PEARSON EDEXCEL IAL CHEMISTRY · YCH11

CHEMISTRY



EXAM QUESTION PACK

UNIT 4: LATTICE ENERGY

SCORE	PERCENTAGE
/107	%

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Q1.

This question is about ammonia and ammonium chloride.

(a) Ammonia is produced by reacting nitrogen and hydrogen as shown.

$$N_2(g) + 3H_2(g) \leftrightarrow 2NH_3(g)$$

(i) Write the expression for the equilibrium constant, K_p.

(1)

(ii) An equilibrium was established by mixing nitrogen and hydrogen in a 1 : 3 ratio by volume, at a temperature of 450 °C and pressure of 200 atm.
The equilibrium mixture contained 28 % of ammonia by volume.

Complete the table.

(3)

Substance	Mole fraction	Partial pressure / atm
N_2		
H_2		
NH_3	0.28	56

(iii) Calculate the equilibrium constant.

Give your answer to an appropriate number of significant figures and include units, if required.

(3)

(iv) When the temperature was reduced to 400 °C at the same pressure, the equilibrium mixture contained 36 % of ammonia.

Explain what can be deduced about this reaction from this information.

(2)

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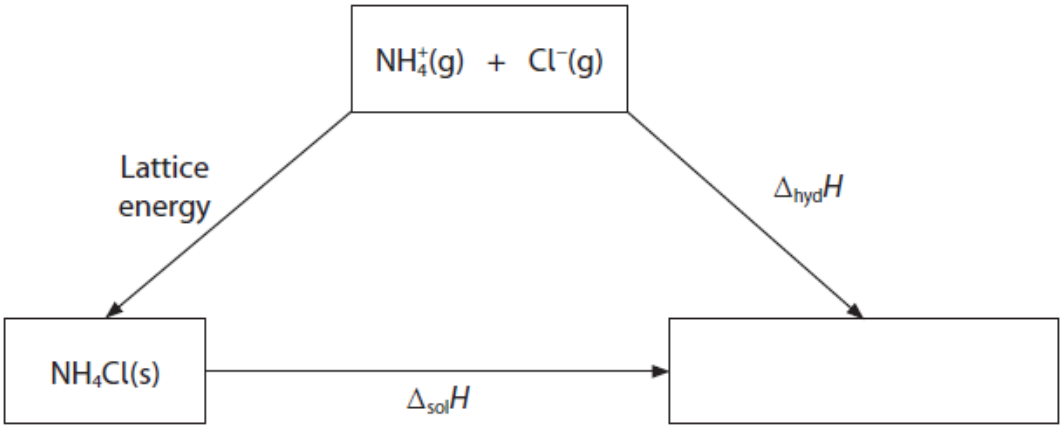
(b) Ammonium chloride can be produced by reacting ammonia with hydrogen chloride.

Ammonium chloride is a white solid that is very soluble in water.

Hess's Law can be used to calculate the enthalpy of solution of ammonium chloride, using hydration enthalpies and lattice energy.

(i) Complete the Hess cycle by filling in the empty box.

(1)



(ii) Complete the expression for the enthalpy change of solution using the hydration enthalpies and lattice energy.

(1)

$\Delta_{sol}H$ =

(iii) Calculate the enthalpy change of solution, using your expression in (b)(ii) and these data.

Enthalpy change of hydration of NH_4^+ = −307 kJ mol^{-1}

Enthalpy change of hydration of Cl^- = −378 kJ mol^{-1}

Lattice energy of NH_4Cl = −705 kJ mol^{-1}

(2)

(iv) A student suggested that the enthalpy change of solution of ammonium bromide would be of a similar magnitude to the enthalpy change of solution of ammonium chloride.

Comment on this suggestion in terms of the hydration enthalpies and lattice energies of these two compounds.

(3)

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(c) Write an **ionic** equation to show why aqueous solutions of ammonium chloride are acidic. State symbols are not required.

(1)

(Total for question = 17 marks)

Q2.

Answer the question with a cross in the box you think is correct ☒ . If you change your mind about an answer, put a line through the box ☒ and then mark your new answer with a cross ☒ .

Which equation represents the standard enthalpy change of atomisation, $\Delta_{at}H$, of bromine?

☒ **A** $\frac{1}{2}Br_2(l) \rightarrow Br(g)$

☒ **B** $Br_2(l) \rightarrow 2Br(g)$

☒ **C** $\frac{1}{2}Br_2(g) \rightarrow Br(g)$

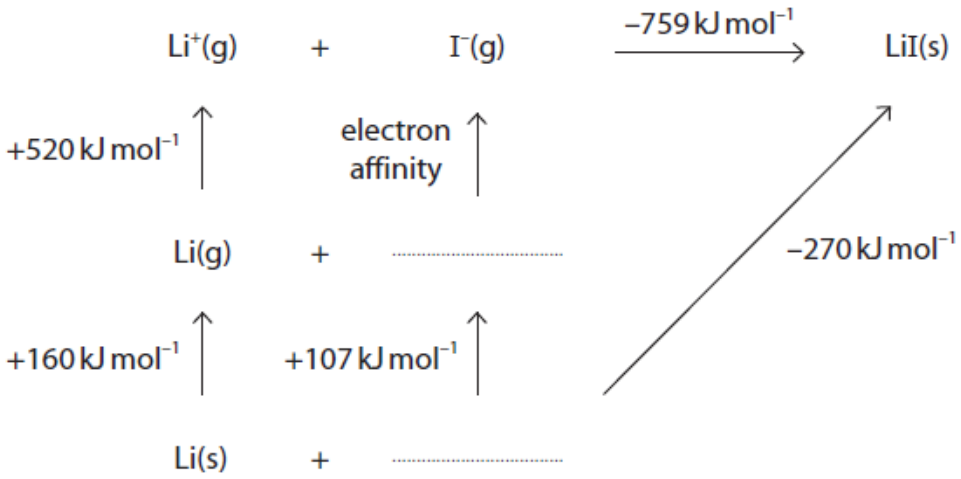
☒ **D** $Br_2(g) \rightarrow 2Br(g)$

(Total for question = 1 mark)

Q3.

For each question, select one answer from A to D and put a cross in the box ☒. If you change your mind about an answer, put a line through the box ☒ and then mark your new answer with a cross ☒.

A simplified Born-Haber cycle for the formation of lithium iodide is shown.



(a) The enthalpy change of atomisation of iodine (+107 kJ mol^{-1}) is given by the equation

(1)

☒ **A** $\frac{1}{2}I_2(g) \rightarrow I(g)$

☒ **B** $\frac{1}{2}I_2(s) \rightarrow I(g)$

☒ **C** $I_2(g) \rightarrow 2I(g)$

☒ **D** $I_2(s) \rightarrow 2I(g)$

(b) Use the information in the cycle to calculate the electron affinity of iodine.

(1)

☒ **A** –298 kJ mol^{-1}

☒ **B** –242 kJ mol^{-1}

☒ **C** +242 kJ mol^{-1}

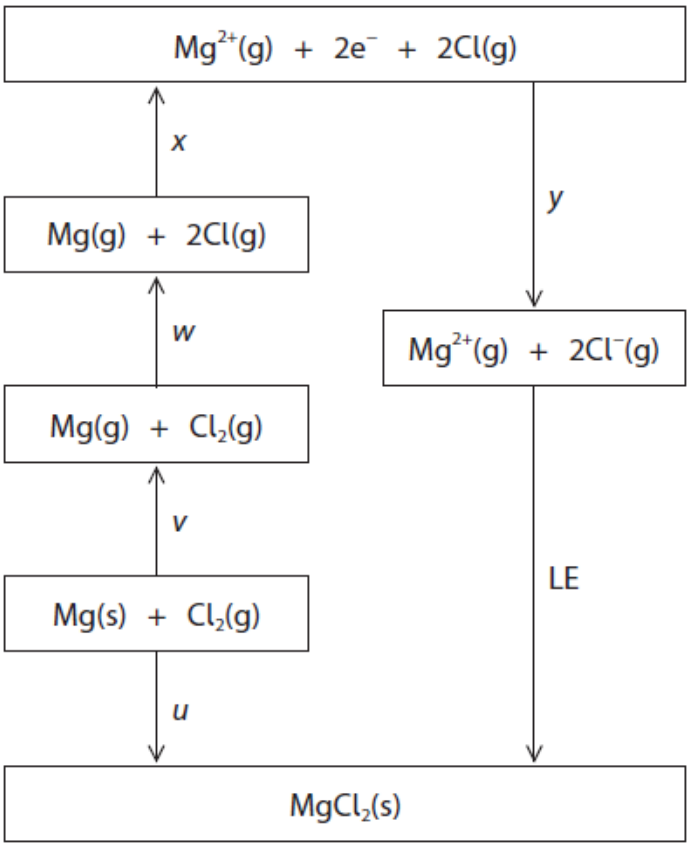
☒ **D** +298 kJ mol^{-1}

(Total for question = 2 marks)

Q4.

Answer the question with a cross in the boxes you think are correct ☒. If you change your mind about an answer, put a line through the box ☒ and then mark your new answer with a cross ☒.

The diagram shows the Born-Haber cycle for magnesium chloride.



(a) Which of these is the electron affinity of chlorine?

(1)

☒ **A** y

☒ **B** $y/2$

☒ **C** $(w + y)$

☒ **D** $(w + y)/2$

(b) Which expression gives the lattice energy (LE) for magnesium chloride?

(1)

☒ **A** $LE = u - (v + w + x + y)$

☒ **B** $LE = v + w + x + y - u$

☒ **C** $LE = y - u - (v + w + x)$

☒ **D** $LE = v + w + x - y + u$

(c) Which energy change in the cycle does x represent?

(1)

☒ **A** the first ionisation energy of magnesium

☒ **B** the second ionisation energy of magnesium

☒

C the sum of the first and second ionisation energies of magnesium

☒ **D** the sum of the enthalpy change of atomisation and the first and second ionisation energies of magnesium

(Total for question = 3 marks)

Q5.

This question concerns calcium chloride, $CaCl_2$.

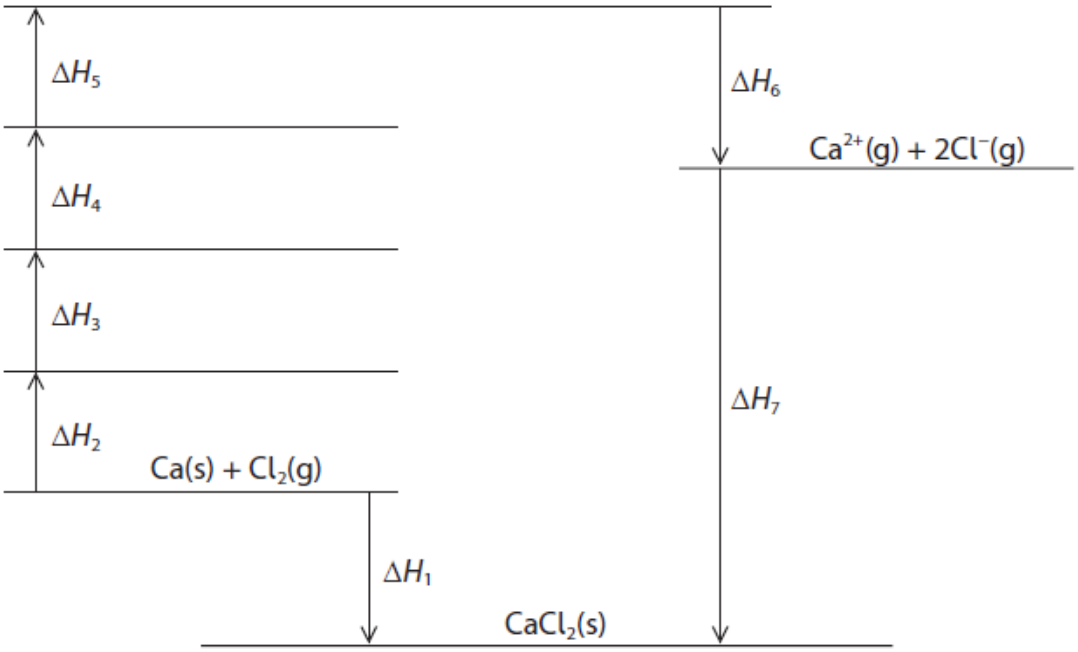
Some energy changes related to calcium chloride are shown.

Energy change	Value / kJ mol^{-1}
Atomisation energy of calcium	+178.2
Atomisation energy of chlorine	+121.7
Electron affinity of chlorine	−348.8
First ionisation energy of calcium	+590.0
Standard enthalpy change of formation of calcium chloride	−795.8
Experimental lattice energy of calcium chloride	−2 258
Second ionisation energy of calcium	To be calculated

(i) Complete the Born-Haber cycle by writing appropriate chemical formulae on the horizontal lines.

Include state symbols and relevant electrons.

(4)



(ii) Calculate the second ionisation energy of calcium using the cycle and the values given in the table.

Include a sign and units with your value.

(3)

(b) The theoretical lattice energy of formation of $CaCl_2$ is $-2\,223\,kJ\,mol^{-1}$.

Explain why the experimental lattice energy of $CaCl_2$ is more exothermic than the theoretical value.

(3)

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(c) The table shows the theoretical lattice energies of some chlorides of Group 2.

Group 2 metal chloride	magnesium chloride	calcium chloride	strontium chloride	barium chloride
Lattice energy / kJ mol^{-1}	−2326	−2223	−2127	−2033

Explain the trend in **theoretical** lattice energies on descending Group 2.

(3)

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(d) Calculate the enthalpy change of solution of calcium chloride, $CaCl_2$.

Data

$\Delta_{hyd}H^{\ominus}(Ca^{2+}) = -1\,650\ kJ\ mol^{-1}$ $\Delta_{hyd}H^{\ominus}(Cl^{-}) = -364\ kJ\ mol^{-1}$

Experimental lattice energy ($CaCl_2$) = $-2\,258\ kJ\,mol^{-1}$

(2)

(Total for question = 15 marks)

Q6.

Answer the question with a cross in the box you think is correct ☒ . If you change your mind about an answer, put a line through the box ☒ and then mark your new answer with a cross ☒ .

The enthalpy change of solution of sodium sulfate, Na_2SO_4 , may be calculated using three pieces of data. Which of these pieces of data is **not** required?

☒ **A** lattice energy of Na_2SO_4

☒ **B** enthalpy change of hydration of Na^+

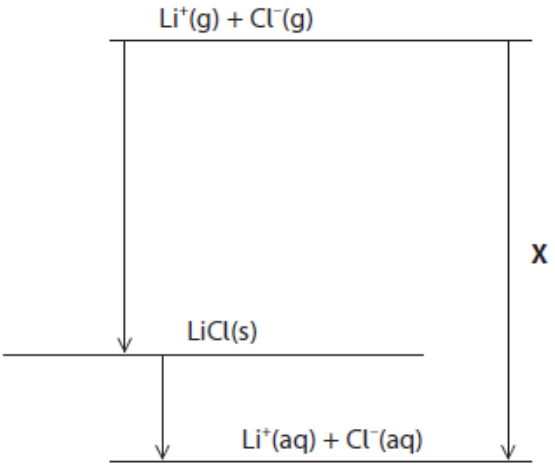
☒ **C** enthalpy change of formation of Na_2SO_4

☒ **D** enthalpy change of hydration of SO_4^{2-}

(Total for question = 1 mark)

Q7.

What does **X** represent on the diagram?



☒ **A** sum of enthalpy changes of hydration of the gaseous ions

☒ **B** enthalpy change of formation of LiCl

☒ **C** enthalpy change of solution of LiCl

☒ **D** lattice energy of LiCl

(Total for question = 1 mark)

Q8.

For each question, select one answer from A to D and put a cross in the box ☒. If you change your mind about an answer, put a line through the box ☒ and then mark your new answer with a cross ☒.

Some energy changes are given in the table.

Energy change	Value / kJ mol^{-1}
Lattice energy for $CaCl_2(s)$	–2258
Enthalpy change of solution of $CaCl_2(s)$	–120
Enthalpy change of hydration of $Cl^-(g)$	–364

Use these data to calculate the enthalpy change of hydration of $Ca^{2+}(g)$.

☒ **A** –1410 kJ mol^{-1}

☒ **B** –1650 kJ mol^{-1}

☒ **C** –2014 kJ mol^{-1}

☒ **D** –3106 kJ mol–

(Total for question = 1 mark)

Q9.

Answer the question with a cross in the box you think is correct ☒. If you change your mind about an answer, put a line through the box ☒ and then mark your new answer with a cross ☒.

Experimental lattice energy values determined using the Born-Haber cycle often differ from calculated theoretical values.
The ionic radii and charges of some ions are shown.

P, Q, R and S are **not** the chemical symbols of the elements.

Ion	Ionic radius / nm
P^+	0.076
Q^+	0.167
R^-	0.133
S^-	0.220

Which of these compounds would be expected to show the largest percentage difference between the experimental and theoretical lattice energies?

☒ **A** **PR**

☒ **B** **PS**

☒ **C** **QR**

☒ **D** **QS**

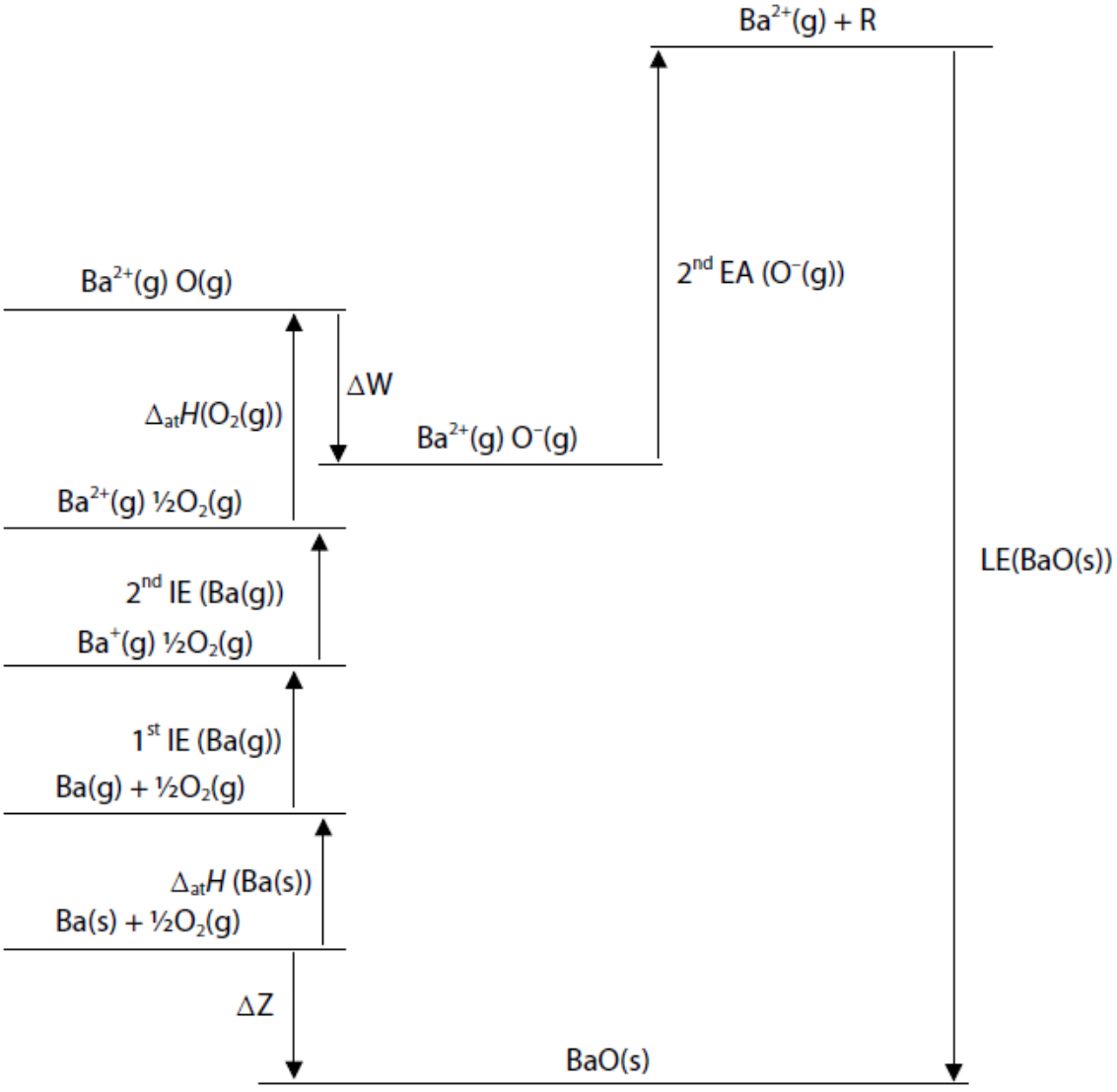
(Total for question = 1 mark)

Q10.

Barium oxide is an ionic compound that reacts with water to form barium hydroxide.

(a) A Born-Haber cycle for barium oxide, BaO, is shown.

Some of the detail is missing. The letters **R**, **W** and **Z** represent some missing information.



(i) Identify the missing detail represented by the following letters.

(2)

R .....

W .....

(ii) Use the following data to calculate a value for the quantity ΔZ shown on the Born-Haber cycle.

Include a sign and units in your answer.

(3)

Energy quantity	Enthalpy change / kJ mol^{-1}
Enthalpy change of atomisation of barium, $\Delta_{at}H$(Ba(s))	+180.0
Enthalpy change of atomisation of oxygen, $\Delta_{at}H$ (½O_2(g))	+249.2
First ionisation energy of barium, Ist IE (Ba(g))	+503.0
Second ionisation energy of barium, 2nd IE (Ba(g))	+965.0
ΔW	–141.1
Second electron affinity of oxygen, 2nd EA (O^-(g))	+798.0
Lattice energy barium oxide, $\Delta_{LE}H$(BaO(s))	–3054.0

(iii) The table gives some information about the lattice energies of barium oxide and magnesium iodide and shows the % difference between the theoretical and experimental values.

	Lattice energy / kJ mol^{-1}		
	Experimental	Theoretical	% difference
BaO(s)	–3054	–3029	0.8
MgI_2(s)	–2327	–1944	16.5

Explain why there is closer agreement for barium oxide than for magnesium iodide.

(3)

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(b) The table gives some information about Group 2 ions, M^{2+}, and their hydroxides.

Formula of hydroxide	Lattice energy / kJ mol^{-1}	$\Delta_{sol}H$ / kJ mol^{-1}	Solubility / mol per 100 g	Ion	$\Delta_{hyd}HN^{2+}$ / kJ mol^{-1}
$Mg(OH)_2$	–3000	+150	2.0×10^{-5}	Mg^{2+}	–1930
$Ca(OH)_2$	–2640	+140	1.6×10^{-4}	Ca^{2+}	–1580
$Sr(OH)_2$	–2475	+105	3.3×10^{-4}	Sr^{2+}	–1450
$Ba(OH)_2$	–2230		2.4×10^{-4}	Ba^{2+}	–1360

(i) Calculate the enthalpy change of solution, $\Delta_{sol}H$, of $Ba(OH)_2$ using a fully-labelled Hess's cycle.

[The hydration enthalpy of the hydroxide ion, OH^- = –460 kJ mol^{-1}.]

(4)

(ii) Explain why strontium hydroxide is slightly soluble in water, even though the enthalpy change of solution is endothermic.

(2)

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(Total for question = 14 marks)

Q11.

This question is about halides.

(a) Silicon tetrachloride, $SiCl_4$, is used in the manufacture of optical fibres. It can be made by

the reaction of silicon carbide, SiC, with hydrogen chloride using a catalyst of nickel(II) chloride.

$$SiC(s) + 4HCl(g) \rightarrow SiCl_4(l) + CH_4(g) \qquad \Delta H = -631.3\,kJ\,mol^{-1}$$

The standard molar entropies $S^{\ominus}$, of the substances are shown in the table.

Substance	SiC(s)	HCl(g)	$SiCl_4(l)$	$CH_4(g)$
$S^{\ominus}/JK^{-1}\,mol^{-1}$	+16.5	+186.8	+239.7	+186.2

(i) Calculate the total entropy change, ΔS_{total}, for this reaction, at 298 K, using the information given.

Include a sign and units in your answer which should be given to an appropriate number of significant figures.

(5)

(ii) In industry, the reaction is carried out at 700 °C.

By considering entropy and other relevant factors, justify the use of this temperature.

(3)

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(iii) Use your answer from (a)(i) to calculate the equilibrium constant for the reaction at 298 K.

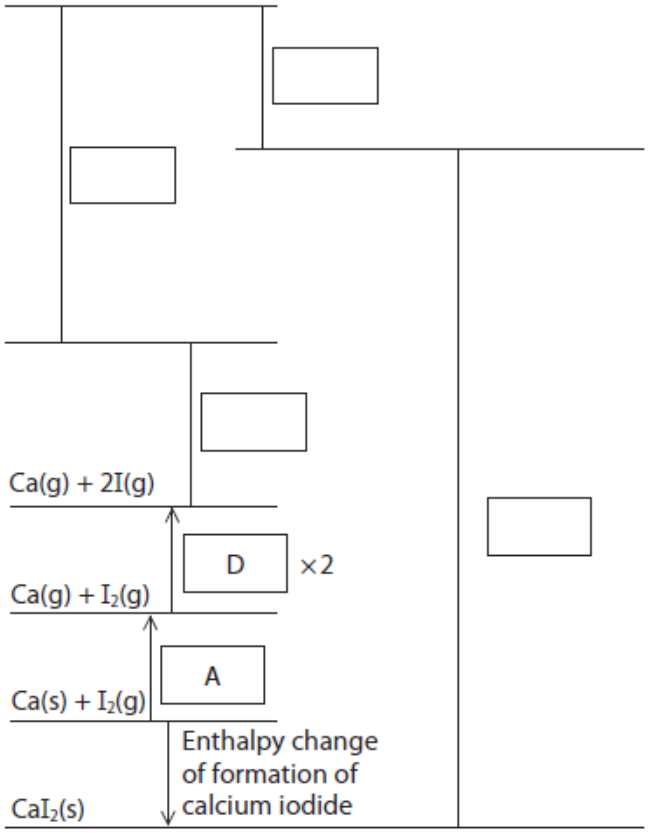
(2)

(b) The following data can be used in a Born-Haber cycle for calcium iodide, CaI_2.

Letter	Energy change	Value / kJ mol^{-1}
A	Enthalpy change of atomisation of calcium	+178.2
B	First ionisation energy of calcium	+590
C	Second ionisation energy of calcium	+1145
D	Enthalpy change of atomisation of iodine ($\frac{1}{2}I_2(s) \rightarrow I(g)$)	+106.8
E	Electron affinity of iodine	−295.4
F	Lattice energy of calcium iodide	−2074

(i) Complete the Born-Haber cycle by adding letters in the boxes for the energy changes, relevant species on the blank lines and arrowheads to show the direction of each energy change.

(3)



(ii) Use the data to calculate the value for the enthalpy change of formation of calcium iodide.

(2)

(iii) The value for the lattice energy of calcium iodide determined experimentally by using the Born-Haber cycle differs significantly from the theoretical calculated value.

Explain why the Born-Haber and the theoretical values for the lattice energies are similar for calcium fluoride but significantly different for calcium iodide.

(4)

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(c) The electron affinity of iodine is –295.4 kJ mol^{-1}.

Explain how the electron affinity of chlorine differs from that of iodine.

(3)

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(Total for question = 22 marks)

Q12.

Answer the question with a cross in the box you think is correct ☒ . If you change your mind about an answer, put a line through the box ☒ and then mark your new answer with a cross ☒ .

This question is about four ionic compounds.

(a) Which of these compounds would be expected to have the **least** exothermic lattice energy?

(1)

☒ **A** calcium chloride

☒ **B** magnesium chloride

☒ **C** potassium bromide

☒ **D** sodium bromide

(b) Which of these compounds would be expected to have the **largest** difference between their experimental (Born–Haber) and theoretical lattice energies?

(1)

☒ **A** calcium chloride

☒ **B** magnesium chloride

☒ **C** potassium bromide

☒ **D** sodium bromide

(Total for question = 2 marks)

Q13.

This question is about oxides of iron.

(a) The equation for the reduction of iron(III) oxide by carbon is shown.

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

Some data relating to this reaction are shown.

Substance	Fe_2O_3	C	Fe	CO
$\Delta_f H^{\ominus}$ / kJ mol^{-1}	−824.2	0	0	−110.5
$S^{\ominus}$ / J K^{-1} mol^{-1}	87.4	5.7	27.3	197.6

(i) Calculate the standard enthalpy change, $\Delta_r H^{\ominus}$, for the reduction of iron(III) oxide by carbon.

(2)

(ii) Calculate the entropy change, ΔS_{system}, for this reaction.

(3)

(iii) Calculate the temperature at which this reaction becomes feasible, using your answers from (a)(i) and (a)(ii).

(3)

(b) The equation for the reduction of iron(III) oxide by carbon monoxide is shown.

$$Fe_2O_3(s) + 3CO(g) \rightarrow 2Fe(s) + 3CO_2(g) \qquad \Delta H^{\ominus} = -24.8 \text{ kJ mol}^{-1}$$

The entropy change, $\Delta S^{\ominus}_{system}$, for this reaction is +15.2 J mol^{-1} K^{-1}.

(i) Explain why the reaction should be feasible at any temperature.

(2)

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(ii) Explain how an increase in temperature would affect $\Delta S^{\ominus}_{total}$ total of this reaction. No calculation is required.

(3)

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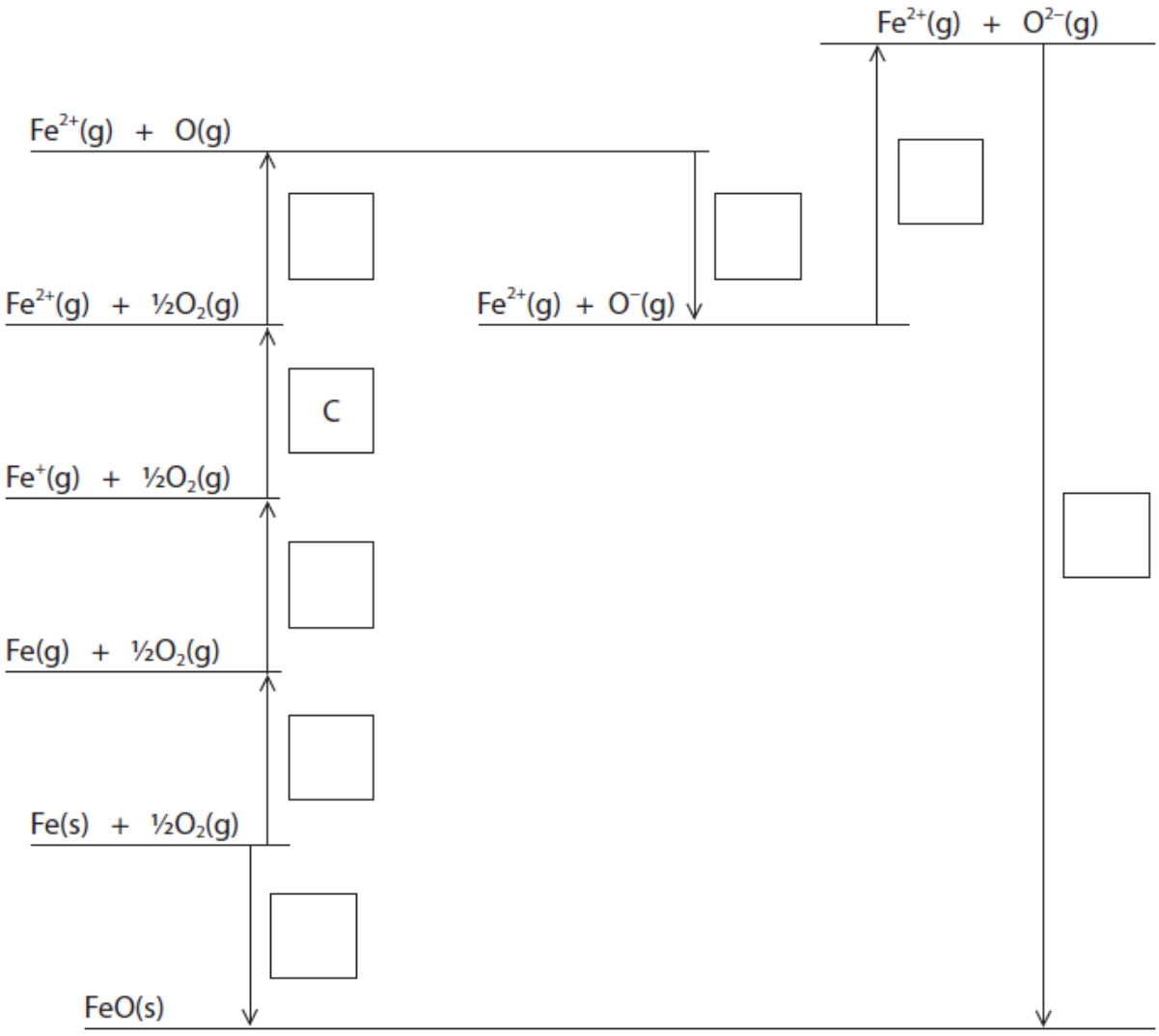
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(c) Iron also forms iron(II) oxide. The data in the table can be used to construct a Born-Haber cycle for iron(II) oxide, FeO.

Letter	Enthalpy change	Value /kJ mol^{-1}
A	Enthalpy change of atomisation of iron	+416
B	First ionisation energy of iron	+759
C	Second ionisation energy of iron	
D	Enthalpy change of formation of iron(II) oxide	−272
E	First electron affinity of oxygen	−141
F	Second electron affinity of oxygen	+798
G	Lattice energy of iron(II) oxide	−3920
H	Enthalpy change of atomisation of oxygen ($\frac{1}{2}O_2(g) \rightarrow O(g)$)	+249

(i) Complete the Born-Haber cycle by putting letters in the boxes to label the energy changes.

(3)



(ii) Calculate the value for second ionisation energy of iron, C.

(2)

(iii) Suggest why the second electron affinity of oxygen is positive.

(2)

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(Total for question = 20 marks)

Q14.

Answer the question with a cross in the box you think is correct ☒ . If you change your mind about an answer, put a line through the box ☒ and then mark your new answer with a cross ☒ .

The standard enthalpy change of solution of potassium chloride, KCl, is +17 kJ mol^{-1}.

The solubility of potassium chloride in water at 298 K is 359 g dm^{-3}.

Which of these explains the solubility of potassium chloride in water?

☐ **A** the hydration enthalpy of K^+ and the lattice energy of KCl are exothermic

☐ **B** the hydration enthalpy of K^+ and the lattice energy of KCl are endothermic

☐ **C** the total entropy change when KCl dissolves is positive

☐ **D** the total entropy change when KCl dissolves is negative

(Total for question = 1 mark)

Q15.

* The table shows the theoretical and experimental (Born-Haber) lattice energy data for two metal halide compounds, sodium chloride and magnesium iodide.

	Lattice energy / kJ mol^{-1}	
Metal halide	Theoretical	Experimental (Born-Haber)
Sodium chloride	−770	−780
Magnesium iodide	−1944	−2327

Using the data, compare and contrast the type and strength of bonding in these compounds. Give reasons for your answers.

(6)

(Total for question = 6 marks)

Mark Scheme

Q1.

Question Number	Answer	Additional Guidance	Mark
(a)(i)	$Kp = \frac{p_2NH_3}{pN_2\ p^3H_2}$	Allow round or no brackets Allow upper case Allow pp/PP Allow $p(NH_3)_2$ $p\,NH_{32}$ etc Ignore units even if incorrect Do not award square brackets	(1)

<table>
<tr><th>Question Number</th><th>Answer</th><th>Additional Guidance</th><th>Mark</th></tr>
<tr><td>(a)(ii)</td><td>• mole fraction of N_2 (1)
• mole fraction of H_2 (1)
• both partial pressures (1)</td><td>Example of completed table
<table><tr><th>Substance</th><th>Mole fraction</th><th>Partial pressure/atm</th></tr><tr><td>N_2</td><td>0.18</td><td>36</td></tr><tr><td>H_2</td><td>0.54</td><td>108</td></tr><tr><td>NH_3</td><td>0.28</td><td>56</td></tr></table>TE for M3 on calculated mole fractions multiplied by 200</td><td>(3)</td></tr>
</table>

Question Number	Answer	Additional Guidance	Mark
(a)(iii)	An answer that makes reference to the following points: • correct use of K_p expression **(1)** • correct answer **and** 1 or 2 SF **(1)** • correct units **(1)**	Example of calculation $56^2 \div (108^3 \times 36)$ 7 or 6.9×10^{-5} / 0.00007 or 0.000069 Allow 3SF 6.92×10^{-5} /0.0000692 Do not award 7.0×10^{-5} / 0.000070 atm^{-2} Allow TE from (a)(i) and (a)(ii) If mole fractions are used for the calculation max score 1 for the correct answer **and** 1-3 SF Correct answer with or without working scores 3	**(3)**

Question Number	Answer	Additional Guidance	Mark
(a)(iv)	An answer that makes reference to the following points: • the (forward) reaction is/ must be exothermic **(1)** • (more ammonia shows that) the equilibrium has moved/shifted to the right **OR** (more ammonia shows that) a new K_p is established which is larger **(1)**	Allow reverse argument Allow favours forward reaction/shifts to the product side Allow K_p increases/eqm constant increases Ignore just 'more ammonia produced' or 'yield increases'	**(2)**

Question Number	Answer	Additional Guidance	Mark
(b)(i)	• $NH_4^+(aq) + Cl^-(aq)$	Do not award $NH_4^+Cl^-(aq)$ Do not award $NH_4Cl(aq)$ Do not award any other state symbols	**(1)**

Question Number	Answer	Additional Guidance	Mark
(b)(ii)	• $\Delta_{sol}H = \Delta_{hyd}H$ – Lattice Energy or $\Delta_{sol}H = -$ Lattice Energy + $\Delta_{hyd}H$	Allow LE for Lattice Energy Allow $\Delta_{sol}H = -$ Lattice Energy + hydration enthalpies Allow $\Delta_{sol}H = -$ Lattice Energy + hydration enthalpies Allow ΔH_{hyd} etc Ignore standard signs	**(1)**

Question Number	Answer	Additional Guidance	Mark
(b)(iii)	• enthalpy change of hydration of ammonium chloride **(1)** • enthalpy change of solution **(1)**	Example of calculation $-307 + (-378) = -685$ (kJ mol^{-1}) Allow (kJ mol$^-$) $705 + (-685) = (+)20$ (kJ mol^{-1}) Allow TE on arithmetical errors Do not award use of incorrect expression Correct answer with or without working scores 2 Units are not required but if wrong penalise only once.	**(2)**

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Question Number	Answer	Additional Guidance	Mark
(b)(iv)	An explanation that makes reference to three of the following points • M1 the bromide (ion) is larger than the chloride (ion) **(1)** And any 2 of the following • M2 hydration enthalpy of the bromide ion less exothermic/less negative (than the chloride) **(1)** • M3 lattice energy of ammonium bromide would be less exothermic/less negative (than ammonium chloride) **(1)** • M4 the enthalpy of solutions depends on the values of both hydration and lattice energies (so the enthalpies of solution should be similar) **(1)**	Allow bromine ion larger than the chlorine ion Do not award larger atomic radius Allow smaller/lower Allow hydration enthalpy of bromine would be less exothermic/less negative (than the chlorine) Allow hydration enthalpy of ammonium bromide would be less exothermic/less negative (than ammonium chloride) Allow smaller/lower Accept because we don't know the magnitude of the reduction in hydration and lattice energies it is not possible to assess the overall effect Allow reverse arguments for MP1, MP2 and MP3 Ignore any reference to reactivity, polarisation and charge density	(3)

Question Number	Answer	Additional Guidance	Mark
(c)	• $NH_4^+ + H_2O \longrightarrow NH_3 + H_3O^+$	Accept $NH_4^+ \longrightarrow NH_3 + H^+$ Allow eqm sign Ignore $NH_4Cl \longrightarrow NH_4^+ + Cl^-$ Ignore $NH_4Cl + aq \longrightarrow NH_4^+ + Cl^-$ Ignore state symbols even if incorrect Do not award $NH_4Cl + aq \longrightarrow NH_3 + HCl$ Do not award $NH_4Cl \longrightarrow NH_3 + HCl$ Do not award $NH_4Cl \longrightarrow NH_3 + H^+ + Cl^-$ Do not award $NH_4^+ + OH^- \longrightarrow NH_3 + H_2O$	(1)

Q2.

Question Number	Answer	Mark
	The only correct answer is A ($\frac{1}{2}Br_2(l) \rightarrow Br(g)$) ***B*** *is not correct because the standard enthalpy change of atomisation refers to the formation of 1 mol of atoms* ***C*** *is not correct because bromine's standard state is as a liquid* ***D*** *is not correct because bromine exists as diatomic molecules in the liquid state in its standard state and only 1 mol of atoms should be formed*	(1)

Q3.

Question Number	Correct Answer	Mark
(a)	**The only correct answer is B** ($\frac{1}{2}I_2(s) \rightarrow I(g)$) ***A*** *is incorrect because atomisation of an element is from its standard state and iodine is a solid* ***C*** *is incorrect because atomisation produces 1 mole of atoms and requires solid iodine* ***D*** *is incorrect because atomisation produces 1 mole of atoms*	(1)

Question Number	Correct Answer	Mark
(b)	**The only correct answer is A** ($-298\ kJ\,mol^{-1}$) ***B*** *is incorrect because this value has had 28 added to –270 rather than subtracted from it* ***C*** *is incorrect because first electron affinity values are always exothermic* ***D*** *is incorrect because first electron affinity values are always exothermic and the wrong sign has been used for the enthalpy change of hydration*	(1)

Q4.

Question number	Answer	Mark
(a)	**The only correct answer is B** ($y/2$) ***A*** *is incorrect because the electron affinity of an element refers to a single atom of that element* ***C*** *is incorrect because this includes the atomisation energy of two atoms of chlorine* ***D*** *is incorrect because this includes the atomisation energy of chlorine*	**(1)**

Question number	Answer	Mark
(b)	**The only correct answer is A**(LE= $u - (v + w + x + y)$) ***B*** *is incorrect because this expression gives $-LE$* ***C*** *is incorrect because the electron affinity (x2) term and the enthalpy of formation have the wrong sign* ***D*** *is incorrect because this is the reverse of C which itself is incorrect.*	**(1)**

Question number	Answer	Mark
(c)	**The only correct answer is C** (the sum of the first and second ionisation energies of magnesium) ***A*** *is incorrect because x includes the second ionisation energy* ***B*** *is incorrect because x includes the first ionisation energy* ***D*** *is incorrect because xdoes not include the atomisation energy of Mg*	**(1)**

Q5.

Question Number	Answer	Additional guidance	Mark
	• Top line **(1)** • Bottom line **(1)** • Middle 2 lines **(2)**	Penalise missing or incorrect state symbol once only Penalise lack of electrons or too few electrons once only Penalise the writing of the change for each step e.g. $Ca(s) \rightarrow Ca(g)$ once only. Assume that the other substance is unchanged $Ca^{2+}(g) + 2Cl(g) + 2e^{(-)}$ Either $Ca(s) + 2Cl(g)$ or $Ca(g) + Cl_2(g)$ any two of $Ca^{+}(g) + 2Cl(g) + e^{(-)}$ or $Ca(g) + 2Cl(g)$ or $Ca^{+}(g) + Cl_2(g) + e^{(-)}$ or $Ca^{2+}(g) + Cl_2(g) + 2e^{(-)}$ Allow TE from one line to the next, so penalising any error once only.	**(4)**

Question Number	Answer	Additional guidance	Mark
(a)(ii)	• An equation linking enthalpy changes with correct signs and / or values **(1)** • Multiplies atomisation of chlorine OR electron affinity of chlorine by 2 **(1)** • Calculates final value of second ionisation energy of calcium with sign **(1)**	Example of calculation: $\Delta H_1 = \Delta H_2 + \Delta H_3 + \Delta H_4 + \Delta H_5 + \Delta H_6 + \Delta H_7$ OR $\Delta H_6 + \Delta H_7 = \Delta H_1 - \Delta H_2 - \Delta H_3 - \Delta H_4 - \Delta H_5$ OR $\Delta H_5 = - \Delta H_4 - \Delta H_3 - \Delta H_2 + \Delta H_1 - \Delta H_7 - \Delta H_6$ OR $\Delta H_5 = - 590.0 - 178.2 - ((2 \text{ x}) 121.7) + -795.8 - - 2258 - ((2 \text{ x}) - 348.8)$ Similar numerical expressions of the other equations also score 2 x 121.7 / 243.4 / 243 OR 2 x – 348.8 / – 697.6 / – 698 (+) 1148.2 / (+) 1148 / (+) 1150 ($kJ\ mol^{-1}$)	**(3)**

		ALLOW TE on all stages of calculation for max 2. Correct answer with no working scores (3) Ignore SF except 1 SF Common incorrect answers include: – 1148.2 / – 1148 / – 1150 ($kJ\ mol^{-1}$) scores (2) (+)799.4 / (+)799 / (+)780 ($kJ\ mol^{-1}$) (1 x 348.8) scores (2) (+)1269.9 / (+)1270 ($kJ\ mol^{-1}$) (1 x 121.7) scores (2) (+)921.1 / (+)921 / (+) 920 ($kJ\ mol^{-1}$) (1 x 348.8 and 121.7) scores (1) (+)2512.7 (Changing sign of $\Delta H_6 + \Delta H_7$ and no 2 x) scores (0)	

Question Number	Answer	Additional guidance	Mark
(b)	An explanation that makes reference to the following points: **EITHER** • Bonding is partially covalent / not purely ionic / has covalent character **(1)** • Ca^{2+} ion is small (and highly charged) **(1)** • Leading to polarisation / distortion in the electron cloud of the chloride / Cl^- (ion) / anion **(1)**	Penalise the use of calcium and / or chlorine (atom) once only Ignore descriptions of possible macroscopic features of covalent character such as structures etc. Allow calcium ion is small and highly charged / has a high charge density Do not award chlorine Do not award distortion by calcium / calcium atom	**(3)**

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	OR • Bonding is almost purely ionic / slightly covalent **(1)** • Ca^{2+} is not sufficiently small (and highly charged) **(1)** • To polarise the chloride / Cl^- (ion) very much / to distort the electron cloud of the chloride / Cl^- (ion) **(1)**	Allow virtually 100% ionic Do not award purely ionic / 100 % ionic calcium ion is not sufficiently small and highly charged / has too small a charge density Do not award calcium / calcium atom is not sufficiently small / charged Allow chloride (ion) is not very polarised / is not very polarisable Do not award chlorine Do not award chloride is not polarised / polarisable	

Question Number	Answer	Additional guidance	Mark
(c)	An explanation that makes reference to the following points: • (on descending the group) lattice enthalpy becomes less exothermic **(1)** • as the radius of metal ion / M^{2+} ion / cation increases (and charge on ions remains the same / 2+) **(1)** • (down group) weaker forces of **attraction** between **ions** **(1)**	Penalise mention **specifically** of atoms instead of ions once only Penalise mention **specifically** of molecules once only Award reverse arguments if clearly referring to ascending the group Ignore discussion of polarising power Allow less negative / less energy is released Ignore increases / decreases Allow "size" instead of "radius" Ignore atomic radius increases Allow correct formulae of cations Do not award just "charge density decreases" without explanation Allow less attraction to chloride ion Do not award just "weaker bonds" or "weaker bonding"	**(3)**

Question Number	Answer	Additional guidance	Mark
(d)	• An expression linking enthalpy of solution, lattice enthalpy and hydration enthalpies **(1)** • Value of $\Delta_{sol}H$ **(1)**	Example of calculation $\Delta_{sol}H = -\Delta_{latt}H + (\Sigma)\Delta_{hyd}H$ OR $\Delta_{sol}H = -(-2258) + (-1650) + (2 \times -364)$ -120 (kJ mol^{-1}) Correct answer with no working scores (2) (+)120 / (+)244 / -4636 (kJ mol^{-1}) scores (1)	**(2)**

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Q6.

Q	Correct Answer	Mark
	The only correct answer is C (enthalpy change of formation of Na_2SO_4) ***A*** *is incorrect as lattice energy is used to find the enthalpy change of solution* ***B*** *is incorrect as enthalpy change of hydration is used to find the enthalpy change of solution* ***D*** *is incorrect as enthalpy change of hydration is used to find the enthalpy change of solution*	1

Q7.

Question Number	Answer	Mark
	The only correct answer is **A** (sum of enthalpies of hydration of the gaseous ions) *B is incorrect as it would be* $Li(s) + \frac{1}{2}Cl_2(g) \rightarrow LiCl(s)$ *C is incorrect as it would be* $LiCl(s) \rightarrow Li^+(aq) + Cl^-(aq)$ *D is incorrect as it would be* $Li^+(g) + Cl^-(g) \rightarrow LiCl(s)$	1

Q8.

Question Number	Correct Answer	Mark
	The only correct answer is B ($-1650\ kJ\ mol^{-1}$) ***A*** *is incorrect because this uses the wrong sign for the enthalpy change of solution* ***C*** *is not correct because this uses only one mole of chloride ions* ***D*** *is not correct because this does not change the sign of the lattice enthalpy*	(1)

Q9.

Question Number	Answer	Mark
	The only correct answer is B (PS) *A is not correct because R is smaller than S* *C is not correct because Q is larger than P and R is smaller than S* *D is not correct because Q is larger than P*	(1)

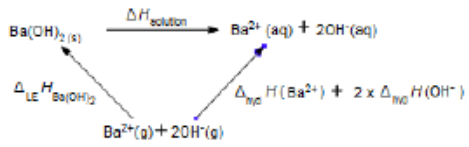
Q10.

Question number	Answer	Additional guidance	Mark
(a)(i)	• R = O^{2-}(g) (1) • W = first electron affinity O(g) (1)	Allow alternative ways to express electron affinity, e.g. EA State required Do not allow O_2/O^-	2

Question number	Answer	Additional guidance	Mark
(a)(ii)	• correct application of cycle (1) • correct value (1) • correct sign and units (1)	Example of calculation: $\Delta_f H$ (BaO(s)) = $\Delta_{at}H$(Ba(s))+$\Delta_{at}H$(½O_2(g))+ 1^{st} IE (Ba)(g) +2^{nd} IE (Ba(g))+2^{nd} EA (O(g))+1^{st} EA (O(g)) +$\Delta_{LE}H$ (BaO(s)) or Correct numbers = 180.0+249.2+503+965+798−141.1−3054 (−)499.9/(−)500 (kJ mol^{-1}) Allow TE from incorrect application of cycle Allow TE for incorrect numbers Correct answer with no working scores 3	3

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Question number	Answer		Additional guidance	Mark
(a)(iii)	• ionic radius of Ba^{2+} >> ionic radius of Mg^{2+}/(have) lower charge density **and** Ba^{2+} (ions are) less polarising/(have) lower charge density	(1)	Allow reverse argument	3
	• iodide ions/I^- are large **and** their electron clouds are easily distorted/polarised (by Group 2 cations) or oxide ions/O^{2-} are small(er) **and** their electron clouds are less easily distorted/polarised	(1)		
	• more distortion/covalency leads to greater difference between theoretical and experimental values	(1)		

Question number	Answer		Additional guidance	Mark
(b)(i)			Do not allow energy profile or energy level diagrams	4
	• all arrows in the correct direction	(1)	Species at each corner must be approximately correct	
	• correct formulae at each corner and enthalpies of hydration, and solution and LE correctly identified	(1)	Allow missing minor detail: brackets, position of subscripts, etc. but not absence of subscripts	
	• correct expression or correct substitution of values	(1)	Example of calculation: $\Delta_{sol}H = (\Delta_{hyd}H\,(Ba^{2+}) + 2\Delta_{hyd}H(OH^-)) -$ LE $(Ba(OH)_2)$ or $= (-1360 + (2 \times -460)) - (-2230)$	
	• correct evaluation	(1)	$= -50$ (kJ mol^{-1}) Allow TE from their cycle if $\Delta_{hyd}H(OH^-)$ is not doubled	

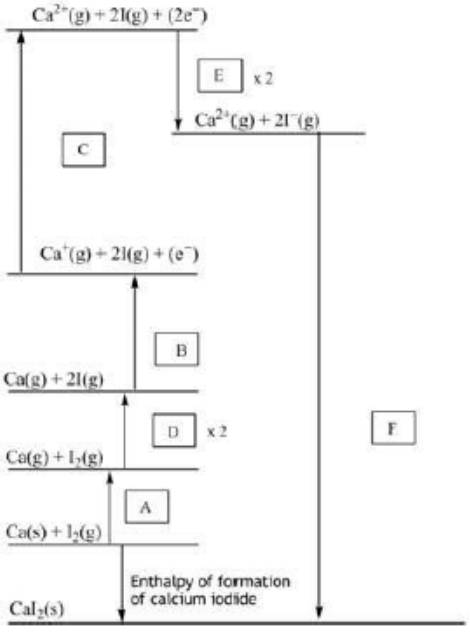
Question number	Answer		Additional guidance	Mark
b(ii)	• entropy (change) of system/ΔS_{system}/$\Delta S_{dissolving}$ is large and positive (and outweighs negative $\Delta S_{surroundings}$ ($-\Delta H/T$))	(1) (1)		2
	• overall entropy change/ΔS_{total} is positive or			
	• use of $\Delta S_{total} = \Delta S_{surroundings} + \Delta S_{system}$	(1)		
	• $\Delta S_{total} = \Delta S_{surroundings} + (-\Delta H/T)$	(1)	Allow use of ΔG	

Q11.

Question Number	Acceptable Answers	Additional Guidance	Mark
(a)(i)	**M1** Expression for ΔS_{system} (1) **M2** Value for ΔS_{system} (1) **M3** Expression for $\Delta S_{surroundings}$ (1) **M4** Value for $\Delta S_{surroundings}$ (1) **M5** Value for ΔS_{total} to 2 or 3 SF and units (1)	Example of calculation: (186.2 + 239.7) – (16.5 + (4 x 186.8)) —337.8 (J K^{-1} mol^{-1}) $\Delta S_{surroundings} = -\frac{\Delta H}{T} = -(-631.3 \times 10^3) / 298$ = (+) 2118.5 (J K^{-1} mol^{-1}) / (+)2.1185 (kJ K^{-1} mol^{-1}) (= 2118.5 + (– 337.8) = (+)1780.7 = (+)1780 / (+)1800 J K^{-1} mol^{-1} (+)1.78 / (+)1.80 kJ K^{-1} mol^{-1} Allow TE at each stage Correct answer with no working scores 5 (+)2340 J K^{-1} mol^{-1} scores 4 (1 x 186.8) (+) 2460 J K^{-1} mol^{-1} scores 3 (react-prod)	5

Question Number	Acceptable Answers	Additional Guidance	Mark
(a)(ii)	An answer that makes reference to: • A higher temperature would result in a less positive / lower $\Delta S_{surroundings}$ (ΔS_{system} is relatively unaffected by temperature) (1) • So ΔS_{total} is less positive / lower, which makes reaction less feasible /reduces yield (1) COMMENT: For M1 and M2 allow correct calculation of ΔS_{total} (at 973K) >0 to show that the reaction is feasible. • but high temperature is used to increase rate (1)	Ignore references to Le Chatelier for M1 and M2. Allow A higher temperature would result in a an insignificant change in $\Delta S_{surroundings}$ as its value is so large (ΔS_{system} is relatively unaffected by temperature) So ΔS_{total} is unchanged (in sign), which means feasibility of reaction is unchanged Ignore less easily / readily Standalone mark	3

Question Number	Acceptable Answers	Additional Guidance	Mark
(a)(iii)	Recall of expression for K (1) Rearrangement of expression and calculation of ln K and value for K (1) **Allow TE from (a)(i) but no TE if incorrect expression given in M1.**	Example of calculation: $\Delta S_{total} = R \ln K$ $\ln K = \Delta S_{total} / R = 1780.7 / 8.31$ $= 214.1998$ 1.15440×10^{93} Allow any answer between 1.06×10^{93} and 1.18×10^{94} Ignore any units; Ignore SF Correct answer with no working scores 2	2

Question Number	Acceptable Answers	Additional Guidance	Mark
(b)(i)	Arrows upwards for first and second ionisation energies for calcium and correct labels, B and C in boxes (1) Downward arrows for electron affinity and lattice enthalpy and correct labels E x 2 and F in boxes (1) Correct species including state symbols on horizontal lines (1)  	Only penalise lack of arrow once in M1 and M2. If electrons are included, they must be correct but allow e for e^-	3

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Question Number	Acceptable Answers	Additional Guidance	Mark
(b)(ii)	Correct expression (1) Evaluation (1)	Example of calculation: [(178.2 + 590 + 1145+ (106.8 x 2) – (295.4 x 2)] – 2074 = —538 (kJ mol^{-1}) If E x 2 penalised in b(i), allow use of 1 x 295.4 as TE. In this case only -242.6(kJ mol^{-1}) scores 2 However, if E x 2 not penalised in b(i) then penalise failure to multiply by 2 once only in b(ii) -349.4(kJ mol^{-1}) scores 1 (misses both x 2) -242.6(kJ mol^{-1}) scores 1 (misses 2 x 295.4) -644.8 (kJ mol^{-1}) scores 1 (misses 2 x 106.8) +538 (kJ mol^{-1}) scores 1 (expression wrong way round) ignore SF except 1 SF	2

Question Number	Acceptable Answers	Additional Guidance	Marks
(b)(iii)	Bonding in calcium fluoride is (virtually) 100% ionic (1) Whereas bonding in calcium iodide has a degree of covalency / somecovalent character (1) Then any **2** from these 3 marking points The calcium **ion** is polarizing (1) The fluoride (ion) is small so not easily polarised / electron cloud not soeasily distorted (1) the iodide (ion) is larger and so is easily polarised / electron cloud iseasily distorted (1)	 Allow Iodide / I^- has some covalent character Penalise the use of fluorine and iodine once only	4

Question Number	Acceptable Answers	Additional Guidance	Mark
(c)	**M1** More exothermic / more negative / greater in magnitude (1) **M2** As (the atomic radius of) chlorine is smaller / less shielding between nucleus and electron (to be gained) / chlorine has fewer shells (of electrons) (1) **M3** Stronger attraction (between nucleus and electron to be gained) (1)	Ignore larger / less / higher Allow 'more energy released' Do not award chloride for chlorine Allow chlorine is more electronegative than iodine Allow reverse argumentfor M2 and M3	3

Q12.

Question Number	Answer	Mark
(a)	**The only correct answer is C** (potassium bromide) *A is not correct because the least exothermic lattice energy is between the largest ions with the smallest charge and calcium ions are smaller and have a higher charge than potassium ions* *B is not correct because the least exothermic lattice energy is between the largest ions with the smallest charge and magnesium ions are smaller and have a higher charge than potassium ions* *D is not correct because sodium ions are smaller than potassium ions*	(1)

Question Number	Answer	Mark
(b)	**The only correct answer is B** (magnesium chloride) *A is not correct because Ca^{2+} ions are larger than magnesium ions so will polarise less* *C is not correct because K^{+} ions are larger than magnesium ions and have a lower charge so will polarise less* *D is not correct because Na^{+} ions are larger than magnesium ions and have a lower charge so will polarise less*	(1)

Q13.

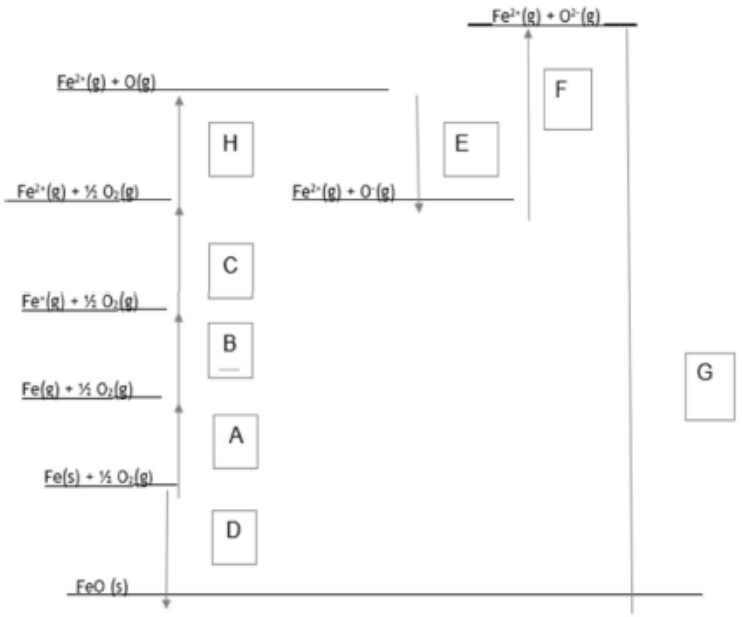
Question Number	Answer	Additional Guidance	Mark
(a)(i)	• correct use of enthalpy data **(1)** • correct enthalpy change **(1)**	Example of calculation $-(-824.2) + (3 \times -110.5)$ $= (+)492.7$ (kJ mol^{-1}) Correct answer with or without working scores 2 The following score 1 for a single error: (+) 713.7 (kJ mol^{-1}) not x3 -492.7 (kJ mol^{-1}) signs reversed Allow 3SF Penalise wrong units once only in (a)(i) and (ii)	(2)

Question Number	Answer	Additional Guidance	Mark
(a)(ii)	• $\sum S$ products (1) • $\sum S$ reactants (1) • $\Delta S_{system} = \sum S$ products $- \sum S$ reactants (1)	Example of calculation S = products (2 x 27.3) + (3 x 197.6) = 647.4 ($J\,K^{-1}\,mol^{-1}$) S = reactants 87.4 + (3 x 5.7) = 104.5 ($J\,K^{-1}\,mol^{-1}$) ΔS_{system} = 647.4 − 104.5 = (+)542.9 ($J\,K^{-1}\,mol^{-1}$) Correct answer with no working scores 3 Allow TE for M3	(3)

Question Number	Answer	Additional Guidance	Mark
(a)(iii)	• use of $\Delta S_{surroundings} = -\frac{\Delta H}{T}$ (1) • at equilibrium $\Delta S_{total} = 0$ $= \Delta S_{surroundings} + \Delta S_{system}$ (1) • calculation of temperature (1)	Example of calculation $\Delta S_{surroundings} = -(+492.7) \times 1000/T$ $0 = -492.7 \times 1000/T + 542.9$ $\geq$ 907.53(K) 0.90753 scores 2 (not x 1000) Ignore SF TE on (a)(i) and (a)(ii) Correct answer based on ai and aii without working scores 3 Allow use of $\Delta G = \Delta H - T\Delta S_{system}$	(3)

Question Number	Answer	Additional Guidance	Mark
(b)(i)	An answer that makes reference to the following points: • $\Delta S_{surroundings}$ **and** ΔS_{system} are positive (1) • so ΔS_{total} will always be positive (so reaction will be feasible) (1) **OR** Using $\Delta G = \Delta H - T\Delta S_{system}$ • Allow ΔH is negative **and** ΔS_{system} is positive (1) • so ΔG will always be negative (so reaction will be feasible) (1)	Allow ΔH is negative/reaction exothermic **and** ΔS_{system} is positive M2 **dependent** on M1 M2 **dependent** on M1	(2)

Question Number	Answer	Additional Guidance	Mark
(b)(ii)	An answer that makes reference to the following points: • at a higher temperature $\Delta S_{surroundings}$ will decrease **(1)** • ΔS_{system} does not change (significantly) **(1)** • so ΔS_{total} will decrease/become less positive **(1)**	Ignore reference to $\Delta S_{total} = R\ln k$	**(3)**

Question Number	Answer	Additional Guidance	Mark
(c)(i)	 All 7 correct 3 marks 4–6 correct 2 marks 2–3 correct 1 mark	Allow values instead of letters	**(3)**

Question Number	Answer	Additional Guidance	Mark
(c)(ii)	• correct expression **(1)** • correct calculation **(1)**	Example of calculation $-759 - 416 - 272 + 3920 - 798 + 141 - 249$ $= (+)1567$ (kJ mol^{-1}) Allow 3SF Correct answer with or without working scores 2 marks Allow 1 mark for one mistake	**(2)**

Question Number	Answer	Additional Guidance	Mark
(c)(iii)	• the electron is being added to a negative ion **(1)** • and so there is repulsion (so energy is required) **(1)**	This can be shown by an equation Allow repulsion between the electrons	**(2)**

Q14.

Question Number	Answer	Mark
	The only correct answer is C (the total entropy when KCl dissolves is positive) *A is not correct because the enthalpy change of hydration for all ions and lattice energy for all ionic compounds are exothermic so this does not explain why KCl is soluble* *B is not correct because the enthalpy change of hydration for all ions and lattice energy for all ionic compounds are exothermic* *D is not correct because the total entropy must be positive for a spontaneous reaction*	(1)

Q15.

Q	Answer	Additional Guidance	Mark
	This question assesses the student's ability to show a coherent and logically structured answer with linkages and fully sustained reasoning. Marks are awarded for indicative content and for how the answer is structured and shows lines of reasoning. The following table shows how the marks should be awarded for indicative content. The following table shows how the marks should be awarded for structure and lines of reasoning	Guidance on how the mark scheme should be applied. The mark for indicative content should be added to the mark for lines of reasoning. For example, a response with five indicative marking points that is partially structured with some linkages and lines of reasoning scores 4 marks (3 marks for indicative content and 1 mark for partial structure and some linkages and lines of reasoning). If there were no linkages between the points, then the same indicative marking points would yield an overall score of 3 marks (3 marks for indicative content and no marks for linkages).	

Number of indicative marking points seen in answer	Number of marks awarded for indicative marking points
6	4
5-4	3
3-2	2
1	1
0	0

	Number of marks awarded for structure of answer and sustained lines of reasoning
Answer shows a coherent logical structure with linkages and fully sustained lines of reasoning demonstrated throughout	2
Answer is partially structured with some linkages and lines of reasoning	1
Answer has no linkages between points and is unstructured	0

	Indicative Points • **IP1** Bonding in sodium chloride is (almost) 100% ionic bonds **and** as the theoretical and Born-Haber values are (very) similar • **IP2** Bonding in magnesium iodide has some covalent character **and** as theoretical and Born-Haber values are (significantly) different • **IP3** Anion is (more) polarised in magnesium iodide (than sodium chloride) • **IP4** Magnesium ion has a greater charge density (than sodium ion), so greater polarising power • **IP5** Iodide ion is larger (than chloride ion), so is more easily polarised • **IP6** Magnesium iodide has stronger bonding than sodium chloride because the charge on the magnesium ion is twice as large (as the charge on the sodium ion)	If neither IP1 or IP2 scored can get 1IP for Bonding in sodium chloride is (almost) 100% ionic bonds and bonding in magnesium iodide has some covalent character ALLOW Magnesium ion has a greater charge/smaller than sodium ion, so greater polarising power polarisation must be mentioned at least once in IP3, IP4 and IP5 Penalise use of 'atoms' instead of ions once only in IP3 IP4 and IP5 Penalise lack of comparative language once only in IP4, IP5 and IP6 Allow magnesium iodide has stronger bonding (than expected) due to polarisation / covalent character Allow both compounds have strong bonds as large amounts of energy needed to break up lattice / released when lattice forms / needed to break many strong bonds	
			(Total for Question = 6 marks)