Q1.

In Europe, some of the glucose from crops is fermented to produce ethanol.

Use of a carbon-neutral fuel leads to no net emissions of carbon dioxide to the atmosphere.

(a) The ethanol produced by fermentation of glucose may be regarded as a carbon-neutral fuel.

Justify this statement. Include the relevant chemical equations in your answer.

(4)

Coffee beans from South America are exported to Europe in an outer layer called silverskin.

The waste silverskin can be fermented to produce a solution containing propanone, ethanol and butan-1-ol.

(b) Suggest why ethanol produced in Europe using silverskin from South America is less likely to be carbon-neutral than ethanol produced from crops grown in Europe.

(1)

(c) **Table 1** shows the enthalpies of combustion of the three fuels from the fermentation of silverskin.

Table 1

Fuel	**Standard enthalpy of combustion / kJ mol^{-1}**	**Energy released per mole of CO_2 produced / kJ**
ethanol, $C_2H_5OH(l)$	–1371	
butan-1-ol, $C_4H_9OH(l)$	–2673	
propanone, $C_3H_6O(l)$	–1786	

One way to measure a fuel's environmental impact is to measure the amount of energy released per mole of CO_2 produced.

Complete **Table 1**.

Use your answers to deduce the fuel with the lowest environmental impact by this measure.

_____

_____

(2)

(d) A student investigated the combustion of propanone (C_3H_6O) using calorimetry.

A copper calorimeter containing water was heated by the complete combustion of some propanone. The student did not record the final temperature of the water.

Table 2 shows the student's results.

Table 2

Mass of propanone burned / g	1.18
Mass of water / g	260
Initial temperature of water / °C	22.3
Final temperature of water / °C	Not recorded

Use the results in **Table 2** to calculate a value for final temperature of the water in the experiment.

Assume that no heat was lost in the experiment and that the heat capacity of the calorimeter is negligible.

For propanone, enthalpy of combustion = –1786 kJ mol^{-1}

For water, specific heat capacity = 4.18 J g^{-1} K^{-1}

Final temperature of water _____ °C

(4)

(e) Butan-1-ol can be added to petrol for cars.

An equation for the complete combustion of gaseous butan-1-ol is shown.

$$C_4H_9OH(g) + 6\ O_2(g) \rightarrow 4\ CO_2(g) + 5\ H_2O(g) \quad \Delta H = -2504\ kJ\ mol^{-1}$$

Table 3 shows some mean bond enthalpy data.

Table 3

Bond	C=O	C–H	C–O	O–H	O=O
Mean bond enthalpy / kJ mol^{-1}	805	412	360	463	496

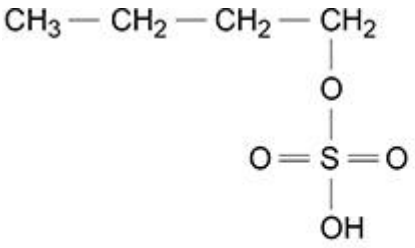
Use these data to calculate a value for the mean C–C bond enthalpy in gaseous butan-1-ol.

C–C bond enthalpy _____ kJ mol^{-1}

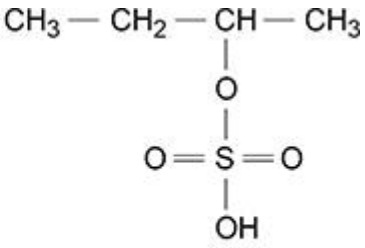
(3)

Butan-1-ol can be manufactured by reacting steam with but-1-ene in the presence of the catalyst, concentrated sulfuric acid.

In the first part of this process, but-1-ene reacts with concentrated sulfuric acid to form compounds **W** and **X**.



Compound **W**



Compound **X**

Butan-1-ol is then made from compound **W**.

(f) Name and outline a mechanism to show the conversion of but-1-ene into compound **W** in the first part of this process.

Name of mechanism _____

Outline of mechanism

(5)

(g) There is a very low yield of butan-1-ol from but-1-ene in this manufacturing process.

Explain why.

_____

_____

_____

_____

(2)

(Total 21 marks)

Q2.

This question is about the preparation of hexan-2-ol.
Hexan-2-ol does not mix with water and has a boiling point of 140 °C

Hexan-2-ol can be prepared from hex-1-ene using this method.

a Measure out 11.0 cm^3 of hex-1-ene into a boiling tube in an ice bath.

b Carefully add 5 cm^3 of concentrated phosphoric acid to the hex-1-ene.

c After 5 minutes add 10 cm^3 of distilled water to the mixture and transfer the boiling tube contents to a separating funnel.

d Shake the mixture and allow it to settle.

e Discard the lower (aqueous) layer.

f Add a fresh 10 cm^3 sample of distilled water and repeat steps **d** and **e**.

g Transfer the remaining liquid to a beaker.

h Add 2 g of anhydrous magnesium sulfate and allow to stand for 5 minutes.

i Filter the mixture under reduced pressure.

j Distil the filtrate and collect the distillate that boils in the range 130–160 °C

(a) It is important to wear eye protection and a lab coat when completing this experiment.

Suggest, with a reason, **one** other appropriate safety precaution for this experiment.

Precaution _____

Reason _____

_____

(2)

(b) Give a reason for adding the distilled water in steps **c** and **f**.

_____

_____

(1)

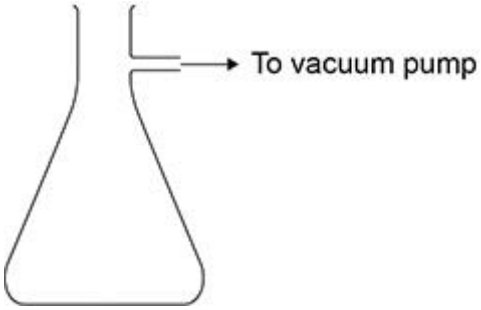
(c) Give a reason for adding anhydrous magnesium sulfate in step **h**.

_____

_____

(1)

(d) Complete and label the diagram of the apparatus used to filter the mixture under reduced pressure in step **i**.



(2)

(e) Identify the most likely organic impurity, other than hex-1-ene, in the distillate collected in step **j**.

Suggest **one** reason why it could be difficult to remove this impurity.

Impurity _____

Reason _____

_____

(2)

(f) Calculate the mass, in g, of hexan-2-ol formed from 11.0 cm^3 of hex-1-ene if the yield is 31.0%

Give your answer to 1 decimal place.

Density of hex-1-ene = 0.678 g cm^{-3}

Mass _____ g

(4)

(Total 12 marks)

Q3.

Which statement is **not** correct for both primary and secondary alcohols?

A They are easily oxidised to carboxylic acids by acidified $K_2Cr_2O_7$ solution. ⬭

B They can be formed from bromoalkanes by hydrolysis. ⬭

C They form esters with carboxylic acids. ⬭

D They show hydrogen bonding in the liquid state. ⬭

(Total 1 mark)

Q4.

Which pair of reagents does **not** produce ethanol?

A CH_3CH_2Br and NaOH(aq) ⬭

B CH_3COOCH_3 and NaOH(aq) ⬭

C $HCOOCH_2CH_3$ and NaOH(aq) ⬭

D CH_3CHO and $NaBH_4$(aq) ⬭

(Total 1 mark)

Q5.

Which statement is **not** correct about the industrial production of ethanol from ethene at 300 °C?

$$C_2H_4(g) + H_2O(g) \rightleftharpoons C_2H_5OH(g) \quad \Delta H = -46 \text{ kJ mol}^{-1}$$

A The reaction is catalysed by an acid. ⬭

B The reaction has 100% atom economy. ⬭

C An increase in temperature decreases the equilibrium yield of ethanol. ⬭

D An increase in pressure increases the value of K_c ⬭

(Total 1 mark)

Q6.

This question is about fuels.

(a) The petrol fraction obtained from crude oil can be used as fuel in cars.

State the meaning of fraction, as used in the term petrol fraction.

_____

_____

_____

(1)

(b) Hexadecane ($C_{16}H_{34}$) can be cracked at high temperature to form petrol.

Complete the equation to show the cracking of one molecule of hexadecane to form hexane and cyclopentane only.

Give the name of a catalyst used in this cracking reaction.

$C_{16}H_{34} \rightarrow$ _____ + _____

Catalyst _____

(3)

(c) Carbon dioxide is formed when petrol is burned.
Carbon dioxide acts as a greenhouse gas when it absorbs infrared radiation.

Give a reason why carbon dioxide absorbs infrared radiation.

_____

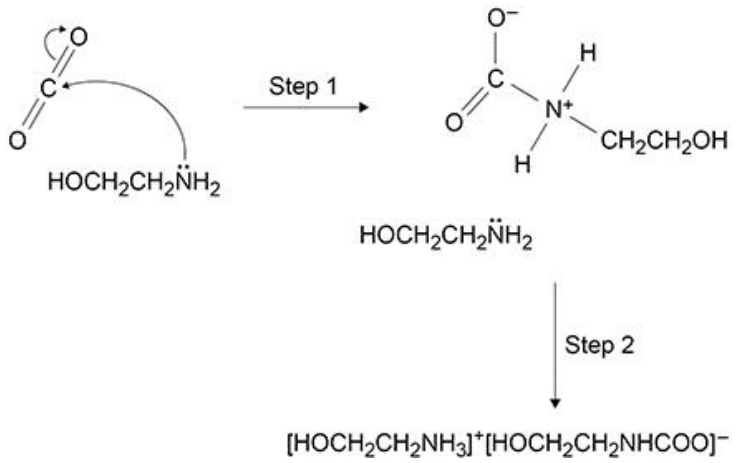
_____

_____

(1)

(d) Compound **Z** ($HOCH_2CH_2NH_2$) can be used to remove carbon dioxide from the mixture of waste gases produced in some power stations.

The figure below shows part of a suggested mechanism for the reaction of **Z** with carbon dioxide.



Draw **two** curly arrows to complete the mechanism in the figure above.

Name compound **Z** ($HOCH_2CH_2NH_2$)

Deduce the role of **Z** in step **2** of the mechanism.

Name _____

Role _____

(4)

(e) $HOCH_2CH_2NH_2$ can be represented as XNH_2
$[HOCH_2CH_2NH_3]^+$ can be represented as $[XNH_3]^+$

Draw the shape of XNH_2 and of $[XNH_3]^+$

State whether the H–N–H bond angle in XNH_2 is greater than, the same as, or smaller than that in $[XNH_3]^+$

Explain your answer.

Shape of XNH_2 Shape of $[XNH_3]^+$

Bond angle _____

Explanation _____

_____

(4)

(f) Bioethanol is used as an alternative to fossil fuels.

This statement appeared on a website.

"The fact that bioethanol is a carbon-neutral fuel outweighs the environmental disadvantages of producing bioethanol."

Evaluate this statement.

In your answer you should include:
- an outline of how bioethanol is produced
- relevant equations
- analysis of the environmental impacts.

(6)

(Total 19 marks)

Q7.

Which statement is correct about the production and use of ethanol as a biofuel?

A Biofuel ethanol is produced by the fermentation of glucose in the presence of yeast and air. ⬭

B Biofuel ethanol is purified by fractional distillation. ⬭

C No carbon dioxide is released when biofuel ethanol is burned. ⬭

D Biofuel ethanol burns with a cleaner flame than ethanol made by hydration of ethene. ⬭

(Total 1 mark)

Q8.

In the UK industrial ethanol is now produced by the direct hydration of ethene. This process has largely replaced the fermentation method.

Which is a likely reason for this change of method?

A The direct hydration route produces purer ethanol. ⬭

B The direct hydration route employs milder conditions. ⬭

C The direct hydration route does NOT use a catalyst. ⬭

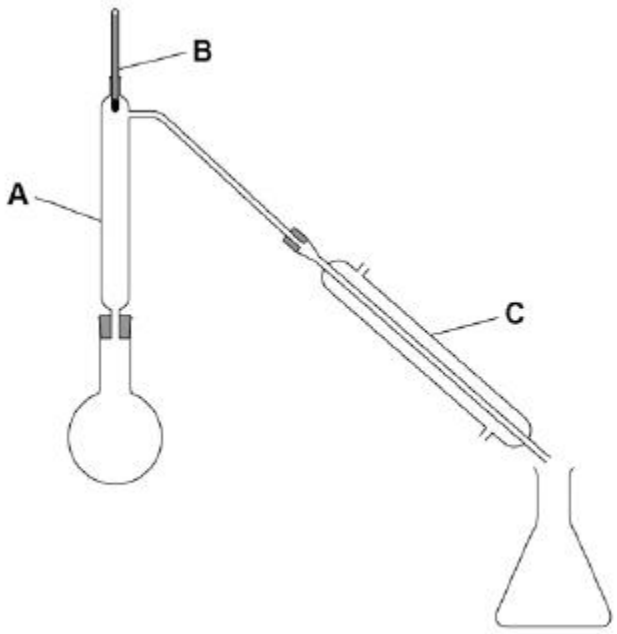
D The direct hydration route produces ethanol by a slower reaction. ⬭

(Total 1 mark)

Q9.

A group of students wanted to produce a biofuel to power the central heating system in their school. They collected scraps of fruits and vegetables from the kitchens and fermented them with yeast, in the absence of air, in order to produce ethanol.
The aqueous mixture was filtered to remove the remaining solids.

The students then set up the apparatus shown in the diagram below and placed the aqueous mixture in the round bottomed flask.



(a) Describe how the students would use this apparatus to collect a sample of ethanol.
Include in your answer the functions of the parts of the apparatus labelled **A**, **B** and **C**.

(6)

(b) The students collected a 20 cm^3 sample of liquid and weighed it. The mass of the sample was 16 g.

The density of ethanol is 0.79 g cm^{-3} and that of water 1.00 g cm^{-3}.

Use these data to calculate the mass of ethanol in the sample collected.
You should assume that the volume of the sample is equal to the sum of the volumes of water and ethanol.

Mass of ethanol = _____ g

(2)

(Total 8 marks)

Mark schemes

Q1.

(a) **M1** $6CO_2 + 6H_2O \rightarrow C_6H_{12}O_6 + 6O_2$ **1**

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

Allow C_2H_6O for ethanol formula **1**

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

M1/2/3 *allow multiples*

M3 *$C_2H_5OH + 3O_2 \rightarrow 2CO_2 + 3H_2O$* **1**

M4 explains with reference to relevant equations that formation of $C_6H_{12}O_6$ takes in $6CO_2$ and fermentation and combustion of ethanol gives out $6CO_2$

M4 *depends on having appropriate equations in* ***M1/2/3*** *showing 6 CO_2 in and out* **1**

(b) transport (from South America to Europe) produces CO_2 / has C emissions / has larger C footprint

Process to separate ethanol from propanone and butan-1-ol produces CO_2 / has C emissions / has larger C footprint **1**

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

M1 *ignore any minus sign on values* **1**

M2 depends on their answer to **M1** − must be the compound giving most energy per mole of CO_2 released (correct **M1** would give ethanol)

M2 *need evidence of attempt to calculate energy released per C atom (i.e. per mole of CO_2 formed)* **1**

(d) **M1** amount propanone = $\frac{1.18}{58.0}$ (= 0.0203 mol) **1**

M2 q = **M1** × 1786 (= 36.3 kJ = 36300 J) **1**

M3 $\Delta T \left(= \frac{q}{mc} = \frac{\text{M2 (in J)}}{260 \times 4.18}\right)$ = 33.4 (°C) (allow 32.8-33.4)

M3 *ignore sign* **1**

M4 final temperature = (22.3 + **M3**) = 55.7 (°C) (allow 55-596)

M4 *must show a temperature rise* **1**

Correct answer scores 4 marks

Allow ECF at each stage

(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)

***M1** could show broken as:*
3(C-C) + 9(412) + (360) + (463) + 6(496)
or 7507 + 3(C-C)

and, could show made as
8(805) + 10(463)
or 11070

1

M2 (bonds broken) − (bonds made) = −2504
7507 + 3(C-C) − 11070 = −2504
3(C–C) = 1059

*Allow ECF from **M1** to **M2***

*Ignore incorrect number of C-C bonds in **M1/2**, but should be 3 for **M3***

1

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

*Allow ECF from **M2** to **M3** (if **M2** is negative value, then ignore sign for **M3**)*

1

Correct answer scores 3 marks;

265 scores 2 marks if from 4(C-C) bonds

1188 scores 2 marks (not included −2504)

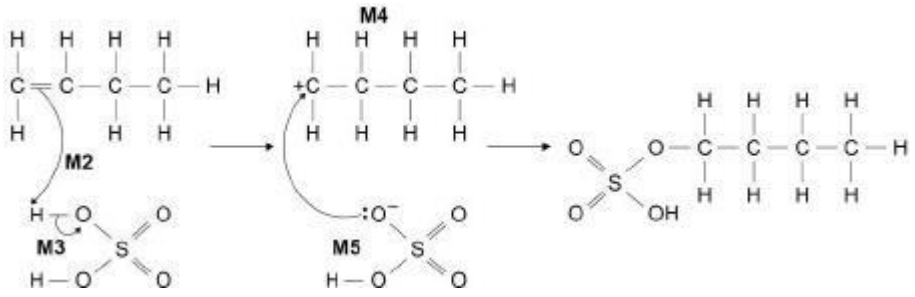
2022 scores 2 marks (using (made − broken))

−353 scores 2 marks

±834 scores 2 marks (use of C-O in CO_2)

±836 scores 1 marks (use of C-O in CO_2 and using (made − broken))

(f) **M1** electrophilic addition



1

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

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

1

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

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

1

M4 is for the structure of the correct carbocation

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

1

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

1

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*

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^-*)*

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

M1 *must be clear that it is the stability of the carbocation that matters rather than the stability of the alcohol*

1

M2 formed from primary rather than secondary carbocation

M2 *allow 1 mark for primary carbocation is less stable than secondary carbocation even if not clear that product is formed from a carbocation (but must be clear that the alcohols are not the carbocations)*

1

[21]

Q2.

(a) Wear gloves

1

Conc phosphoric acid is corrosive

1

Allow wash spillages with lots of water

OR

Use a fume cupboard
Volatile organic compounds are harmful / toxic

Allow work in a well-ventilated lab space

OR

Keep away from naked flames
Organic compounds are flammable

Other valid suggestions eg heating mantle or electric heater

Not water bath

OR

Periodically release pressure inside separating funnel
Prevent build-up of pressure

(b) To remove (water) soluble impurities

Allow to remove (excess) acid

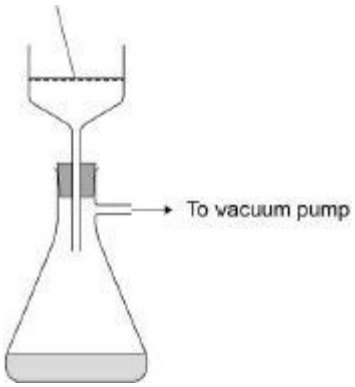
1

(c) To remove water / absorb water / dry the liquid

Allow drying agent

1

(d)



Deduct a mark(s) for error(s) / omission(s)

Minimum

- *Cross sectional (ie funnel top and end shown open)*
- *Bung or collar drawn*
- *(Buchner) Funnel − approximate shape WITH label*
- *Filter paper − WITH label*

2

(e) Impurity: hexan-1-ol

If hexan-3-ol allow ecf for M2

M1

Reason: It is likely to have a similar boiling point

M2

(f) Mass hex-1-ene = 11.0 × 0.678 (or = 7.46 g)

Allow consequential marks for M2,M3,M4

M1

n hex-1-ene = $\frac{7.46}{84.0}$ (or = 0.0888)

M2

Mass of product = 0.0888 × 0.31 × 102

M3

Mass product = 2.8 g

Allow answers 2.8 or 2.9 only

M4

[12]

Q3.

A

They are easily oxidised to carboxylic acids by acidified $K_2Cr_2O_7$ solution.

[1]

Q4.

B

CH_3COOCH_3 and NaOH(aq)

[1]

Q5.

D

An increase in pressure increases the value of K_c

[1]

Q6.

(a) A group of (hydrocarbons/compounds) with similar boiling points

Allow compounds that boil in a similar range of temperatures

Compounds with similar (carbon) chain length with C5-C12 range or within range

1

(b) zeolite

Allow Aluminosilicate or aluminium oxide

M1

All formulae correct

M2

Balanced equation $C_{16}H_{34} \rightarrow C_6H_{14} + 2\ C_5H_{10}$

M3

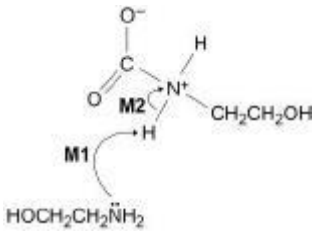
(c) C=O bonds vibrate at the same frequency as IR

The difference in energy between the ground and first excited vibrational state of CO_2 is equal to the energy of the infrared radiation.

Allow
Bond vibrations match frequency of IR radiation
C=O bonds vibrate in range 1680-1750cm^{-1}
C=O bonds are polar

1

(d)



Curly arrow from N lp to H
Curly arrow from N-H bond to N^{+}

M1
M2

2-aminoethanol

Allow 2-hydroxyethylamine 2-hydroxyethanamine ethanolamine

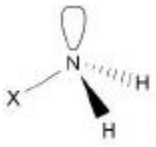
M3

Base

Allow proton acceptor / removes H^{+} / electron pair donor M1

M4

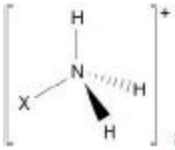
(e)



allow with/without lone pair

Allow these shapes with lines instead of wedges and dashed lines

M1



allow with/without charge

M2

Smaller

Allow comparison of correct numbers

M3

lone (or non-bonding) pair repulsion greater than bond pair repulsion

M4

(f)

This question is marked using Levels of Response. Refer to the Mark Scheme Instructions for Examiners for guidance.	
Level 3 **5-6**	All stages are covered and each stage is generally correct and virtually complete.

marks	Answer is communicated coherently and shows a logical progression from Stage 1 to Stages 2 and 3 Covers at least 2 points for stage 1, 2 for stage 2 and 3 for stage 3.
Level 2 **3-4 marks**	All stages are covered but stage(s) may be incomplete or may contain inaccuracies **OR** two stages are covered and are generally correct and virtually complete. Answer is communicated mainly coherently and shows a logical progression from Stage 1 to Stages 2 and 3. Covers at least 1 point for stage 1 to stages 2 and 3.
Level 1 **1-2 marks**	Two stages are covered but stage(s) may be incomplete or may contain inaccuracies **OR** only one stage is covered but is generally correct and virtually complete. Answer includes isolated statements but these are not presented in a logical order.
Level 0	Insufficient correct chemistry to gain a mark

Indicative Chemistry content

Stage 1 names of processes

1a Photosynthesis (is the natural process in plants that takes CO_2 from the air)

1b Fermentation (is the process used to make bioethanol releasing some CO_2)

1c Combustion (is the process where bioethanol is burned and releases CO_2)

Stage 2 Equations

2a $6CO_2 + 6H_2O \rightarrow C_6H_{12}O_6 + 6O_2$

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

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

Stage 3 Carbon neutrality and environmental issues

3a Deforestation / Sacrifice land that could be used for food

3b Loss of biodiversity / habitat

3c $6CO_2$ in and $6CO_2$ out but it isn't actually C neutral as fuel is used in production, distribution, etc

6

[19]

Q7.

B

Biofuel ethanol is purified by fractional distillation

[1]

Q8.

A

[1]

Q9.

(a) This question is marked using levels of response. Refer to the Mark Scheme Instructions for Examiners for guidance on how to mark this question.

Level 3
All stages are covered and the explanation of each stage is generally correct and virtually complete.

Answer communicates the whole process coherently and shows a logical progression through the distillation apparatus. The first two points in stage 1 are in the correct order and all other steps are in a logical order for carrying out the practical.

5-6 marks

Level 2
All stages are covered but the explanation of each stage may be incomplete or may contain inaccuracies.

Answer is mainly coherent and shows a progression through the distillation apparatus.

Some steps in each stage may be out of order and incomplete but the first two points in stage 1 are in the correct order.

3-4 marks

Level 1
Most points are covered but the explanation of each stage may be incomplete or may contain inaccuracies.

Answer includes some isolated statements, but these are not presented in a logical order or show confused reasoning. The first two points in stage 1 are present but not necessarily in the correct order.

1-2 marks

Level 0
Insufficient correct chemistry to warrant a mark.

Omission of heating of the apparatus.

0 marks

Indicative content:

Stage 1

- *Turn on the water.*
- *Heat the flask, with a Bunsen burner.*
- *This causes water and ethanol vapours to be produced.*

Stage 2

- *Vapours pass up the fractionating column A.*
- *Water and ethanol are separated in column A.*
- *Water condenses back into the flask in column A.*

Stage 3

- *Observe the thermometer at B to keep the temperature at or below the boiling point of ethanol.*

  Only ethanol vapour (with a little water) passes into the condenser.
- *Use the condenser at part C to cool the vapours and condense the ethanol back into a liquid.*

(b) Volume of sample = volume of ethanol + volume of water

Let m = mass of ethanol

$20 = m / 0.79 + (16–m) / 1.00$

$1.266m - m = 20 - 16$

1

$0.266m = 4$ so $m = 15$ (g)

1

[8]