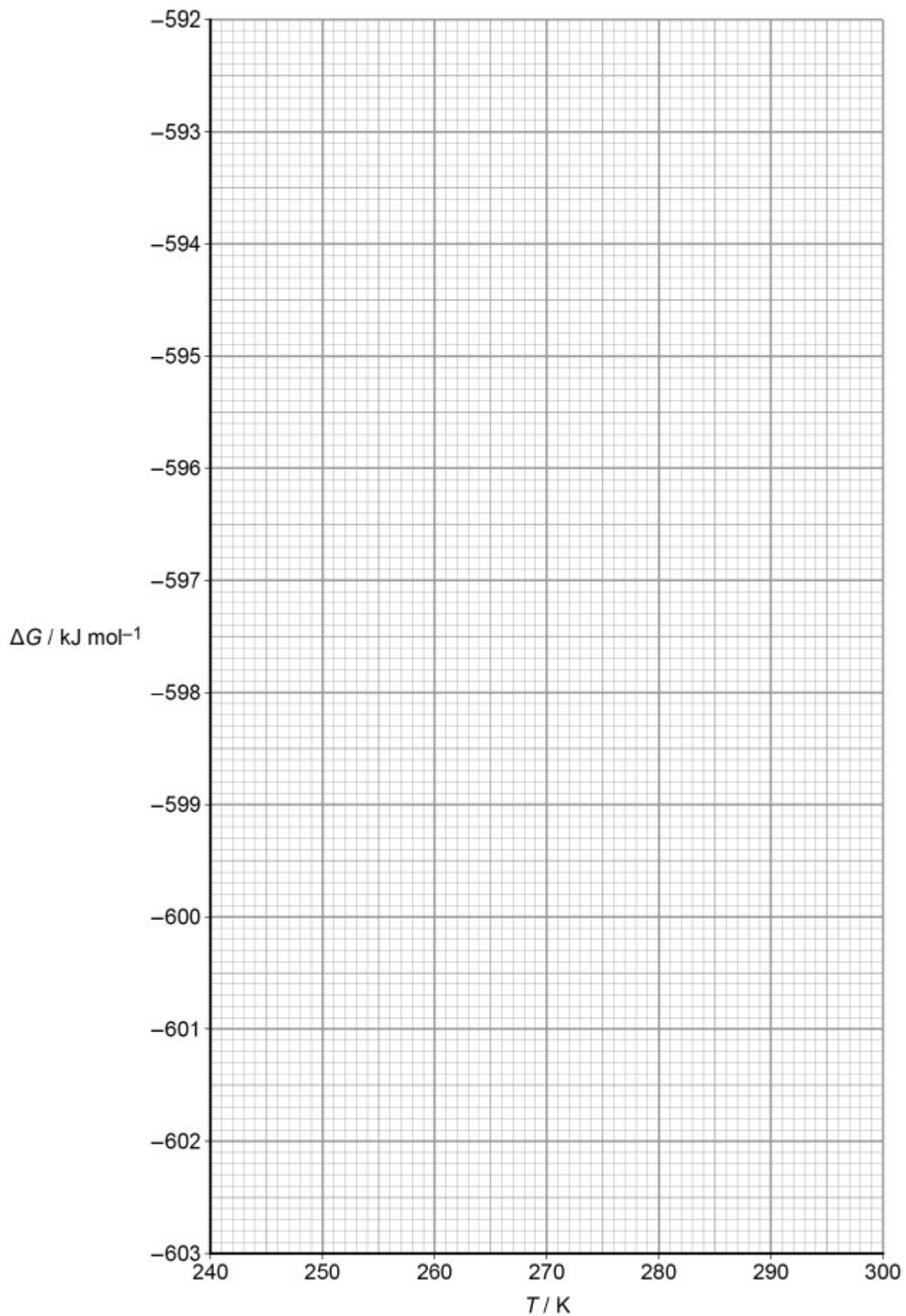
Table 2

T / K	$\Delta G / \text{kJ mol}^{-1}$
298	-592.5
288	-594.2
273	-596.7
260	-598.8
240	-602.2

Use these data to plot a graph of free-energy change against temperature on the grid below.

Calculate the gradient of the line on your graph and hence calculate the entropy change, ΔS , in $\text{J K}^{-1} \text{mol}^{-1}$, for the formation of anhydrous magnesium chloride from its elements.

Show your working.



ΔS _____ $\text{JK}^{-1} \text{mol}^{-1}$

Q4.

A reaction is exothermic and has a negative entropy change.

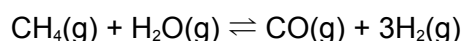
Which statement is correct?

- | | | |
|----------|--|-----------------------|
| A | The reaction is always feasible | ☐ |
| B | The reaction is feasible above a certain temperature | ☐ |
| C | The reaction is feasible below a certain temperature | ☐ |
| D | The reaction is never feasible | ☐ |

(Total 1 mark)

Q5.

Hydrogen can be manufactured by the reaction of methane with steam. An equilibrium is established as shown by the equation.



- (a) Use Le Chatelier's principle to predict the effect on the equilibrium yield of hydrogen if the overall pressure is increased.
Explain your answer.

Effect on yield _____

Explanation _____

(3)

- (b) Explain why the equilibrium yield of hydrogen is unchanged if a catalyst is used in the reaction.

(2)

- (c) The table shows the standard enthalpy of formation and the standard entropy for each substance in this equilibrium reaction.

	CH ₄ (g)	H ₂ O(g)	CO(g)	H ₂ (g)
$\Delta_f H^\ominus / \text{kJ mol}^{-1}$	-75	-242	-111	0
$S^\ominus / \text{J K}^{-1} \text{mol}^{-1}$	186	189	198	131

Use data from the table to calculate the standard enthalpy change for this equilibrium reaction.

Standard enthalpy change _____ kJ mol⁻¹

(2)

Use your answer from part (c) and the entropy data from the table above to calculate the minimum temperature, in °C, needed for this reaction to be feasible. Give your answer to the appropriate number of significant figures.

(If you did not complete part (c) you should assume a value of 120 kJ mol⁻¹ for the standard enthalpy change. This is **not** the correct value).

Minimum temperature _____ °C

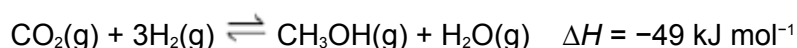
(5)

(Total 12 marks)

Q6.

The table below contains some entropy data relevant to the reaction used to synthesise methanol from carbon dioxide and hydrogen. The reaction is carried out at a temperature of 250 °C.

Substance	CO ₂ (g)	H ₂ (g)	CH ₃ OH(g)	H ₂ O(g)
Entropy ($S^\ominus$) / J K ⁻¹ mol ⁻¹	214	131	238	189



- (a) Use this enthalpy change and data from the table to calculate a value for the free-energy change of the reaction at 250 °C. Give units with your answer.

Free-energy change = _____ Units = _____

(4)

- (b) Calculate a value for the temperature when the reaction becomes feasible.

Temperature = _____ K

(2)

- (c) Gaseous methanol from this reaction is liquefied by cooling before storage.

Draw a diagram showing the interaction between two molecules of methanol.
Explain why methanol is easy to liquefy.

Diagram

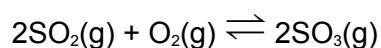
Explanation _____

(4)

(Total 10 marks)

Q7.

In the Contact Process sulfur dioxide reacts with oxygen to form sulfur trioxide as shown in the equation.



The table shows some thermodynamic data.

	$\Delta H_f^\circ / \text{kJ mol}^{-1}$	$S^\circ / \text{J K}^{-1} \text{mol}^{-1}$
$\text{SO}_2(\text{g})$	-297	248
$\text{O}_2(\text{g})$	0	205

SO ₃ (g)	–395	256

- (a) Use data from the table to calculate the standard enthalpy change for this reaction.

(2)

- (b) Use data from the table to calculate the standard entropy change for this reaction.

(2)

- (c) State what the sign of the entropy change in your answer to part **(b)** indicates about the product of this reaction relative to the reactants.

(1)

- (d) Use your answers to parts **(a)** and **(b)** to calculate a value for the free–energy change for this reaction at 50°C.

(If you were unable to calculate ΔH in part **(a)** assume a value of -250 kJ mol^{-1} .
If you were unable to calculate ΔS in part **(b)** assume a value of $-250 \text{ J K}^{-1} \text{ mol}^{-1}$.
These are not the correct values.)

(3)

- (e) Use your answer to part **(d)** to explain whether the reaction is feasible at 50°C.

(1)

(f) Vanadium(V) oxide acts as a heterogeneous catalyst in the Contact Process.

(i) State what is meant by the term heterogeneous.

(1)

(ii) Write **two** equations that show how this catalyst is involved in the Contact Process.

(2)

(iii) Suggest why the vanadium(V) oxide is used in small pellet form rather than as large lumps.

(1)

(iv) State why the reactants should be purified before they come into contact with the vanadium(V) oxide.

(1)

(Total 14 marks)

Q8.

Hydrogen can be manufactured from the reaction of steam with methane.



(a) The table contains some enthalpy of formation and entropy data.

Substance	$\Delta H_f^\ominus / \text{kJ mol}^{-1}$	$S^\ominus / \text{J K}^{-1} \text{mol}^{-1}$
$\text{CH}_4(\text{g})$	-75	186
$\text{H}_2\text{O}(\text{g})$	-242	189
$\text{CO}(\text{g})$	-111	198
$\text{H}_2(\text{g})$	0	131
$\text{CO}_2(\text{g})$	-394	214

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- (i) Use data from the table to calculate the enthalpy change, ΔH , for the reaction of steam with methane.

(3)

- (ii) Use data from the table to calculate the entropy change, ΔS , for the reaction of steam with methane.

(2)

- (b) Use your values of ΔH and ΔS from parts (a)(i) and (a)(ii) to calculate the temperature above which this reaction is feasible.

(4)

- (c) The temperature used for this manufacture of hydrogen is usually about 1300 K. Suggest **one** reason, other than changing the position of equilibrium, why this

temperature is used rather than the value that you calculated in part (b).

(1)

- (d) Hydrogen can also be obtained by reaction of carbon monoxide with steam.



- (i) Explain, using a calculation, why this reaction should **not** occur at 1300 K.

(3)

- (ii) Explain how the conditions for the reaction could be changed to allow this reaction to take place.

(2)

(Total 15 marks)

Q9.

The following table shows some enthalpy change and entropy change data.

	$\Delta H / \text{kJ mol}^{-1}$	$\Delta S / \text{J K}^{-1} \text{ mol}^{-1}$
$\text{AgCl(s)} \longrightarrow \text{Ag}^{\text{+}}(\text{g}) + \text{Cl}^{\text{-}}(\text{g})$	+905	
$\text{AgCl(s)} \longrightarrow \text{Ag}^{\text{+}}(\text{aq}) + \text{Cl}^{\text{-}}(\text{aq})$	+77	+33
$\text{AgF(s)} \longrightarrow \text{Ag}^{\text{+}}(\text{aq}) + \text{F}^{\text{-}}(\text{aq})$	-15	to be calculated
$\text{Ag}^{\text{+}}(\text{g}) \longrightarrow \text{Ag}^{\text{+}}(\text{aq})$	-464	

- (a) Define the term **enthalpy of hydration** of an ion.

(2)

- (b) Use data from the table to calculate a value for the enthalpy of hydration of the chloride ion.

(2)

- (c) Suggest why hydration of the chloride ion is an exothermic process.

(2)

- (d) Silver chloride is insoluble in water at room temperature.

Use data from the table to calculate the temperature at which the dissolving of silver chloride in water becomes feasible.

Comment on the significance of this temperature value.

Calculation of temperature _____

Significance of temperature value _____

(4)

- (e) When silver fluoride dissolves in water at 25 °C, the free-energy change is – 9 kJ mol⁻¹.

Use this information and data from the table to calculate a value, with units, for the entropy change when silver fluoride dissolves in water at 25 °C.

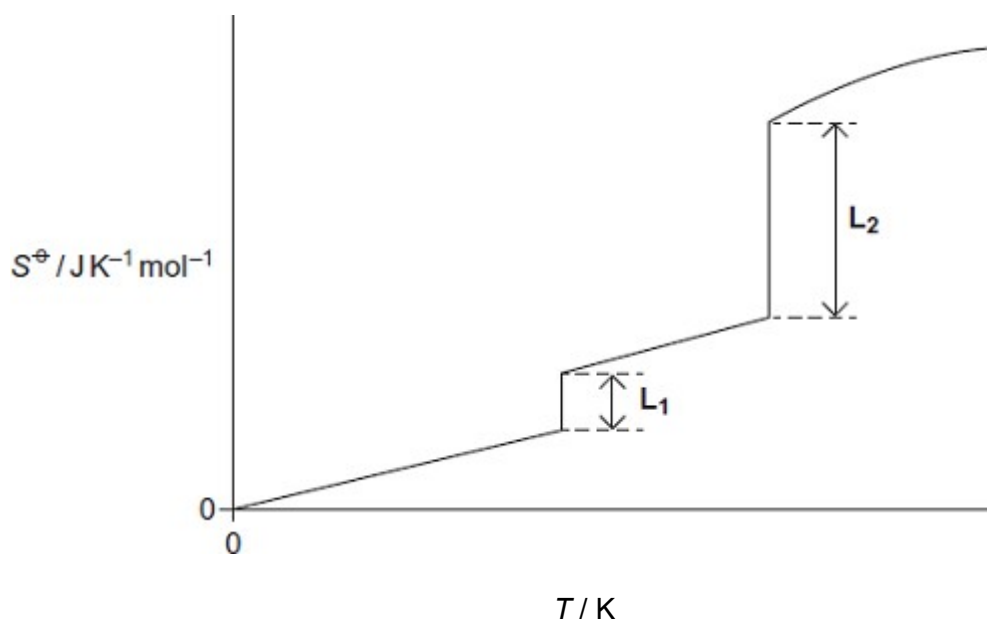
(3)

(Total 13 marks)

Q10.

- (a) **Figure 1** shows how the entropy of a molecular substance **X** varies with temperature.

Figure 1



- (i) Explain, in terms of molecules, why the entropy is zero when the temperature is zero Kelvin.

(2)

- (ii) Explain, in terms of molecules, why the first part of the graph in **Figure 1** is a line that slopes up from the origin.

(2)

- (iii) On **Figure 1**, mark on the appropriate axis the boiling point (T_b) of substance **X**.

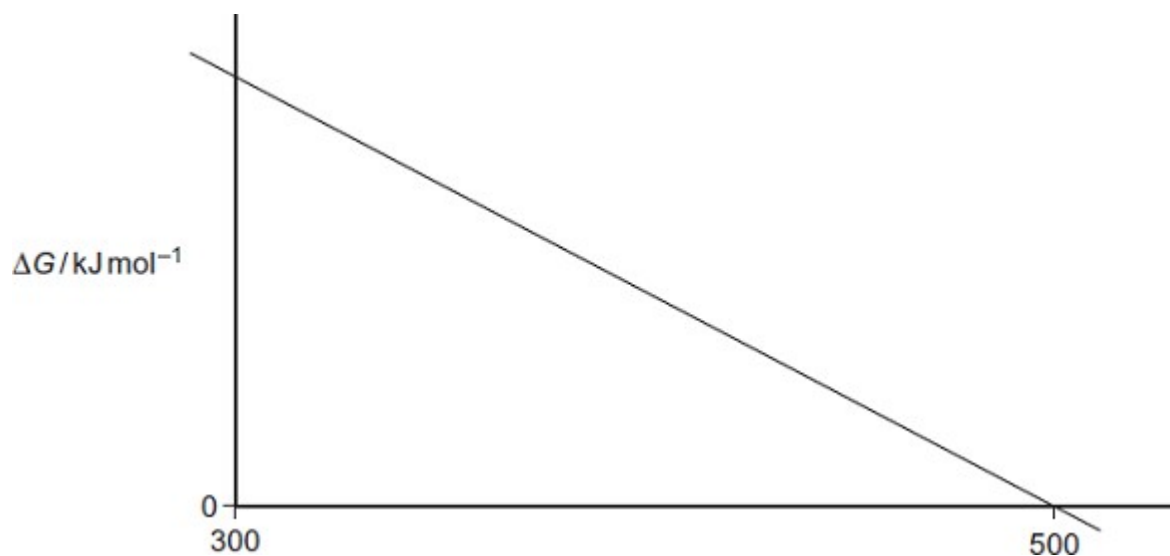
(1)

- (iv) In terms of the behaviour of molecules, explain why L_2 is longer than L_1 in **Figure 1**.

(2)

- (b) **Figure 2** shows how the free-energy change for a particular gas-phase reaction varies with temperature.

Figure 2



T / K

- (i) Explain, with the aid of a thermodynamic equation, why this line obeys the mathematical equation for a straight line, $y = mx + c$.

(2)

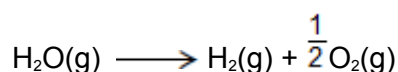
- (ii) Explain why the magnitude of ΔG decreases as T increases in this reaction.

(1)

- (iii) State what you can deduce about the feasibility of this reaction at temperatures lower than 500 K.

(1)

- (c) The following reaction becomes feasible at temperatures above 5440 K.



The entropies of the species involved are shown in the following table.

	$\text{H}_2\text{O}(\text{g})$	$\text{H}_2(\text{g})$	$\text{O}_2(\text{g})$
$S / \text{J K}^{-1} \text{mol}^{-1}$	189	131	205

- (i) Calculate the entropy change ΔS for this reaction.

(1)

- (ii) Calculate a value, with units, for the enthalpy change for this reaction at 5440 K.

(If you have been unable to answer part (c)(i), you may assume that the value of the entropy change is $+98 \text{ J K}^{-1} \text{mol}^{-1}$. This is **not** the correct value.)

(3)

(Total 15 marks)

Q11.

The feasibility of a physical or a chemical change depends on the balance between the thermodynamic quantities of enthalpy change (ΔH), entropy change (ΔS) and temperature (T).

- (a) Suggest how these quantities can be used to predict whether a change is feasible.

(2)

- (b) Explain why the evaporation of water is spontaneous even though this change is endothermic.
In your answer, refer to the change in the arrangement of water molecules and the entropy change.

(4)

- (c) This table contains some thermodynamic data for hydrogen, oxygen and water.

	$S^\ominus / \text{J K}^{-1} \text{mol}^{-1}$	$\Delta H_f^\ominus / \text{kJ mol}^{-1}$
$\text{H}_2(\text{g})$	131	0
$\text{O}_2(\text{g})$	205	0
$\text{H}_2\text{O}(\text{g})$	189	-242
$\text{H}_2\text{O}(\text{l})$	70	

- (i) Calculate the temperature above which the reaction between hydrogen and oxygen to form gaseous water is **not** feasible.

(4)

- (ii) State what would happen to a sample of gaseous water that was heated to a temperature higher than that of your answer to part (c)(i).
Give a reason for your answer.

What would happen to gaseous water _____

Reason _____

(2)

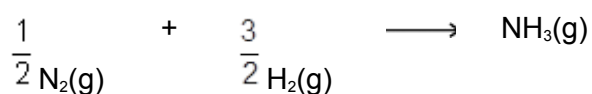
- (d) When hydrogen is used as a fuel, more heat energy can be obtained if the gaseous water formed is condensed into liquid water.

Use entropy data from the table in part (c) to calculate the enthalpy change when one mole of gaseous water is condensed at 373 K.
Assume that the free-energy change for this condensation is zero.

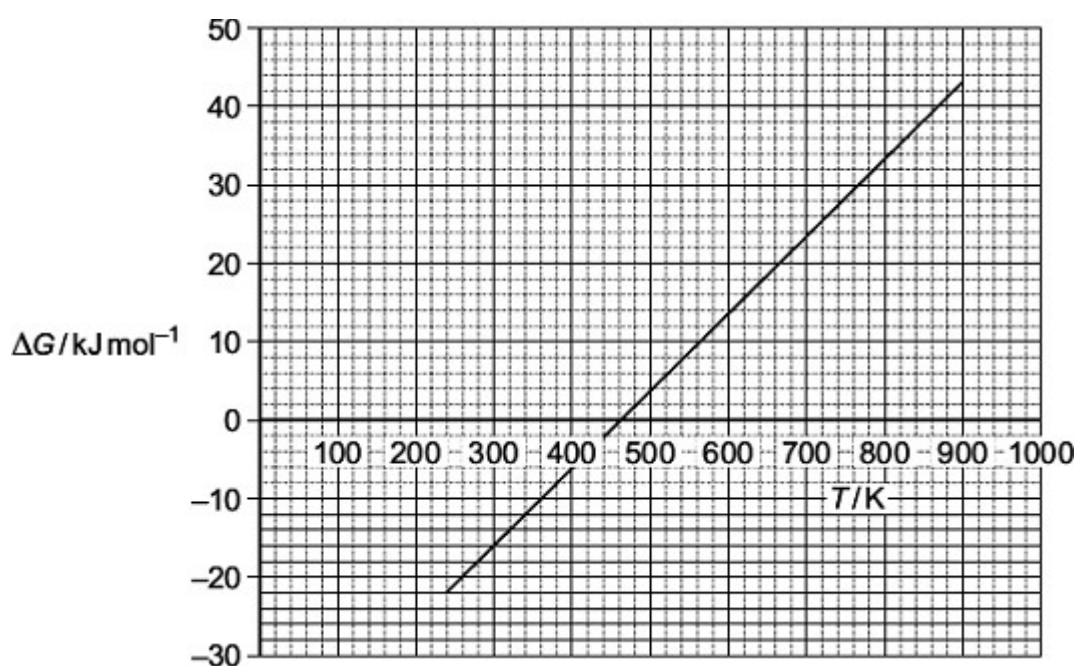
(3)
(Total 15 marks)

Q12.

The following equation shows the formation of ammonia.



The graph shows how the free-energy change for this reaction varies with temperature above 240 K.



- (a) Write an equation to show the relationship between ΔG , ΔH and ΔS .

(1)

- (b) Use the graph to calculate a value for the slope (gradient) of the line. Give the units of this slope and the symbol for the thermodynamic quantity that this slope represents.

Value of the slope _____

Units _____

Symbol _____

(3)

- (c) Explain the significance, for this reaction, of temperatures below the temperature value where the line crosses the temperature axis.

(2)

- (d) The line is not drawn below a temperature of 240 K because its slope (gradient) changes at this point.

Suggest what happens to the ammonia at 240 K that causes the slope of the line to change.

(1)

(Total 7 marks)

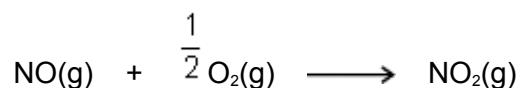
Q13.

The oxides nitrogen monoxide (NO) and nitrogen dioxide (NO₂) both contribute to atmospheric pollution.

The table gives some data for these oxides and for oxygen.

	$S^\ominus / \text{JK}^{-1} \text{mol}^{-1}$	$\Delta H_f^\ominus / \text{kJ mol}^{-1}$
O ₂ (g)	211	0
NO(g)	205	+90
NO ₂ (g)	240	+34

Nitrogen monoxide is formed in internal combustion engines. When nitrogen monoxide comes into contact with air, it reacts with oxygen to form nitrogen dioxide.



- (a) Calculate the enthalpy change for this reaction.

(2)

- (b) Calculate the entropy change for this reaction.

(2)

- (c) Calculate the temperature below which this reaction is spontaneous.

(2)

- (d) Suggest **one** reason why nitrogen dioxide is **not** formed by this reaction in an internal combustion engine.

(1)

- (e) Write an equation to show how nitrogen monoxide is formed in an internal combustion engine.

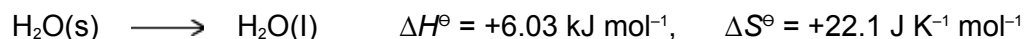
(1)

- (f) Use your equation from part (e) to explain why the free-energy change for the reaction to form nitrogen monoxide stays approximately constant at different temperatures.

(2)
(Total 10 marks)

Q14.

Consider the following process that represents the melting of ice.



- (a) State the meaning of the symbol $^\ominus$ in $\Delta H^\ominus$.

(1)

- (b) Use your knowledge of bonding to explain why $\Delta H^\ominus$ is positive for this process.

(2)

- (c) Calculate the temperature at which $\Delta G^\ominus = 0$ for this process. Show your working.

(3)

- (d) The freezing of water is an exothermic process. Give **one** reason why the temperature of a sample of water can stay at a constant value of 0 °C when it freezes.

(1)

- (e) Pure ice can look pale blue when illuminated by white light. Suggest an explanation for this observation.
-

(2)

(Total 9 marks)

Q15.

This question is about magnesium oxide. Use data from the table below, where appropriate, to answer the following questions.

	$\Delta H^\ominus / \text{kJ mol}^{-1}$
First electron affinity of oxygen (formation of $\text{O}^-(\text{g})$ from $\text{O}(\text{g})$)	-142
Second electron affinity of oxygen (formation of $\text{O}^{2-}(\text{g})$ from $\text{O}^-(\text{g})$)	+844
Atomisation enthalpy of oxygen	+248

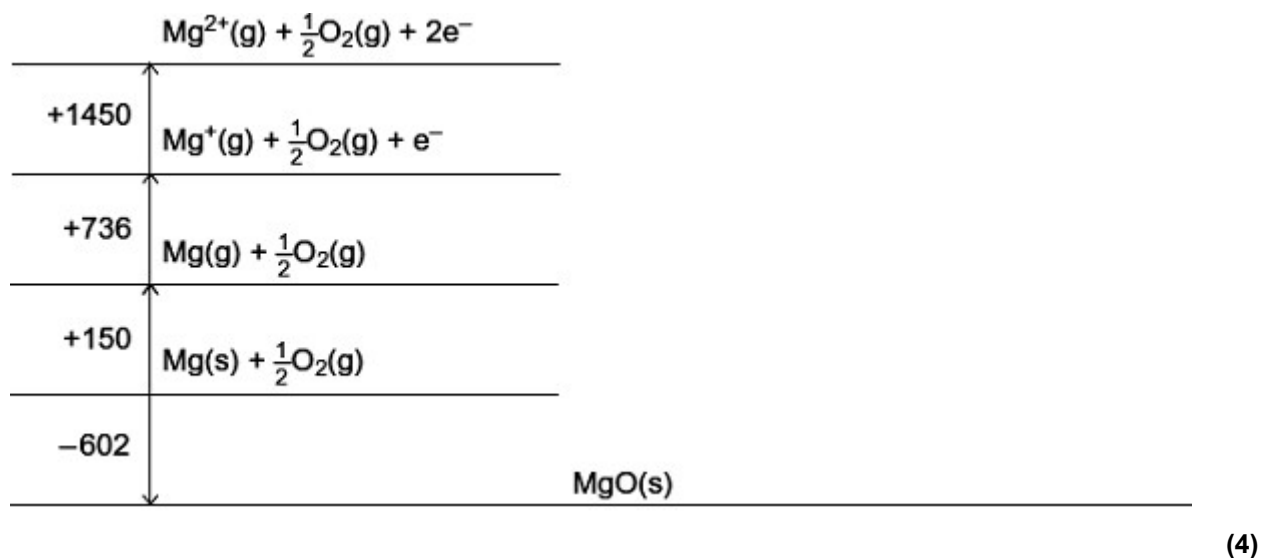
- (a) Define the term *enthalpy of lattice dissociation*.

(3)

- (b) In terms of the forces acting on particles, suggest **one** reason why the first electron affinity of oxygen is an exothermic process.

(1)

- (c) Complete the Born–Haber cycle for magnesium oxide by drawing the missing energy levels, symbols and arrows.
The standard enthalpy change values are given in kJ mol^{-1} .



- (d) Use your Born–Haber cycle from part (c) to calculate a value for the enthalpy of lattice dissociation for magnesium oxide.

(2)

- (e) The standard free-energy change for the formation of magnesium oxide from magnesium and oxygen, $\Delta G_f^\ominus = -570 \text{ kJ mol}^{-1}$. Suggest **one** reason why a sample of magnesium appears to be stable in air at room temperature, despite this negative value for $\Delta G_f^\ominus$.

(1)

- (f) Use the value of $\Delta G_f^\ominus$ given in part (e) and the value of $\Delta H_f^\ominus$ from part (c) to calculate a value for the entropy change $\Delta S^\ominus$ when one mole of magnesium oxide is formed from magnesium and oxygen at 298 K. Give the units of $\Delta S^\ominus$.

(3)

- (g) In terms of the reactants and products and their physical states, account for the sign of the entropy change that you calculated in part (f).

(2)

(Total 16 marks)

Q16.

When potassium nitrate (KNO_3) dissolves in water the value of the enthalpy change $\Delta H = +34.9 \text{ kJ mol}^{-1}$ and the value of the entropy change $\Delta S = +117 \text{ J K}^{-1} \text{ mol}^{-1}$.

- (a) Write an equation, including state symbols, for the process that occurs when potassium nitrate dissolves in water.

(1)

- (b) Suggest why the entropy change for this process is positive.

(1)

- (c) Calculate the temperature at which the free-energy change, ΔG , for this process is zero.

(3)

- (d) (i) Deduce what happens to the value of ΔG when potassium nitrate dissolves in water at a temperature lower than your answer to part (c).

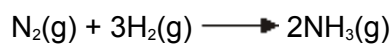
(1)

- (ii) What does this new value of ΔG suggest about the dissolving of potassium nitrate at this lower temperature?

Q17.

Ammonia can be manufactured by the Haber Process.

The equation for the reaction that occurs is shown below.



(a) The table below contains some bond enthalpy data.

	$\text{N} \equiv \text{N}$	$\text{H}-\text{H}$	$\text{N}-\text{H}$
Mean bond enthalpy / kJ mol^{-1}	944	436	388

- (i) Use data from the table to calculate a value for the enthalpy of formation for one mole of ammonia.

(3)

- (ii) A more accurate value for the enthalpy of formation of ammonia is -46 kJ mol^{-1} .
Suggest why your answer to part (a) (i) is different from this value.

(1)

(b) The table below contains some entropy data.

	$\text{H}_2(\text{g})$	$\text{N}_2(\text{g})$	$\text{NH}_3(\text{g})$
$\text{Se} / \text{J K}^{-1} \text{ mol}^{-1}$	131	192	193

Use these data to calculate a value for the entropy change, with units, for the formation of one mole of ammonia from its elements.

(3)

(c) The synthesis of ammonia is usually carried out at about 800 K.

- (i) Use the ΔH value of -46 kJ mol^{-1} and your answer from part (b) to calculate a value for ΔG , with units, for the synthesis at this temperature.
(If you have been unable to obtain an answer to part (b), you may assume that the entropy change is $-112 \text{ J K}^{-1} \text{ mol}^{-1}$. This is not the correct answer.)

(3)

- (ii) Use the value of ΔG that you have obtained to comment on the feasibility of the reaction at 800 K.

(1)

(Total 11 marks)

Q18.

The balance between enthalpy change and entropy change determines the feasibility of a reaction. The table below contains enthalpy of formation and entropy data for some elements and compounds.

	$\text{N}_2(\text{g})$	$\text{O}_2(\text{g})$	$\text{NO}(\text{g})$	$\text{C}(\text{graphite})$	$\text{C}(\text{diamond})$
$\Delta H_f^\circ / \text{kJ mol}^{-1}$	0	0	+90.4	0	+1.9
$S^\circ / \text{J K}^{-1} \text{ mol}^{-1}$	192.2	205.3	211.1	5.7	2.4

- (a) Explain why the entropy value for the element nitrogen is much greater than the entropy value for the element carbon (graphite).

(2)

- (b) Suggest the condition under which the element carbon (diamond) would have an entropy value of zero.

_____ (1)

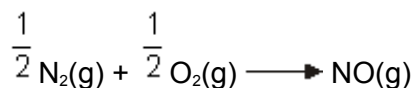
- (c) Write the equation that shows the relationship between ΔG , ΔH and ΔS for a reaction.

_____ (1)

- (d) State the requirement for a reaction to be feasible.

_____ (1)

- (e) Consider the following reaction that can lead to the release of the pollutant NO into the atmosphere.



Use data from the table above to calculate the minimum temperature above which this reaction is feasible.

_____ (5)

- (f) At temperatures below the value calculated in part (e), decomposition of NO into its elements should be spontaneous. However, in car exhausts this decomposition reaction does **not** take place in the absence of a catalyst. Suggest why this spontaneous decomposition does **not** take place.

_____ (1)

- (g) A student had an idea to earn money by carrying out the following reaction.



Use data from the table above to calculate values for ΔH° and ΔS° for this reaction.
Use these values to explain why this reaction is **not** feasible under standard pressure at any temperature.

ΔH° _____

ΔS° _____

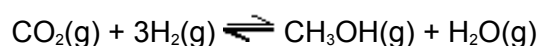
Explanation _____

(3)

(Total 14 marks)

Q19.

Methanol can be regarded as a carbon-neutral fuel because it can be synthesised from carbon dioxide as shown in the equation below.



Standard enthalpy of formation and standard entropy data for the starting materials and products are shown in the following table.

	$\text{CO}_2(\text{g})$	$\text{H}_2(\text{g})$	$\text{CH}_3\text{OH}(\text{g})$	$\text{H}_2\text{O}(\text{g})$
$\Delta H_f^\ominus / \text{kJ mol}^{-1}$	−394	0	−201	−242
$S^\ominus / \text{J K}^{-1} \text{mol}^{-1}$	214	131	238	189

- (a) Calculate the standard enthalpy change for this reaction.

(3)

- (b) Calculate the standard entropy change for this reaction.

- Calculate the temperature at which the reaction becomes feasible.

(If you have been unable to calculate values for ΔH and ΔS you may assume that they are -61 kJ mol^{-1} and $-205 \text{ J K}^{-1} \text{ mol}^{-1}$ respectively. These are **not** the correct values.)

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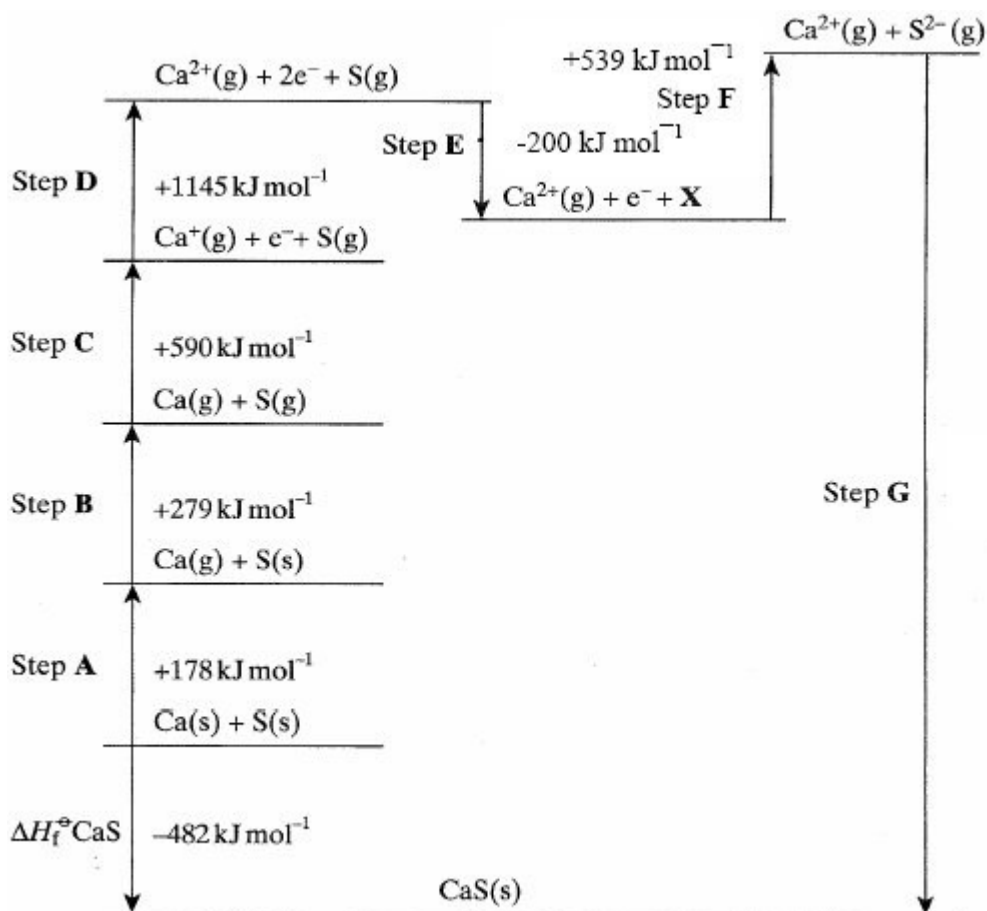
- (e) Give **one** reason why methanol, synthesised from carbon dioxide and hydrogen, may **not** be a carbon-neutral fuel.

(1)

(Total 17 marks)

Q20.

- (a) A Born–Haber cycle for the formation of calcium sulphide is shown below. The cycle includes enthalpy changes for all steps except step **G**. (The cycle is not drawn to scale.)



- (i) Give the full electronic configuration of the ion S^{2-}

- (ii) Suggest why step **F** is an endothermic process.

- (iii) Name the enthalpy changes in steps **B** and **D**.

Step **B** _____

Step **D** _____

- (iv) Explain why the enthalpy change for step **D** is larger than that for step **C**.

- (v) Use the data shown in the cycle to calculate a value for the enthalpy change for step **G**.

(9)

- (b) Using a Born–Haber cycle, a value of -905 kJ mol^{-1} was determined for the lattice enthalpy of silver chloride. A value for the lattice enthalpy of silver chloride using the ionic model was -833 kJ mol^{-1} .

Explain what a scientist would be able to deduce from a comparison of these values.

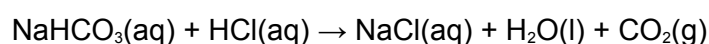
(3)

- (c) Some endothermic reactions occur spontaneously at room temperature. Some exothermic reactions do not occur if the reactants are heated together to a very high temperature.

In order to explain the following observations, another factor, the entropy change, ΔS , must be considered. The equation which relates ΔS to ΔH is given below.

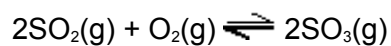
$$\Delta G = \Delta H - T\Delta S$$

- (i) Explain why the following reaction occurs at room temperature even though the reaction is endothermic.



- (ii) Explain why the following reaction does not occur at very high temperatures

even though the reaction is exothermic.

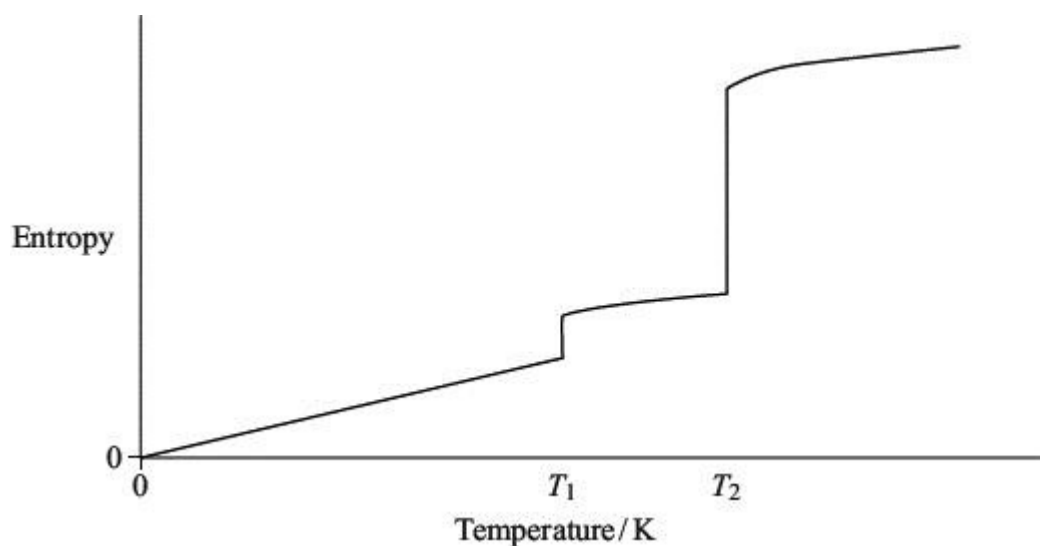


(6)

(Total 18 marks)

Q21.

The sketch graph below shows how the entropy of a sample of water varies with temperature.



- (a) Suggest why the entropy of water is zero at 0 K.

(1)

- (b) What change of state occurs at temperature T_1 ?

(1)

- (c) Explain why the entropy change, ΔS , at temperature T_2 is much larger than that at temperature T_1 .

(2)

- (d) It requires 3.49 kJ of heat energy to convert 1.53 g of liquid water into steam at

373 K and 100 kPa.

- (i) Use these data to calculate the enthalpy change, ΔH , when 1.00 mol of liquid water forms 1.00 mol of steam at 373 K and 100 kPa.

- (ii) Write an expression showing the relationship between free-energy change, ΔG , enthalpy change, ΔH , and entropy change, ΔS .

- (iii) For the conversion of liquid water into steam at 373 K and 100 kPa, $\Delta G = 0 \text{ kJ mol}^{-1}$

Calculate the value of ΔS for the conversion of one mole of water into steam under these conditions. State the units.

(If you have been unable to complete part (d)(i) you should assume that $\Delta H = 45.0 \text{ kJ mol}^{-1}$. This is not the correct answer.)

Calculation _____

Units _____

(6)

(Total 10 marks)

Q22.

Which one of the equations below represents a reaction that is feasible at all temperatures?

- | | | |
|----------|---|-------------|
| A | $\text{P(s)} \rightarrow \text{Q(s)} + \text{R(g)}$ | endothermic |
| B | $2\text{L(g)} + \text{M(g)} \rightarrow 2\text{N(g)}$ | exothermic |
| C | $\text{S(g)} \rightarrow 2\text{T(g)}$ | exothermic |
| D | $\text{A(g)} + \text{B(g)} \rightarrow \text{C(g)}$ | endothermic |

(Total 1 mark)

Q23.

Which one of the following reactions in aqueous solution has the most positive change in entropy?

- A** $[\text{Cu}(\text{H}_2\text{O})_6]^{2+} + 4\text{NH}_3 \rightarrow [\text{Cu}(\text{NH}_3)_4(\text{H}_2\text{O})_2]^{2+} + 4\text{H}_2\text{O}$

- B** $[\text{Cu}(\text{H}_2\text{O})_6]^{2+} + 4\text{Cl}^- \rightarrow [\text{CuCl}_4]^{2-} + 6\text{H}_2\text{O}$
- C** $[\text{Cu}(\text{H}_2\text{O})_6]^{2+} + \text{EDTA}^{4-} \rightarrow [\text{Cu}(\text{EDTA})]^{2-} + 6\text{H}_2\text{O}$
- D** $[\text{Cu}(\text{H}_2\text{O})_6]^{2+} + 2\text{H}_2\text{NCH}_2\text{CH}_2\text{NH}_2 \rightarrow [\text{Cu}(\text{H}_2\text{NCH}_2\text{CH}_2\text{NH}_2)_2(\text{H}_2\text{O})_2]^{2+} + 4\text{H}_2\text{O}$

(Total 1 mark)

Q24.

This question is about the reaction given below.



Enthalpy data for the reacting species are given in the table below.

Substance	CO(g)	H ₂ O(g)	CO ₂ (g)	H ₂ (g)
$\Delta H_f^\ominus / \text{kJ mol}^{-1}$	-110	-242	-394	0

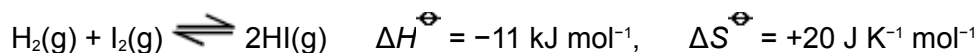
Which one of the following statements is **not** correct?

- A** The value of K_p changes when the temperature changes.
- B** The activation energy decreases when the temperature is increased.
- C** The entropy change is more positive when the water is liquid rather than gaseous.
- D** The enthalpy change is more positive when the water is liquid rather than gaseous.

(Total 1 mark)

Q25.

Refer to the following reaction



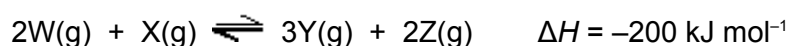
Which one of the following statements is correct?

- A** This is a redox reaction.
- B** The reaction is **not** feasible below 298 K
- C** At equilibrium, the yield of hydrogen iodide is changed by increasing the pressure.
- D** At equilibrium, the yield of hydrogen iodide increases as the temperature is increased.

(Total 1 mark)

Q26.

- (a) The gaseous reactants **W** and **X** were sealed in a flask and the mixture left until the following equilibrium had been established.



[illegible]

(b) Ethyl ethanoate can be prepared by the reactions shown below.

$$\text{CH}_3\text{COOH}(\text{l}) + \text{C}_2\text{H}_5\text{OH}(\text{l}) \rightleftharpoons \text{CH}_3\text{COOC}_2\text{H}_5(\text{l}) + \text{H}_2\text{O}(\text{l}) \quad \Delta H^\ominus = -2.0 \text{ kJ mol}^{-1}$$
$$\text{CH}_3\text{COCl(l)} + \text{C}_2\text{H}_5\text{OH(l)} \rightarrow \text{CH}_3\text{COOC}_2\text{H}_5\text{(l)} + \text{HCl(g)} \quad \Delta H^\ominus = -21.6 \text{ kJ mol}^{-1}$$

-
-
-
-

(ii) Use the information given above and the data below to calculate values for the standard entropy change, $\Delta S^\ominus$, and the standard free-energy change, $\Delta G^\ominus$, for **Reaction 2** at 298 K.

Standard entropy change, $\Delta S^\ominus$ _____

(6)

- (b) The data below apply to a different gas phase reversible reaction.

Standard enthalpy change, $\Delta H^\ominus = +208 \text{ kJ mol}^{-1}$

Standard entropy change, $\Delta S^\ominus = +253 \text{ J K}^{-1} \text{ mol}^{-1}$

- (i) Deduce the effect of an increase in temperature on the position of the equilibrium in this reaction. Use Le Chatelier's principle to explain your answer.

Effect _____

Explanation _____

- (ii) Calculate the minimum temperature at which this reaction is feasible.

(7)

(Total 13 marks)

Q28.

- (a) (i) Draw a fully-labelled Born–Haber cycle for the formation of solid barium chloride, BaCl_2 , from its elements. Include state symbols for all species involved.

- (ii) Use your Born–Haber cycle and the standard enthalpy data given below to calculate a value for the electron affinity of chlorine.

Enthalpy of atomisation of barium	+180 kJ mol ⁻¹
Enthalpy of atomisation of chlorine	+122 kJ mol ⁻¹
Enthalpy of formation of barium chloride	–859 kJ mol ⁻¹
First ionisation enthalpy of barium	+503 kJ mol ⁻¹
Second ionisation enthalpy of barium	+965 kJ mol ⁻¹
Lattice formation enthalpy of barium chloride	–2056 kJ mol ⁻¹

(9)

- (b) Use data from part (a)(ii) and the entropy data given below to calculate the lowest temperature at which the following reaction becomes feasible.



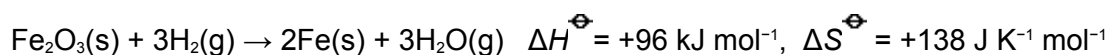
	BaCl ₂ (s)	Ba(s)	Cl ₂ (g)
$S^\ominus / \text{J K}^{-1} \text{mol}^{-1}$	124	63	223

(4)

(Total 13 marks)

Q29.

Using the information below, answer this question.



	Fe ₂ O ₃ (s)	H ₂ (g)	Fe(s)
$\Delta H_f^\ominus / \text{kJ mol}^{-1}$	–822.0	0	0
$\Delta S^\ominus / \text{J K}^{-1} \text{mol}^{-1}$	90.0	131.0	27.0

The standard entropy value for steam is

- A +332 J K⁻¹ mol⁻¹
- B +189 J K⁻¹ mol⁻¹
- C +145 J K⁻¹ mol⁻¹
- D +85 J K⁻¹ mol⁻¹

(Total 1 mark)

Q30.

In which one of the following reactions is there a decrease in entropy?

- A $[\text{Fe}(\text{H}_2\text{O})_6]^{3+}(\text{aq}) + 3\text{C}_2\text{O}_4^{2-}(\text{aq}) \rightarrow [\text{Fe}(\text{C}_2\text{O}_4)_3]^{3-}(\text{aq}) + 6\text{H}_2\text{O}(\text{l})$
- B $[\text{Cu}(\text{H}_2\text{O})_6]^{2+}(\text{aq}) + \text{EDTA}^{4-}(\text{aq}) \rightarrow [\text{Cu}(\text{EDTA})]^{2-}(\text{aq}) + 6\text{H}_2\text{O}(\text{l})$
- C $[\text{CoCl}_4]^{2-}(\text{aq}) + 6\text{H}_2\text{O}(\text{l}) \rightarrow [\text{Co}(\text{H}_2\text{O})_6]^{2+}(\text{aq}) + 4\text{Cl}^-(\text{aq})$
- D $\text{Na}_2\text{CO}_3(\text{s}) + 2\text{H}^+(\text{aq}) \rightarrow 2\text{Na}^+(\text{aq}) + \text{CO}_2(\text{g}) + \text{H}_2\text{O}(\text{l})$

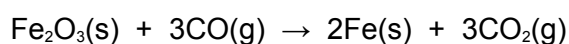
(Total 1 mark)

Q31.

Use the data in the table below to answer the questions which follow.

Substance	Fe ₂ O ₃ (s)	Fe(s)	C(s)	CO(g)	CO ₂ (g)
$\Delta H_f^\ominus / \text{kJ mol}^{-1}$	-824.2	0	0	-110.5	-393.5
$S^\ominus / \text{J K}^{-1} \text{mol}^{-1}$	87.4	27.3	5.7	197.6	213.6

- (a) The following equation shows one of the reactions which can occur in the extraction of iron.



- (i) Calculate the standard enthalpy change and the standard entropy change for this reaction.

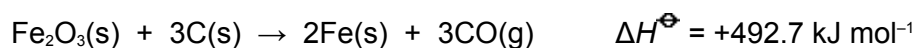
Standard enthalpy change _____

Standard entropy change _____

- (ii) Explain why this reaction is feasible at all temperatures.

(9)

- (b) The reaction shown by the following equation can also occur in the extraction of iron.



The standard entropy change, $\Delta S^\ominus$, for this reaction is $+542.6 \text{ J K}^{-1} \text{ mol}^{-1}$

Use this information to calculate the temperature at which this reaction becomes feasible.

(3)

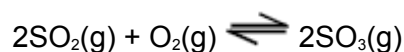
- (c) Calculate the temperature at which the standard free-energy change, $\Delta G^\ominus$ has the same value for the reactions in parts (a) and (b).

(3)

(Total 15 marks)

Q32.

This question relates to the equilibrium gas-phase synthesis of sulphur trioxide:



Thermodynamic data for the components of this equilibrium are:

Substance	$\Delta H_f^\ominus / \text{kJ mol}^{-1}$	$S^\ominus / \text{J K}^{-1} \text{mol}^{-1}$
$\text{SO}_3(\text{g})$	-396	+257
$\text{SO}_2(\text{g})$	-297	+248
$\text{O}_2(\text{g})$	0	+204

This equilibrium, at a temperature of 585 K and a total pressure of 540 kPa, occurs in a vessel of volume 1.80 dm³. At equilibrium, the vessel contains 0.0500 mol of $\text{SO}_2(\text{g})$, 0.0800 mol of $\text{O}_2(\text{g})$ and 0.0700 mol of $\text{SO}_3(\text{g})$.

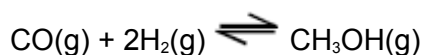
The standard entropy change for this reaction is

- A -222 J K⁻¹ mol⁻¹
- B -195 J K⁻¹ mol⁻¹
- C -186 J K⁻¹ mol⁻¹
- D +198 J K⁻¹ mol⁻¹

(Total 1 mark)

Q33.

The following information concerns the equilibrium gas-phase synthesis of methanol.



At equilibrium, when the temperature is 68 °C, the total pressure is 1.70 MPa. The number of moles of CO, H₂ and CH₃OH present are 0.160, 0.320 and 0.180, respectively.

Thermodynamic data are given below.

Substance	$\Delta H_f^\ominus / \text{kJ mol}^{-1}$	$S^\ominus / \text{J K}^{-1} \text{mol}^{-1}$
$\text{CO}(\text{g})$	-110	198
$\text{H}_2(\text{g})$	0	131
$\text{CH}_3\text{OH}(\text{g})$	-201	240

The standard entropy change for this reaction is

- A -220 J K⁻¹ mol⁻¹
- B +220 J K⁻¹ mol⁻¹
- C -89 J K⁻¹ mol⁻¹

D +89 J K⁻¹ mol⁻¹

(Total 1 mark)

Q34.

The compound lithium tetrahydridoaluminate(III), LiAlH₄, is a useful reducing agent. It behaves in a similar fashion to NaBH₄. Carbonyl compounds and carboxylic acids are reduced to alcohols. However, LiAlH₄ also reduces water in a violent reaction so that it must be used in an organic solvent.

Which one of the following concerning the violent reaction between LiAlH₄ and water is **false**?

- A** A gas is produced.
- B** The activation energy for the reaction is relatively high.
- C** The reaction has a negative free-energy change.
- D** Aqueous lithium ions are formed.

(Total 1 mark)

Mark schemes

Q1.

(a) $(\Delta S = \Sigma(S \text{ products}) - \Sigma(S \text{ reactants}))$

$$= [(4 \times 211) + (6 \times 189)] - [(4 \times 193) + (5 \times 205)] = (1978 - 1797)$$

1

$$181 \text{ (J K}^{-1} \text{ mol}^{-1}\text{)}$$

1

(b) $(\Delta G = \Delta H - T\Delta S) = -905 - (600 + 273) \times 181 \times 10^{-3}$

If answer to (a) is incorrect, mark consequentially:

$$-905 - (873 \times (a) \times 10^{-3})$$

1

$$\Delta G = -1063 / -1060 \text{ (kJ mol}^{-1}\text{)}$$

If alternative value of $\Delta S = 211$ used, answer = -1089 (kJ mol⁻¹)

1

(c) ΔG becomes more negative/less positive

Ignore increase/decrease/larger/smaller ΔG

1

The entropy change / ΔS is positive / $T\Delta S$ gets bigger / $-T\Delta S$ gets more negative.

Consequential on wrong (a)

If candidate does a calculation in (a) to produce ΔS negative then allow ΔG becomes less negative or more positive

1

(d) Reactant(s) adsorbed onto the (platinum surface) / (platinum) provides a surface / active sites

1

Reaction (on the surface) or bond breaking(weakening) / bond making occurs (on the surface)

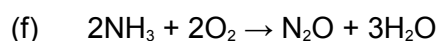
1

Desorption (of the product) or wtte

1

(e) (Oxidation state changes from) -3 to +2 OR (+) 5

1



Allow multiples

Ignore state symbols

1

[11]

Q2.

$$\Delta S = \Sigma S \text{ products} - \Sigma S \text{ reactants or}$$

$$253 + (2 \times 198) - (2 \times 223 + 2 \times 5.7 + 50.2) = (649 - 507.6)$$

This expression could also score M1

1

$$\Delta S = 141(.4) \text{ (J K}^{-1}\text{mol}^{-1}\text{)}$$

This scores M1 and M2

Allow ecf for M3, M4 and M5 from incorrect M2

1

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

1

$$\Delta G = -60 - (1262 \times 141(.4) \times 10^{-3})$$

This expression also scores M3.

For M4, allow $\Delta G = -60 - (1262 \times \text{their M2} \times 10^{-3})$

1

$$= -238 \text{ (kJ mol}^{-1}\text{) to 3 sig figs}$$

If calculated in joules

M4: Allow $\Delta G = -60 \times 10^3 - (1262 \times 141(.4))$

M5: Allow $-238\,000 \text{ J mol}^{-1}$ providing units shown

1

feasible since ΔG is negative/less than zero

Allow consequential M6 from their ΔG

1

[6]

Q3.

- (a) Not possible to prevent some dissolving

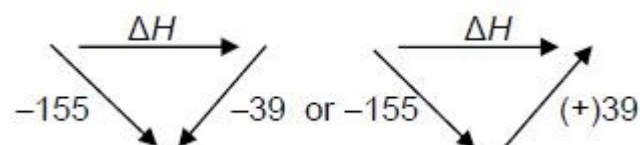
ALLOW It is soluble / dissolves / other hydrates may form / suggestions related to difficulty of measuring T (change) of a solid

1

- (b) $(\Delta_{\text{hyd}}H) = -155 - (-39)$

OR labelled cycle

Minimum needed for 'labelled cycle'



1

$$-116 \text{ (kJ mol}^{-1}\text{)}$$

1/2 for (+)116 or for -29 or for seeing -116 that has then be processed further

1

- (c) This question is marked using levels of response. Refer to the Mark Scheme Instructions for examiners for guidance on how to mark this question

Level 3 (5 – 6 marks)

All stages are covered and the explanation of each stage is correct and virtually complete.
Stage 2 must include use of a graphical method for Level 3 (i.e. 'highest T reached' method is max Level 2)

Answer communicates the whole explanation, including reference to enthalpy, coherently and shows a logical progression through all three stages. Answer is full and detailed and is supported by an appropriate range of relevant points such as those given below:

For the answer to be coherent there must be some indication of **how** the graph is used to find ΔT

Level 2 (3 – 4 marks)

All stages are covered (NB 'covered' means min 2 from each of stage 1 and 3) but the explanation of each stage may be incomplete or may contain inaccuracies
OR two stages covered and the explanations are generally correct and virtually complete

Answer is coherent and shows some progression through all three stages. Some steps in each stage may be out of order and incomplete

Level 1 (1 – 2 marks)

Two stages are covered but the explanation of each stage may be incomplete or may contain inaccuracies
OR only one stage is covered but the explanation is generally correct and virtually complete

Answer shows some progression between two stages

Level 0 (0 marks)

Insufficient correct Chemistry to warrant a mark

Indicative Chemistry Content

Stage 1 Method

- (1a) Measures water with named appropriate apparatus
- (1b) Suitable volume/mass / volume/mass in range 10 – 200 cm³/g
- (1c) Into insulated container / polystyrene cup (NOT just 'lid')
- (1d) Add known mass of MgCl₂(s)
- (1e) Use of 'before and after' weighing method. NOT 'added with washings'

Stage 2 Measurements (could mark from diagram)

- (2a) Record initial temperature (min 2 measurements)
- (2b) Record T at regular timed intervals for 5+ mins / until trend seen
- (2c) Plot T vs time

Stage 3 Use of Results (3a and 3b could come from diagram)

- (3a) Extrapolate lines to when solid added (to find initial and final T)
- (3b) $T_{\text{final}} - T_{\text{initial}} = \Delta T$ / idea of finding ΔT from graph at point of addition
- (3c) $q = mc\Delta T$
- (3d) amount = mass/Mr (0.80/95.3 = 8.39×10^{-3} mol)

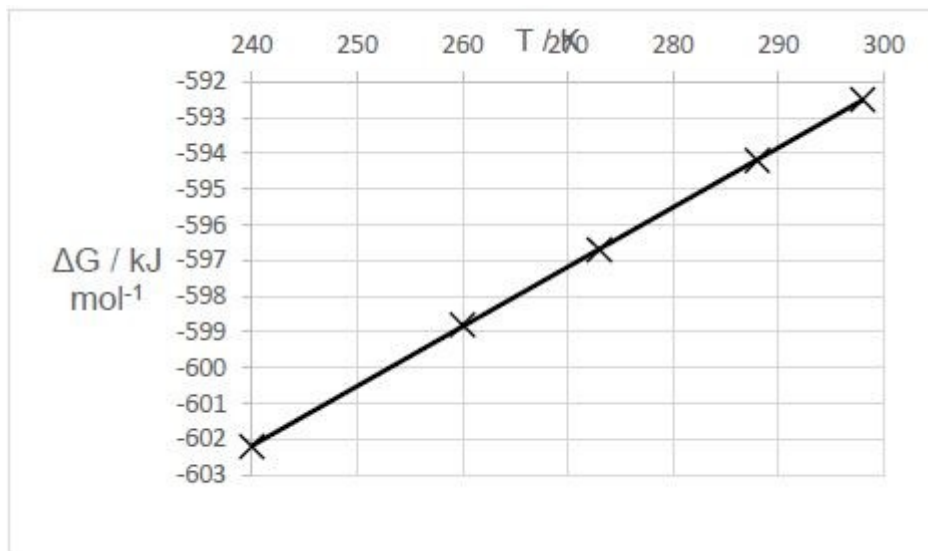
(3e) $\Delta H_{\text{soln}} = -q/8.39 \times 10^{-3}$ or in words

This could all be described in words without showing actual calculations but describing stages

If method based on 'combustion' Max Level 1

6

(d)



M1 = 5 points correctly plotted

M2 = line drawn correctly (NOT if curved, doubled or kinked)

(Check line of best fit –

if through 250, -600.5 and 280, -595.5 +/- one small square then award **M2**, if all crosses on line award **M1** as well)

2

Gradient = $\Delta(\Delta G)/\Delta T = 0.167 \text{ (kJ K}^{-1} \text{ mol}^{-1}\text{)}$

1

$(\Delta G = \Delta H - T\Delta S \text{ so gradient} = -\Delta S)$

$\Delta S = -167 \text{ (J K}^{-1} \text{ mol}^{-1}\text{)}$

M4 = unit conversion i.e. **M3** $\times 1000$; **M5** = -sign (process marks)

Correct answer with sign gets **M3**, **M4** and **M5**

ALLOW -163 to -171

1+1

[14]

Q4.

c

[1]

Q5.

(a) Decrease

1

Increasing pressure moves equilibrium to the side of least moles i.e. backward reaction

1

To oppose the increase in pressure or to decrease the pressure

1

(b) A catalyst speeds up the rate of the forward and backward reaction

1

By the same amount

1

(c) $\Delta H = -111 - (-75 - 242)$

1

206 (kJ mol⁻¹)

1

(d) $\Delta S = 3 \times 131 + 198 - (186 + 189) = 216 \text{ J K}^{-1} \text{ mol}^{-1}$

1

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

1

$$0 = 206 - T \frac{216}{1000}$$

1

$T = 953.7$ or 954 K

1

$T = 681 \text{ (}^\circ\text{C)}$

If the value given in the question is used then the answer is 283 (°C)

1

[12]

Q6.

(a) $\Delta S = 238 + 189 - 214 - 3 \times 131 = -180 \text{ J K}^{-1} \text{ mol}^{-1}$

1

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

1

$$= -49 - \frac{523 \times (-180)}{1000}$$

1

$= +45.1 \text{ kJ mol}^{-1}$

Units essential

1

(b) When $\Delta G = 0$, $\Delta H = T\Delta S$ therefore $T = \Delta H / \Delta S$

1

$$= -49 \times 1000 / -180 = 272 \text{ (K)}$$

Mark consequentially to ΔS in part (a)

1

(c) Diagram marks

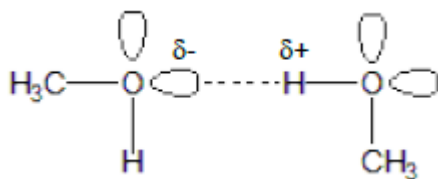


Diagram of a molecule showing O–H bond and two lone pairs on each oxygen

1

Labels on diagram showing $\delta+$ and $\delta-$ charges

Allow explanation of position of $\delta+$ and $\delta-$ charges on H and O

1

Diagram showing $\delta+$ hydrogen on one molecule attracted to lone pair on a second molecule

1

Explanation mark

Hydrogen bonding (the name mentioned) is a strong enough force (to hold methanol molecules together in a liquid)

1

[10]

Q7.

(a) $\Delta H^\circ = \sum \Delta H_f^\circ \text{ products} - \sum \Delta H_f^\circ \text{ reactants}$

1

or $(2 \times -395) - (2 \times -297)$

$= -196 \text{ (kJ mol}^{-1}\text{)}$

Penalise incorrect units, ignore missing units

1

(b) $\Delta S^\circ = \sum S^\circ \text{ products} - \sum S^\circ \text{ reactants}$

1

$= (2 \times 256) - 205 - (2 \times 248)$

$= -189 \text{ JK}^{-1} \text{ mol}^{-1}$

Allow -0.189 kJ K⁻¹ mol⁻¹

Units must be given and must match value

1

(c) Causes an increase in order / a decrease in disorder

Allow products more ordered / products less disordered

If answer to (b) is +ve, allow products are less ordered / causes an increase in disorder / causes a decrease in order

(d) $\Delta G^\ominus = \Delta H^\ominus - T\Delta S^\ominus$

Do not insist on standard state symbol

$= -196 - 323 (-189/1000)$

If conversion of T or ΔS incorrect, then can only score M1

$= -134.9 \text{ kJ mol}^{-1}$

Must have correct units

Allow answers in J mol^{-1}

-135 kJ mol^{-1}

If both alternative values used then -169(.3) kJ mol^{-1}

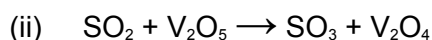
Allow alternative ΔH and/or alternative ΔS in calculation

(e) Feasible because ΔG is negative

Allow mark if a correct deduction from answer to (d)

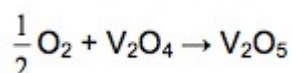
Both a reference to feasibility and to ΔG needed

(f) (i) (The catalyst is in) a different state or phase (from the reactants)



Allow 2VO_2 instead of V_2O_4

Allow multiples



Must have equations in this order

(iii) Surface area is increased

(iv) So that the catalyst is not poisoned

Allow correct reference to the blocking active sites

Q8.

(a) (i) $\Delta H = \Sigma(\text{enthalpies formation products}) - \Sigma(\text{enthalpies formation reactants})$
Or correct cycle with enthalpy changes labelled

$= -111 - (-75 - 242)$

$$= (+)206 \text{ (kJ mol}^{-1}\text{)}$$

-206 scores 1 only
Units not essential if ans in kJ mol⁻¹ but penalise incorrect units

1

(ii) $\Delta S = \Sigma(\text{entropies of products}) - \Sigma(\text{entropies reactants})$

$$= 198 + 3 \times 131 - (186 + 189)$$

1

$$= (+) 216 \text{ (J K}^{-1} \text{ mol}^{-1}\text{)}$$

OR
 $0.216 \text{ kJ K}^{-1} \text{ mol}^{-1}$

Units not essential but penalise incorrect units

1

(b) When $\Delta G = 0$ OR $\Delta H = T\Delta S$

1

$$T = \Delta H / \Delta S$$

M2 also scores M1

1

$$= 206 \times 1000 / 216$$

Allow error carried forward from (a)(i) and (a)(ii)
Ignore unexplained change of sign from - to +

1

$$= 954 \text{ K}$$

Allow 953 – 955, Units of K essential, must be +ve
If values from (a)(i) and (a)(ii) lead to negative value in M3
allow M1 to M3 but do not allow negative temperature for M4
If negative value changed to positive for M4, allow M4

1

(c) To speed up the rate of reaction OR wtte

Allow so that more molecules have energy greater than the activation energy

IF T in (b) > 1300 allow answers such as;

to reduce energy cost

to slow down reaction

do NOT allow to increase rate

1

(d) (i) **Method 1**

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

$$\Delta G = -41 - (1300 \times -42 / 1000) \text{ (M1)}$$

If 42 and not 42 / 1000 used can score M3 only

but allow $\Delta G = -41 \times 1000 - (1300 \times -42) \text{ (M1)}$

1

$$= +13.6 \text{ kJ mol}^{-1}$$

$$= 13600 \text{ J mol}^{-1} \text{ (M2)}$$

ΔG must be negative for the reaction to be feasible.

OR ΔG is positive so reaction is not feasible

1

Method 2

For reaction to be feasible ΔG must be negative or zero

1

T when $\Delta G = 0 = \Delta H / \Delta S = 976K$

1

ΔS is -ve so ΔG must be +ve at temperatures above 976K / at 1300 K

1

(ii) If the temperature is lowered

(Ignore reference to catalyst and / or pressure)

Alternative mark scheme (if T is calculated)

Allow T reduced to 976 K or lower M1

1

ΔG will become (more) negative because

the $-T\Delta S$ term will be less positive / $T\Delta S > \Delta H$

At this temperature (the reaction becomes feasible because)

$\Delta G \leq 0$ M2

1

[15]

Q9.

(a) Enthalpy change / ΔH when 1 mol of a gaseous ion

Enthalpy change for $X^{+/-}(g) \rightarrow X^{+/-}(aq)$ scores M1 and M2

1

forms aqueous ions

Allow heat energy change instead of enthalpy change

Allow 1 mol applied to aqueous or gaseous ions

If substance / atoms in M1 CE = 0

If wrong process (eg boiling) CE = 0

1

(b) $\Delta H(\text{solution}) = \Delta H(\text{lattice}) + \Sigma(\Delta H_{\text{hydration}})$

OR $+77 = +905 - 464 + \Delta H(\text{hydration, Cl}^-)$

OR $\Delta H(\text{hydration, Cl}^-) = +77 - 905 + 464$

Allow any one of these three for M1 even if one is incorrect

1

$= -364 \text{ (kJ mol}^{-1}\text{)}$

Allow no units, penalise incorrect units, allow kJ mol⁻¹

Allow lower case j for J (Joules)

+364 does not score M2 but look back for correct M1

1

- (c) Water is polar / water has $\text{H}\delta^+$

1

(Chloride ion) attracts (the H in) water molecules

(note chloride ion can be implied from the question stem)

Idea that there is a force of attraction between the chloride ion and water

Do not allow H bonds / dipole–dipole / vdW / intermolecular but ignore loose mention of bonding

Do not allow just chlorine or chlorine atoms / ion

Mark independently

1

- (d) $\Delta G = \Delta H - T\Delta S$

Look for this equation in part (d) and / or (e); equation can be stated or implied by correct use. Record the mark in part (d)

1

$(\Delta G = 0 \text{ so}) T = \Delta H / \Delta S$

1

$T = 77 \times 1000 / 33 = 2333 \text{ K}$ (allow range 2300 to 2333.3)

Units essential, allow lower case k for K (Kelvin)

Correct answer with units scores M1, M2 and M3

2.3 (K) scores M1 and M2 but not M3

1

Above the boiling point of water (therefore too high to be sensible) / water would evaporate

Can only score this mark if M3 >373 K

1

- (e) $\Delta S = (\Delta H - \Delta G) / T$ OR $\Delta S = (\Delta G - \Delta H) / -T$

1

$= ((-15 + 9) \times 1000) / 298$ OR $(-15 + 9) / 298$

1

$= -20 \text{ J K}^{-1} \text{ mol}^{-1}$ OR $-0.020 \text{ kJ K}^{-1} \text{ mol}^{-1}$

(allow -20 to -20.2) (allow -0.020 to -0.0202)

Answer with units must be linked to correct M2

For M3, units must be correct

Correct answer with appropriate units scores M1, M2 and M3 and possibly M1 in part (d) if not already given

Correct answer without units scores M1 and M2 and possibly M1 in part (d) if not already given

Answer of -240 / -0.24 means temperature of 25 used instead of 298 so scores M1 only

If ans = $+20$ / $+0.020$ assume AE and look back to see if M1 and possibly M2 are scored

1

Q10.

- (a) (i) (At 0 K) particles are stationary / not moving / not vibrating

Allow have zero energy.

Ignore atoms / ions.

1

No disorder / perfect order / maximum order

Mark independently.

1

- (ii) As T increases, particles start to move / vibrate

Ignore atoms / ions.

Allow have more energy.

If change in state, $CE = 0$

1

Disorder / randomness increases / order decreases

1

- (iii) Mark on temperature axis vertically below second 'step'

Must be marked as a line, an 'x', T_b or 'boiling point' on the temperature axis.

1

- (iv) L_2 corresponds to boiling / evaporating / condensing / $l \rightarrow g$ / $g \rightarrow l$

And L_1 corresponds to melting / freezing / $s \rightarrow l$ / $l \rightarrow s$

There must be a clear link between L_1 , L_2 and the change in state.

1

Bigger change in disorder for L_2 / boiling compared with L_1 / melting

M2 answer must be in terms of changes in state and not absolute states eg must refer to change from liquid to gas not just gas.

Ignore reference to atoms even if incorrect.

1

- (b) (i) $\Delta G = \Delta H - T\Delta S$

1

$\Delta H = c$ and $(-)\Delta S = m$ / ΔH and ΔS are constants (approx)

Allow ΔH is the intercept, and $(-)\Delta S$ is the slope / gradient.

Can only score M2 if M1 is correct.

1

- (ii) Because the entropy change / ΔS is positive / $T\Delta S$ gets bigger

Allow $-T\Delta S$ gets more negative

1

- (iii) Not feasible / unfeasible / not spontaneous

1

(c) (i) $+ 44.5 \text{ J K}^{-1} \text{ mol}^{-1}$

Allow answer without units but if units given they must be correct (including mol^{-1})

1

(c) (ii) At 5440 $\Delta H = T\Delta S$

$= 5440 \times 44.5 = 242\,080$

1

(**OR** using given value $= 5440 \times 98 = 533\,120$)

Mark is for answer to (c)(i) $\times 5440$

1

$\Delta H = 242 \text{ kJ mol}^{-1}$

(**OR** using given value $\Delta H = 533 \text{ kJ mol}^{-1}$)

Mark is for correct answer to M2 with correct units (J mol^{-1} or kJ mol^{-1}) linked to answer.

If answer consequentially correct based on (c)(i) except for incorrect sign (eg -242), max 1 / 3 provided units are correct.

1

[15]

Q11.

(a) $\Delta G = \Delta H - T\Delta S$

Or expression $\Delta H - T\Delta S$ must be evaluated

1

If ΔG / expression ≤ 0 reaction is feasible

Or any explanation that this expression ≤ 0

Do not allow just $\Delta G = 0$

1

(b) The molecules become more disordered / random when water changes from a liquid to a gas / evaporates

For M1 must refer to change in state AND increase in disorder

1

Therefore the entropy change is positive / Entropy increases

Only score M2 if M1 awarded

1

$T\Delta S > \Delta H$

Allow M3 for T is large / high (provided M2 is scored)

1

$\Delta G < 0$

Mark M3, M4 independently

1

(c) (i) Condition is $T = \Delta H / \Delta S$

1

$$\Delta S = 189 - 205 / 2 - 131 = -44.5;$$

1

$$\Delta H = -242 \text{ therefore } T = (-242 \times 1000) / -44.5)$$

1

$$= 5438 \text{ K (allow 5400 – 5500 K)}$$

Units essential (so 5438 alone scores 3 out of 4)

2719 K allow score of 2

5.4 (K) scores 2 for M1 and M2 only

1646 (K) scores 1 for M1 only

1

(ii) It would decompose into hydrogen and oxygen / its elements

Can score this mark if mentioned in M2

1

Because ΔG for this reaction would be ≤ 0

Allow the reverse reaction / decomposition is feasible

Only score M2 if M1 awarded

1

(d) $\Delta H = T\Delta S$

Allow correct substituted values instead of symbols

1

$$\Delta S = 70 - 189 = -119 \text{ JK}^{-1} \text{ mol}^{-1}$$

1

$$\Delta H = (-119 \times 373) / 1000 = -44.4 \text{ kJ (mol}^{-1}) \text{ (allow -44 to -45)}$$

Allow -44000 to -45000 J (mol⁻¹)

Answer must have correct units of kJ or J

1

[15]

Q12.

(a) $\Delta G = \Delta H - T\Delta S$

Ignore e

1

(b) 0.098 or 98

Allow 0.097 to 0.099/97 to 99

Allow 0.1 only if 0.098 shown in working

1

$$\text{kJ K}^{-1} \text{ mol}^{-1}$$

$$\text{J K}^{-1} \text{ mol}^{-1}$$

Allow in any order

Unless slope is approx. 100(90-110) accept only kJ K⁻¹ mol⁻¹.

If no slope value given, allow either units

1

$$-\Delta S/\Delta S$$

1

- (c) ΔG becomes negative
Mark independently unless ΔG +ve then CE = 0 1
- So reaction becomes spontaneous/feasible
Or reaction can occur below this temperature
Or reaction is not feasible above this temperature 1
- (d) Ammonia liquefies (so entropy data wrong/different)
Allow any mention of change in state or implied change in state even if incorrect
eg freezing/boiling 1

[7]

Q13.

- (a) $\Delta H = \Sigma(\Delta H_f \text{ products}) - \Sigma(\Delta H_f \text{ reactants})$
Allow correct cycle 1
- $\text{I} = +34 - +90$
 $= -56 \text{ kJ mol}^{-1}$
- Ignore no units, penalise incorrect units* 1
- (b) $\Delta S = \Sigma(S \text{ products}) - \Sigma(S \text{ reactants})$ 1
- $\text{I} = 240 - (205 + 211/2)$
 $= -70.5 \text{ J K}^{-1} \text{ mol}^{-1} / -0.0705 \text{ kJ K}^{-1} \text{ mol}^{-1}$
- Ignore no units, penalise incorrect units*
Allow -70 to -71 / -.070 to -.071 1
- (c) $T = \Delta H / \Delta S$ / $T = (\text{Ans to part(a)} \times 1000) / \text{ans to part(b)}$
Mark consequentially on answers to parts (a) and (b) 1
- $\text{I} = -56 / (-70.5 \div 1000)$
 $= 794 \text{ K (789 to 800 K)}$
Must have correct units
Ignore signs; allow + or – and –ve temps 1
- (d) Temperatures exceed this value 1
- (e) $\text{N}_2 + \text{O}_2 \rightarrow 2\text{NO}$
Allow multiples 1
- (f) there is no change in the number of moles (of gases)

Can only score these marks if the equation in (e) has equal number of moles on each side

Numbers, if stated must match equation

1

So entropy/disorder stays (approximately) constant / entropy/disorder change is very small / $\Delta S=0$ / $T\Delta S=0$

1

[10]

Q14.

- (a) Standard pressure (100 kPa) (and a stated temperature)

Allow standard conditions. Do not allow standard states

Allow any temperature

Allow 1 bar but not 1 atm

Apply list principle if extra wrong conditions given

Penalise reference to concentrations

1

- (b) Hydrogen bonds between water molecules

1

Energy must be supplied in order to break (or loosen) them

Allow M2 if intermolecular forces mentioned

Otherwise cannot score M2

CE = 0/2 if covalent or ionic bonds broken

1

- (c) $T = \Delta H / \Delta S$

1

$$= (6.03 \times 1000) / 22.1$$

1

$$= 273 \text{ K}$$

Allow 272 to 273; units K must be given

Allow 0°C if units given

0.273 (with or without units) scores 1/3 only

Must score M2 in order to score M3

Negative temperature can score M1 only

1

- (d) The heat given out escapes

1

- (e) (Red end of white) light (in visible spectrum) absorbed by ice

Allow complementary colour to blue absorbed

1

Blue light / observed light is reflected / transmitted / left

Penalise emission of blue light

1

[9]

Q15.

- (a) Enthalpy change when 1 mol of an (ionic) compound/lattice (under standard conditions)

Allow heat energy change

1

Is dissociated/broken/separated into its (component) ions

1

The ions being in the gaseous state (at infinite separation)

Mark independently. Ignore any conditions.

1

- (b) There is an attractive force between the nucleus of an O atom and an external electron.

Allow any statement that implies attraction between the nucleus and an electron

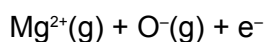
1

- (c) $\text{Mg}^{2+}(\text{g}) + \text{O}(\text{g}) + 2\text{e}^{-}$

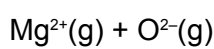
Ignore lack of state symbols

Penalise incorrect state symbols

1



1



1

First new level for Mg^{2+} and O above last on L

If levels are not correct allow if steps are in correct order with arrows in the correct direction and correct ΔH values

1

Next level for Mg^{2+} and O^{-} below that

Next level for Mg^{2+} and O^{2-} above that and also above that for Mg^{2+} and O

Allow +124

Allow M4 with incorrect number of electrons

- (d) $\text{LE MgO} = 602 + 150 + 736 + 1450 + 248 - 142 + 844$

Note use of 124 instead of 248 CE=0

1

$$= +3888 \text{ kJ mol}^{-1}$$

Allow 1 for -3888

Allow no units

Penalise wrong units

1

- (e) Forms a protective layer/barrier of MgO / MgO prevents oxygen attacking Mg

Allow activation energy is (very) high

Allow reaction (very) slow

1

(f) $\Delta G = \Delta H - T\Delta S$

$$\Delta S = \frac{(\Delta H - \Delta G)}{T}$$

1

$$\Delta S = (-602 - (-570)) \times 1000 / 298$$

1

$$= -107 \text{ J K}^{-1} \text{ mol}^{-1} / -0.107 \text{ kJ K}^{-1} \text{ mol}^{-1}$$

If units not correct or missing, lose mark

Allow -107 to -108

+107 with correct units scores max 1/3

1

- (g) 1 mol of solid and 0.5 mol of gas reactants form 1 mol solid products

Decrease in number of moles (of gas/species)

Allow gas converted into solid

Numbers of moles/species, if given, must be correct

1

System becomes more ordered

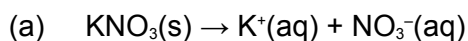
Allow consequential provided ΔS is -ve in 1(f)

If ΔS is +ve in 1(f) can only score M1

1

[16]

Q16.



do not allow equations with H_2O

allow aq and the word 'water' in equation

1

- (b) increase in disorder because solid $\rightarrow$ solution / increase in number of particles / 1 mol (solid) gives 2 mol (ions/particles) / particles are more mobile

allow random or chaos instead of disorder

penalise if molecules/atoms stated instead of ions

allow any reference to increase in number of particles even if number of particles wrong

1

(c) $\Delta G = \Delta H - T\Delta S / T = \Delta H / \Delta S$

1

$$T = \Delta H / \Delta S = (34.9 \times 1000) / 117$$

also scores M1

1

$$= 298 \text{ K}$$

correct answer scores 3, units essential

0.298 scores M1 only

1

- (d) (i) positive / increases / $\Delta G > 0$

Allow more positive

1

- (ii) if ans to (d) (i) positive, dissolving is no longer spontaneous / no longer feasible / potassium nitrate does not dissolve / less soluble

if ans to (d) (i) negative, dissolving is spontaneous / feasible / potassium nitrate dissolves / more soluble

If no mention of change to ΔG in (d)(i),

Mark = 0 for (d)(ii)

1

[7]

Q17.

- (a) (i) $\Delta H = \Sigma \text{ bonds broken} - \Sigma \text{ bonds formed}$

1

$$= 944/2 + 3/2 \times 436 - 3 \times 388$$

1

$$= -38 \text{ (kJ mol}^{-1}\text{)}$$

ignore units even if incorrect

correct answer scores 3

-76 scores 2/3

+38 scores 1/3

1

- (ii) mean / average bond enthalpies are from a range of compounds
or
mean / average bond enthalpies differ from those in a single compound / ammonia

1

- (b) $\Delta S = \Sigma S \text{ products} - \Sigma S \text{ reactants}$

1

$$= 193 - (192/2 + 131 \times 3/2)$$

1

$$= -99.5 \text{ J K}^{-1} \text{ mol}^{-1}$$

units essential for M3

correct answer with units scores 3

-199 J K⁻¹ mol⁻¹ & -99.5 score 2/3

-199 and + 99.5 J K⁻¹ mol⁻¹ score 1/3

1

- (c) (i) $\Delta G = \Delta H - T\Delta S = -46 + 800 \times 99.5/1000$

mark is for putting in numbers with 1000

if factor of 1000 used incorrectly CE = 0

1

= 33.6 or 33600

allow 33 to 34 (or 33000 to 34000)

1

kJ mol⁻¹ with J mol⁻¹

correct units for answer essential

if answer to part (b) is wrong or if -112 used, mark consequentially e.g.

• -199 gives 113 to 114 kJ mol⁻¹ (scores 3/3)

• -112 gives 43 to 44 kJ mol⁻¹ (scores 3/3)

1

(ii) If answer to (c) (i) is positive: not feasible / not spontaneous

If answer to (c) (i) is negative: feasible / spontaneous

if no answer to (c) (i) award zero marks

1

[11]

Q18.

(a) Because it is a gas compared with solid carbon

Mark independently

1

Nitrogen is more disordered/random/chaotic/free to move

1

(b) 0 K/-273 C/absolute zero

1

(c) $\Delta G = \Delta H - T\Delta S$

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

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

$\Delta S = (\Delta H - \Delta G)/T$

Ignore θ in ΔG°

1

(d) ΔG is less than or equal to zero ($\Delta G \leq 0$)

Allow ΔG is less than zero ($\Delta G < 0$)

Allow ΔG is equal to zero ($\Delta G = 0$)

Allow ΔG is negative

1

(e) When $\Delta G = 0$ $T = \Delta H/\Delta S$

1

$\Delta H = +90.4$

Allow $\Delta H = +90$

1

$\Delta S = \Sigma S(\text{products}) - \Sigma S(\text{reactants})$

		1
	$\Delta S = 211.1 - 205.3/2 - 192.2/2 = \underline{12.35}$	1
	$T = (90.4 \times 1000)/12.35 = 7320 \text{ K}/7319.8 \text{ K}$ <i>Allow 7230 to 7350 K (Note 7.32 K scores 4 marks)</i> <i>Units of temperature essential to score the mark</i>	1
(f)	Activation energy is high <i>Allow chemical explanation of activation energy</i> <i>Allow needs route with lower activation energy</i> <i>Allow catalyst lowers activation energy</i>	1
(g)	$\Delta H = 1.9 \text{ (kJ mol}^{-1}\text{)}$	1
	$\Delta S = 2.4 - 5.7 = -3.3 \text{ (J K}^{-1} \text{ mol}^{-1}\text{)}$ <i>for M1 and M2 allow no units, penalise wrong units</i>	1
	ΔG is always positive <i>This mark can only be scored if ΔH is +ve and ΔS is -ve</i>	1

[14]

Q19.

(a)	$\Delta H = \Sigma \Delta H_f(\text{products}) - \Sigma \Delta H_f(\text{reactants})$	1
	$= -201 - 242 - (-394)$	1
	$= -49 \text{ kJ mol}^{-1}$ <i>+49 kJ mol⁻¹ = 1 mark</i> <i>units not required, wrong units lose 1 mark</i>	1
(b)	$\Delta S = \Sigma S(\text{products}) - \Sigma S(\text{reactants})$	1
	$= 238 + 189 - (214 + 3 \times 131)$	1
	$= -180 \text{ J K}^{-1} \text{ mol}^{-1}$ <i>+180 = 1 mark</i> <i>units not required, wrong units lose 1 mark</i>	1
(c)	$\Delta G = \Delta H - T\Delta S$ <i>If use G not ΔG penalise M1 but not M2 and M3</i>	1

(ΔS is negative so) at high temp $-T\Delta S$ (is positive and) greater than ΔH /large

Do not award M2 or M3 if positive ΔS value used

1

So $\Delta G > 0$

Independent mark unless positive ΔS value used

1

(Limiting condition $\Delta G = 0$ so) $T = \Delta H/\Delta S$

1

= 272 K

Allow 297-298 if used given values.

Do not award M5 if T -ve or if M4 should give T -ve

1

Reaction is too slow at this temperature/to speed up the reaction

1

(d) $\text{CH}_3\text{OH} + 3/2\text{O}_2 \rightarrow \text{CO}_2 + 2\text{H}_2\text{O}$

Allow multiples.

Ignore state symbols.

Do not allow equation for wrong compound but mark on provided number of moles increases or stays the same.

If no equation or equation that gives a decrease in the number of moles,

CE = 0

1

2.5 mol give 3 mol (gases)

Allow statement 'increase in number of moles/molecules'

If numerical values given, they must match the equation in M1

Ignore the effect of incorrect state symbols on the number of moles of particles unless used correctly

1

Therefore ΔS is positive/entropy increases

If correct deduction from wrong equation is $\Delta S = 0$ or ΔS very small must say H -ve

1

(combustion exothermic so ΔH -ve so $\Delta H - T\Delta S$) and hence ΔG always negative (less than zero)

1

Allow G instead of ΔG

Can score 3 out of 4 marks if equation wrong but leads to increase or no change in number of moles

M4 dependent on M3

Note, if equation wrong AND there is an incorrect deduction about the change in number of moles, CE = 0

(e) $\text{CO}_2/\text{CO}/\text{CH}_4$ may be produced during H_2 manufacture/building the plant/transport/operating the plant

1

[17]

Q20.

- (a) (i) $1s^2 2s^2 2p^6 3s^2 3p^6$ 1
- (ii) The negative S^- ion 1
- repels the added electron 1
- (iii) Step B is the atomisation enthalpy of sulphur 1
- Step D is the second ionisation enthalpy of calcium 1
- (iv) Electrons nearer to the nucleus 1
- Electrons removed from a positive species or more strongly attracted 1
- (v) $+178 + 279 + 590 + 1145 - 200 + 539 + G + 482 = 0$ 1
- $G + 3013 = 0$ hence $G = -3013$ 1
- (b) The model used assumes the ions are spherical and in a lattice 1
- The calculated value is smaller than the cycle value or stronger attraction 1
- Indicating some covalent character or ions are polarised 1
- (c) (i) For a reaction to occur $\Delta G < 0$ 1
- ΔS is positive and large as a gas is evolved 1
- $T\Delta S$ is larger than ΔH and ΔG is negative 1
- (ii) ΔS is negative 1
- Four moles gaseous reactant forming or more moles of gaseous product 1
- At high temperature $T\Delta S$ is larger than ΔH and ΔG is positive 1

[18]**Q21.**

- (a) Particles are in maximum state of order
(or perfect order or completely ordered or perfect crystal or minimum disorder or no disorder)
(entropy is zero at 0 K by definition) 1
- (b) (Ice) melts
(or freezes or changes from solid to liquid or from liquid to solid) 1
- (c) Increase in disorder 1
- Bigger (at T_2) 1
- Second mark only given if first mark has been awarded*
- (d) (i) Moles of water = $1.53/18$ (= 0.085) 1
- Heat change per mole = $3.49/0.085 = 41.1$ (kJ mol⁻¹)
(allow 41 to 41.1, two sig. figs.)
(penalise -41 (negative value), also penalise wrong units but allow kJ only) 1
- (ii) $\Delta G = \Delta H - T\Delta S$ 1
- (iii) $\Delta H = T\Delta S$ or $\Delta S = \Delta H/T$
(penalise if contradiction) 1
- $\Delta S = 41.1/373 = 0.110$ kJ K⁻¹ (mol⁻¹) (or 110 (J K⁻¹ (mol⁻¹))
(allow 2 sig. figs.)
(if use value given of 45, answer is 0.12 (or 120 to 121)
(if ΔH is negative in (d) (i), allow negative answer)
(if ΔH is negative in (d) (i), allow positive answer)
(if ΔH is positive in (d) (i), penalise negative answer) 1
- Correct units as above (mol⁻¹ not essential) 1

[10]

Q22.
C

[1]

Q23.
C

[1]

Q24.

B

[1]

Q25.

A

[1]

Q26.

(a) M1 $K_p = (p_Y)^3 \cdot (p_Z)^2 / (p_W)^2 \cdot (p_X)$ NB [] wrong

1

M2 temperature

1

M3 increase

1

M4 particles have more energy or greater velocity/speed

1

M5 more collisions with $E > E_a$ or more successful collisions

1

M6 Reaction exothermic or converse

1

M7 Equilibrium moves in the left

1

Marks for other answers

Increase in pressure or concentration allow M1, M5, M6 Max 3

Addition of a catalyst; allow M1, M5, M6 Max 3

Decrease in temperature; allow M1, M2, M6 Max 3

Two or more changes made; allow M1, M6 Max 2

(b) (i) Advantage; reaction goes to completion, not reversible or faster

1

Disadvantage; reaction vigorous/dangerous

(exothermic must be qualified)

or HCl(g) evolved/toxic

or CH₃COCl expensive

NB Allow converse answers

Do not allow reactions with other reagents e.g. water or ease of separation

1

(ii) $\Delta S = \Sigma S \text{ products} - \Sigma S \text{ reactants}$

1

$\Delta S = (259 + 187) - (201 + 161)$

1

$$\Delta S = 84 \text{ (JK}^{-1} \text{ mol}^{-1}) \quad (\text{Ignore units})$$

Allow – 84 to score (1) mark

1

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

1

$$\begin{aligned} &= -21.6 - 298 \times 84/1000 \\ &= -46.6 \text{ kJ mol}^{-1} \text{ or } -46\,600 \text{ J mol}^{-1} \end{aligned}$$

1

Allow (2) for – 46.6 without units

(Mark ΔG consequentially to incorrect ΔS)

(e.g. $\Delta S = -84$ gives $\Delta G = +3.4 \text{ kJ mol}^{-1}$)

1

[15]

Q27.

- (a) Standard enthalpy change, $\Delta H^\ominus$: $\Delta H_R = \Sigma \Delta H_{f \text{ products}} - \Sigma \Delta H_{f \text{ reactants}}$ (1)
or cycle

$$\begin{aligned} \Delta H_R &= (0 + [2 \times -242]) - (4 \times -92) \text{ (1)} \\ &= -484 + 368 \\ &= -116 \text{ (kJ mol}^{-1}) \end{aligned}$$

Allow max 1 for +116

Standard entropy change, $\Delta S^\ominus$: $\Delta S = \Sigma \Delta H_{f \text{ products}} - \Sigma \Delta H_{f \text{ reactants}}$

$$\Delta S = ([2 \times 223] + [2 \times 189]) - (205 + [4 \times 187]) \text{ (1)}$$

$$= 824 - 953$$

$$= -129 \text{ (J K}^{-1} \text{ mol}^{-1})$$

allow max one for +129

6

- (b) (i) Effect: Equilibrium displaced to right / to products (1)
Explanation: Reaction is endothermic (1)
Constraint reduced (1)

mark separately

- (ii) Feasible when $\Delta G \leq 0$ (1)

$$\Delta G = \Delta H - T\Delta S \text{ (1)}$$

$$T = \Delta H / \Delta S = 208 \times 1000 \text{ (1)} / 253$$

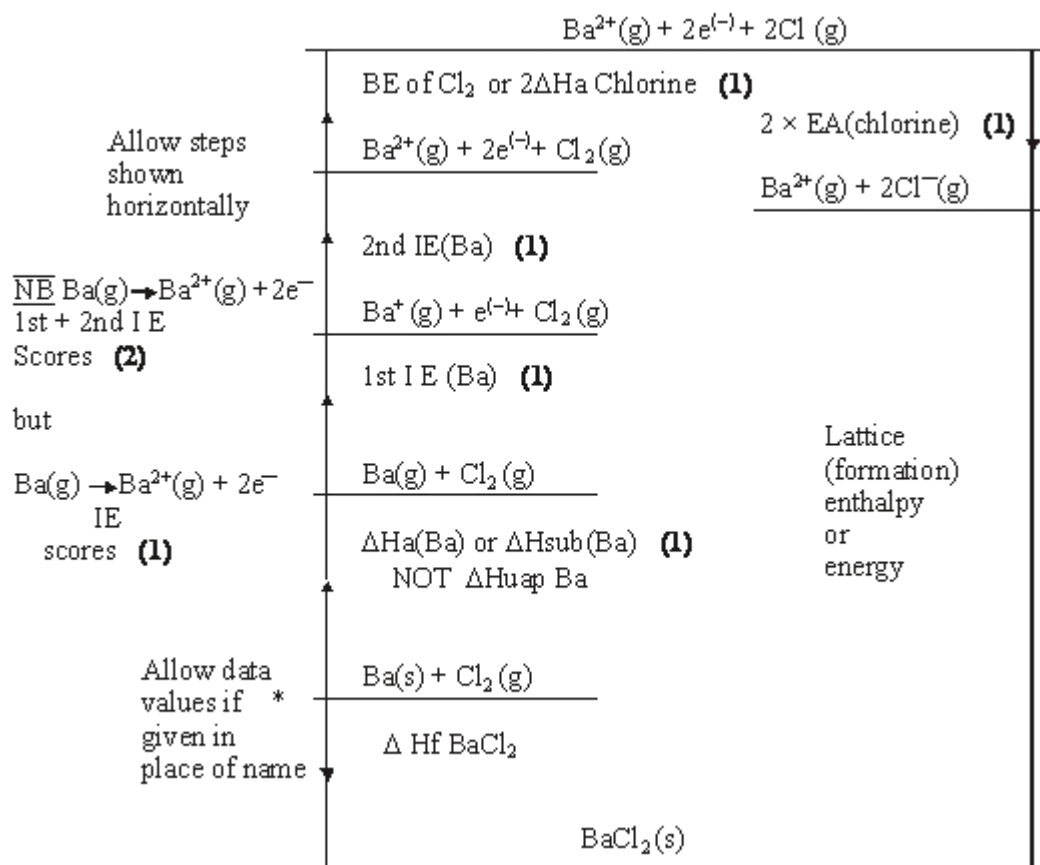
$$= 822 \text{ K (1)}$$

7

[13]

Q28.

(a) (i)



ONLY consider species involved in the step marked

(ii) Cycling clockwise about (*)

CE if step missing

$$\Delta H_{\text{a}}\text{Ba} + 1^{\text{st}} \text{IEBa} + 2^{\text{nd}} \text{IE Ba} + 2\Delta H_{\text{a}}\text{Cl} + 2\text{EA}\text{Cl} + \text{LE} - \Delta H_{\text{f}}\text{BaCl}_2 = 0 \quad (1)$$

$$+180 + 503 + 965 + 2 \times 122 + 2\text{EA} - 2056 + 859 = 0 \quad (1)$$

$$\text{EA} = -695/2 = - (347 \text{ to } 348) \quad (1)$$

Ignore units

Calculation -1 for each error

Mark conseq.

Notes: -695 scores (2)

+(347 to 348) scores (2)

-(286 to 287) scores (2)

+(286 to 287) scores (1)

-573 scores (1)

+573 scores (0)

9

(b) $\Delta S = \Sigma S \text{ products} - \Sigma S \text{ reactants}$
 $= (63 + 223) - 124 = 162 \quad (1)$

$$\Delta G = \Delta H - T\Delta S \quad \text{or} \quad \Delta H = T\Delta S \quad \text{or} \quad T = \Delta H/\Delta S \quad (1)$$

or used correctly

$$\Delta H = 859 \times 10^3 \quad (1) = T \times 162$$

$$T = (5 \, 300 \text{ to } 5304) \text{ K} \quad (1)$$

Penalise if units °C
 -1 for each error + mark conseq.

4

[13]

Q29.

B

[1]

Q30.

C

[1]

Q31.

- (a) (i) *Standard enthalpy change:*
 $\Delta H_R = \Sigma \Delta H_f(\text{products}) - \Sigma \Delta H_f(\text{reactants})$ (1)
or cycle

$$\Delta H_R = ([2 \times 0] + [3 \times -393.5]) - (-824.2 + [3 \times -110.5])$$
 (1)

$$= -24.8 \text{ (kJ mol}^{-1}\text{)}$$
 (1)

Allow + 24.8 max one

Standard entropy change: $\Delta S = \Sigma S(\text{products}) - \Sigma S(\text{reactants})$ (1)

$$\Delta S = ([2 \times 27.3] + [3 \times 213.6]) - (87.4 + [3 \times 197.6])$$
 (1)

$$= (54.6 + 640.8) - (87.4 + 592.8)$$
 (1)

$$= 15.2 \text{ (JK}^{-1}\text{mol}^{-1}\text{)}$$
 (1)

Allow -15.2 max one

- (ii) $\Delta G = \Delta H - T\Delta S$ (1)
 ΔH negative and $-T\Delta S$ is negative (or ΔS positive or
 or correct calc) (1)
 Hence ΔG is always negative
 (or feasible when $\Delta G \leq 0$) (1)

9

- (b) $\Delta G = 0 = \Delta H - T\Delta S$ Hence $\Delta H = T\Delta S$ (1)

$$T = \Delta H / \Delta S = 492.7 \times 1000 / 542.6$$
 (1)

$$= 908 \text{ K}$$
 (1)

penalise missing 1000 by one mark

3

- (c) $\Delta G(b) = \Delta G(a)$
 $(492.7 \times 10^3 - T \times 542.6) = (-24.8 \times 10^3 - T \times 15.2)$ (1)
 $517.5 \times 10^3 = 527.4 T$ (1)
 $T = 981.2 \text{ K}$ (1)

Allow 980 - 982

Penalise missing 1000 by one mark

3

[15]

Q32.

C

[1]

Q33.

A

[1]

Q34.

B

[1]

Examiner reports

Q1.

- (a) Nearly all students (91.1%) gained both marks here.
- (b) Although 73.9% of students scored two marks, common errors here included a failure to convert temperature into kelvin or using inconsistent energy units.
- (c) Students found the explanation in this part more challenging and many could not state that the Gibbs free-energy would become more negative. Many students, however, scored the second mark for a correct reference to a change in entropy.
- (d) Many students discussed the general principles of homogeneous catalysis or the lowering of activation energy rather than the reaction on the platinum surface. The mark most commonly missed was the idea that the product desorbed from or left the surface of the catalyst. Surprisingly, over 10% of students made no attempt at this question.
- (e) 74.4% of students answered this correctly, although a few students thought the oxidation state of N in ammonia was +3.
- (f) Many students gave hydrogen as the other product or failed to balance an equation in which water was the other product.

Q2.

Most students calculated ΔS correctly and gave the correct expression for ΔG . Many students then went on to calculate the value of ΔG correctly. Some students failed to convert the temperature to a value in kelvins, some failed to convert the energy into kilojoules, and some did not give the value of ΔG to the required precision.

Q3.

- (a) This proved to be a much tougher starter question than had been anticipated, with only 12% of students earning the mark. Students did not recognise that enthalpy change could not be measured directly. In this case, the enthalpy change was for the formation of a hydrated salt from an anhydrous one, with the expected answer being that it would be impossible to prevent some salt dissolving during the addition of water to the anhydrous salt. An alternative answer, related to the difficulty in measuring the temperature of a solid, was also allowed.

Some students' answers revealed confusion between calorimetry and colorimetry, with suggested answers including the lack of colour change during the reaction. Some students also seemed to believe that calorimetry is only possible if something is being burned.

- (b) This calculation was answered reasonably well, with less than 20% of students failing to score. There was confusion about the 'direction' around the Hess Cycle, and evidence of many students thinking that an equation of the form $\Delta H = \sum \Delta H_f(\text{products}) - \sum \Delta H_f(\text{reactants})$ can be used universally, when it only applies to the specific use of enthalpies of formation.
- (c) Most students' encounter with this 'extended response' style of question produced a good spread of marks, although 37% of students failed to score. This was usually due to a completely inappropriate method being described, with incorrect answers

such as: “making a solution of magnesium chloride”, “using it to fill a spirit burner and lighting it under a beaker of water” and “putting a solution of magnesium chloride in a polystyrene cup and heating it over a Bunsen burner”. Other incorrect answers included descriptions of the preparation of a standard solution followed by a titration and the addition of magnesium chloride to acid instead of to water.

This question was marked using a ‘levels of response’ mark scheme. The key to success was for students to concentrate first on the inclusion of as much correct chemistry as possible to ensure access to Level 3 (worth 5 or 6 marks). Within a level, the mark awarded depended on the clarity and coherence of an answer, together with a clear, logical progression through the description. Appropriate apparatus and quantities should have been mentioned as necessary. For example, rather than writing ‘add water to a container’, a good start to the answer would be to write ‘A measuring cylinder was used to measure 50 cm³ of water into a polystyrene cup’.

Despite the fact that many students suggested in part (a), that it is difficult to measure the temperature of a solid, many then suggested putting the magnesium chloride into the polystyrene cup first and then recording its initial temperature, before adding the water.

- (d) This was a challenging question, but one for which it proved relatively easy to score two marks; nearly 20% of students scored full marks here. Most students could successfully plot the points and draw a best fit line, although the negative scale on the y-axis confused some. Most students were also able to calculate the gradient of their line, although, as mentioned previously, it was not always clear what their suggested answer was. The calculation of ΔS proved trickier, with many trying to use the relationship $\Delta G = \Delta H - T\Delta S$, and either ignoring their calculated gradient or substituting it in for ΔH . Relatively few students recognised that this equation can be taken as $y = mx + c$ ($y = c - xm$ in this case) so that this graph of ΔG (y) vs T (x) gives a straight line with a gradient of $-\Delta S$.

Q7.

Most students scored highly in part (a). Incorrect units for entropy change were often seen in part (b). Students generally understood the concept of disorder and scored the mark in part (c). The majority of students could use their own values to calculate the free-energy change in part (d); common errors included incorrect units, failure to convert temperature into Kelvins and using a mixture of joules and kilojoules in their calculation. The relationship between ΔG and feasibility was well known in part (e). The meaning of heterogeneous was well known in part (f)(i) and the equations in part (f)(ii) were generally well known. Students answered part (f)(iii) well although in part (f)(iv) a few referred to impurities being produced without any reference to poisoning of the catalyst.

Q8.

The calculations in parts (a)(i) and (a)(ii) were usually correct although errors in part (a)(ii) sometimes occurred due to a failure to recognise the three moles of hydrogen. Parts (b) and (c) were also answered well and it was pleasing to see that most students ensured that the enthalpy and entropy changes were in the same units before calculating the temperature. Part (d)(i) was answered well by many students though many of these scored only 2 out of the three marks available because the units of free energy were omitted. Students should be encouraged to remember to give units for all numerical answers. Part (d)(ii) proved to be very challenging and only the best students were able to express in words why a lowering of the temperature would eventually lead to a negative value for the free-energy change.

Q9.

Answers to part (a) usually gained both marks but some students lost a mark because they gave imprecise answers. Most students calculated the enthalpy of hydration correctly for part (b) but part (c) was found to be more challenging and only the highest-scoring students were able to describe the interaction between a chloride ion and a polar water molecule. In part (d), the calculation of temperature was usually correct but most students did not mention that, at this temperature, water would no longer be a liquid. The value for the entropy change in part (e) was usually correct but the units were sometimes missing or incorrect. A number of students omitted the negative sign for this entropy change possibly in the mistaken belief that entropy would always increase when a solid dissolves.

Q10.

This question was answered well by most students except for parts (a)(iv) and (b)(ii). In part (a)(iv), students were asked to explain why one line on the Figure 1 was longer than the other in terms of the behaviour of molecules. A question of this type demands an answer that compares one feature with another. Most students did not discuss the change in disorder accompanying a change in state and did not compare melting with boiling. In part (b)(ii), many students did not explain that the $T\Delta S$ term in the equation would increase as T increases.

Q11.

Part (a) was answered well by most students. In part (b), most students scored the first 2 marks for a recognition that the entropy increases when water becomes more disordered as it changes into a gas. Only the highest-scoring students went on to explain that the free energy change is negative when the $T\Delta S$ term is greater than ΔH . Good students were able to score full marks for part (c)(i). A common error amongst weaker students was a failure to recognise that only half a mole of oxygen is involved. Part (c)(ii) also discriminated well with only the highest-scoring students giving a correct reason why water would change into hydrogen and oxygen. In part (d), good students usually scored full marks but weaker students did not get beyond a statement that $\Delta H = T\Delta S$.

Q12.

It is pleasing to report that a majority of students scored very well in this question. Some students did lose a mark for a lack of precision in their calculation of the slope giving an answer of 0.1 instead of the expected 0.098.

Q13.

This question, except for part (d), was answered well by many students of all abilities. In part (d), only the best students appreciated that the reaction would not be feasible above 794 K and, therefore, predicted that this temperature is exceeded in internal combustion engines.

Q14.

In part (a), about half of all students knew the meaning of the symbol. Answers to part (b) were very disappointing. Answers were characterised by a lack of precise language and a lack of understanding that hydrogen bonds between water molecules must be broken when ice melts. Students are expected to understand that the bonds broken are between the molecules. It is pleasing to report that answers to part (c) were almost always correct. However, in part (d) this 'how science works' question was not understood and only 11% of students gained a mark. Part (e), however, was answered correctly by the great majority of students and it is pleasing to report that the concept of colour was understood

well, despite the context being unfamiliar.

Q15.

Most answers to part (a) were correct and scored all three marks. The most common error was to confuse enthalpy of lattice dissociation with enthalpy of formation. Part (b) was not answered so well. Weak students often confused electron affinity with ionisation. Part (c) was answered well and many correct answers were seen. Answers to part (d) were less good. The most common error was to confuse atomisation enthalpy for oxygen with bond enthalpy and therefore to use a value of 124 kJ mol^{-1} in the calculation instead of 248 kJ mol^{-1} . Another common error was to give a negative value for the answer – presumably due to confusion of the enthalpy of lattice formation with the required enthalpy of lattice dissociation. About half of all students gave a correct answer to part (e). Answers to part (f) were often wrong. The usual error was a failure to use a factor of 1000 in order to make enthalpy and entropy have the same units. Part (g) was answered well and those students who calculated a negative entropy change in part (f) usually scored full marks.

Q16.

This question also produced very low scores, especially in parts (a) and (b). It was very disappointing to find that only 27% of candidates could write a correct equation for part (a). Most candidates appear to think that when potassium nitrate dissolves in water, it forms potassium hydroxide and nitric acid. In part (b) many candidates confused the liquid and the aqueous states of an ionic compound; they often stated incorrectly that potassium nitrate became a liquid when it dissolved in water. Answers to the remainder of the question were very often correct.

Q17.

Only 28% of candidates gained all three marks in part (a)(i). The usual error was a failure to follow the instruction in the question that required an enthalpy change for only one mole of ammonia. In part (a)(ii) many candidates were unable to explain clearly that individual bond enthalpies in a specific compound will differ from data book values of mean bond enthalpies that are an average of bond enthalpy values from a range of different compounds. The remainder of this question was well answered by most candidates.

Q18.

This question proved to be easier than Question 1. Most candidates scored full marks in part (a) but part (b) was answered less well and was not attempted by a significant number of candidates. Parts (c) and (d) were answered correctly by almost all candidates. A majority of candidates scored full marks for part (e). The most common error was, as usual, a failure to convert the entropy term into kJ, the same units as the enthalpy change. In part (f), over half of the candidates did not recognise that this question was concerned with rate of reaction and hence the activation energy and they attempted to argue incorrectly in terms of thermodynamics. Just over half of all candidates gained full marks for part (e). A common error was to give a value with the wrong sign for the enthalpy change or for the entropy change.

Q19.

In this question, parts (a) and (b) were answered well but the remainder of the question proved to be much more difficult. In part (c) the most difficult part of the question concerned an explanation why the reaction was not feasible at high temperatures. Candidates were expected to argue that, because the entropy change was negative, the term $-T\Delta S$ was positive and large at high values of T so that the entropy effect would

more than compensate for a negative enthalpy change leading to positive ΔG values. Only the best candidates were able to argue in these terms. The calculation of temperature caused problems for weaker candidates who failed to use the factor of 1000 to ensure that ΔH and $T\Delta S$ were in the same units. In part (d) it was rather distressing to discover the large number of candidates who were unable to write a balanced equation for the combustion of methanol. Some candidates did not read the question carefully and failed to register that the combustion was in the gas phase. Answers to part (e) were very disappointing. Candidates should realise that re-stating the question to suggest that the reactants are not carbon neutral is not sufficient to gain a mark. Also, it was not generally recognised that the term 'carbon neutral' refers not to carbon but to the balance of carbon-containing gases in the atmosphere.

Q21.

This question also produced a wide range of marks. A major misconception was to relate entropy directly to the energy of particles rather than to their disorder. Most candidates gave a correct answer to part (b). In part (c) weak candidates often discussed the breaking of bonds rather than referring to disorder. Others just reiterated the question by stating that the entropy would increase. Good candidates usually gained one mark by stating that the disorder of particles increases when a liquid changes to a gas but only the best candidates answered the question fully by referring also to the smaller change in order on melting. It was pleasing to note that part (d) was answered correctly by many candidates. Marks were sometimes lost when giving units in part (d)(iii) that did not tally with the numerical answer. For example, when the numerical answer should have corresponded to $\text{J K}^{-1} \text{mol}^{-1}$ the units were frequently given as $\text{kJ K}^{-1} \text{mol}^{-1}$.

Q26.

Many candidates gave a correct expression for the equilibrium constant, K_p , for the reaction given in part (a). Some, who gave correct indices, lost a mark as they included square brackets, which are specific used to indicate concentration, in their expression. Identifying the one change which would increase the rate of reaction and decrease the value of K_p proved challenging but part marks were awarded for answers which addressed either of the two required changes. Candidates who gave more than one change of condition were able to score one mark for a correct K_p expression. There were many vague answers to part (b)(i), some of which assumed there were other reactants present with the most common example being water in Reaction 2. By contrast, (b)(ii) was very well answered with many candidates scoring full marks. Most candidates now remember to use either kJ mol^{-1} or J mol^{-1} throughout these calculations but a small number still failed to do this. Consequential marks were awarded in each part of the calculation.

Q27.

This question was very well answered with many candidates scoring full, or nearly full marks. Just a few of the weaker candidates made errors when calculating the standard enthalpy change, ΔH° , and the standard entropy change, ΔS° , and marks were awarded consequentially to an arithmetic error. In part (b), most deduced correctly the effect of an increase in temperature on the equilibrium reaction but not all gave a full explanation of their answer. The calculation of the minimum temperature for the reaction to be feasible was also well done with few failing to use the same units for the enthalpy and the entropy changes.

Q28.

All of the required enthalpy changes involved in the Born-Haber cycle for the formation of BaCl_2 were given in section (ii) of part (a) and the question specifically stated that a full

labelled cycle was required with symbols for all species. Nevertheless, many candidates lost marks when they omitted state symbols, electrons and steps and gave incorrect species.

Consequential marks were awarded in (a)(ii) and only candidates who made three errors failed to score in this section. Part (b) was well answered. Candidates who failed to convert the values of the enthalpy and entropy changes into the same units lost one mark as did those who chose the wrong value for the enthalpy of the reaction from the data given.

Q31.

It is pleasing to report that this question was well answered with many candidates scoring full marks for the calculation in parts (a) and (b). Part (c) was intended to be more testing, and so it proved. Nevertheless, a pleasing number of the better candidates made correct deductions.

In part (c), full marks could be scored consequentially by candidates who had made errors in part (a)