Question Number	Answer	Mark
9	**The only correct answer is C** (positive negative) *A is incorrect because this pair of values will never be thermodynamically feasible* *B is incorrect because this pair of values is only thermodynamically feasible if the enthalpy change of reaction when divided by the temperature is greater in magnitude than the entropy change of the system* *D is incorrect because this pair of values is only thermodynamically feasible if the entropy change of the system is greater in magnitude than the value obtained from the enthalpy change of reaction divided by the temperature*	**(1)**

Question Number	Answer	Mark
1	**The only correct answer is B** ($K_c = \frac{[Y]^2[Z]}{[W][X]}$) *A is incorrect because Y has been multiplied by 2 instead of raised to the power of its coefficient* *C is incorrect because the expression has been inverted and because Y has been multiplied by 2 instead of raised to the power of its coefficient* *D is incorrect because the expression has been inverted*	**(1)**

Question Number	Answer	Mark
11	**The only correct answer is B** (W and X only) *A is incorrect because reaction X and W will give a positive value for* ΔS_{total} *C is incorrect because reaction Y will give a negative value for* ΔS_{total} *D is incorrect because reaction Z will give a negative value for* ΔS_{total}	**(1)**

Question Number	Answer	Mark
11	**The only correct answer is B** ($(CH_3)_3CCl$) *A is not correct because* CH_3CH_2Cl *is a primary halogenoalkane* *C is not correct because* $CH_3CHClCH_3$ *is a secondary halogenoalkane* *D is not correct because* $(CH_3)_3CCH_2Cl$ *is a primary halogenoalkane*	**(1)**

Question Number	Answer	Mark
15	**The only correct answer is B** (132 minutes) *A is incorrect because this is the time taken for the concentration to reach* 5.5×10^{-3} *mol* dm^{-3} *which is half-way between the starting concentration and the final concentration* *C is incorrect because this is half of the time shown on the graph* *D is incorrect because this is the time at the end of the graphical data*	**(1)**

Question Number	Answer	Mark
13(a)	**The only correct answer is C** ($K_p = \frac{(pSO_3)^2}{(pSO_2)^2 \times (pO_2)}$) *A is not correct because the partial pressures in the equation have been multiplied by 2 instead of squared* *B is not correct because this is the expression for K_c* *D is not correct because the expression has been inverted*	(1)

Question Number	Answer	Mark
13(b)	**The only correct answer is B** (decreasing the pressure decreases the equilibrium yield of SO_3) *A is not correct because changing pressure has no effect on K_p* *C is not correct because a catalyst will not affect the equilibrium yield* *D is not correct because a catalyst will not affect K_p*	(1)

Question Number	Answer	Mark
5	**The only correct answer is A** (the value of K is less than 1) *B is not correct because this would give a positive total entropy change* *C is not correct because the value of K cannot be negative* *D is not correct because the position of equilibrium would lie to the left*	1

Question number	Answer	Mark
5	**The only correct answer is C** (increases; unchanged) *A is incorrect because the energy of the system does not change for an ideal gas* *B is incorrect because the entropy of the system increases and the energy of the system does not change for an ideal gas* *D is incorrect because the entropy of the system increases*	(1)

Question number	Answer	Mark
1(a)	**The only correct answer is A** (rate = $k[NO]^2[O_2]$; rate = $k[NO]^2[O_2]$) *B is incorrect because the rate equation is not determined by the stoichiometric equation* *C is incorrect because the rate cannot depend only on the concentration of products* *D is incorrect because the rate cannot depend only on the concentration of products*	(1)

Question number	Answer	Mark
1(b)	**The only correct answer is B**(colorimetry; volume change) *A is incorrect because titration cannot be used for continuous monitoring of a reaction* *C is incorrect because the mass of the system does not change* *D is incorrect because the mass of the system does not change and titration cannot be used for continuous monitoring of a reaction*	(1)

Question Number	Answer	Mark
10(a)	**The only correct answer is B** (the mixture becomes more purple) *A is incorrect because although there is no change in position of equilibrium the increase in pressure results in the purple iodine molecules being closer together so the colour becomes more intense* *C is incorrect because iodine vapour is not brown* *D is incorrect because iodine vapour is not brown*	**(1)**

Question Number	Answer	Mark
10(b)	**The only correct answer is B** (a decrease in temperature only) *A is incorrect because a change in pressure does not affect the value of K_p* *C is incorrect because only temperature has an effect on the value of K_p and an increase will result in K_p decreasing and not increasing* *D is incorrect because temperature does have an effect on the value of K_p*	**(1)**

Question Number	Answer	Mark
10(c)	**The only correct answer is A** (the equilibrium position has shifted towards the products) *B is incorrect because the increase in the value of K_p indicates a shift in the position of equilibrium to the products* *C is incorrect because the change in the value of K_p does indicate a shift in the extent of reaction* *D is incorrect because the change in the value of K_p is insufficient to result in almost complete conversion*	**(1)**

Question Number	Answer	Mark
1(a)	**The only correct answer is B** (measurement of change in volume) *A is incorrect because none of the gases is coloured* *C is incorrect because there is no loss or gain of mass* *D is incorrect because there are no bases in the mixture*	(1)

Question Number	Answer	Mark
1(b)	**The only correct answer is D** (quenching followed by titrating with acid) *A is incorrect because nothing in the mixture is coloured* *B is incorrect because there is no change in volume* *C is incorrect because there is no loss or gain of mass*	(1)

Question Number	Answer	Mark
3	**The only correct answer is D** ($FeCl_3$) *A is not correct because FeO is a less complex substance than $FeCl_3$* *B is not correct because FeS is a less complex substance than $FeCl_3$* *C is not correct because $FeCl_2$ is a less complex substance than $FeCl_3$*	**(1)**

Section A

Question Number	Answer	Mark
1(a)	**The only correct answer is A** (colorimetry) ***B*** *is not correct because there is no change in mass* ***C*** *is not correct because titration is not a continuous monitoring method* ***D*** *is not correct because no gas is produced*	**1**

Question Number	Answer	Mark
1(b)	**The only correct answer is D** ($dm^9\ mol^{-3}\ s^{-1}$) ***A*** *is not correct because these are the units of rate* ***B*** *is not correct because these are the units of the rate constant for a second order reaction* ***C*** *is not correct because these are the units of the rate constant for a third order reaction*	**1**

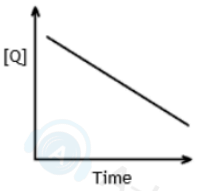
Question Number	Answer	Mark
1(c)	**The only correct answer is D** (1/16) ***A*** *is not correct because the rate would change by this factor for an overall first order reaction* ***B*** *is not correct because the rate would change by this factor for an overall second order reaction* ***C*** *is not correct because the rate would change by this factor for an overall third order reaction*	**1**

Question number	Answer	Mark
9(a)	**The only correct answer is D**($K_c = \frac{[H_2]^4}{[H_2O]^4}$) ***A*** *is incorrect because the solids are not included in the K_c expression for this equilibrium* ***B*** *is incorrect because the solids are not included in the K_c expression for this equilibrium* ***C*** *is incorrect because the solids are not included in the K_c expression for this equilibrium*	**(1)**

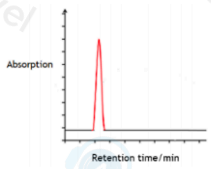
Question number	Answer	Mark
9(b)	**The only correct answer is D**(K_c unchanged; K_c decreases) ***A*** *is incorrect because K_c is not affected by the state of division of the solid and K_c decreases for an exothermic reaction* ***B*** *is incorrect because K_c decreases for an exothermic reaction* ***C*** *is incorrect because K_c is not affected by the state of division of the solid*	**(1)**

Question number	Answer	Mark
3	**The only correct answer is A** (rate = k[**E**][**F**]) ***B*** *is incorrect because the rate depends on concentrations of the reacting species in the slow step and the stoichiometry of this step* ***C*** *is incorrect because the rate equation cannot include intermediate concentrations* ***D*** *is incorrect because the rate depends on concentrations of the reacting species in the slow step and the stoichiometry of this step and the rate equation cannot include intermediate concentrations*	**(1)**

Question Number	Answer	Mark
6	**The only correct answer is D** ($K_p = (pNO_2)^4 \times (pO_2)$) ***A*** *is incorrect because solids are not included in the K_p expression and the value should be raised to the power not multiplied by the number from the equation* ***B*** *is incorrect because solids are not included in the K_p expression* ***C*** *is incorrect because the value should be raised to the power not multiplied by the number from the equation*	(1)

Question Number	Answer	Mark
3(a)	**The only correct answer is A (**  **)** ***B** is incorrect because the graph shows a reaction where the rate decreases as concentration of Q increases* ***C** is incorrect because the graph shown is correct when rate is plotted against concentration of Q* *D is incorrect because the graph shows a reaction where the rate increases as concentration of Q increases*	(1)

Question Number	Answer	Mark
3(b)	**The only correct answer is B** (20s) ***A** is incorrect because the half-life for a first order reaction is constant* ***C** is incorrect because the half-life for a first order reaction is constant* *D is incorrect because the half-life for a first order reaction is constant*	(1)

Question Number	Answer	Mark
3(c)	**The only correct answer is D (**  **)** ***A** is incorrect because the area under the curve is unchanged and the retention time has doubled* ***B** is incorrect because the retention time has doubled* ***C** is incorrect because the area under the curve is unchanged*	**(1)**

Question Number	Answer	Mark
9	**The only correct answer is A** ($K_p = p(NO_2)^2\, p(O_2)^{½}$) ***B** is incorrect because the stoichiometric coefficients to balance the equation have been doubled in the equilibrium expression* ***C** is incorrect because solid species have been included in the equilibrium expression* ***D** is incorrect because the stoichiometric coefficients to balance the equation have been doubled and solid species have been included in the equilibrium expression*	**(1)**

Question Number	Answer	Mark
3	**The only correct answer is C** (atm^{-2}) ***A** is incorrect because coefficients have not been taken into account* ***B** is incorrect because coefficients have not been taken into account and the expression has been inverted* ***D** is incorrect because these are the units for the inverted expression*	**(1)**

Question Number	Answer	Mark
2	**The only correct answer is D** (0.125) *A is incorrect because this is the amount that has decomposed after three half-lives* *B is incorrect because this is the concentration remaining after one half-life* *C is incorrect because this is the concentration remaining after two half-lives*	**(1)**

Question Number	Answer	Mark
6	**The only correct answer is A** ($\frac{1}{2}I_2(s) \rightarrow I(g)$) *B is incorrect because the standard state of iodine is solid* *C is incorrect because atomisation is for the formation of one mole of gaseous atoms* *D is incorrect because atomisation is for the formation of one mole of gaseous atoms and the standard state of iodine is solid*	**(1)**

Question Number	Answer	Mark
10	**The only correct answer is B** (12) *A is not correct because this is the rate increase when the rate has been multiplied by 6 (2 × 3)* *C is not correct because this is the rate increase when the concentration of NO has been tripled and the O_2 doubled* *D is not correct because this is the rate increase when the concentrations of both the NO and O_2 have been tripled*	**(1)**

Question Number	Answer	Mark
7	**The only correct answer is A** ($O^-(g) + e^- \rightarrow O^{2-}(g)$) *B is incorrect because this is the equation for the first and the second electron affinities of oxygen* *C is incorrect because this is the equation for the second ionisation energy of oxygen* *D is incorrect because this is the equation for the first and second ionisation energies of oxygen*	**(1)**

Question number	Answer	Mark
4	**The only correct answer is D** (graph 4) *A is incorrect because entropy increases with temperature and the entropy change for the change from liquid to gas is greater than that for solid to liquid* *B is incorrect because entropy increases with temperature* *C is incorrect because the entropy change for the change from liquid to gas is greater than that for solid to liquid*	**(1)**

Question Number	Answer	Mark
7	**The only correct answer is A** (rate = $k[H_2O_2]^2[I^-]$) *B is incorrect because the concentration of hydrogen peroxide should be squared* *C is incorrect because this includes an intermediate* *D is incorrect because the concentration of hydrogen peroxide should be squared and includes an intermediate*	**(1)**

Question Number	Answer	Mark
1(a)	**The only correct answer is B** (the collisions do not have sufficient energy) *A is incorrect because low reactant concentrations will reduce the number of collisions but not the proportion that are successful* *C is incorrect because at equilibrium both the forward and reverse reactions occur at the same rate* *D is incorrect because the reacting ratio does not reflect the mechanism of the reaction*	(1)

Question Number	Answer	Mark
1(b)	**The only correct answer is A** (atm) *B is incorrect because the expression for K_p is inverted* *C is incorrect because the different state of one of the products has not been taken into account* *D is incorrect because the expression for K_p is inverted and the different state of one of the products has not been taken into account*	(1)

Question Number	Answer	Mark
5(a)	**The only correct answer is A** (2.0×10^{12}) *B is incorrect because this value is determined by subtracting two from both the number 4 and its power* *C is incorrect because this value is determined by not including the power in the square root calculation* *D is incorrect because this value is K_p unchanged from equation 1*	(1)

Question Number	Answer	Mark
5(b)	**The only correct answer is D** (9.77×10^{25}) *A is incorrect because this value is determined by using $\Delta n = +1$ instead of -1* *B is incorrect because this value is determined by using $\Delta n = +1$ instead of -1 and from using the temperature in ℃ instead of K* *C is incorrect because this value is determined from using the temperature in ℃ instead of K*	(1)

Question Number	Answer	Mark
6	**The only correct answer is C** (negative, positive) *A is incorrect because a gas is changing to a liquid so ΔS_{system} is reduced* *B is incorrect because a gas is changing to a liquid so ΔS_{system} is reduced and condensation is exothermic* *D is incorrect because condensation is exothermic*	(1)

Question Number	Answer	Mark
3(a)	**The only correct answer is C** (it alters the enthalpy change of the reaction) *A is incorrect because a catalyst does lower the activation energy of the reaction* *B is incorrect because a catalyst has no effect on the equilibrium constant for the reaction* *D is incorrect because a catalyst does reduce the energy cost of the reaction*	**(1)**

Question Number	Answer	Mark
3(b)	**The only correct answer is B** (a temperature of 400 K and a pressure of 200 atm) *A is incorrect because the pressure is lower and there is a reduction in volume in the forward direction* *C is incorrect because the temperature is higher and the forward reaction is exothermic and the pressure is lower and there is a reduction in volume in the forward direction* *D is incorrect because the temperature is higher and the forward reaction is exothermic*	**(1)**

Question Number	Answer		Additional Guidance	Mark
20(a)(i)	• expression or suitable working • correct answer	**(1)** **(1)**	Example of a calculation: $(192 + 0.5 \times 205) - (220)$ (+)74.5 (J K^{-1} mol^{-1}) Correct answer scores 2 –74.5 scores 0 TE on small errors in M1 e.g., miss out 0.5, as long as the answer is positive Penalise incorrect units once only for ai-aiii Allow J K^{-} mol^{-} Allow J/K mol but not J/K/mol	**(2)**

Question Number	Answer		Additional Guidance	Mark
20(a)(ii)	• balanced equation or suitable working • correct answer	**(1)** **(1)**	Example of a calculation: ΔS surroundings = $-\Delta H/T$ = – (–82000) ÷ (2048) = 82000 ÷ 2048 (+) 40.039 (J K^{-1} mol^{-1}) Correct answer scores 2 Ignore SF – 40 scores 1 mark 0.04 scores 1 mark with correct units or without units, 2 marks with kJ K^{-1} mol^{-1}	**(2)**

Question Number	Answer	Additional Guidance	Mark
20(a)(iii)	• total entropy change	Example of a calculation: 74.5 + 40.0 = (+)114.5 (J K^{-1} mol^{-1}) TE on ai and aii, but both must be in the correct units Ignore SF except 1SF	(1)

Question Number	Answer	Additional Guidance	Mark
20(b)	• gradient (1) • activation energy (1)	Example of a calculation: $\frac{(-197)-(-190)}{(0.00673)-(0.00649)} = \frac{-7}{0.00024}$ gradient = −29 167 (K) (allow any negative value between 28 300-30 000) (− 8.31 × − 29 167) ÷1000 = (+)242.4 (kJ mol^{-1}) (allow values between 235.1 to 249.3 for 2 marks) Ignore SF except 1 SF Allow TE from M1 Answers in J mol^{-1} score both marks if in the allowed range (235100-249300)	(2)

Question Number	Answer	Additional Guidance	Mark
20(c)	An explanation that makes reference to the following points: • (thermodynamically) feasible because ΔS_{total} is positive (1) • activation energy high so the reaction is very slow (at low temperatures) (1)	Ignore thermodynamically stable/unstable Allow high temperature will provide E_a so reaction will proceed Allow reaction may not happen as E_a is (very) high Allow high E_a so kinetically stable Allow high E_a so kinetically non-feasible TE on 20(a)(iii) but not on 20(b)	(2)

(Total for Question 20 = 9 marks)

Section B

Question Number	Answer	Additional Guidance	Mark
14(a)	An explanation that makes reference to the following points: • (after initially getting darker) the mixture would turn yellower / more yellow (1) • (so eqm shifts left / favours the LHS as there are) fewer molecules/ mol on the LHS (1)	Allow less green Allow more yellow gas Allow darker yellow Allow just turns yellow Ignore initial colour Allow mole ratio2:3 and this may be shown on the equation Allow reverse argument Do not award eqm shifts right There is no TE	(2)

Question Number	Answer	Additional Guidance	Mark
14(b)(i)	An answer that makes reference to the following point: • $(K_c =) \frac{[NO]^2[Cl_2]}{[NOCl]^2}$	Ignore state symbols Do not award round brackets/ pp Do not award if the ^{2} is inside the bracket	(1)

Question Number	Answer	Additional Guidance	Mark
14(b)(ii)	An answer that makes reference to the following points: • second row correct **(1)** • third row correct **(1)**	<table><tr><td>Substance</td><td>NOCl</td><td>NO</td><td>Cl_2</td></tr><tr><td>Initial mol</td><td>0.250</td><td>0</td><td>0</td></tr><tr><td>Equilibrium mol</td><td>**0.218**</td><td>**0.032**</td><td>0.016</td></tr><tr><td>Concentration / mol dm^{-3}</td><td>**0.436**</td><td>**0.064**</td><td>**0.032**</td></tr></table> Allow TE on second row	**(2)**

Question Number	Answer	Additional Guidance	Mark
14(b)(iii)	• correct use of K_c expression **(1)** • correct answer **(1)** • with units and 1 to 3 SF **(1)**	Example of calculation: $(0.064)^2 \times 0.032 \div 0.436^2$ 6.8950×10^{-4} / 0.00068950 6.9×10^{-4} / 6.90×10^{-4} / 7×10^{-4} mol dm^{-3} Allow TE from *Kc* expression in (b)(i) and numbers in (b)(ii)	**(3)**

Question Number	Answer	Additional Guidance	Mark
14(b)(iv)	An explanation that makes reference to the following points: • (forward) reaction is endothermic/ ΔH is positive **(1)** • (at the lower temperature) reaction moves in the exothermic direction/backwards/to the left (making the value of K_c smaller) **(1)**	Standalone marks Allow reverse argument if reverse reaction is stated Allow equilibrium shifts left Allow favours instead of moves/shifts Allow makes more reactants/NOCl	**(2)**

(Total for Question 14 = 10 marks)

Question Number	Answer	Additional Guidance	Mark
15(a)(i)	An answer that makes reference to the following points: • any one or two types of bonding **(1)** • third type of bonding **(1)**	Ignore giant throughout • covalent (in SiO_2) Ignore macromolecular Do not award simple/molecular Do not award dative/coordinate • metallic (in Mg) Allow metal • ionic (in MgO) Allow ion	**2**

Question Number	Answer	Additional Guidance	Mark
15(a)(ii)	An answer that makes reference to the following points: • (as) moles (decreases) from 5 to 3 **(1)** • decreases in disorder **(1)**	Accept reverse arguments Allow particles or molecules for moles Ignore any reference to standard entropies of reactants and products Allow just number of moles decreases Do not award incorrect numbers of moles Do not award incorrect explanation relating to states Accept fewer ways of distributing energy (in products) Accept fewer ways of arranging moles (in products) Ignore just less arranged for less disordered Ignore randomness for disorder Ignore just decreases in entropy	**2**

Question Number	Answer	Additional Guidance	Mark
15(a)(iii)	• expression for $\Delta S_{surroundings}$ **(1)** • value of $\Delta S_{surroundings}$ **(1)**	Example of calculation: $\Delta S_{surroundings} = \frac{-\Delta H}{T} = \frac{-(-370 \times 10^3)}{(23.0 + 273)}$ Allow just –(–370)/–(–370000)/370/370000 divided by any temperature in K or °C (+)1250 ($J\,K^{-1}\,mol^{-1}$) Allow (+)1.25 $kJ\,K^{-1}\,mol^{-1}$ Ignore SF except 1 SF Do not award any other answer Correct answer with some working scores (2) If neither mark awarded, –1250 ($J\,K^{-1}\,mol^{-1}$) / –1.25 $kJ\,K^{-1}\,mol^{-1}$ scores (1)	**2**

Question Number	Answer	Additional Guidance	Mark
15(a)(iv)	• expression for ΔS_{total} **(1)** • calculation of ΔS_{total} to 2, 3 or 4 SF **(1)**	Example of calculation: $\Delta S_{total} = \Delta S_{system} + \Delta S_{surroundings} = -43.8 +$ answer to (a)(iii) where answer to (a)(iii) is 1250 ($J\,K^{-1}\,mol^{-1}$) ΔS_{total} = (+)1206 / 1210 / 1200 ($J\,K^{-1}\,mol^{-1}$) Allow (+)1.206 / 1.21 / 1.2 $kJ\,K^{-1}\,mol^{-1}$ where answer to (a)(iii) is –1250 ($J\,K^{-1}\,mol^{-1}$) ΔS_{total} = –1294 / –1290 / –1300 ($J\,K^{-1}\,mol^{-1}$) Allow –1.294 / –1.29 / –1.3 $kJ\,K^{-1}\,mol^{-1}$ TE on transcription error of –48.3 for –43.8 No TE on incorrect expression from M1	**2**

Question Number	Answer	Additional Guidance	Mark
15(a)(v)	An answer that makes reference to the following point: • bonding / electrostatic attraction (in SiO_2) is strong **or** a large amount of energy is needed to break bond(s) (in SiO_2)	Ignore SiO_2/reaction/reactants is/are kinetically stable Ignore reactions between solids are slow Allow Mg/reactants for SiO_2 Allow a large amount of energy is needed to break covalent / metallic bond(s) Do not award any reference to the breaking of ionic bonds / intermolecular forces	**1**

Question Number	Answer	Additional Guidance	Mark
15(b)(i)	An answer that makes reference to the following point: • correct equation	<u>Examples of equation:</u> $Mg_2Si + 4HCl \rightarrow SiH_4 + 2MgCl_2$ Allow ionic equations: $Mg_2Si + 4H^+ \rightarrow SiH_4 + 2Mg^{2+}$ $Mg_2Si + 4H^+ + 4Cl^- \rightarrow SiH_4 + 2Mg^{2+} + 4Cl^-$ Allow multiples Allow reversible arrow Ignore state symbols even if incorrect	**1**

Question Number	Answer		Additional Guidance	Mark
15(b)(ii)	An answer that makes reference to the following points: • name of shape • bond angle	**(1)** **(1)**	 tetrahedral Allow tetrahedron 109.5(°) Allow 109(°) No TE on incorrect shape	**2**

Question Number	Answer		Additional Guidance	Mark
15(c)(i)	• use of $\Delta S_{system} = \Sigma S^{\ominus}_{products} - \Sigma S^{\ominus}_{reactants}$ • calculation of ΔS_{system}	**(1)** **(1)**	<u>Example of calculation:</u> $\Delta S_{system} = (41.8 + 2 \times 69.9) - (204.5 + 2 \times 205.0)$ Allow just $\Delta S_{system} = \Sigma S^{\ominus}_{products} - \Sigma S^{\ominus}_{reactants}$ –432.9 TE on $\Delta S_{system} = \Sigma S^{\ominus}_{reactants} - \Sigma S^{\ominus}_{products}$ TE on incorrect numbers of moles and transcription errors Ignore units, even if incorrect Ignore SF except 1SF Correct answer with some working scores (2) +432.9 / –297.8 / +297.8 scores (1)	**2**

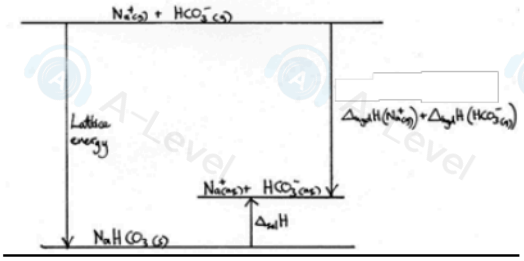
Question Number	Answer	Additional Guidance	Mark
15(c)(ii)	An answer that makes reference to the following point: • O–H bonds are strong(er than Si–H bonds)	Accept reverse arguments Ignore $\Delta S_{surroundings}$ is (very) positive Ignore reaction is (highly) exothermic / ΔH is (very) negative Allow Si–O bonds are strong(er than Si–H bonds) Allow (covalent) bonding in H_2O / SiO_2 / products is strong Allow formation of product bonds releases more energy (than is required to break reactant bonds) Allow more energy required to break product bonds (than reactant bonds) Ignore any reference to O=O bond strength (which is greater than O–H / Si–O) Do not award intermolecular forces for bonds Do not award $\Delta S_{surroundings}$ is negative Do not award reaction is endothermic / ΔH is positive	**1**

(Total for Question 15 = 15 marks)

Question Number	Answer		Additional Guidance	Mark
19(a)	An answer that makes reference to the following points:			**(2)**
	• a gas (and liquid products) are produced (from solids)	**(1)**	Ignore just carbon dioxide produced Ignore just change of state Do not award reference to two gases/H_2O gas	
	• more moles of products than reactants / increase in moles	**(1)**	Accept moles increase from 4 to 7 Allow reference to molecules / particles Do not award if numbers of moles incorrect Ignore references to exothermic / endothermic	

Question Number	Answer		Additional Guidance	Mark
19(b)	An explanation that makes reference to the following points:			**(3)**
	• in solids the particles are fixed / in a lattice (so unable to move)	**(1)**		
	• so they cannot collide and react	**(1)**	Allow M2 if applied to the dissolved ions being able to collide and react Do not award reference to an increase in kinetic energy	
	• but when dissolved in water the particles are mobile	**(1)**	Allow when dissolved the ions are dissociated / spread out (in solution) Ignore references to entropy / energy changes / activation energy	

Question Number	Answer	Additional Guidance	Mark
19(c)	• calculation of enthalpy change value **(1)** • sign **and** units **(1)**	Example of calculation $\Delta H = (- \Delta S_{surroundings} \times T = - -234.9 \times 298 =)$ $\Delta H = + 70000.2 / 70000 / 7.0 \times 10^4$ J mol^{-1} or $\Delta H = + 70.002 / 70 / 7.0 \times 10^1$ kJ mol^{-1} Ignore SF Allow J / mol or kJ / mol for units If two answers are given then both must be correct Correct answer without working scores (2) Allow M2 for incorrect value provided the units match the value, e.g. use of 25 instead of 298 gives +5872.5 J mol^{-1} or 5.8725 kJ mol^{-1}	**(2)**

Question Number	Answer	Additional Guidance	Mark
19(d)	• enthalpy of solution labelled arrow shown to go up from solid $NaHCO_3$ **(1)** • lattice energy gaseous species and labelled arrow to go down **(1)** • enthalpy of hydration labelled arrow to go down and both aqueous ions species **(1)**	Example of sketch  Accept two labelled arrows if the hydration enthalpies for the ions are written separately Allow just singular $\Delta_{hyd}H$ for hydration enthalpy of both ions Accept +18.6 for $\Delta_{sol}H$ Allow ΔH_{hyd} for $\Delta_{hyd}H$ and ΔH_{sol} for $\Delta_{sol}H$ Allow any lengths of arrows	**(3)**

Question number	Answer	Additional guidance	Mark
20(a)(i)	• substitution of values into $\Delta S^{o}_{system} = S_{products} - S_{reactants}$ (1) • calculation of value from correct equation **and** sign and units (1)	In parts (i), (ii), (iii) and (iv) penalise omission of or incorrect units once only Allow units in any order Allow (e.g.) J/K/mol Do not award J/K mol Positive signs are not required Ignore SF except 1 SF throughout (a). Example of calculation $\Delta S^{o}_{system} = 229.5 + 219.5 - 310.1$ $= (+)138.9 \text{ J K}^{-1} \text{ mol}^{-1}$ TE for transcription errors on values only Correct answer with no working scores (2)	(2)

Question number	Answer	Additional guidance	Mark
20(a)(ii)	• substitution of values into $\Delta_r H^{o} = \Delta_f H^{o}(\text{products}) - \Delta_f H^{o}(\text{reactants})$ (1) • calculation of value from correct equation **and** sign and units (1)	Example of calculation $\Delta_r H^{o} = (-84.7 + 52.2) - (-126.5)$ $= (+)94.0 \text{ kJ mol}^{-1}$ Correct answer with no working scores (2) TE for transcription errors on values $-94.0 \text{ kJ mol}^{-1}$ scores (1) $-159.0 \text{ kJ mol}^{-1}$ scores (1) $(+)263.4 \text{ kJ mol}^{-1}$ scores (1) $-10.4 \text{ kJ mol}^{-1}$ scores (1)	(2)

Question number	Answer	Additional guidance	Mark
20(a)(iii)	• equation for $\Delta S^{o}_{surroundings}$ **and** substitution of values (1) • calculation of value from correct equation **and** sign and units (1)	Example of calculation $\Delta S^{o}_{surroundings} = -\Delta H / T$ $= -94000 \div 298$ Accept $= -94 \div 298$ $= -315.44 \text{ J K}^{-1} \text{ mol}^{-1} / -0.31544 \text{ kJ K}^{-1} \text{ mol}^{-1}$ TE on $\Delta_r H^{o}$ from (a)(ii) Do not award use of incorrect equation Correct answer with no working scores (2)	(2)

Question number	Answer	Additional guidance	Mark
20(a)(iv)	• equation for ΔS^{o}_{total} **and** substitution of values **and** calculated value with sign and units	Example of calculation $\Delta S^{o}_{total} = \Delta S^{o}_{system} + \Delta S^{o}_{surroundings}$ $= +138.9 + -315.44$ $= -176.54 \text{ J K}^{-1} \text{ mol}^{-1}$ Accept $= +0.1389 + -0.31544$ $= -0.17654 \text{ kJ K}^{-1} \text{ mol}^{-1}$ TE on valuesfrom (a)(i) and (a)(iii) Do not award use of incorrect equation Do not award value obtained using mixed units Correct answer with no working scores (1)	(1)

Question number	Answer	Additional guidance	Mark
20(a)(v)	• equation for feasibility (1) substitution of values **and** evaluation of T (1)	Example of calculation $(\Delta S^{o}_{system} + (-\Delta H/T) = \Delta S^{o}_{total} = 0)$ $\Delta S^{o}_{system} = \Delta H/T$ or $-\Delta S^{o}_{system} = -\Delta H/T$ $T = 94000 \div 138.9$ $= 676.746$ (K) (from unrounded values) Accept 403.746(°C) TE on valuesfrom (a)(i) and (a)(ii) Do not award use of incorrect equation (e.g. omission of negative sign in $\Delta S^{o}_{surroundings}$ expression) Do not award value obtained using mixed units Correct answer with no working scores (2)	**(2)**

Question number	Answer	Additional guidance	Mark
20(b)(i)	• equilibrium constant expression	Example of expression $K_p = \frac{p(C_2H_6) \times p(C_2H_4)}{p(C_4H_{10})}$ Accept p_x where x = formula or pp(X) Ignore state symbols even if incorrect Do not award square brackets	**(1)**

Question number	Answer	Additional guidance	Mark
20(b)(ii)	• moles of reactants and products (1) • mole fractions (1) • partial pressures (1) • substitution of values into K_p equation **and** evaluation (1) • units (1)	Example of calculation $K_p = \frac{0.56508^2}{0.069841} = 4.5721$ (4.5720 with unrounded numbers) $= (4.5721)$ atm Ignore SF except 1 SF TE on expression in (b)(i) that contains at least two species TE at each stage Correct answer with units but no working scores (5) Omission of partial pressure gives $K_p = 3.8100$ atm scores (4) Omission of mole fraction gives $K_p = 43.21$ atm scores (4)	**(5)**

	C_4H_{10}	C_2H_6	C_2H_4
mol at equil^{m}	5 – 4.45 = 0.55	4.45	4.45
mole fraction	$\frac{0.55}{9.45}$ = 0.05820	$\frac{4.45}{9.45}$ = 0.47090	$\frac{4.45}{9.45}$ = 0.47090
partial pressures	1.20 x 0.05820 = 0.06984	1.20 x 0.47090 = 0.56508	1.20 x 0.47090 = 0.56508

(Total for Question 20 = 15 marks)

Question Number	Answer	Additional Guidance	Mark
20(a)(i)	• expression for calculation of $\Delta S^{\theta}_{system}$ (1) • calculation of $\Delta S^{\theta}_{system}$ (1)	Example of calculation (70.4 + 213.6) – 112.1 = (+)171.9 (J K^{-1} mol^{-1}) Accept (+)172 (J K^{-1} mol^{-1}) Accept (+) 0.1719 kJ K^{-1} mol^{-1} If units are given for M2, they must be correct Allow 1 mark for final answer of – 171.9 (J K^{-1} mol^{-1}) Ignore SF except 1 SF Correct answer with no working scores (2) The only TE allowed from M1 to M2 is a transcription error in copying the data from the table	(2)

Question Number	Answer	Additional Guidance	Mark
20(a)(ii)	• recognition that at the minimum temperature for decomposition $\Delta S^{\theta}_{surr} = -\Delta S^{\theta}_{system}$ (1) • conversion of temperature to Kelvin (1) • calculation of ΔH **and** answer to **2 or 3 SF** (1) Alternative for M1 • recognition that at the minimum temperature for decomposition $\Delta G^{\theta} = 0$ OR T = $\Delta H \div \Delta S$	Example of calculation Allow TE from (a)(i) ΔS^{θ}_{surr} = –171.9 (J K^{-1} mol^{-1}) M1 can be subsumed within award of M3 712 + 273 = 985 (K) ΔH = – (985 × – 0.1719) = (+) 169.3 = (+) 169 / 170 (kJ mol^{-1}) Allow ΔH = – (985 × – 171.9) = (+) 169300 = 169000 / 170000 J mol^{-1} Allow TE from M1 to M3 Correct answer with no working scores 3	(3)

Question Number	Answer	Additional Guidance	Mark
20(b)	• calculation of energy released (1) • calculation of moles of anhydrous magnesium chloride (1) • calculation of $\Delta_{sol}H$, including sign and unit (1)	Example of calculation Allow TE throughout 4.18 × 200 × 6.8 = 5684.8 (J) Ignore any signs in M1 Do not award use of mass = 204.26 4.26 ÷ 95.3 = 0.044701 (mol) 5684.8 ÷ 0.044701 = 127170 J mol^{-1} so $\Delta_{sol}H$ = – 127 kJ mol^{-1} / – 127170 J mol^{-1} Correct answer with no working scores 3 Ignore SF except 1 SF	(3)

Question Number	Answer	Additional Guidance	Mark
20(c)(i)	An answer that makes reference to the following points: • correct formulae and state symbols in left hand box **and** correct formula and state symbol in right hand box	$Mg^{2+}(g) + 2Cl^-(g)$ $MgCl_2(s)$	(1)

Question Number	Answer	Additional Guidance	Mark
20(c)(ii)	• expression for standard enthalpy of hydration (1) • calculation of enthalpy of hydration of chloride ions (1) • calculation of standard enthalpy of hydration of chloride ions (1)	Example of calculation $-2526 + (-127) = -1920 + 2\Delta_{hyd}H[Cl^-(g)]$ $2\Delta_{hyd}H[Cl^-(g)] = [-2526 + (-127)] + 1920 = -733$ (kJ mol^{-1}) $-733 \div 2 = -366.5 / -367$ (kJ mol^{-1}) OR $-2526 + (-155) = -1920 + 2\Delta_{hyd}H[Cl^-(g)]$ $2\Delta_{hyd}H[Cl^-(g)] = [-2526 + (-155)] + 1920 = -761$ (kJ mol^{-1}) $(= -761 \div 2) = -380.5 / -381$ (kJ mol^{-1}) Allow TE from b for M1 No TE from M1 into M2 for incorrect expression, apart from transcription error from b, or value carried though from (b) with incorrect units Allow TE from M2 to M3 Correct answer with no/some working scores (3) Ignore SF except 1 SF Allow use of – 155 even if an answer is evaluated in (b)	(3)

Question Number	Answer	Additional Guidance	Mark
20(d)(i)	An answer that makes reference to two of the following points: • the bonding is 100% ionic / the bonding is **only** ionic **(1)** • the ions are in contact with each other **(1)** • the ions are perfect spheres **(1)** • the charges are point charges **(1)**	Allow no covalent character Allow 'it is 100% ionic' Allow no distortion of electron cloud of Cl^- / chloride ion Allow no polarisation of Cl^- / chloride ion Ignore polarisation of chlor**ine** Allow the charge is distributed evenly across the ions	**(2)**

Question Number	Answer	Additional Guidance	Mark
20(d)(ii)	An explanation that makes reference to the following points: • experimental value is more exothermic **(1)** • (because the) chloride ion is polarised (by the magnesium ion) **(1)** • giving (the bonding in) magnesium chloride some covalent character (so the bonding is stronger) **(1)**	Allow reverse argument for M1 and M3 Allow more negative Allow greater in magnitude Ignore experimental value is larger / smaller	**(3)**

Question Number	Answer	Additional Guidance	Mark
20(e)(i)	• calculation of moles of $BaCO_3$ **and** HCl **(1)** • show that number of moles of $BaCO_3$ is less than that required to react with moles of HCl **(1)**	<u>Example of calculation</u> $5.00 \div 197.3 = 0.025342$ (mol) **and** $(120 \div 1000) \times 0.5 = 0.06$ (mol) Both correct answers with no working scores (1) Allow use of 137 for A_r of Ba $0.02534 < (0.06 \div 2) / 0.02534 < 0.03$ Allow reverse argument i.e. HCl (0.06) is > 2 × $BaCO_3$ (0.05068) Allow TE from M1 only if it shows HCl in excess	**(2)**

Question Number	Answer		Additional Guidance	Mark
20(e)(ii)	• calculation of moles of $BaCO_3$ (= moles of $BaCl_2$) **and** calculation of relative formula mass of $BaCl_2 \cdot nH_2O$	(1)	Example of calculation (5.00 ÷ 197.3 =) 0.02534 (mol) 6.19 ÷ 0.02534 = 244.26 (g mol^{-1})	(3)
	• calculation of formula mass due to nH_2O	(1)	244.26 – (137.3 + 71) = 35.96	
	• calculation of n to nearest whole number	(1)	(35.96 ÷ 18 = 1.9978) = 2 Correct final answer with no working scores M3 only	
	Alternative method			
	• deduction of moles of anhydrous $BaCl_2$ **and** calculation of mass of anhydrous $BaCl_2$	(1)	0.02534 × (137.3 + 71) = 5.2788 (g)	
	• calculation of mass of water of crystallisation	(1)	6.19 – 5.2788 = 0.9112 (g)	
	• calculation of mole of water of crystallisation **and** n to nearest whole number	(1)	0.9122 ÷ 18 = 0.05062 0.05062 ÷ 0.02534 = 1.9977 = 2	

(Total for Question 20 = 22 marks)
TOTAL FOR SECTION C = 22 MARKS
TOTAL FOR PAPER = 90 MARKS

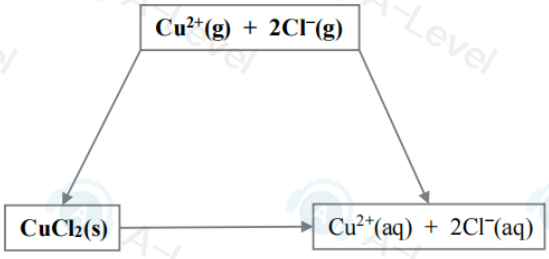
Question Number	Answer		Additional Guidance	Mark
19(a)(i)	• correct use of data	(1)	Example of calculation: −285.8 × 5 (+) −771.4 (–) –2279.6 (kJ mol^{-1})	(2)
	• correct answer	(1)	(+)79.2 / 79 (kJ mol^{-1}) Correct answer with or without working scores 2 TE M1	

Question Number	Answer		Additional Guidance	Mark
19(a)(ii)	• $\sum S$ products	(1)	Example of calculation: S = products (5 × 69.9) + 109.0 = 458.5 (J K^{-1} mol^{-1})	(2)
	• $\Delta S = \sum S$ products − $\sum S$ reactants	(1)	458.5 – 300.4 = (+)158.1 / 158 / 160 (J K^{-1} mol^{-1}) TE on M1	

Question Number	Answer	Additional Guidance	Mark
19(a)(iii)	• rearrangement of expression **(1)** • numbers inserted into rearranged expression **(1)** • calculation of temperature **(1)**	Example of calculation: T= $\frac{\Delta H}{\Delta S_{system}}$ $T = \frac{79.2 \times 1000}{158.1}$ 500.95(K) / 500.9(K) / 501(K) / 227.95ºC / 228ºC K is in brackets but if converted to ºC the units must be seen	**(3)**

Question Number	Answer	Additional Guidance	Mark
19(b)	• calculation of mol of copper sulfate **(1)** • calculation of joules **(1)** • rearrangement to give ΔT **(1)** • correct answer **(1)**	Example of calculation: 21.36 ÷ 249.6 = 0.085577 (mol) 12.3 × 0.085577 × (1000) = 1052.6 (J) or 1.0526 (kJ) ΔT = 1052.6 (J) ÷ (121.36 × 3.7) = (–) 2.344 / 2.3 / 2(ºC) Ignore SF Ignore sign Correct answer without working scores 4	**(4)**

Question Number	Answer	Additional Guidance	Mark
19(c)(i)	An explanation that makes reference to the following points: • enthalpy change when 1 mol of **gaseous** ions **(1)** • **completely** hydrated (in water)/ forms an infinitely dilute solution (with water)/ dissolve until there is no further temperature or heat change **(1)**	Do not award any reference to heat needed or energy required. Allow is **completely** dissolved (in water) Allow dissolved in water to produce a 1.0 mol dm^{-3} solution Ignore any reference to standard conditions Do not award dissolved in 1 mol of water	**(2)**

Question Number	Answer	Additional Guidance	Mark
19(c)(ii)	• both bold boxes correct scores 1		**(1)**

Question Number	Answer	Additional Guidance	Mark
19(c)(iii)	• $\Delta_{sol}H$ = (sum of) $\Delta_{hyd}H$ − Lattice energy OR $\Delta_{sol}H$ = − Lattice energy + (sum of) $\Delta_{hyd}H$	Allow $\Delta_{hyd}H$ (Cu^{2+}) + 2$\Delta_{hyd}H$ (Cl^-) for $\Delta_{hyd}H$	**(1)**

Question Number	Answer	Additional Guidance	Mark
19(c)(iv)	• calculation of enthalpy of hydration of copper(II) chloride **(1)** • calculation of enthalpy of solution **(1)**	Example of calculation −2100 + − (378 × 2) = −2856 (kJ mol^{-1}) −2856 (−) −2811 = −45 (kJ mol^{-1}) (+) 45 (kJ mol^{-1}) scores 1 Allow TE from M1 to M2 Ignore SF except 1SF Correct answer with or without working scores 2	**(2)**

Question Number	Answer	Additional Guidance	Mark
19(c)(v)	• Cu^+ less highly charged/ less positive (than Cu^{2+}) **(1)** • less strong (electrostatic) forces of attraction with **water** (so less energy is released when the ions are hydrated) **(1)**	Allow Cu^+ (has a) is larger (ionic radius) (than Cu^{2+}) Allow Cu^+ (has a) lower charge density (than Cu^{2+}) Do not award reference to atoms Allow there is a weaker attraction between the Cu^+ ions and **water** molecules. Allow weaker bonds with **water** Accept weaker ion- dipole forces with **water** Do not award intermolecular forces Do not award if there is any indication of energy required Allow reverse argument for both points	**(2)**

(Total for Question 19 = 19 marks)

TOTAL FOR SECTION C = 19 MARKS
TOTAL FOR PAPER = 90 MARKS