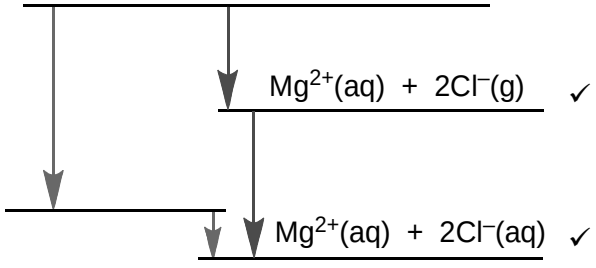
Question			er	Mark	Guidance
1	(a)		(The enthalpy change that accompanies) the formation of **one mole** of a(n ionic) compound ✓ from its **gaseous ions** ✓ (under standard conditions)	**2**	**IGNORE** 'Energy needed' **OR** 'energy required' **ALLOW** as alternative for compound: lattice, crystal, substance, solid **Note**: 1st mark requires **1 mole** **2nd mark** requires **gaseous ions** **IF** candidate response has '1 mole of gaseous ions', award 2nd mark but **NOT** 1st mark **IGNORE**: $Mg^{2+}(g) + 2Cl^{-}(g) \longrightarrow MgCl_2(s)$ (question asks for words)
	(b)	(i)	Hydration involves bond forming **OR** bonds are made ✓	**1**	**ALLOW** statement of **any type of bond** being formed **ALLOW** (chloride) ions attract water (molecules) **ALLOW** a response in terms of **hydrogen bonds** breaking **AND** bond making **DO NOT ALLOW** response stating that energy is required **DO NOT ALLOW** response that refers to ions in H_2O, eg H^+
		(ii)		**2**	Correct species **AND** state symbols required for both marks Mark each marking point independently **ALLOW** response on upper line: $Mg^{2+}(g) + 2Cl^{-}(aq)$ (ie Cl^- hydrated before Mg^{2+}) **ALLOW** $MgCl_2(aq)$

Question			er	Mark	Guidance
1	(b)	(iii)	**FIRST, CHECK THE ANSWER ON ANSWER LINE** **IF answer = –1921 (kJ mol^{-1}) award 2 marks** --- (–2493) + (–154) = (2 x –363) + $\Delta H_{hyd}(Mg^{2+})$ ✓ $\Delta H_{hyd}(Mg^{2+})$ = (–2493) + (–154) – (2 x –363) = –1921 (kJ mol^{-1}) ✓	**2**	**IF** there is an alternative answer, check to see if there is any **ECF** credit possible using working below. **See list below for marking of answers from common errors** --- **ALLOW** for **1 mark**: –2284 use of Cl^- rather than 2 x Cl^- (+)1921 signs all reversed **OR** lack of 2 for 363 –1613 sign wrong for 154 (+)3065 sign wrong for 2493 –3373 sign wrong for 2 x 363
	(c)		Magnesium ion **OR** Mg^{2+} is smaller **OR** Mg^{2+} has greater charge density ✓ Mg^{2+} has a stronger attraction to H_2O **OR** Mg^{2+} has a stronger bonding with H_2O ✓	**2**	**ORA:** Calcium ion **OR** Ca^{2+} is larger **OR** Ca^{2+} has smaller charge density **IGNORE** idea of close packing of ions **IGNORE** 'atomic' and 'atoms' and assume that Mg or Ca refer to ions, ie **ALLOW** Mg has a smaller (atomic) radius **ALLOW** Mg has a stronger attraction to H_2O **ORA:** e.g. Ca^{2+} has less attraction to H_2O **DO NOT ALLOW** Mg **atoms** have a stronger attraction to H_2O **DO NOT ALLOW** stronger attraction/bonding between ions **Note:** Response must refer to attraction/bonding with H_2O or this must be implied from the whole response
			Total	**9**	

Question			Expected Answers	Marks	Additional Guidance
2	a		**F** **B** **G** **E** **D** **FIVE** correct ✓✓ **FOUR** correct ✓✓ **THREE** correct ✓	3	**ALLOW** **1450** **736** **G** **76** **–6**
	b		Correct calculation –642 – (+76 + (2 × 150) + 736 + 1450 + (2 × –349)) ✓ –642 – 1864 = – 2506 ✓ (kJ mol^{-1})	2	**ALLOW** for 1 mark: –2705 (2 × 150 and 2 × 349 not used for Cl) –2356 (2 × 150 not used for Cl) –2855 (2 × 349 not used for Cl) +2506 (wrong sign **DO NOT ALLOW** any other answers
	c		Magnesium ion **OR** Mg^{2+} has greater charge (than sodium ion **OR** Na^{+}) **OR** Mg^{2+} has greater charge density ✓ Magnesium ion **OR** Mg^{2+} is smaller ✓ Mg^{2+} has a stronger attraction (than Na^{+}) to Cl^{-} ion **OR** Greater attraction between oppositely charged ions ✓	3	***ANNOTATIONS MUST BE USED*** **ALLOW** magnesium/Mg is 2+ but sodium/Na is 1+ **DO NOT ALLOW** Mg **atom** is 2+ but Na **atom** is 1+ **ALLOW** 'charge density' here **only** **ALLOW** Mg **OR** magnesium is smaller **DO NOT ALLOW** Mg^{2+} has a smaller **atomic** radius **ALLOW** anion **OR** negative ion for Cl^{-} **DO NOT ALLOW** chlorine ions **DO NOT ALLOW** Mg has greater attraction **ALLOW** 'attracts with more force' for greater attraction but **DO NOT ALLOW** 'greater force (could be repulsion) **ALLOW** reverse argument throughout in terms of Na^{+}
			Total	**8**	

Question			Expected Answers	Marks	Additional Guidance
3	a		$(K_c =) \frac{[NH_3]^2}{[N_2]\ [H_2]^3}$ ✓	1	Must be square brackets
		ii	$dm^6\ mol^{-2}$ ✓	1	**ALLOW** $mol^{-2}\ dm^6$ **ALLOW ECF** from incorrect K_c expression
	b		**Unless otherwise stated, marks are for correctly calculated values. Working shows how values have been derived.** $[N_2] = \frac{7.2}{6.0}$ **OR** 1.2 (mol dm^{-3}) **AND** $[H_2] = \frac{12}{6.0}$ **OR** 2.0 (mol dm^{-3}) ✓ $[NH_3] = \sqrt{(K_c \times [N_2] \times [H_2]^3)}$ **OR** $\sqrt{(8.00 \times 10^{-2} \times 1.2 \times 2.0^3)}$ ✓ = 0.876 **OR** 0.88 (mol dm^{-3}) ✓ amount $NH_3 = 0.876 \times 6 = 5.26$ **OR** 5.3 (mol) ✓	4	***ANNOTATIONS MUST BE USED*** For **all** parts, **ALLOW** numerical answers from 2 significant figures up to the calculator value 1st mark is for realising that concentrations need to be calculated. **Correct numerical answer with no working would score all previous calculation marks** **ALLOW** calculator value: 0.876356092 down to 0.88, correctly rounded **ALLOW** calculator value down to 5.3, correctly rounded

Question			Expected Answers	Marks	Additional Guidance
	b		**EXAMPLES OF INCORRECT RESPONSES IN (b) THAT MAY BE WORTHY OF CREDIT**		---------- **ALLOW ECF from incorrect concentrations (3 marks)** For example, If concentrations **not** calculated at start, then $[NH_3] = \sqrt{(8.00 \times 10^{-2} \times 7.2 \times 12.0^3)}$ ✓ = 31.5 mol dm^{-3} ✓ Equilibrium amount of $NH_3 = 31.5 \times 6 = 189.6$ (mol) ✓ **---------- IF** candidate has K_c expression upside down, then all **4 marks** are available in **(b)** by **ECF** Correct $[N_2]$ AND $[H_2]$ ✓ $[NH_3] = \sqrt{\frac{[N_2]\,[H_2]^3}{K_c}} = = \sqrt{\frac{1.2 \times 2^3}{8.00 \times 10^{-2}}}$ ✓ = 11.0 mol dm^{-3} ✓ Equilibrium amount of $NH_3 = 11.0 \times 6 = 66.0$ (mol) ✓ **---------- IF** candidate has used K_c value of 8.00×10^{-2} **AND** values for N_2 **AND** H_2 with powers wrong, mark by **ECF** from calculated as below (**3 max in (b)**) Correct $[N_2]$ AND $[H_2]$ ✓ $[NH_3]$ expression ✗ **ECF**: Calculated $[NH_3]$ ✓ **ECF**: Equilibrium amount of NH_3 ✓

Question			Expected Answers	Marks	Additional Guidance
	c	**i**	Equilibrium shifts to right **OR** Equilibrium towards ammonia ✓ Right hand side has fewer number of (gaseous) moles ✓	2	**ALLOW** 'moves right' **OR** 'goes right' **OR** 'favours right' **OR** 'goes forwards' **ALLOW** 'ammonia side' has fewer moles **ALLOW** 'there are more (gaseous) moles on left'
		ii	K_c does not change ✓ Increased pressure increases concentration terms on bottom of K_c expression more than the top **OR** system is now no longer in equilibrium ✓ top of K_c expression increases and bottom decreases until K_c is reached ✓	3	***ANNOTATIONS MUST BE USED*** Any response in terms of K_c changing scores **ZERO** for Part **(ii)** **ALLOW** K_c is temperature dependent only **OR** K_c does not change with pressure **ALLOW** $\frac{[NH_3]^2}{[N_2]\ [H_2]^3}$ no longer equal to K_c
	d	**i**	$CH_4 + H_2O \longrightarrow 3H_2 + CO$ ✓	1	State symbols **NOT** required **ALLOW**: $CH_4 + H_2O \longrightarrow CH_3OH + H_2$ $CH_4 + 2H_2O \longrightarrow 4H_2 + CO_2$ $CH_4 + H_2O \longrightarrow 2H_2 + HCHO$ $CH_4 + 2H_2O \longrightarrow 3H_2 + HCOOH$
		ii	Electrolysis of water **OR** $H_2O \longrightarrow H_2 + ½O_2$ ✓	1	**ALLOW** electrolysis of brine **DO NOT ALLOW** reforming **DO NOT ALLOW** cracking **DO NOT ALLOW** reaction of metal with acid

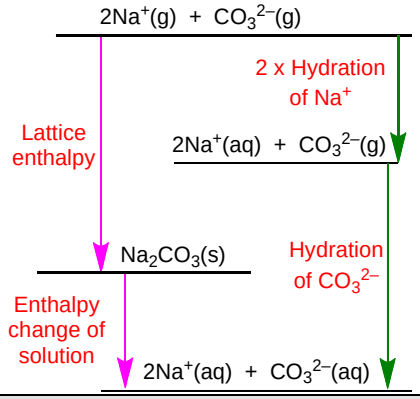
Question			Expected Answers	Marks	Additional Guidance
	e	i	**Unless otherwise stated, marks are for correctly calculated values.** **Working shows how values have been derived.** $\Delta S = \Sigma S$(products) – ΣS(reactants) / = (2 × 192) – (191 + 3 × 131) ✓ = –200 (J K^{-1} mol^{-1}) **OR** –0.200 (kJ K^{-1} mol^{-1}) ✓ Use of 298 K (could be within ΔG expression below) ✓ $\Delta G = \Delta H - T\Delta S$ **OR** ΔG = –92 – (298 × –0.200) **OR** ΔG = –92000 – (298 × –200) ✓ = –32.4 kJ mol^{-1} **OR** –32400 J mol^{-1} ✓ **(Units must be shown)** For feasibility, $\Delta G < 0$ **OR** ΔG is negative ✓	5 1	***ANNOTATIONS MUST BE USED*** See **Appendix 1** for extra guidance for marking **5e(i)** and **5e(ii)** **NO UNITS** required at this stage **IGNORE** units **ALLOW** –32.4 kJ **OR** –32400 J **(Units must be shown)** Award all 5 marks **above** for correct answer with no working **IF** 25 ºC has been used instead of 298 K, correctly calculated ΔG values are = –87 kJ mol^{-1} **OR** –87000 J mol^{-1} **4 marks** are still available up to this point and maximum possible from **(e)(i)** is 5 marks
		ii	As the temperature increases, $T\Delta S$ becomes more negative **OR** $T\Delta S$ becomes more negative than ΔH **OR** $T\Delta S$ becomes more significant ✓ Eventually $\Delta H - T\Delta S$ becomes positive ✓	2	**ALLOW** $T\Delta S > \Delta H$ (i.e. assume no sign at this stage) **ALLOW** 'entropy term' as alternative for $T\Delta S$ **ALLOW** **–**$T\Delta S$ becomes more positive **ALLOW** **–**$T\Delta S$ decreases **ALLOW** ΔG becomes positive **OR** $\Delta G > 0$

Question			Expected Answers	Marks	Additional Guidance
		iii	Activation energy is too high **OR** reaction too slow ✓	1	**ALLOW** increases the rate **OR** more molecules exceed activation energy **OR** more successful collisions **ALLOW** rate constant increases **IGNORE** comments on yield
			Total	**22**	

Question			Expected answers	Marks	Additional guidance
4	a		(The enthalpy change that accompanies) the formation of **one mole** of a(n ionic) compound ✓ from its **gaseous ions** ✓ (under standard conditions)	2	**IGNORE** 'Energy needed' **OR** 'energy required' **ALLOW** as alternative for compound: lattice, crystal, substance, solid, product **Note**: 1st mark requires **1 mole** **2nd mark** requires **gaseous ions** **IF** candidate response has '1 mole of gaseous ions', award 2nd mark but **NOT** 1st mark **IGNORE** reference to 'constituent elements' **IGNORE**: $2Na^+(g) + O^{2-}(g) \longrightarrow Na_2O(s)$ *Question asks for a definition, not an equation*
	b	i	**C (**or 2**C)** **A** **B** **D** **G** **E** (or 2**E**) **F** All seven correct ✓✓✓ Five **OR** six correct ✓✓ Three **OR** four correct ✓	3	**ALLOW** **496 (OR** 992**)** **–141** **790** **249** **G OR** **Lattice enthalpy/LE** [**OR** answer to **(ii)**] **108** (**OR** 216) **–4**
		ii	**FIRST, CHECK THE ANSWER ON ANSWER LINE** **IF answer = –2520 (kJ mol^{-1}) award 2 marks** --- –414 = (2 × 108) + 249 + (2 × 496) + (–141) + 790) + ΔH_{LE} **OR** ΔH_{LE} = –414 – [(2 × 108) + 249 + (2 × 496) + (–141) + 790] ✓ = –414 – 2106 = **–2520** (kJ mol^{-1}) ✓	2	**IF** there is an alternative answer, check **the list below for marking of answers from common errors** --- **ALLOW** for **1 mark**: –1692 wrong sign for 414 –1916 2 × 108 and 2 × 496 not used for Na^+ –2412 2 × 108 not used for Na^+ –2024 2 × 496 not used for Na^+ +2520 wrong sign for final answer –2802 sign changed for 1st electron affinity of oxygen –2395.5 atomisation of oxygen halved

Question			Expected answers	Marks	Additional guidance
					Any other number: **CHECK** for **ECF** from 1st marking point for expressions with **ONE** error only
	c		**ALLOW** reverse argument throughout (**ORA**) ***Comparison of size AND charge of cations*** Mg^{2+} is smaller **AND** Mg^{2+} has a greater charge **OR** Mg^{2+} has **a** greater charge density ✓ ***Comparison of size of anions*** S^{2-} is larger **OR** S^{2-} has a smaller charge density ✓ ***Comparison of attraction of a cation and an anion*** Mg^{2+} has stronger attraction **OR** Na^{+} has weaker attraction **AND** S^{2-} has weaker attraction **OR** O^{2-} has stronger attraction ✓	**3**	***ANNOTATIONS MUST BE USED*** **NOTE**: For **ALL** marking points, assume that the following refer to 'ions', Mg^{2+}, etc. For 'ions', **ALLOW** 'atoms' For Mg^{2+}, Na^{+}, O^{2-} and S^{2-}, **ALLOW** symbols: Mg, Na, O and S **ALLOW** names: magnesium, sodium, oxygen, oxide, sulfur, sulfide **BUT DO NOT ALLOW** molecules *i.e.* **ALLOW** Mg has a smaller (atomic) radius **IGNORE** idea of close packing of ions --- **ORA**: Na^{+} is larger **AND** Na^{+} has a smaller charge **OR** Na^{+} has a smaller charge density ✓ **IGNORE** just Mg^{2+} is small *comparison required* **ORA** O^{2-} is smaller **OR** O^{2-} has a larger charge density ✓ **IGNORE** just S^{2-} is large *comparison required* **ALLOW** pull for attraction **ALLOW** 'attracts with more force' for greater attraction **BUT** … **IGNORE** just 'greater force' (*could be repulsion*) **OR** comparison of bond strength/energy to break bonds **IGNORE** comparisons of numbers of ions

Question			Expected answers	Marks	Additional guidance
	d	**i**	Cycle needs **formation** of CO_3^{2-} ions (from C and O) ✓ *i.e.* ***NOT*** *breaking up of* CO_3^{2-} *ion*	**1**	**ALLOW** carbonate ion contains C and O **ALLOW** carbonate ion contains 2 elements **IGNORE** sodium carbonate contains 3 elements **IGNORE** carbonate ion has covalent bonds
	d	**ii**	See also **Appendix 1** at end of mark scheme **Mark allocation** **1 –** $2Na^+(g) + CO_3^{2-}(g)$ on a top line **AND** $Na_2CO_3(s)$ on a lower line **AND** 'Lattice enthalpy' label (as below) links the lines ✓ **2 –** $2Na^+(g) + CO_3^{2-}(g)$ on a top line **AND** $2Na^+(aq) + CO_3^{2-}(g)$ on a middle line **AND** $2Na^+(aq) + CO_3^{2-}(aq)$ on a lower line **AND** 'ΔH hydration' labels (as below) link the lines ✓ **NOTE:** For hydration labels, see diagram below **2** x hydration of Na^+ **OR** hydration of **2** x Na^+ is **required** **3** – ΔH solution' label **BELOW** $Na_2CO_3(s)$ **AND ALL** arrows in correct directions ✓	**3**	***ANNOTATIONS MUST BE USED*** **MARK AS FOLLOWS** **1.** Mark the cycle **2. IF** there is **no cycle**, mark the equation below --- **State symbols** are required for **ALL** species **IGNORE** direction of any arrows until **MARK 3** **ALLOW** $Na_2CO_3(aq)$ on a lower line as an alternative for $2Na^+(aq) + CO_3^{2-}(aq)$ **ALLOW** CO_3^{2-} hydrated first: i.e. $2Na^+(g) + CO_3^{2-}(aq)$ on middle line **ALLOW** two hydration stages combined i.e. $2Na^+(g) + CO_3^{2-}(g)$ on a top line **AND** $2Na^+(aq) + CO_3^{2-}(aq)$ on a lower line **AND BOTH** 'Hydration' labels link the lines ✓ **IF** cycle shown using $NaCO_3$, Na^+ and CO_3^- **ALLOW ECF** for third marking point only **NOTE: DO NOT ALLOW ECF** from any other species **For simple energy cycles** a maximum of 2 marks only can be awarded **–** See **APPENDIX 1** --- **For an equation,** only **1 mark** can be awarded Lattice enthalpy = $-\Delta H$(solution) Na_2CO_3 + [2 x ΔH(hydration) Na^+] + ΔH(hydration) CO_3^{2-}

Question	Expected answers	Marks	Additional guidance
			**OR** Lattice enthalpy + ΔH(solution) Na_2CO_3 = 2 x ΔH(hydration) Na^+ + ΔH(hydration) CO_3^{2-} ✓ **IGNORE** state symbols for equation approach
	Total	**14**	