

**Q10.**

Glucose can decompose in the presence of microorganisms to form a range of products. One of these is a carboxylic acid ($M_r = 88.0$) containing 40.9% carbon and 4.5% hydrogen by mass.

- (a) Deduce the empirical and molecular formulas of the carboxylic acid formed.

Empirical formula = _____ Molecular formula = _____

(4)

- (b) Ethanol is formed by the fermentation of glucose.
A student carried out this fermentation reaction in a beaker using an aqueous solution of glucose at a temperature of 25 °C in the presence of yeast.

Write an equation for the reaction occurring during fermentation.

(1)

- (c) In industry, this fermentation reaction is carried out at 35 °C rather than 25 °C.

Suggest **one** advantage and **one** disadvantage for industry of carrying out the fermentation at this higher temperature.

Advantage _____

Disadvantage _____

(2)

- (d) The method used by the student in part (b) would result in the ethanol being contaminated by ethanoic acid.

How does this contamination occur?

(1)



- (e) Give **two** differences between the infrared spectrum of a carboxylic acid and that of an alcohol other than in their fingerprint regions.
Use **Table A** on the Data Sheet.

Difference 1 _____

Difference 2 _____

(2)
(Total 10 marks)

Q11.

Alcohols can be prepared from alkenes in various ways.

- (a) On a laboratory scale, a mixture of propan-1-ol and propan-2-ol can be prepared from propene in two steps.

In step 1, propene reacts with cold, concentrated sulfuric acid to form intermediate compounds.

In step 2, the intermediate compounds react with water to form the mixture of alcohols.

Name and outline the mechanism for the reaction between propene and concentrated sulfuric acid to form the intermediate compound which gives propan-2-ol in step 2.

Explain why propan-2-ol is the major product of this preparation.

(7)

**Q12.**

Ethanol is an important fuel.

- (a) A dilute aqueous solution of ethanol can be produced by the fermentation of an aqueous solution of glucose.
It is claimed that the ethanol obtained from this solution is a carbon-neutral biofuel.

Write an equation for this fermentation reaction.

Give **two** other essential conditions for this reaction to produce a good yield of ethanol.

Name a process used to produce a much more concentrated solution of ethanol from a dilute aqueous solution.

State the meaning of the term **carbon-neutral** in the context of this biofuel.

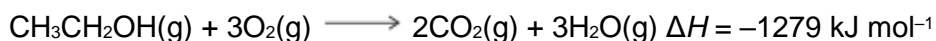
(5)



(ii) Consider the mean bond enthalpy data in the following table.

	C—H	C—C	C—O	O=O	C=O	O—H
Mean bond enthalpy / kJ mol ⁻¹	412	348	360	to be calculated	805	463

Use the data in the table above and the equation shown to calculate a value for the bond enthalpy for the O=O double bond in an oxygen molecule.



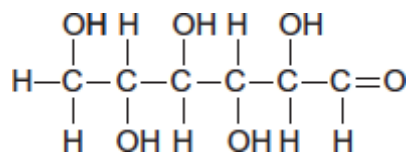
(3)

(Total 15 marks)

Q13.

Glucose is an organic molecule. Glucose can exist in different forms in aqueous solution.

(a) In aqueous solution, some glucose molecules have the following structure.

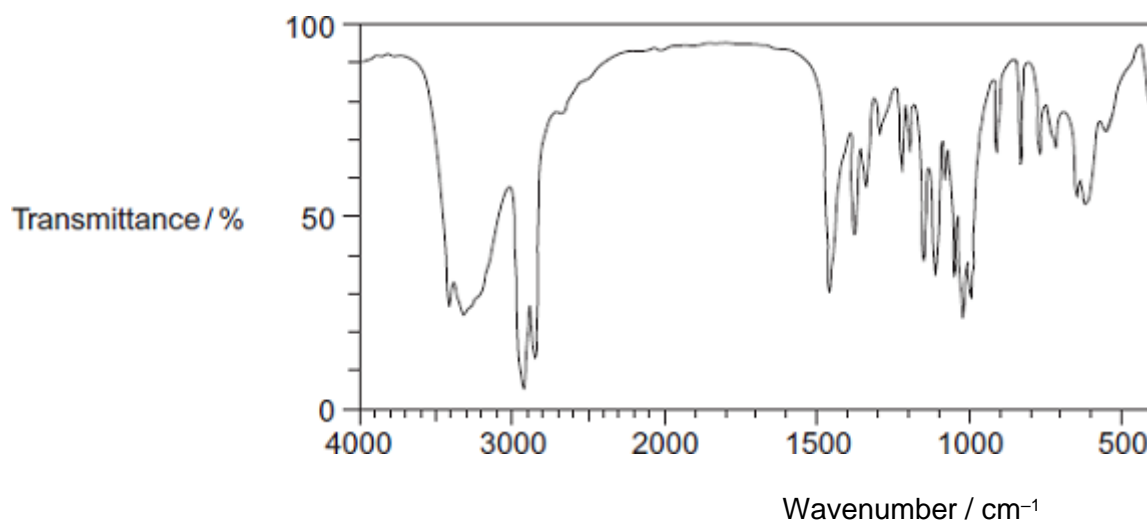


(i) Deduce the empirical formula of glucose.

(1)



- (ii) Consider the infrared spectrum of solid glucose.



State why it is possible to suggest that in the solid state very few molecules have the structure shown.

You may find it helpful to refer to **Table 1** on the Data Sheet.

(1)

- (b) In the absence of oxygen, an aqueous solution of glucose can be fermented to produce ethanol for use in alcoholic drinks.

Write an equation for this fermentation reaction.

Give **two** other essential conditions for the production of ethanol in this fermentation.

Equation

Condition 1 _____

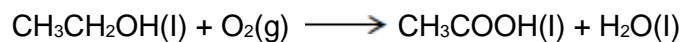
Condition 2 _____

(3)



- (c) Any ethanol present in the breath of a drinker can be detected by using a breathalyser. The ethanol is converted into ethanoic acid. The breathalyser has negative and positive electrodes. A current is measured and displayed in terms of alcohol content.

The overall redox equation is as follows



- (i) Draw the displayed formula for ethanoic acid.

(1)

- (ii) Deduce a half-equation for the reduction of atmospheric oxygen to water in acidic solution at one electrode of the breathalyser.

(1)

- (iii) Deduce a half-equation for the oxidation of ethanol in water to ethanoic acid at the other electrode of the breathalyser.

(1)

- (iv) The earliest breathalysers used laboratory chemicals to oxidise the ethanol to ethanoic acid. Detection was by a colour change.

Identify a reagent or combination of reagents that you would use in the laboratory to oxidise ethanol to ethanoic acid.

State the colour **change** that you would expect to see.

Reagent or combination of reagents _____

Colour change _____

(2)



(d) The fermentation of glucose from crops is the main method for the production of ethanol. The product is called bioethanol. The European Union has declared that bioethanol is carbon-neutral.

(i) State the meaning of the term *carbon-neutral*.

(1)

(ii) Other than carbon-neutrality, state the **main** advantage of the use of glucose from crops as the raw material for the production of ethanol.

(1)

(iii) Give *one* disadvantage of the use of crops for the production of ethanol.

(1)

(Total 13 marks)

Q14.

The reaction of butane-1,4-diol with butanedioic acid produces the polymer PBS used in biodegradable packaging and disposable cutlery.
Butanedioic acid is produced by two different processes.

Process 1

- Aqueous sodium hydroxide reacts with 1,4-dibromobutane to make butane-1,4-diol.
- Butane-1,4-diol is oxidised to butanedioic acid.

Process 2

- Glucose reacts with carbon dioxide in the presence of microorganisms to produce butanedioic acid directly.
- The carbon dioxide used in this process is obtained from a local factory that produces bioethanol.



- (a) Deduce **one** safety reason and one environmental reason why **Process 2** is preferred to **Process 1**.

(2)

- (b) (i) Name and outline a mechanism for the following reaction that occurs in **Process 1**.



(3)



(ii) The infrared spectra shown are those of three compounds.

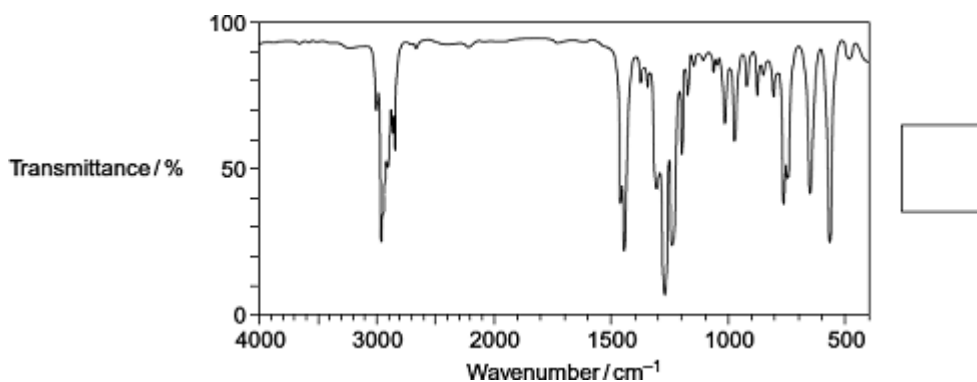
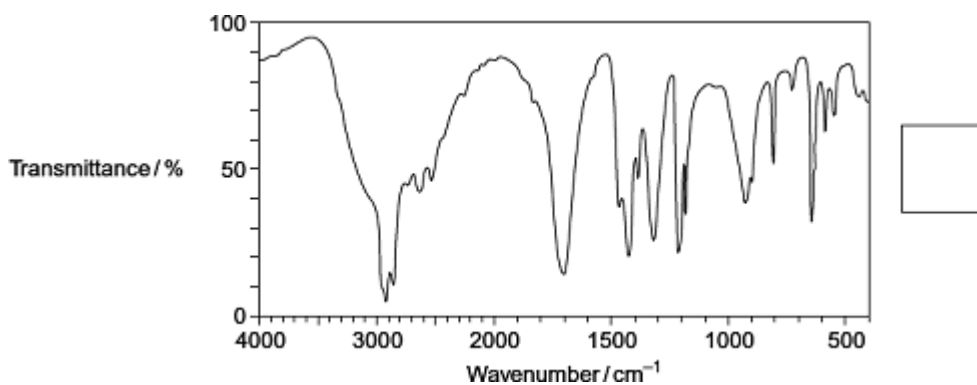
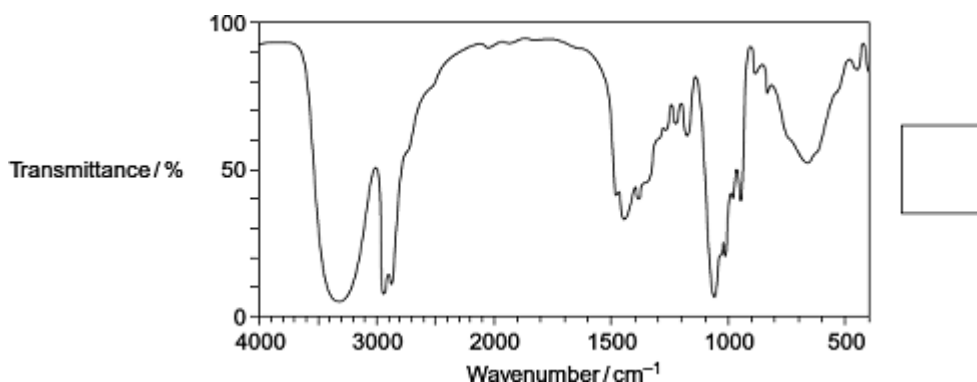
Compound **A** 1,4-dibromobutane

Compound **B** butane-1,4-diol

Compound **C** butanedioic acid

Identify the compound responsible for each spectrum by writing the correct letter, **A**, **B** or **C**, in the box next to each spectrum.

You may find it helpful to refer to **Table 1** on the Data Sheet.



(3)



- (c) In the production of bioethanol, glucose ($C_6H_{12}O_6$) is converted into a dilute aqueous solution of ethanol and carbon dioxide.

Give the name of this process and state **three** essential conditions necessary to produce a good yield of ethanol.

(4)

- (d) State the class of alcohols to which the diol butane-1,4-diol belongs.

Identify a suitable reagent or combination of reagents for the conversion of butane-1,4-diol into butanedioic acid ($HOOCCH_2CH_2COOH$).

Write an equation for this oxidation reaction using [O] to represent the oxidising agent.

(3)

(Total 15 marks)

**Q10.**

(a) Percentage of oxygen by mass = $100 - 40.9 - 4.5 = 54.6$

1

	C	H	O
%	<u>40.9</u>	<u>4.5</u>	<u>54.6</u>
Divide by A_r	<u>12</u>	<u>1</u>	<u>16</u>
	= 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 ($3230-3550\text{ cm}^{-1}$) from acid OH absorption ($2500-3000\text{ cm}^{-1}$)

1

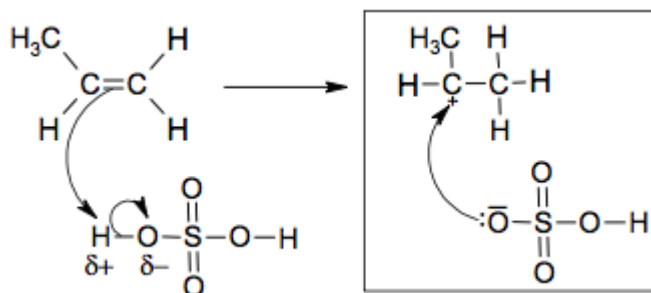
The C=O in acids has an absorption at $1680-1750\text{ cm}^{-1}$

1

[10]**Q11.**

(a) Electrophilic addition

1



M2 = curly arrow from C=C towards H of H-O on 'their' sulfuric acid

M3 = curly arrow to break H-O

Penalise incorrect dipole/full charges

M4 = intermediate

M5 = correct anion, lone pair on correct O and curly arrow from that lone pair to C+ on their carbocation

IGNORE position of minus sign unless displayed structure

IGNORE product

1
1
1
1

Major product/propan-2-ol formed via most stable carbocation/carbonium ion
secondary carbocation/carbonium ion more stable (than primary)
or reverse argument

M6 for idea of carbocation stability

This statement gets M6 and M7

NOT stability of alcohols

1
1

(b) Hot/High T (and High P)

ALLOW 200-450 C/473-723 K (Quoted)

1

(SiO₂ coated in) phosphoric acid (catalyst)

NOT (aq)

1

advantages of fermentation

- Low(er) T and P / lower energy use
- Less use of non-renewable fossil fuels/renewable/sustainable (resources)
- Low(er) equipment/plant/capital costs
IGNORE carbon neutral
max 2

1
1



Disadvantages of fermentation

- Slow(er) reaction
- Low atom economy
- Impure product/extra purification/distillation required
- Batch process/labour intensive/difficult to automate
- Land used for sugar crops (so not available for food crops)

IGNORE low yield

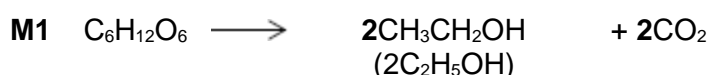
Max 2

1
1

[13]

Q12.

(a)



Penalise $\text{C}_2\text{H}_6\text{O}$ 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
- $25\text{ }^\circ\text{C} \leq T \leq 42\text{ }^\circ\text{C}$ OR $298\text{ K} \leq T \leq 315\text{ K}$
- 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 / CO₂ given out equals the carbon dioxide / CO₂ that was taken in from the atmosphere.

5

- (b) **M1** $q = m c \Delta T$ (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.*

$$\mathbf{M2} = (75 \times 4.18 \times 5.5)$$

$$1724 \text{ (J) OR } 1.724 \text{ (kJ) OR } 1.72 \text{ (kJ) OR } 1.7 \text{ (kJ)}$$

(also scores **M1**)

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

M3 Using 0.0024 mol

therefore $\Delta H = \underline{\mathbf{-718}}$ (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 $\Delta T = 278.5$, 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**

$$\underline{\sum B(\text{reactants}) - \sum B(\text{products}) = \Delta H}$$



OR

$$\text{Sum of bonds broken} - \text{Sum of bonds formed} = \Delta H$$

OR

$$B(\text{C-C}) + B(\text{C-O}) + B(\text{O-H}) + 5B(\text{C-H}) + 3B(\text{O=O}) \\ - 4B(\text{C=O}) - 6B(\text{O-H}) = \Delta H = -1279$$

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 2CO₂ and 3H₂O OR a clear statement of **M1** which could be in words and scores **only M1**.

M2 (also scores **M1**)

$$348+360+463+5(412)+ 3B(\text{O=O})$$

$$\begin{array}{r} (3231) \qquad \qquad \qquad (\text{or } 2768 \text{ if O-H cancelled}) \\ - 4(805) - 6(463) = \Delta H = - 1279 \end{array}$$

$$\begin{array}{r} (5998) \qquad \qquad \qquad (\text{or } 5535 \text{ if O-H cancelled}) \end{array}$$

$$3B(\text{O=O}) = \underline{1488} \text{ (kJ mol}^{-1}\text{)}$$

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

$$B(\text{O=O}) = \underline{496} \text{ (kJ mol}^{-1}\text{)}$$

Award 1 mark for -496

Students may use a cycle and gain full marks

3

[15]

Q13.

(a) (i) CH₂O

Atoms in any order

Accept a clear indication that C₆H₁₂O₆ yields CH₂O as the answer

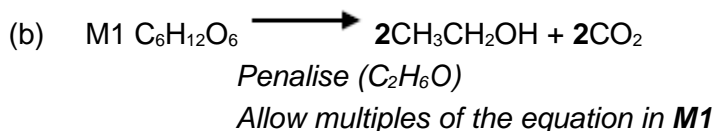
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(ii) No peak / no absorption / no C=O in the **range 1680 to 1750** (cm⁻¹) (suggesting no evidence of C=O)

Allow the words “dip”, “spike”, “low transmittance” and “trough” as alternatives for absorption

Ignore references to other wavenumbers

1



Either order

M2 (enzymes from) yeast or zymase

M3 $25\text{ }^\circ\text{C} \leq T \leq 42\text{ }^\circ\text{C}$ OR $298\text{ K} \leq T \leq 315\text{ K}$

For **M2** and **M3**

Ignore "aqueous"

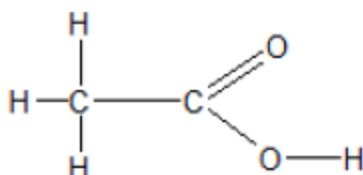
Ignore "anaerobic / absence of oxygen"

Ignore "controlled pH"

Ignore "warm"

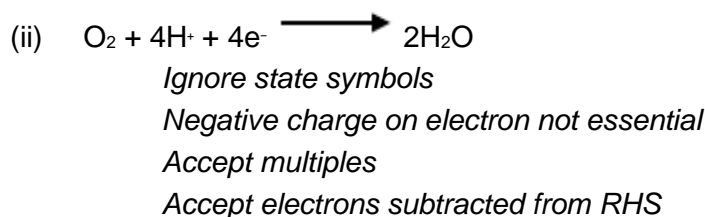
3

(c) (i) Displayed formula for CH_3COOH

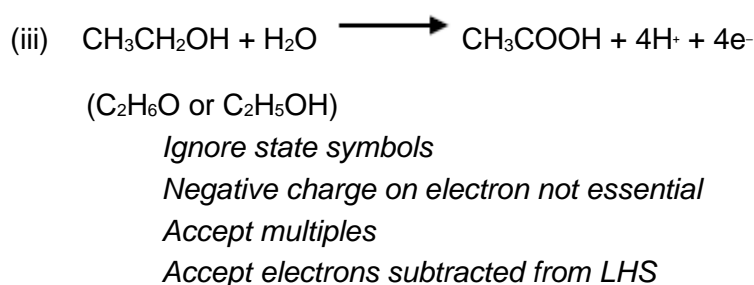


All bonds must be drawn out, but ignore bond angles

1



1



1

(iv) M1 Acidified potassium or sodium dichromate
 For **M1**, it must be a whole reagent and / or correct formulae

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

Do not penalise incorrect attempt at formula if name is correct or vice versa

OR correct combination of formula and name

If oxidation state given in name, it must be correct, but mark on from an incorrect attempt at a correct reagent.



M2 (requires an attempt at M1)

orange to green

*Credit **acidified** potassium chromate(VI) / $H_2SO_4 + K_2CrO_4$*

Possible alternative

M1 (acidified) potassium manganate(VII) **OR** $KMnO_4 / H_2SO_4$

M2 purple to colourless

*Other alternatives will be accepted but **M2** is dependent on **M1** in every case*

M2** requires an attempt at a correct reagent for **M1

Ignore reference to states

2

- (d) (i) An activity which has no net / overall (annual) carbon emissions to the atmosphere / air

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

OR

An activity which has no net / overall (annual) greenhouse gas emissions to the atmosphere / air.

Answer must refer to the atmosphere or air

OR

There is no change in the total amount of carbon dioxide / carbon / greenhouse gas present in the atmosphere / air

1

- (ii) Renewable / sustainable ONLY

Ignore references to global warming or greenhouse gases

1

- (iii) **Any one statement about this process from**

Subject to weather / climate

Ignore "batch"

OR

Depletes food supply OR the land use for (specified) food

OR

Requires use of / uses more fossil fuels

OR

Not carbon-neutral OR CO_2 produced during a named process (eg harvest, transport etc.)

OR



Slow process / slow rate of reaction / takes a long time (to grow crops)

OR

This route leads to the production of a mixture of water and ethanol / impure ethanol that requires separation / further processing

1

[13]

Q14.

(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 CO₂ / CO₂ from the factory / CO₂ from the bioethanol (or biofuel) production

OR

reduces or limits the amount of CO₂ released / given out (into the atmosphere)

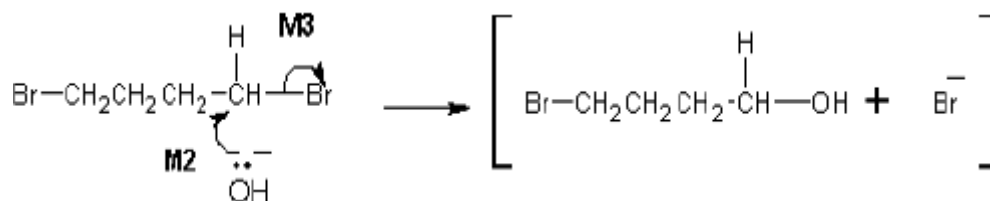
OR

Process 2 uses renewable glucose / renewable resource(s)

2

(b) (i) **M1** nucleophilic substitution

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 original molecule

*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** fermentation

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

Three conditions in any order 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 acidified potassium or sodium dichromate

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

OR H₂SO₄ / K₂Cr₂O₇ OR H⁺ / K₂Cr₂O₇

Do not penalise incorrect attempt at formula if name is correct or vice versa

Accept phonetic spelling

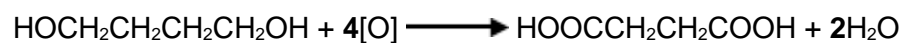
If oxidation state given in name, it must be correct.

*For **M2** accept acidified potassium manganate(VII)*



OR correct combination of formula and name

M3



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

3

[15]