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EDEXCEL A LEVEL CHEMISTRY: QUESTIONS BY TOPIC

Energetics II (13)

A Level Chemistry Topic 13

13 questions · 127 marks · Mark schemes included

Pearson Edexcel A Level Chemistry (9CH0), June 2017 - June 2025

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HOW TO USE THIS BOOKLET

Questions are grouped by specification sub-topic; within each sub-topic they run from the lowest mark tariff to the highest.

Click any sub-topic heading or question row below to jump straight to it.

On every question page, click ANSWER in the top-right corner to jump to its mark scheme.

Diagrams, graphs, tables and data are printed exactly as they appeared in the original papers.

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QUESTIONS

13 questions · 127 marks · grouped by sub-topic



SUB-TOPIC 13(a)

LATTICE ENERGY AND BORN-HABER CYCLES

6 questions in this sub-topic · 54 marks · lowest tariff first



7 This question is about lattice energy.

(a) Which statement defines the lattice energy of an ionic solid?

(1)

- ☐ **A** the energy absorbed when 1 mol of an ionic substance is formed from its gaseous ions
- ☐ **B** the energy change when 1 mol of an ionic substance is formed from its elements in their standard states
- ☐ **C** the energy change when 1 mol of an ionic substance is formed from its gaseous ions
- ☐ **D** the energy absorbed when 1 mol of an ionic substance is formed from its elements in their standard states

(b) Which substance has the lattice energy with the most exothermic value?

(1)

- ☐ **A** NaCl
- ☐ **B** NaI
- ☐ **C** KCl
- ☐ **D** KI

(c) Which ionic solid would have the greatest difference between the theoretical and experimental lattice energies?

(1)

- ☐ **A** NaCl
- ☐ **B** NaI
- ☐ **C** KCl
- ☐ **D** KI

(Total for Question 7 = 3 marks)



2 This question is about the formation of ions.

(a) Explain the trend in the values of the first electron affinities of the elements shown.

(4)

Element	First electron affinity / kJ mol^{-1}
chlorine	–349
bromine	–325
iodine	–295

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(b) Which of these isoelectronic ions has the **smallest** ionic radius?

(1)

- ☐ **A** S^{2-}
- ☐ **B** Cl^-
- ☐ **C** K^+
- ☐ **D** Ca^{2+}



- (c) Some series of successive ionisation energies in kJ mol^{-1} are shown.
The letters do not refer to the symbols of the elements.

Element	Successive ionisation energies / kJ mol^{-1}				
A	578	1817	2745	11 578	14 831
B	653	1592	2987	4740	6686
C	738	1451	7733	10 541	13 629
D	1086	2353	4621	6223	37 832

- (i) Which element in the table could be in Group 4?

(1)

- ☐ A
- ☐ B
- ☐ C
- ☐ D

- (ii) Which element in the table could be described as an *s*-block element?

(1)

- ☐ A
- ☐ B
- ☐ C
- ☐ D

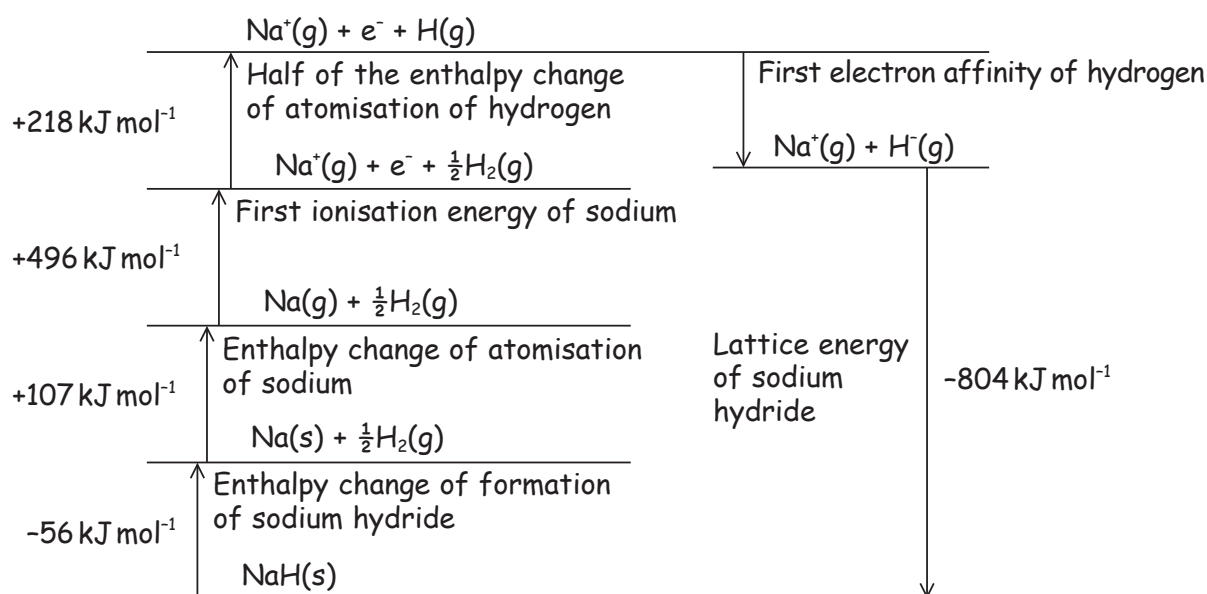
(Total for Question 2 = 7 marks)



8 Sodium hydride, NaH, can be used to generate hydrogen for fuel cells.

(a) In order to calculate the first electron affinity of hydrogen, a student was asked to draw a Born-Haber cycle for sodium hydride.

The cycle had **two** errors but the numerical data were correct.



(i) Identify and correct the **two** errors in this Born-Haber cycle.

(2)

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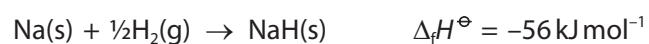
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(ii) Calculate the first electron affinity, in kJ mol^{-1} , of hydrogen, using the values given in the cycle.

(1)

(b) The equation for the formation of sodium hydride is



The standard entropy change of the system, $\Delta S_{\text{system}}^\ominus$, for this reaction is $-76.5 \text{ J K}^{-1} \text{ mol}^{-1}$.

- (i) Deduce the feasibility of this reaction at 298 K by calculating the free energy change, ΔG .

(2)

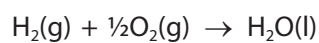
- (ii) Calculate the temperature at which $\Delta G = 0$.

(1)

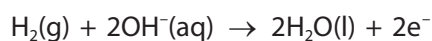


- (c) The sodium hydride is crushed in the presence of water to release the hydrogen gas for a fuel cell.

The overall equation for the reaction occurring in the fuel cell is



In an alkaline fuel cell the oxidation half-equation is



Deduce the reduction half-equation for the alkaline fuel cell.

State symbols are not required.

(1)

- (d) Lattice energies provide an indication of ionic bond strength.

Which are the lattice energies of the hydrides NaH, KH and MgH_2 ?

(1)

Lattice energy / kJ mol^{-1}			
	Sodium hydride, NaH	Potassium hydride, KH	Magnesium hydride, MgH_2
☐ A	–804	–711	–1018
☐ B	–804	–711	–2718
☐ C	–804	–911	–1018
☐ D	–804	–911	–2718

(Total for Question 8 = 8 marks)



6 Magnesium bromide, MgBr_2 , is an ionic compound.

- (a) (i) Draw a dot-and-cross diagram to show the bonding in magnesium bromide.
Only outer shell electrons are required.

(1)

- (ii) State all the conditions under which magnesium bromide conducts electricity.

(1)

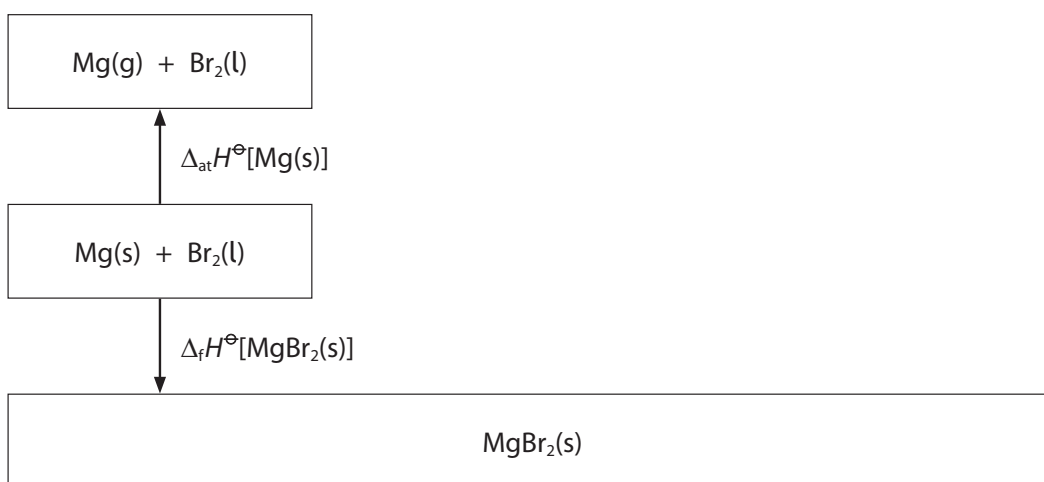


- (b) The table shows the enthalpy changes needed to calculate the first electron affinity of bromine.

Enthalpy change	Value / kJ mol^{-1}
enthalpy change of atomisation of magnesium, $\Delta_{\text{at}}H^\ominus[\text{Mg(s)}]$	+148
1 st ionisation energy of magnesium, 1 st IE[Mg(g)]	+738
2 nd ionisation energy of magnesium, 2 nd IE[Mg ⁺ (g)]	+1 451
enthalpy change of atomisation of bromine, $\Delta_{\text{at}}H^\ominus[\frac{1}{2}\text{Br}_2(\text{l})]$	+112
lattice energy of magnesium bromide, LE[MgBr ₂ (s)]	–2 440
enthalpy change of formation of magnesium bromide, $\Delta_f H^\ominus[\text{MgBr}_2(\text{s})]$	–524

- (i) Complete the Born-Haber cycle for magnesium bromide with formulae, electrons and labelled arrows. The cycle is not drawn to scale.

(3)



(ii) Calculate the first electron affinity of bromine, in kJ mol^{-1} .

(2)

(c) (i) The first ionisation energy of sodium is 496 kJ mol^{-1} .

Explain why the first ionisation energy of magnesium is higher than that of sodium.

(3)

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(ii) Write the equation, including state symbols, to show the **third** ionisation energy of magnesium.

(1)

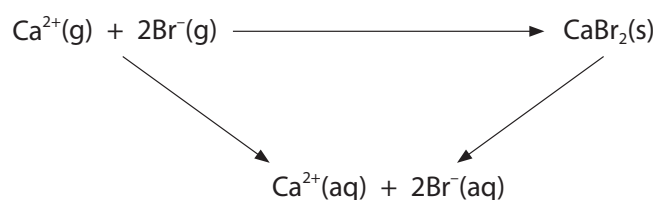
(Total for Question 6 = 11 marks)



(ii) Calculate the lattice energy of copper(II) oxide.

(1)

(c) A different energy cycle can be used to calculate lattice energy.



Enthalpy change	Value / kJ mol^{-1}
enthalpy change of solution of CaBr_2	–73
enthalpy change of hydration of Ca^{2+}	–1577
enthalpy change of hydration of Br^{-}	–336

Calculate the lattice energy of calcium bromide.

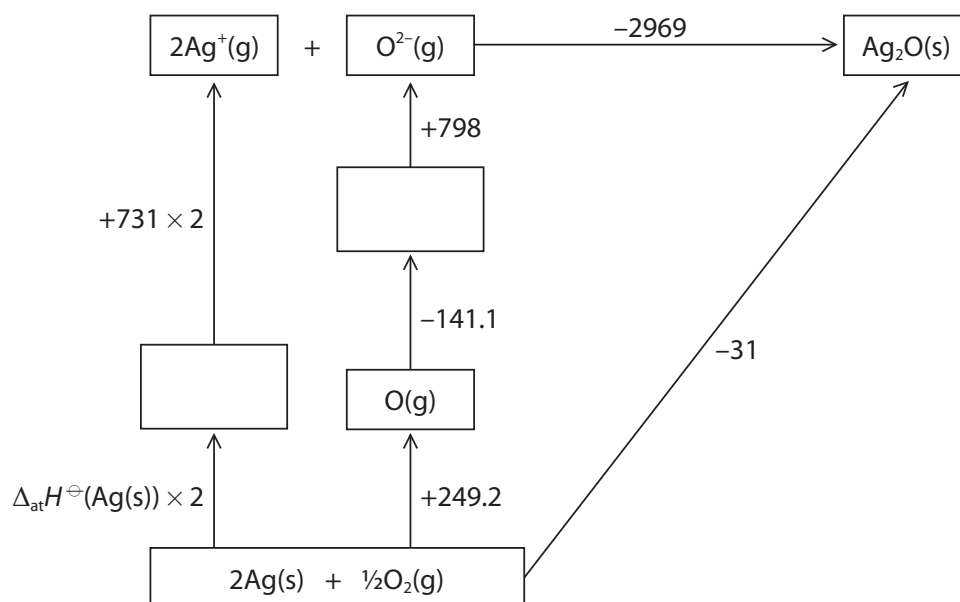
(2)

(Total for Question 9 = 12 marks)



9 This question is about silver compounds.

- (a) The diagram shows a Born–Haber cycle for the formation of silver(I) oxide, Ag_2O . All quantities are measured in kJ mol^{-1} .



- (i) Complete the diagram by adding appropriate species and state symbols to the empty boxes. (2)
- (ii) Explain why the value for the first electron affinity of oxygen is negative and the value for the second electron affinity is positive. (3)

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(iii) Calculate a value for the standard enthalpy change of atomisation of silver, $\Delta_{\text{at}}H^{\ominus}$, using the Born–Haber cycle.

(3)



- (b) Another silver compound is silver chloride, AgCl. Values for its lattice energy can be found by experiment or by theoretical calculation.

Compound	Experimental lattice energy / kJ mol^{-1}	Theoretical lattice energy / kJ mol^{-1}
Silver chloride	–905	–833

- (i) Give **two** assumptions used in the model to calculate the theoretical lattice energy.

(2)

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- (ii) Explain the difference in the two values for the lattice energy of silver chloride by considering the possible bonding models.

(3)

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(Total for Question 9 = 13 marks)



SUB-TOPIC 13(c)

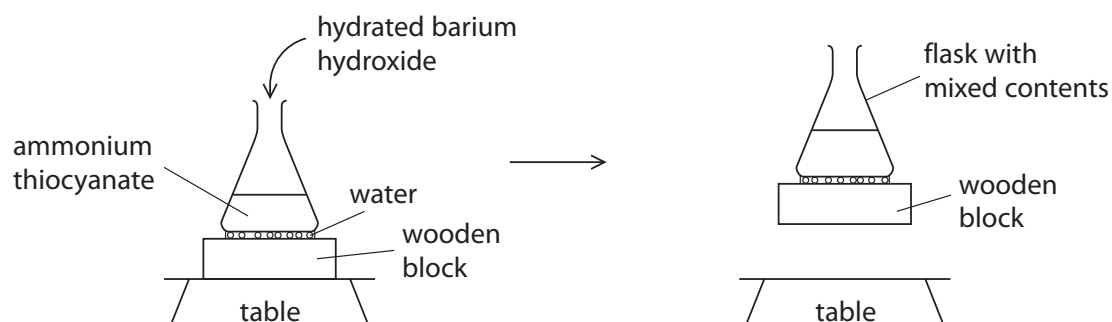
ENTROPY AND GIBBS ENERGY

7 questions in this sub-topic · 73 marks · lowest tariff first



6 This question is about entropy.

- (a) Some hydrated barium hydroxide is added to ammonium thiocyanate in a flask which is placed on a few drops of water on a wooden block. After the addition, the contents are stirred and then the flask can be lifted up with the wooden block attached, as shown.



The equation for the reaction is



- (i) Give **two** reasons why you would expect $\Delta S_{\text{system}}^\ominus$ to be positive.

(2)

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- (ii) Explain why the wooden block is lifted up by the flask.

(2)

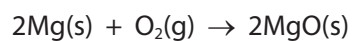
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(b) What is the standard molar entropy change, $\Delta S_{\text{system}}^{\ominus}$, in $\text{JK}^{-1} \text{mol}^{-1}$, for the reaction shown?



Substance	Standard molar entropy, $S^{\ominus} / \text{JK}^{-1} \text{mol}^{-1}$
Mg(s)	32.7
O ₂ (g)	205.0
MgO(s)	26.9

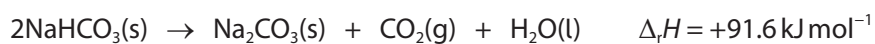
(1)

- ☒ A +210.8
- ☒ B -210.8
- ☒ C +216.6
- ☒ D -216.6

(Total for Question 6 = 5 marks)

- 9 Sodium hydrogencarbonate is used as a raising agent in baking as carbon dioxide gas is released when it undergoes thermal decomposition.

(a) Show that this reaction is **not** feasible at 298 K by calculating ΔG .



(3)

Compound	$\text{NaHCO}_3(\text{s})$	$\text{Na}_2\text{CO}_3(\text{s})$	$\text{CO}_2(\text{g})$	$\text{H}_2\text{O}(\text{l})$
Standard molar entropy $/\text{J K}^{-1} \text{ mol}^{-1}$	101.7	135.0	213.6	69.9

- (b) Calculate the minimum temperature, in degrees Celsius ($^{\circ}\text{C}$), at which an oven should be set for this reaction to be thermodynamically feasible.

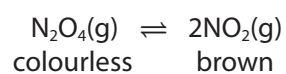
(2)

Minimum temperature = ... $^{\circ}\text{C}$

(Total for Question 9 = 5 marks)



- 5 This question is about the decomposition of dinitrogen tetroxide.
The reaction eventually reaches equilibrium.



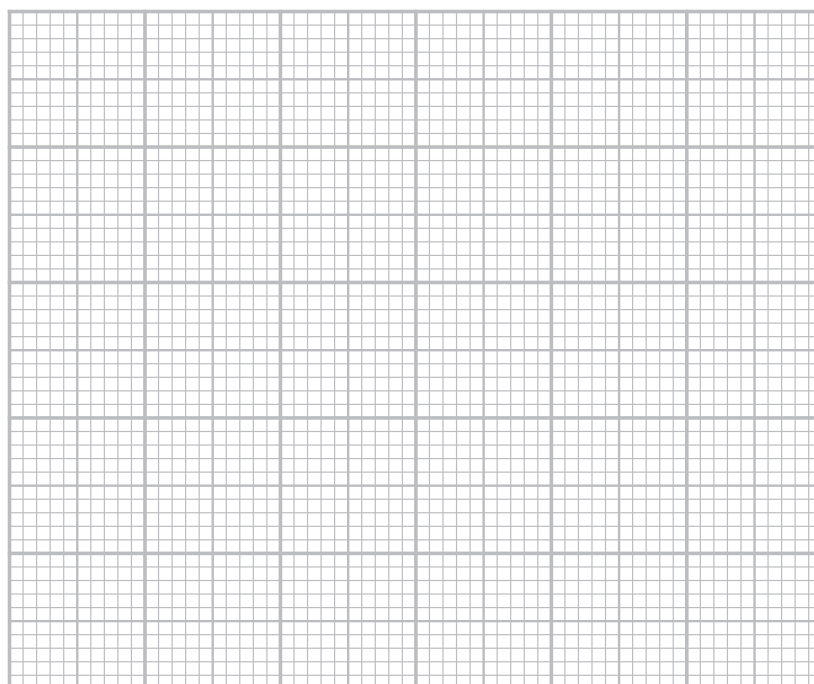
- (a) The table shows values of ΔG at different temperatures for this reaction.

Temperature / K	$\Delta G / \text{kJ mol}^{-1}$
350	-4.0
400	-13
450	-22
500	-31
550	-40

- (i) Plot a graph of ΔG against temperature.

(2)

$\Delta G / \text{kJ mol}^{-1}$



Temperature / K



- (ii) Calculate the entropy change of the system, ΔS_{system} , in $\text{JK}^{-1} \text{mol}^{-1}$, using your straight line from the graph in (a)(i) and the equation shown.

$$\Delta G = -T\Delta S_{\text{system}} + \Delta H \quad (3)$$

- (iii) What feature of the graph in (a)(i) gives the enthalpy change of the reaction?

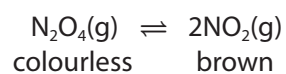
(1)

- ☐ **A** intercept of the x-axis
- ☐ **B** (intercept of the x-axis) $\times -1$
- ☐ **C** intercept of the y-axis
- ☐ **D** (intercept of the y-axis) $\times -1$



- (b) What happens to the position of the equilibrium and the colour of the mixture when the pressure is increased?

The volume of the system remains constant.



(1)

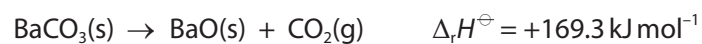
	Position of equilibrium	Change in colour
☐ A	moves to the right	mixture gets lighter
☐ B	moves to the right	mixture gets darker
☐ C	moves to the left	mixture gets lighter
☐ D	moves to the left	mixture gets darker

(Total for Question 5 = 7 marks)



4 This question is about the white solid barium carbonate.

- (a) Barium carbonate decomposes under suitable conditions to form barium oxide and carbon dioxide.



Standard molar entropy data related to this reaction are shown.

Substance	Standard molar entropy, $S^\ominus$ / $\text{JK}^{-1} \text{ mol}^{-1}$
$\text{BaCO}_3(\text{s})$	112.1
$\text{BaO}(\text{s})$	70.4
$\text{CO}_2(\text{g})$	213.6

- (i) Show that barium carbonate is thermally stable at 298 K, using the data in the equation and in the table.

(5)



- (ii) Calculate the lowest temperature, in $^{\circ}\text{C}$, at which it is thermodynamically feasible for barium carbonate to decompose.
Give your answer to three significant figures.

(3)

- (b) Explain whether magnesium carbonate is more or less thermally stable than barium carbonate.

(3)

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- (c) A white solid was thought to be barium carbonate. A student suggested that the presence of the carbonate ion could be tested for by adding a small amount of sulfuric acid.

Explain whether or not this suggestion is valid.

(2)

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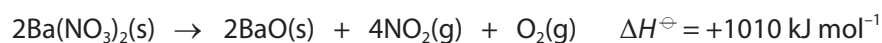
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(Total for Question 4 = 13 marks)



4 This question is about the white crystalline solid, barium nitrate.

- (a) Barium nitrate decomposes under suitable conditions to form barium oxide, nitrogen dioxide and oxygen.



Standard molar entropy data related to this reaction are shown.

Substance	Standard molar entropy, $S^\ominus / \text{JK}^{-1} \text{mol}^{-1}$
$\text{Ba}(\text{NO}_3)_2(\text{s})$	213.8
$\text{BaO}(\text{s})$	70.4
$\text{NO}_2(\text{g})$	240.0
$\text{O}_2(\text{g})$	205.0

- (i) Show that barium nitrate is thermally stable at 298 K.

(5)



- (ii) Calculate the **minimum** temperature, in °C, at which it is thermodynamically feasible for barium nitrate to decompose.

Give your answer to an appropriate number of significant figures.

(3)

- (b) Explain why calcium nitrate is less thermally stable than barium nitrate.

(3)

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- (c) A qualitative test for nitrate ions involves heating an alkaline solution of the suspected nitrate with aluminium.

- (i) Complete the ionic equation for this redox reaction, using oxidation numbers. State symbols are not required.

(1)



- (ii) Describe a test to confirm that ammonia, NH_3 , has been produced.

(1)

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(Total for Question 4 = 13 marks)



9 This question is about entropy and free energy.

- (a) Complete the table by giving the sign of the entropy change of the system, ΔS_{system} , for each reaction.

(2)

Reaction	Sign of ΔS_{system}
$\text{CO}_2(\text{s}) \rightarrow \text{CO}_2(\text{g})$	
$\text{NaCl}(\text{s}) + \text{aq} \rightarrow \text{NaCl}(\text{aq})$	
$\text{N}_2(\text{g}) + 3\text{H}_2(\text{g}) \rightarrow 2\text{NH}_3(\text{g})$	

- (b) Calculate the total entropy change, ΔS_{total} , for the thermal decomposition of calcium carbonate at 298 K.



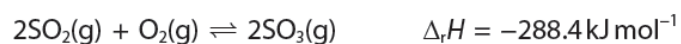
[Data: $\Delta_r H = +178 \text{ kJ mol}^{-1}$

$\Delta S_{\text{system}} = +160 \text{ J K}^{-1} \text{ mol}^{-1}$]

(3)



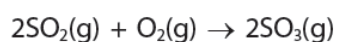
(c) Sulfur dioxide reacts with oxygen to form sulfur trioxide.



The standard molar entropy values at 298 K are given in the table.

	$\text{SO}_2(\text{g})$	$\text{O}_2(\text{g})$	$\text{SO}_3(\text{g})$
$S^\ominus / \text{JK}^{-1} \text{mol}^{-1}$	+248.1	+205.0	+95.6

- (i) Calculate the entropy change of the system, ΔS_{system} , for the forward reaction. Include a sign and units in your answer.



(2)

- (ii) Calculate the free energy change, ΔG , at 298 K and hence deduce whether the reaction is feasible.

(3)

(iii) In industry, the reaction is carried out at about 700 K using a vanadium(V) oxide catalyst.

Calculate the value of the equilibrium constant, K , at 700 K.

ΔG at 700 K is -60 kJ mol^{-1}

(3)

(iv) The equilibrium constant has a larger value at 298 K than at 700 K.
Explain why the reaction is carried out at 700 K and not at 298 K.

(2)

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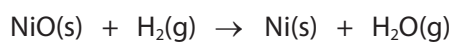
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(Total for Question 9 = 15 marks)



10 The Mond Process is an industrial method of purifying nickel.

(a) The first step involves the reaction of nickel oxide with hydrogen gas at 473 K.



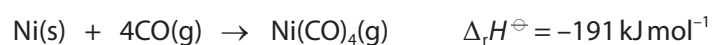
The nickel is not pure because the impurities also react with the hydrogen gas.

Complete the electronic configuration of the Ni^{2+} ion.

(1)

1s²

(b) The second step involves passing carbon monoxide over impure nickel at 323 K. The impurities do not react. The nickel reaction is



(i) Calculate the total entropy change, $\Delta S_{\text{total}}^\ominus$, for this reaction. Include a sign and units in your answer.

Substance	$S^\ominus / \text{J mol}^{-1} \text{K}^{-1}$
Ni(s)	+29.9
CO(g)	+197.6
Ni(CO) ₄ (g)	+313.4

(5)



- (ii) Predict the sign of the Gibbs Free Energy change, ΔG , for this reaction and justify your choice. No calculation is required.

(1)

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- (iii) 50.0 mol of carbon monoxide is mixed with excess impure solid nickel at 323 K in an industrial reactor.
At equilibrium, 0.750 mol of carbon monoxide remains. The pressure is maintained at 1.5 atm throughout.

Calculate the value of K_p at 323 K. Include units with your answer.

(6)



- (c) The final stage of the Mond Process is the thermal decomposition of the nickel carbonyl gas, Ni(CO)_4 , to give pure nickel and carbon monoxide. The reaction mixture is heated to 523 K.

Explain, in qualitative terms, why the entropy change of the system, ΔS_{system} , for this decomposition reaction is positive.

(2)

(Total for Question 10 = 15 marks)



MARK SCHEMES

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Question Number	Answer	Mark
7(a)	The only correct answer is C (the energy change when 1 mol of an ionic substance is formed from its gaseous ions) <i>A is not correct because it is the energy change not the energy absorbed</i> <i>B is not correct because it is gaseous ions and not the elements in their standard states</i> <i>D is not correct because it is the energy change and gaseous ions</i>	(1)

Question Number	Answer	Mark
7(b)	The only correct answer is A (NaCl) <i>B is not correct because the I^- ion is larger than the Cl^- ion and so the lattice energy is less exothermic than that of NaCl</i> <i>C is not correct because the K^+ ion is larger than Na^+ and so the lattice energy is less exothermic than that of NaCl</i> <i>D is not correct because K^+ and I^- are both larger than Na^+ and Cl^- respectively and so the lattice energy is less exothermic than that of NaCl</i>	(1)



Question Number	Answer	Mark
7(c)	The only correct answer is B (NaI) <i>A is not correct because NaCl has a smaller difference between the experimental and theoretical lattice energies because the Cl^- ion is not polarised as much as I^- by the Na^+ ion as it is small compared to I^-</i> <i>C is not correct because KCl has a smaller difference between the experimental and theoretical lattice energies because the Cl^- ion is not polarised as much as I^- by the K^+ ion as it is small compared to I^-</i> <i>D is not correct because the difference in polarisation between K^+ and I^- is not as great as between Na^+ and I^- because K^+ is a larger ion than Na^+</i>	(1)

(Total for Question 7 = 3 marks)



Question Number	Acceptable Answer	Additional Guidance	Mark
2(a)	An explanation that makes reference to the following points: - electron affinity becomes less negative / less exothermic / less energy is released going from chlorine to iodine / down the group - atomic radius increases / number of shells increases / increased distance between the nucleus and the outer / valence electron(s) and there is less attraction between the nucleus and the incoming / added electron / valence electron(s) (there is) increased shielding (from inner electron shells) (increased) shielding outweighs the effect of increasing nuclear charge or (increased) repulsion between the (inner) electron shells and the incoming electron outweighs the effect of increasing nuclear charge or (increased) distance of the outer shell / energy level outweighs the effect of increasing nuclear charge	Allow reverse arguments up the group / comparison of specific elements. Penalise ‘losing an electron’ or incorrect reference to oxidation once. (1) Allow the electron affinity becomes more positive / more endothermic going from chlorine to iodine Ignore electron affinity increases / decreases Do not award requires / produces energy (1) Do not award any reference to ions, ionic radius, charge or charge density for M2 unless point is clearly made that ions are being formed from atoms (1) Allow there is an increase in repulsion between the (inner) electron shells and the incoming electron(s) (1)	(4)



Question Number	Answer	Mark
2(b)	The only correct answer is D (Ca^{2+}) <i>A is not correct because S^{2-} has fewer protons than Ca^{2+} and has the largest ionic radius of those listed</i> <i>B is not correct because Cl^- has fewer protons than Ca^{2+} and has the second largest ionic radius</i> <i>C is not correct because K^+ has fewer protons than Ca^{2+} and has the second smallest ionic radius</i>	(1)

Question Number	Answer	Mark
2(c)(i)	The only correct answer is D (1086, 2353, 4621, 6223, 37832) <i>A is not correct because these are the successive ionisation energies of a Group 3 element</i> <i>B is not correct because these are the successive ionisation energies of a transition element</i> <i>C is not correct because these are the successive ionisation energies of a Group 2 element</i>	(1)

Question Number	Answer	Mark
2(c)(ii)	The only correct answer is C (738, 1451, 7733, 10541, 13629) <i>A is not correct because these are the successive ionisation energies of a p-block element</i> <i>B is not correct because these are the successive ionisation energies of a d-block element</i> <i>D is not correct because these are the successive ionisation energies of a p-block element</i>	(1)

(Total for Question 2 = 7 marks)



Question Number	Answer	Additional Guidance	Mark
8(a)(i)	An answer that makes reference to the following points: - identification and correction of the first error (1) - identification and correction of the second error (1)	Allow corrections to be made on the diagram Error 1 – arrow for enthalpy change of formation should go down/be reversed Error 2 – the word ‘half’ should be deleted from the enthalpy change of atomisation of hydrogen	(2)

Question Number	Answer	Additional Guidance	Mark
8(a)(ii)	calculation of first electron affinity of hydrogen	<u>Example of calculation</u> $1^{\text{st}} \text{ EA} = -(218+496+107)-56 + 804$ $= -73 \text{ (kJ mol}^{-1}\text{)}$ Allow a TE $1^{\text{st}} \text{ EA} = +39 \text{ (kJ mol}^{-1}\text{)}$ if the first arrow reversed direction is not identified	(1)



Question Number	Answer	Additional Guidance	Mark
Penalise incorrect or missing units in (b)(i) and (b)(ii) once only			
8(b)(i)	- calculation of ΔG (1) ΔG is negative/ <0 and so reaction is feasible (1)	<u>Example of calculation</u> $\Delta G = -56 - (298 \times \frac{-76.5}{1000})$ $= -33.203 \text{ (kJ mol}^{-1}\text{)}$ or $\Delta G = -56000 - (298 \times -76.5)$ $= -33203 \text{ (J mol}^{-1}\text{)}$ Ignore SF except 1 Allow ≤ 0 and so reaction is feasible Standalone mark Allow TE on own ΔG calculated value	(2)

Question Number	Answer	Additional Guidance	Mark
8(b)(ii)	calculation of T	<u>Example of calculation</u> $\Delta G = 0$, so $\Delta H = T\Delta S_{(\text{system})}$ or $T = \Delta H/\Delta S_{(\text{system})}$ $T = 56/0.0765 = 732 \text{ K}$ or $T = 56000/76.5 = 732 \text{ K}$ or $T = 459^\circ\text{C}$ Ignore SF except 1 SF Do not award -732K TE on incorrect values penalised already in (b)(i)	(1)



Question Number	Answer	Additional Guidance	Mark
8(c)	reduction half-equation	Example of half equation $\frac{1}{2}\text{O}_2 + \text{H}_2\text{O} + 2\text{e}^- \rightarrow 2\text{OH}^-$ Allow multiples Ignore state symbols even if incorrect	(1)

Question Number	Answer	Mark
8(d)	The only correct answer is B (-804, -711, -2718) <i>A is not correct because the lattice energy of magnesium hydride is not exothermic enough</i> <i>C is not correct because the lattice energy of potassium hydride should be less exothermic than sodium hydride and also that the lattice energy of magnesium hydride is not exothermic enough</i> <i>D is not correct because the lattice energy of potassium hydride should be less exothermic than sodium hydride</i>	(1)

(Total Question 8 = 8 marks)

Question Number	Answer	Mark
	The only correct answer is D (resists changes in pH if small quantities of acid or base are added) <i>A is not correct because buffer solutions can be alkaline or acidic</i>	(1)



Question Number	Answer	Additional Guidance	Mark
6(a)(i)	dot-and-cross diagram and charges	<u>Example of diagram</u>  Circles are not needed Allow no electrons or 8 electrons on outer shell of Mg Allow dots or crosses for all electrons Allow diagrams without square brackets, provided charges are shown Allow alternative ways of showing that there are 2 bromide ions Ignore inner shell electrons	(1)

Question Number	Answer	Additional Guidance	Mark
6(a)(ii)	(conducts electricity when) molten / liquid and dissolved in water / (in) aqueous (solution)	Both needed for the mark Ignore gaseous Allow 'in solution / dissolved'	(1)

Question Number	Answer and Additional Guidance	Mark
6(b)(i)	Box 3 $\text{Mg}^{2+}(\text{g}) + 2\text{Br}(\text{g}) + 2\text{e}^{(-)}$ ↑ $2\Delta_{\text{at}}H[\frac{1}{2}\text{Br}_2(\text{l})]/2 \times (+)112/(+)224$ Box 2 $\text{Mg}^{2+}(\text{g}) + \text{Br}_2(\text{l}) + 2\text{e}^{(-)}$ ↑ $2^{\text{nd}} \text{IE}[\text{Mg}^+(\text{g})]/(+)1451$ Box 1 $\text{Mg}^+(\text{g}) + \text{Br}_2(\text{l}) + \text{e}^{(-)}$ ↑ $1^{\text{st}} \text{IE}[\text{Mg}(\text{g})]/(+)738$ $\text{Mg}(\text{g}) + \text{Br}_2(\text{l})$ ↑ $\Delta_{\text{at}}H[\text{Mg}(\text{g})]/(+)148$ $\text{Mg}(\text{s}) + \text{Br}_2(\text{l})$ ↓ $\Delta_{\text{f}}H[\text{MgBr}_2(\text{s})]/-524$ $\text{MgBr}_2(\text{s})$ ↓ $2 \times \text{EA}[\text{Br}(\text{g})]$ $\text{Mg}^{2+}(\text{g}) + 2\text{Br}^-(\text{g})$ ↓ $\text{LE}[\text{MgBr}_2(\text{s})]/-2440$ $\text{MgBr}_2(\text{s})$ Box 4 - Correct arrows with 1st and 2nd IE of Mg labelled and correct Mg symbols with state symbols in boxes 1 and 2 or 2 and 3 (1) $2 \times \Delta_{\text{at}}H[\frac{1}{2}\text{Br}_2(\text{l})] / 2 \times (+)112 / (+)224$ and $2\text{Br}(\text{g})$ in box 3 or 1 and $2 \times \text{EA}[\text{Br}(\text{g})]$ labelled and $2\text{Br}^-(\text{g})$ in box 4 and correct arrows (1) $\text{LE}[\text{MgBr}_2(\text{s})] / -2440$ labelled and arrow in correct direction (1) Allow any unambiguous labels for the arrows with words and/or numbers – state symbols not required Accept enthalpy change of atomisation of bromine before IEs of magnesium Ignore missing electrons / $2\text{e}^{(-)}$ in boxes 1, 2 and 3 Allow 1 state symbol missing but penalise 2 missing, or an incorrect state symbol in boxes once only	(3)

Question Number	Answer	Additional Guidance	Mark
6(b)(ii)	- correct expression for 2 x EA(Br) in numbers or symbols (1) - calculation of EA(Br) (1)	<u>Example of calculation</u> $2 \times \text{EA}(\text{Br}) = - (2 \times +112) - (+1451) - (+738) - (+148) + (-524) - (-2440)$ $\text{EA}(\text{Br}) = \frac{-645}{2} = -322.5 / -323 \text{ (kJ mol}^{-1}\text{)}$ Correct answer with no working scores (2) Allow for 1 mark: (+)322.5 / (+)323 (wrong sign) -266.5 / -267 (2 missing from $\Delta_{\text{at}}H$ (Br)) -645 (2 missing from EA) -533 (both 2s missing for Br) Ignore units No TE on incorrect arrows in (b)(i)	(2)



Question Number	Answer	Additional Guidance	Mark
6(c)(i)	An explanation that makes reference to the following points: Nuclear charge magnesium (atom) / Mg has more protons than sodium (atom) / Na or magnesium / Mg has a greater (effective) nuclear charge (than sodium / Na) (1) Shielding (outer) electron in magnesium (atom) / Mg in the same (quantum) shell / energy level / sub-shell / orbital as in a sodium atom / Na or shielding in magnesium atom / Mg similar to / same as that in sodium atom / Na (1) Attraction so the force of attraction between the nucleus and the (outer) electron is greater in magnesium (atom) / Mg (than in sodium atom / Na) (1)	Penalise reference to ion once only Ignore reference to atomic radius Allow correct E.C of both atoms Allow same number of (quantum) shells / energy levels in Mg and Na Allow the (outer) electron in Mg is held more tightly to the nucleus (than in Na) Note An answer that describes the trend across a period, without one reference to either sodium or magnesium, scores maximum (2) marks	(3)



Question Number	Answer	Additional Guidance	Mark
6(c)(ii)	correct equation with state symbols	<u>Examples of equations</u> $\text{Mg}^{2+}(\text{g}) \rightarrow \text{Mg}^{3+}(\text{g}) + \text{e}^{(-)}$ $\text{Mg}^{2+}(\text{g}) - \text{e}^{(-)} \rightarrow \text{Mg}^{3+}(\text{g})$ Ignore state symbol for the electron Do not allow $\rightleftharpoons$	(1)

(Total for Question 6 = 11 marks)



Question Number	Answer	Additional Guidance	Mark
9(a)(i)	An answer that includes barium iodide has (almost) 100% ionic (bonds)	Allow small amount of/zero covalency Ignore just it is 'ionic'	(1)

Question Number	Answer	Additional Guidance	Mark
9(a)(ii)	An answer that includes - the magnesium ion is small and highly charged - the iodide ion has a large ionic radius - the iodide ion is polarised by the magnesium ion (so) the bonding in magnesium iodide has (partial) covalent character (which is why the lattice energy values are different)	(1) Allow magnesium ion has a high charge density (1) Allow iodide ion has a much larger radius Ignore reference to atomic radius (1) ALLOW description of polarisation such as distortion of the iodide electron cloud by the magnesium ion Do not award magnesium iodide is covalent Do not award 'MgI' Penalise once only reference to magnesium/iodine/iodide without 'ion' in marking points 1 to 3	(4)



Question Number	Answer	Additional Guidance	Mark
9(b)(i)	An answer that includes - species on lines - state symbols - energy changes / values - arrows indicating direction	<u>Example of Born-Haber cycle and calculation</u> Allow omission of electrons but if included then must be correct A and B can be drawn in either order or A then C followed by B Exemplar cycle: Each different species error can be penalised so four different species errors scores (0)	(4)

Question Number	Answer	Additional Guidance	Mark
9(b)(ii)	calculation of lattice energy	LE = -4105 (kJ mol ⁻¹)	(1)



Question Number	Answer	Additional Guidance	Mark
9(c)	• application of Hess's law • evaluation of lattice energy	<u>Example of calculation</u> LE = $(-1577 + (2 \times -336) - (-73)) =$ $= -2176 \text{ kJ mol}^{-1}$ Final answer without working scores (2) (+) 2176 kJ mol^{-1} scores (1) for TE on incorrect application of Hess's law $-1840 \text{ kJ mol}^{-1}$ scores (1) for use of single -336 instead of double	(2)

(Total Question 9 = 12 marks)



Question Number	Answer	Additional Guidance	Mark
9(a)(i)	All quantities are measured in kJ mol^{-1}	Allow $\text{O}^{1-}(\text{g})$ Ignore $+ \frac{1}{2}\text{O}_2(\text{g})$ in left hand box Penalise missing state symbols once only Penalise incorrect / missing charges in each species Penalise addition of electrons once only	(2)
Question Number	Answer	Additional Guidance	Mark
9(a)(ii)	An explanation that makes reference to the following points: (first electron affinity is exothermic / negative) due to attraction between (positive) nucleus (in neutral atom) and (incoming) electron (1) (second electron affinity is endothermic / positive) due to repulsion (1) - between negative ion and (incoming) electron (1)	Reference to removing electron(s) scores (0) overall Ignore just ‘negative species’	(3)



Question Number	Answer	Additional Guidance	Mark
9(a)(iii)	- expression based on Hess cycle (1) - calculation of missing value from cycle (1) - calculation of $\Delta_{\text{at}}H^\ominus$ (1)	$2\Delta_{\text{at}}H^\ominus + (1462 + 249.2 - 141.1 + 798 - 2969) = -31$ This can be subsumed in M2 $2\Delta_{\text{at}}H^\ominus = -31 - (1462 + 249.2 - 141.1 + 798 - 2969) = 569.9$ No TE on incorrect expression in M1 $569.9 \div 2 = (+) 284.95 \text{ (kJ mol}^{-1}\text{)}$ TE on M2 Correct answer, with or without working, scores (3) Ignore SF except 1 SF Ignore units	(3)

Question Number	Answer	Additional Guidance	Mark
9(b)(i)	An answer that makes reference to two of the following points: - model assumes bonding is 100% / completely / purely ionic (1) - the ions are (perfect) spheres (1) - the charge is distributed evenly across the ions / the ions are point charges (1) - ions are in contact with one another (1)	Penalise use of atom / molecule / compound instead of ion once only Ignore reference to standard conditions Allow there is no covalent bonding / character Allow no polarisation of ions / electron cloud Allow electrons are fully transferred Ignore almost 100% ionic Allow no distortion of ions / electron cloud Ignore circular Allow charge dispersed equally Ignore ions with fixed charges	(2)



Question Number	Answer	Additional guidance	Mark
9(b)(ii)	An answer that makes reference to the following points - as the silver ion polarises / distorts the chloride ion / electron cloud (1) - so the bonding (is ionic and) has some covalent character (1) - which is stronger (than ionic alone so experimental value is more exothermic / more negative) (1)	Penalise use of incorrect ions in M1 only Ignore reference to electronegativity Ignore silver chloride is a polar molecule Do not award if incorrect charges on ions Do not award if silver ion is larger than chloride ion Ignore just ‘bonding is not purely ionic’ Do not award covalent with ionic character Allow ‘releases more energy when bond forms’ (than ionic alone so experimental value is more exothermic / more negative)	(3)

(Total for Question 9 = 13 marks)

Question number	Answer	Additional guidance	Mark
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Question Number	Answer	Additional Guidance	Mark
6(a)(i)	An answer that makes reference to the following points: - there is an increase of number of moles (1) - change of state as gas / liquid / solution are produced from solids (1)	Allow particles for moles 3 to 13 moles Do not award 11 to 13 moles Do not award reference to 'more types' of products than reactants Ignore references to ΔH	(2)

Question Number	Answer	Additional Guidance	Mark
6(a)(ii)	An explanation that makes reference to the following points: - the reaction is endothermic (1) (and so) freezes the water (which attaches the wooden block to the flask) (1)	Allow description of endothermic	(2)

Question Number	Answer	Mark
6(b)	The only correct answer is D (-216.6) <i>A is not correct because the values for magnesium and magnesium oxide have not been doubled and the entropy for the products has been incorrectly subtracted from the reactants entropy</i> <i>B is not correct because the values for magnesium and magnesium oxide have not been doubled</i> <i>C is not correct because the entropy for the products has been incorrectly subtracted from the entropy of the reactants</i>	(1)

(Total Question 6 = 5 marks)



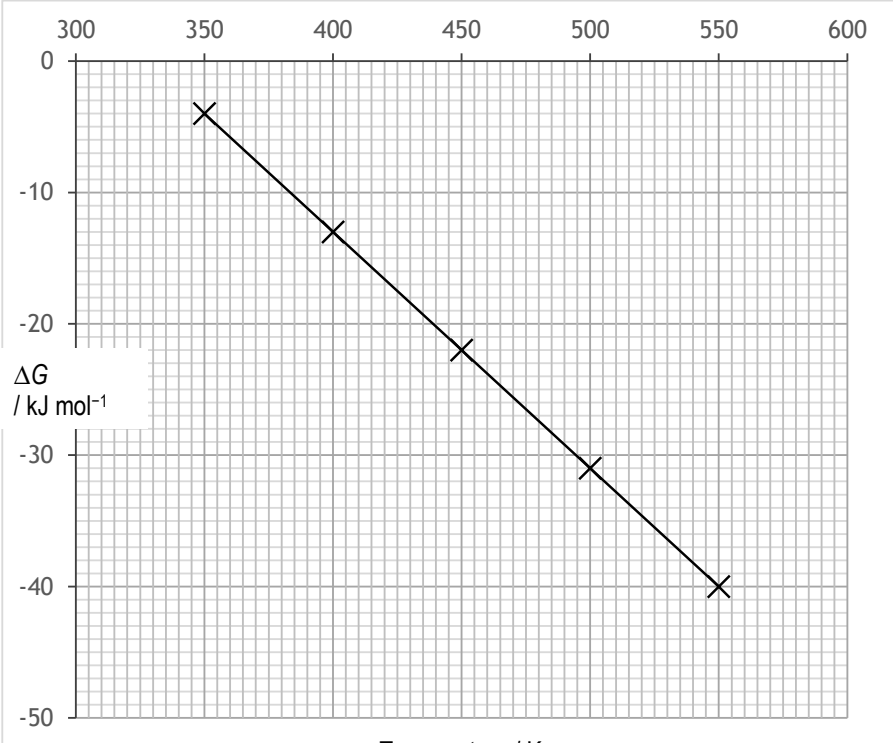
Question Number	Acceptable Answer	Additional Guidance	Mark
9(a)	- calculation of ΔS_{system} (1) - calculation of $\Delta G^\ominus$ with appropriate units (1) - reason why not feasible (1)	<u>Example of calculation</u> $= (135 + 213.6 + 69.9) - (2 \times 101.7)$ $= (+) 215.1 \text{ (J K}^{-1} \text{ mol}^{-1}) /$ $(+) 0.2151 \text{ (kJ K}^{-1} \text{ mol}^{-1})$ $(\Delta G = \Delta H - T \Delta S_{\text{system}})$ $= (+ 91.6 \times 1000) - (298 \times 215.1)$ $= (+) 27500 \text{ J mol}^{-1} / 27500.2 \text{ J mol}^{-1} /$ $(+) 27.500 \text{ kJ mol}^{-1} / 27.5002 \text{ kJ mol}^{-1}$ TE on answer to M1 Ignore SF except 1SF ΔG positive / $\geq$ / >0 so not feasible (standalone mark)	(3)



Question Number	Acceptable Answer	Additional Guidance	Mark
9(b)	- rearrangement of ΔG expression and calculation of feasible temperature (1) - conversion to degrees Celsius (1)	<u>Example of calculation</u> $T = \Delta H / \Delta S_{\text{system}}$ $T = 91.6 / 0.2151 = 425.8 \text{ K}$ $425.8 \text{ K} - 273 = 152.8 / 153 (^{\circ}\text{C})$ Allow 160 ($^{\circ}\text{C}$) Do not award 150 ($^{\circ}\text{C}$) if rounded down Do not award a negative answer for the temperature. Credit can be given for working that uses $\Delta S_{\text{tot}} = 0$ $\Delta S_{\text{tot}} = 0 = 215.1 + (-91600 / T)$ $T = -91600 / -215.1 = 425.8$ (1) Conversion to $^{\circ}\text{C} = 425.8 - 273 = 152.8 ^{\circ}\text{C}$ (1) TE from answer to 9(a) Ignore SF except 1SF	(2)

(Total for Question 9 = 5 marks)



Question Number	Answer	Additional Guidance	Mark
5(a)(i)	A graph that shows - suitable scale, points must cover at least half the available space in both directions (1) - all points plotted correctly and straight line of best fit (1)	 Allow break in x axis Allow x axis values at top or bottom of graph y axis must go in correct direction Stand alone mark based on scale used Allow $\pm \frac{1}{2}$ a square	(2)

Question Number	Answer	Additional Guidance	Mark
5(a)(ii)	- deduction that gradient = $-\Delta S_{\text{system}}$ (1) - calculation of gradient (1) - calculation of ΔS_{system} in $\text{J K}^{-1} \text{mol}^{-1}$ (1)	<u>Example of calculation</u> ($y = mx + c$ so) $m = -\Delta S_{\text{system}}$ M1 could be subsumed within award of M2 $(36 \div (-200)) = -0.18 \text{ (kJ K}^{-1} \text{mol}^{-1})$ TE on graph in (i) M2 can be subsumed within M3 Allow this left as a fraction e.g. $-9/50$ Penalise absence of negative sign once only in M1 and M2 $= (+)180 \text{ (J K}^{-1} \text{mol}^{-1})$ TE on M2 Correct answer, with or without working, scores (3) Ignore SF except 1 SF Do not award incorrect units but allow $\text{J K}^{-1} \text{mol}^{-1}$ Note Allow use of 2 simultaneous equations or calculation of intercept and substitution	(3)



Question Number	Answer	Mark
5(a)(iii)	The only correct answer is C (intercept of the y axis) <i>A is not correct because the value would have units of temperature</i> <i>B is not correct because the value would have units of temperature and be a negative value in K</i> <i>D is not correct because this value is $-\Delta H$</i>	(1)

Question Number	Answer	Mark
5(b)	The only correct answer is C (moves to the left, mixture gets lighter) <i>A is not correct because there are more particles on the right-hand side, so increase in P moves equilibrium to the left</i> <i>B is not correct because there are more particles on the right-hand side, so increase in P moves equilibrium to the left and N_2O_4 is colourless, so mixture lightens</i> <i>D is not correct because N_2O_4 is colourless, so mixture lighten</i>	(1)

(Total for Question 5 = 7 marks)



Question Number	Answer	Additional Guidance	Mark
4(a)(i)	- calculation of ΔS_{system} (1) - calculation of $\Delta S_{\text{surroundings}}$ (1) - conversion of ΔS_{system} or $\Delta S_{\text{surroundings}}$ for consistent units (1) - calculation of ΔS_{total} and corresponding units (1) - comment on thermal stability at 298 K (1) Alternative method on next page	Marks should be awarded for method 1 or method 2 but not via mixed methods. If both methods used, then award higher mark. <u>Example of calculation</u> $(213.6 + 70.4) - 112.1 = 171.9 \text{ (J K}^{-1} \text{ mol}^{-1}\text{)}$ $-169.3 / 298 = -0.56812 \text{ (kJ K}^{-1} \text{ mol}^{-1}\text{)}$ or $(-169.3 \times 1000) / 298 = -568.12 \text{ (J K}^{-1} \text{ mol}^{-1}\text{)}$ $\Delta S_{\text{surroundings}}$ converted to $\text{J K}^{-1} \text{ mol}^{-1}$ or ΔS_{system} converted to $\text{kJ K}^{-1} \text{ mol}^{-1}$ M3 could be subsumed as part of either M1 or M2 $171.9 + (-568.12) = -396.22 \text{ J K}^{-1} \text{ mol}^{-1}$ or $0.1719 + (-0.56812) = -0.39622 \text{ kJ K}^{-1} \text{ mol}^{-1}$ Allow units to be missing here if correct units given for ΔS_{system} and $\Delta S_{\text{surroundings}}$ Correct answer with units with some or no working scores (4) Ignore SF except 1 SF Allow TE throughout calculation Stand alone mark on any negative value for ΔS_{total} Negative value / <0 and so reaction is not feasible / it is thermodynamically stable (at 298 K)/ Ignore just 'so the reaction is not feasible' No TE for positive values for ΔS_{total}	(5)



4(a)(i) continued	Alternative method using ΔG	<u>Example of calculation</u>	(5)
	calculation of ΔS_{system} (1)	$(213.6 + 70.4) - 112.1 = 171.9 \text{ (J K}^{-1} \text{ mol}^{-1}\text{)}$	
	calculation of $T\Delta S_{\text{system}}$ (1)	$298 \times 171.9 = 51226 \text{ (J mol}^{-1}\text{)}$ M2 could be subsumed as part of M3	
	conversion of $T\Delta S_{\text{system}}$ or ΔS_{system} or ΔH for consistent units (1)	ΔH converted to J mol^{-1} or ΔS_{system} converted to $\text{kJ K}^{-1} \text{ mol}^{-1}$ or $T\Delta S_{\text{system}}$ converted to kJ mol^{-1} M3 could be subsumed as part of M4	
	calculation of ΔG_{total} and corresponding units (1)	$169300 - 51226 = (+) 118074 \text{ J mol}^{-1}$ or $(+) 118.074 \text{ kJ mol}^{-1}$ Correct answer with units with some or no working scores (4) Ignore SF except 1 SF Allow TE from M1 to M4	
	comment on thermal stability at 298 K (1)	Stand alone mark on any positive value for ΔG Positive value / >0 and so reaction is not feasible (at 298 K) Ignore just 'so reaction is not feasible' No TE on negative values for ΔG	



Question Number	Answer	Additional Guidance	Mark
4(a)(ii)	- recognition that $\Delta S_{\text{surroundings}} \geq -171.9 \text{ J K}^{-1} \text{ mol}^{-1}$ for decomposition to be feasible (1) - substitution and rearrangement to find T (1) - calculation of T and conversion to $^{\circ}\text{C}$ and answer given to 3 SF (1)	<u>Example of calculation</u> $\Delta S_{\text{total}} = \Delta S_{\text{system}} - \frac{\Delta H}{T} = 0$ Or $\Delta S_{\text{system}} = \frac{\Delta H}{T}$ Allow this equation rearranged This may be subsumed in M2 $-171.9 = (-169.3 \times 1000) / T$ $T = (-169.3 \times 1000) / -171.9$ TE on ΔS_{system} from 4(a)(i) (= 984.87 K) (= 711.87$^{\circ}\text{C}$) = 712$^{\circ}\text{C}$ TE on M1 and M2 but do not award any temperature below 0$^{\circ}\text{C}$ Correct answer to 3 SF and in $^{\circ}\text{C}$ scores (3) Alternative method for M1 and M2 $\Delta G = \Delta H - T\Delta S = 0$ or $\Delta H = T\Delta S$ This may be subsumed in M2 (1) $169300 = T \times 171.9$ $T = 169300/171.9$ (1) TE on ΔS_{system} from 4(a)(i)	(3)

Question Number	Answer	Additional Guidance	Mark
4(b)	An explanation that makes reference to the following points: (Magnesium carbonate is less thermally stable because) Size - the magnesium ion / Mg^{2+} is smaller / has a greater charge density (1) Polarising power - so more likely to polarise / distort (the carbonate (ion) / anion) (1) Bonds - and so weaken the C-O bond or the bond(s) within the carbonate ion (1)	Allow reverse arguments Ignore reference to 'covalent character' Ignore reference to lattice energies Allow ionic radius of cation increases down the group / charge density of cation decreases down the group Allow magnesium carbonate has a smaller cation Allow magnesium ions have fewer shells of electrons Ignore 'magnesium (atom) is smaller' Ignore atomic radius Do not award M1 if mention of different / incorrect charges on magnesium and barium ions Allow 'magnesium ion has more polarising power' Allow polarising power decreases down the group Allow magnesium ion has more electron pulling power on (the carbonate (ion) / anion) Do not award if MgCO_3 stated as more stable Allow break (more easily) for weaken Allow C=O bonds for C-O Do not award reference to weakening unspecified bonds Do not award weakening bond between cation and anion	(3)



Question Number	Answer	Additional Guidance	Mark
4(c)	An answer that makes reference to the following points: (usually carbonates react with acids and) produce a (colourless) gas / CO_2 (which is an expected observation for the test) (1) (but) the barium sulfate produced is insoluble (so the carbonate may appear to not react / not dissolve in acid) (1)	Allow effervescence / fizzing / bubbles for observation Allow little / no gas / CO_2 formed when sulfuric acid is used Ignore references to limewater / lighted splint to test for CO_2 Allow a (white) precipitate (of barium sulfate) forms Allow they should have used hydrochloric / nitric acid as the salts formed are soluble Accept bubbles of gas would not be expected because barium sulfate is insoluble for 2 marks	(2)

(Total for Question 4 = 13 marks)



Question Number	Answer	Additional Guidance	Mark
4(a)(i)	- calculation of $\Delta S^\ominus_{\text{system}}$ (1) - calculation of $\Delta S^\ominus_{\text{surroundings}}$ (1) - consistent units for $\Delta S^\ominus_{\text{system}}$ and $\Delta S^\ominus_{\text{surroundings}}$ (1) - calculation of $\Delta S^\ominus_{\text{total}}$ (1) - comment on thermal stability at 298 K (1)	<u>Example of calculation</u> $((2 \times 70.4) + (4 \times 240.0) + 205.0) - (2 \times 213.8) = 878.2 \text{ (J K}^{-1} \text{ mol}^{-1})$ $(-1010 \times 1000) \div 298 = -3389.26 / 3389.3 \text{ (J K}^{-1} \text{ mol}^{-1})$ or $(-1010 \div 298) = -3.38926 / 3.3893 \text{ (kJ K}^{-1} \text{ mol}^{-1})$ $\Delta S^\ominus_{\text{surroundings}}$ converted to $\text{J K}^{-1} \text{ mol}^{-1}$ or $\Delta S^\ominus_{\text{system}}$ converted to $\text{kJ K}^{-1} \text{ mol}^{-1}$ M3 could be subsumed as part of either M1 or M2 $= 878.2 + (-3389.3)$ $= -2511.1 \text{ (J K}^{-1} \text{ mol}^{-1})$ or $-2.5111 \text{ (kJ K}^{-1} \text{ mol}^{-1})$ Penalise incorrect units for M4 only Negative value, so reaction is not feasible /compound thermally stable (at 298 K) Standalone mark Do not award on positive values for $\Delta S^\ominus_{\text{total}}$ Ignore SF except 1 SF Allow TE from M1 to M4 provided M4 is negative A negative value for $\Delta S^\ominus_{\text{system}}$ loses M3 to M4 so can only score M2 and M5 $\Delta S^\ominus_{\text{total}} = +874.8$ scores (2) for M1 and M2 but the failure to convert to consistent units means a positive $\Delta S^\ominus_{\text{total}}$ is obtained that does not match the question	(5)



	Alternative method using ΔG • calculation of $\Delta S^\ominus_{\text{system}}$ (1) • calculation of $T\Delta S^\ominus_{\text{system}}$ (1) • consistent units for $T\Delta S^\ominus_{\text{system}}$ and $\Delta H^\ominus$ (1) • calculation of ΔG (1) • reason why thermally stable at 298 K (1)	<u>Example of calculation</u> $((2 \times 70.4) + (4 \times 240.0) + 205.0) - (2 \times 213.8) = (+) 878.2 \text{ (J K}^{-1} \text{ mol}^{-1})$ $298 \times 878.2 = 261703.6 \text{ (J mol}^{-1})$ M2 could be subsumed as part of either M3 or M4 $\Delta H^\ominus$ converted to J mol^{-1} OR $T\Delta S^\ominus_{\text{system}}$ converted to kJ mol^{-1} M3 could be subsumed as part M4 $(\Delta G = \Delta H - T \Delta S_{\text{system}})$ $= (+) 1010\,000 - 261703.6$ $= (+) 748296.4 \text{ (J mol}^{-1})$ $= (+) 748.296 \text{ (kJ mol}^{-1})$ Penalise incorrect units for M4 only Ignore SF except 1 SF Allow TE from M1 to M4 provided M4 is positive ΔG positive / > 0 so reaction is not feasible/ compound is stable (at 298 K) Standalone mark but Do not award on negative values for $\Delta G^\ominus$ A negative value for $\Delta S^\ominus_{\text{system}}$ loses M3 to M4 so can only score M2 and M5 $\Delta G = -260693.6$ scores (2) for M1 and M2 but the failure to convert to consistent units means a negative ΔG is obtained that does not match the question	
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Question Number	Answer	Additional Guidance	Mark
4(a)(ii)	- rearrangement of ΔG expression - calculation of T - conversion to $^{\circ}\text{C}$ to 2/3 SF	<u>Example of calculation</u> (1) $T = \Delta H / \Delta S_{\text{system}}$ (1) $(T = (1010 \times 1000) / 878.2)$ $= 1150.1 \text{ (K)}$ M2 subsumes M1 so the numerical value scores (2) (1) $= 877 \text{ (}^{\circ}\text{C)} / 880 \text{ (}^{\circ}\text{C)}$ Allow 878 ($^{\circ}\text{C}$) Do not award an answer below 25°C for M3	(3)



Question Number	Answer	Additional Guidance	Mark
4(b)	An explanation that makes reference to the following points: (calcium nitrate is less thermally stable because) • (both ions have the same charge but) the calcium ion is smaller / has a greater charge density (1) • so polarises (the anion) to a greater extent (1) • and so weaken the N–O bond / bond(s) within the nitrate ion (1)	Allow reverse arguments Ignore ‘calcium atom is smaller’ Do not award references to electronegativity Do not award reference to electron density Allow so more likely to polarise (the nitrate (ion) / calcium ion has more polarising power Allow reference to polarisation of the bond Allow a description of polarisation such as the distortion of the anion electron cloud to a greater extent Do not award reference to breaking of/polarising the ionic bond between the calcium and the nitrate	(3)

Question Number	Answer	Additional Guidance	Mark
4(c)(i)	An answer that makes reference to the following point: • $8\text{Al} + 3\text{NO}_3^- + 5\text{OH}^- + 18\text{H}_2\text{O} \rightarrow 8\text{Al}(\text{OH})_4^- + 3\text{NH}_3$		(1)



Question Number	Answer	Additional Guidance	Mark
4(c)(ii)	An answer that makes reference to the following point: (ammonia turns damp red) litmus paper blue	Allow (ammonia turns damp) UI paper blue Do not award if litmus paper bleached after turning blue Allow (ammonia produces) white smoke with HCl (gas) Do not award white fumes/misty fumes If two tests given then both must be correct to score	(1)

(Total for Question 4 = 13 marks)



Question Number	Acceptable Answer	Additional Guidance	Mark								
9(a)	all 3 correct (2) any 2 correct (1)	Example of table <table><tr><th>Reaction</th><th>Sign of ΔS_{system}</th></tr><tr><td>$\text{CO}_2(\text{s}) \rightarrow \text{CO}_2(\text{g})$</td><td>positive / + / +ve / plus</td></tr><tr><td>$\text{NaCl}(\text{s}) + \text{aq} \rightarrow \text{NaCl}(\text{aq})$</td><td>positive / + / +ve / plus</td></tr><tr><td>$\text{N}_2(\text{g}) + 3\text{H}_2(\text{g}) \rightarrow 2\text{NH}_3(\text{g})$</td><td>negative / - / -ve / minus</td></tr></table>	Reaction	Sign of ΔS_{system}	$\text{CO}_2(\text{s}) \rightarrow \text{CO}_2(\text{g})$	positive / + / +ve / plus	$\text{NaCl}(\text{s}) + \text{aq} \rightarrow \text{NaCl}(\text{aq})$	positive / + / +ve / plus	$\text{N}_2(\text{g}) + 3\text{H}_2(\text{g}) \rightarrow 2\text{NH}_3(\text{g})$	negative / - / -ve / minus	(2)
Reaction	Sign of ΔS_{system}										
$\text{CO}_2(\text{s}) \rightarrow \text{CO}_2(\text{g})$	positive / + / +ve / plus										
$\text{NaCl}(\text{s}) + \text{aq} \rightarrow \text{NaCl}(\text{aq})$	positive / + / +ve / plus										
$\text{N}_2(\text{g}) + 3\text{H}_2(\text{g}) \rightarrow 2\text{NH}_3(\text{g})$	negative / - / -ve / minus										

Question Number	Acceptable Answer	Additional Guidance	Mark
9(b)	- use of $\Delta S_{\text{surroundings}} = -\Delta H/T$ (1) - calculation of $\Delta S_{\text{surroundings}}$ (1) - calculation of ΔS_{total} and sign and units (1)	Example of calculation $-(178000 \div 298) / -(178 \div 298)$ $-597(.315) \text{ (J K}^{-1} \text{ mol}^{-1})$ or $-0.597(315) \text{ (kJ K}^{-1} \text{ mol}^{-1})$ TE on equation with minus sign missing $160 + (-0.597315) = -0.437(315) \text{ kJ K}^{-1} \text{ mol}^{-1}$ 1000 or $160 + (-0.597315 \times 1000)$ $= -437.(315) \text{ J K}^{-1} \text{ mol}^{-1}$ TE on $\Delta S_{\text{surroundings}}$ Allow correct units shown once in answer for ΔS_{total} or $\Delta S_{\text{surroundings}}$ Ignore SF except 1SF Correct answer with sign and units without working scores 3 marks	(3)



Question Number	Acceptable Answer	Additional Guidance	Mark
9(c)(i)	- correct working (1) - correct answer and sign (1)	<u>Example of calculation</u> $(2 \times 95.6) - ((2 \times 248.1) + 205.0) / (2 \times 95.6) - (2 \times 248.1) - 205.0$ -510(.0) (J K⁻¹ mol⁻¹) or -0.510 (kJ K⁻¹ mol⁻¹) TE on working Ignore SF except 1SF Correct answer with sign and without working scores both marks	(2)

Question Number	Acceptable Answer	Additional Guidance	Mark
9(c)(ii)	- use of $\Delta G = \Delta H - T\Delta S_{\text{system}}$ (1) - calculation of ΔG and sign and units (1) ΔG is negative / less than 0 / <0 and so the reaction is feasible (1)	<u>Example of calculation</u> The equation may be stated or numbers substituted directly e.g. $-288.4 - (298 \times -0.510) / -288400 - (298 \times -510)$ $-136(.42) \text{ kJ mol}^{-1} / -136420 \text{ J mol}^{-1}$ TE on ΔS_{system} in (i) Ignore SF except 1SF Correct answer with sign and units without working scores both marks Conditional on a stated number TE on sign of ΔG: ΔG is positive / greater than 0 / >0 so the reaction is not feasible	(3)

Question Number	Acceptable Answer	Additional Guidance	Mark
9(c)(iii)	• use of $\Delta G = -RT \ln K$ (1) • rearrangement of equation and substitution of correct values (1) • calculation of K (1)	<u>Example of calculation</u> $-60000 = -8.31 \times 700 \ln K$ $(\ln K = -\Delta G/RT)$ $\ln K = \frac{-(-60000)}{(8.31 \times 700)}$ Allow $\ln K = \frac{60000}{8.31 \times 700}$ Allow $\ln K = 10.3146 / 10.315 / 10.32 / 10.3 / 10$ TE on equation, provided equation involves all of ΔG, K, R and T and no others e.g. S $K = e^{10.315} = 3.016975 \times 10^4 / 30169.75$ TE on $\ln K$ expression / value Allow answers based on earlier correct rounding Ignore SF including 1SF Ignore units Correct answer without working scores 3 marks	(3)

Question Number	Acceptable Answer	Additional Guidance	Mark
9(c)(iv)	An explanation that makes reference to any two of the following points: • Yield - even though the (percentage) yield / amount of SO_3 is higher at 298 K / lower temperature (1) • Rate - the rate of reaction is slower at 298 K / lower temperature (1) • Compromise - so 700 K is a compromise between a (high) yield and (high) rate (1)	Allow reverse argument for M1 and M2 Ignore reference to changing the pressure Allow the unused reactants can be recycled to increase the yield / products are removed to increase the yield Allow the reaction does not reach equilibrium in industry so there is no effect on the yield Ignore just a reference to 'equilibrium shifting' Ignore references to activation energy Allow at 700K the amount of product per unit time is larger Ignore just '700 K is more economically viable' Note If three points are made related to yield, rate and compromise and one of these is incorrect, maximum mark is (1) for 1 correct point	(2)

(Total for Question 9 = 15 marks)

Question Number	Answer	Additional Guidance	Mark
10(a)	$1s^2 2s^2 2p^6 3s^2 3p^6 3d^8$	Allow omission of superscripts Allow [Ar] for $1s^2 2s^2 2p^6 3s^2 3p^6$ Allow 2p and 3p split into x, y and z Ignore $4s^0$	(1)

Question Number	Answer	Additional Guidance	Mark
10(b)(i)	- expression for entropies of reactants and products - calculation of ΔS_{system} - expression of $\Delta S_{\text{surroundings}}$ - calculation of $\Delta S_{\text{surroundings}}$ - calculation of ΔS_{total} with sign and units	<u>Example of calculation</u> (1) $\Delta S_{\text{system}} = (313.4) - ((4 \times 197.6) + 29.9)$ (1) $\Delta S_{\text{system}} = -506.9 \text{ (J mol}^{-1} \text{ K}^{-1}\text{)}$ (1) $\Delta S_{\text{surroundings}} = -(\Delta H \div T) = -(-191\,000 \div 323)$ (1) $\Delta S_{\text{surroundings}} = (+) 591.3 \text{ (J mol}^{-1} \text{ K}^{-1}\text{)}$ (1) $\Delta S_{\text{total}} = (591.3 - 506.9) = +84.4 \text{ J mol}^{-1} \text{ K}^{-1}$ Ignore SF except 1SF Allow $+0.0844 \text{ kJ mol}^{-1} \text{ K}^{-1}$ Accept units in any order Allow mol^{-1} for mol^{-1} TE throughout Correct answer with no working scores (5)	(5)



Question Number	Answer	Additional Guidance	Mark
10(b)(ii)	An answer that makes reference to the following points: • negative (sign) and the reaction is feasible (since it is an industrial process) or negative (sign) and ΔS_{total} is positive (so reaction is feasible because the enthalpy change is negative)	Ignore just $\Delta G < 0$ and $\Delta S_{\text{total}} > 0$	(1)



Question Number	Answer	Additional Guidance	Mark
10(b)(iii)	• (M1) calculation of equilibrium moles of $\text{Ni}(\text{CO})_4$ (1) • (M2) calculation of CO and $\text{Ni}(\text{CO})_4$ mole fractions (1) • (M3) calculation of CO and $\text{Ni}(\text{CO})_4$ partial pressures (1) • (M4) expression of K_p (1) • (M5) calculation of K_p (1) • (M6) units (1)	<u>An example of calculation</u> $n(\text{Ni}(\text{CO})_4) = ((50 - 0.75) \div 4 =) 12.3125 \text{ (mol)}$ Total number of moles = $0.750 + 12.3125 = 13.0625$ $\chi_{\text{CO}} = (0.75 \div 13.0625 =) 0.057416$ $\chi_{\text{Ni}(\text{CO})_4} = (12.3125 \div 13.0625 =) 0.942584$ $p(\text{CO}) = 0.057416 \times 1.5 = 0.086124 \text{ (atm)}$ $p(\text{Ni}(\text{CO})_4) = 0.942584 \times 1.5 = 1.413876 \text{ (atm)}$ $K_p = (p(\text{Ni}(\text{CO})_4) \div (p(\text{CO})^4))$ Do not award square brackets $K_p = (1.413876 \div 0.086124^4)$ $= 25698.9/25699/25700$ TE throughout Ignore SF except 1SF Correct answer with or without working scores (5) atm^{-3}	(6)



Question Number	Answer	Additional Guidance	Mark
10(c)	An explanation that makes reference to the following points: - number of moles of gases increases (which have greater entropy) (1) - increase from forming 4CO(g) is larger in magnitude than the decrease from forming solid Ni (1)	Allow number of gaseous moles goes from 1 to 4 Allow particles for moles Allow more gaseous molecules Ignore just more molecules Ignore just equation Do not allow reference to nickel as molecule(s) Allow comparison such as ‘entropy change is positive even though a solid made’	(2)

(Total Question 10 = 15 marks)

