1)

(u)(ii)	CH_3OH + **1½**O_2 ⟶ CO_2 + **2**H_2O	1	Ignore state symbols Accept multiples
(u)(iii)	**3**H_2 + **1½**O_2 ⟶ **3**H_2O ***OR*** **2**H_2 + O_2 ⟶ **2**H_2O	1	Ignore state symbols Accept multiples Extra species must be crossed through
(b)	**M1** q = m c ΔT ***OR*** q =140 x 4.18 x 7.5 **M2** = 4389 (J) OR 4.389 (kJ) OR 4.39 (kJ) OR 4.4 (kJ) (also scores M1) **M3** Using 0.0110 mol therefore ΔH = **– 399** ($kJmol^{-1}$) OR **– 400** **+399 or +400 gains 2 marks**	3	Award full marks for correct answer Ignore the case for each letter Penalise **M3** ONLY if correct numerical answer but sign is incorrect; **+399 gains 2 marks** Penalise **M2** for arithmetic error and mark on In **M1**, do not penalise incorrect cases in the formula If ΔT = 280.5; score q = m c ΔT only If c = 4.81 (leads to 5050.5) penalise **M2** ONLY and mark on for **M3** = – 459 Ignore incorrect units

2)

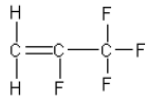
(a)	**2**$Ca_5F(PO_4)_3$ + 9SiO_2 + **15**C ⟶ 9$CaSiO_3$ + CaF_2 +**15**CO + **6**P	1	
(b)	**M1** (P_4 =) **0** **M2** (H_3PO_4 =) **(+) 5**	2	Accept Roman numeral V for **M2**
(c)	H_2SO_4 M_r = 2(1.00794) + 32.06550 + 4(15.99491) = **98.06102 or 98.0610 or 98.061 or 98.06 or 98.1** **and** H_3PO_4 M_r = 3(1.00794) + 30.97376 + 4(15.99491) = **97.97722 or 97.9772 or 97.977 or 97.98 or 98.0**	1	**Both numbers** required Calculations not required
d)(i)	A substance that speeds up a reaction OR alters / increases the rate of a reaction **AND** is chemically unchanged at the end / not used up.	1	**Both ideas** needed Ignore reference to activation energy or alternative route.
d)(ii)	The addition of water (**QoL**) to a molecule / compound	1	**QoL- for the underlined words**
(d)(iii)	**M1** $CH_3CH=CH_2$ + H_2O ⟶ $CH_3CH(OH)CH_3$ (C_3H_6) **M2** propan-2-ol	2	For **M1** insist on correct structure for the alcohol but credit correct equations using either C_3H_6 or double bond not given.

3)

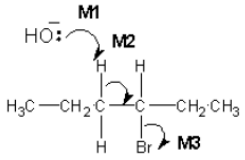
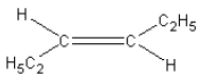
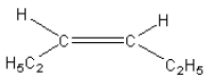
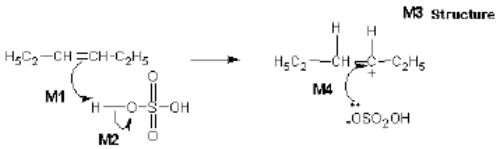
(a)(i)	Ba + **2**H_2O ⟶ $Ba(OH)_2$ + H_2	1	Ignore state symbols Credit multiples and correct ionic equations
(a)(ii)	(Reactivity with water) increase(s) / increasing / increased (down the Group / from Mg to Ba)	1	Accept "greater" or "gets more" or similar words to that effect. Ignore reference to "increase in solubility / gets more soluble"
(b)	$Mg(OH)_2$	1	Accept $Mg^{2+}(OH^-)_2$ / $Mg(HO)_2$ Insist on brackets and correct case
(c)	**M1** Barium meal / barium swallow / barium enema or (internal) X-ray or to block X-rays **M2** $BaSO_4$ / barium sulfate is insoluble (and therefore not toxic)	2	Accept a correct reference to **M1** written in the explanation in **M2**, unless contradictory For **M2** NOT barium ions NOT barium NOT barium meal and NOT "It" Ignore radio-tracing

4)

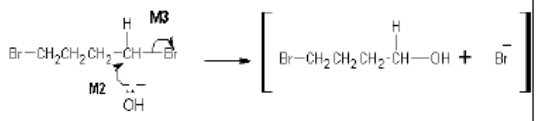
(a)(i)	**M1** **Initiation** $Cl_2 \longrightarrow 2Cl\bullet$ **M2** **First propagation** $Cl\bullet + CH_2Cl_2 \longrightarrow \bullet CHCl_2 + HCl$ **M3** **Second propagation** $Cl_2 + \bullet CHCl_2 \longrightarrow CHCl_3 + Cl\bullet$	3	Penalise absence of dot once only. Penalise + or – charges every time Accept dot anywhere on $CHCl_2$ radical but if the structure is drawn out, the dot must be on the carbon atom. Penalise this error once only Penalise once only for a line and two dots to show a bond. Penalise once only for double headed curly arrows Mark independently
(a)(ii)	**M1 Condition** ultra-violet / uv / sun light ***OR*** high temperature ***OR*** 400°C ≤ T ≤ 900 °C **M2 Type of mechanism** (free-) radical substitution (mechanism)	2	
(b)(i)	$CHCl_3 + Cl_2 \longrightarrow CCl_4 + HCl$	1	Allow X as alternative to CCl_4 only if X is clearly identified as CCl_4
(b)(ii)	**M1** Trichloromethane / $CHCl_3$ has a C–H bond ***OR*** X / CCl_4 / it has no C-H bond **M2** The infrared spectrum shows (absorption / peak for C–H in range) **2850 to 3300** (cm^{-1}) is missing	2	**M1** must refer to presence or absence of the C–H bond in a compound **M2** answer must refer to / imply the spectrum Allow the words "dip" OR "spike" OR "low transmittance" as alternatives for absorption. Ignore references to other absorptions.
(c)	**M1 a statement about bond breakage / formation of Cl•** C-Cl / carbon-chlorine bond breakage occurs ***OR*** Cl• / chlorine (free) radical forms ***OR*** correct equation $CHClF_2 \longrightarrow Cl\bullet + \bullet CHF_2$ **M2** $Cl\bullet + O_3 \longrightarrow ClO\bullet + O_2$ **M3** $ClO\bullet + O_3 \longrightarrow Cl\bullet + 2O_2$ **M4** $CHClF_2$ / chlorine-containing compounds/ CFCs damage / react with / decrease the ozone layer ***OR*** this overall decomposition occurs; $2O_3 \longrightarrow 3O_2$ ***OR*** without an ozone layer or with a decreased ozone layer, uv radiation is not being "filtered" / prevented from passing through the atmosphere or there is a concern about an increase in skin cancer etc. ***OR*** Cl• catalyses the decomposition of ozone / a single Cl• causes (chain) reaction / decomposition of many ozone molecules / ozone layer	4	Penalise **M1**, if Cl• is formed from Cl_2 as the only reaction or an additional reaction Do not penalise an incorrect equation using $CHClF_2$ if correct reference is made to Cl• formation or C-Cl / carbon-chlorine bond breakage **M2** and **M3** either order Penalise absence of dot once only. Accept dot anywhere on ClO radical Award **M4** for the general idea behind the EU justification for banning the use of CFCs as refrigerants Penalise **M4** if overall ozone decomposition equation is incorrect Ignore "greenhouse effect", "global warming" etc.

(d)(i)		1	All bonds must be drawn out
(d)(ii)	2,3,3,3-tetrafluoropropene / it does not contain chlorine (atoms) / C-Cl (bonds) ***OR*** It does not produce Cl• / does not produce chlorine (free) radical(s) ***OR*** chlorodifluoromethane does contain chlorine / does produce Cl• / does produce chlorine (free) radical(s) ***OR*** C–F is too strong and does not break / create radicals ***OR*** C–F is stronger than C–Cl	1	Ignore "chlorine molecules"

5)

(a)(i)	 **M1** must show an arrow from the lone pair on oxygen of a negatively charged hydroxide ion to the correct H atom **M2** must show an arrow from the correct C-H bond to the correct C-C bond. Only award if an arrow is shown attacking the H atom of the correct C-H bond in **M1** **M3** is independent but **CE=0 if nucleophilic substitution** **N.B these are double- headed arrows**	3	Penalise one mark from their total if half-headed arrows are used Penalise **M3** for formal charge on C of the C-Br or incorrect partial charges on C-Br Ignore other partial charges Penalise once only in any part of the mechanism for a line and two dots to show a bond.
(a)(ii)	**M1** E isomer  **M2** Z isomer 	2	Award 1 mark if both correct stereoisomers but in the wrong places Accept no other alkenes. Be reasonably lenient on the bonds to ethyl (or to CH_2CH_3) since the question is about E and Z positions but penalise once only if connection is clearly to the CH_3 of CH_2CH_3 Accept linear structures
'(a)(iii)	**M1** (Compounds / molecules with) the same structural formula **M2** with atoms/bonds/groups arranged differently in space *OR* atoms/bonds/groups that have different spatial arrangements / different orientation.	2	Penalise **M1** if "same structure" Ignore references to " same molecular formula" or "same empirical formula" or any reference to "displayed formula" Mark independently
(b)	 **M1**must show an arrow from the double bond towards the H atom of the H – O bond OR HO on a compound with molecular formula for H_2SO_4 M1 could be to an H+ ion and M2 an independent O – H bond break on a compound with molecular formula for H_2SO_4 **M2** must show the breaking of the O – H bond. **M3** is for the structure of the carbocation. **M4** must show an arrow from the lone pair of electrons on the correct oxygen of the negatively charged ion towards a correct (positively charged) carbon atom. **NB The arrows here are double-headed**	4	**M1** Ignore partial negative charge on the double bond. **M2** Penalise partial charges on O – H bond if wrong way and penalise formal charges In M2 do not penalise incorrect structures for H_2SO_4 **M4** NOT HSO_4^- For **M4**, credit as shown or $^-OSO_3H$ ONLY with the negative charge anywhere on this ion OR correctly drawn out with the negative charge placed correctly on oxygen Penalise once only in any part of the mechanism for a line and two dots to show a bond Max 3 of any 4 marks for wrong organic reactant or wrong organic product (if shown) Accept the correct use of "sticks"

6)

)(a)	**M1 Safety (in Process 1)** Sodium hydroxide / alkali is corrosive / harmful / caustic or sodium hydroxide is alkali(ne) *OR* Bromine compounds are toxic / poisonous **M2 Environmental** Process 2 could be used as a carbon sink / for carbon capture *OR* uses waste / recycled CO_2 / CO_2 from the factory / CO_2 from the bioethanol (or biofuel) production *OR* reduces or limits the amount of CO_2 released / given out (into the atmosphere) *OR* Process 2 uses renewable glucose / renewable resource(s)	2	Ignore references to chromium compounds "Carbon-neutral" alone is insufficient for **M2** Ignore references to greenhouse gases
3(b)(i)	**M1** nucleophilic substitution  **M2** must show an arrow from the lone pair of electrons on the oxygen atom of the negatively charged hydroxide ion to the C atom. **M3** must show the movement of a pair of electrons from the C– Br bond to the Br atom. Mark **M3** independently provided it is from the original molecule For **M2** and **M3** award full marks for an S_N1 mechanism **NB The arrows here are double-headed**	3	For **M1, both words** required Penalise **M2** if covalent NaOH / KOH is used Penalise one mark from **M2** or **M3** if half-headed arrows are used Penalise **M3** for formal charge on C of the C-Br or incorrect partial charges on C-Br Penalise once only for a line and two dots to show a bond. For **M2** and **M3**, maximum 1 of 2 marks for the mechanism if wrong reactant is used. Penalise **M3** if an extra arrow is drawn from the Br of the C-Br bond to, for example, K^+ Accept the correct use of "sticks
3(b)(ii)	**M1** B **M2** C **M3** A	3	
(c)	**M1** fermentation **Three conditions in any order for M2 to M4** **M2** (enzymes from) yeast or zymase **M3** 25°C ≤ T ≤ 42°C OR 298 K ≤ T ≤ 315 K **M4** anaerobic / no oxygen / no air OR neutral pH	4	Mark **M2** to **M4** independently Penalise "bacteria" and "phosphoric acid" using the list principle Ignore reference to "aqueous" or "water", "closed container", "pressure, "lack of oxygen", "concentration of ethanol" and "batch process" (i.e. not part of the list principle)
(d)	**M1** primary OR 1° (alcohol) **M2** acidified potassium or sodium dichromate *OR* H_2SO_4 / $K_2Cr_2O_7$ OR H^+ / $K_2Cr_2O_7$ *OR* correct combination of formula and name **M3** $HOCH_2CH_2CH_2CH_2OH + 4[O] \longrightarrow HOOCCH_2CH_2COOH + 2H_2O$	3	Mark independently For **M2,** it must be a whole reagent and/or correct formulae Do not penalise incorrect attempt at formula if name is correct or *vice versa* Accept phonetic spelling If oxidation state given in name, it must be correct. For **M2** accept acidified potassium manganate(VII) For **M3** structures must be correct and not molecular formula

7)

(a)(i)	**M1** iodine *OR* I_2 *OR* I_3^- **M2** $Cl_2 + 2I^- \longrightarrow 2Cl^- + I_2$ *OR* $\frac{1}{2}Cl_2 + I^- \longrightarrow Cl^- + \frac{1}{2}I_2$ **M3** redox or reduction-oxidation or displacement	3	Ignore state symbols Credit **M1** for "iodine solution" Penalise multiples in M2 except those shown **M2** accept correct use of I_3^-
(a)(ii)	**M1** (the white precipitate is) <u>silver chloride</u> **M2** $Ag^+ + Cl^- \longrightarrow AgCl$ **M3** (white) precipitate / it <u>dissolves</u> *OR* <u>colourless solution</u>	3	**M1** <u>must be named</u> and for <u>this mark</u> ignore incorrect formula For **M2** ignore state symbols Penalise multiples Ignore references to "clear" alone
(b)(i)	**M1** $H_2SO_4 + 2Cl^- \longrightarrow 2HCl + SO_4^{2-}$ *OR* $H_2SO_4 + Cl^- \longrightarrow HCl + HSO_4^-$ *OR* $H^+ + Cl^- \longrightarrow HCl$ **M2** hydrogen chloride *OR* HCl *OR* hydrochloric acid	2	For **M1** ignore state symbols Penalise multiples for equations and apply the list principle
(b)(ii)	**M1 and M2 in either order** **M1** $2I^- \longrightarrow I_2 + 2e^-$ *OR* $8I^- \longrightarrow 4I_2 + 8e^-$ **M2** $H_2SO_4 + 8H^+ + 8e^- \longrightarrow H_2S + 4H_2O$ OR $SO_4^{2-} + 10H^+ + 8e^- \longrightarrow H_2S + 4H_2O$ **M3** <u>oxidising agent</u> / <u>oxidises the iodide</u> (ions) *OR* <u>electron acceptor</u> **M4** sulfur *OR* S *OR* S_2 *OR* S_8 *OR* sulphur	4	For **M1** and **M2**, ignore state symbols and credit multiples Do not penalise absence of charge on the electron Credit electrons shown correctly on the other side of each equation Additional equations should not contradict
(b)(iii)	**M1** The <u>NaOH / OH^- / (sodium) hydroxide reacts with / neutralises the H^+ / acid / HBr</u> (lowering its concentration) *OR* a correct neutralisation equation for H^+ or HBr with NaOH or with hydroxide ion **M2** **Requires a correct statement for M1** The (position of) <u>equilibrium moves / shifts</u> (from L to R) • <u>to replace the H^+ / acid / HBr that has been removed / lost</u> • *OR* <u>to increase the H^+ / acid / HBr concentration</u> • *OR* <u>to make more H^+ / acid / HBr / product(s)</u> • *OR* <u>to oppose the loss of H^+ / loss of product(s)</u> • *OR* <u>to oppose the decrease in concentration</u> of product(s) **M3** The (health) benefit outweighs the risk or wtte *OR* a clear statement that once it has done its job, little of it remains *OR* used in (very) dilute concentrations / small amounts / low doses	3	Ignore reference to NaOH reacting with bromide ions Ignore reference to NaOH reacting with HBrO alone In **M2**, answers must refer to the (position of) <u>equilibrium shifts / moves</u> and is not enough to state simply that it / the system / the reaction shifts to oppose the change.