1 (a) (i) **M1 Initiation**

$Cl_2 \longrightarrow 2Cl\bullet$

Penalise absence of dot once only.

M2 First propagation

$Cl\bullet + CHF_3 \longrightarrow CF_3\bullet + HCl$

Penalise + or − charges <u>every time</u>.

M3 Second propagation

$Cl_2 + CF_3\bullet \longrightarrow CClF_3 + Cl\bullet$

Credit $CF_3\bullet$ with the radical dot above / below / to either side.

M4 Termination (must make C_2F_6)

$2\ CF_3\bullet \longrightarrow C_2F_6$ or CF_3CF_3

Mark independently.

4

(ii) ultra-violet / uv / sun light

OR (very) high temperature

OR 500 °C ≤ T ≤ 1000 °C

OR 773 K ≤ T ≤ 1273 K

1

(b) (i) $Cl\bullet$ **OR** chlorine atom / chlorine (free−) radical / Cl (atom)

Not 'chlorine' alone.

Credit 'Cl' alone on this occasion.

1

(ii) $\mathbf{2}O_3 \longrightarrow \mathbf{3}O_2$

Or multiples.

Ignore state symbols.

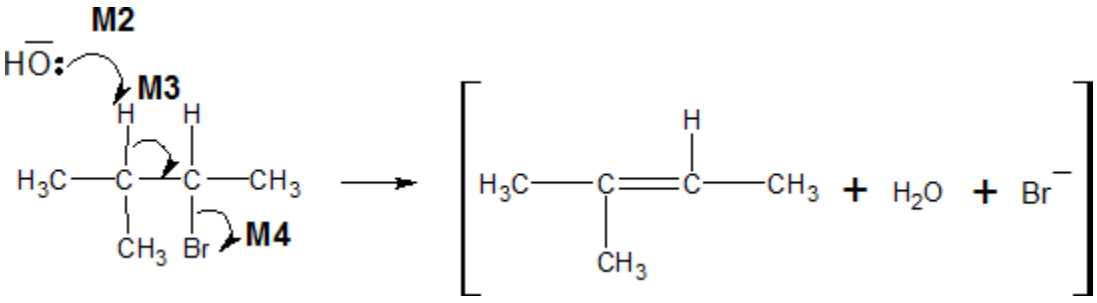
If the correct answer is on the line OR clearly identified below some working, then ignore any working.

1

[7]

2 (a) (i) M1 **Elimination**

M1 *Credit "base elimination" but no other prefix.*



*Penalise **M2** if covalent KOH*

*Penalise **M4** for formal charge on C or Br of C−Br or incorrect partial charges on C−Br*

M2 must show an arrow from the lone pair on the oxygen of a negatively charged hydroxide ion to a correct H atom

Ignore other partial charges

M3 must show an arrow from a correct C−H bond adjacent to the C−Br bond to a correct C-C bond. Only award if an arrow is shown attacking the H atom of a correct adjacent C−H bond in **M2**

*Penalise **once only** in any part of the mechanism for a line and two dots to show a bond*

M4 is independent provided it is from their original molecule, **BUT CE=0 for the mechanism (penalise M2, M3 and M4 only) if nucleophilic substitution mechanism is shown**

Maximum any 2 of 3 marks for the mechanism *for wrong organic reactant or wrong organic product (if shown).*

Credit the correct use of "sticks" for the molecule except for the C−H being attacked

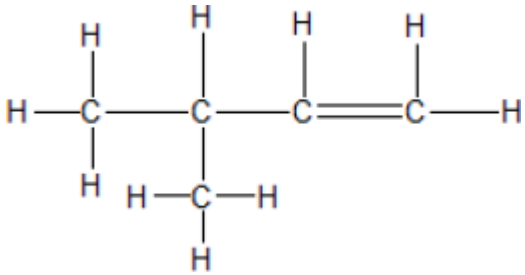
Award full marks for an E1 mechanism in which **M4** is on the correct carbocation

*Penalise **M4**, if an additional arrow is drawn from Br eg to K^+*

NB These are double-headed arrows

4

(ii) Displayed formula for 3-methylbut-1-ene



All bonds and atoms must be drawn out, but ignore bond angles

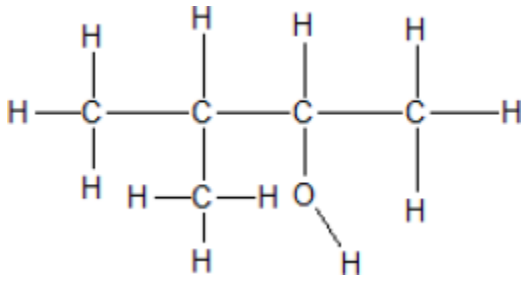
1

(iii) Position(al) (isomerism or isomer)

Penalise any other words that are written in addition to these.

1

(b) (i) Displayed formula for 3-methylbutan-2-ol



All bonds and atoms must be drawn out, but ignore bond angles.

1

(ii) Any **one** from

- Lower / decreased temperature **OR** cold
- Less concentrated (comparative) ***OR*** dilute KOH
- Water (as a solvent) / (aqueous conditions)

Ignore "pressure".

1

(iii) Nucleophilic substitution

Both words needed - credit phonetic spelling.

1

(iv) (Strong / broad) absorption / peak in the range **3230 to 3550** cm^{-1} or specified value in this range or marked correctly on spectrum

*Allow the words "dip" **OR** "spike" **OR** "trough" **OR** "low transmittance" as alternatives for absorption.*

1

[10]

3

(a) **Initiation**

$Cl_2 \longrightarrow 2Cl\bullet$

Penalise absence of dot once only.

First propagation

$Cl\bullet + CH_3Cl \longrightarrow \bullet CH_2Cl + HCl$

Credit the dot anywhere on the radical.

Second propagation

$Cl_2 + \bullet CH_2Cl \longrightarrow CH_2Cl_2 + Cl\bullet$

Termination (must make 1,2-dichloroethane)

$2 \bullet CH_2Cl \longrightarrow CH_2ClCH_2Cl$

Penalise $C_2H_4Cl_2$

4

(b) (i) (chlorine free) radical

Ignore formula.

1

(ii) M1 $Cl\bullet + O_3 \longrightarrow ClO\bullet + O_2$

M2 $ClO\bullet + O_3 \longrightarrow Cl\bullet + 2O_2$

***M1** and **M2** could be in either order.*

Credit the dot anywhere on the radical.

Penalise absence of dot once only.

Individual multiples acceptable but both need to be doubled if two marks are to be awarded.

2

[7]

4

(a) Structure for 3-methylbut-1-ene

$H_2C{=}CHCH(CH_3)_2$

Any correct structural representation.

Credit "sticks" and require the double bond.

1

(b) Structure for 2-methylpropan-2-ol

$(CH_3)_3COH$

Any correct structural representation.

Credit "sticks".

1

(c) Structure for propene

$H_2C{=}CHCH_3$

Any correct structural representation.

Credit "sticks" and require the double bond.

1

(d) Structure for 2-aminobutane

$CH_3CH_2CH(NH_2)CH_3$

Any correct structural representation.

Credit "sticks".

1

[4]

5

(a) (i) (Free-) radical substitution

Both underlined words are required

Penalise a correct answer if contradicted by an additional answer

1

(ii) **Initiation**

$F_2 \longrightarrow 2F\bullet$

Penalise absence of dot once only

First propagation

$F\bullet + CH_3F \longrightarrow \bullet CH_2F + HF$

Penalise + or − charges every time

Second propagation

$F_2 + \bullet CH_2F \longrightarrow CH_2F_2 + F\bullet$

Accept dot anywhere on CH_2F radical
Mark independently

Termination (must make 1,2-difluoroethane)

$2 \bullet CH_2F \longrightarrow \underline{CH_2FCH_2F}$

Use of half-headed arrows must be correct to score, but if not correct then penalise once only in this clip

4

(iii) $CH_3CH_3 + \mathbf{5}F_2 \longrightarrow CF_3CHF_2 + \mathbf{5}HF$

(C_2H_6) (C_2HF_5)

1

(b) 1,1,1,2-tetrachloro-2,2-difluoroethane

Accept phonetic spelling eg "fluro, cloro"
Penalise "flouro" and "floro", since ***QoL***

OR

1,2,2,2-tetrachloro-1,1-difluoroethane

Ignore commas and hyphens

1

(c) (i) $\mathbf{2}O_3 \longrightarrow \mathbf{3}O_2$

ONLY this equation or a multiple
Ignore NO over the arrow
Other species must be cancelled

1

(ii) $O + NO_2 \longrightarrow NO + O_2$

ONLY this answer and NOT multiples
Ignore any radical dot on the O atom

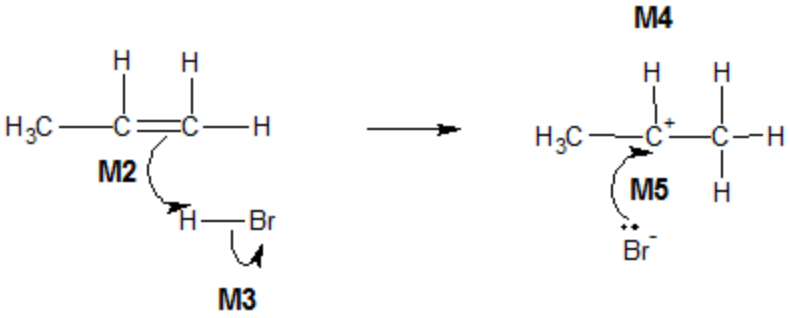
1

[9]

6 (a) **M1 <u>electrophilic addition</u>**

*For **M1**, both words required*

Accept phonetic spelling



For the mechanism

***M2** Ignore partial negative charge on the double bond*

M2 must show an arrow from the double bond towards the H atom of the H–Br molecule

***M3** Penalise partial charges on H–Br bond if wrong way and penalise formal charges*

M3 must show the breaking of the H–Br bond

Penalise once only in any part of the mechanism for a line and two dots to show a bond

M5 must show an arrow from the lone pair of electrons on the negatively charged bromide ion towards the correct (positively charged) carbon atom

***<u>Maximum any 3 of 4 marks for the mechanism</u>** for wrong (organic) reactant **OR** wrong organic product (if shown) **OR** primary carbocation*

Accept the correct use of sticks

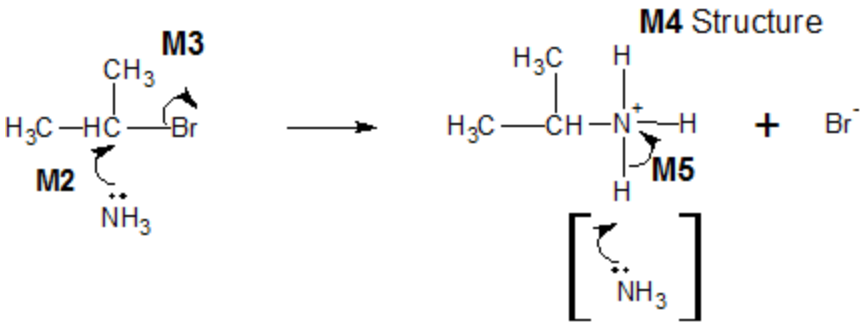
NB These are double-headed arrows

5

(b) **M1 <u>Nucleophilic substitution</u>**

*For **M1**, both words required*

Accept phonetic spelling



For the mechanism

*Penalise **M2** if NH_3 is negatively charged*

M2 must show an arrow from the lone pair of electrons **on the nitrogen atom** of an ammonia molecule to the correct C atom

*Penalise **M3** for formal charge on C of the C−Br or incorrect partial charges on C−Br*

*Penalise **M3** for an additional arrow from the Br to something else*

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 <u>their original molecule</u>

*The second mole of ammonia is not essential for **M5**; therefore ignore any species here*

M4 is for the structure of the alkylammonium ion, which could be a condensed formula. A positive charge **must** be shown on / or close to, the N atom

Penalise once only for a line and two dots to show a bond

M5 is for an arrow from the N–H bond to the N atom

***<u>Maximum any 3 of 4 marks for the mechanism</u>** for wrong organic reactant **OR** wrong organic product if shown*

Award full marks for an S_N1 mechanism in which **M2** is the attack of the ammonia on the intermediate carbocation

Accept the correct use of "sticks"

NB These are double-headed arrows

5

(c) M1 (addition) polymerisation OR poly-addition

Ignore "additional"

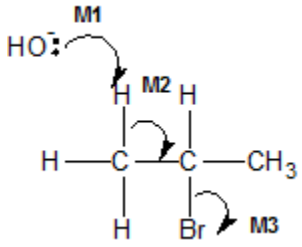
Credit polyprop-1-ene and polypropylene

M2 poly(propene) / polypropene

Penalise "condensation polymerisation"

2

(d)



*Penalise **M1** if covalent KOH*

M1 must show an arrow from the lone pair on the oxygen of a negatively charged hydroxide ion to a correct H atom

*Penalise **M3** for formal charge on C of C–Br or incorrect partial charges on C−Br.*

M2 must show an arrow from a correct C–H bond adjacent to the C–Br bond to the appropriate C–C bond. Only award if an arrow is shown attacking the H atom of a correct C−H bond in **M1**

Ignore other partial charges

Penalise once only in any part of the mechanism for a line and two dots to show a bond

M3 is independent provided it is from their original molecule, but **CE=0 if nucleophilic substitution**

***Maximum any 2 of 3 marks** for wrong organic reactant*

Award full marks for an E1 mechanism in which **M3** is on the correct carbocation.

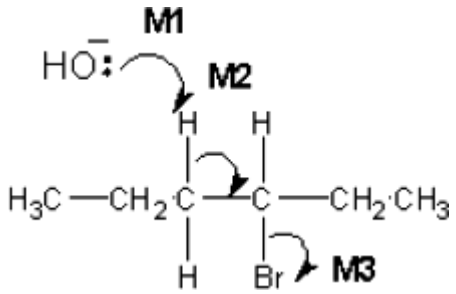
Accept the correct use of "sticks" for the molecule except for the C–H being attacked

NB These are double-headed arrows

3

[15]

7 (a) (i)



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

M1 must show an arrow from the lone pair on oxygen of a negatively charged hydroxide ion <u>to the correct</u> H atom

Penalise once only in any part of the mechanism for a line and two dots to show a bond.

M2 must show an arrow from the correct C–H bond to the correct C–C bond. Only award if an arrow is shown <u>attacking</u> the H atom of the correct C–H bond in **M1**

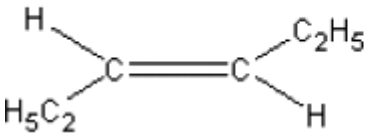
M3 is independent but **CE=0 if nucleophilic substitution**

N.B these are double-headed arrows

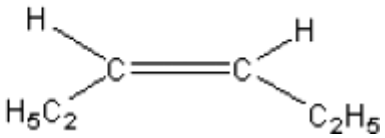
3

(ii)

M1 E isomer



M2 Z isomer



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

2

(iii) **M1** (Compounds / molecules with) the <u>same structural formula</u>

*Penalise **M1** if "same structure"*

M2 with <u>atoms/bonds/groups</u> arranged <u>differently in space</u>

Ignore references to "same molecular formula" or "same empirical formula" or any reference to "displayed formula"

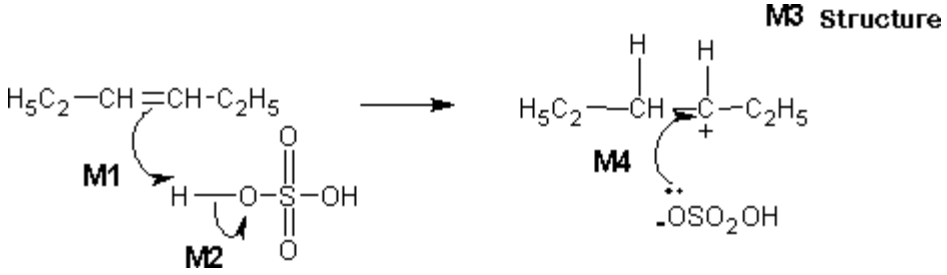
OR

<u>atoms/bonds/groups</u> that have <u>different spatial arrangements / different orientation</u>.

Mark independently

2

(b)



M1must 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

M1 *Ignore partial negative charge on the double bond.*

M2 must show the breaking of the O – H 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

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.

M4 *NOT* HSO_4^-

For ***M4****, credit <u>as shown</u> or* $^{-}\!:\!OSO_3H$ *<u>ONLY</u> with the negative charge anywhere on this ion*

OR <u>correctly</u> 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

NB The arrows here are double-headed

<u>Max 3 of any 4 marks</u> for wrong organic reactant or wrong organic product (if shown)

Accept the correct use of "sticks"

4

[11]

8 (a) **M1 Safety (in Process 1)**

Sodium hydroxide / alkali is corrosive / harmful / caustic or sodium hydroxide is alkali(ne)

Ignore references to chromium compounds

OR

Bromine compounds are toxic / poisonous

"Carbon-neutral" alone is insufficient for ***M2***

M2 Environmental

Ignore references to greenhouse gases

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)

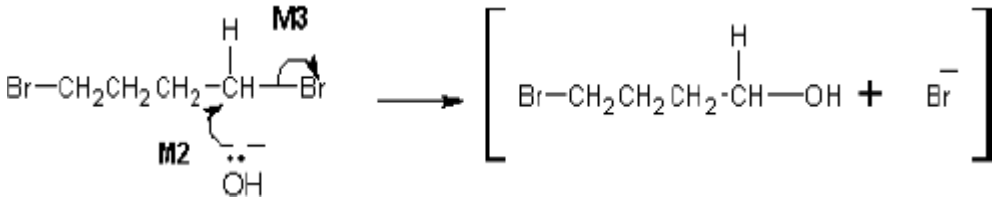
OR

Process 2 uses renewable glucose / renewable resource(s)

2

(b) (i) M1 <u>nucleophilic substitution</u>

*For **M1, both words** required*



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.

*Penalise **M2** if covalent NaOH / KOH is used*

*Penalise one mark from **M2** or **M3** if half-headed arrows are used*

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 <u>original molecule</u>

*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** award full marks for an S_N1 mechanism

*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

NB The arrows here are double-headed

3

(ii) **M1** B

M2 C

M3 A

3

(c) **M1** <u>fermentation</u>

*Mark **M2** to **M4** independently*

Three conditions <u>in any order</u> for M2 to M4

Penalise "bacteria" and "phosphoric acid" using the list principle

M2 (enzymes from) yeast or zymase

M3 25°C ≤ T ≤ 42°C OR 298 K ≤ T ≤ 315 K

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)

M4 anaerobic / no oxygen / no air OR neutral pH

4

(d) **M1** primary OR 1° (alcohol)

Mark independently

M2 <u>acidified potassium or sodium dichromate</u>

*For **M2**, it must be a whole reagent and/or correct formulae*

OR H_2SO_4 / $K_2Cr_2O_7$ OR H^+ / $K_2Cr_2O_7$

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)*

OR correct combination of formula and name

M3

$HOCH_2CH_2CH_2CH_2OH + \mathbf{4}[O] \longrightarrow HOOCCH_2CH_2COOH + \mathbf{2}H_2O$

*For **M3** structures must be correct and not molecular formula*

3

[15]

9 (a) **M1** $C_6H_{12}O_6 \longrightarrow \mathbf{2}CH_3CH_2OH + \mathbf{2}CO_2$
($2C_2H_5OH$)

Mark independently

For M1 and M3 ignore state symbols and credit multiples

For M1 and M3 penalise C_2H_6O once only

M2 fermentation

M3 $CH_3CH_2OH + \mathbf{3}O_2 \longrightarrow \mathbf{2}CO_2 + \mathbf{3}H_2O$
(C_2H_5OH)

M4 A specified process e.g. planting / harvesting / transport / extracting sugar / distilling ethanol solution / fertiliser production etc.

M5 The specified process uses / burns (fossil) fuel that releases CO_2

For M5, "releases / increases carbon emissions" is insufficient as an alternative to releases CO_2

5

(b) **M1** sodium or potassium hydroxide / NaOH / KOH

Mark on to M2 from hydroxide ion

M2 depends on correct M1

Ignore OH^- if KOH/ OH^-

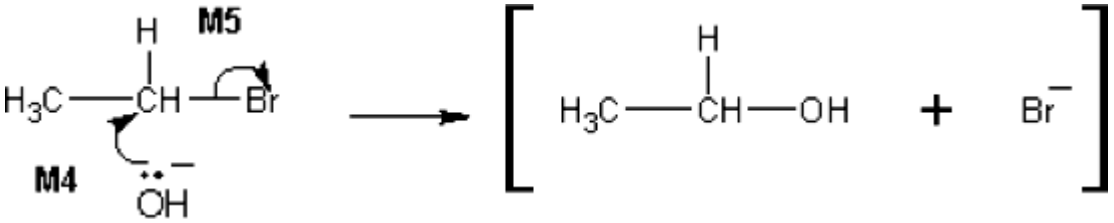
warm / heat / reflux <u>and</u> aqueous or (aq) or water

For M2 ignore "dilute"

For M2 penalise T > 100 °C

M3 <u>nucleophilic substitution</u>

Acidified KOH/NaOH or H_2SO_4 with KOH/NaOH loses M1 and M2



For M3, both words required

NB The arrows here are double-headed

M4 must show an arrow from the lone pair of electrons on the oxygen atom of the negatively charged hydroxide ion to the C atom.

Penalise M4 if covalent NaOH / KOH is used

Penalise one mark from M4 or M5 if half-headed arrows are used

M5 must show the movement of a pair of electrons from the

C— Br bond to the Br atom. Mark M5 independently provided it is from their <u>original molecule.</u>

Penalise M5 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 M4 and M5, award full marks for an S_N1 mechanism

For M4 and M5, maximum 1 of 2 marks if wrong reactant is used.

Penalise M5 if an extra arrow is drawn from the Br of the C–Br bond

to, for example, K^+span>

Do not penalise the use of "sticks"

M6 One statement from

- The yield is (very) low / not a high yield OR elimination occurs / ethene formed
- The rate of reaction slow
- <u>Bromoethane</u> has to be manufactured / made first
- <u>Bromoethane</u> is expensive

For M6 ignore references to other costs and expenses

6

(c) **M1** <u>concentrated</u> phosphoric acid / <u>conc</u>. H_3PO_4 ***OR*** <u>concentrated</u> sulfuric acid / conc. H_2SO_4

Answers in any order

Ignore reference to support medium in M1

M2 hydration or (electrophilic) addition

For M3 and M4 <u>any two</u> from

Do not apply the list principle to these three chosen criteria in M3 and M4

- <u>Excess</u> ethene

  OR <u>Excess</u> steam / water / H_2O

  OR remove the ethanol as it forms

  OR recycle the ethene

- <u>Specified</u> Pressure

  50 atm ≤ P ≤ 100 atm

  OR 5000 kPa ≤ P ≤ 10000 kPa

  OR 5 MPa ≤ P ≤ 10 MPa

- <u>High</u>Temperature unless they give a value that is not in the ranges given here;

  OR 300 °C ≤ T ≤ 600 °C

  OR 570 K ≤ T ≤ 870 K

  Accept a reference to "low temperature" if they specify a correct temperature range or a correct temperature in the range

4

[15]