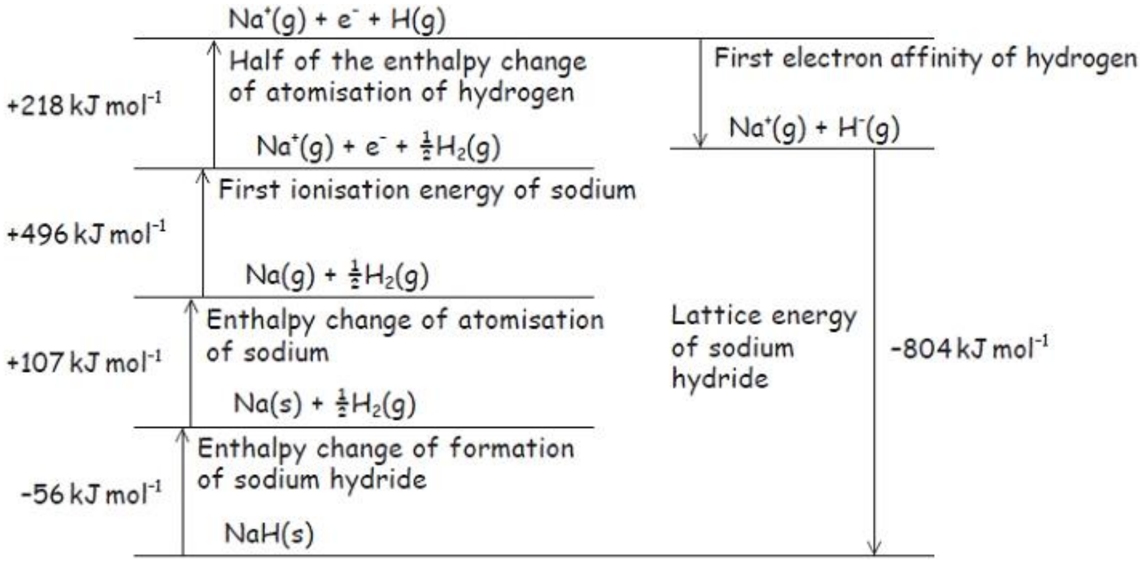
Questions

Q1.

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

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

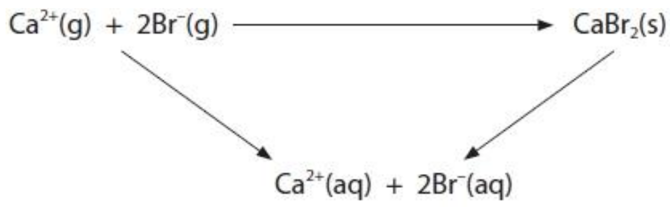
(1)

(Total for question = 3 marks)

Q2.

This question is about lattice energies.

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 = 2 marks)

Q3.

This question is about lattice energies.

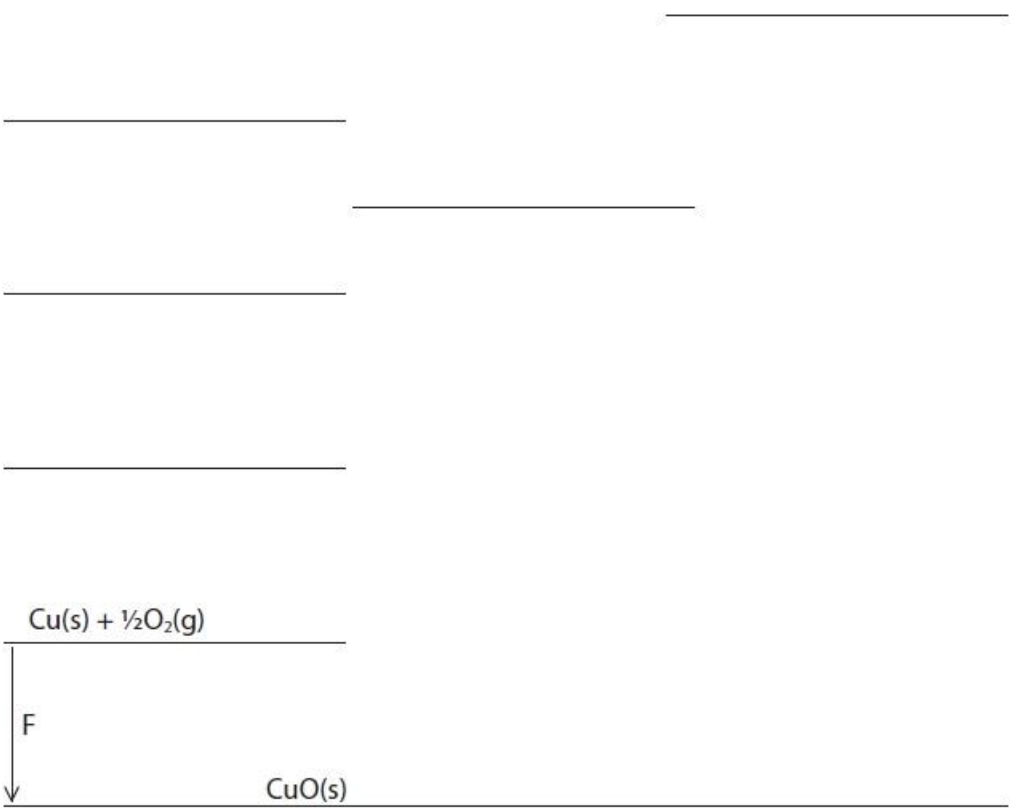
Data for the Born-Haber cycle for copper(II) oxide are given in the table.

Label	Energy change	Value / kJ mol^{-1}
A	standard enthalpy change of atomisation of copper	+338
B	standard enthalpy change of atomisation of oxygen	+249
C	sum of first and second ionisation energies of copper	+2704
D	first electron affinity of oxygen	−141
E	second electron affinity of oxygen	+798
F	standard enthalpy change of formation of copper(II) oxide	−157

(i) Complete the diagram of the Born-Haber cycle for copper(II) oxide.

Include labels of enthalpy changes with arrows indicating the direction of change, and the respective species with state symbols.

(4)



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

(1)

(Total for question = 5 marks)

Q4.

This question is about enthalpy changes and energy changes.

Use the data in the table to answer the questions.

Enthalpy change	Value / kJ mol^{-1}
Enthalpy change of hydration of K^+	−322
Enthalpy change of hydration of Ca^{2+}	−1650
Enthalpy change of solution of KCl	+17.2
Lattice energy of KCl	−711

(i) Name the two properties of ions that affect the value of their enthalpy change of hydration.

(2)

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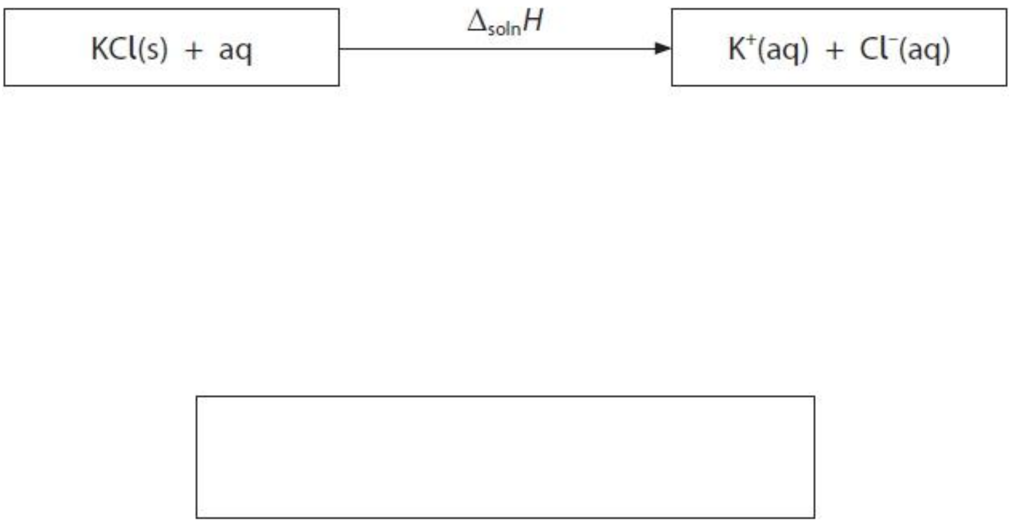
(ii) Calculate the enthalpy change of hydration for chloride ions by completing the energy cycle, including labels, and using the data in the table.

(3)



enthalpy change of hydration for Cl^- ions .... kJ mol^{-1}

(Total for question = 5 marks)

Q5.

This question is about the solubility of metal hydroxides.

When excess magnesium hydroxide is added to water and shaken, a saturated solution is formed and the mixture reaches equilibrium.

$$Mg(OH)_2(s) \rightleftharpoons Mg^{2+}(aq) + 2OH^-(aq)$$

The equilibrium constant, K_c , for this reaction is

$$K_c = [Mg^{2+}(aq)][OH^-(aq)]^2$$

(i) Give a reason why the magnesium hydroxide is not included in the expression for K_c.

(1)

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(ii) Give the units for K_c.

(1)

(iii) Calculate the enthalpy change of solution of magnesium hydroxide, using the following data.

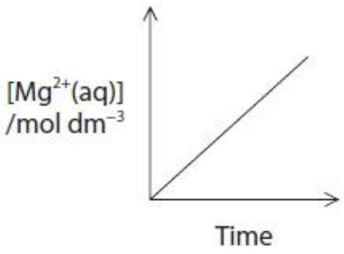
Energy or enthalpy change	Value / kJ mol^{-1}
Lattice energy of $Mg(OH)_2(s)$	−2842
$\Delta_{hyd}H$ ($Mg^{2+}(aq)$)	−1920
$\Delta_{hyd}H$ ($OH^-(aq)$)	−460

(2)

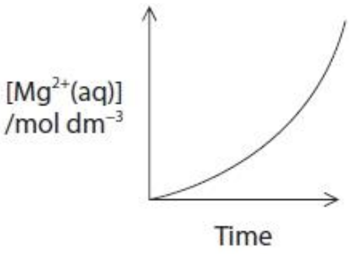
(iv) Which graph shows the change in the concentration of the $Mg^{2+}(aq)$ ions when some solid magnesium hydroxide is shaken with water and left to reach equilibrium?

(1)

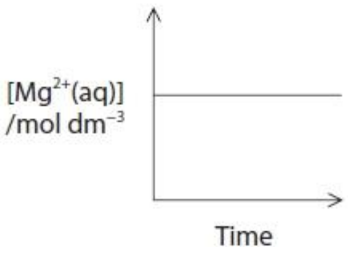
☐ **A**



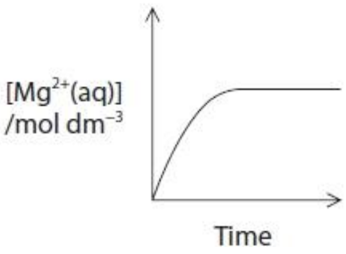
☐ **B**



☐ **C**



☐ **D**



(v) Predict the effect, if any, of adding each of the following to a saturated solution of magnesium hydroxide in contact with solid magnesium hydroxide. Justify your answers in terms of the effect on the equilibrium.

$$Mg(OH)_2(s) \rightleftharpoons Mg^{2+}(aq) + 2OH^-(aq)$$

(4)

Magnesium sulfate solution

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Dilute hydrochloric acid

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(Total for question = 9 marks)

Q6.

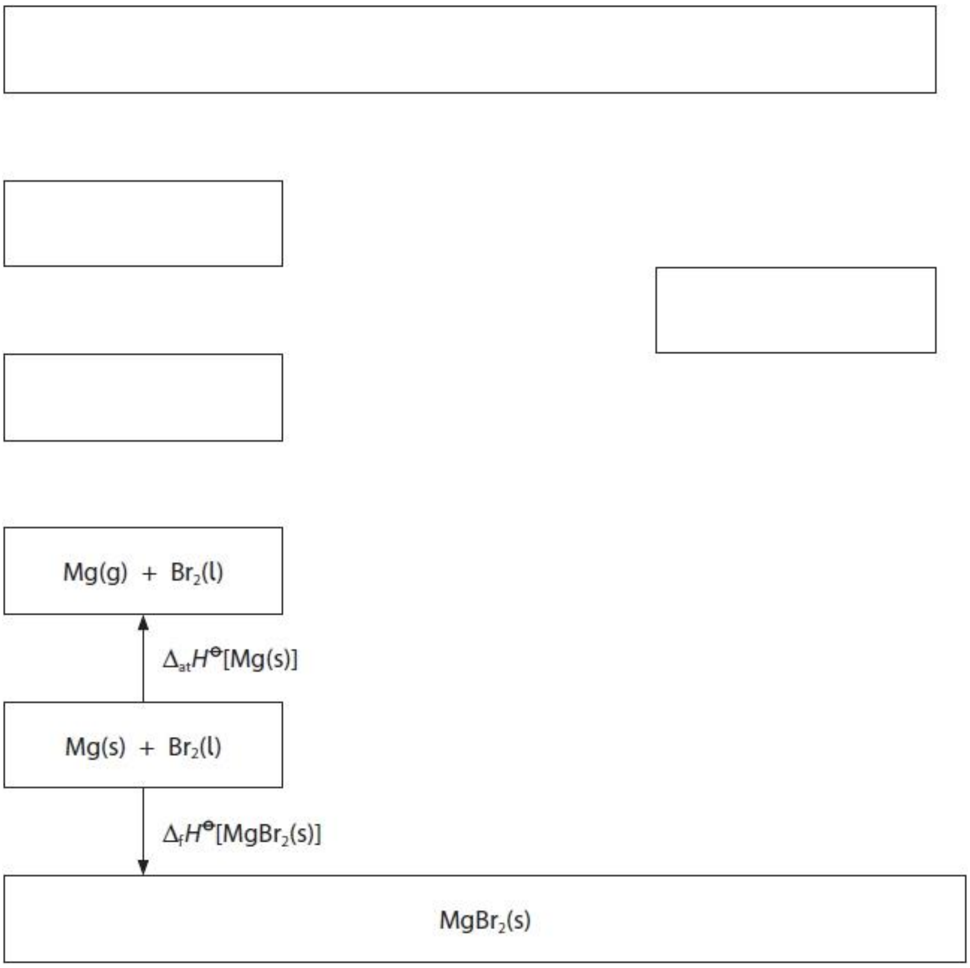
Magnesium bromide, $MgBr_2$, is an ionic compound.

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, $\Delta_{at}H^{\ominus}$[Mg(s)]	+148
1st ionisation energy of magnesium, 1st IE[Mg(g)]	+738
2nd ionisation energy of magnesium, 2nd IE[Mg^+(g)]	+1451
enthalpy change of atomisation of bromine, $\Delta_{at}H^{\ominus}$[½Br_2(l)]	+112
lattice energy of magnesium bromide, LE[$MgBr_2$(s)]	−2440
enthalpy change of formation of magnesium bromide, $\Delta_f H^{\ominus}$[$MgBr_2$(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)

(Total for question = 5 marks)

Q7.

This question is about lattice energies.

The table shows the theoretical and experimental lattice energy values of two compounds.

Compound	Theoretical lattice energy / $kJ\,mol^{-1}$	Experimental lattice energy / $kJ\,mol^{-1}$
magnesium iodide	−1944	−2327
barium iodide	−1831	−1877

(i) State what can be deduced by the close similarity of the lattice energy values for barium iodide.

(1)

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(ii) Explain why there is a significant difference in the lattice energy values for magnesium iodide.

(4)

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(Total for question = 5 marks)

Q8.

This question is about ions and ionic compounds.

* The table shows the theoretical and experimental lattice energy values of two compounds.

Compound	Theoretical lattice energy / $kJ\,mol^{-1}$	Experimental lattice energy / $kJ\,mol^{-1}$
lithium chloride, $LiCl$	−845	−848
magnesium iodide, MgI_2	−1944	−2327

Comment on the theoretical and experimental lattice energy values, giving the reasons for any differences and similarities.

(6)

(Total for question = 6 marks)

Q9.

This question is about chlorine.

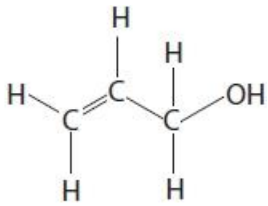
Write the equation for the first electron affinity of chlorine. Include state symbols.

(2)

(Total for question = 2 marks)

Q10.

Prop-2-en-1-ol is an unsaturated alcohol with the structure shown.



A student planned to use bond enthalpy data to calculate a value for the enthalpy change of combustion of prop-2-en-1-ol.

(i) When researching the bond enthalpy data, the student claimed that it was not necessary to find the value for the C=C
bond as they could use the value for a C–C bond and multiply it by two.
Explain why the student is **incorrect**.

(2)

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(ii) Calculate a value for the enthalpy of combustion of prop-2-en-1-ol using the data shown.

$$C_3H_6O(g) + 4O_2(g) \rightarrow 3CO_2(g) + 3H_2O(g)$$

Bond	C–C	C=C	C–O	C=O	O–H	C–H	O=O
Bond enthalpy / kJ mol^{-1}	347	612	358	805	464	413	498

(3)

(iii) Explain, in terms of entropy, why the combustion of prop-2-en-1-ol is always feasible in the gaseous state.

(2)

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(Total for question = 7 marks)

Mark Scheme

Q1.

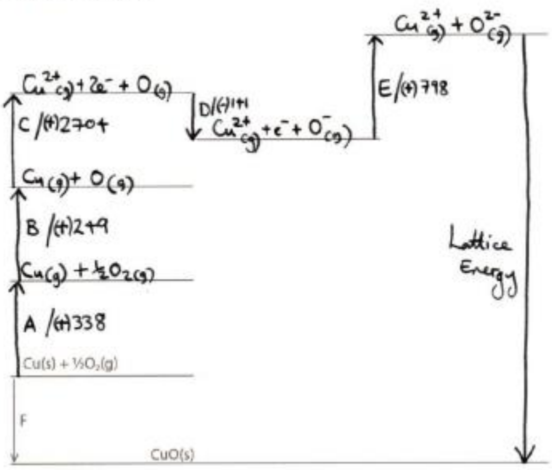
Question Number	Answer	Additional Guidance	Mark
(i)	An answer that makes reference to the following points: • identification and correction of the first error (1) • identification and correction of the second error (1)	Allow corrections to be made on the diagram Error 1 – arrow for enthalpy change of 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
(ii)	• calculation of first electron affinity of hydrogen	Example of calculation 1st EA= −(218+496+107)−56 +804 = −73 (kJ mol^{-1}) Allow a TE 1st EA = +39(kJ mol^{-1}) if the first arrow reversed direction is not identified	(1)

Q2.

Question Number	Answer	Additional Guidance	Mark
	• application of Hess's law (1) • evaluation of lattice energy (1)	Example of calculation LE = (−1577 + (2 × −336) − (−73)) = = −2176 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 kJ mol^{-1} scores (1) for use of single −336 instead of double	(2)

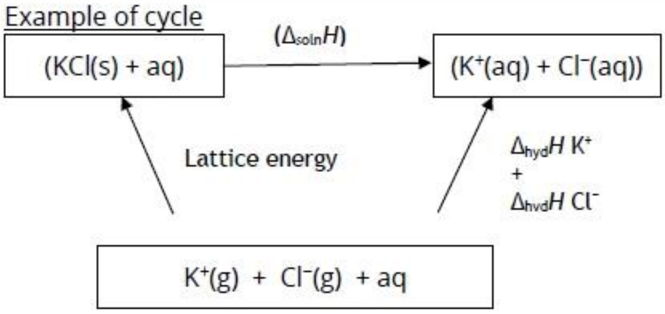
Q3.

Question Number	Answer	Additional Guidance	Mark
(i)	An answer that includes • species on lines (1) • state symbols (1) • energy changes / values (1) • arrows indicating direction (1)	<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
(ii)	• calculation of lattice energy	LE= −4105 (kJ mol^{-1})	(1)

Q4.

Question Number	Answer	Additional Guidance	Mark
(i)	An answer that makes reference to the following points: • (ionic) radius **(1)** • (ionic) charge **(1)**	 Allow size (of ions) Do not award atomic radius/size of atoms Do not award atomic charge/charge of atoms Allow charge density for 1 mark if no other mark awarded	**(2)**

Question Number	Answer	Additional Guidance	Mark
(ii)		Example of cycle 	(3)
	• correct species with state symbols in bottom box **(1)**	Ignore missing aq	
	• arrows in correct directions **and** labelled **(1)**	Allow any clear labels for arrows, including values for lattice energy and $\Delta_{hyd}H$ K^+, e,g, LE, HE Allow arrow on left reversed if labelled **-** lattice energy/+711 Allow two separate arrows on the RHS	
	• calculation of enthalpy change of hydration of Cl^- ions **(1)**	Standalone mark $\Delta_{hyd}H$ Cl^- = −711 +17.2 – (−322) = −371.8 (kJ mol^{-1}) No TE on incorrect arrows Ignore SF apart from 1SF	

Q5.

Question Number	Acceptable Answer	Additional Guidance	Mark
(i)	An answer that makes reference to the following point: • the concentration of a solid / $Mg(OH)_2$ is constant / unchanged / changes very little	Allow magnesium hydroxide is in a different phase / state (from the aqueous ions) Ignore solids do not appear in K_c expressions / just 'it is solid' Ignore solid does not affect the concentration of the solution Ignore it is a heterogeneous equilibrium Ignore it is difficult to measure the concentration of a solid Do not award the solid does not have a concentration	(1)

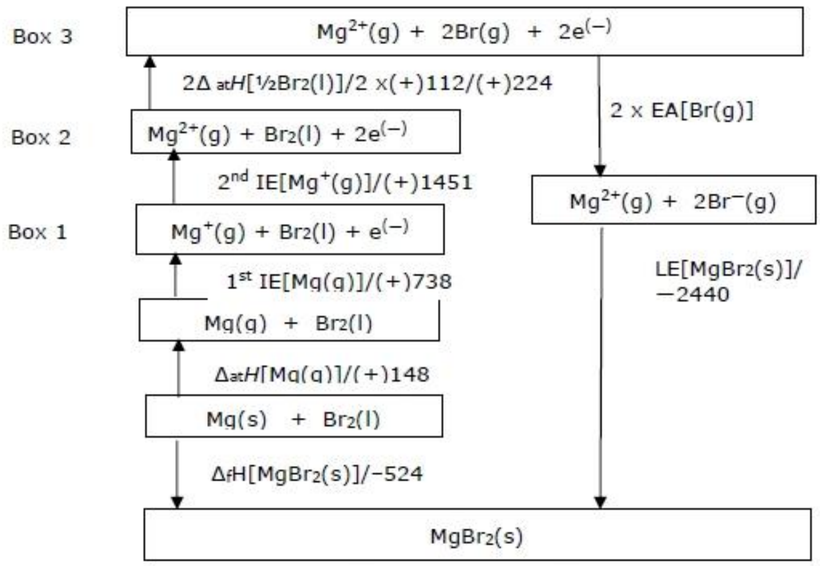
Question Number	Acceptable Answer	Additional Guidance	Mark
6(b)(ii)	• $mol^3\ dm^{-9}$	Allow $dm^{-9}\ mol^3$ mol^3/dm^9 Ignore any working before the answer	(1)

Question Number	Acceptable Answer	Additional Guidance	Mark
(iii)	• use of $\Delta_{sol}H = \Delta_{hyd}H[Mg^{2+}(aq)] + 2\Delta_{hyd}H[OH^{-}(aq)] - \Delta_{latt}H[Mg(OH)_2(s)]$ **(1)** • calculation of $\Delta_{sol}H$ **(1)**	<u>Example of calculation</u> $\Delta_{sol}H = -1920 + 2(-460) - (-2842)$ Allow this shown on a Hess cycle $\Delta_{sol}H = (+)2$ (kJ mol^{-1}) Allow 2000 J mol^{-1} Correct answer with no working scores 2	(2)

Question Number	Answer	Mark
(iv)	**The only correct answer is D** ***A*** *is not correct because it should not be linear and should level off* ***B*** *is not correct because it should not increase in that way and should level off* ***C*** *is not correct because it should not be horizontal*	(1)

Question Number	Acceptable Answer	Additional Guidance	Mark
(v)	An answer that makes reference to the following points: Addition of magnesium sulfate solution: • equilibrium position shifts to the left / in the backwards direction **(1)** • because increased concentration / amount of magnesium ions / Mg^{2+}((aq)) **(1)** Addition of dilute hydrochloric acid: • equilibrium shifts to the right / in the forwards direction **(1)** • because the hydrogen ions / H^{+}((aq)) react with / neutralise / removes the hydroxide ions / OH^{-}((aq)) **(1)**	Mark independently Allow more magnesium hydroxide precipitates / forms Allow more Mg^{2+} ions present Allow more magnesium hydroxide dissolves / dissociates Allow H^{+}((aq)) + OH^{-}((aq)) $\rightarrow H_2O$((l)) Allow magnesium hydroxide reacts with / is neutralised by acid / equation to show this Allow acid / HCl reacts with / neutralises / removes hydroxide ions Penalise reference to K_c changing once only	(4)

Q6.

Question Number	Answer and Additional Guidance	Mark
(i)	 • 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 x $\Delta_{at}H^{\circ}[\frac{1}{2}Br_2(l)]$ / 2 x(+)112 / (+)224 **and** 2Br(g) in box 3 or 1 **and** 2 x EA[Br(g)] labelled **and** $2Br^{-}(g)$ in box 4 **and** correct arrows **(1)** • LE[$MgBr_2(s)$] / −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 / $2e^{(-)}$ 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) Box 4

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

Q7.

Question Number	Answer	Additional Guidance	Mark
(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
(ii)	An answer that includes • the magnesium ion is small and highly charged (1) • the iodide ion has a large ionic radius (1) • the iodide ion is **polarised** by the magnesium ion (1) • (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 Allow iodide ion has a much larger radius Ignore reference to atomic radius 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)

Q8.

Question Number	Acceptable Answers	Additional Guidance	Mark
*	This question assesses a 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.	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, an answer 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 are no linkages between points, the same five indicative marking points would yield an overall score of 3 marks (3 marks for indicative content and no marks for linkages).	(6)

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 line of reasoning
Answer shows a coherent and 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

General points to note

If there is any incorrect chemistry, deduct mark(s) from the reasoning. If no reasoning mark(s) awarded do not deduct mark(s). e.g.
penalise any reference to 'molecule' once only
or
penalise 'ion' not mentioned in word or formula at least once in answer, once only

Allow reverse arguments for IP3 to IP6 Ignore mention of stoichiometry Ignore references to electronegativity

	Indicative content • **IP1 - Ionic** lithium chloride / LiCl (has very similar theoretical and experimental lattice energy values so) is (almost 100%) ionic	Allow **very** small amount of / no covalent character in LiCl Allow assumption that ions act as point charges / are spherical is true for LiCl	
	• **IP2 - Covalency** magnesium iodide / MgI_2 (has different theoretical and experimental lattice energy values so) has (some) covalent character	Allow MgI_2 more covalent character than LiCl	
	• **IP3 - Charge on cations** magnesium is Mg^{2+} and lithium is Li^+ • **IP4 - Polarising** – what does the polarising magnesium ion/Mg^{2+} is (more) polarising / has a large(r) polarising power (than lithium ion)	Allow magnesium has 2+ charge and lithium has 1+ charge / magnesium ion has a larger charge than a lithium ion Allow charge density for charge	
	• **IP5 - Size of anion** iodide ion / I^- is larger (than chloride ion / Cl^-)	Allow iodine ion / I^- is a large atom / has a large atomic radius Ignore size of cation Do not award iodide has a larger charge density	
	• **IP6 – Polarisable** – what is polarised iodide ion / I^- is (more easily) polarised / distorted	Allow this shown in a diagram Ignore just 'greater attraction to cation'	

Q9.

Question Number	Answer	Additional Guidance	Mark
	• equation (1) • state symbols (1)	Example of equation $Cl(g) + e^- \rightarrow Cl^-(g)$ Allow just e for electron Stand alone mark for species on both sides of equation Ignore state symbol for electron	(2)

Q10.

Question Number	Answer	Additional guidance	Mark
(i)	An explanation that makes reference to the following points • C=C bond is weaker than 2 x C-C bond **(1)** • as it consists of a pi and a sigma bond (rather than 2 sigma bonds) **(1)**	Ignore pi bond formed by sideways / less effective orbital overlap	**(2)**

Question number	Answer	Additional guidance	Mark
(ii)	• calculation of energy required to break reactant bonds **(1)** • calculation of energy release when product bonds form **(1)** • calculation of enthalpy change **(1)**	Example of calculation: 5(C-H) + (C=C)+(C- C)+(C-O)+(O-H)+4(O=O) 5(413) + (612) + (347) + (358) + (464) + (4x498) = 5838 (kJ mol^{-1}) 6(C=O) + 6(O-H) (6x805) + (6x464) = 7614 (kJ mol^{-1}) 5838 – 7614 = –1776 (kJ mol^{-1}) Ignore SF except 1 SF Allow TE from M1 and M2 Correct answer no working scores 3	**(3)**

Question Number	Answer	Additional Guidance	Mark
(iii)	An explanation that makes reference to one of the following points EITHER • ΔS_{total} is always positive (1) **(1)** • As both $\Delta S_{surroundings}$ and ΔS_{system} are positive **(1)** • OR • ΔG is always negative **(1)** • as ΔH is negative and $\Delta S_{(system)}$ is positive **(1)**	If no marking points awarded allow 1 mark for idea that ΔS_{system} / $\Delta S_{surroundings}$ / entropy increases with correct explanation	**(2)**