2 This question is about energy changes involved in the formation of ionic compounds.

(a) What is the order of increasing first ionisation energy for the elements beryllium, helium and lithium?

(1)

☒ **A** lithium < helium < beryllium

☒ **B** beryllium < lithium < helium

☒ **C** helium < beryllium < lithium

☒ **D** lithium < beryllium < helium

(b) The **second** ionisation energy of calcium has a magnitude of 1150 kJ mol^{-1}.

Which of the following represents the **second** ionisation energy of calcium?

(1)

☒ **A** $Ca(g) \rightarrow Ca^{2+}(g) + 2e^-$ $\Delta H^{\ominus} = +1150$ kJ mol^{-1}

☒ **B** $Ca^+(g) \rightarrow Ca^{2+}(g) + e^-$ $\Delta H^{\ominus} = +1150$ kJ mol^{-1}

☒ **C** $Ca(g) \rightarrow Ca^{2+}(g) + 2e^-$ $\Delta H^{\ominus} = -1150$ kJ mol^{-1}

☒ **D** $Ca^+(g) \rightarrow Ca^{2+}(g) + e^-$ $\Delta H^{\ominus} = -1150$ kJ mol^{-1}

(c) The formation of potassium ions can be represented by the equation

$$K(s) \rightarrow K^+(g) + e^-$$

Which statement corresponds to the energy change for this process?

(1)

☒ **A** the first electron affinity of potassium

☒ **B** the first ionisation energy of potassium

☒ **C** the sum of the enthalpy change of atomisation of potassium and the first electron affinity of potassium

☒ **D** the sum of the enthalpy change of atomisation of potassium and the first ionisation energy of potassium

(d) The table shows the ionic radius and charge of each of six ions.

Ion	D^+	E^+	G^{2+}	X^-	Y^-	Z^{2-}
Ionic radius / nm	0.14	0.18	0.15	0.14	0.18	0.15

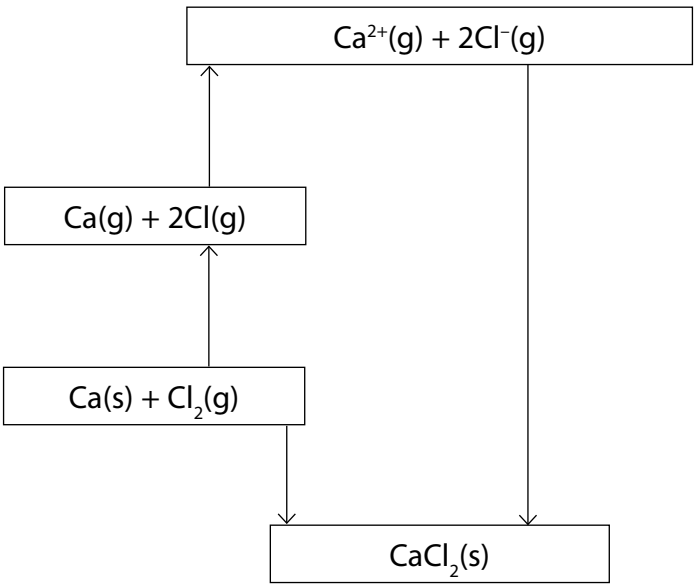
The ionic solids DX, EY and GZ have the same lattice structure.

Deduce the order of magnitude of their lattice energies, giving the most exothermic first.

Justify your answer.

(3)

(e) The diagram shows a Born-Haber cycle for calcium chloride, $CaCl_2$.



	kJ mol^{-1}
Enthalpy of formation of $CaCl_2(s)$	–796
Lattice energy of $CaCl_2(s)$	–2258
Enthalpy of atomisation of $Ca(s) \rightarrow Ca(g)$	178
Enthalpy of atomisation of $\frac{1}{2}Cl_2(g) \rightarrow Cl(g)$	122
First ionisation energy of Ca(g)	590
Electron affinity of Cl(g)	–349

Calculate the second ionisation energy of calcium, in kJ mol^{-1}.

(2)

(Total for Question 2 = 8 marks)

8 This question is about ions and ionic compounds.

(a) The first three ionisation energies of calcium are shown in the table.

	First ionisation	Second ionisation	Third ionisation
Ionisation energy / kJ mol^{-1}	590	1145	4912
Orbital			

(i) Complete the table by identifying the specific orbital from which each electron is removed.

(2)

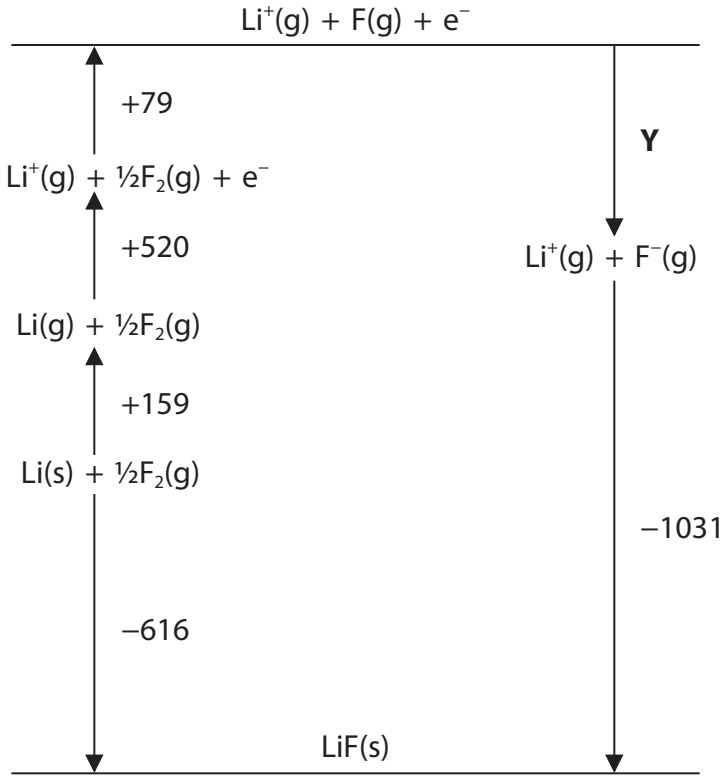
(ii) Write the equation for the **third** ionisation energy of calcium. Include state symbols.

(1)

(iii) Explain why the difference between the second and third ionisation energies of calcium is much larger than the difference between the first and second ionisation energies.

(2)

(b) The diagram, which is not drawn to scale, shows the Born-Haber cycle for lithium fluoride. The energy changes are given in kJ mol^{-1}.



What is the value for **Y**, in kJ mol^{-1}?

(1)

☒ **A** −273

☒ **B** −343

☒ **C** −432

☒ **D** −889

*(c) 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)

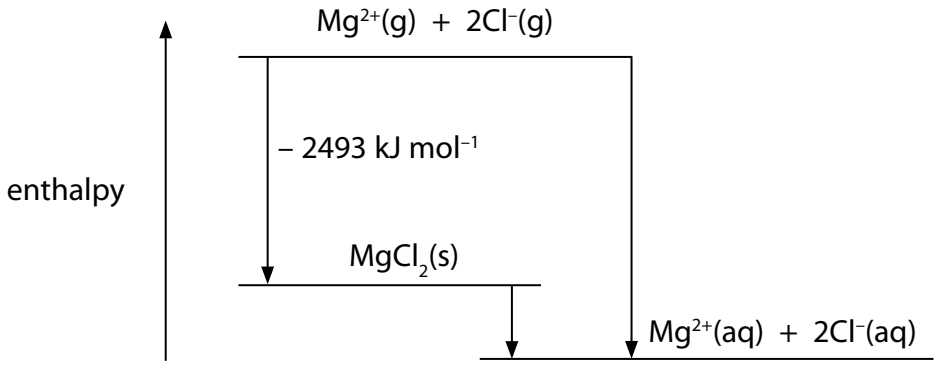
(Total for Question 8 = 12 marks)

10 This question is about some Group 2 compounds.

(a) Explain the trend in the thermal stability of carbonates in Group 2.

(3)

(b) Magnesium chloride is soluble in water. The enthalpy level diagram for the dissolving of magnesium chloride is



The enthalpy changes of hydration of the ions are:

Mg^{2+} $-1920\ kJ\ mol^{-1}$

Cl^- $-364\ kJ\ mol^{-1}$

Calculate the enthalpy change of solution, $\Delta H_{solution}$, of $MgCl_2(s)$ in $kJ\ mol^{-1}$.

(2)

(c) The table shows some data relating to the dissolving of magnesium sulfate, $MgSO_4$, in water at 298 K.

$\Delta H^{\ominus}_{solution}$ / kJ mol^{-1}	$\Delta S^{\ominus}_{system}$ / J K^{-1} mol^{-1}
–87	–210

(i) Explain why the dissolving of magnesium sulfate in water is exothermic by considering the enthalpy changes involved.

(2)

(ii) Use the data in the table to calculate $\Delta G^{\ominus}$ when magnesium sulfate dissolves in water at 298 K. State the significance of your answer.

(2)

*(d) The table shows some data relating to the dissolving of barium sulfate and calcium sulfate in water at 298 K.

Salt	$\Delta H^{\ominus}_{solution}$ / kJ mol^{-1}	$T\Delta S^{\ominus}_{system}$ / kJ mol^{-1}
$BaSO_4$	+19	–31
$CaSO_4$	– 18	–43

Comment on the relative solubility in water of barium sulfate and calcium sulfate at 298 K, using data from the table.

(6)

(Total for Question 10 = 15 marks)

TOTAL FOR PAPER = 90 MARKS

6 This question is about the solubility of metal hydroxides.

(a) Which of these metal hydroxides is the most soluble in water?

(1)

☒ **A** barium hydroxide

☒ **B** calcium hydroxide

☒ **C** magnesium hydroxide

☒ **D** potassium hydroxide

(b) 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)

.....

.....

.....

.....

(ii) Give the units for K_c.

(1)

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

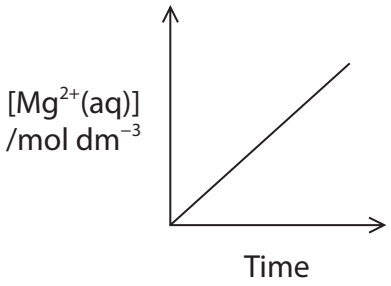
Energy or enthalpy change	Value / kJ mol^{-1}
Lattice energy of $Mg(OH)_2(s)$	−2842
$\Delta_{hyd}H$ ($Mg^{2+}(aq)$)	−1920
$\Delta_{hyd}H$ ($OH^-(aq)$)	−460

(2)

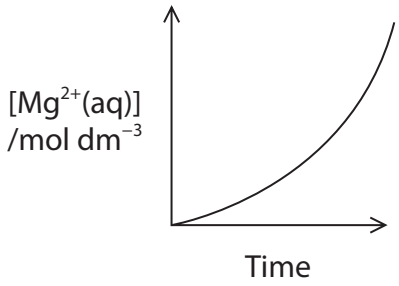
(iv) Which graph shows the change in the concentration of the $Mg^{2+}(aq)$ ions when some solid magnesium hydroxide is shaken with water and left to reach equilibrium?

(1)

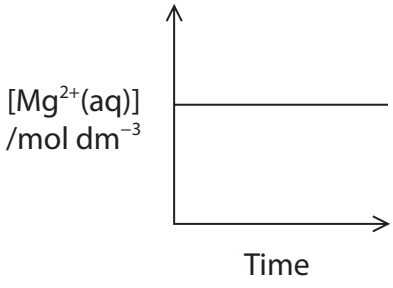
☒ **A**



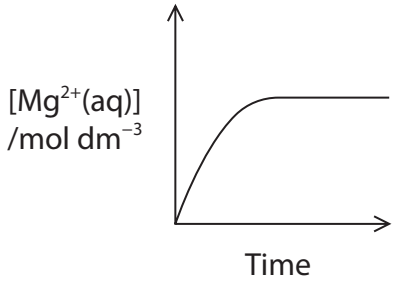
☒ **B**



☒ **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

Dilute hydrochloric acid

(Total for Question 6 = 10 marks)

Question number	Answer	Additional guidance	Marks
2(a)	D		**1**
2(b)	B		**1**
2(c)	D		**1**
2(d)	• order: GZ > DX > EY (1) Justification: • the ions in GZ have higher charges (than those in both EY and DX) (1) • the ions in DX are smaller than those in EY (1)		**3**
2(e)	• construction of balanced cycle (1) • substitution and evaluation of 2^{nd} IE (1)	Example calculation $-2258 = -590 - 2^{nd}\text{ IE} + 2(349) - 178 - 2(122) - 796$ hence 2^{nd} IE = (+) 1148 (kJ mol^{-1}) correct answer, no working scores 2 marks	**2**

(Total for Question 2 = 8 marks)

Question Number	Acceptable Answer	Additional Guidance	Mark
8(a)(i)	• any 2 correct **(1)** • all 3 correct **(2)**	Example of table 1st IE: (590) 4s; 2nd IE: (1145) 4s; 3rd IE: (4912) 3p Accept $3p_x$ / $3p_y$ / $3p_z$ for 3rd IE Ignore any superscript numbers by 4s and 3p Allow (1) for just 's, s, p' or 's, s, p' with one or more incorrect numbers in front	**(2)**

Question Number	Acceptable Answer	Additional Guidance	Mark
8(a)(ii)	• correct equation	Examples of equations $Ca^{2+}(g) \rightarrow Ca^{3+}(g) + e^{(-)}$ **or** $Ca^{2+}(g) - e^{(-)} \rightarrow Ca^{3+}(g)$ Correct state symbols are required Ignore any state symbol for the electron	**(1)**

Question Number	Acceptable Answer	Additional Guidance	Mark
8(a)(iii)	An explanation that makes reference to the following points: • (there is a much larger difference between the 2nd and 3rd ionisation energies because the) 3rd electron is lost from a shell / energy level / sub-shell / (3p) orbital closer to the nucleus **or** the 3rd electron is lost from a shell / energy level / sub-shell / (3p) orbital of lower energy **(1)** • (there is a smaller difference between the 1st and 2nd ionisation energies because the) 1st and 2nd electrons removed from the same shell / energy level / sub-level / orbital **or** the first two electrons experience similar shielding (from the inner electrons) **or** there is only a small change in electron-electron repulsion as the first two electrons are removed **(1)**	Ignore electron is lost from a full (sub-)shell / a full (sub-)shell is more stable Ignore just '3rd electron lost is more strongly attracted to the nucleus' Allow the same amount of shielding Allow the 3rd electron (to be lost) experiences less shielding (from inner electrons)	**(2)**

Question Number	Answer	Mark
8(b)	**The only correct answer is B** ***A*** *is incorrect because (−1031) + (79 + 520 + 159) is incorrect* ***C*** *is incorrect because (−1031) + (79 + 520) is incorrect* ***D*** *is incorrect because (−1031) + 79 +520 +159 – 616 is incorrect*	**(1)**

<table>
<tr><th>Question Number</th><th>Acceptable Answers</th><th>Additional Guidance</th><th>Mark</th></tr>
<tr><td>8(c)*</td><td>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.

<table>
<tr><th>Number of indicative marking points seen in answer</th><th>Number of marks awarded for indicative marking points</th></tr>
<tr><td>6</td><td>4</td></tr>
<tr><td>5-4</td><td>3</td></tr>
<tr><td>3-2</td><td>2</td></tr>
<tr><td>1</td><td>1</td></tr>
<tr><td>0</td><td>0</td></tr>
</table>

The following table shows how the marks should be awarded for structure and lines of reasoning.</td><td>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).

In general it would be expected that 5 or 6 indicative points would get 2 reasoning marks, and 3 or 4 indicative points would get 1 mark for reasoning, and 0, 1 or 2 indicative points would score zero marks for reasoning.</td><td>(6)</td></tr>
</table>

	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

Comment:
Look for the indicative marking points first, then consider the mark for structure of answer and sustained line of reasoning

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 • **IP2 - Covalency** magnesium iodide / MgI_2 (has different theoretical and experimental lattice energy values so) has (some) covalent character • **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) • **IP5 - Size of anion** iodide ion / I^- is larger (than chloride ion / Cl^-) • **IP6 – Polarisable** – what is polarised iodide ion / I^- is (more easily) polarised / distorted	Allow **very** small amount of / no covalent character in LiCl Allow assumption that ions act as point charges / are spherical is true for LiCl Allow MgI_2 more covalent character than LiCl 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 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 Allow this shown in a diagram Ignore just 'greater attraction to cation'	

(Total for Question 8 = 12 marks)

Question number	Answer	Additional guidance	Marks
10(a)	An explanation that makes reference to the following points: • they get more stable down the group (1) • because the size of the cations increases/charge density of cations decreases (1) • and so carbonate ions are less polarised (1)		**3**
10(b)	• rearrangement of equation (1) • calculation of $\Delta H_{solution}$ (1)	Example of calculation $-2493 + \Delta H_{solution} = -1920 + (-2 \times 364)$ $\Delta H_{solution} = -155$ (kJ mol^{-1}) Correct sign must be given in final answer Correct answer and sign with no working scores 2 marks	**2**
10(c)(i)	An explanation that makes reference to the following points: • breaking the lattice is endothermic and the hydration of ions is exothermic (1) • (therefore the dissolving of magnesium sulphate is exothermic) because the enthalpy of hydration (of the ions) is greater in magnitude than the lattice energy (of $MgSO_4$) (1)		**2**
10(c)(ii)	• $\Delta G^{\ominus} = -87 - (298 \times -0.210)$ $= -24(.42)$ (kJ mol^{-1}) (1) • since ΔG is negative the process/reaction is spontaneous/feasible (1)		**2**

<table>
<tr><th>Question number</th><th>Answer</th><th>Additional guidance</th><th>Marks</th></tr>
<tr><td>*10(d)</td><td>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.

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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).
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<tr><td>*10(d) cont.</td><td>The following table shows how the marks should be
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<tr><td></td><td>Number of marks awarded for structure of answer and sustained line of reasoning</td></tr>
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<tr><td>Answer has no linkages between points and is unstructured.</td><td>0</td></tr>
</table>
awarded for structure and lines of reasoning.
Indicative content
($\Delta G^{\ominus}_{solution} = \Delta H^{\ominus}_{solution} - T\Delta S^{\ominus}_{system}$)
• for $BaSO_4$: $\Delta H^{\ominus}_{solution}$ and $-T\Delta S^{\ominus}_{system}$ are both positive (1)
• for $CaSO_4$: $\Delta H^{\ominus}_{solution}$ is negative and $-T\Delta S^{\ominus}_{system}$ is positive (1)
• but the magnitude of $-T\Delta S^{\ominus}_{system}$ is greater than that of $\Delta H^{\ominus}_{solution}$ (1)
• therefore $\Delta G^{\ominus}_{solution}$ for both salts is positive (1)
• when $\Delta G^{\ominus}_{solution}$ is positive the salt is only slightly soluble (1)
• $BaSO_4$ is less soluble than $CaSO_4$ because $\Delta G^{\ominus}_{solution}$ is more positive (1)</td><td></td><td></td></tr>
</table>

(Total for Question 10 = 15 marks)

Question Number	Answer	Mark
6(a)	**The only correct answer is D** ***A*** *is not correct because it is the 2nd most soluble* ***B*** *is not correct because it is the 3rd most soluble* ***C*** *is not correct because it is the least soluble*	**(1)**

Question Number	Acceptable Answer	Additional Guidance	Mark
6(b)(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
6(b)(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)**	Example of calculation $\Delta_{sol}H = -1920 + 2(-460) - (-2842)$ 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
6(b)(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
6(b)(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)**

(Total for Question 6 = 10 marks)