1. A student reacted 8.72 g of bromobutane with an excess of OH^-. The student produced 4.28 g of butan-1-ol.

In this reaction the hydroxide ion acts as a nucleophile.

(i) What name is given to this type of reaction?

.....

[1]

(ii) Explain the term *nucleophile*.

.....

[1]

(iii) Outline the mechanism for this reaction.

Show curly arrows and relevant dipoles.

[4]

[Total 6 marks]

2. Bromobutane, $CH_3CH_2CH_2CH_2Br$, can be reacted with hot aqueous sodium hydroxide to prepare butan-1-ol.

$$CH_3CH_2CH_2CH_2Br + OH^- \rightarrow CH_3CH_2CH_2CH_2OH + Br^-$$

The butan-1-ol produced can be analysed by mass spectrometry.

(i) Predict **two** fragment ions that you would expect to see in the mass spectrum of butan-1-ol and state the *m*/*z* value of each ion.

.....

.....

[2]

(ii) State a use of mass spectrometry outside of the laboratory.

.....

[1]

[Total 3 marks]

3. Ethanol, C_2H_5OH, is manufactured on a large scale for a wide range of uses such as alcoholic drinks, as an industrial solvent and as a raw material for the synthesis of many organic compounds.

Ethanol, C_2H_5OH, is manufactured on a large scale by two methods:

- Fermentation, using yeast, of sugars, such as glucose, $C_6H_{12}O_6$.

  $C_6H_{12}O_6(aq) \rightarrow 2C_2H_5OH(aq) + 2CO_2(g)$

  The ethanol is then distilled off.

- Hydration of ethene, C_2H_4, with steam in the presence of an acid catalyst.

  $C_2H_4(g) + H_2O(g) \rightarrow C_2H_5OH(g)$

Compare the sustainability of these methods of manufacturing ethanol in terms of:

- availability of starting materials and energy requirements;
- atom economy.

In your answer, you should make clear how the atom economy of the processes links with chemical theory.

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

[Total 7 marks]

4. In the laboratory, ethanol can be oxidised with acidified potassium dichromate(VI).

(a) The ethanol can be oxidised to form either ethanal, CH_3CHO (**Fig. 1**), or ethanoic acid, CH_3COOH (**Fig. 2**).

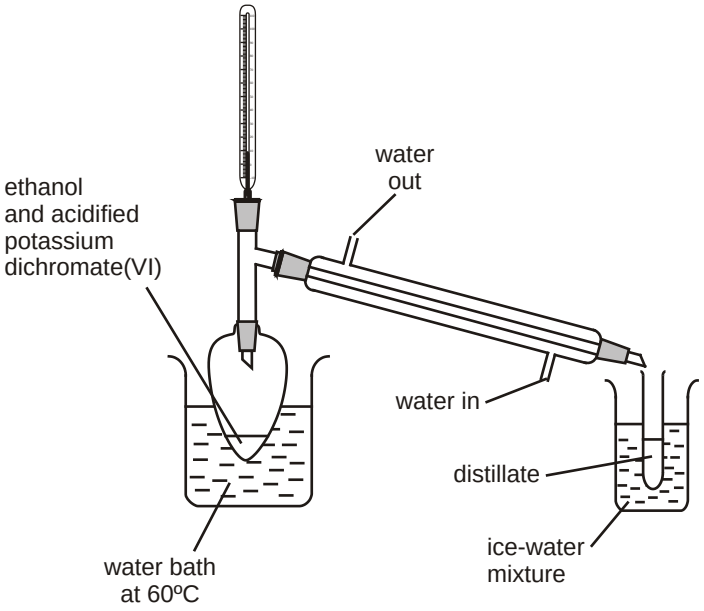


Fig. 1

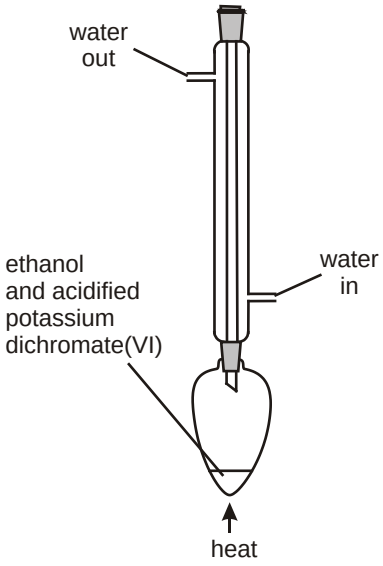


Fig. 2

The boiling points of ethanol, ethanal and ethanoic acid are given in the table below.

	CH_3CH_2OH	CH_3CHO	CH_3COOH
boiling point / °C	8	21	118

Use this table of boiling points to explain:

(i) why the organic product is likely to be ethanal if the apparatus shown in **Fig. 1** is used,

.....

.....

[2]

(ii) why the organic product is likely to be ethanoic acid if the apparatus shown in **Fig. 2** is used.

.....

.....

[2]

(b) Write a balanced equation for the oxidation of ethanol to ethanoic acid. Use [O] to represent the oxidising agent.

.....

[2]

[Total 6 marks]

5. Ethanol can be formed by fermentation of glucose, $C_6H_{12}O_6$.

(i) Write a balanced equation, including state symbols, for the formation of ethanol by fermentation.

.....

[2]

(ii) Fermentation only occurs in the presence of yeast. State **two** other essential conditions.

.....

.....

[2]

(iii) How would you know when fermentation of glucose is complete?

.....

.....

[1]

[Total 5 marks]

6. (a) Propan-2-ol can be formed by the hydration of an alkene in the presence of a catalyst.

(i) Suggest a suitable catalyst for this reaction.

.....

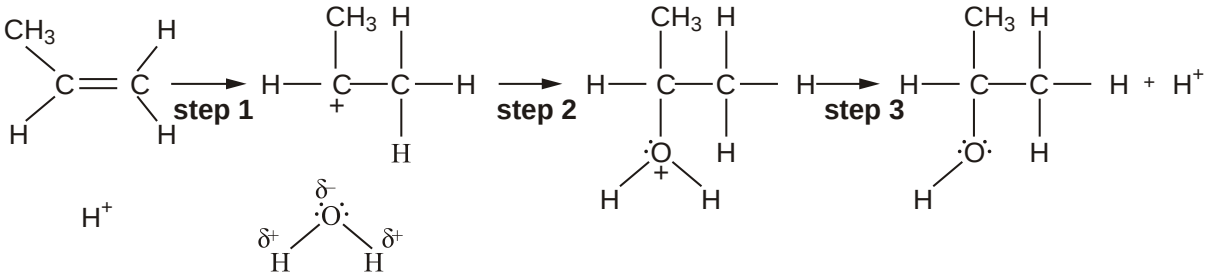
[1]

(ii) This is an electrophilic addition reaction. What is meant by the term *electrophile*?

.....

[1]

(b) A mechanism for the reaction in (a) is shown below.



(i) Add 'curly arrows' to the mechanism to show the movement of electron pairs in steps **1**, **2** and **3**.

[3]

(ii) Suggest, with a reason, the role of the H^+.

.....

[1]

[Total 6 marks]

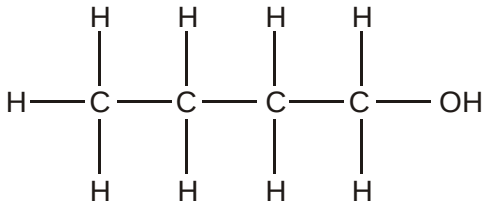
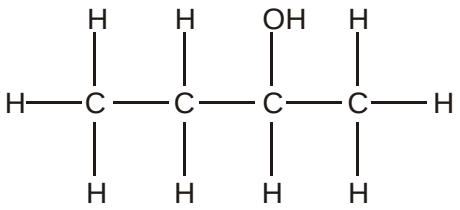
7. Propan-2-ol is flammable and readily burns.

Write a balanced equation for the complete combustion of propan-2-ol.

.....

[Total 2 marks]

8. Four possible structural isomers of $C_4H_{10}O$ are alcohols. Two are shown below.

	
butan-1-ol	butan-2-ol

(i) Draw the other two structural isomers of $C_4H_{10}O$ that are alcohols

isomer 1	isomer 2

[2]

(ii) Name isomer 1. .....

[1]

[Total 3 marks]

9. Butan-2-ol can be dehydrated to produce a mixture of three alkenes each with a molecular formula C_4H_8.

Draw the displayed formula for each of the three alkenes.

[Total 3 marks]

10. (a) Butan-1-ol can be oxidised to form butanal.

(i) State a suitable oxidising mixture for this reaction.

.....

[2]

(ii) State the colour change you would see during this oxidation.

from ..... to .....

[1]

(b) A sample of the butanal from (a) was analysed using infra-red spectroscopy. The infra-red spectrum contained an absorption in the region 1680–1750 cm^{-1} but did **not** contain a broad absorption in the region 2500–3300 cm^{-1}.

Refer to the Data Sheet for Chemistry provided.

(i) What does the absorption in the region 1680–1750 cm^{-1} indicate?

.....

[1]

(ii) What does the absence of a broad absorption in the region 2500–3300 cm^{-1} indicate?

.....

[1]

(iii) The reaction in (a) was carried out using distillation and **not** reflux.

Explain why.

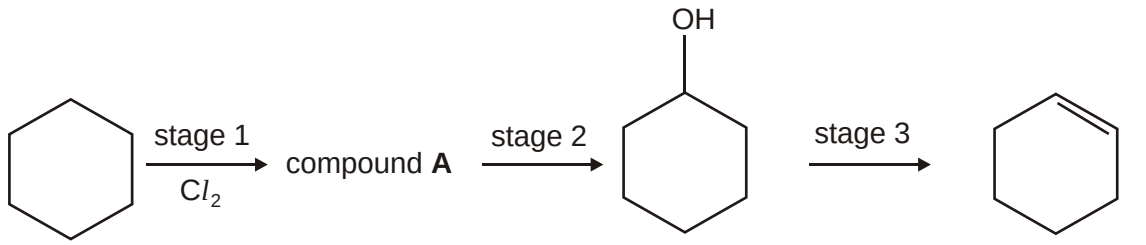
.....

.....

[2]

[Total 7 marks]

11. (a) Cyclohexane can be converted into cyclohexene via a three-stage synthesis.



cyclohexane **cyclohexanol** **cyclohexene**

(i) In stage 1, cyclohexane reacts with chlorine to form the organic product, compound **A**.

Show the structure of compound **A**.

[1]

(ii) Stage 3 involves the dehydration of an alcohol.

State a suitable reagent for dehydrating an alcohol.

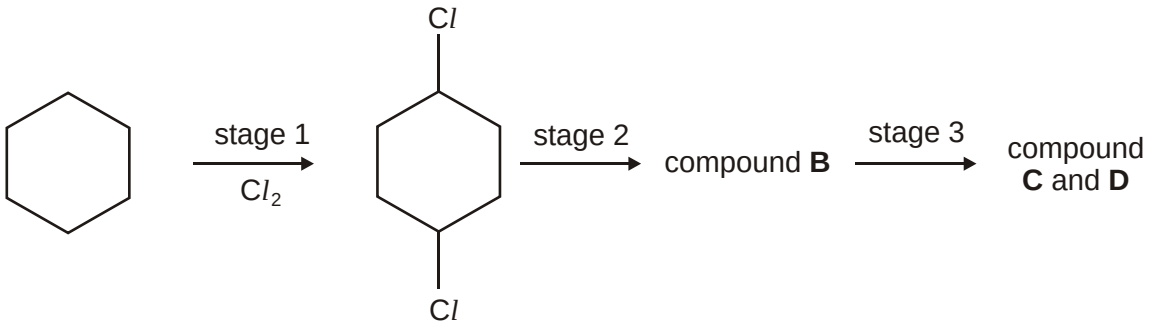
.....

[1]

(iii) Write a balanced equation for the dehydration of cyclohexanol, $C_6H_{11}OH$.

[1]

(b) The reaction in stage 1 is difficult to control. One other possible chlorinated product is 1,4-dichlorocyclohexane.This is shown below.



cyclohexane **1,4-dichlorocyclohexane**

1,4-Dichlorocyclohexane reacts in the same way as compound **A** in stages 2 and 3.

(i) Suggest the structure of compound **B**.

[1]

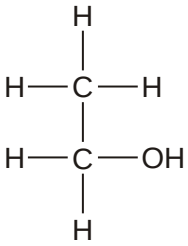
(ii) Two cyclic alkenes, **C** and **D** are formed in stage 3. **C** and **D** are structural isomers. Suggest the structures of **C** and **D**.

[2]

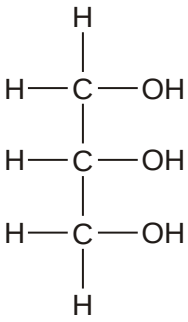
[Total 6 marks]

12. Ethanol and glycerol (propane-1,2,3-triol) are both produced industrially on a large scale.

Ethanol is manufactured by both fermentation and the hydration of ethene.
Glycerol is produced as a by-product of soap manufacture.



ethanol



glycerol

The relatively low volatility of alcohols such as ethanol can be explained by the existence of intermolecular bonds.

(i) Explain what is meant by the terms:

low volatility, ...

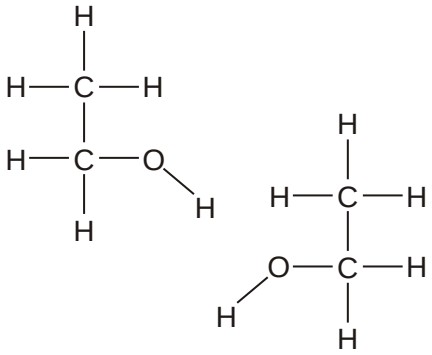
.....

intermolecular bonds .....

.....

[2]

(ii) On the ethanol molecules below, label any relevant dipoles, show the intermolecular bond formed and state the type of intermolecular bond.



type of intermolecular bond .....

[3]

(iii) Glycerol forms the same type of intermolecular bonds as ethanol. Predict, with a reason, whether the boiling point of glycerol will be higher or lower than that of ethanol.

The boiling point of glycerol will be ..... than that of ethanol because

.....

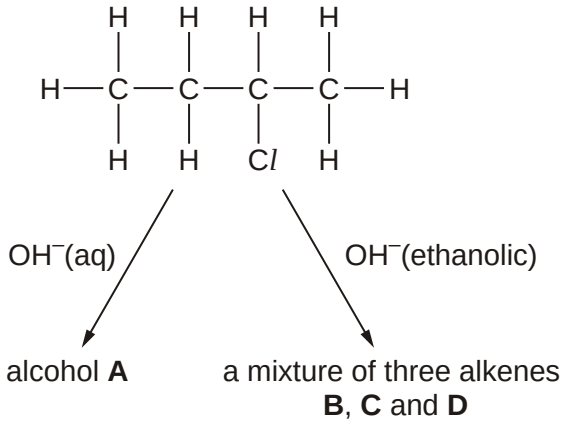
.....

[1]

[Total 6 marks]

13. This question is about the halogenoalkane 2-chlorobutane.

2-Chlorobutane reacts with NaOH, but the products are dependent on the solvent used.



2-Chlorobutane reacts with OH^- in aqueous conditions to produce alcohol **A**.

(i) Identify alcohol **A**.

[1]

(ii) Describe, with the aid of curly arrows, the movement of the electrons in the mechanism. Show any relevant dipoles, lone pairs of electrons and the products.

[4]

[Total 5 marks]

14. Compound **E** can be oxidised to form a carboxylic acid.

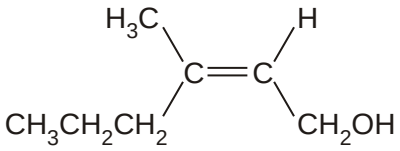
(i) State a suitable oxidising mixture for this reaction.

.....

[2]

(ii) Write a balanced equation for this oxidation of compound **E**.

Use [O] to represent the oxidising mixture.



compound **E**

[3]

(iii) Explain how compound **E** and the carboxylic acid could be distinguished by infra-red spectroscopy.

.....

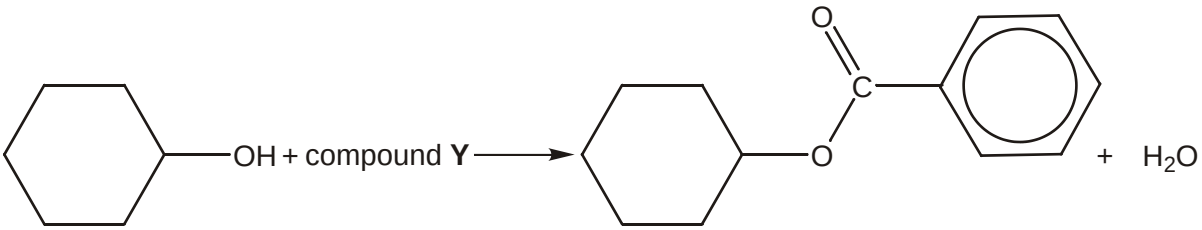
.....

[1]

[Total 6 marks]

15. (a) In the presence of a suitable catalyst, cyclohexanol reacts with compound **Y**.

The organic product is shown in the equation below.



organic product

(i) State a suitable catalyst.

.....

[1]

(ii) Identify compound **Y**.

[1]

(b) Cyclohexanol can also be oxidised to form cyclohexanone.

(i) State a suitable oxidising agent for this reaction.

.....

[1]

(ii) Write a balanced equation for the oxidation of cyclohexanol to cyclohexanone. Use [O] to represent the oxidising agent.

[1]

[Total 4 marks]

16. Trifluorochloromethane, CF_3Cl, is an example of a chlorofluorocarbon, CFC, that was commonly used as a propellant in aerosols. Nowadays, CFCs have limited use because of the damage caused to the ozone layer.

(i) Draw a diagram to show the shape of a molecule of CF_3Cl.

[1]

(ii) Predict an approximate value for the bond angles in a molecule of CF_3Cl.

bond angle .....

[1]

(iii) Suggest a property that made CF_3Cl suitable as a propellant in an aerosol.

.....

[1]

(iv) When CFCs are exposed to strong ultraviolet radiation in the upper atmosphere, homolytic fission takes place to produce free radicals.

Explain what is meant by the term *homolytic fission*.

.....

.....

[2]

(v) Suggest which bond is most likely to be broken when CF_3Cl is exposed to ultraviolet radiation. Explain your answer.

bond .....

reason .....

[1]

(vi) Identify the **two** free radicals most likely to be formed when CF_3Cl is exposed to ultraviolet radiation.

..... and .....

[2]

[Total 8 marks]

17. Ethanol, C_2H_5OH, can be produced by the fermentation of glucose, $C_6H_{12}O_6$.

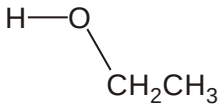
Write a balanced equation for the fermentation of glucose.

.....

[Total 2 marks]

18. Ethanol has a relatively high boiling point. This can be explained in terms of intermolecular hydrogen bonds.

Draw a second molecule of ethanol alongside the one drawn below and show how a hydrogen bond could be formed. Clearly show any relevant dipoles and lone pairs of electrons.



[Total 3 marks]

19. (a) When ethanol is heated with acidified potassium dichromate(VI) solution, it can be oxidised to form either ethanal, CH_3CHO (Fig. 1), or ethanoic acid, CH_3COOH (Fig. 2).

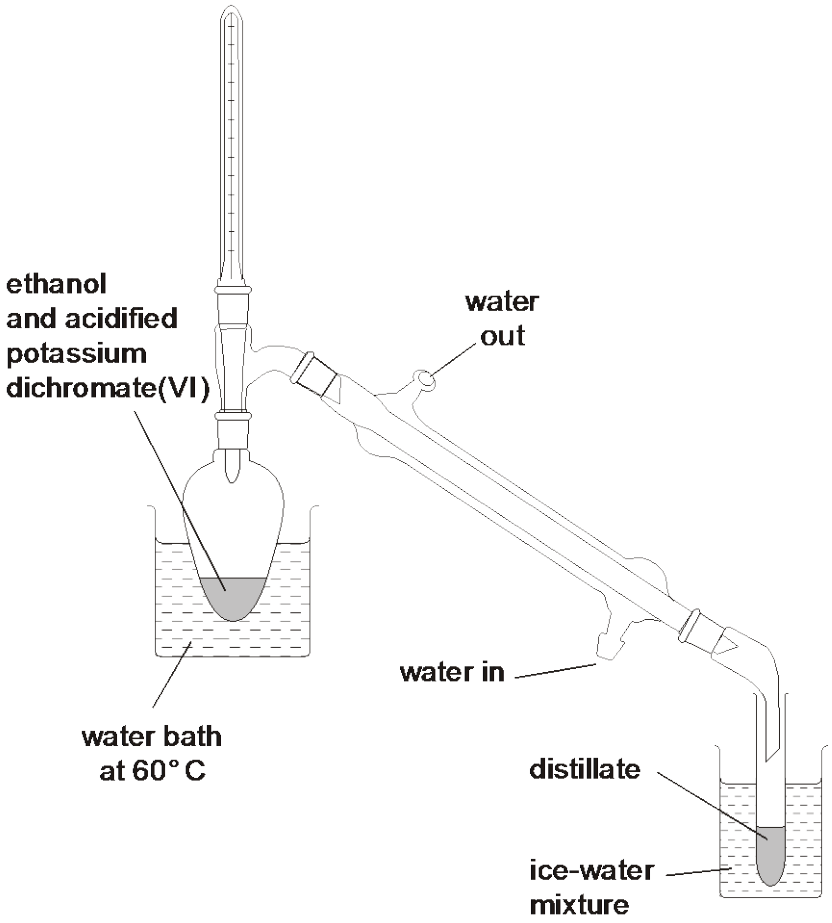


Fig. 1

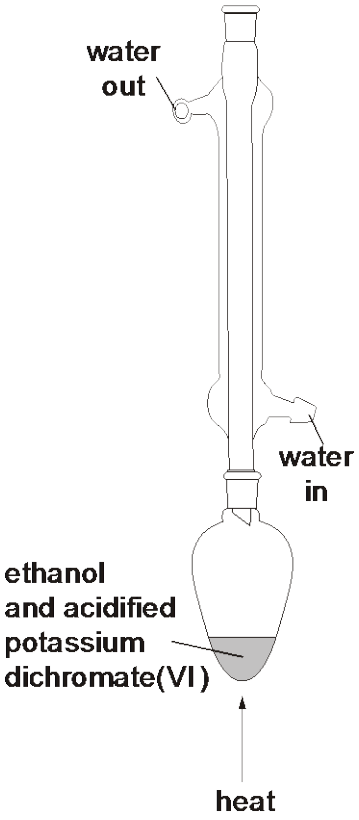


Fig. 2

The boiling points of ethanol, ethanal and ethanoic acid are given in the table below.

	CH_3CH_2OH	CH_3CHO	CH_3COOH
boiling point/ °C	78	21	118

Use this table of boiling points to explain

(i) why the organic product is likely to be ethanal if the apparatus shown in Fig. 1 is used,

.....

.....

[2]

(ii) why the organic product is likely to be ethanoic acid if the apparatus shown in Fig. 2 is used.

.....

.....

[2]

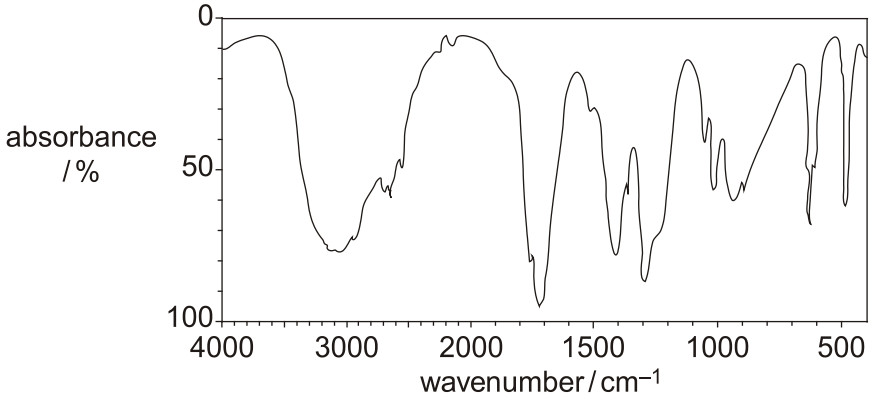
(b) Write a balanced equation for the oxidation of ethanol to ethanoic acid. Use (O) to represent the oxidising agent.

.....

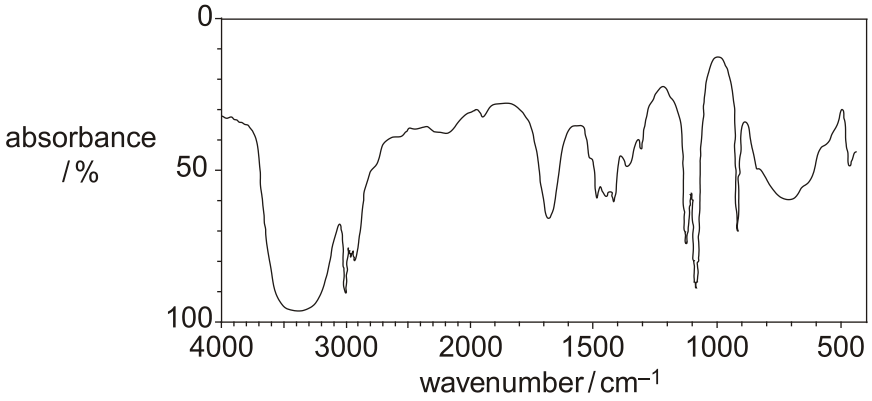
[2]

(c) The ethanal collected using the apparatus shown in Fig. 1 was analysed by infra-red spectroscopy. Use your *Data Sheet* to justify which of the three spectra shown below is most likely to be that of ethanal.

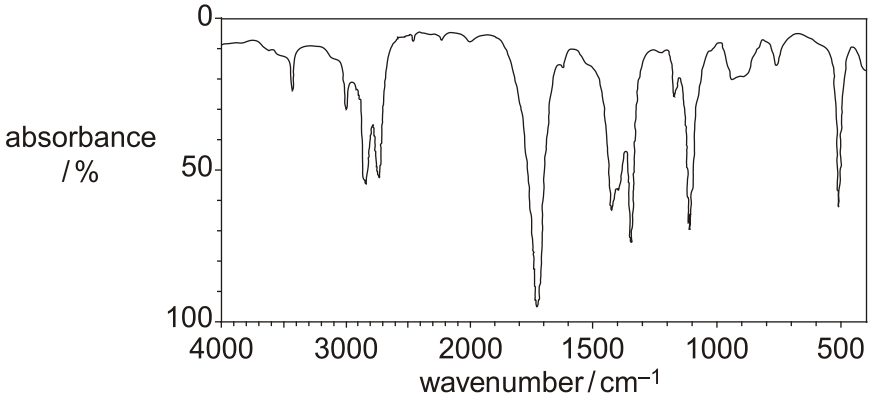
spectrum **A**



spectrum **B**



spectrum **C**



The organic product collected when using the apparatus shown in Fig. 1 is most likely to be that shown by spectrum ..... because.....

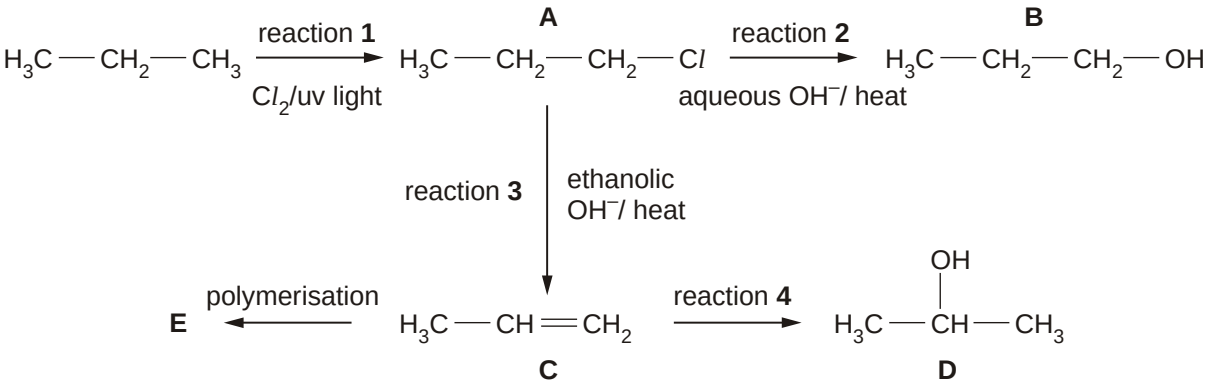
.....

.....

[3]

[Total 9 marks]

20. Propane, C_3H_8, is used in the reaction sequence shown below.



(a) The reaction sequence shows several important reaction mechanisms. Select from reactions **1** to **4**, the reaction that shows

(i) free radical substitution, reaction .....

[1]

(ii) electrophilic addition, reaction .....

[1]

(iii) elimination, reaction .....

[1]

(b) In reaction **2**, the aqueous OH^- acts as a nucleophile.

(i) State what is meant by the term *nucleophile*.

.....

[1]

(ii) Complete, with the aid of curly arrows, the mechanism involved in reaction **2**. Show any relevant dipoles.

$H_3C — CH_2 — CH_2 — Cl \longrightarrow H_3C — CH_2 — CH_2 — OH \quad + \quad .....$

OH^-

[4]

(c) Compounds **B** and **D** are structural isomers of each other.

(i) State what is meant by the term *structural isomers*.

.....

.....

[2]

(ii) Draw the skeletal formulae of compounds **B** and **D**.

Compound **B**	Compound **D**

[2]

(d) Compound **C** can be polymerised to form compound **E**.

(i) State the type of polymerisation. .....

[1]

(ii) Name compound **E**. .....

[1]

(iii) Draw a section of compound **E**. Show **two** repeat units.

[1]

[Total 15 marks]

21. Acrolein, $CH_2{=}{=}CHCHO$, and acrylic acid, $CH_2{=}{=}CHCOOH$, are both used in industry

for the manufacture of plastic resins and polymers. Both acrolein and acrylic acid can be made from prop-2-en-1-ol, $CH_2{=}{=}CHCH_2OH$.

(a) (i) Draw the structures of prop-2-en-1-ol and acrolein. Clearly display the functional groups in each compound.

prop-2-en-1-ol	**acrolein**

[2]

(ii) Name the functional group common to **both** prop-2-en-1-ol and acrolein.

.....

[1]

(b) Prop-2-en-1-ol can be oxidised to form either acrolein or acrylic acid.

(i) Identify a suitable oxidising mixture.

.....

[2]

(ii) Write a balanced equation for the oxidation of prop-2-en-1-ol into acrolein. Use (O) to represent the oxidising agent.

.....

[1]

[Total 6 marks]

22. Acrylic acid reacts with prop-2-en-1-ol to produce an ester.

(i) Complete the balanced equation for this reaction.

$CH_2{=}{=}CHCOOH + CH_2{=}{=}CHCH_2OH \rightarrow$ ..... + ...

[2]

(ii) Draw the structure of the ester. Clearly display **all** of the functional groups.

[2]

[Total 4 marks]

23. In this question, one mark is available for the quality of spelling, punctuation and grammar.

The rates of hydrolysis of chloroethane, bromoethane and iodoethane are different.

- Describe how you would monitor the reaction rates.
- Explain why chloroethane, bromoethane and iodoethane react at different rates.

Use suitable equations in your answer.

[Total 6 marks]

24. In 1930, an American engineer, Thomas Midgley, demonstrated a new refrigerant. As part of his demonstration, he inhaled a lung full of dichlorodifluoromethane, CCl_2F_2, and used it to blow out a candle.

Use Midgley's demonstration to suggest **two** properties of CCl_2F_2. Explain, with a reason, **two** other uses of chemicals such as CCl_2F_2, other than as a refrigerant.

.....

.....

.....

.....

.....

.....

.....

.....

.....

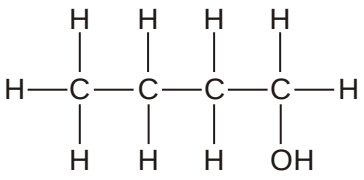
.....

.....

[Total 4 marks]

25. (a) There are four structural isomers of $C_4H_{10}O$ that are alcohols. One of the isomers has been drawn for you.

Complete the table below to show the other structural isomers.

			
butan-1-ol	isomer **1**	isomer **2**	isomer **3**

[3]

(b) Butan-1-ol is oxidised by an acidified solution of potassium dichromate(VI) to form a carboxylic acid.

(i) State the colour change that you would see.

Colour changes from ……..…… to ……..…….....

[1]

(ii) Write a balanced equation for this oxidation of butan-1-ol to form a carboxylic acid. Use [O] to represent the oxidising agent.

.....

[2]

(iii) Identify which of the isomers, **1**, **2** or **3**, in (a) could also be oxidised to form a carboxylic acid.

isomer …….....

[1]

(c) Butan-1-ol reacts with hot concentrated sulphuric acid to form compound **B**.

(i) Compound **B** has an empirical formula of CH_2 and a relative molecular mass of 56. Use this information to deduce the molecular formula of compound **B**. Show your working.

[2]

(ii) Write a balanced equation to show the conversion of butan-1-ol into compound **B**.

.....

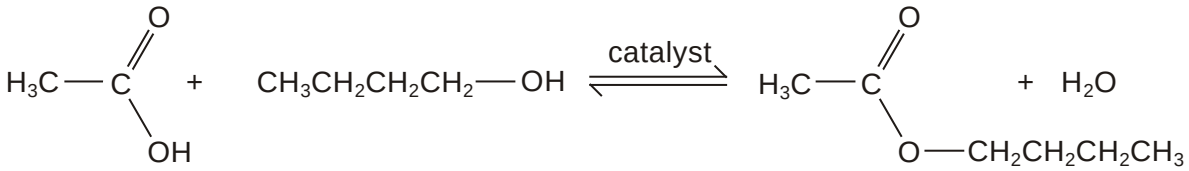
[1]

(iii) One of the isomers, **1**, **2** or **3**, in (a) also reacts with hot concentrated sulphuric acid to form compound **B**.

Identify which isomer. isomer …….....

[1]

(d) The ester, $CH_3COOCH_2CH_2CH_2CH_3$, was formed by reacting ethanoic acid with butan-1-ol.



butan-1-ol **ester**
M_r = 116

(i) State a catalyst for this reaction.

.....

[1]

(ii) In an experiment, 6.96 g of the ester was produced from 0.100 mol of butan-1-ol.
Calculate the number of moles of ester produced.

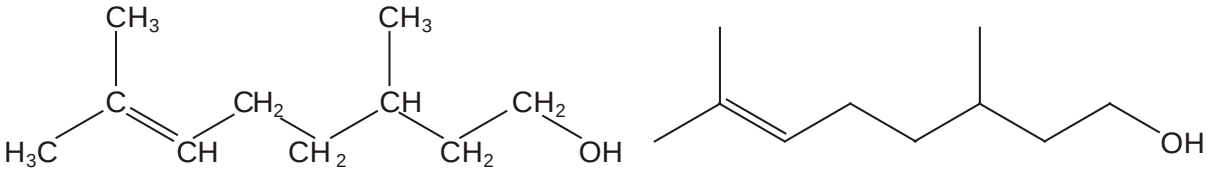
[1]

(iii) Calculate the percentage yield.

[1]

[Total 14 marks]

26. Citronellol, $C_{10}H_{20}O$, occurs naturally in both rose and geranium oils. The structural and skeletal formulae of citronellol are shown below.



structural formula **skeletal formula**

(a) Name the **two** functional groups present in citronellol.

…….....……..…… and .....

[2]

(b) The functional groups in citronellol can be identified either by chemical tests or by infrared spectroscopy.

(i) State which of the two functional groups you named in (a) is:

1 identified when bromine is added to citronellol, ...

2 more easily identified from the infra-red spectrum. .....

[1]

(ii) State what you would **see** when bromine is added to citronellol.

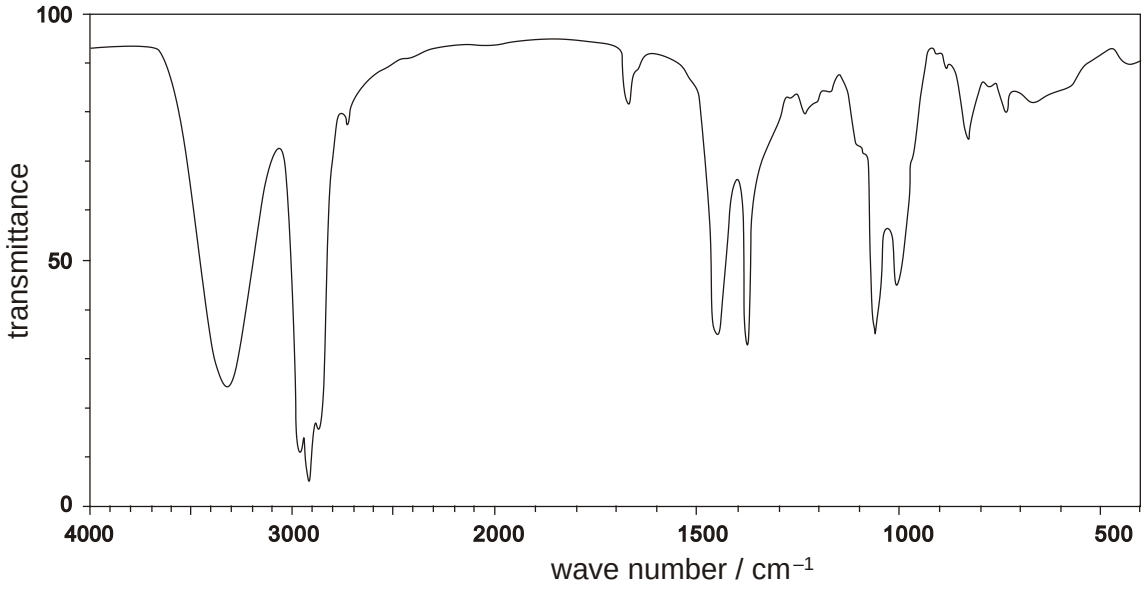
.....

[1]

(iii) Draw the skeletal formula of the organic product formed when bromine is added to citronellol.

[1]

(iv) The infra-red spectrum of citronellol is shown below. Mark on this spectrum, with the letter **X**, the absorption that confirms the presence of the functional group that is most easily identified from this spectrum.



[1]

(c) Reaction of a sample of citronellol, $C_{10}H_{20}O$, with hydrogen in the presence of a catalyst results in the formation of a saturated compound **C**.

(i) Suggest a catalyst for this reaction.

.....

[1]

(ii) Determine the molecular formula of the saturated compound **C**.

.....

[1]

(iii) Construct a balanced equation for this reaction.

.....

[1]

[Total 9 marks]

27. (a) Write an equation for the combustion of ethanol.

.....

[2]

(b) In this question, one mark is available for the quality of written communication.

Describe, with the aid of equations, the industrial manufacture of ethanol from glucose, $C_6H_{12}O_6$, and from ethene, C_2H_4. Name each type of reaction and state all essential conditions.

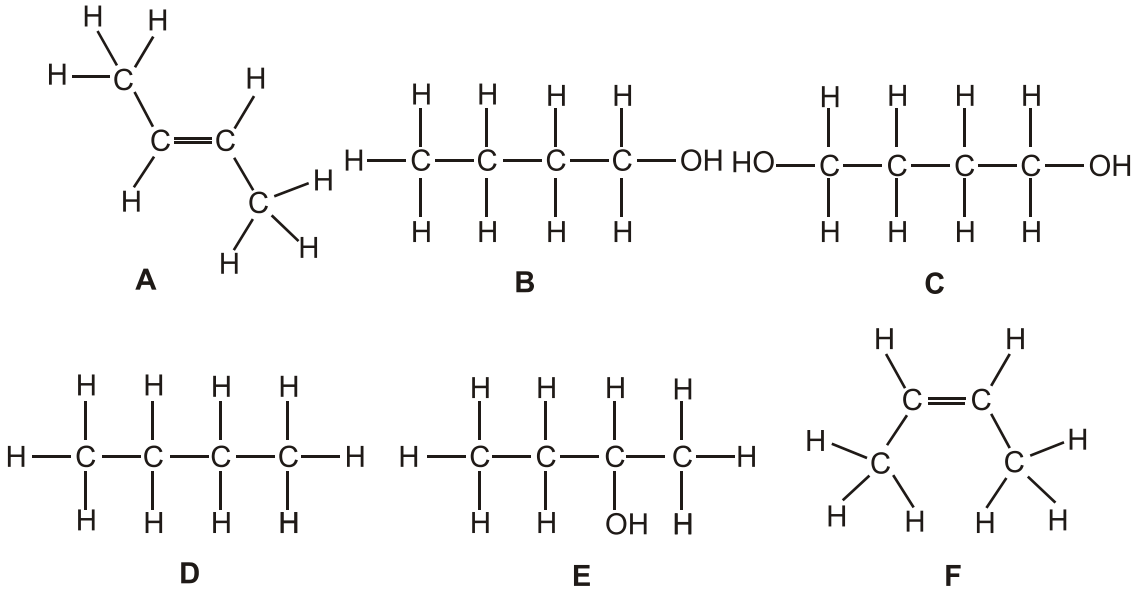
Future supplies of ethanol are likely to come from glucose rather than from ethene. Explain why.

[9]

Quality of Written Communication [1]

[Total 12 marks]

28. This question is about the compounds **A-F** below.



(a) Answer the following questions by referring to the compounds **A-F**.

(i) What is the molecular formula of compound **D**?

.....

[1]

(ii) What is the empirical formula of compound **C**?

.....

[1]

(iii) Which two compounds are structural isomers of each other?

..... and .....

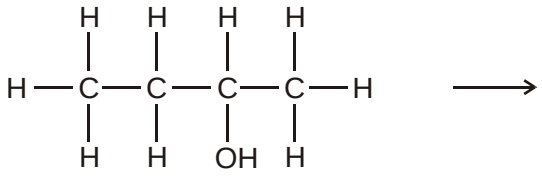
[1]

(iv) Which two compounds are *cis-trans* isomers of each other?

..... and .....

[1]

(b) Compound **E** can be dehydrated to form compound **A**. Complete a balanced equation for this reaction.



[1]

(c) Compound **C** can be dehydrated to form a new compound, **G**, with the molecular formula, C_4H_6. Suggest a structural formula and a name for **G**.

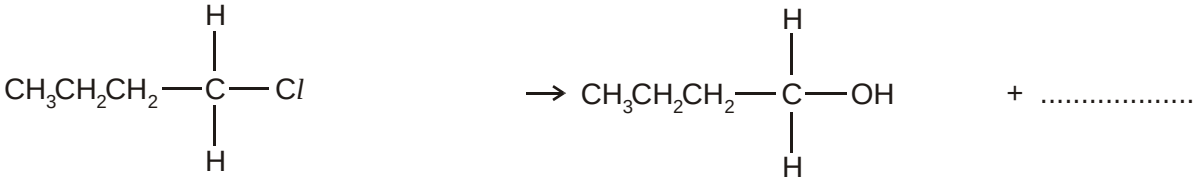
name .....

[2]

[Total 7 marks]

29. Halogenoalkanes, such as 1-chlorobutane, are hydrolysed with hot aqueous alkali, $OH^-(aq)$, to form alcohols.

(a) Describe, with the aid of curly arrows, the mechanism of the hydrolysis of 1-chlorobutane with $OH^-(aq)$ ions to produce butan-1-ol. Show any relevant lone pairs of electrons and dipoles.



[4]

(b) Another halogenoalkane, **H**, has a relative molecular mass of 127 and has the following composition by mass:
C, 37.8%; H, 6.3%; C*l*, 55.9%.

(i) Show that the empirical formula of compound **H** is C_2H_2Cl.

[2]

(ii) Deduce the molecular formula of compound **H**.

[1]

(iii) Compound **H** can also be hydrolysed with hot aqueous alkali to form butane-1,3-diol. Draw the structure of butane-1,3-diol

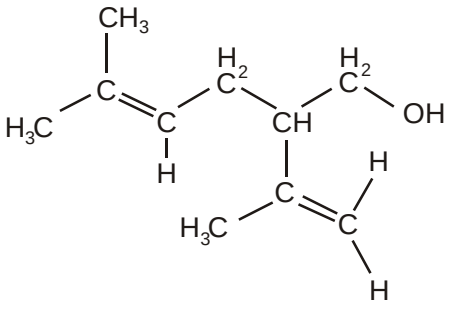
[1]

(iv) Deduce the structure of compound **H**.

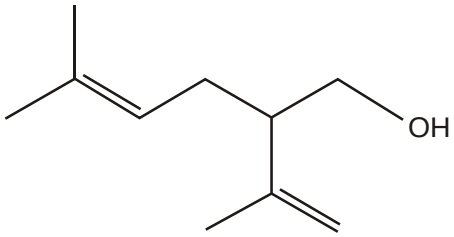
[1]

[Total 9 marks]

30. Lavandulol, $C_{10}H_{18}O$, is a fragrant oil which is found in lavender. The structural and the skeletal formulae of lavandulol are shown below.



structural formula



skeletal formula

(a) (i) Identify **two** different functional groups in lavandulol.

..... and .....

[2]

(ii) Why does lavandulol **not** have *cis-trans* isomerism?

.....

.....

[1]

(b) Lavandulol, $C_{10}H_{18}O$, also reacts with bromine to form a saturated organic product.

State what you would see in this reaction and deduce the molecular formula of the organic product.

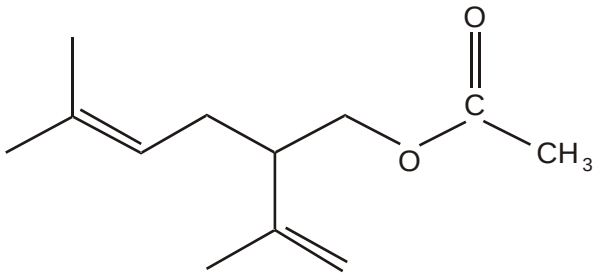
observation .....

[1]

molecular formula .....

[2]

(c) Lavandulol could be converted into an ester **X**, which is also found in lavender oil.



ester **X**

State a reagent and a catalyst that could be used to form ester **X** from lavandulol.

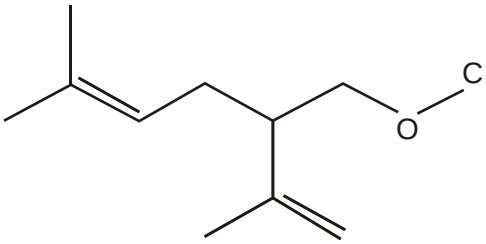
reagent .....

[1]

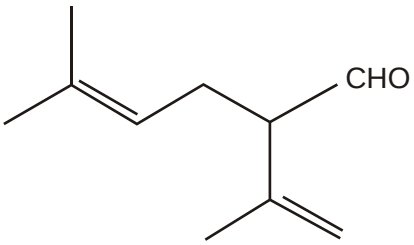
catalyst .....

[1]

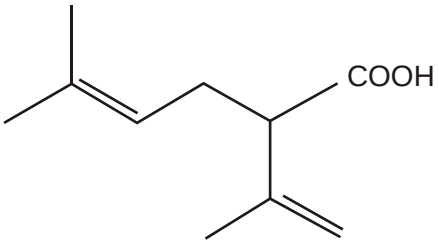
(d) Lavanduloi can be oxidised to produce either compound **Y** or compound **Z**.



lavandulol
$C_{10}H_{18}O$



compound **Y**
$C_{10}H_{16}O$



compound **Z**
$C_{10}H_{16}O_2$

(i) Write a balanced equation for the oxidation of lavandulol to produce compound **Z**. Use the molecular formulae given above and use [O] to

represent the oxidising agent.

.....

[2]

(ii) An infra-red spectrum of either compound **Y** or compound **Z** was obtained and was found to contain an absorption between 1680 – 1750 cm^{-1}. However, there was no broad absorption between 2500 – 3300 cm^{-1}.

By referring to your *Data Sheet*, use this information to deduce whether the infra-red spectrum was of compound **Y** or of compound **Z**. Show your reasoning.

The infra-red spectrum was of compound ..... because .....

.....

.....

.....

[2]

[Total 12 marks]