A-Level Chemistry

Alcohol Production

Mark Scheme

Time available: 79 minutes
Marks available: 76 marks

Mark schemes

1. (a) Percentage of oxygen by mass = 100 – 40.9 – 4.5 = 54.6 **1**

	C	H	O
%			
Divide by A_r	$\frac{40.9}{12}$	$\frac{4.5}{1}$	$\frac{54.6}{16}$
	= 3.41	= 4.5	= 3.41

1

Divide by smallest =	$\frac{3.41}{3.41} = 1$	$\frac{4.5}{3.41} = 1.32$	$\frac{3.41}{3.41} = 1$
Nearest whole number ratio =	1 × 3	1.32 × 3	1 × 3

= 3 : 3.96 : 3

Nearest integer ratio = 3 : 4 : 3 **1**

Empirical formula $C_3H_4O_3$

Empirical formula mass = 88 = molecular formula mass

Therefore, molecular formula is same as the empirical formula - $C_3H_4O_3$ **1**

(b) $C_6H_{12}O_6 \longrightarrow 2C_2H_5OH + 2CO_2$ **1**

(c) Advantage – ethanol is produced at a faster rate **1**

Disadvantage – more energy is used / required in the reaction **1**

(d) Air gets in / oxidation occurs **1**

(e) Alcohol OH absorption in different place (3230–3550 cm^{-1}) from acid OH absorption (2500–3000 cm^{-1}) **1**

The C=O in acids has an absorption at 1680–1750 cm^{-1} **1**

[10]

2. (a)

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

*Penalise C_2H_6O for ethanol in **M1**.*

M2 and **M3**

*Mark **M2** and **M3** independently.*

Any **two** conditions **in any order** for **M2** and **M3** from

- (enzymes from) yeast or zymase
- 25 °C ≤ T ≤ 42 °C OR 298 K ≤ T ≤ 315 K
- anaerobic / no oxygen / no air OR neutral pH

  A lack of oxygen can mean either without oxygen or not having enough oxygen and does not ensure no oxygen, therefore only credit "lack of oxygen" if it is qualified.

  Penalise 'bacteria', 'phosphoric acid', 'high pressure' using the list principle.

M4 (fractional) distillation or GLC

Ignore reference to 'aqueous' or 'water' (ie not part of the list principle).

M5 Carbon-neutral **in this context** means

There is no net / overall (annual) carbon dioxide / CO_2 emission to the atmosphere

OR

There is no change in the total amount / level of carbon dioxide / CO_2 present in the atmosphere

*For **M5** – must be about CO_2 and the atmosphere.*

The idea that the carbon dioxide / CO_2 given out equals the carbon dioxide / CO_2 that was taken in from the atmosphere.

5

(b) **M1** q = m c ΔT (this mark for correct mathematical formula)

*Full marks for **M1**, **M2** and **M3** for the correct answer.*

*In **M1**, do not penalise incorrect cases in the formula.*

M2 = (75 × 4.18 × 5.5)

1724 (J) **OR** 1.724 (kJ) **OR** 1.72 (kJ) **OR** 1.7 (kJ)

(also scores **M1**)

*Ignore incorrect units in **M2**.*

M3 Using 0.0024 mol

therefore ΔH = **− 718** (kJ mol^{-1})

(Accept a range from −708 to −719 but do not penalise more than 3 significant figures)

*Penalise **M3** ONLY if correct numerical answer but sign is incorrect. Therefore **+718 gains two marks**.*

*If units are quoted in **M3** they must be correct.*

*If ΔT = 278.5, CE for the calculation and penalise **M2** and **M3**.*

M4 and **M5** in any order

Any **two** from

- incomplete combustion
- heat loss
- heat capacity of Cu not included
- some ethanol lost by evaporation
- not all of the (2.40 × 10^{-3} mol) ethanol is burned / reaction is incomplete

*If c = 4.81 (leads to 1984) penalise **M2** ONLY and mark on for **M3** = − 827*

5

(c) (i) **M1** enthalpy / heat / energy change (at constant pressure) or enthalpy / heat / energy needed in breaking / dissociating (a) covalent bond(s)

Ignore bond making.

M2 averaged for that type of bond over different / a range of molecules / compounds

Ignore reference to moles.

2

(ii) **M1**

∑ B(**reactants**) − ∑ B(**products**) = ΔH

OR

Sum of bonds broken − Sum of bonds formed = ΔH

OR

B(C-C) + B(C-O) + B(O-H) + 5B(C-H) + 3B(O=O)
– 4B(C=O) – 6B(O–H) = ΔH = −1279

Correct answer gains full marks.

*Credit **1 mark for − 496** (kJ mol^{-1})*

For other incorrect or incomplete answers, proceed as follows

- *check for an arithmetic error (AE), which is either a transposition error or an incorrect multiplication; this would score 2 marks (**M1** and **M2**).*

*If no AE, check for a correct method; this requires either a correct cycle with $2CO_2$ and $3H_2O$ OR a clear statement of **M1** which could be in words and scores **only M1**.*

M2 (also scores **M1**)
348+360+463+5(412)+ 3B(O=O)

(**3231**) (or **2768** if O–H cancelled)
− 4(805) − 6(463) = ΔH = − 1279

(**5998**) (or **5535** if O–H cancelled)

3B(O=O) = **1488** (kJ mol^{-1})

*Credit a maximum of one mark if the only scoring point is bonds formed adds up to **5998 (or 5535) OR** bonds broken includes the calculated value of **3231 (or 2768)**.*

M3

B(O=O) = **496** (kJ mol^{-1})

Award 1 mark for −496

Students may use a cycle and gain full marks

3

[15]

3. (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^-

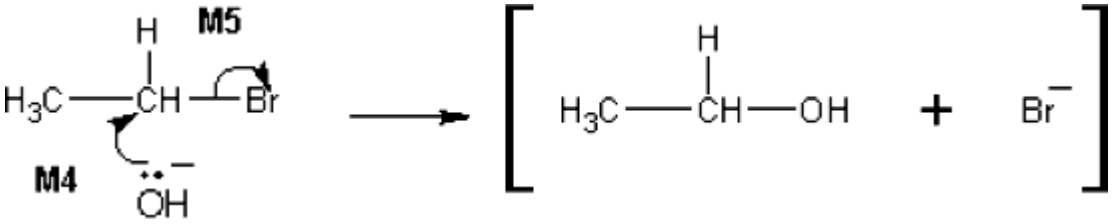
warm / heat / reflux and aqueous or (aq) or water

For M2 ignore "dilute"

For M2 penalise T > 100 °C

M3 nucleophilic substitution

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 original molecule.

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^+

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
- Bromoethane has to be manufactured / made first
- Bromoethane 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]

4. (a) **Three conditions <u>in any order</u> for M1 to M3**

M1 yeast or zymase

M2 30 °C ≥ T ≤ 42 °C

M3 anaerobic/no oxygen/no air OR neutral pH

M4 $C_6H_{12}O_6 \longrightarrow \mathbf{2}C_2H_5OH + \mathbf{2}CO_2$
OR
$\mathbf{2}C_6H_{12}O_6 \longrightarrow \mathbf{4}C_2H_5OH + \mathbf{4}CO_2$

Mark independently

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

Ignore reference to "aqueous" or "water" (i.e. not part of the list principle)

Or other multiples

4

(b) **M**1 Carbon-neutral

Ignore "biofuel"

1

M2 <u>6 (mol/molecules) CO_2/carbon dioxide taken in/used/used up</u> (to form glucose or in photosynthesis)

1

M3 <u>6 (mol/molecules) CO_2/carbon dioxide</u> given out <u>due to **2** (mol/molecules) CO_2/carbon dioxide from fermentation/ Process 2 and **4** (mol/molecules) CO_2/carbon dioxide from combustion/Process 3</u>

It is NOT sufficient in M2 and M3 for equations alone without commentary or annotation or calculation

1

(c) **M1 (could be scored by a correct mathematical expression)**

(Sum of) <u>bonds broken</u> – (Sum of) <u>bonds made/formed = Δ*H*</u>

OR

(Σ) $B_{reactants}$ – (Σ) $B_{products}$ = Δ*H*

(where B = <u>bond</u> enthalpy/<u>bond</u> energy)

For M1 there must be a <u>correct</u> mathematical expression using ΔH or "enthalpy change"

M2 Reactants = (+) <u>4719</u>
OR
Products = (–) <u>5750</u>

M3 Overall + 4719 – 5750 = **–1031** (kJ mol^{-1}) **(This is worth 3 marks)**

Award full marks for correct answer.

Ignore units.

M2 is for either value underlined

M3 is NOT consequential on M2

3

Award 1 mark ONLY for +1031

Candidates may use a cycle and gain full marks.

M4 Mean bond enthalpies are not specific for this reaction *OR* they are average values from many different compounds/molecules

Do not forget to award this mark

1

(d) **M1** q = m c ΔT (this mark for correct mathematical formula)

M2 = 6688 (J) OR 6.688 (kJ) OR 6.69 (kJ) OR 6.7 (kJ)

M3 0.46g is 0.01 mol
therefore ΔH = **– 669** kJ mol^{-1} OR – **670** $kJmol^{-1}$
OR **–668.8** kJ mol^{-1}

Award M1, M2 and M3 for correct answer to the calculation

Penalise M3 ONLY if correct answer but sign is incorrect

In M1, do not penalise incorrect cases in the formula

If m = 0.46 or m = 200.46 OR if ΔT = 281, CE and penalise M2 and M3

If c = 4.81 (leads to 7696) penalise M2 ONLY and mark on for M3 = –769.6 OR –770

Ignore incorrect units in M2

M4 Incomplete combustion

Do not forget to award this mark. Mark independently

4

[15]

5. (a) **M1** $6CO_2 + 6H_2O \rightarrow C_6H_{12}O_6 + 6O_2$

1

M2 $C_6H_{12}O_6 \rightarrow 2C_2H_5OH + 2CO_2$

1

M3 $2C_2H_5OH + 6O_2 \rightarrow 4CO_2 + 6H_2O$

$C_2H_5OH + 3O_2 \rightarrow 2CO_2 + 3H_2O$

1

M4 shows that formation of $C_6H_{12}O_6$ takes in $6CO_2$ and fermentation and combustion of ethanol gives out $6CO_2$

1

(b) CO_2 / carbon emissions from transport (from South America to Europe)

Energy needed to separate ethanol from propanone and butan-1-ol

1

(c) **M1** 685.5 (686), 668(.25), 595(.33…) in third column of table

ignore any minus sign on values

1

M2 ethanol

need evidence of attempt to calculate energy released per C atom

1

(d) **M1** amount propanone = $\frac{1.18}{58.0}$ (= 0.0203 mol)

1

M2 q = **M1** x 1786 (= 36.3 kJ = 36300 J)

1

M3 $\Delta T = \frac{q}{mc} = \frac{36300}{260 \times 4.18}$ = 33.4°C

1

M4 final temperature = 22.3 + **M3** = 55.7°C

1

(e) **M1** correctly showing how many of which types of bonds are broken / made
(broken) 3(C-C) + 9(C-H) + (C-O) + (O-H) + 6(O=O)
(made) 8(C=O) + 10(O-H)

1

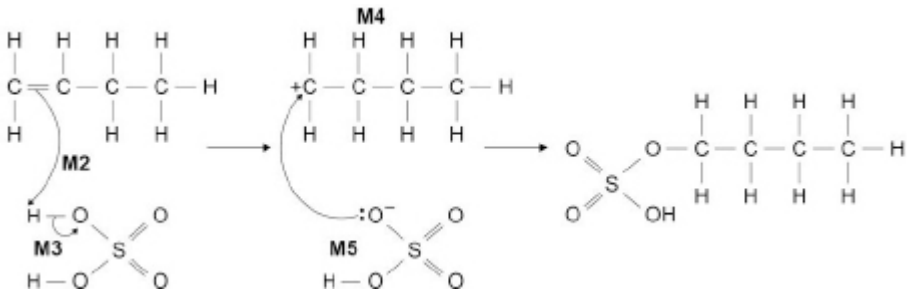
M2 3(C–C)
= 8(C=O) + 10(O–H) – 2504 – 9(C–H) – (C-O) – (O-H) – 6(O=O)
= 8(805) + 10(463) – 2504 – 9(412) – 360 – 463 – 6(496)
= 1059

1

M3 (C–C) = $\frac{M2}{3}$ = 353 (kJ mol^{-1})

1

(f) **M1** electrophilic addition



1

M2 must show an arrow from the double bond towards the H atom of the H_2SO_4 molecule

1

M3 must show the breaking of the H-O bond in H_2SO_4

1

M4 is for the structure of the correct carbocation

1

M5 must show an arrow from the lone pair of electrons on the negatively charged oxygen of HSO_4^- towards the positively charged atom of their carbocation drawn

*All arrows are double-headed. Penalise one mark from the total for **2-5** if half headed arrows are used*

Do not penalise the "correct" use of "sticks"

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

*For **M2 / 3**, the full structure of H_2SO_4 does not need to be shown, but the key features for the mechanism should be shown and the formula must be correct. Penalise only once in **M2 / 3** an incorrect but genuine attempt at the structure of sulfuric acid*

***M2** ignore partial negative charges on the double bond*

***M3** penalise incorrect partial charges on the H–O bond and penalise formal charges*

*Penalise **M4** if there is a bond drawn to the positive charge*

***Max 3 of 4 marks (M2-5)** for wrong organic reactant or wrong carbocation (ignore structure of product)*

*If attack is shown from C=C to H^+ rather than H_2SO_4, then allow **M2** but not **M3***

*For **M5**, credit attack on a partially positively charged carbocation structure, but penalise **M4** for the structure of the carbocation*

*For **M5**, the full structure of HSO_4^- is not essential, but attack must come from a lone pair on an individual oxygen on HSO_4^-, but the – sign could by anywhere on the ion (eg $:OSO_3H^-$)*

1

(g) **M1** formed from less stable carbocation

1

M2 formed from primary rather than secondary carbocation

1

[21]