Mark Scheme (Results)

January 2023

Pearson Edexcel International Advanced Subsidiary Level in Chemistry (WCH12) Paper 01 Energetics, Group Chemistry, Halogenoalkanes and Alcohols

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Using the mark scheme

Examiners should look for qualities to reward rather than faults to penalise. This does NOT mean giving credit for incorrect or inadequate answers, but it does mean allowing candidates to be rewarded for answers showing correct application of principles and knowledge. Examiners should therefore read carefully and consider every response: even if it is not what is expected it may be worthy of credit.

The mark scheme gives examiners:
- an idea of the types of response expected
- how individual marks are to be awarded
- the total mark for each question
- examples of responses that should NOT receive credit.

/ means that the responses are alternatives and either answer should receive full credit. ( ) means that a phrase/word is not essential for the award of the mark, but helps the examiner to get the sense of the expected answer.

Phrases/words in **bold** indicate that the meaning of the phrase or the actual word is **essential** to the answer. ecf/TE/cq (error carried forward) means that a wrong answer given in an earlier part of a question is used correctly in answer to a later part of the same question.

Candidates must make their meaning clear to the examiner to gain the mark. Make sure that the answer makes sense. Do not give credit for correct words/phrases which are put together in a meaningless manner. Answers must be in the correct context.

Quality of Written Communication

Questions which involve the writing of continuous prose will expect candidates to:
- write legibly, with accurate use of spelling, grammar and punctuation in order to make the meaning clear
- select and use a form and style of writing appropriate to purpose and to complex subject matter
- organise information clearly and coherently, using specialist vocabulary when appropriate.

Full marks will be awarded if the candidate has demonstrated the above abilities. Questions where QWC is likely to be particularly important are indicated (QWC) in the mark scheme, but this does not preclude others.

Section A

Question Number	Answer	Mark
1(a)	**The only correct answer is C** (6.3 %) ***A*** *is not correct because the uncertainty has been halved rather than doubled* ***B*** *is not correct because this is the uncertainty for a single measurement only* ***D*** *is not correct because the uncertainty has been doubled twice*	**(1)**

Question Number	Answer	Mark
1(b)	**The only correct answer is C** (16.0 °C) ***A*** *is not correct because this is being calculated by using times 2/3 of the mass of methanol rather than times 3/2* ***B*** *is not correct because this would be the expected temperature change had the mass of methanol burned remained at 0.20 g* ***D*** *is not correct because this is being calculated by using times 3/2 of the volume of water rather than times 2/3*	**(1)**

Question Number	Answer	Mark
1(c)	**The only correct answer is D** (use of the molar mass of ethanol, C_2H_5OH, in the calculation) ***A*** *is not correct because this would produce a smaller temperature change and result in a less exothermic value for the combustion enthalpy* ***B*** *is not correct because this would produce a smaller temperature change and result in a less exothermic value for the combustion enthalpy* ***C*** *is not correct because this would result in a larger apparent mass of methanol burned and a less exothermic value for the combustion enthalpy*	**(1)**

Question Number	Answer	Mark
2	**The only correct answer is A** ($\frac{1}{2}Br_2(l) \rightarrow Br(g)$) ***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)**

Question Number	Answer	Mark
3	**The only correct answer is A** ($(0.5 \times 436 + 0.5 \times 242) - 431$) ***B*** *is not correct because the bond enthalpies of the reactants have been subtracted from the bond enthalpy of the product and this is for the formation of two moles of HCl* ***C*** *is not correct because the bond enthalpies of the reactants have been subtracted from the bond enthalpy of the product* ***D*** *is not correct because this is for the formation of two moles of HCl*	**(1)**

Question Number	Answer	Mark
4	**The only correct answer is D** (CF_4) ***A*** *is not correct because HF also has hydrogen bonds and permanent dipole-permanent dipole interactions* ***B*** *is not correct because* OF_2 *also has permanent dipole-permanent dipole interactions* ***C*** *is not correct because* PF_3 *also has permanent dipole-permanent dipole interactions*	**(1)**

Question Number	Answer	Mark
5	**The only correct answer is C** ($(CH_3)_3COH$) ***A*** *is not correct because the electronegative nitrogen is not bonded directly to a hydrogen* ***B*** *is not correct because the electronegative fluorine is not bonded directly to a hydrogen* ***D*** *is not correct because the electronegative oxygen is not bonded directly to a hydrogen*	**(1)**

Question Number	Answer	Mark
6	**The only correct answer is B** (HF > HI > HBr > HCl) ***A*** *is not correct because the trend in boiling temperature of the hydrogen halides depends on the strength of the London forces as well as polarity* ***C*** *is not correct because HF has hydrogen bonding and a higher boiling temperature than HI* ***D*** *is not correct because HF has hydrogen bonding and the highest boiling temperature*	**(1)**

Question Number	Answer	Mark
7	**The only correct answer is A** (VO^{2+}) ***B*** *is not correct because the oxidation number of vanadium is +5 in this ion* ***C*** *is not correct because the oxidation number of vanadium is +5 in this ion* ***D*** *is not correct because the oxidation number of vanadium is +5 in this ion*	**(1)**

Question Number	Answer	Mark
8	**The only correct answer is B** (K_2MnO_4) ***A*** *is not correct because the oxidation number of manganese is +7 in this compound* ***C*** *is not correct because the oxidation number of manganese is +5 in this compound* ***D*** *is not correct because there are two atoms of manganese and the oxidation number of manganese is +3 in this compound*	**(1)**

Question Number	Answer	Mark
9	**The only correct answer is C** ($Sr(NO_3)_2$) ***A*** *is not correct because LiCl would not form a precipitate when mixed with a solution of potassium sulfate* ***B*** *is not correct because* $NaNO_3$ *produces a yellow flame colour and would not form a precipitate when mixed with a solution of potassium sulfate* ***D*** *is not correct because* $BaCl_2$ *produces a green flame colour*	**(1)**

Question Number	Answer	Mark
10	**The only correct answer is C** ($Sr + H_2O \rightarrow$) ***A*** *is not correct because MgO is the only product of this reaction* ***B*** *is not correct because* $CaCl_2$ *is the only product of this reaction* ***D*** *is not correct because* $Ba(OH)_2$ *is the only product of this reaction*	**(1)**

Question Number	Answer	Mark
11	**The only correct answer is D** ($2F^-(aq) + At_2(aq) \rightarrow 2At^-(aq) + F_2(aq)$) ***A*** *is not correct because iodine is more reactive than astatine* ***B*** *is not correct because chlorine is more reactive than bromine* ***C*** *is not correct because chlorine is more reactive than iodine*	**(1)**

Question Number	Answer	Mark
12	**The only correct answer is D** ($8KI(s) + 9H_2SO_4(aq) \rightarrow 8KHSO_4(aq) + 4I_2(s) + H_2S(g) + 4H_2O(l)$) ***A*** *is not correct because this is not a redox reaction* ***B*** *is not correct because this is not a redox reaction* ***C*** *is not correct because one mole of* H_2SO_4 *oxidises only ⅔ moles of bromide ions*	**(1)**

Question Number	Answer	Mark
13	**The only correct answer is A** ($(CH_3)_3CI$) ***B*** *is not correct because iodoalkanes have higher rates of hydrolysis than chloroalkanes* ***C*** *is not correct because tertiary halogenoalkanes have higher rates of hydrolysis than primary halogenoalkanes* ***D*** *is not correct because iodoalkanes have higher rates of hydrolysis than chloroalkanes and tertiary halogenoalkanes have higher rates of hydrolysis than primary halogenoalkanes*	**(1)**

Question Number	Answer	Mark
14	**The only correct answer is D** (four) ***A*** *is not correct because E and Z isomers of both hex-2-ene and hex-3-ene are possible* ***B*** *is not correct because E and Z isomers of both hex-2-ene and hex-3-ene are possible* ***C*** *is not correct because E and Z isomers of both hex-2-ene and hex-3-ene are possible*	**(1)**

Question Number	Answer	Mark
15	**The only correct answer is B** ($CH_3CH_2NHCH_3$) ***A*** *is not correct because this molecule has a prominent peak at m/z = 43 in its mass spectrum (due to* CH_3CO^+*)* ***C*** *is not correct because this molecule has a prominent peak at m/z = 43 in its mass spectrum (due to* $(CH_3)_2CH^+$*)* ***D*** *is not correct because this molecule has a prominent peak at m/z = 43 in its mass spectrum (due to* $CH_3CH_2CH_2^+$*)*	**(1)**

Question Number	Answer	Mark
16	**The only correct answer is A** ($H_2NCH_2CH_2C{\equiv}N$) ***B*** *is not correct because this molecule does not have a triple bond so no peak at 2250* cm^{-1} ***C*** *is not correct because this molecule does not have an O-H or N-H bond so no peak at 3415* cm^{-1} ***D*** *is not correct because this molecule does not have a triple bond so no peak at 2250* cm^{-1}	**(1)**

Question Number	Answer	Mark
17(a)	**The only correct answer is B** (all molecules possess some energy) ***A*** *is not correct because all molecules possess some energy* ***C*** *is not correct because the temperature cannot be 0 K* ***D*** *is not correct because this relates to the activation energy, and rate, for a chemical reaction*	**(1)**

Question Number	Answer	Mark
17(b)	**The only correct answer is B** (decreases, shifts to the left) ***A*** *is not correct because the area under the curve decreases (as there are fewer molecules)* ***C*** *is not correct because the area under the curve decreases (as there are fewer molecules) and the peak shifts to the left (as the molecules have less energy)* ***D*** *is not correct because the peak shifts to the left (as the molecules have less energy)*	**(1)**

(Total for Section A = 20 marks)

Section B

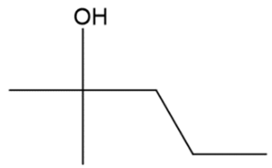
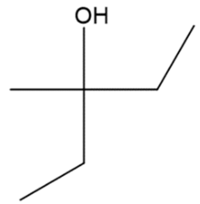
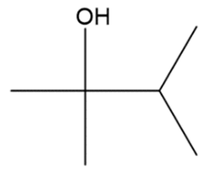
Question Number	Answer		Additional Guidance	Mark
18(a)	An explanation that makes reference to the following points:			**(3)**
	• disproportionation (of chlorine)	**(1)**	Ignore redox Do not award disproportionation of calcium/oxygen/hydrogen	
	• (oxidation numbers of chlorine) 0 (in Cl_2) **and** (+)1 in $Ca(ClO)_2$ **and** −1 in $CaCl_2$	**(1)**	Allow annotations on the equation Allow 1− Do not award if any other element is also changing oxidation number	
	• oxidised from 0 to +1 **and** reduced from 0 to −1	**(1)**	Allow oxidation is increase in oxidation number **and** reduction is decrease in oxidation number TE on oxidation numbers given in M2, even for Ca/O/H Ignore any reference to oxidising agents / reducing agents Ignore any reference to electron transfer	

Question Number	Answer	Additional Guidance	Mark
18(b)	An answer that makes reference to the following points: • M_r of $Ca(ClO)_2$ **(1)** • percentage atom economy (by mass) **(1)**	Examples of calculation: $M_r = 40.1 + 2 \times 16.0 + 2 \times 35.5 = 143.1$ Allow 143.0 / 143 $\frac{143.1}{(143.1 + 111.1 + 2 \times 18.0)} \times 100 = 49.311(\%)$ Allow use of 143 for M_r of $Ca(ClO)_2$ and 111 for M_r of $CaCl_2$ giving 49.310(%) OR $\frac{143.1}{(2 \times 74.1 + 2 \times 71.0)} \times 100 = 49.311(\%)$ Allow use 143 for M_r of $Ca(ClO)_2$ and 74 for M_r of $Ca(OH)_2$ giving 49.310(%) TE on M_r of $Ca(ClO)_2$ Ignore SF except 1SF Correct answer with some working scores (2)	**(2)**

Question Number	Answer		Additional Guidance	Mark
18(c)(i)			Example of calculation: **In M1 and M2, Allow expression and/or evaluation**	**(3)**
	• volume of swimming pool water	**(1)**	volume = 50 × 25 × 2.0 = 2500 (m^3) Ignore units, even if incorrect	
	• mass of $Ca(ClO)_2$ = concentration × volume	**(1)**	mass = 2500 (× 10^3) × 4.2 (× 10^{-3}) = 10500 (g) Ignore units, even if incorrect Do not award multiplication by 143.1 / 143 / molar mass	
	• mass of $Ca(ClO)_2$ in kg	**(1)**	10.5 (kg) TE only if 10500 × 143.1 (or 143) in M2, giving 1502.55 (or 1501.5) (kg) Ignore SF except 1 SF Correct answer with some working scores (3)	

Question Number	Answer	Additional Guidance	Mark
18(c)(ii)	• moles $Ca(ClO)_2$ **(1)** • moles Cl_2 **(1)** • volume Cl_2 in dm^3 OR volume Cl_2 in cm^3 OR volume Cl_2 in m^3 **(1)**	Example of calculation: moles = 10500 ÷ 143.1 = 73.375 TE on mass $Ca(ClO)_2$ from (c)(i) TE on $M(Ca(ClO)_2)$ from (b) Allow 73.427 from $M(Ca(ClO)_2)$ = 143 moles = 73.375 × 2 = 146.75 TE on moles $Ca(ClO)_2$ Allow 146.85 from $M(Ca(ClO)_2)$ = 143 volume = 146.75 × 24 = 3522.0/3522/3520/3500 (dm^3) volume = 146.75 × 24000 = 3.5220/3.522/3.52/3.5 × 10^6 (cm^3) volume = 146.75 × 0.024 = 3.5220/3.522/3.52/3.5 (m^3) TE on moles Cl_2 Allow omission of units Do not award incorrect units Ignore SF except 1 SF Correct answer with some working scores (3)	**(3)**

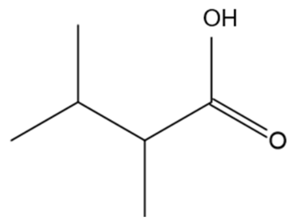
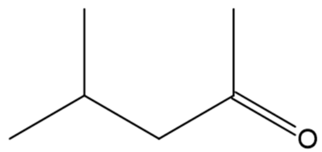
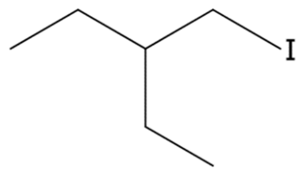
(Total for Question 18 = 11 marks)

Question Number	Answer	Additional Guidance	Mark
19(a)	An answer that makes reference to the following points: • skeletal formula of 2-methylpentan-2-ol **(1)** • skeletal formula of 3-methylpentan-3-ol **(1)** • skeletal formula of 2,3-dimethylbutan-2-ol **(1)**	Example of correct skeletal formulae in any order: **Penalise non-skeletal formulae once only** Ignore bond lengths and bond angles Ignore names, even if incorrect Ignore connectivity   	**(3)**

Question Number	Answer	Additional Guidance	Mark
19(b)(i)	An answer that makes reference to the following points: • 3,3-dimethylbutan-1-ol	Accept 3,3-dimethyl-1-butanol Do not award 3,3-dimethylbutanol Do not award 3-dimethylbutan-1-ol	**(1)**

Question Number	Answer	Additional Guidance	Mark
19(b)(ii)	An explanation that makes reference to the following points: • (alcohol B has) stronger London forces **(1)** • (as) greater (contact) surface area (between molecules) **(1)**	**M1 and M2 independent marks** Accept reverse argument Ignore any reference to hydrogen bonding / permanent dipole-permanent dipole forces Accept stronger dispersion / instantaneous-induced dipole / temporary-induced dipole forces Allow stronger van der Waals' forces Allow "more" / "greater" for "stronger" Ignore just stronger intermolecular forces Allow more points of contact Allow less branched / fewer side chains / fewer methyl groups Allow longer carbon chain Ignore straight-chained Ignore pack more closely Do not award more electrons Do not award more/stronger covalent bonds	**(2)**

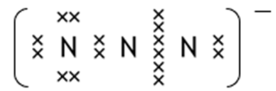
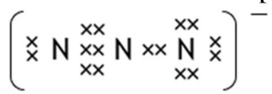
Question Number	Answer	Additional Guidance	Mark
19(b)(iii)	An explanation that makes reference to the following points: **M1 – London forces** • London forces between B and ethanol (aiding complete solubility) **(1)** **M2 – hydrogen bonds** • hydrogen bonds between B and water (aiding slight solubility) **(1)** **M3 – comparison of intermolecular forces formed and broken** • intermolecular forces (formed) between B and ethanol are stronger than / similar in strength to those in B and/or in ethanol OR intermolecular forces (formed) between B and water are weaker than those in B and/or in water **(1)**	Accept dispersion / instantaneous-induced dipole / temporary-induced dipole for London Allow just London forces in B (limit solubility in water) Ignore just London forces in ethanol Accept H-bond for hydrogen bond Ignore just B, ethanol and water all have hydrogen bonding Ignore any reference to strength / number of hydrogen bonds **Accept reverse arguments in M3** London forces between B and ethanol are stronger than / similar to those in B scores (2) for M1 and M3 Hydrogen bonds between B and water are weaker than hydrogen bonds in water scores (2) for M2 and M3 Hydrogen bonds between B and water are weaker than London forces in B scores (3)	**(3)**

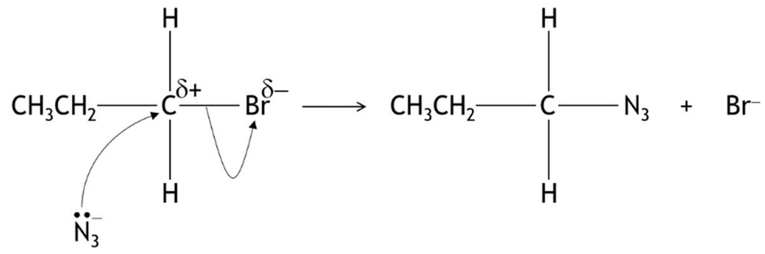
Question Number	Answer	Additional Guidance	Mark
19(c)	An answer that makes reference to the following points:	**Mark independently** Example of correct structures: Accept any type of structure Ignore connectivity Ignore bond lengths and bond angles Ignore names, even if incorrect Ignore inorganic products even if incorrect Do not award additional incorrect organic products in each reaction (but ignore aldehyde in M1) Penalise incorrect carbon chains once only	**(3)**
	• structure of product from Reaction 1 **(1)**		
	• structure of product from Reaction 2 **(1)**		
	• structure of product from Reaction 3 **(1)**		

(Total for Question 19 = 12 marks)

Question Number	Answer	Additional Guidance	Mark
20(a)	An answer that makes reference to the following points: • hydrogen chloride / $HCl((g))$	Allow hydrochloric acid / $HCl(aq)$ Ignore any reference to conditions Do not award any additional reagents	**(1)**

Question Number	Answer	Additional Guidance	Mark
20(b)	An answer that makes reference to the following points: • CH_3CH_2CN / C_2H_5CN	Accept displayed or skeletal formula Ignore any inorganic products, even if incorrect Ignore any reagents / conditions Do not award any additional organic products Do not award C_3H_5N	**(1)**

Question Number	Answer	Additional Guidance	Mark
20(c)(i)	An answer that makes reference to the following points: • 8 electrons surrounding central N atom **or** 8 electrons surrounding **both** terminal N atoms **(1)** • 8 electrons surrounding **all** N atoms **and** a total of 16 outer shell electrons **(1)**	**Mark independently** Examples of correct diagram:    Do not award incorrect charge Allow any symbols to represent outer shell electrons and allow any combination, eg  Allow bonded electrons to be shown as pairs, eg  Allow circles to indicate outer shells Ignore inner shell electrons Ignore lines representing bonds Ignore displayed diagrams	**(2)**

Question Number	Answer		Additional Guidance	Mark
20(c)(ii)	An answer that makes reference to the following points:		Example of correct mechanism:  Penalise half-headed arrows once in M1 and M2	**(3)**
	• lone pair on N of N_3^- **and** curly arrow from lone pair to C of C–Br	**(1)**	Do not award curly arrow from negative charge on N_3^-	
	• dipole shown on C–Br **and** curly arrow from C–Br bond to (δ–)Br	**(1)**		
	• organic product **and** bromide ion	**(1)**	Allow $CH_3CH_2CH_2N_3$ for organic product Allow $C_3H_7N_3$ for organic product Ignore structure of N_3 group if displayed Do not award charged organic product Allow $K^{(+)}Br^{(-)}$ Ignore K^+ spectator ion Do not award K–Br Do not award Br atom Do not award any additional inorganic product	

Question Number	Answer		Additional Guidance	Mark
20(d)(i)	An answer that makes reference to the following points: • alcohol (solvent)	**(1)**	Accept ethanol Allow aqueous ethanol Ignore concentrated/excess NH_3 Do not award KOH/NaOH/alkaline	**(2)**
	• under (high) pressure	**(1)**	Allow any stated pressure above 100 kPa / 1 atm Ignore any reference to heat	

Question Number	Answer	Additional Guidance	Mark
20(d)(ii)	An answer that makes reference to one of the following points: • secondary amine / tertiary amine / quarternary (ammonium) salt may form	Allow further **substitution** may occur Allow product may react with 1-bromopropane Allow 1-bromopropane/haloalkane in excess Allow NH_3/ammonia not in excess Ignore just amine reacts further Ignore just side products / side reactions Do not award any reference to atom economy	**(1)**

(Total for Question 20 = 10 marks)

<table>
<tr><th>Question Number</th><th>Answer</th><th>Additional Guidance</th><th>Mark</th></tr>
<tr><td>21</td><td>This question assesses a student’s ability to show a coherent and logically structured answer with linkages and fully-sustained reasoning.

Marks are awarded for indicative content and for how the answer is structured and shows lines of reasoning.

The following table shows how the marks should be awarded for indicative content.
<table>
<tr><th>Number of indicative marking points seen in answer</th><th>Number of marks awarded for indicative marking points</th></tr>
<tr><td>6</td><td>4</td></tr>
<tr><td>5-4</td><td>3</td></tr>
<tr><td>3-2</td><td>2</td></tr>
<tr><td>1</td><td>1</td></tr>
<tr><td>0</td><td>0</td></tr>
</table>

The following table shows how the marks should be awarded for structure and lines of reasoning.
<table>
<tr><th></th><th>Number of marks awarded for structure and sustained lines of reasoning</th></tr>
<tr><td>Answer shows a coherent and 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>
</td><td>The mark for indicative content should be added to the mark for lines of reasoning. For example, an answer with five indicative marking points that is partially structured with some linkages and lines of reasoning scores 4 marks (3 marks for indicative content and 1 mark for partial structure and some linkages and lines of reasoning).

If there are no linkages between points, the same five indicative marking points would yield an overall score of 3 marks (3 marks for indicative content and no marks for linkages).

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.</td><td>(6)</td></tr>
</table>

	Indicative points: • **IP1:** thermal stability increases down Group (2) • **IP2:** ionic radius / size of ions increases (down groups) **and** polarising power (of cations) decreases / charge remains the same/2+ • **IP3:** N–O breaks less easily / requires more energy to break (down groups) • **IP4:** $LiNO_3$ decomposes like Group 2 nitrates OR Group 1 nitrates other than lithium form (metal) nitrite/ nitrate(III)/MNO_2 • **IP5:** equation for thermal decomposition of $NaNO_3$ • **IP6:** equation for thermal decomposition of $Mg(NO_3)_2$	**Accept reverse arguments** Allow decompose less easily Ignore any stated trend for Group 1 Accept charge density of (cat)ions decreases (down groups) Ignore atomic radius Allow anion/nitrate (ion) for N–O Allow less polarised / less distorted for breaks less easily Do not award nitrate molecule Do not award ionic bonds break less easily Allow $LiNO_3$ decomposes to form lithium oxide and/or nitrogen dioxide Allow partial/unbalanced equation, eg $LiNO_3 \rightarrow Li_2O + NO_2$ Ignore just brown fumes $2NaNO_3 \rightarrow 2NaNO_2 + O_2$ Allow mulitples Allow equation for any Group 1 nitrate except $LiNO_3$ $2Mg(NO_3)_2 \rightarrow 2MgO + 4NO_2 + O_2$ Allow mulitples Allow equation for any Group 2 nitrate Ignore state symbols	

(Total for Question 21 = 6 marks)
(Total for Section B = 39 marks)

Section C

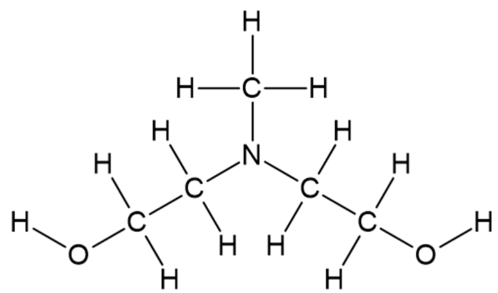
Question Number	Answer	Additional Guidance	Mark
22(a)(i)	An answer that makes reference to one of the following points: • shifts position of equilibrium to the right OR increases the (equilibrium) yield (of H_2)	Ignore to increase rate (of forward reaction) Ignore cheaper to have steam in excess Ignore 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)**

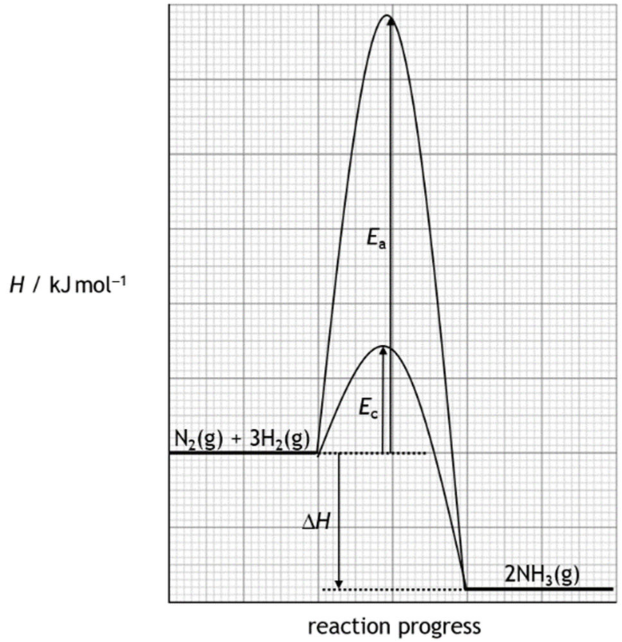
Question Number	Answer	Additional Guidance	Mark
22(a)(iii)	An answer that makes reference to the following point: • overall equation for Stage 1	Example of correct equation: $CH_4 + 2H_2O \rightarrow 4H_2 + CO_2$ Allow $\rightleftharpoons$ for $\rightarrow$ Allow multiples Ignore state symbols even if 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)**

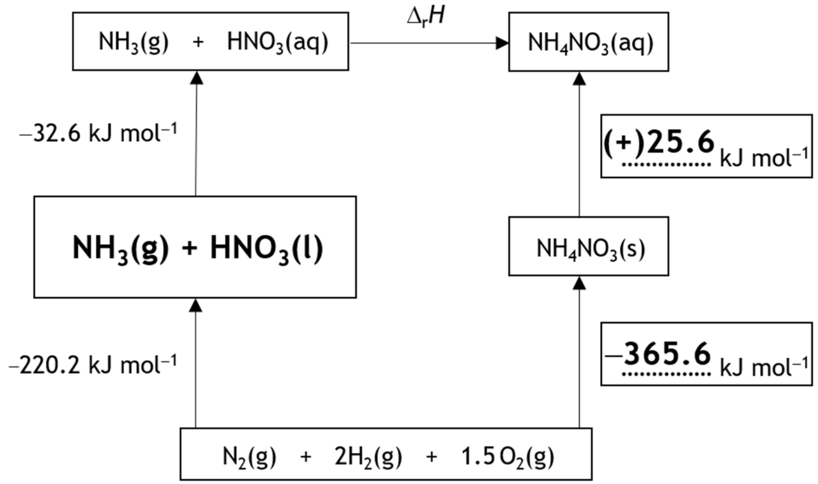
Question Number	Answer	Additional Guidance	Mark
22(d)(i)	An answer that makes reference to the following points:	Example of labelled reaction profile:  Allow arrows to start/end within one small square of correct placement and penalise incorrect placement once only	**(3)**
	• ΔH labelled **and** arrow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

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 NH_3 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) **(1)** • shifting position of equilibrium (in first reaction) to right **and** increasing the yield (of NO_2) **(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: $\Delta_r H = -(-32.6) - (-220.2) + (-365.6) + 25.6$ $= -87.2 / -87$ (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)

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