Question Number	Answer
8	**The only correct answer is B** (9×10^{22}) *A is not correct because the number of moles has not been multiplied by 3* *C is not correct because the number of moles has been multiplied by 4* *D is not correct because the number of moles has been multiplied by 5*

Question Number	Answer	Mark
3	**The only correct answer is D** (C_9H_{20}) *A is incorrect because the increment is ~630 kJ mol^{-1} so expected enthalpy change of combustion would be* -4139 *kJ mol^{-1}* *B is incorrect because the increment is ~630 kJ mol^{-1} so expected enthalpy change of combustion would be* -4769 *kJ mol^{-1}* *C is incorrect because the increment is ~630 kJ mol^{-1} so expected enthalpy change of combustion would be* -5399 *kJ mol^{-1}*	**(1)** **Computer**

Question Number	Answer
7	**The only correct answer is A** $(20 \text{ cm}^3 \text{ of } 0.25 \text{ mol dm}^{-3} \text{ sulfuric acid})$ *B is not correct because this contains twice as many moles of sulfuric acid for neutralisation* *C is not correct because this contains four times as many moles of sulfuric acid for neutralisation* *D is not correct because this contains twice as many moles of sulfuric acid for neutralisation*

Number		Answer
8(a)	The only correct answer is A (4.5×10^{-5}) B is incorrect because this is the rate at 100 seconds C is incorrect because this is the average rate D is incorrect because this is the rate at 385 seconds	

Question Number		Answer
8(b)	The only correct answer is B ($\text{mol dm}^{-3}\ \text{s}^{-1}$) A is incorrect because this is not a change in concentration C is incorrect because the power of the volume should be negative D is incorrect because all the powers have the incorrect sign	

Question Number	Answer
2	The only correct answer is A (letter W) B is not correct because X is the activation energy of the reverse reaction C is not correct because Y is the enthalpy change of the reaction D is not correct because Z is not a valid enthalpy change

Question Number	Answer	Mark
2	The only correct answer is A ($-554 - 394 + 1216$)	(1)
	B is incorrect because the sign of the enthalpy change of formation of the reactant is incorrect	Computer
	C is incorrect because the sign of the enthalpy change of formation of the products is incorrect	

Question number	Answer	Mark
3	**The only correct answer is A**(+491 kJ mol^{-1}) **B** *is incorrect because the $\Delta_r H^\circ$ value for the formation of carbon monoxide has not been tripled* **C** *is incorrect because* $-491 kJ \, mol^{-1}$ *is the enthalpy change for the reverse reaction* **D** *is incorrect because* $-713 kJ \, mol^{-1}$ *is a calculation for the reverse reaction in which the $\Delta_r H^\circ$ value for the formation of carbon monoxide has not been tripled*	(1)

Question Number	Answer
8	**The only correct answer is D** (75%) *A is incorrect because 0.15 is the number of moles of carbon dioxide produced* *B is incorrect because 0.20 is the number of moles of calcium carbonate used* *C is incorrect because 25% is the percentage of the impurities*
14	**The only correct answer is D** (1.012) *A is incorrect because this is the mass divided by the volume* *B is incorrect because this is the M_r divided by the volume in cm^3* *C is incorrect because this is the number of moles*

Question Number	Answer	Mark
2	**The only correct answer is A** (½Br$_2$(l) $\rightarrow$ Br(g)) *B is not correct because bromine is a liquid in its standard state* *C is not correct because this shows the formation of two moles of gaseous bromine atoms* *D is not correct because bromine is a liquid in its standard state and this shows the formation of two moles of gaseous bromine atoms*	(1)

12(a)	The only correct answer is **D** $(0.702 \text{ mol dm}^{-3})$
	A is incorrect because the stoichiometry has been used incorrectly
	B is incorrect because volumes have been used the wrong way around
	C is incorrect because the stoichiometry has not been used

Question Number	Answer
12(b)	The only correct answer is **D** (0.68%)
	A is incorrect because this is the error of a burette in cm^3 times two
	B is incorrect because this is the error if only one reading is taken
	C is incorrect because this is the error using the pipette value

Question number	Answer	Mark
2(a)	**The only correct answer is C** (14.7 %)) *A is incorrect because ±7.37 is an uncertainty based on halving the difference between the experimental and data book values and taking this as a percentage of the data book value* *B is incorrect because ±8.65 is an uncertainty based on halving the difference between the experimental and data book values and taking this as a percentage of the experimental value* *D is incorrect because 17.3 compares the difference in values to the experimental rather than the data book value*	(1)

Question number	Answer	Mark
2(b)	**The only correct answer is B** (lowers the error in the final value obtained) *A is incorrect because increasing the specific heat capacity increases the magnitude of the final value which will then be closer to the data book value* *C is incorrect because the difference is 8.6% which is significant* *D is incorrect because 8.6% is large compared with the measurement uncertainties*	(1)

Question Number	Answer	Mark
1	**The only correct answer is C** ($CF_4(g) \rightarrow C(g) + 4F(g)$) *A is incorrect because this equation represents the bond formation of 4 CF bonds and is exothermic* *B is incorrect because this equation represents the enthalpy change of formation of CF_4 from its elements* *D is incorrect because this equation represents the enthalpy change of the reaction of CF_4 to its elements*	(1) Computer

15	**The only correct answer is C** ($0.683 \ \text{mol dm}^{-3}$) *A is incorrect because this is the number of moles in the sample* *B is incorrect because this is double the number of moles in the sample* *D is incorrect because this is double the value of the concentration*

Question Number	Answer
7	**The only correct answer is B** ($\frac{1}{2}I_2(s) \rightarrow I(g)$) *A is not correct because two moles of atoms have been produced* *C is not correct because it should not be a gas on the LHS and two moles of atoms have been produced* *D is not correct because it should not be a gas on the LHS*

| 16(a) | **The only correct answer is C** (0.123 m^3)

A is incorrect because this is the volume of O_2 produced

B is incorrect because this is the volume of NO_2 produced

D is incorrect because this is the volume of gas formed from 2 mols of magnesium nitrate |

Question Number	Answer
16(b)	**The only correct answer is D** (62.0%) *A is incorrect because this is 25 divided by the mass of the nitrogen(IV) oxide* *B is incorrect because this is 25 divided by the mass of one mole of magnesium nitrate* *C is incorrect because this is 25 divided by the mass of 2MgO*

Question Number	Answer
1(a)	**The only correct answer is D** ($-(55 \times 4.18 \times 6.5) \div 0.03$) *A is incorrect because only the volume and moles of sodium hydroxide have been used* *B is incorrect because only the volume and moles of ethanoic acid have been used* *C is incorrect because the moles of sodium hydroxide have been used*

Question Number	Answer
1(b)	**The only correct answer is C** (15.4%) *A is incorrect because the measurement uncertainty for a single reading and this has been halved* *B is incorrect because that is the percentage uncertainty for a single reading* *D is incorrect because the percentage uncertainty has been doubled for each reading*

Question number	Answer	Mark
1	**The only correct answer is C** (2Cl(g) → Cl₂(g)) A *is incorrect because the diagram represents an exothermic reaction and atomisation is always endothermic* B *is incorrect because the diagram represents an exothermic reaction and ionisation is always endothermic* D *is incorrect because the diagram represents an exothermic reaction and dissolving NH_4NO_3 is endothermic*	**(1)**

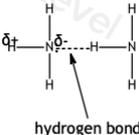| Question Number	Answer
3	**The only correct answer is D** ($Cu(s) + C(s) + 1\frac{1}{2}O_2(g) \rightarrow CuCO_3(s)$) *A is not correct because the oxygen is not in its standard state* *B is not correct because the equation has been doubled* *C is not correct because the copper and carbon are not in their standard states*

Question number	Answer	Additional guidance	Mark

20(a)(i)	
	
	• identification and number of bonds broken
	and
	the values needed (1)
	• evaluation of energy required (1)
	
	• identification of bonds formed
	and
	the values needed
	and
	evaluation of energy produced (1)
	• evaluation of enthalpy change of combustion (1)
		Here and throughout the paper
		Do not penalise correct premature rounding
		Penalise incorrect rounding only in their final answer
		
		Example of calculation
		Bonds broken:
		$7 \times$ C—C $+ 18 \times$ C—H $+ 12.5 \times$ O=O
		E (bond breaking) $= 7 \times 347 + 18 \times 413 + 12.5 \times 498$
		           $= (+)16088$ (kJ mol⁻¹)
		TE only if at least 2 bonds used
		Bonds formed:
		E (bond forming) $= 16 \times$ C=O $+ 18 \times$ O—H
		           $= 16 \times 805 + 18 \times 464$
		
		           $= (-)21232$ (kJ mol⁻¹)
		$\Delta_c H = 16088 - 21232 = -5144$ (kJ mol⁻¹)
		TE at each stage (even if final value is positive)
		Ignore SF except 1 SF
		Units are not required but if given must be correct for the **final** value
		Correct answer with some working scores (4)
			(4)

Question number	Answer	Additional guidance	Mark
20(a)(ii)	An answer that makes reference to the following • the bond enthalpies are averaged over a (large) number of compounds (1) • bond enthalpies always refer to substances in the gas phase **and** octane and water are liquids when the value of $\Delta_c H^{\ominus}$ is obtained (1)	Allow just bond enthalpies are average values Allow just octane is a liquid or water is a liquid Allow calculations using mean bond enthalpies do not include changes of state Ignore non-standard conditions Do not award explanations for experimental error such as heat loss, or incomplete combustion	(2)

Question number	Answer	Additional guidance	Mark
20(a)(iii)	• calculation of molar mass of octane (1) • conversion of kJ mol^{-1} to MJ kg^{-1} **and** calculation of percentage efficiency (1)	Example of calculation $M = 8 \times 12 + 18 = 114$ g mol^{-1} Allow mol octane $= 1000 \div (8 \times 12 + 18 \times 1) = 8.772$ Ignore just $(8 \times 12 + 18 \times 1)$ $1000 \times 5470 \div 114 = 47982$ kJ kg^{-1} = 47.982 MJkg^{-1} Efficiency $= 100 \times 11 \div 47.982 = 22.925 / 22.9 / 23\%$ Allow conversion of MJ kg^{-1} to kJ mol^{-1} $= 114 \times 11 \times 1000 \div 1000 = 1254$ (kJ mol^{-1}) and Efficiency $= 100 \times 1254 \div 5470 = 22.925 / 22.9 / 23\%$ Ignore SF except 1 SF TE unless % efficiency > 100 Correct answer with no working scores (2) Allow calculation using $\Delta_c H^{\ominus}$ from mean bond enthalpy data (-5144 kJ mol^{-1}): Efficiency $= 24.378\%$ Allow calculation using stated incorrect $\Delta_c H^{\ominus}$ from mean bond enthalpy data unless % efficiency > 100	(2)

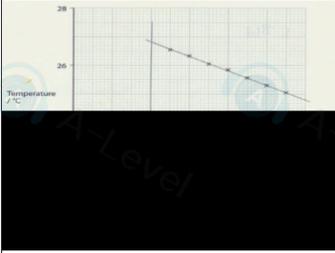| Question number	Answer	Additional guidance	Mark
20(a)(iv)	An answer that makes reference to **two** of the following • heat loss to the surroundings (1) • energy is used to bring the engine to operating temperature (1) • incomplete combustion (of the fuel) (1)	Accept specific examples such as Heat loss due to friction in the engine Heat loss via hot exhaust Allow just 'converted to heat' Allow energy loss to the surroundings Ignore just 'friction' Allow energy is used to warm up the engine Allow energy is used to start the engine Allow energy is used for aircon / electronic devices Allow combustion is not smooth Ignore inefficient combustion Ignore references to standard conditions Ignore fuel evaporates Ignore petrol not 100% octane Ignore the idea that some other force is moving the car e.g. car is going downhill	(2)

Question number	Answer	Additional guidance	Mark
*20(b)	This question assesses the student's ability to show a coherent and logically structured answer with linkages and fully sustained reasoning. Marks are awarded for indicative content and for how the answer is structured and shows lines of reasoning. The following table shows how the marks should be awarded for indicative content. <table><tr><td>Number of indicative marking points seen in answer</td><td>Number of marks awarded for indicative marking points</td></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 <table><tr><td></td><td>Number of marks awarded for structure of answer and sustained lines of reasoning</td></tr><tr><td>Answer shows a coherent logical structure with linkages and fully sustained lines of reasoning demonstrated throughout</td><td>2</td></tr><tr><td>Answer is partially structured with some linkages and lines of reasoning</td><td>1</td></tr><tr><td>Answer has no linkages between points and is unstructured</td><td>0</td></tr></table>	Guidance on how the mark scheme should be applied. The mark for indicative content should be added to the mark for lines of reasoning. For example, a response with five indicative marking points that is partially structured with some linkages and lines of reasoning scores 4 marks (3 marks for indicative content and 1 mark for partial structure and some linkages and lines of reasoning). If there were no linkages between the points, then the same indicative marking points would yield an overall score of 3 marks (3 marks for indicative content and no marks for linkages). In general it would be expected that 5 or 6 indicative points would get **2** reasoning marks 3 or 4 indicative points would get **1** reasoning mark 0, 1 or 2 indicative points would get **0** reasoning marks. If there is any incorrect chemistry, deduct mark(s) from the reasoning. If no reasoning mark(s) awarded do not deduct mark(s). **Comment**: Look for the indicative marking points first, then consider the mark for the structure of the answer and sustained line of reasoning	6

Question	Answer	Additional guidance	Mark
*20(b) cont	**Indicative points** **Similarities** • **IP1** both hydrogen and ammonia form London / dispersion forces • **IP2** a temporary dipole forms in a molecule and induces a dipole in an adjacent molecule • **IP3** the attraction (between the temporary dipoles) is small(er) in hydrogen because the H_2 electron cloud is not easily polarised **Differences** • **IP4** ammonia forms hydrogen bonds (because nitrogen is very electronegative) hydrogen bond • **IP5** Accept hydrogen bond forms between the nitrogen lone pair and the (δ+) hydrogen (of a different molecule) • **IP6** ammonia liquefies more easily than hydrogen because hydrogen bonds are stronger than London forces	Allow van der Waals forces Ignore permanent dipole-dipole forces in ammonia Do not award H_2 forms hydrogen bonds / permanent dipole-dipole forces Accept fluctuating electron clouds result in differences in electron density within the molecule Allow instantaneous dipole-dipole attractions between molecules Allow because H_2 has only two / few electrons Allow attraction is greater in ammonia because it has more electrons Do not award ammonia forms hydrogen bonds with water IP4 and IP5 may be scored by a diagram showing dipole and lone pair and with H bond labelled Allow N----H—N bond angle not equal to 180 Allow hydrogen bond forms between the $\delta-$ nitrogen and the δ+ hydrogen (of a different molecule) Allow permanent dipole-dipole forces for H bonds here Ignore just 'H-bonding is the strongest IMF' Ignore reference to boiling temperatures Do not award hydrogen liquefies to form water Do not award energy is required to liquefy a gas	6

(Total for Question 20 = 16 marks)

Question Number	Answer	Additional Guidance	Mark
18(a)(i)	An answer that makes reference to the following point: 1. balanced ionic equation	 $H^+ \ + \ OH^- \ \rightarrow \ H_2O$ Accept $H_3O^+ \ + \ OH^- \ \rightarrow \ 2H_2O$ Accept multiples Ignore full equation as working Ignore state symbols even if incorrect Do not award uncancelled spectator ions	**(1)** **Graduate**

18(a)(ii)	An answer that makes reference to the following points:		(2)
	1. heat energy released under standard conditions **(1)**	Allow enthalpy change under standard conditions	**Expert**
		Allow for standard conditions 1 atm / 1(.01) x10^{5}Pa and a stated temperature / 298K / 25°C	
		Ignore standard states	
		Do not award energy required	
	2. (when) 1 mol of **water** is produced (by the reaction of acid **(1)** with alkali)		

Question Number	Answer	Additional Guidance	Mark
18(b)(i)	An answer that makes reference to the following points:		(2)
	3. two lines of best fit drawn **(1)**	Cooling may be shown as straight line or smooth curve	**Expert**
		$\Delta T = 26.8 - 22.4 = 4.4\,^{O}C$	
	4. value ±0.2 **(1)**	Accept value between 4.2 ^{O}C and 4.6 ^{O}C from a correct vertical extrapolation at 120s	
		Example of extrapolation	

Question Number	Answer		Additional Guidance	Mark
18(b)(ii)	An answer that makes reference to the following points:	Example of calculation:		(3)
	5. energy transferred to solutions (1)	$0.05 \times 4.2 \times 4.4 = 0.924$ (kJ) $50 \times 4.2 \times 4.4 = 924$ (J)		Expert
	6. moles of water formed (1)	$(25 \div 1000) \times 0.8 = 0.02$(mol)		
	7. enthalpy change of neutralisation with negative sign and units (1)	$0.924 \div 0.02 = -46.2$ kJ mol^{-1} / $-46{,}200$ J mol^{-1} TE on b(i) and throughout b(ii) Ignore SF except 1 SF		

Question Number	Answer		Additional Guidance	Mark
18(b)(iii)	An explanation that makes reference to the following points:			(2)
	1. (because the calculation has not taken into account the) energy required to heat the calorimeter/ the (total) heat capacity would be greater	(1)	Ignore references to the relative heat capacity of copper/water(solution)	Expert
	2. the value(of the enthalpy change of neutralisation) would be more exothermic/more negative	(1)	Allow higher/ increase/ greater	

Question Number	Answer	Additional Guidance	Mark
18(c)(i)	An answer that makes reference to the following points:		(1)
	nucleophilic **and** substitution(reaction)	Allow nucleophile substitution	Clerical

Question Number	Answer	Additional Guidance	Mark
18(c)(ii)	An answer that makes reference to the following points:	<u>Example of mechanism</u>	**(3)**
			Expert
	3. dipole on C-Br bond		
	4. lone pair on O of OH⁻		
	5. curly arrow from lone pair to **C of C-Br**. If no lone pair shown, allow curly arrow from O		
		Allow product as structural formula	
	6. arrow from C-Br to Br or just beyond	Allow NaBr	
	7. organic product	Ignore Na^+	
		Do not award HBr	
	8. Br^-	6 points correct scores (3)	
		4 /5 points correct scores (2)	

		Additional Guidance	
		2 / 3 points correct scores (1)	
		Ignore intermediate/ transition state if shown	

Question Number	Answer	Additional Guidance	Mark
18(c)(iii)	An answer that makes reference to the following points:		**(2)**
			Graduate
	1. elimination **(1)**	Do not award addition/substitution/dehydration/acid/base	
	2. ethanol / alcohol **(1)**	Allow ethanolic /alcoholic solution	

(Total for Question 18 = 16 marks)

Section C

Question Number	Answer		Additional Guidance	Mark
22(a)	An explanation that makes reference to the following points:		Allow reverse arguments for all points	(3)
	• method 2 is more sustainable because it does not use methane/fossil fuels	(1)	Allow method 2 is more sustainable as method 1 uses methane/fossil fuels Ignore it produces oxygen	
	• methane/fossil fuels are a finite resource / solar power is renewable	(1)	Allow methane is a finite energy (resource) Allow water is renewable if related to method 2 Ignore clean energy from solar power Ignore solar is a sustainable resource	
	• because it does not produce CO_2 / does not produce greenhouse gases / contribute to global warming	(1)	Ignore good for the environment Ignore any reference to atom economy etc Ignore any reference to intermolecular forces etc Penalise wrong chemistry only once	

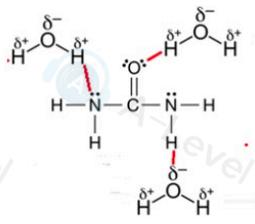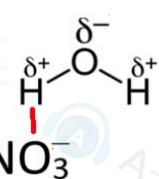| Question Number	Answer	Additional Guidance	Mark
22(b)(i)	• calculation of % N	Example of calculation: $28 \div 80 \times 100 = 35\%$ Correct answer with no working scores 1	(1)

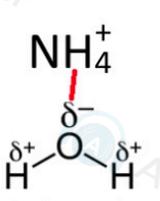| Question Number	Answer		Additional Guidance	Mark
22(b)(ii)	An answer that makes reference to the following points:			(2)
	• advantage: ammonia has a high % N	(1)	Allow just contains more N	
	• disadvantage: ammonia is a gas (so hard to apply)	(1)	Allow ammonia (as it is a gas) will escape Allow ammonia is a base/alkali/will increase the pH Allow it is toxic Allow it is corrosive Allow it will evaporate Allow (as it is a gas) it is harder to transport/store Ignore it has a bad smell Ignore it is a greenhouse gas Ignore any reference to cost/atom economy	

Question Number	Answer	Additional Guidance	Mark
22(c)(i)	• $HNO_3 + NH_3 \longrightarrow NH_4NO_3$ Or $HNO_3 + NH_4OH \longrightarrow NH_4NO_3 + H_2O$	Allow NH_4^+ and NO_3^- Ignore state symbols even if incorrect	(1)

Question Number	Answer	Additional Guidance	Mark
22(c)(ii)	An answer that makes reference to the following points: • neutralisation (reaction)/neutralization (reaction)	Allow acid/base (reaction)	(1)

Question Number	Answer		Additional Guidance	Mark
22(d)	An answer that makes reference to the following points:			(2)
	• correct electrons round C ie a double bond to the O and 2 singles to the Ns	(1)	Allow all dots or crosses or any combination of any symbols	
	• rest of the electrons correct	(1)		

Question Number	Answer	Additional guidance	Mark
*22(e)	This question assesses the student's ability to show a coherent and logically structured answer with linkages and fully sustained reasoning. Marks are awarded for indicative content and for how the answer is structured and shows lines of reasoning. The following table shows how the marks should be awarded for indicative content.	Guidance on how the mark scheme should be applied. The mark for indicative content should be added to the mark for lines of reasoning. For example, a response with five indicative marking points that is partially structured with some linkages and lines of reasoning scores 4 marks (3 marks for indicative content and 1 mark for partial structure and some linkages and lines of reasoning). If there were no linkages between the points, then the same indicative marking points would yield an overall score of 3 marks (3 marks for indicative content and no marks for linkages).	6 exp

Table for indicative content:

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

The following table shows how the marks should be awarded for structure and lines of reasoning.

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

Additional guidance (continued):

In general it would be expected that
5 or 6 indicative points would get **2** reasoning marks
3 or 4 indicative points would get **1** reasoning mark
0, 1 or 2 indicative points would get **0** reasoning marks.

If there is any incorrect chemistry, deduct mark(s) from the reasoning. If no reasoning mark(s) awarded do not deduct mark(s).

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

Question Number	Answer	Additional Guidance
*22(e)	**Indicative points** **IP1 hydrogen bonds** are formed between water and urea **IP2** urea is soluble in water as the hydrogen bonds formed are stronger/ similar in magnitude to the intermolecular forces between the individual molecules **IP3** diagram showing **one** hydrogen bond between urea and water Note ignore lack of lone pairs, dipoles and bond angles, including the hydrogen bond If the hydrogen bond is labelled this will score IP1 and IP3 **IP4** ammonium nitrate is soluble in water as the water **hydrates** the ions (and the bonds formed are stronger/ similar in magnitude to the ionic bonds) **IP5** diagram showing the interaction between nitrate ions and water Ignore lack of diploes	Allow H bonds Allow both water and urea have hydrogen bonds Allow a comparison with any intermolecular force/ London forces/dipole-dipole forces/hydrogen bonds Ignore if multiple water molecules and hydrogen bonds are shown. Allow ion- dipole interaction The H must be adjacent to the nitrate ion
	IP6 diagram showing the interaction between ammonium ions and water	The hydration attraction does not need to be shown Ignore if both Hs of a water molecule are attracted to the same ion Ignore multiple water molecules attracted to a single ion The O must be must be adjacent to the ammonium ion The hydration attraction does not need to be shown Ignore multiple water molecules attracted to a single ion **IP3**, **5** and **6** must be scored via diagrams. **IP1** and **4** may be scored by annotated diagrams.

Question Number	Answer		Additional Guidance	Mark
22(f)			Example of calculation	**(4)**
	• calculation of the number of hectares	**(1)**	$(500 \times 640) \div 10000 = 32$ ha	
	• calculation of the mass of N required	**(1)**	$32 \times 160 \times 1000 = 5120000$ g / 5120 kg/ 5.12×10^6 (g)	
	• calculation of the mass of urea required	**(1)**	5120000 (g) $\times$ 100/46.7 = 10963597 g / 1.0963597×10^7 g / 10964 kg/ 10.964 tonnes	
	• answer in tonnes to 2 or 3 SF	**(1)**	11 (tonnes)/11.0 (tonnes) TE throughout Correct answer with no working scores 4	

(Total for Section C = 20 marks)
TOTAL FOR PAPER = 80 MARKS

Section C

Question Number	Answer	Additional Guidance	Mark
22(a)(i)	An answer that makes reference to one of the following points: • shifts position of equilibrium to the right OR increases the (equilibrium) yield (of H_2)	Ignore to increase rate (of forward reaction) Ignore cheaper to have steam in excess Ignore to react with most of the CH_4 Allow to increase yield (of CO / products) Do not award so all of the CH_4 reacts / so reaction goes to completion Do not award to increase the moles of gas/pressure	**(1)**

Question Number	Answer	Additional Guidance	Mark
22(a)(ii)	An answer that makes reference to the following points: • T_1 (is higher) **and** (first reaction is) endothermic	**Accept reverse argument** Allow positive enthalpy change for endothermic Allow (first reaction) absorbs (heat) energy for endothermic Ignore just +206 for endothermic Ignore correct reference to effect of temperature on equilibrium yields Do not award absorbs more energy to break (reactant) bonds	**(1)**

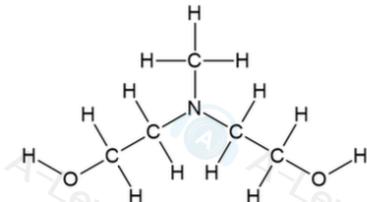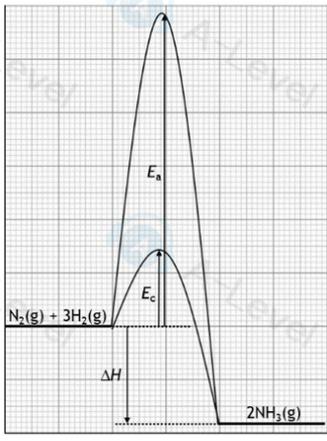| Question Number	Answer	Additional Guidance	Mark
22(a)(iii)	An answer that makes reference to the following point: • overall equation for Stage 1	Example of correct equation: $CH_4 + 2H_2O \rightarrow 4H_2 + CO_2$ Allow $\rightleftharpoons$ for $\rightarrow$ Allow multiples Ignore state symbols even if incorrect Ignore working Do not award uncancelled CO	**(1)**

Question Number	Answer	Additional Guidance	Mark
22(b)(i)	An answer that makes reference to one of the following points: • to reduce greenhouse gas emissions OR to sell (to increase profit) OR to prevent poisoning of the catalyst(s) in later stages	Ignore any reference to position of equilibrium in Stage 1 reactions Allow CO_2 / it is a greenhouse gas Allow CO_2 / it causes global warming / climate change Ignore (to make the process more) carbon neutral / to reduce carbon footprint Ignore CO_2 is harmful to the environment Ignore just to reduce air pollution Do not award reference to ozone layer	**(1)**

Question Number	Answer	Additional Guidance	Mark
22(b)(ii)	An answer that makes reference to the following point: • neutralisation	Accept acid-base Ignore addition Ignore reversible Ignore formation Do not award hydration Do not award redox	**(1)**

Question Number	Answer	Additional Guidance	Mark
22(b)(iii)	An answer that makes reference to the following points: • displayed formula of N-methyldiethanolamine	Example of displayed formula: Allow OH for O–H Ignore bond angles and bond lengths Do not award C–HO connectivity	**(1)**

Question Number	Answer	Additional Guidance	Mark
22(c)	An answer that makes reference to the following points: • advantage of using high pressure **(1)** • disadvantage of using high pressure **(1)**	Examples of advantage: shifts position of equilibrium to right / products OR increases (equilibrium) yield (of NH_3) OR increases rate OR increases occupation of catalyst active sites Ignore any reference to collisions Examples of disadvantage: requires more energy OR costs more for energy/fuel OR requires expensive/specialist equipment (to withstand pressure) Ignore just expensive / costs more Ignore dangerous / risk of explosion	**(2)**

Question Number	Answer	Additional Guidance	Mark
22(d)(i)	An answer that makes reference to the following points: • ΔH labelled **and** arrow pointing downwards **(1)** • **labelled** reaction profiles for uncatalysed **and** catalysed reactions **(1)** • correct scale for activation energies **(1)**	Example of labelled reaction profile: Allow arrows to start/end within one small square of correct placement and penalise incorrect placement once only Allow −92 / 'enthalpy change' for ΔH Do not award double headed arrow Allow any form of unambiguous labelling, eg values Allow double headed arrows Do not award downward arrows Do not award $E_{cat} > E_a$ Accept accuracy of ± one small square Ignore scale shown on y-axis	**(3)**

Question Number	Answer	Additional Guidance	Mark
22(d)(ii)	An answer that makes reference to one of the following points: • less energy (needed) / (works at a) lower temperature OR less fuel (required)	Ignore lowers E_a Ignore catalyst can be reused Ignore reduces carbon footprint / carbon emissions	**(1)**

Question Number	Answer	Additional Guidance	Mark
22(e)(i)	An answer that makes reference to one of the following points: • increase rate OR rate is slow at low temperature OR catalyst does not work at low temperature OR so more reactants/collisions have $E \geq E_a$ OR to break O=O/N–H bonds	Do not award to increase yield Do not award to shift position of equilibrium (to left / right) Do not award reverse reaction is endothermic Allow to increase the number of successful collisions Ignore to increase collision frequency Allow catalyst more efficient at high temperature Allow to activate the catalyst Accept (to reach) high activation energy Allow to break bonds in oxygen/ammonia/reactants	**(1)**

Question Number	Answer	Additional Guidance	Mark
22(e)(ii)	An answer that makes reference to the following points: • (forward reaction is highly) exothermic OR (forward reaction) releases (a lot of) heat (energy)	Ignore any reference to catalysis Allow thermal energy for heat Do not award NH₃ from Stage 2 is hot Do not award 1100 K is not very high	**(1)**

Question Number	Answer		Additional Guidance	Mark
22(f)	An explanation that makes reference to the following points: • NO_2 removed (in second reaction) • shifting position of equilibrium (in first reaction) to right **and** increasing the yield (of NO_2)	**(1)** **(1)**	Allow (as) NO formed (in second reaction) Ignore HNO_3 is formed (in second reaction) Ignore reaction is irreversible Ignore NO_2 dissolves Allow shifting reaction to right **and** increasing yield (of NO_2)	**(2)**

Question Number	Answer	Additional Guidance	Mark
22(g)(i)	An answer that makes reference to the following points: • left hand side of enthalpy cycle **(1)** • right hand side of enthalpy cycle **(1)**	Example of completed enthalpy cycle: Do not award omission/incorrect state symbols Do not award multiples Do not award numbers in opposite order Do not award -25.6 Do not award $+365.6$ / 365.6	(2)

Question Number	Answer	Additional Guidance	Mark
22(g)(ii)	An answer that makes reference to the following point: • calculation of $\Delta_r H$	Example of calculation: $\Delta_r H = -(-32.6) - (-220.2) + (-365.6) + 25.6$ $\quad = -87.2 / -87$ (kJ mol^{-1}) Allow omission of units Allow kJ TE on cycle in (g)(i)	(1)

Question Number	Answer	Additional Guidance	Mark
22(h)	An answer that makes reference to two of the following points: • cheaper to produce H_2/NH_3/NO/HNO_3 than to purchase (from other suppliers) **(1)** OR • (better) knowledge of chemical purity / chemical quality **(1)** OR • lower transportation / travel costs (between sites) **(1)** OR • prevents (more) chemical waste through transfer losses **(1)** OR • energy produced in exothermic reactions can be used (in endothermic processes) **(1)** OR • smaller workforce required **(1)** OR • less land required **(1)** OR • saves time so cheaper operational costs **(1)**	**Ignore just cheaper (operational costs)** **Ignore just less energy required** **Ignore just saves time / makes product faster** Ignore just chemicals need transporting Ignore just chemical lost through transportation Ignore just higher yield Do not award higher atom economy Allow lower energy costs Allow reduces carbon footprint Allow lower workforce costs Allow saves building / maintenance costs	(2)

(Total for Question 22 = 21 marks)
(Total for Section C = 21 marks)
(Total for Paper = 80 marks)

Question Number	Answer	Additional Guidance	Mark
22(a)	An explanation that makes reference to the following points:		(2)
	• 1 mol of substance / compound / MgO **(1)**	Allow 1 mol of product	
	• formed from element(s) in standard state(s) **(1)**	Ignore Mg(s) and O_2(g) / reactant(s) for element(s) Ignore normal/natural etc for standard Ignore any reference to standard conditions	

Question Number	Answer	Additional Guidance	Mark
22(b)		Here and throughout the paper: • penalise incorrect rounding once only and only if the final answer is incorrect • do not penalise correct premature rounding • penalise incorrect units once only • Allow mol^- for mol^{-1} Example of calculation: Correct answer to **3SF or 2SF** with some working scores (4) Ignore SF except 1SF and penalise use of 1SF once only Ignore sign in M1 and M3	(4)
	• calculation of energy transferred **(1)**	energy = 25.0 × 4.18 × (28.0 − 21.5) = 679.25 (J) Allow 0.67925 (kJ)	
	• calculation of amount of MgO **(1)**	amount = 0.189 ÷ 40.3 = 0.0046898 / 4.6898 × 10^{-3} (mol) Allow 0.004725 / 4.725 × 10^{-3} (mol) from M_r = 40	
	• calculation of Δ_rH_2 **(1)**	Δ_rH_2 = 679.25 ÷ 0.0046898 = 144830 (J mol^{-1}) Accept 144.83 (kJ mol^{-1}) Allow 143760 (J mol^{-1}) / 143.76 (kJ mol^{-1}) from M_r = 40 TE on M1 and M2	
	• negative sign and answer to 3SF or 2SF **(1)**	−145 / −140 (kJ mol^{-1}) Allow −145000 / −140000 J mol^{-1} Allow −144 (kJ mol^{-1}) / −144000 J mol^{-1} from M_r = 40 TE on M3	

Question Number	Answer	Additional Guidance	Mark
22(c)		Example of calculation: Correct answer with some working scores (2)	(2)
	• correct expression for Δ_rH_1 **(1)**	Δ_rH_1 = −462 + (−286) − answer to (b)	
	• calculation of Δ_rH_1 **(1)**	Δ_rH_1 = −462 + (−286) − (−145) = −603 (kJ mol^{-1}) Ignore SF TE on answer to (b) No TE on incorrect expression from M1 Allow −604 (kJ mol^{-1}) from M_r = 40 in (b) If using −100 (kJ mol^{-1}) for answer to (b) Δ_rH_1 = −462 + (−286) − (−100) = −648 (kJ mol^{-1})	

(Total for Question 22 = 8 marks)

Question Number	Answer	Additional Guidance	Mark
18(a)	• conversion of temperature to K **and** conversion of kPa to Pa **(1)** • conversion of cm^3 to m^3 **(1)** • rearrangement of ideal gas equation **(1)** • calculation of n **(1)** • calculation of relative molecular mass **(1)**	<u>Example of calculation:</u> $95 + 273 = 368$ $99 \times 1000 = 99000$ (Pa) $81 \times 10^{-6} = 8.1 \times 10^{-5}$ (m^3) $n = \dfrac{pV}{RT}$ $\dfrac{99000 \times 8.1 \times 10^{-5}}{8.31 \times 368} = 2.6222 \times 10^{-3}$ (mol) $\dfrac{0.12}{2.6222 \times 10^{-3}} = 45.763$ (g mol^{-1}) TE throughout Ignore intermediate rounding Ignore SF except 1 Correct answer with some working scores 5	**(5)**

Question Number	Answer	Additional Guidance	Mark
18(b)	An answer that makes reference to the following point: • ethanol/ $CH_3CH_2OH/C_2H_5OH/C_2H_6O$	Accept methoxymethane/CH_3OCH_3 Allow dimethyl ether Allow TE from (a) provided it is a formula that could exist	**(1)**

(Total for Question 18 = 6 Marks)

Question Number	Answer		Additional Guidance	Mark
17(a)			Example of calculation	(7)
	• moles of NaOH in titre	(1)	$27.15 \div 1000 \times 0.0960 = 2.6064 \times 10^{-3}$ / 0.0026064 / 0.00261 (mol)	
	• total moles of HCl in solution after reaction with the carbonate	(1)	$0.0026064 \times 10 = 2.6064 \times 10^{-2}$ / 0.026064 / 0.0261 (mol)	
	• moles of HCl which reacted with $MgCO_3 \cdot nH_2O$	(1)	$0.0600 - 0.026064 = 3.3936 \times 10^{-2}$ / 0.033936 / 0.0339 (mol)	
	• moles of $MgCO_3 \cdot nH_2O$ in sample	(1)	$0.033936 \div 2 = 1.6968 \times 10^{-2}$ / 0.016968 / 0.0170 (mol)	
	• mass $MgCO_3$ in the sample	(1)	$0.016968 \times (24.3 + 12.0 + 3(16.0)) = 1.43040$ / 1.4304 / 1.43 (g)	
	• mass of water	(1)	$2.35 - 1.4304 = 0.9196$ (g)	
	• value of n to 1 SF	(1)	$(0.9196 \div 18) : 0.016968 = 3.01 = 3$ to 1 SF Allow TE throughout Ignore SF throughout	
	Alternative method for M5,6,7 • M_r hydrated salt	(1)	$2.35 \div 0.016968 = 138.500$	
	• mass of water	(1)	$138.500 - (24.3 + 12.0 + 3(16.0)) = 54.196$	
	• value of n to 1 SF	(1)	$54.196 \div 18 = 3.0109 = 3$ to nearest whole number	

Question Number	Answer		Additional Guidance	Mark
17(b)(i)			Example of calculation	(3)
	• calculation of energy produced	(1)	$Q = 40 \times 30.8 \times 4.18 = 5149.8$ / 5150 (J)	
	• calculation of mols magnesium oxide and use in calculation	(1)	$1.92 \div (24.3 + 16) = 4.76 \times 10^{-2}$ / 0.047643 / 0.0476 / 0.048 (mol)	
	• calculation of $\Delta_r H_1$ and sign and units	(1)	$5149.8 \div 1000 \div 0.047643 = -108.09$ /$- 108.1$/ -108 kJ mol^{-1} Allow -108090 J mol^{-1} Ignore SF except 1 SF Correct answer with no working scores (3) Allow TE throughout +108.09 scores 2 marks	

Question Number	Answer		Additional Guidance	Mark
17(b)(ii)			Example of calculation	(3)
	• completed Hess cycle	(1)	$MgCO_3(s) \longrightarrow MgO(s) + CO_2(g)$ (2HCl) ↘ ↓ (2HCl) $MgCl_2(aq) + H_2O(l) + CO_2(g)$	
	• $\Delta_r H = \Delta_r H_2 - \Delta_r H_1$	(1)	$3.58 - (-108.09)$	
	• answer to 2/3 SF	(1)	$= (+)\ 111.67$ / 111.7 / 112 / 110 $= (+)112$ / $(+)110$ (kJ mol^{-1}) TE from (i) Correct answer with no working scores M2 and M3	

Question Number	Answer	Additional Guidance	Mark
17(b)(iii)	An answer that makes reference to the following point: • it is difficult to measure the **temperature** of a solid/powder/ while it is being heated	Ignore references to non-standard conditions	**(1)**

Question Number	Answer	Additional Guidance	Mark
17(c)(i)	An explanation that makes reference to the following points: • the temperature required to decompose calcium carbonate is higher (than that for magnesium carbonate)/the thermal stability of the Group 2 carbonates increases down the Group **(1)** • (because) the calcium ion is larger than magnesium ion/ the surface charge density of calcium ion is less/ magnesium ion is more polarising **(1)** • (so the) carbon - oxygen bond is less weakened **(1)**	Allow reverse arguments for M1 and M2 Do not award references to electronegativity/intermolecular forces Allow so carbon - oxygen bond is less polarised	**(3)**

Question Number	Answer	Additional Guidance	Mark
17(c)(ii)	An explanation that makes reference to the following points: • the (forward) reaction is exothermic so a low(er) temperature increases the yield of methanol **(1)** • but the rate will be too low (so a compromise temperature is used) **(1)** • there are fewer moles of gas on the RHS/products **(1)** • so high pressure will move the equilibrium position to the RHS/ increase the yield of methanol **(1)**	Allow reverse arguments Allow shifts the equilibrium position to RHS for increasing the yield of methanol Allow annotation on the equation Allow high pressure will cause more collisions / increase rate Ignore references to catalysts	**(4)**

(Total for Question 17 = 21 marks)

TOTAL FOR SECTION C = 21 MARKS
TOTAL FOR PAPER = 80 MARKS