1. Haloalkanes can undergo hydrolysis.

A student carries out an experiment to find the relative rate of hydrolysis of 1-chloropropane, C_3H_7Cl, 1-bromopropane, C_3H_7Br, and 1-iodopropane, C_3H_7I.

The student adds 2 cm^3 of ethanol to 2 cm^3 of aqueous silver nitrate to three test tubes labelled **A**, **B** and **C**.

The student adds 5 drops of a different haloalkane to each test-tube in rapid succession and shakes each tube. The student measures the time for a precipitate to form in each test-tube.

The results are shown below.

Test tube	Haloalkane	Time taken for reaction to take place
A	C_3H_7Cl	about half an hour
B	C_3H_7Br	a few minutes
C	C_3H_7I	a few seconds

i. Write an **ionic** equation involving aqueous silver nitrate for formation of **one** of the precipitates.

[1]

ii. What do the experimental results tell you about the carbon–halogen bond enthalpies?

[1]

iii. How could the student modify their experiment so that it could be completed in less time?

[1]

2. CN^- ions react with haloalkanes and with carbonyl compounds.

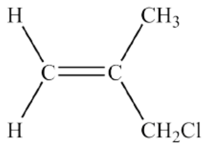
Which row gives the correct mechanisms for the reactions?

	Reaction of CN^- with haloalkanes	**Reaction of CN^- with carbonyl compounds**
A	Electrophilic substitution	Electrophilic addition
B	Electrophilic substitution	Nucleophilic addition
C	Nucleophilic substitution	Electrophilic addition
D	Nucleophilic substitution	Nucleophilic addition

Your answer ☐

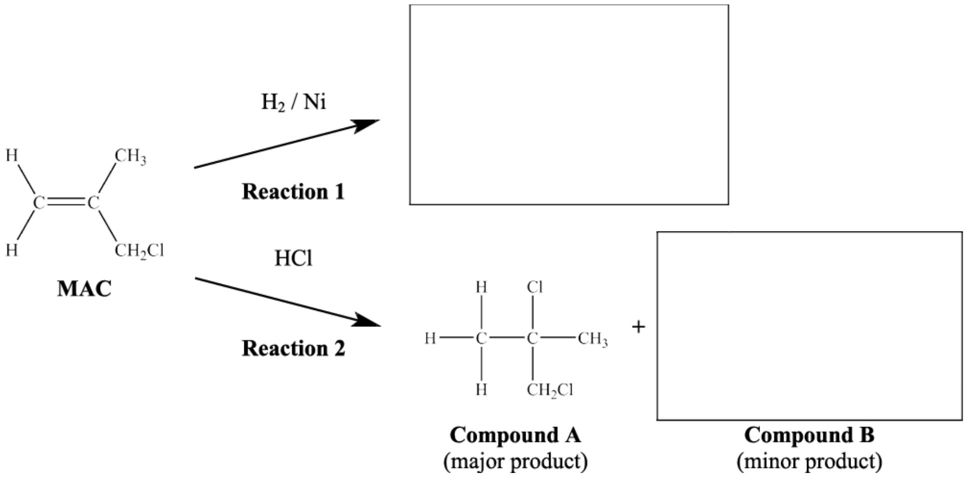
[1]

3. Methyl allyl chloride, MAC, is a chemical used in the production of insecticides. The structure of MAC is shown below.



MAC

The flowchart below shows some reactions of MAC.



i. Complete the flowchart above.
  - Draw the structure of the product of **Reaction 1**.
  - Draw the structure of the minor organic product of **Reaction 2** (Compound **B**).

[2]

ii. **Reaction 2** creates a mixture of compounds. Compound **A** is the major product.

Draw the mechanism for the formation of compound **A**.

Use curly arrows and show relevant dipoles.

[3]

iii. Explain why compound **B** is the minor product of **Reaction 2**.

[1]

iv. **MAC** reacts with water in the presence of $AgNO_3$(aq) and ethanol.

Draw the structure of the organic product of this reaction.

State what you would **observe** in this reaction and identify the compound responsible for the observation.

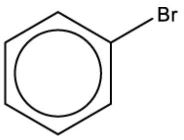
[2]

4. An organic compound is heated with aqueous silver nitrate and ethanol.

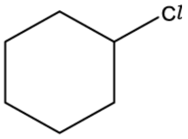
A cream solid forms.

Which structure is most likely to be the organic compound?

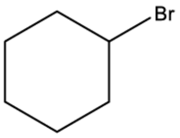
A



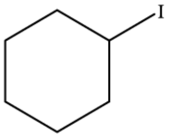
B



C



D



Your answer ☐

[1]

5. A chemist investigates the rate of hydrolysis of the haloalkanes.

Which of the following statements is / are true?

1: A fluoroalkane gives the slowest rate of hydrolysis.

2: The rate of reaction depends on the strength of the carbon–halogen bond.

3: The rate of reaction depends on the polarity of the carbon–halogen bond.

A. 1, 2 and 3
B. Only 1 and 2
C. Only 2 and 3
D. Only 1

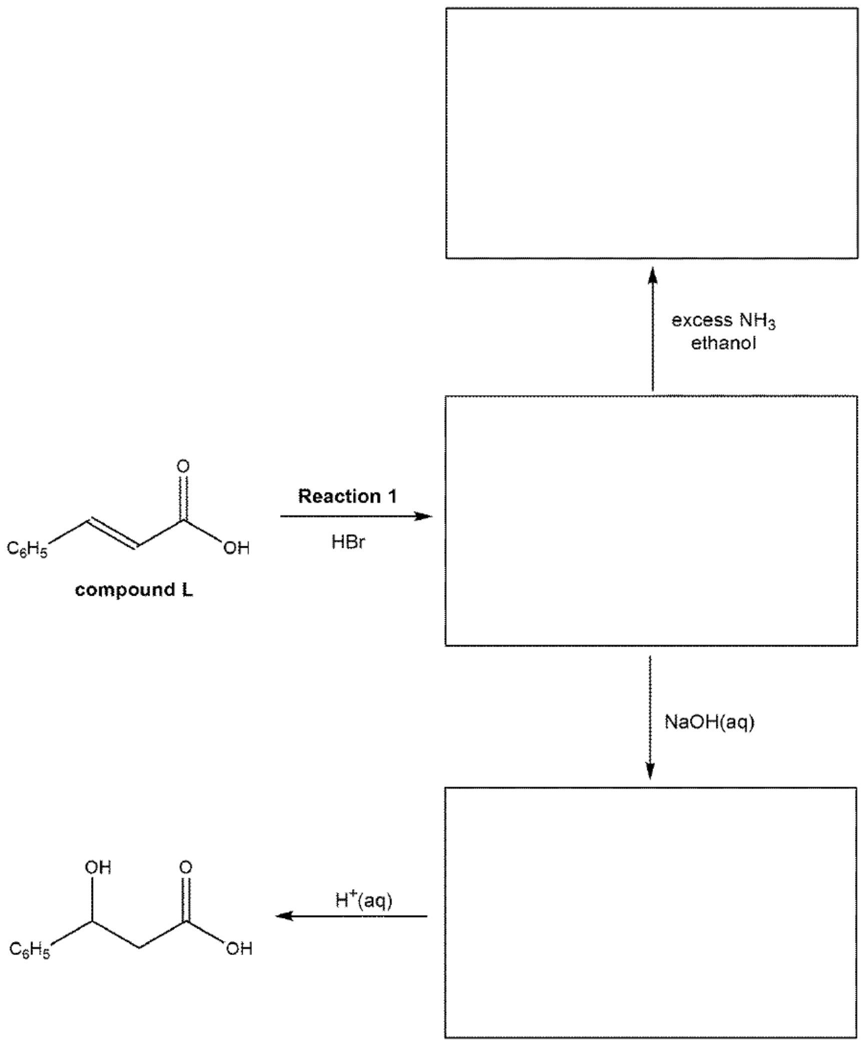
Your answer ☐

[1]

6(a). This question is about the reactions of compounds with more than one functional group.

A chemist investigates some reactions of compound **L**, as shown in the flowchart below.

Complete the flowchart by showing the missing organic structures in the boxes.



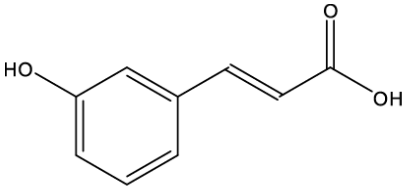
[3]

(b). Outline the mechanism that occurs in **Reaction 1**.

Include curly arrows, relevant dipoles and the name of the mechanism.

name of mechanism .... **[4]**

(c). The chemist synthesises compound **M**, which can undergo both addition and condensation polymerisation.



compound M

i. Draw the repeat unit of the **addition** polymer formed from compound **M**.

[1]

ii. Draw **two** repeat units of the **condensation** polymer formed from compound **M**.

[2]

7(a). Ethers are a homologous series of organic compounds containing the R−O−R functional group.

The structures and names of two ethers are shown in **Fig. 4.1.**

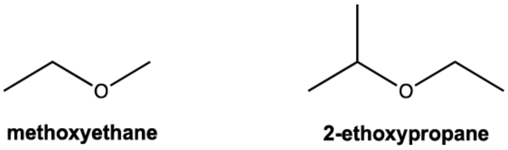


Fig. 4.1

Draw the **skeletal** formula of the ether, 2-ethoxy-3-methylbutane.

[1]

(b). Ethers can be prepared by nucleophilic substitution of haloalkanes with alkoxide ions, RO^-.

i. Alkoxide ions can be prepared by reacting sodium with an alcohol. A gas is also formed.

Write an equation for the formation of methoxide ions from sodium and an alcohol.

[1]

ii. Methoxyethane, shown in **Fig. 4.1**, can be prepared by reacting bromoethane, CH_3CH_2Br, with methoxide ions, CH_3O^-.

Suggest the mechanism for the nucleophilic substitution of CH_3CH_2Br with CH_3O^-.

Show curly arrows, charges, relevant dipoles, and products.

[3]

iii. In this mechanism, explain how CH_3O^- ions have acted as a nucleophile.

State the type of bond fission that takes place.

____

____

[1]

(c). 2-Ethoxypropane, shown in **Fig. 4.1**, is analysed by ^1H NMR spectroscopy.

Complete the table to predict the ^1H NMR spectrum of 2-ethoxypropane.

You may **not** need to use all the rows.

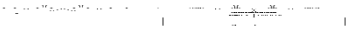
Chemical shift, δ/ppm	Relative peak area	Splitting pattern

[4]

(d). In organic reactions, alkoxide ions can also act as a base.

The diagram below shows an incomplete mechanism for the reaction of a diester with methoxide ions, CH_3O^- (**Step 1**), followed by reaction of the intermediate with bromoethane (**Step 2**).

i. For **Step 1**, add curly arrows to show how CH_3O^- reacts with the diester to form the intermediate. In the box, draw the structure of the organic product formed in **Step 2**.



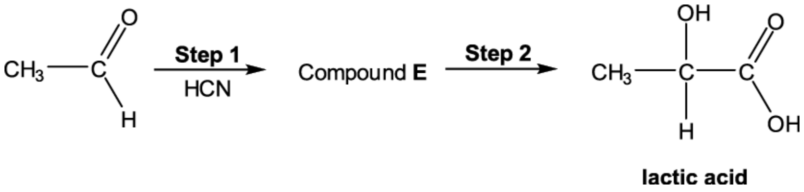
[3]

ii. Explain how CH_3O^- ions have acted as a base in this mechanism.

____

[1]

8(a). Lactic acid is a naturally occurring chemical, which can be synthesised from ethanal, CH_3CHO, as shown in the steps below.



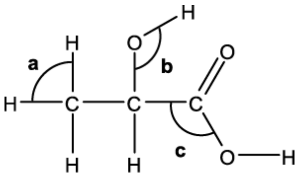
i. Draw the structure for compound **E**.

[1]

ii. Suggest a reagent that could be used for **Step 2**.

[1]

iii. The displayed formula of lactic acid is shown below.



lactic acid

Suggest a value for each bond angle **a–c**.

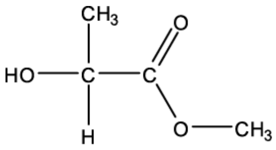
Bond angle **a**: ....

Bond angle **b**: ....

Bond angle **c**: ....

[2]

(b). Methyl lactate is an ester of lactic acid which is used as a solvent.



methyl lactate

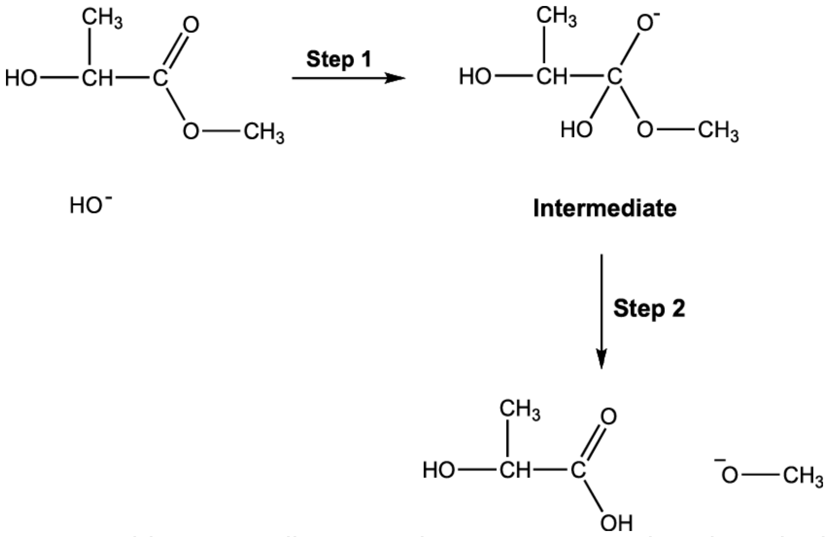
Methyl lactate can be hydrolysed by refluxing with sodium hydroxide solution.

In this reaction the hydroxide ion acts as a nucleophile.

i. Suggest how the hydroxide ion can act as a nucleophile.

[1]

ii. Part of the mechanism for the hydrolysis is shown below.

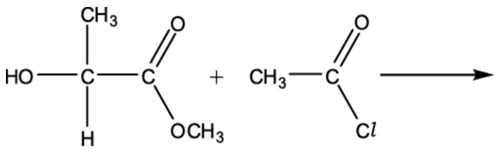


- Add relevant dipoles and curly arrows to show how the intermediate is formed in **Step 1** of the mechanism.
- Add curly arrows to show how the carboxylic acid and $^{-}OCH_3$ ion are formed from the intermediate in **Step 2** of the mechanism.

[4]

iii. Methyl lactate can also react with ethanoyl chloride.

Complete the equation for this reaction.



[2]

9(a). 1-Bromobutane, $CH_3CH_2CH_2CH_2Br$, reacts with methoxide ions, CH_3O^-, by nucleophilic substitution.

Suggest how the methoxide ion can act as a nucleophile.

---

[1]

(b). Using the 'curly arrow' model, suggest the mechanism for this reaction.

Show any relevant dipoles.

[3]

(c). 1-Iodobutane also reacts with methoxide ions.

Indicate, by placing a tick in one of the boxes, how the use of 1-iodobutane would affect the rate of reaction compared with that of 1-bromobutane.

1-Iodobutane does not change the rate	
1-Iodobutane increases the rate	
1-Iodobutane decreases the rate	

Explain your answer.

---

[1]

(d). The ethanoate ion, CH_3COO^- acts as a nucleophile when reacting with 1-bromobutane in a substitution reaction.

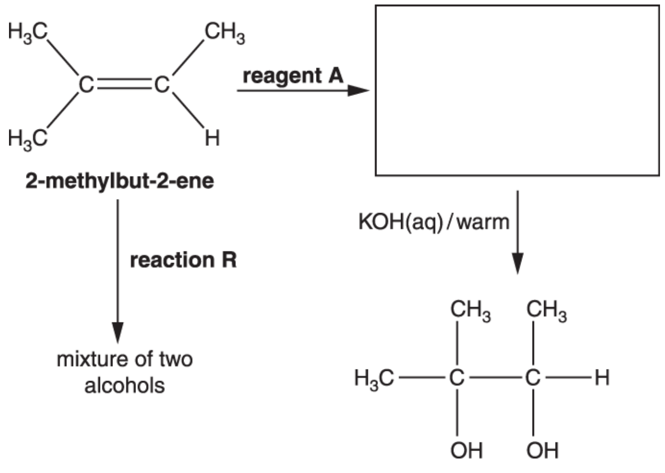
Draw the skeletal formula and give the name of the organic product formed in this reaction.

skeletal formula

name of product .... **[2]**

10(a). The flowchart shows how 2-methylbut-2-ene can be converted into a number of organic products.

Complete the flowchart by drawing an organic structure in the box below.



[1]

(b). Identify reagent **A**.

[1]

(c). In the flowchart, **reaction R** forms a mixture of two alcohols that are structural isomers of $C_5H_{12}O$.

i. State the reagents and conditions needed for **reaction R**.

[1]

ii. What is meant by the term *structural isomers*?

[1]

iii. Draw the two structural isomers of $C_5H_{12}O$ formed in **reaction R**.

[2]

iv. Suggest why 2-methylbut-2-ene is less soluble in water than either of the structural isomers formed.

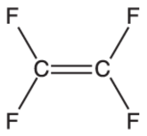
[2]

11. Give chemical explanations for the following statements.

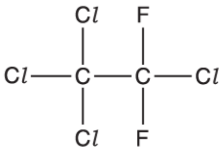
The rate of hydrolysis of 1-bromobutane is faster than that of 1-chlorobutane.

[1]

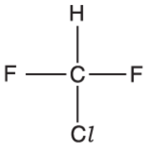
12. This question is about the compounds shown below.



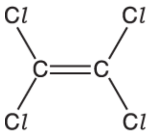
B



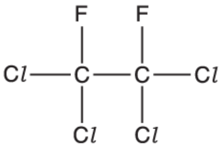
C



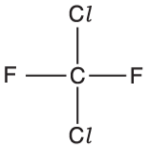
D



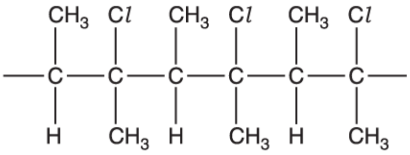
E



F



G



H

Compound **G** was once used as a propellant in aerosols. Compound **G** has been linked with depletion of the ozone layer in the stratosphere.

i. State **two** properties that made compound **G** suitable for use as an aerosol.

1

2

[1]

ii. Explain the following statements, using equations where appropriate.

- Life on Earth benefits from the presence of an ozone layer.
- The concentration of ozone is maintained in the ozone layer.
- Compound **G** produces radicals which catalyse the breakdown of ozone.

[5]

iii. Alternative ‘ozone-friendly‘ compounds are now used as propellants instead of compound **G**.

Which compound, **B** to **H**, might be suitable as an ‘ozone-friendly‘ propellant?

[1]

13(a). Reaction mechanisms use curly arrows and can involve electrophiles and nucleophiles.

i. What does a *curly arrow* represent in mechanisms?

[1]

ii. What is meant by the term *nucleophile*?

[1]

(b). Allyl bromide, $CH_2{=}CHCH_2Br$, reacts with aqueous sodium hydroxide.

i. Outline the mechanism of this reaction.

Include curly arrows, relevant dipoles and final product(s).

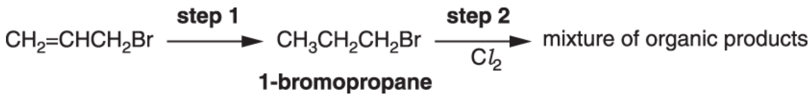
[3]

ii. Name the type of mechanism.

[1]

(c). Allyl bromide, $CH_2{=}CHCH_2Br$, is used in the production of polymers.

Allyl bromide is reacted as shown below.



$$CH_2{=}CHCH_2Br \xrightarrow{\textbf{step 1}} \underset{\textbf{1-bromopropane}}{CH_3CH_2CH_2Br} \xrightarrow[Cl_2]{\textbf{step 2}} \text{mixture of organic products}$$

i. State the reagents and conditions for **step 1**.

[1]

ii. In **step 2**, 1-bromopropane reacts with chlorine by radical substitution.

Outline the mechanism for the monochlorination of 1-bromopropane.
In your mechanism, you can show the formula of 1-bromopropane as C_3H_7Br.

Include the names of the three stages in this mechanism, state the essential conditions and all termination steps.

[5]

iii. Radical substitution produces a mixture of organic products.

Suggest **two** reasons why.

[2]

14. Nitrogen forms several different oxides.

N_2O is a useful anaesthetic and NO has been linked to the depletion of ozone in the stratosphere.

NO radicals catalyse the breakdown of ozone in the stratosphere.

Write **two** equations to show how NO radicals catalyse this breakdown.

[2]

15. A reaction sequence is shown below:

Step 1 $CH_3CH=CHCH_3 + HBr \rightarrow CH_3CH_2CHBrCH_3$

Step 2 $CH_3CH_2CHBrCH_3 + NaOH \rightarrow CH_3CH_2CH(OH)CH_3 + NaBr$

Which type of reaction mechanism is involved in each step?

	Step 1	**Step 2**
A	electrophilic addition	electrophilic substitution
B	electrophilic addition	nucleophilic substitution
C	nucleophilic addition	electrophilic substitution
D	nucleophilic addition	nucleophilic substitution

Your answer ☐

[1]

16. When heated with NaOH(aq), 1-iodobutane is hydrolysed at a much faster rate than 1-chlorobutane.

Which statement explains the different rates?

A The C−I bond enthalpy is greater than the C−C*l* bond enthalpy.

B The C−I bond is less polar than the C−C*l* bond.

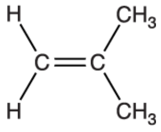
C The C−I bond has a C atom with a greater δ+ charge than in the C−C*l* bond.

D The C−I bond requires less energy to break than the C−C*l* bond.

Your answer ☐

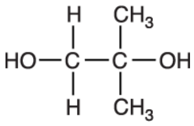
[1]

17. Compound **B**, shown below, can be used to synthesise organic compounds with different functional groups.



Compound B

The structure of compound **F** is shown below.



Compound F

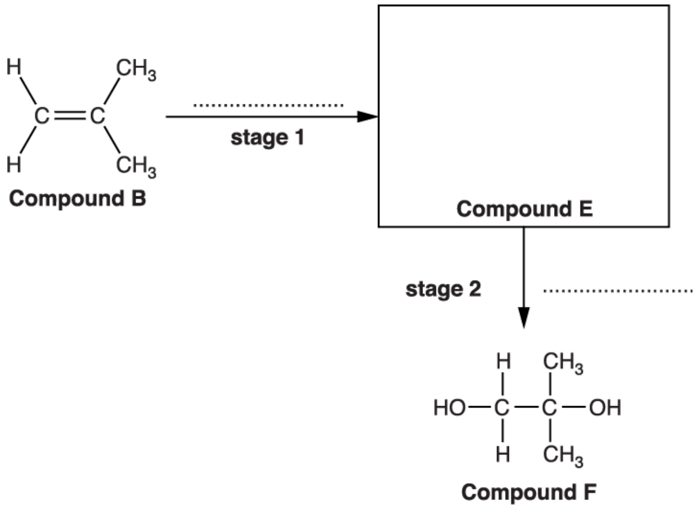
i. What is the empirical formula of compound **F**?

[2]

ii. A student plans a two-stage synthesis for preparing compound **F** from compound **B.**

The synthesis first prepares compound **E**, as shown in the flowchart.

Draw the structure of compound **E** in the box and state the reagents for each stage on the dotted lines.



[3]

18. Alcohols can be prepared from halogenoalkanes. 2,2-dimethylpropan-1-ol can be prepared by hydrolysis of a chloroalkane with aqueous sodium hydroxide.

i. Write the equation for this reaction.

Use structures for the organic compounds.

[1]

ii. Outline the mechanism for this reaction.

Show curly arrows and relevant dipoles.

[2]

19. In the stratosphere, nitrogen oxides can catalyse the breakdown of ozone.

i. State **two** sources of nitrogen oxides in the stratosphere.

[1]

ii. Write equations to show how nitrogen monoxide catalyses the breakdown of ozone.

[2]

20(a). A student was provided with a mixture of two structural isomers. Each isomer has the percentage composition by mass C, 29.29%; H, 5.70%; Br, 65.01%. The relative molecular mass of each isomer is less than 150.

Determine the structures of the two structural isomers.

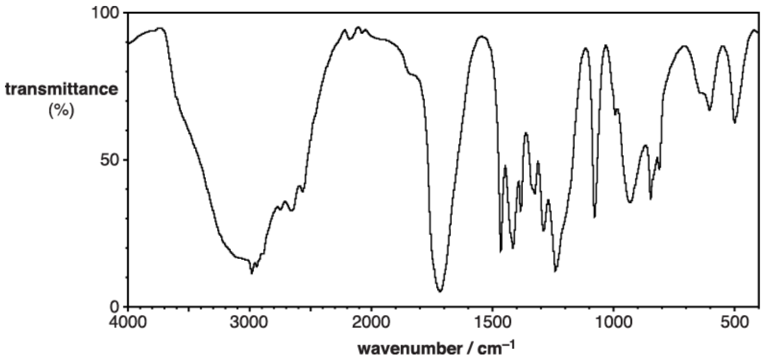
Show your working.

✎ *In your answer you should link the evidence with your explanation.*

[5]

(b). The student heats the mixture of the two structural isomers from **(a)** under reflux with aqueous sodium hydroxide to form two compounds, **E** and **F**. The student separates the two compounds.

Compound **E** is heated under reflux with acidified potassium dichromate(VI) to form compound **G**, which gives the infrared spectrum below.



i. Analyse the information and spectrum to determine the structures of **E**, **F** and **G**.

Include an equation for the formation of **G** from **E**.

In your answer you should link the evidence with your explanation.

[6]

ii. Compound **G** is heated with compound **F** in the presence of a small amount of concentrated sulfuric acid to form organic compound **H**.

Draw the structure of the organic compound **H**.

[2]

21(a). Haloalkanes are hydrolysed by aqueous sodium hydroxide.

i. Outline the mechanism of the reaction of 1-bromobutane with aqueous sodium hydroxide.

Include curly arrows, relevant dipoles and the structure of the organic product.

[3]

ii. Name the type of mechanism in **(i)**.

[1]

iii. The organic product in **(i)** can be formed faster using a different haloalkane than 1-bromobutane.

Identify this haloalkane.

Explain your answer.

Haloalkane ………

Explanation ………

---

[1]

(b). The use of some haloalkanes, such as chlorotrifluoromethane, has been banned as they form C*l* • radicals which break down ozone.

i. Construct an equation to show the formation of C*l* • radicals from chlorotrifluoromethane.

[1]

ii. Ozone is broken down by C*l* • radicals in a two-step process.

Write the equations for the two steps and the overall equation for this process.

Step 1 ………

Step 2 ………

Overall equation ……………………………………………………………………………………………

[3]

iii. A research chemist found that 1.00 g of C*l* • radicals can breakdown 135 kg of O_3.

Calculate the number of O_3 molecules removed by one C*l* • radical.

Give your answer in **standard form** and to **three** significant figures.

number of O_3 molecules = ... **[3]**

22. A chemist compares the rates of hydrolysis of 1-chloropropane and 1-bromopropane in ethanol.

Which reagent in aqueous solution should be used?

A Silver chloride
B Silver nitrate
C Potassium chloride
D Potassium nitrate

Your answer ☐ **[1]**

23. This question is about organic compounds containing nitrogen.

Sodium cyanide, NaCN, can be reacted with many organic compounds to increase the length of a carbon chain.

i. 1-Chloropropane, $CH_3CH_2CH_2Cl$, reacts with ethanolic sodium cyanide by nucleophilic substitution.

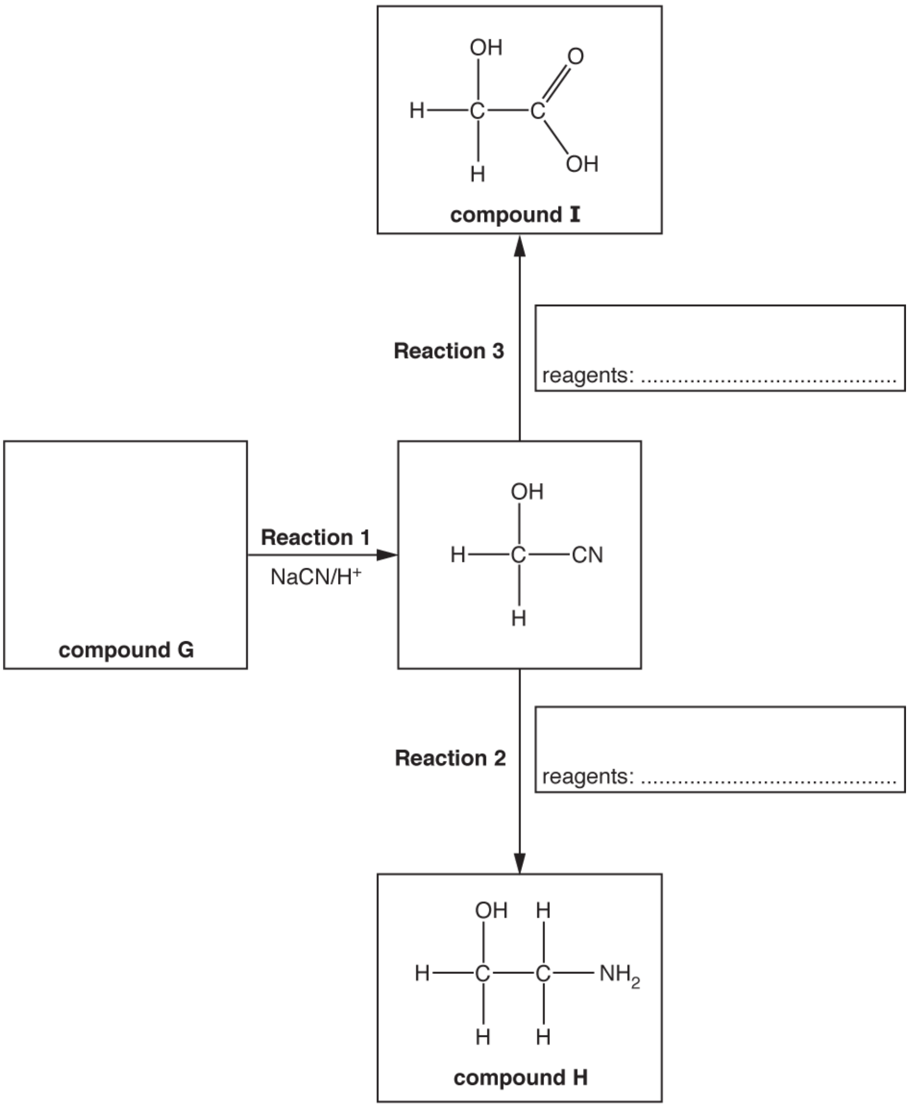
   Outline the mechanism for this reaction.

   Include curly arrows, relevant dipoles and the structure of the organic product.

[3]

ii. Compound **G** is used to synthesise compounds **H** and **I** as shown in the flowchart below.

Complete the flowchart showing the structure of compound **G** and the **formulae** of the reagents for **Reaction 2** and **Reaction 3**.



[3]

iii. Compound **H** reacts with dilute hydrochloric acid to form a salt.

Explain why compound **H** can react with dilute hydrochloric acid and suggest a structure for the salt formed.

Explanation

Structure

[2]

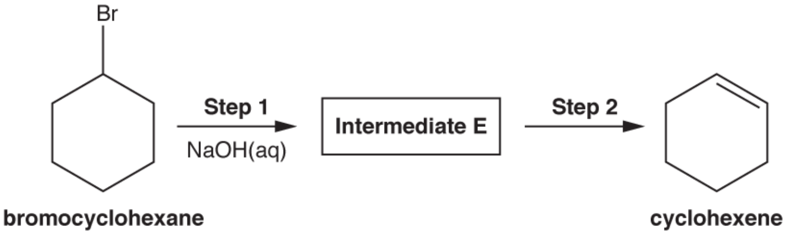
iv.

v. Compound **I** is the monomer for the biodegradable polymer **J**.
Draw **two** repeat units of polymer **J** and suggest a reason why it is biodegradable.

[3]

24. Organic compounds can be prepared in the laboratory using synthetic routes with two or more stages.

A student devises a two-stage synthesis of cyclohexene from bromocyclohexane.



i. Suggest the structure of **intermediate E** and the reagent(s) and conditions for **step 2**.

reagent(s) and conditions **[2]**

ii.

iii. The student carries out this synthesis and obtains 1.23 g of pure cyclohexene from 5.50 g of bromocyclohexane.

Calculate the percentage yield of cyclohexene.

Give your final answer to an **appropriate** number of significant figures.

percentage yield = ... % **[3]**

25. Alcohols are used in organic synthesis.

Pentan-2-ol can be prepared by the alkaline hydrolysis of 2-iodopentane.

$$CH_3CH(I)CH_2CH_2CH_3 + NaOH \rightarrow CH_3CH(OH)CH_2CH_2CH_3 + NaI$$

The reaction mixture is boiled for 20 minutes.

i. State the most appropriate technique that could be used to boil the reaction mixture for 20 minutes.

[1]

ii. Describe the mechanism for the alkaline hydrolysis of 2-iodopentane.

In your answer, include the name of the mechanism, curly arrows and relevant dipoles.

name of mechanism: ....

[4]

26. Which compound does **not** react with nucleophiles?

A CH_3CH_2CHO

B CH_3CHCH_2

C $CH_3CH_2COCH_3$

D $CH_3CH_2CH_2Cl$

Your answer ☐ **[1]**

27. The breakdown of ozone is catalysed by NO radicals.

Which equation is a propagation step in the mechanism for this process?

A $NO + O_2 \rightarrow N + O_3$

B $NO + O_2 \rightarrow NO_2 + O$

C $N + O_3 \rightarrow NO + O_2$

D $NO_2 + O \rightarrow NO + O_2$

Your answer ☐ **[1]**

28(a). This question is about the hydrolysis of haloalkanes.

The rate of hydrolysis of a haloalkane depends on the halogen present.

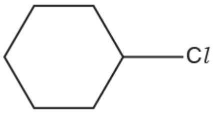
State and explain how the halogen in the haloalkane affects the rate of hydrolysis.

[2]

(b). Chlorocyclohexane is hydrolysed with aqueous sodium hydroxide.

Outline the mechanism for this reaction.

Show curly arrows, relevant dipoles and the products.



[3]

(c). A student hydrolyses a haloalkane, **E**, using the following method.

- 0.0100 mol of haloalkane **E** is refluxed with excess NaOH(aq) to form a reaction mixture containing an organic product **F**.
- The reaction mixture is neutralised with dilute nitric acid.
- Excess $AgNO_3$(aq) is added to the reaction mixture. 1.88 g of a precipitate **G** forms.

Organic product, **F**, has a molar mass of 74.0 g mol^{-1} and has a chiral carbon atom.

i. Draw a **labelled** diagram to show how the student would carry out the hydrolysis of haloalkane **E**.

[2]

ii. Analyse the information to identify **E**, **F** and **G**.

Show your working.

[3]

29. An alcohol can be prepared by hydrolysing the haloalkane $C_2H_5CHBrCH_3$ with aqueous sodium hydroxide.

i. Outline the mechanism for this reaction.

Show curly arrows and relevant dipoles.

[3]

ii.

iii. The infrared (IR) spectrum for $C_2H_5CHBrCH_3$ is shown in **Fig. 25.2**.
The C–Br bond absorption is labelled.

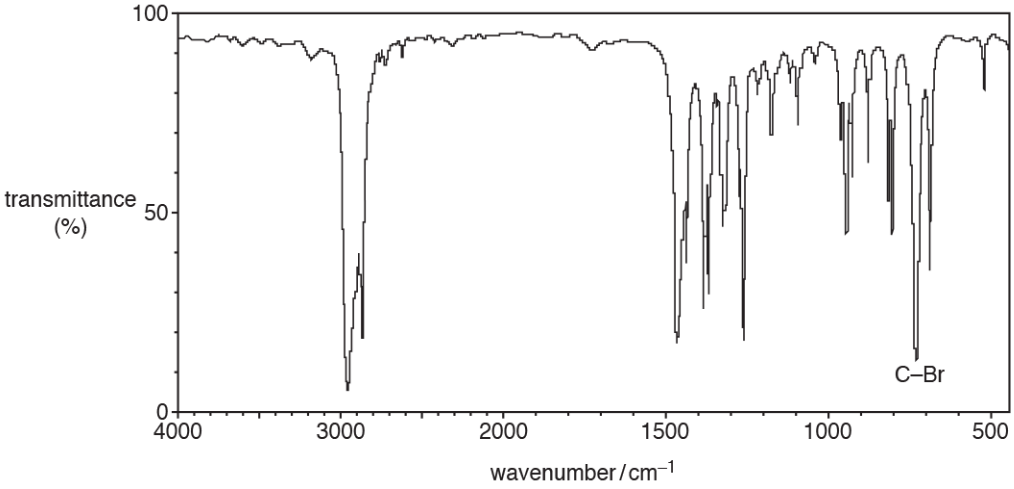
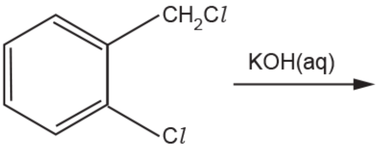


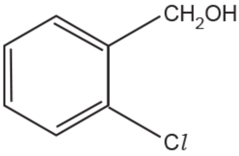
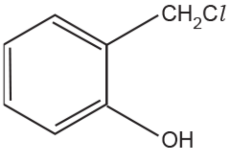
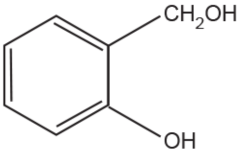
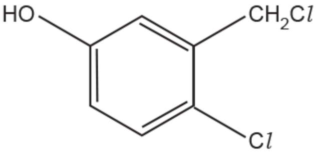
Fig. 25.2

Outline how IR spectroscopy could be used to show that the bromoalkane functional group has reacted and that the alcohol functional group has formed.

[2]

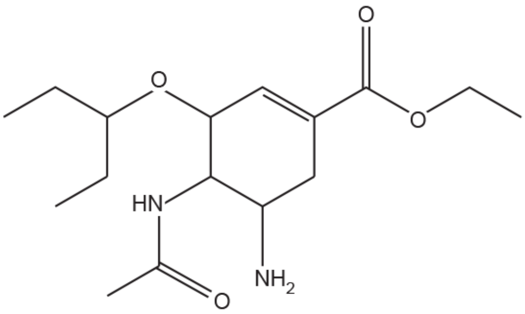
30. What is the organic product of the reaction below?



A	
B	
C	
D	

Your answer ☐ **[1]**

31. The structure of a compound used to treat influenza is shown below.



Which functional group(s) is/are in a molecule of the compound?

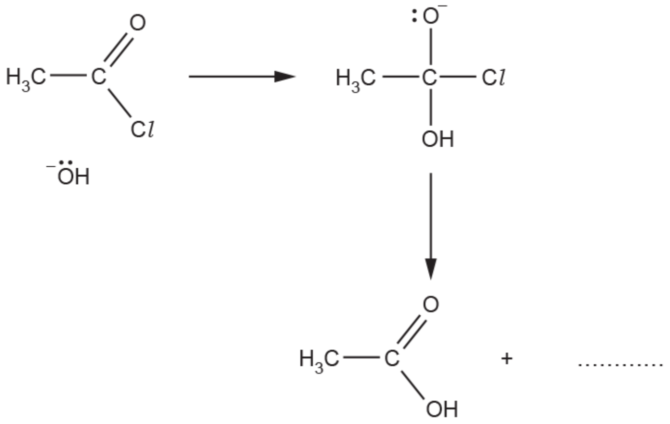
1 Ester
2 Secondary amide
3 Ketone

A 1, 2 and 3
B Only 1 and 2
C Only 2 and 3
D Only 1

Your answer ☐ **[1]**

32. An incomplete reaction mechanism is shown below.

i. Complete the mechanism by adding curly arrows and any missing species.



[4]

ii. What is the role of OH^- in this mechanism?

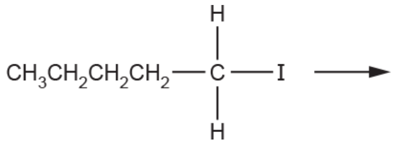
[1]

33. This question is about 1-iodopentane, $CH_3CH_2CH_2CH_2CH_2I$.

1-Iodopentane can be hydrolysed by aqueous sodium hydroxide.

i. Outline the mechanism for this reaction.

Include curly arrows, relevant dipoles and the final product(s).



[3]

ii. 1-Iodopentane can also be hydrolysed by water using aqueous silver nitrate, with ethanol as the solvent.

A student uses this method to compare the rates of hydrolysis of 1-iodopentane and 1-bromopentane.

What measurement and observation would allow the student to compare the rates of hydrolysis?

[1]

iii. 1-Iodopentane was found to react faster than 1-bromopentane.

Explain why.

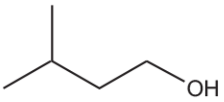
[2]

34. Which row describes a nucleophile?

A	electron pair donor	attracted to high electron density
B	electron pair donor	attracted to low electron density
C	electron pair acceptor	attracted to high electron density
D	electron pair acceptor	attracted to low electron density

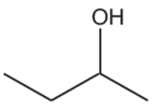
Your answer ☐ **[1]**

35(a). This question is about the alcohols **A–F** shown below.

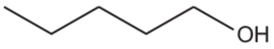


A

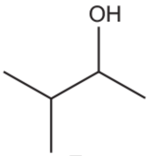
B



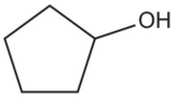
C



D



E



F

Alcohol **A** can be prepared by the alkaline hydrolysis of the bromoalkane, $(CH_3)_2CHCH_2CH_2Br$.

The hydrolysis with aqueous NaOH is shown in **equation 5.1**.

$(CH_3)_2CHCH_2CH_2Br + NaOH \rightarrow (CH_3)_2CHCH_2CH_2OH + NaBr$ **equation 5.1**

alcohol A

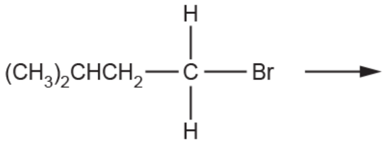
A student gently heats a mixture of $(CH_3)_2CHCH_2CH_2Br$ and NaOH(aq) for 25 minutes.

i. Calculate the atom economy for the preparation of alcohol **A** in **equation 5.1.**

atom economy = ... % **[2]**

ii. Outline the mechanism for the alkaline hydrolysis of $(CH_3)_2CHCH_2CH_2Br$.
The structure of $(CH_3)_2CHCH_2CH_2Br$ has been provided.

Show curly arrows, relevant lone pairs and dipoles, and the products.



[3]

iii. Name this type of mechanism.

[1]

(b). The student decides to prepare alcohol **A** using the same method as in the part above but using the chloroalkane $(CH_3)_2CHCH_2CH_2Cl$ instead of the bromoalkane, $(CH_3)_2CHCH_2CH_2Br$.

State and explain how the rates of hydrolysis of the chloroalkane and the bromoalkane would differ.

[2]

36. Which of the following reactions produce propan-1-ol?

1 The alkaline hydrolysis of 1-chloropropane.

2 The acid hydrolysis of propyl methanoate.

3 The acid hydrolysis of propanenitrile.

A 1, 2 and 3

B Only 1 and 2

C Only 2 and 3

D Only 1

Your answer ☐ **[1]**

37. Which statement about absorption of radiation is correct?

A Absorption of IR radiation can break covalent bonds, forming radicals.

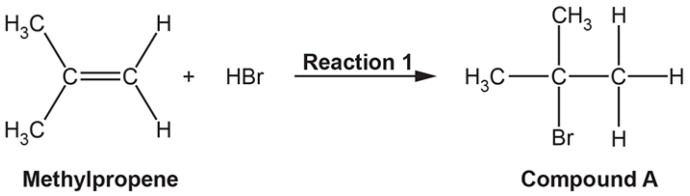
B Absorption of IR radiation causes covalent bonds to vibrate more.

C Absorption of UV radiation is a major cause of global warming and climate change.

D Absorption of UV radiation is used in modern breathalysers to measure ethanol in the breath.

Your answer ☐ **[1]**

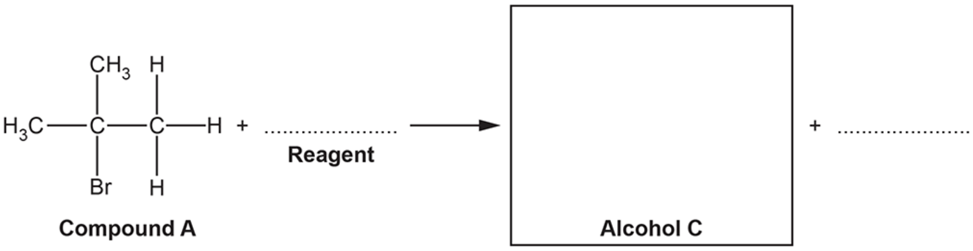
38. A student reacts methylpropene with hydrogen bromide, HBr, as shown in **Reaction 1**.



Compound A can be refluxed with a reagent to make alcohol C.

i. Choose a reagent for this reaction and complete the equation for this reaction.

Your equation should show the structure of alcohol **C**.



[2]

ii. Draw a labelled diagram to show how you would set up apparatus for reflux.

[2]

39. Which reaction is **not** a reduction?

A $C_6H_5NO_2 \rightarrow C_6H_5NH_2$

B $CH_3CN \rightarrow CH_3CH_2NH_2$

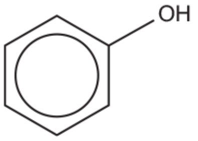
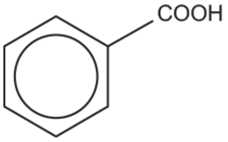
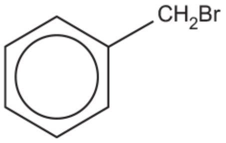
C $CH_3CH_2Cl \rightarrow CH_3CH_2NH_2$

D $CH_3COCH_3 \rightarrow CH_3CHOHCH_3$

Your answer ☐ **[1]**

40. Compounds **1**, **2** and **3** are heated with NaOH(aq).

Which compound(s) react(s)?

1	
2	
3	

A 1, 2 and 3

B Only 1 and 2

C Only 2 and 3

D Only 1

Your answer ☐ **[1]**

41. This question is about haloalkanes and polymers.

Freon-13, is a CFC with the molecular formula $CCl F_3$.
In the upper atmosphere, the presence of Freon-13 can lead to ozone depletion.

Explain, with the aid of equations, how Freon-13 can lead to this ozone depletion.

Use ‘dots’ (•) to show the position of unpaired electrons.

[3]

42. The ester, methyl ethanoate, can be synthesised by reacting a haloalkane with a carboxylate ion.

The mechanism is nucleophilic substitution.

Outline the mechanism for this reaction.

[3]

43. When heated with NaOH(aq), 1-chlorobutane is hydrolysed at a slower rate than 1-bromobutane.

Which statement explains the different rates?

A The C–Br bond enthalpy is greater than the C–C*l* bond enthalpy.

B The C–Br bond enthalpy is less than the C–C*l* bond enthalpy.

C The C–Br bond is less polar than the C–C*l* bond.

D The C–Br bond is more polar than the C–C*l* bond

Your answer ☐ **[1]**

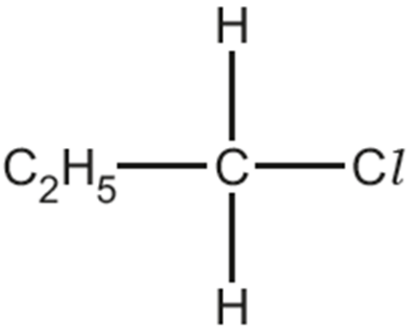
44. This question is about haloalkanes.

1-Chloropropane, $C_2H_5CH_2Cl$, can be hydrolysed with aqueous sodium hydroxide, NaOH.

Outline the mechanism for this reaction.

The structure of 1-chloropropane has been provided.

Show curly arrows, relevant dipoles and product(s).



$C_2H_5CH_2Cl$

[3]

45. Which statement is correct for the different rates of hydrolysis of RC*l* and RBr?

A RBr is hydrolysed faster because C*l* is more electronegative than Br.

B RBr is hydrolysed faster because the C–C*l* bond enthalpy is greater than C–Br.

C RC*l* is hydrolysed faster because C*l* is more electronegative than Br.

D RC*l* is hydrolysed faster because the C–Br bond enthalpy is greater than C–C*l*.

Your answer ☐ **[1]**

46. Which statement about absorption of radiation is correct?

A Infrared radiation can result in the breakdown of the ozone layer.

B Ultraviolet radiation can cause some polymers to photodegrade to benefit the environment.

C Ultraviolet radiation is linked to global warming.

D Ultraviolet radiation is used in modern breathalysers to measure ethanol in the breath.

Your answer ☐ **[1]**

47. Which species could react as a nucleophile?

1 NH_3

2 OH^-

3 CH_3NH_2

A 1, 2 and 3

B Only 1 and 2

C Only 2 and 3

D Only 1

Your answer ☐ **[1]**

48. * Carbon-carbon bond formation is used in synthesis to increase the length of a carbon chain.

Describe the formation of carbon−carbon bonds in aliphatic compounds by **two** different mechanisms.

Your answer should include mechanisms for each aliphatic compound.

Additional answer space if required.

[6]

49. Butan-1-ol reacts with sodium bromide and sulfuric acid to form 1-bromobutane by nucleophilic substitution.

The mechanism for this reaction takes place by two steps.

Step 1 The oxygen atom of the alcohol group accepts a proton to form a positively- charged intermediate.

Step 2 Bromide ions react with the intermediate from **Step 1** by nucleophilic substitution to form 1-bromobutane.

Show both steps in this mechanism.

[4]

50(a). This question is about halogens and halogen compounds.

A student is studying the hydrolysis of haloalkanes.

The equation for the alkaline hydrolysis of 2-bromopropane, $CH_3CHBrCH_3$, is shown below.

$CH_3CHBrCH_3 + OH^- \rightarrow CH_3\ CHOHCH_3 + Br^-$

Use the curly arrow model to outline the mechanism for the alkaline hydrolysis of 2-bromopropane.

Show relevant dipoles and lone pairs, and name the mechanism.

name of mechanism .... **[3]**

(b). The student sets up an experiment to compare the rates of hydrolysis of 2-bromopropane and 2-iodopropane.

The student uses the method below.

Step 1	Place two test tubes, both containing aqueous silver nitrate and ethanol, in a water bath at 60 °C.
Step 2	Add five drops of 2-bromopropane to one test tube and five drops of 2-iodopropane to the other test tube.
Step 3	Record the time taken for a precipitate to appear in each test tube.

i. Complete the table below to show the formula and colour of each precipitate formed.

Haloalkane	Formula of precipitate	Colour of precipitate
2-bromopropane		
2-iodopropane		

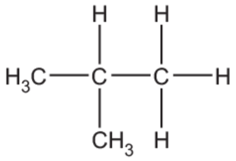
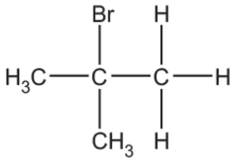
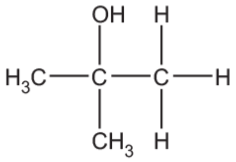
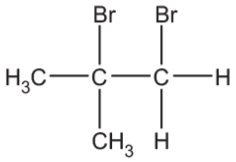
[2]

ii. Predict which precipitate would form first and explain the difference in the rates of hydrolysis of 2-bromopropane and 2-iodopropane.

[1]

51. A student has planned the two-stage synthesis shown below.

Which compound could be the intermediate for this synthesis?

A	
B	
C	
D	

Your answer ☐ **[1]**

52. A student investigates the rate of hydrolysis of different iodoalkanes using aqueous silver nitrate in ethanol.

What colour of precipitate is seen?

A Brown
B Cream
C White
D Yellow

Your answer ☐ **[1]**

53. Which statement gives a valid scientific reason for global warming?

A Infrared radiation causes bonds in CH_4 molecules to vibrate more.
B Infrared radiation causes O_2 molecules to vibrate more.
C Ultraviolet radiation causes bonds in CO_2 to vibrate more.
D Ultraviolet radiation causes bonds in CFC molecules to break.

Your answer ☐ **[1]**

54. The CFC CCl_2F_2 can cause the breakdown of ozone in the upper atmosphere.

Which initiation step could occur with ultraviolet radiation to catalyse this breakdown?

A $CCl_2F_2 \rightarrow \bullet C + \bullet Cl_2F_2$

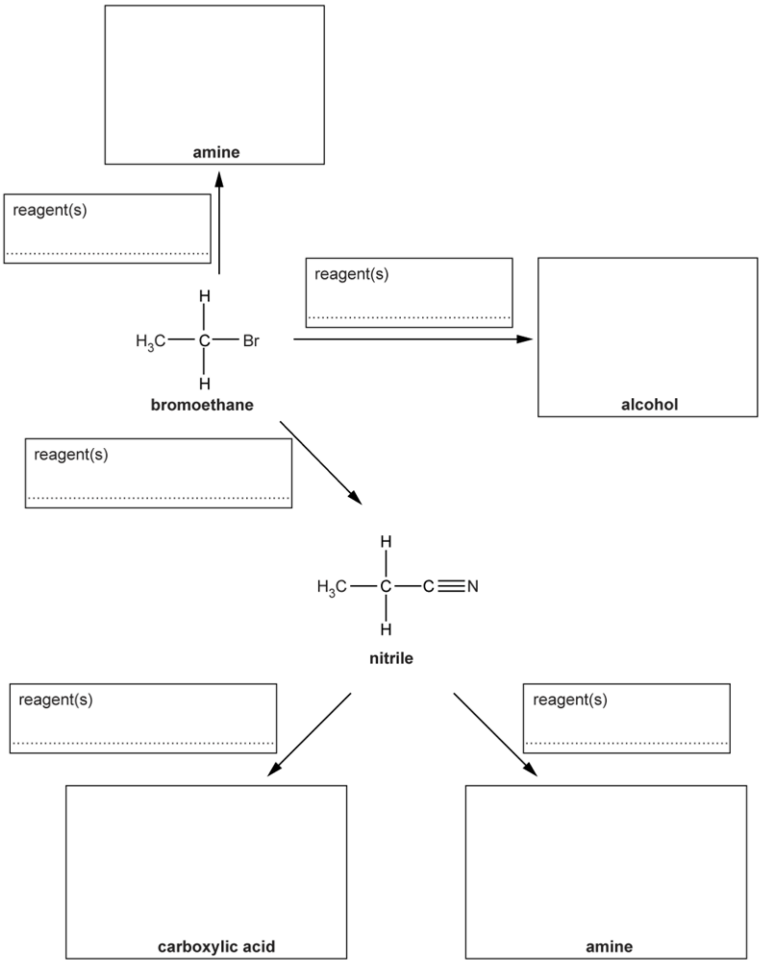
B $CCl_2F_2 \rightarrow \bullet F + \bullet CCl_2F$

C $CCl_2F_2 \rightarrow \bullet Cl + \bullet CClF_2$

D $CCl_2F_2 \rightarrow \bullet Cl_2 + \bullet CF_2$

Your answer ☐ **[1]**

55. Complete the flowchart by filling in each box.



[9]

56. This question is about the analysis of organic compounds.

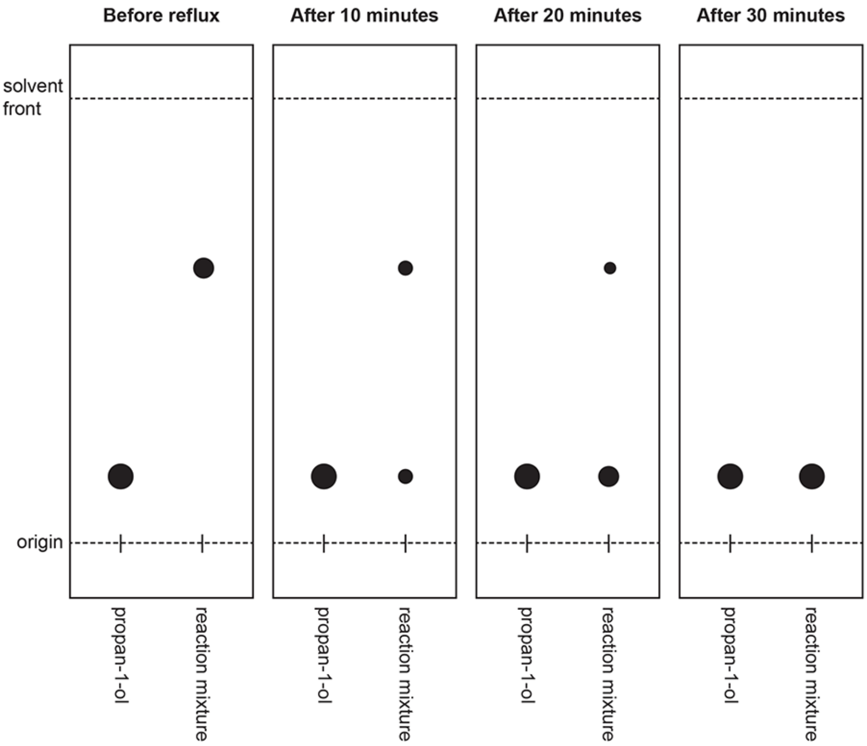
A student investigates the alkaline hydrolysis of 1-bromopropane as outlined below.

Step 1 The student adds 1-bromopropane to an excess of aqueous potassium hydroxide, KOH(aq), in a pear-shaped flask.

Step 2 A TLC chromatogram is run using propan-1-ol and the reaction mixture.

Step 3 The reaction mixture is refluxed.
A TLC chromatogram of the reaction mixture is run every 10 minutes.

The TLC chromatograms are shown below



i. Determine the R_f value of propan−1−ol.

Show your working.

R_f = ... **[1]**

ii. Write an equation for the alkaline hydrolysis of 1−bromopropane.

Show structures of organic compounds.

[1]

iii. A student investigates the alkaline hydrolysis of 1−chloropropane using the same method as for 1−bromopropane.

Predict, with reasons, how the appearance of the reaction mixture in the chromatogram produced after 20 minutes would be different when 1−chloropropane is used instead of 1−bromopropane.

Suggest why propan−1−ol is run alongside the reaction mixture.

[3]

57. Alcohols can be prepared by the hydrolysis of haloalkanes with aqueous alkali.

i. Write an equation for the hydrolysis of 2- bromo- 2- methylpropane.

Show organic compounds as structures.

[2]

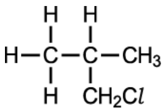
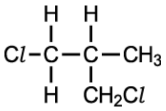
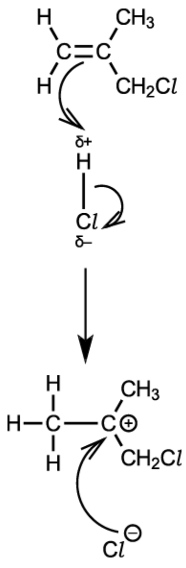
ii. A student hydrolyses a chloroalkane, RC*l*, a bromoalkane, RBr, and an iodoalkane, RI.

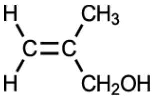
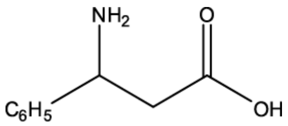
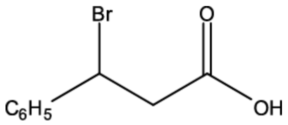
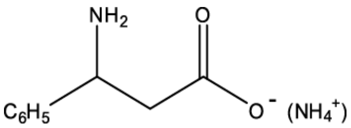
For a fair comparison, the student has chosen the same R group for each haloalkane.

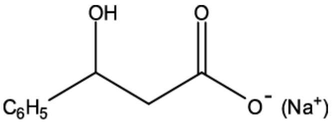
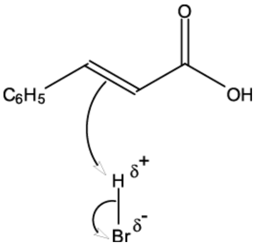
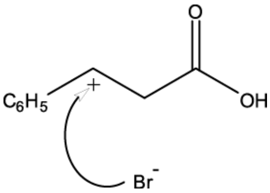
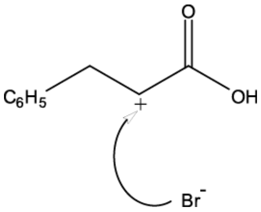
Predict, with a reason, the relative rates of hydrolysis of these three haloalkanes.

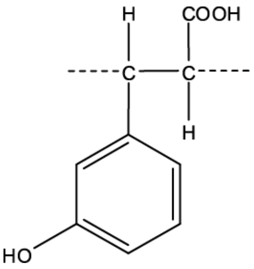
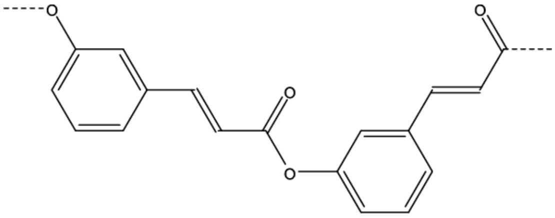
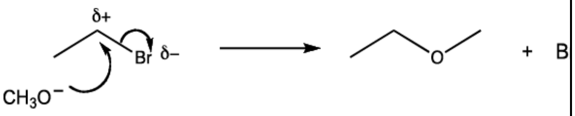
[2]

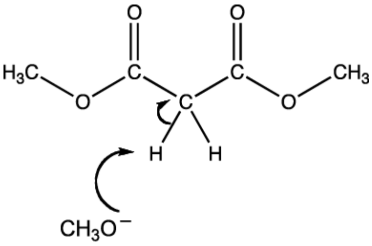
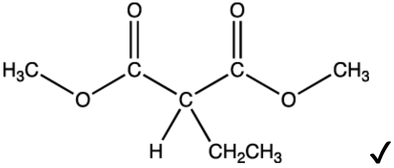
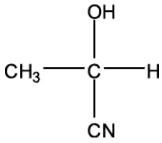
Mark scheme

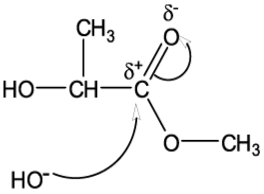
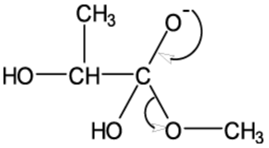
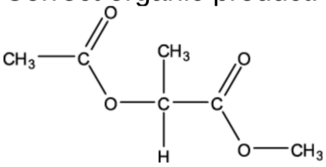
Question			Answer/Indicative content	Marks	Guidance
1		i	$Ag^+ + Cl^- \rightarrow AgCl$ **OR** $Ag^+ + Br^- \rightarrow AgBr$ **OR** $Ag^+ + I^- \rightarrow AgI$	1	
		ii	Bond enthalpy decreases C−Cl > C−Br > C−I	1	**allow** chlorine–carbon bonds are strongest.
		iii	Heat the test tubes in a water bath.	1	
			Total	**3**	
2			D	1	
			Total	**1**	
3		i	From **Reaction 1** =  compound **B** = 	2	**ALLOW** correct structural **OR** displayed **OR** skeletal formulae **OR** a combination of above as long as unambiguous
		ii	 Curly arrow from C=C to attack the H atom Correct dipole on H—Cl **AND** curly arrow from bond to Cl Correct carbocation / carbonium ion with full	3	**ALLOW** correct structural **OR** displayed **OR** skeletal formulae **OR** a combination of above as long as unambiguous. Curly arrow must start from covalent bonds and not atoms. **DO NOT ALLOW** any other partial charges *e.g.* shown on double bond. **DO NOT ALLOW** $C^{\delta+}$ for charge on carbonium ion. Curly arrow from Cl^- can start from the negative charge or the lone pair. **DO NOT ALLOW** delta negative, *i.e.* $Cl^{\delta-}$.

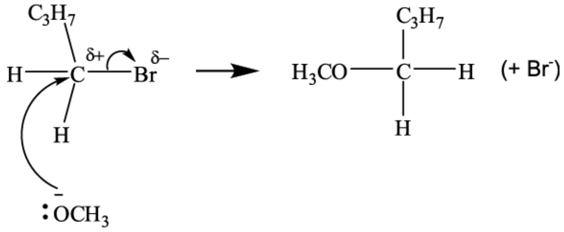
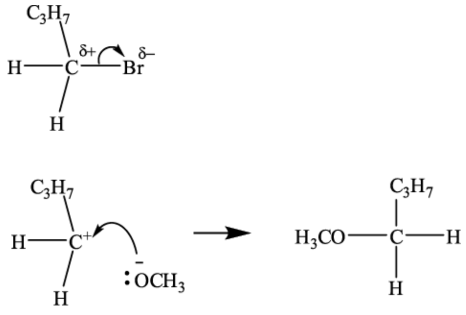
			positive charge shown **AND** correct curly arrow from negative charge of Cl^- to correct carbon atom **OR** correct curly arrow from lone pair of Cl^- to correct carbon atom		
		iii	because the intermediate / carbocation in the formation of compound **B** is less stable (than the intermediate in the formation of compound **A**)	1	
		iv	 (Formation of) white precipitate / solid / suspension **AND** (ppt is) silver chloride / AgCl	2	**ALLOW** correct structural **OR** displayed **OR** skeletal formulae **OR** a combination of above as long as unambiguous.
			Total	**8**	
4			C	1	
			Total	**1**	
5			B	1	
			Total	**1**	
6	a		**Product from NH_3/ethanol**  .... **Product from Reaction 1** 	3	**ALLOW** any combination of skeletal **OR** structural **OR** displayed formula as long as unambiguous **ALLOW**  **ALLOW ECF** from 2-bromo compound as product from Reaction 1 .... **DO NOT ALLOW** 2-bromo compound *(inconsistent with final product shown)*

			……………………………………………………		……………………………………………………
			Product from NaOH(aq) 		**DO NOT ALLOW ECF** from 2-bromo compound as product from Reaction 1 *(inconsistent with final product shown)*
	b		Curly arrow from C=C bond to H of H-Br		**ANNOTATE ANSWER WITH TICKS AND CROSSES** **ALLOW** any combination of skeletal **OR** structural **OR** displayed formula as long as unambiguous
			Correct dipole shown on H–Br **AND** curly arrow showing the breaking of H-Br bond  ……………………………………………………		**DO NOT ALLOW** partial charges shown on C=C double bond
			Correct carbocation **AND** curly arrow from Br^- to C^+ of carbocation  ……………………………………………………		**DO NOT ALLOW** δ+ on C of carbocation **ALLOW** formation of the 2-bromo isomer  Curly arrow must come from a lone pair on Br^- **OR** from the negative sign of Br^- ion (then lone pair on Br^- ion does not need to be shown)
			Electrophilic addition		

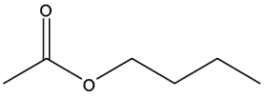
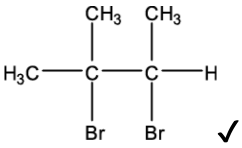
	c	i		1	**ALLOW** any combination of skeletal **OR** structural **OR** displayed formula as long as unambiguous 'End bonds' **MUST** be shown (do not have to be dotted) **IGNORE** brackets **IGNORE** *n*
		ii	 Ester link Rest of structure	2	**ALLOW** any combination of skeletal **OR** structural **OR** displayed formula as long as unambiguous 'End bonds' **MUST** be shown (do not have to be dotted)
			Total	**10**	
7	a		✓	1	
	b	i	$2Na + 2CH_3OH \rightarrow 2Na^+ + 2CH_3O^- + H_2$ ✓	1	**ALLOW** $2Na + 2CH_3OH \rightarrow 2CH_3ONa + H_2$
		ii	 Curly arrow from CH_3O^- to carbon atom of C-Br bond ✓ Dipole shown on C–Br bond, $C^{\delta+}$ and $Br^{\delta-}$ **AND** curly arrow from C–Br bond to the Br atom ✓ Products of reaction (must not be ambiguous) ✓	3	**ALLOW** correct structural **OR** skeletal **OR** displayed formula **OR** mixture of the above as long as non-ambiguous. The curly arrow must start from **O atom** of CH_3O^- **AND** must start either from a lone pair or from the negative charge. No need to show lone pair if curly arrow comes from negative charge. **ALLOW** S_N1 Dipole shown on C–Br bond, $C^{\delta+}$ and $Br^{\delta-}$, and curly arrow from C–Br bond to the Br atom. Correct carbocation drawn. **AND** curly arrow from CH_3O^- to carbocation. The curly arrow must start from the oxygen atom of the CH_3O^-, and must

					start either from a lone pair or from the negative charge.
		iii	CH_3O^- donates an electron pair **AND** heterolytic fission ✓	1	**ASSUME** ‘it’ refers to CH_3O^-
	c		**Chemical shift, δ/ppm** | **Relative peak area** | **Splitting pattern** 0.5−1.9 | 3 | Triplet ✓ 3.0−4.3 | 2 | Quartet ✓ 0.5−1.9 | 6 | Doublet ✓ 3.0−4.3 | 1 | Heptet ✓	4	**ALLOW** δ values ± 0.2 ppm, as a range or a value within the range **ALLOW** multiplet for heptet
	d	i	 Curly arrow from CH_3O^- to H of CH_2 ✓ Curly arrow from C–H bond to C of CH_2 ✓  ✓	3	The curly arrow must start from **O atom** of CH_3O^- **AND** must start either from a lone pair or from the negative charge. No need to show lone pair if curly arrow comes from negative charge. **ALLOW** any unambiguous structure, skeletal, displayed, structural or combination.
		ii	CH_3O^- accepted a proton ✓	1	**ASSUME** ‘it’ refers to CH_3O^-
			Total	**14**	
8	a	i		1	**ALLOW** any combination of skeletal **OR** structural **OR** displayed formula as long as unambiguous
		ii	**aqueous** acid **OR** H^+ / **H_2O**	1	**ALLOW** $H^+(aq)$ / $H_2SO_4(aq)$ / $HCl(aq)$

		iii	Angle a = 109.5° Angle b = 104.5° Angle c = 120° **Two** correct All **three** correct	2	**ALLOW** 109–110° **ALLOW** 104–105°
	b	i	It is an electron pair donor **OR** donates a lone pair	1	
		ii	 Curly arrow from HO^- to carbon atom of C=O bond Correct dipole **AND** curly arrow from C=O bond to $O^{\delta-}$ ....  Curly arrow from negative charge on oxygen to C–O bond (to reform carbonyl π-bond) Curly arrow from C–O single bond to oxygen atom (to form methoxide ion)	4	Curly arrow must come from lone pair on O of HO^- **OR** OH^- **OR** from minus sign on HO^- ion (No need to show lone pair if curly arrow came from negative charge on O) **IGNORE** dipole on C–O single bond Curly arrow must come from lone pair on O **OR** from minus sign on O^- ion (No need to show lone pair if curly arrow came from negative charge on O)
		iii	Correct organic product:  HC*l*	2	**ALLOW** any combination of skeletal **OR** structural **OR** displayed formula as long as unambiguous
			Total	**11**	
9	a		It is an electron pair donor **OR** can donate a lone pair ✓	1	**Examiner's Comments**

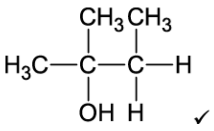
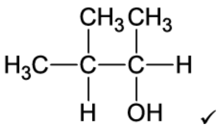
					Most candidates were able to state that the methoxide ion acted as an electron pair donor. In some cases imprecise responses such as ‘donates electrons’ were seen. Candidates should be encouraged to give specific answers when asked to explain scientific terms.
	b		 Dipole shown on the C-Br bond, $C^{\delta+}$ and $Br^{\delta-}$ and curly arrow from the C-Br bond to the Br atom ✓ Curly arrow from $:\bar{O}CH_3$ to carbon atom in the C-Br bond ✓ Correct organic product ✓ **S_N1 mechanism** 	3	**ANNOTATE ANSWER WITH TICKS AND CROSSES ETC** **IGNORE** connectivity to C_3H_7 throughout **IGNORE** alkyl group in first marking point. Curly arrow must start from C–Br bond and not from C atom. Dipole must be partial charge and not full charge CH_3O^- curly arrow must come from one lone pair on O of CH_3O^- ion **OR** from negative sign on O of the CH_3O^- ion **ALLOW** arrow from lone pair on O in OCH_3^- Lone pair not required **DO NOT ALLOW** $CH_3O^{\delta-}$ **DO NOT ALLOW** incorrect connectivity of CH_3O group in the final product $-CH_3O$ **IGNORE** $Br^{\delta-}$ as a product **ALLOW S_N1 mechanism** Dipole shown on the C—Br bond, $C^{\delta+}$ and $Br^{\delta-}$ and curly arrow from C—Br bond to the Br atom ✓ curly arrow from CH_3O^- to carbonium ion ✓ correct organic product ✓ **Examiner's Comments** This question required candidates to apply their knowledge of the nucleophilic substitution mechanism in an unfamiliar context.

					The first mark was awarded for showing the dipole on the C-Br bond and the curly arrow to demonstrate the heterolytic fission of the bond. This proved to be the most accessible mark and most candidates scored it. The second mark was awarded for the curly arrow from the methoxide ion to the C atom of the C-Br bond. The more able candidates were able to show their understanding and provided accurately drawn arrows. A common misconception was to start the curly arrow from a lone pair on the C atom of the methoxide ion. The third mark was awarded for the correct organic product and was often scored by the stronger candidates. As a consequence of showing nucleophilic attack from the C atom of the CH_3O^- ion, a significant number of responses showed the incorrect connectivity, as the nucleophile was joined via the C atom rather than the O atom. Unfortunately a number of candidates attempted to show the mechanism using OH^- ions as the nucleophile rather than CH_3O^-. Although they were able to score the first mark no other marks were awarded. A very small proportion of candidates chose to show the S_N1 mechanism rather than the expected S_N2 and full credit was allowed if the response was correct.
	c		1-Iodobutane increases the rate ☑ **AND** C—I bonds are weaker (than C—Br) **OR** C—I bond has a lower bond enthalpy **OR** C—I bond needs a smaller amount of energy to break **OR** C—I bond is easier to break ✓	1	All statements must be **comparative** **ALLOW ORA** **IGNORE** C—I bond is longer **IGNORE** polarity and references to electronegativity **Examiner's Comments**

					Many candidates were able to predict that the rate of the reaction would increase. In addition to this the Mark Scheme required candidates to explain this by referring to the effect of the different C-halogen bond. Most candidates were able to identify that the C-I bond would be weaker. Some candidates often referred to 1-iodobutane having weaker bonds but failed to specify which bond. Other candidates referred to the reactivity of iodine and bromine.
	d		 ✓ butyl ethanoate ✓	2	**ALLOW** only skeletal formula **DO NOT ALLOW** ECF from incorrect structure. **ALLOW** butylethanoate **ALLOW** butanyl for butyl **DO NOT ALLOW** but**ly** **Examiner's Comments** This question required candidates to interpret the information and deduce that an ester would be produced. Many candidates found this challenging but the strongest candidates were able to provide a correct skeletal formula and name for the product. Common incorrect responses showed carboxylic acid structures and names.
			Total	**7**	
10	a		 ✓	1	**ALLOW** correct structural **OR** displayed **OR** skeletal formula **OR** mixture of the above **DO NOT ALLOW** molecular formula **ALLOW** dichloro or diiodo compound instead of the dibromo compound as the **only** alternatives. **Examiner's Comments** This question required candidates to interpret the reaction scheme and

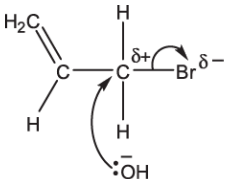
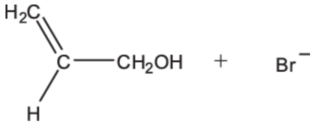
					suggest an intermediate compound that could be formed from 2-methylbut-2-ene that could be also hydrolysed to give the diol shown. The most able candidates demonstrated their understanding of this scheme and often suggested the correct dihalo compound. Most candidate favoured the dibromo compound however some chose to show the dichloro or diiodo compound. All of these responses received credit. A large proportion of structures suggested were obtainable from 2-methylbut-2-ene but could not be hydrolysed. These included the products of hydrogenation e.g. 2-methylbutane, or hydration e.g. 2-methylbutan-2-ol. Consequently only the most able candidates achieved a mark in part (b), as this was essentially dependant on part (a).
	b		Reagent **A**: correct halogen✓ e.g. Br_2 / bromine	1	**ALLOW** Cl_2 if dichloro compound drawn **ALLOW** I_2 if diiodo compound drawn **IGNORE** state symbols Answer must match box from **(a)** to score **Examiner's Comments** This question required candidates to interpret the reaction scheme and suggest an intermediate compound that could be formed from 2-methylbut-2-ene that could be also hydrolysed to give the diol shown. The most able candidates demonstrated their understanding of this scheme and often suggested the correct dihalo compound. Most candidate favoured the dibromo compound however some chose to show the dichloro or diiodo compound. All of these responses received credit. A large proportion of structures

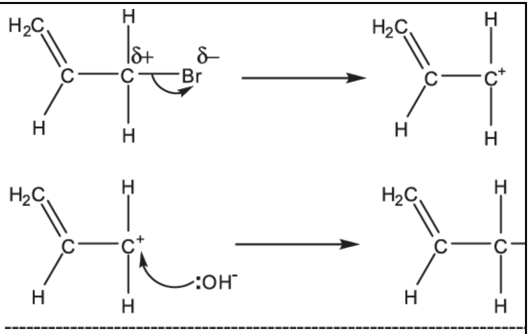
					suggested were obtainable from 2-methylbut-2-ene but could not be hydrolysed. These included the products of hydrogenation e.g. 2-methylbutane, or hydration e.g. 2-methylbutan-2-ol. Consequently only the most able candidates achieved a mark in part (b), as this was essentially dependant on part (a).
	c	i	Steam **AND** acid catalyst ✓	1	**ALLOW** H^+ / named acid / H_2SO_4 / H_3PO_4 **ALLOW** $H_2O(g)$ **ALLOW** water only if a temperature of 100 °C or above is quoted. **IGNORE** any temperature given with steam **IGNORE** pressure **Examiner's Comments** One would expect the majority of candidates to do well in a question which required them to state the reagents and conditions required for the hydration of alkenes; however this was not the case. The most able candidates provided accurate responses which referred to both steam and the acid catalyst, which was often shown to be H_3PO_4. Other candidates stated only one of the two required responses and it was common to see the acid catalyst stated alongside a temperature and pressure but with no reference to steam. Some candidates stated the reagent as H_2O instead of steam and this was allowed if accompanied by a temperature of over 100 °C. Candidates should be encouraged to learn reagents and conditions required for organic reactions.
		ii	(compounds or molecules) having the same molecular formula but different structural formulae ✓	1	**ALLOW** different structure **OR** different displayed formula **OR** different skeletal formula for structure

					Same formula is **not** sufficient Different arrangement of atoms is **not** sufficient **Examiner's Comments** The majority of candidates were able to explain the term structural isomers.
		iii	 $H_3C-\underset{OH}{\overset{CH_3}{C}}-\underset{H}{\overset{CH_3}{C}}-H$ ✓  $H_3C-\underset{H}{\overset{CH_3}{C}}-\underset{OH}{\overset{CH_3}{C}}-H$ ✓	2	**ALLOW** correct structural **OR** displayed **OR** skeletal formula **OR** mixture of the above **ALLOW** any vertical bond to OH **DO NOT ALLOW** OH− **Examiner's Comments** Many candidates found this question difficult and a large number of candidates showed structures of alcohols with the molecular formula $C_5H_{12}O$, but that could not be formed from 2- methylbut-2-ene. Examples of these incorrect responses included 2-methylbutan-1-ol, pentan-1- ol, pentan-2-ol and pentan-3-ol. Only the most able could show the structures of both alcohols produced by the hydration of 2-methlybut-2-ene. Candidates should be reminded to check that any structures they suggest are consistent with the context of the question.
		iv	Does not contain OH group(s) **OR** does not contain hydroxyl group(s) **OR** is not an alcohol ✓ Does not form hydrogen bonds with water ✓	2	**ALLOW ORA** throughout **DO NOT ALLOW** OH^- (ions) / hydroxide (ions) 'Does not form hydrogen bonds' is **not** sufficient **Examiner's Comments** The majority of candidates were able to recognise that the key to the solubility of the isomers in water is that they contain the OH group whereas 2-methylbut-2-ene does not. Most candidates scored the second mark by accurately explaining that the OH group could form hydrogen bonds with water.

			Total	**8**	
11			The C−Br bond is weaker (than the C−Cl bond)	1	**ORA**
			Total	**1**	
12		i	**ANY TWO FROM THE FOLLOWING ✓** Low reactivity **OR** will not burn / non-flammable Volatile **OR** low boiling point non-poisonous **OR** non-toxic	1	**ALLOW** inert **OR** stable **DO NOT ALLOW** inflammable **ALLOW** it is a gas **IGNORE** easily compressed **IGNORE** not harmful **IGNORE** references to solubility **Examiner's Comments** Stronger candidates were able to identify two suitable properties of **G**. Although the majority were able state a single property it was often accompanied by a repetitive or incorrect statement. Vague statements, which included ‘it is a CFC’ and ‘it is easily compressed’ were also frequently seen.
		ii	*Benefit of ozone layer to life (1 mark)* Ozone absorbs **UV** (radiation) ***UV*** at Earth's surface is reduced ✓ **OR** *Maintenance of* O_3 *concentration* (1 mark) $O_3 \rightleftharpoons O_2 + O$ ✓	5	**ANNOTATE ANSWER WITH TICKS AND CROSSES ETC** For all equations, **IGNORE** dots on radicals Essential idea for first mark is that **UV** is removed in some way. **ALLOW** Prevents **UV** damaging life or stated type of damage, e.g. cataracts, skin cancer, mutation, crop damage **DO NOT ALLOW** ozone absorbs IR **ALLOW** $O_3 \rightarrow O_2 + O$

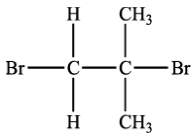
			*Production of radicals from **G** (1 mark)* $CF_2Cl_2 \rightarrow Cl + CF_2Cl$ ✓		**AND** $O_2 + O \rightarrow O_3$ **DO NOT ALLOW** $2O_3 \rightleftharpoons 3O_2$ **OR** $O_3 + O \rightarrow 2O_2$ for this mark
			Breakdown of O_3 (2 marks) $Cl + O_3 \rightarrow ClO + O_2$ ✓ **OR** $ClO + O \rightarrow Cl + O_2$ $ClO + O_3 \rightarrow Cl + 2O_2$ ✓		**DO NOT ALLOW** equations with other CFCs **DO NOT ALLOW** $CF_2Cl_2 \rightarrow 2Cl + CF_2$
					These are the only acceptable equations **IGNORE** overall equation (*does not show role of catalyst*) e.g. $O_3 + O \rightarrow 2O_2$ **Examiner's Comments** This question was answered very well. Almost all candidates were able to recall the benefit of the ozone layer. The equations showing the catalytic breakdown of ozone with C*l* radicals were reproduced accurately by the majority of the cohort. Although most candidates were able explain how the concentration of ozone was maintained in words, the statements were not always accompanied by the relevant equations. The majority of candidates did not provide an equation to show the formation of C*l* radicals from **G** and consequently only the strongest candidates received full marks.
		iii	**D** ✓	1	**ALLOW** CHF_2Cl **ALLOW B OR** C_2F_4 **OR** CF_2CF_2 **Examiner's Comments** The majority of candidates suggested a suitable compound from the selection provided.
			Total	**7**	
13	a	i	Movement of an electron pair ✓	1	**ALLOW** movement of a lone pair **OR** movement of a bond

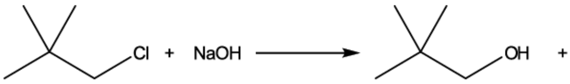
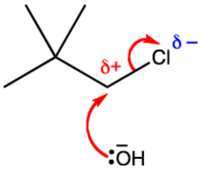
					Examiner's Comments Although the definition of a curly arrow was well known, many imprecise responses were seen. The most common was that a curly arrow represents the movement of electrons. Candidates should be aware that it is important to refer to an electron pair, when describing the meaning of a curly arrow.
		ii	Electron pair donor ✓	1	**ALLOW** can donate a lone pair **Examiner's Comments** Most candidates could state the correct definition. However, as with part (i) a significant number of candidates failed to specify 'electron pair' and stated that a nucleophile is an electron donor.
					ANNOTATE ANSWER WITH TICKS AND CROSSES ETC Curly arrow must come from lone pair on O of HO^- **OR** OH^- **OR** from minus sign on HO^- ion (No need to show lone pair if curly arrow came from negative charge on O)
	b	i	curly arrow from HO^- to carbon atom of C−Br bond ✓ Dipole shown on C−Br bond, $C^{\delta+}$ and $Br^{\delta-}$, **AND** curly arrow from C–Br bond to Br atom ✓  correct organic product **AND** Br^- ✓	3	**ALLOW** S_N1 mechanism: Dipole shown on C–Br bond, $C^{\delta+}$ and $Br^{\delta-}$, **AND** curly arrow from C–Br bond to Br atom ✓ Correct carbocation **AND** curly arrow from HO^- to carbocation Curly arrow must come from lone pair on O of HO^- **OR** OH^- **OR** from minus sign on HO^- ion (No need to show lone pair if curly arrow came from negative charge on O) ✓ correct organic product **AND** Br^- ✓

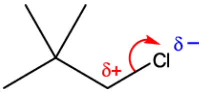
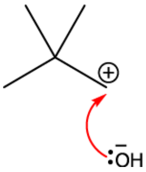
					 **Examiner's Comments** This question discriminated well and most candidates were able to score at least one mark, often by showing the curly arrow and dipole on the C-Br bond. The best responses included neatly drawn structures and accurately placed curly arrows. The use of NaOH, rather than OH^-, by a lot of candidates led to difficulties for both the first and third marking points. The latter of which was missed as candidates stated the inorganic product as NaBr and neglected to show the Br^- ion formed from the heterolytic fission of the C—Br bond. Candidates are advised to only show the relevant ions when drawing mechanisms.
		ii	Nucleophilic substitution ✓	1	**Examiner's Comments** The majority of candidates could name this mechanism as nucleophilic substitution.
	c	i	H_2 **AND** Ni (catalyst) ✓	1	**ALLOW** name or formula for each **IGNORE** any stated temperature and pressure **Examiner's Comments** To score the mark in this question candidates had to state that both hydrogen and nickel were required for step 1. It was often the case that only one of these was stated. Although hydrogen was often seen as a reagent it was common to see an incorrect catalyst, such as H_2SO_4.

		ii	(Initiation) $Cl_2 \rightarrow 2Cl$ **AND** UV ✓ (Propagation) $C_3H_7Br + Cl \rightarrow C_3H_6Br + HCl$ ✓ $C_3H_6Br + Cl_2 \rightarrow C_3H_6BrCl + Cl$ ✓ (Termination) Two from the three termination equations below ✓ $2Cl \rightarrow Cl_2$ $C_3H_6Br + Cl \rightarrow C_3H_6BrCl$ $2C_3H_6Br \rightarrow C_6H_{12}Br_2$ names of steps initiation, propagation and termination linked to one correct equation for each step in this mechanism✓	5	**ANNOTATE ANSWER WITH TICKS AND CROSSES ETC** **DO NOT ALLOW** any ECF in this question **IGNORE** references to temperature **THROUGHOUT, ALLOW** correct molecular formulae **OR** structural **OR** displayed **OR** skeletal **OR** mixture of the above **IGNORE** dots **IGNORE** state symbols **IGNORE** one incorrect termination equation **Examiner's Comments** This question required candidates to apply their knowledge of the radical substitution mechanism to form a bromochloroalkane. Examiners were encouraged by the number of excellent attempts and it is clear that candidates had prepared well for this type of question. Consequently most candidates scored four or five marks. A common reason for a candidate only scoring four marks was the omission of UV radiation as an essential condition.
		iii	further substitution **OR** produces different termination products **OR** More than one termination step✓ substitution at different positions along chain ✓	2	**IGNORE** mixture of organic products (*in question*) **ALLOW** dichloro / multichloro / dibromo / multibromo compounds formed **OR** an example of a further substitution product **OR** an example of a different termination product **ALLOW** more than one hydrogen (atom) can be replaced **ALLOW** radicals react with each other to form other products **ALLOW** forms different structural isomers

					ALLOW a hydrogen (atom) on a different carbon (atom) can be replaced **Examiner's Comments** Candidates often found it difficult to provide clearly written explanations for this question. The majorly of responses focused on further substitution or the idea of different termination steps. Only the best candidates recognised that chlorination of 1-bromopropane would produce a mixture of structural isomers.
			Total	**14**	
14			Propagation step 1 $NO\cdot + O_3 \rightarrow NO_2\cdot + O_2$ ✓ Propagation step 2 $NO_2\cdot + O \rightarrow NO\cdot + O_2$ ✓	1 1	**ALLOW** one mark for both correct symbol equations with (any or all) dots missing or extra dots e.g. $NO + O_3 \rightarrow NO_2\cdot + O_2$ $NO_2 + O \rightarrow NO + O_2\cdot$ **Examiner's Comments** Many incorrect equations or correct symbol equations containing incorrect radicals were observed. A large proportion of candidates scored no marks on this question although the most able often provided both equations to gain two marks.
			Total	**2**	
15			B	1	**Examiner's Comments** Generally scored well.
			Total	**1**	
16			D	1	**Examiner's Comments** Generally scored well.
			Total	**1**	
17		i	C_2H_5O ✓	1	**ALLOW** elements in any order **DO NOT ALLOW** any other answer **Examiner's Comments** This part was answered well by most

					candidates. Some candidates however wrote the molecular rather than the empirical formula, or attempted to show the empirical formula as C_2H_4OH instead of C_2H_5O.
		ii	Compound E:  ✓ **Stage 1**: Compound **E**: Bromine/Br_2 ✓ NaOH/KOH **OR** OH^- ✓ **Stage 2**: *Only award if intermediate contains at least **one** halogen atom*	3	**For structures:** **ALLOW** correct structural **OR** skeletal **OR** displayed formula **OR** mixture of the above **ALLOW** dichloro/diiodo compound **IGNORE** connectivity of bonds to CH_3 **ALLOW** chlorine/Cl_2 **OR** iodine/I_2 **IGNORE** conditions, e.g. u.v. **DO NOT ALLOW** H_2O **IGNORE** conditions **NOTE:** Max of **2 marks** available for **monobrominated** intermediate **1 mark** Reagent: HBr **AND** Intermediate: $CH_3C(CH_3)_2Br$ **OR** $BrCH_2CH(CH_3)_2$ **1 mark** Intermediate: $CH_3C(CH_3)_2Br$ **OR** $BrCH_2CH(CH_3)_2$ **AND** Reagent: NaOH **Examiner's Comments** This demanding part was answered poorly by weaker candidates and was good for differentiating higher ability candidates. The mark scheme allowed some credit for using a hydrogen halide to obtain a monosubstituted haloalkane for compound E.

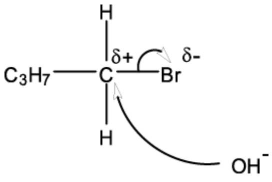
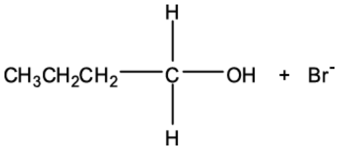
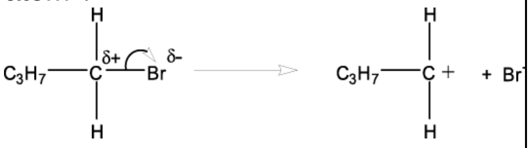
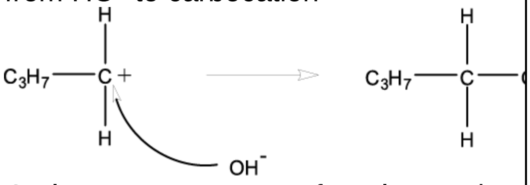
					Surprisingly, reaction mechanism names were often given instead of reagents. Many candidates seemed to guess, sometimes showing the same reagents for both stages in the hope of getting a mark. Many showed an intermediate containing no halogen atom.
			Total	**4**	
18		i		1	**ALLOW** correct structural **OR** displayed **OR** skeletal formula **OR** mixture of the above **ALLOW** equation with OH^- as reactant and Cl^- product e.g $(CH_3)_3CCH_2Cl + OH^- \longrightarrow (CH_3)_3CCH_2OH + Cl^-$ **IGNORE** equations with KOH / H_2O as reactant *(question states sodium hydroxide)* **IGNORE** molecular formulae *(question requires structures)* **Examiner's Comments** Most candidates were able to identify the correct chloroalkane required to produce 2,2-dimethylpropan-1-ol and provided a correctly balanced equation. A small but significant proportion of candidates failed to show the inorganic product in their equation. Candidates are encouraged to check equations carefully to ensure the correct formulae appear on both sides.
		ii	 curly arrow from HO^- to carbon atom of C—Cl bond ✓ Dipole shown on C—Cl bond, $C^{\delta+}$ and $Cl^{\delta-}$	2	Curly arrow must come from lone pair on O of HO^- OR OH^- **OR** from minus sign on O of HO^- ion (No need to show lone pair if curly arrow came from negative charge) **NOTE:** **ALLOW** mechanism involving **ANY** halogenoalkane as structures have been assessed in **(i)** ....

			AND curly arrow from C–Cl bond to Cl atom ✓		**ALLOW** S_N1 mechanism: **First mark** Dipole shown on C—Cl bond, $C^{\delta+}$ and $Cl^{\delta-}$ **AND** curly arrow from C—Cl bond to Cl atom ✓  **Second mark** Correct carbocation **AND** curly arrow from HO^- to carbocation  **Note:** '+' is fine for charge (circle used for clarity) Curly arrow must come from lone pair on O of HO^- **OR** OH^- **OR** from minus sign on O of HO^- ion (No need to show lone pair if curly arrow came from negative charge) ✓ …………………………………………………………… ..... **Examiner's Comments** The mechanism of the hydrolysis of a primary halogenoalkane was well known and consequently most candidates scored both marks. A small, but significant, proportion of candidates started their curly arrow from the H atom of the hydroxide ion. Candidates should be advised to take care when drawing mechanisms to ensure curly arrows are used accurately.
			Total	3	
19		i	Thunderstorms / lightning **AND** aircraft ✓	3	**IGNORE** car engines **Examiner's Comments** This question required candidates to state two sources of nitrogen oxides in the stratosphere. Whilst most candidates identified one, this was

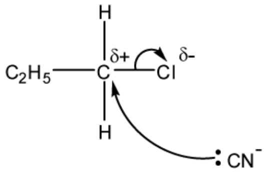
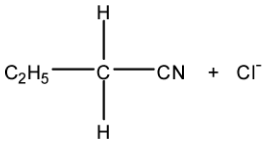
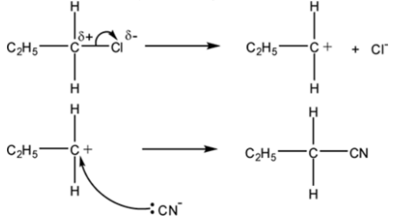
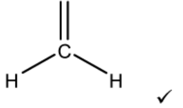
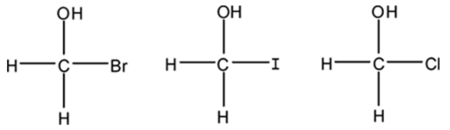
					often accompanied by vague or irrelevant statements such as ‘car engines’ or ‘the burning of fossil fuels’. Consequently only the strongest candidates scored in this part.
		ii	$NO + O_3 \rightarrow NO_2 + O_2$ ✓ $NO_2 + O \rightarrow NO + O_2$ ✓	2	**ALLOW** $NO_2 + O_3 \rightarrow NO + 2O_2$ **IGNORE** dots **IGNORE** $O + O_3 \rightarrow 2O_2$ **IGNORE** $2O_3 \rightarrow 3O_2$ **Examiner's Comments** The majority of candidates were able to provide the two equations that describe the catalytic role of NO in ozone depletion. A small but, significant proportion, of candidates provided equations involving N atoms.
			Total	**3**	
20	a		***Empirical / molecular formula 3 marks*** Mole ratio C : H : Br is 2.44 : 5.70 : 0.814 ✓ (Empirical formula) = C_3H_7Br ✓ **QWC** (Molecular formula) = C_3H_7Br **AND** relative mass linked to 150 evidence ✓ ***Structural isomers 2 marks*** $CH_3CH_2CH_2Br$ ✓ $CH_3CHBrCH_3$ ✓	5	**ANNOTATE ANSWER WITH TICKS AND CROSSES** **ALLOW** $\frac{29.29}{12.0} : \frac{5.70}{1.0} : \frac{65.01}{79.9}$ Evidence could include a calculation of the relative mass of C_3H_7Br as 122.9 linking to M_r being less than 150 **ALLOW** correct structural **OR** displayed **OR** skeletal formula **OR** mixture of the above (as long as unambiguous) **DO NOT ALLOW** missing H atom(s) in a displayed formula for one structure but **ALLOW** missing H atoms in subsequent structure **Note:** structures from an incorrect molecular formula will be credited on their merits. Please consult TL for

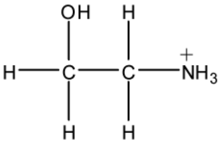
					advice on how to mark the subsequent parts of this question **Examiner's Comments** Calculation of empirical formula has always been a strength of candidates at this level. Consequently the vast majority were able to deduce the structures of the two isomers correctly. A significant number of candidates failed to secure full marks as they did not link the M_r of the empirical formula with the information about the M_r of the isomers being less than 150. Some candidates tried to use the value of 150 to determine the formula of **C** and **D**, ultimately ending up with an incorrect answer. However, error carried forward marks were allowed through subsequent parts of this question where appropriate.
	b	i	***Infrared for G 2 marks*** 1700 cm^{-1} **AND** C=O/carbonyl group ✓ (broad) 2300–3600 cm^{-1} **AND** O–H in carboxylic acid ✓	6	**ANNOTATE ANSWER WITH TICKS AND CROSSES** **LOOK ON THE SPECTRUM** for labelled peaks which can be given credit **ALLOW** ranges from *Data Sheet*: C=O within range 1640−1750 cm^{-1}; (broad) O−H within range 2500−3300 cm^{-1}
		i	***Structures 3 marks*** $CH_3CH_2CH_2OH$ ✓ $CH_3CHOHCH_3$ ✓ CH_3CH_2COOH ✓		**ALLOW** correct structural **OR** displayed **OR** skeletal formula **OR** mixture of the above (as long as unambiguous) **ALLOW** $CH_3CH_2CO_2H$ for carboxylic acid **IGNORE** names **IGNORE** labels **DO NOT ALLOW** missing H atom(s) in a displayed formula for one structure

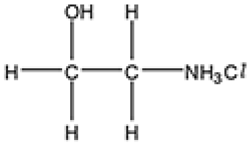
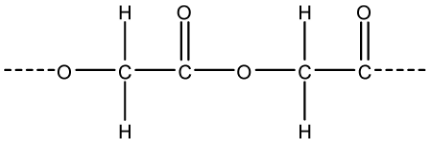
					but **ALLOW** missing H atoms in subsequent structures
		i	***Equation for formation of G 1 mark*** $C_3H_8O + 2[O] \rightarrow C_3H_6O_2 + H_2O$ ✓		**ALLOW** correct structural **OR** displayed **OR** skeletal formula **OR** mixture of the above in equation **Examiner's Comments** Candidates were well prepared for a structural determination question and examiners were encouraged by the number of high quality of responses to this question. Most candidates were able interpret the key peaks in the IR spectrum and identified the O-H bond of a carboxylic acid and C=O bond accurately. Most candidates identified all three structures correctly. Only the strongest responses included a correct equation for the formation of **G** by oxidation of **E**. Many responses failed to include this and others often had H_2 as the inorganic product. Candidates are advised to revise oxidation reactions of alcohols thoroughly as it is often the case that incorrect equations are frequently seen in responses to exam questions.
		ii	2 marks for correct ester. $CH_3CH_2COOCH(CH_3)_2$ ✓✓ Award 1 mark for: $CH_3CH_2COOCH_2CH_2CH_3$ **OR** Ambiguous ester: $CH_3CH_2COOC_3H_7$ ✓	2	**ANNOTATE ANSWER WITH TICKS AND CROSSES** **ALLOW** correct structural **OR** displayed **OR** skeletal formula **OR** mixture of the above (as long as unambiguous) **ALLOW** $C_2H_5CO_2CH(CH_3)_2$ **IF** there is one bond and its H missing from the correct ester award 1 mark **Examiner's Comments** Most candidates were able to show the structure of the ester formed from propanoic acid (**G** and propan-2-ol **(F)** correctly. Some candidates used the incorrect alcohol, propan-1-ol **(E)** and

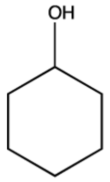
					such responses received only one of the two marks available.
			Total	**13**	
21	a	i	curly arrow from HO^- to carbon atom of C - Br bond ✓ Dipole shown on C–Br bond, $C^{\delta+}$ and $Br^{\delta-}$, **AND** curly arrow from C–Br bond to Br atom ✓  correct organic product **AND** Br^- ✓  $CH_3CH_2CH_2-CH_2-OH + Br^-$	3	**ANNOTATE ANSWER WITH TICKS AND CROSSES** Curly arrow must come from lone pair on O of HO^- **OR** OH^- **OR** from minus on O of HO^- ion (no need to show lone pair if curly arrow came from negative charge) **IGNORE** alkyl group in the first marking point **ALLOW** S_N1 mechanism **First mark** Dipole shown on C–Br bond, $C^{\delta+}$ and $Br^{\delta-}$, **AND** curly arrow from C - Br bond to Br atom ✓  **Second mark** Correct carbocation **AND** curly arrow from HO^- to carbocation  Curly arrow must come from lone pair on O of HO^- **OR** OH^- **OR** from minus on O of HO^- ion (no need to show lone pair if curly arrow came from negative charge) ✓ **Third mark** correct organic product **AND** Br^- ✓
		ii	Nucleophilic substitution ✓	1	
		iii	1-iodobutane **AND**	1	**Note:** the haloalkane could be identified by a correct structure e.g. $CH_3CH_2CH_2CH_2I$ **IGNORE** molecular formula **IGNORE** iodobutane (*no locant*

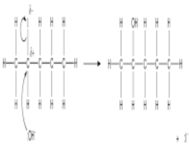
			C–I bonds are weaker (than C-Br) **OR** C–I bond has a lower bond enthalpy **OR** C–I bond needs less energy to break **OR** C–I bond is easier to break ✓		*number*) Statement **must** be comparative **ALLOW ORA** **IGNORE** C–I bond is longer **IGNORE** polarity and references to electronegativity
	b	i	$CF_3Cl \rightarrow CF_3\bullet + Cl\bullet$✓	1	**Note:** dots are **required**
		ii	Step 1: $Cl\bullet + O_3 \rightarrow ClO\bullet + O_2$ ✓ Step 2: $ClO\bullet + O \rightarrow Cl\bullet + O_2$ ✓ Overall equation: $O_3 + O \rightarrow 2O_2$✓	3	**ALLOW** one mark for both correct symbol equations in propagation steps with (any or all) dots missing or extra dots. e.g. $Cl\bullet + O_3\bullet \rightarrow ClO + O_2$ $ClO\bullet + O\bullet \rightarrow Cl + O_2\bullet$
		iii	**FIRST CHECK THE ANSWER ON THE ANSWER LINE** **IF** answer = 9.98×10^4 award 3 marks $n(Cl\bullet) = \frac{1}{35.5} = 0.02817$ (mol)✓ $n(O_3) = \frac{135000}{48} = 2812.5$ (mol) ✓ $n(Cl\bullet) : n(O_3) = \frac{2812.5}{0.02817} = 9.98 \times 10^4$ ✓ *Must be in standard form **AND** to 3SF*	3	**If there is an alternative answer, check to see if there is any ECF credit possible** **ALLOW** 0.0282 up to calculator value of 0.02816901408 correctly rounded to 3 or more sig. fig. **ALLOW 3SF**: 2810 up to calculator value of 2812.5 correctly rounded **Note**: use of 0.0282 mol $Cl\bullet$ gives 9.97×10^4
			Total	**12**	
22			B	1	**Examiner Comments** This question was answered correctly by over 90% of candidates with the most common incorrect response, silver chloride being given by those who may have named a precipitate formed in the test rather than the reagent required.
			Total	**1**	
23		i	curly arrow from ^-CN to carbon atom of C−Cl bond ✓ Dipole shown on C–Cl bond, $C^{\delta+}$ and $Cl^{\delta-}$, **AND** curly arrow from C−Cl bond to Cl atom ✓	**2**	**ANNOTATE ANSWER WITH TICKS AND CROSSES** Curly arrow must come from lone pair on C of ^-CN OR CN^- **OR** from minus sign on C of ^-CN ion (then lone pair on CN^- does not need to be shown)

			 correct organic product **AND** C*l*⁻✓ 		**IGNORE** NaCl **ALLOW** S_N1 mechanism: Dipole shown on C–Cl bond, $C^{\delta+}$ and $Cl^{\delta-}$, **AND** curly arrow from C–C*l* bond to C*l* atom ✓ Correct carbocation **AND** curly arrow from ^-CN to carbocation. Curly arrow must come from lone pair on C of ^-CN **OR** CN^- **OR** from minus sign on C of ^-CN ion (then lone pair on CN^- does not need to be shown) ✓ correct organic product **AND** Cl^- ✓  **Examiner Comments** The mechanism for the reaction of 1-chloropropane was well done with the majority of candidates scoring two or three of the marks. Marks were not awarded when candidates used a negative charge or a lone pair sited on the nitrogen as the starting point for a curly arrow in the first stage of the reaction mechanism. The final marking point was awarded for the production of a C*l*⁻ ion. The placing of curly arrows, dipoles and lone pairs of electrons are important when communicating by mechanisms.
		ii	Compound **G**  **Reagents** **Reaction 2:** H_2 **AND** Ni ✓	**3**	**ALLOW** any combination of skeletal **OR** structural **OR** displayed formula as long as unambiguous **IGNORE** name(s) **ALLOW**  **ALLOW** any suitable metal catalyst e.g. Pt

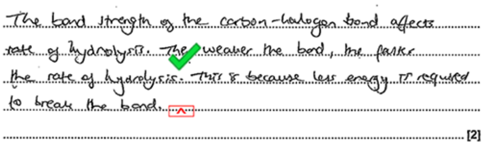
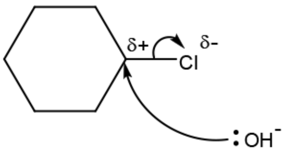
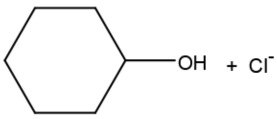
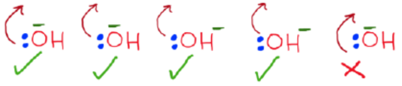
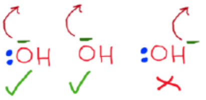
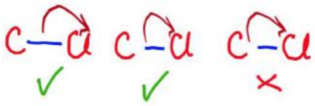
			Reaction 3: Correct formula of an aqueous acid e.g. $HCl(aq)/H_2SO_4(aq)$ ✓		**ALLOW** $LiAlH_4$ for reagent in reaction 2 **DO NOT ALLOW** $NaBH_4$ for reagent in reaction 2 **IGNORE** names *(question asks for formulae)* **IGNORE** references to temperature and/or pressure **ALLOW** $H^+(aq)$ **IGNORE** dilute **ALLOW** formula of an acid **AND** water e.g. HCl **AND** H_2O H_2SO_4 **AND** H_2O **Examiner Comments** Although many candidates were able to provide the structure of methanal as the starting material for this synthesis, the structures of chloromethanol, bromomethanol and iodomethanol were accepted as suitable alternatives. It should be noted that hydrolysis is carried out using aqueous acid and that dilute acid is not a suitable alternative.
		iii	**Explanation** Nitrogen electron pair **OR** nitrogen lone pair **AND** accepts a proton / H^+ ✓ **Structure of salt**  **AND** Cl^- ✓	**2**	**IGNORE** NH_2 group donates electron pair **ALLOW** nitrogen donates an electron pair to $\mathbf{H^+}$ **DO NOT ALLOW** nitrogen donates lone pair to acid **IGNORE** comments about the O in the –OH group Compound **H** is a base is **not sufficient** *(role of lone pair required)* **DO NOT ALLOW** nitrogen/N lone pair accepts hydrogen (*proton/H^+ required*) **ALLOW** any combination of skeletal **OR** structural **OR** displayed formula as long as unambiguous **ALLOW**

					 $HOCH_2CH_2NH_3Cl$ *i.e.* charges not required **IF** charges are shown **both** need to be present **ALLOW** charge either on **N** atom or NH_3^+ **IF** displayed then + charge must be on the nitrogen **Examiner Comments** Only 20% of candidates were awarded both marks for this question. The commonest error was a failure to state that the N atom has a lone pair of electrons that can gain a proton. Answers stating that amines accept protons or that a salt is produced when an acid reacts with a base were not credited. Where a full displayed structure is given the positive charge must be shown on the nitrogen atom, although $-NH_3^+$ is acceptable. As the question required the formula of the salt, the Cl^- had to be included.
		iv	 $-O-CH_2-CO-O-CH_2-CO-$ Ester link ✓ Rest of structure✓ (polymer **J** is biodegradable because) the ester / ester bond / ester group / polyester can be hydrolysed✓	**3**	**ALLOW** any combination of skeletal **OR** structural **OR** displayed formula as long as unambiguous **DO NOT ALLOW** more than two repeat units for second marking point. 'End bonds' **MUST** be shown (do not have to be dotted) **IGNORE** brackets **IGNORE** ***n*** Broken down by water is **not** sufficient **IGNORE** references to photodegradable **Examiner Comments** The most common mark for this question was two out of the three marks available, with candidates giving a correct structure of the polymer but failing to express that the polymer was

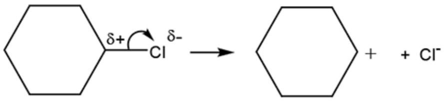
					biodegradable due the ability of the ester functional group to undergo hydrolysis.
			Total	**11**	
24		i	 ✓ Acid (catalyst) **AND** heat ✓	**2**	**ALLOW** correct structural **OR** displayed **OR** skeletal formulae **OR** a combination of above as long as unambiguous **ALLOW** (heat under) reflux **ALLOW** H_3PO_4 OR H_2SO_4 OR H^+ **DO NOT ALLOW** other named acids **IGNORE** concentration / pressure **IGNORE** water / steam **Examiner's Comments** Candidates who were able to give the structure of the intermediate were not always able to state the conditions for the elimination of water from an alcohol. The presence of an acid catalyst and heat are stated in the specification. Some candidates confused this reaction with addition reactions of alkenes suggesting that a Ni catalyst or the presence of steam is required.
		ii	**FIRST CHECK THE ANSWER ON THE ANSWER LINE** **IF** answer = 44.4(%) award all 3 marks for calculation *Amount cyclohexene (m / M)* = 1.23/82 **OR** 0.0150 mol ✓ *Amount of brnmocyclohexane (m / M)* = 5.50/162.9 **OR** 0.0338 mol ✓ % yield = (0.0150/0.0338) × 100 = 44.4(%) ✓ Final answer **must** be to 3 significant figures	**3**	**If there is an alternative answer, check to see if there is any ECF credit possible** **ALLOW 3 SF**: 0.0338 up to calculator value of 0.033763044 correctly rounded **Common ECFs** (2 marks) • Incorrect M_r → incorrect moles of cyclohexene

					• Incorrect M_r → incorrect moles of 2- bromocyclohexane e.g. **ALLOW two marks** for use of incorrect mass of bromocyclohexane with other calculations correct e.g. (5.50/163) = 0.033742331 → 44.5% **ALLOW** calculation in mass *Theoretical mass yield:* $m(C_6H_{10})$ = 0.0338 × 82 = 2.77 g % yield = (1.23/2.77) × 100 = 44.4% **Examiner's Comment:** Although some candidates simply calculated 1.23/5.50, most followed an effective strategy for the calculation of percentage yield. Many gained full marks but a large number of candidates relied on the application of error carried forward when they made one or more careless errors during the calculation of molar mass and / or moles. Intermediate answers were sometimes rounded to 2 significant figures and marks were lost by candidates who presented their final answer to 2 or 4 significant figures.
			Total	**5**	
25		i	Reflux	1	
		ii	Nucleophilic substitution (1) *Mechanism* Curly arrow from lone pair on OH^- to $\delta+$ carbon atom (1) Curly arrow and dipole on C–I bond (1) Correct products (1)	4	The curly arrow must start from the oxygen atom of the OH^- and must start from either the lone pair or the negative charge  **do not allow** attack by NaOH

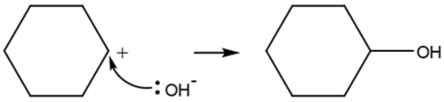
			Total	**5**	
26			**B**	**1**	**Examiner's Comments** The majority of candidates identified B (an alkene) as the compound that does not react with nucleophiles.
			Total	**1**	
27			**D**	**1**	**Examiner's Comments** Candidates found this multiple choice question difficult. While some correctly selected D, many candidates chose B.
			Total	**1**	
28	a		Links rate of reaction to strength of bond/bond enthalpy ✓ e.g. the weaker the bond the faster the reaction stronger bond takes longer to break lower bond enthalpy reacts faster Correct comparison of rate of reaction for at least **two** C–Hal bonds e.g. C–F bond is hydrolysed slow**est** C–I bond is hydrolysed faster than C–Br C–Br has shorter reaction time than C–Cl **OR** Correct comparison of C–Hal bond strength/enthalpy of at least **two** of C–Hal bonds e.g. C–I bond is the weak**est** C–I has lower bond enthalpy than C–Br C–Br is broken more easily/readily than C–Cl C–Hal bond strength decreases down group (7) ✓	**2**	**Each marking point must be a comparison** **IGNORE** references to halogens as elements: *i.e.* chlorine is less reactive than bromine etc. **DO NOT ALLOW** chloride, bromide and iodide **IGNORE** references to bond length, polarity and electronegativity **Examiner's Comments** This question required candidates to link the rate of hydrolysis with the strength of the carbon-halogen bond present in different haloalkanes. Higher ability candidates were able to do this succinctly, making clear comparisons between different C-X bonds. Exemplar 5 shows a commonly seen one mark response. **Exemplar 5**

					 The bond strength of the carbon-halogen bond affects rate of hydrolysis. The weaker the bond, the faster the rate of hydrolysis. This is because less energy is required to break the bond. [2] This response correctly describes the effect of bond strength on the rate of hydrolysis and receives one mark. To score the second mark a comparison of two different carbon-halogen bonds is required.
	b		Curly arrow from HO^- to carbon atom of C−Cl bond ✓ Dipole shown on C–Cl bond, $C^{\delta+}$ and $Cl^{\delta-}$ **AND** curly arrow from C−Cl bond to Cl atom ✓  **IGNORE** presence of Na^+ but OH^- needed i.e. Na^+OH^- can be allowed if criteria met --- Correct organic product **AND** Cl^- ✓  **IGNORE** presence of Na^+ but Cl^- needed i.e. Na^+Cl^- can be allowed **BUT** NaCl does **NOT** show Cl^-	3	**ANNOTATE ANSWER TICKS AND CROSSES** **NOTE:** curly arrows can be straight, snake-like, etc. but **NOT** double headed or half headed arrows **1st curly arrow** must • go to the C of C–Cl AND • start from, OR be traced back to any point across width of lone pair on O of OH^-  • OR start from – charge on O of ^-OH ion  *(Lone pair **NOT** needed if curly arrow shown from O^-)* **2nd curly arrow** must start from, **OR** be traced back to, **any part of** C–Cl bond and go to Cl  --- - **ALLOW** S_N1 mechanism **First mark** Dipole shown on C–Cl bond, $C^{\delta+}$ and $Cl^{\delta-}$,

AND curly arrow from C−Cl bond to Cl atom ✓



Second mark
Correct carbocation **AND** curly arrow from HO⁻ to carbocation



Curly arrow must come from lone pair on O of HO⁻ OR OH⁻
OR from minus on O of HO⁻ ion (no need to show lone pair if curly came from negative charge) ✓

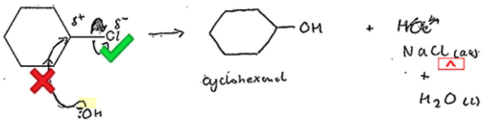
Third mark
Correct organic product **AND** Cl⁻ ✓

-

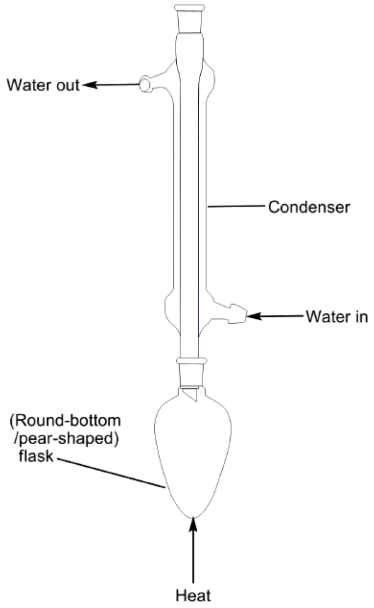
Examiner's Comments

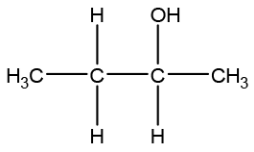
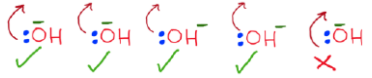
Candidates were very familiar with this nucleophilic substitution mechanism. Consequently the majority of candidates scored two or three marks. Common errors included inaccurate curly arrows from the hydroxide ion and failure to show the chloride ion as a product. Exemplar 6 highlights both of these.

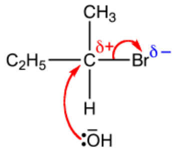
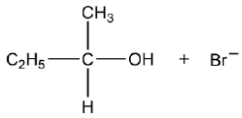
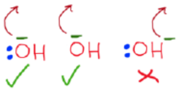
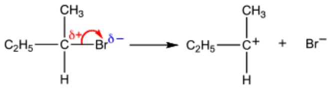
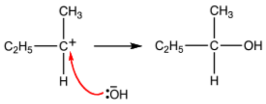
Exemplar 6

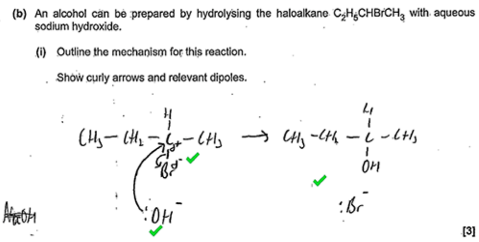
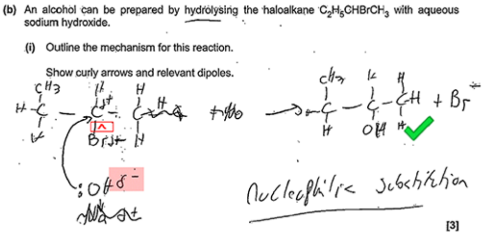


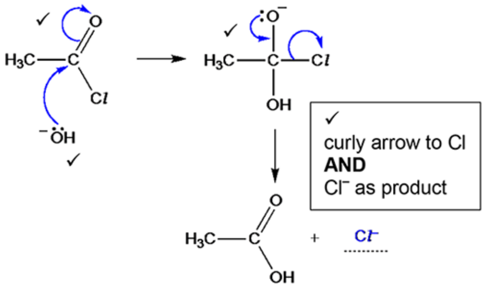
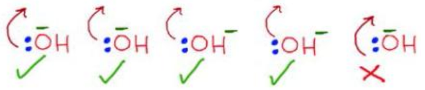
This response demonstrates the two most common errors seen in this part. The first marking point cannot be credited as the curly arrow from the hydroxide ion does not involve either the lone pair or minus sign on the O atom. The organic product is correct but the chloride ion produced by the

					heterolytic fission of the C-C*l* bond is not shown so marking point three cannot be credited. This response only scores one mark for the correct partial charges and curly arrow on the C-C*l* bond. Candidates are encouraged to practice drawing mechanisms so as to avoid costly errors during examinations.
	c	i	**Diagram** Diagram showing round bottom/pear shaped flask **AND** upright condenser ✓  **Labels** (Round-bottom/pear-shaped) flask **AND** condenser **AND** water in at bottom and out at top **AND** heat (source) ✓	**2**	**DO NOT ALLOW** conical flask, volumetric flask, beaker in place of round bottom/pear shaped flask **DO NOT ALLOW** distillation **DO NOT ALLOW** stopper/bung on top of condenser **IGNORE** a thermometer in condenser **IGNORE** a small gap between flask and condenser **ALLOW** diagram of heating apparatus as an alternative to heat label **<u>Examiner's Comments</u>** Most candidates were able to draw a suitable diagram to show the apparatus required for reflux but some included a stopper on top of the condenser. Many of the diagrams were labelled appropriately but common errors included incorrect direction of water flow or omission of the 'flask' label. A small but significant proportion of candidates drew a diagram showing distillation.

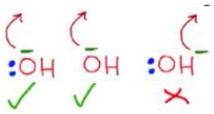
		ii	**Precipitate G** **1 mark** silver bromide/AgBr **AND** M = 1.88/0.01 = 188 (g mol^{-1}) 188 – 107.9 = 80.1 (so halide is Br$^-$)✓ **Alcohol F and Haloalkane E** **2 marks** **E** and **F** clearly identified **F/alcohol:** butan-2-ol  **E/haloalkane:** E is haloalkane of C_4H_9X with • same halogen as **G** **AND** • same carbon chain as **F** ✓	3	**ALLOW** any combination of skeletal **OR** structural **OR** displayed formula as long as unambiguous **Note:** working is **required** for first mark **ALLOW** use of 108 as Ar of Ag **Note: E** and **F** can be identified by correct name or structure **BUT IGNORE** incorrect names **<u>Examiner's Comments</u>** This question, requiring candidates to analyse the information to identify compounds **E**, **F** and **G**, discriminated well. Many candidates deduced that G was a silver halide but not all provided working to back up their choice of AgBr. Some candidates appeared to guess and AgC*l* was commonly seen. Some candidates used the molar mass of **F** provided to deduce the molecular formula of $C_4H_{10}O$ but lower ability responses did not process this further. Higher ability candidates identified **F** as butan-2-ol, showing the chiral carbon clearly. Other alcohols were also seen including butan-1-ol and methylpropan-2-ol. The highest ability candidates linked all the information and provided a structure for **E** that was consistent with their suggestions for **F** and **G**.
			Total	**10**	
29		i	**ANNOTATE ANSWER WITH TICKS AND CROSSES** --- **Curly arrows 2 marks** curly arrow from OH− to C atom of C–Br bond ✓	3	**1st curly arrow must** • go to the C of C–Br **AND** • start from, **OR** be traced back to **any point across width** of lone pair on O of OH$^-$ 

			dipole shown on C−Br bond, $C^{\delta+}$ and $Br^{\delta-}$, **AND** curly arrow from C–Br bond to Br atom  **IGNORE** incorrect R groups for curly arrow marks **IGNORE** presence of Na^+/Na but OH^- needed i.e. Na^+OH^-; $NaOH^-$ can be allowed with correct use of curly arrow --- **Products 1 mark** correct organic product **AND** Br^- ✓  **IGNORE** presence of Na^+ but Br^- needed i.e. Na^+Br^-/$NaBr^-$ can be allowed **BUT** NaBr does **NOT** show Br^- **NOTE**: curly arrows can be straight, snake-like, etc. but **NOT** double headed or half headed arrows		• **OR** start from – charge **on O** of ^-OH ion  *(Lone pair **NOT** needed if curly arrow shown from O^-)* **2nd curly arrow** must start from, **OR** be traced back to, **any part of** C–Br bond and go to Br  --- **ALLOW** S_N1 mechanism for 2 curly arrow marks **First mark** Dipole shown on C–Br bond, $C^{\delta+}$ and $Br^{\delta-}$, **AND** curly arrow from C–Br bond to Br atom  **Second mark** Curly arrow from OH^- **AND** to correct carbocation  Use curly arrow criteria in guidance above **<u>Examiner's Comments</u>** As with 25(a)(i), this question rewarded the well-prepared candidate. The large number of proposed mechanisms showed little resemblance to the accepted mechanism for nucleophilic substitution. Mechanisms were often seen showing curly arrows going in the wrong direction and between the wrong bonds and atoms, charges and dipoles were often incorrect, and partial changes used where full charges were required. Two exemplars are shown. The first exemplar shows clear curly arrows, the role of the lone pair and all charges correct. The second exemplar shows a

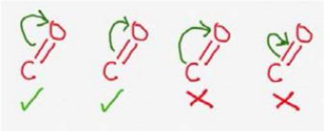
					typical muddled response. Although the curly arrow from the hydroxide ion has been accurately drawn, the hydroxide ion has a partial charge rather than a - charge. There is also no curly arrow showing breaking of the C–Br bond. The only mark available is for the correct organic product and a Br^- ion. Some mechanisms were so poor that it was impossible to credit many candidates with any marks. Writing mechanisms is an important skill in organic chemistry and it is recommended that candidates learn and practice their writing. **Exemplar 7**  (b) An alcohol can be prepared by hydrolysing the haloalkane $C_2H_5CHBrCH_3$ with aqueous sodium hydroxide. (i) Outline the mechanism for this reaction. Show curly arrows and relevant dipoles. [3] **Exemplar 8**  (b) An alcohol can be prepared by hydrolysing the haloalkane $C_2H_5CHBrCH_3$ with aqueous sodium hydroxide. (i) Outline the mechanism for this reaction. Show curly arrows and relevant dipoles. Nucleophilic substitution [3]
		ii	**Disappearance** of peak at 500-800 cm^{-1} **OR** C–Br peak ✓ Appearance of peak at 3200-3600 cm^{-1} **OR** **alcohol** O–H peak	**2**	**ALLOW** value within range 500–800 cmcm^{-1} **ALLOW** value within range 3200–3600 cmcm^{-1} **DO NOT ALLOW** responses that only describe the spectrum shown **<u>Examiner's Comments</u>**

					This part discriminated very well with able candidates identifying that the absorption for the C–Br bond would disappear, with a new peak appearing for the alcohol O–H bond. A significant number of candidates did not seem to understand what was required, with many interpreting the spectrum as that of the alcohol, rather than predicting how the spectrum would change during the reaction. A common error was to interpret the absorption for a C–H bond at ~3000 cm^{-1} as that of an O–H bond.
			Total	**5**	
30			**A**	1 (AO 2.5)	
			Total	**1**	
31			**B**	1 (AO 1.2)	**Examiner's Comments** Most candidates were able to identify the functional groups correctly and selected B. Some candidates opted for A, presumably assuming the C=O at the top of the structure was a ketone. A small, but significant number of candidates chose option C.
			Total	**1**	
32		i	 	4 (AO 3.2 ×4)	**IGNORE** any dipoles shown **NOTE:** curly arrows can be straight, snake-like, etc. but **NOT** double headed or half headed arrows **Curly arrow** from OH$^-$ must • go to the C of C=O **AND** • start from, **OR** be traced back to **any point across width** of lone pair on O of OH$^-$ 

- **OR** start from – charge^{-}OH ion



Curly arrow from C=O bond must start from, **OR** be traced back to, **any part of** C=O bond and go to O

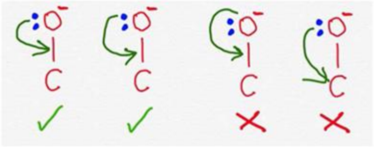


Curly arrow from O^{-}must

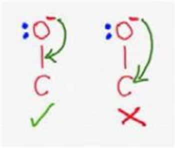
- go to C=O bond

AND

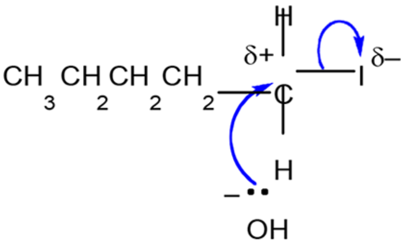
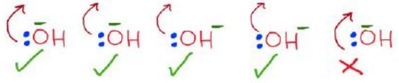
- start from, **OR** be traced back to, **any point across width** of lone pair

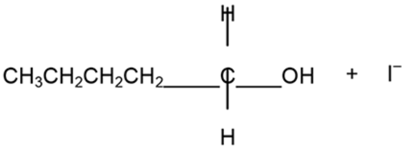
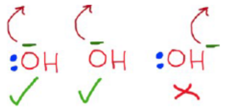
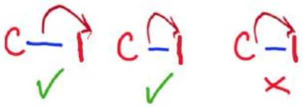
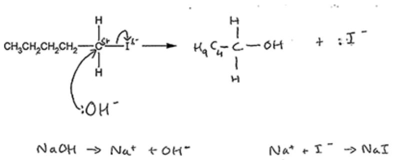


- **OR** start from ‘–‘ charge of O^{-}

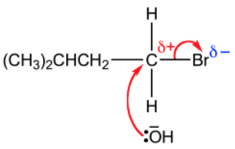
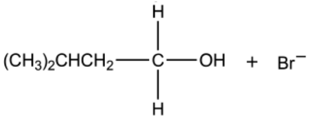
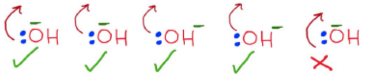
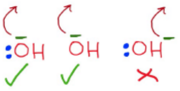
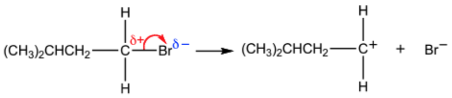
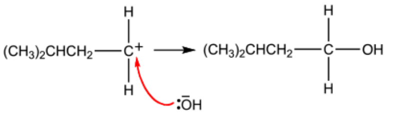


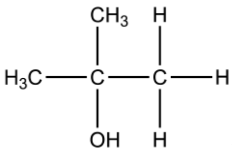
Curly arrow from C–Cl bond must start from, **OR** be traced back to, **any part of** C–Cl bond and go to Cl

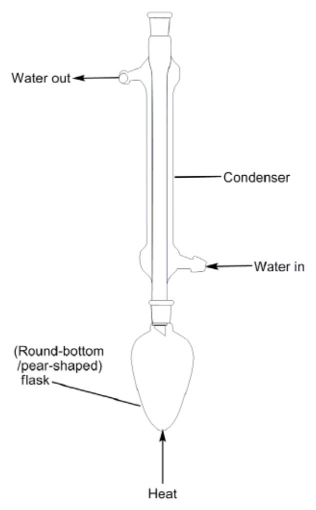
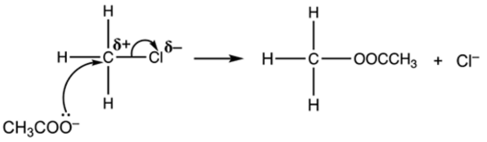
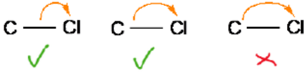
					Examiner's Comments Examiners were encouraged by the number of excellent responses to this question. Candidates were able to confidently apply their knowledge of mechanisms to this unfamiliar example and the majority of the cohort scored at least two marks. In the first step candidates used their understanding of nucleophilic addition to show a correct curly arrow from the hydroxide ion to the C of the C=O bond as well as an arrow from this bond to the O. Many candidates were able to show the breaking of the C–Cl bond and the formation of a chloride ion, drawing on their experience of the reactions of haloalkanes. Some candidates recognised the need to include an arrow to reform the carbon-oxygen double bond, with the best responses showing this accurately. A common error was to draw the bond from the lone pair on O to the C atom, rather than the bond.
		ii	($OH^–$) donates an electron pair/lone pair **OR** ($OH^–$ acts as a) nucleophile ✓	1(AO 1.2)	
			Total	**5**	
3 3		i	Curly arrow from $HO^–$ to carbon atom of C−I bond ✓ Dipole shown on C–I bond, $C^{\delta+}$ and $I^{\delta–}$ **AND** curly arrow from C−I bond to I atom ✓  **IGNORE** presence of Na^+ but OH^- needed i.e. Na^+OH^- can be allowed if the criteria are met	3(AO2.5× 3)	**ANNOTATE ANSWER WITH TICKS AND CROSSES** **NOTE**: curly arrows can be straight, snake-like, etc. but **NOT** double headed or half headed arrows **1st curly arrow** must • go to the C of C–I **AND** • start from, **OR** be traced back to **any point across width** of lone pair on O of $OH^–$ 

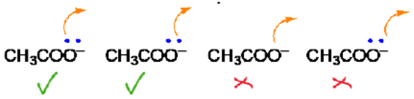
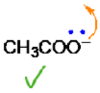
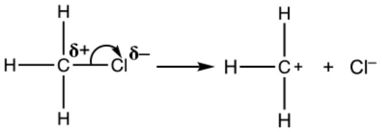
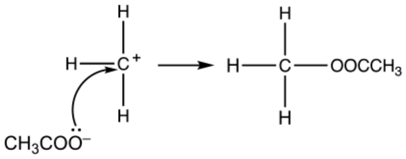
			-- Correct organic product **AND** I^- ✓  $CH_3CH_2CH_2CH_2-\overset{H}{\underset{H}{C}}-OH \quad + \quad I^-$ **IGNORE** presence of Na^+ but I^- needed i.e. Na^+I^- can be allowed BUT NaI does not show I^-		• **OR** start from – charge **on O** of ^-OH ion  *(Lone pair **NOT** needed if curly arrow shown from O^-)* **2nd curly arrow** must start from, **OR** be traced back to, **any part of** C–I bond and go to I  **<u>Examiner's Comments</u>** Those that had learnt this important mechanism scored all 3 marks with very precisely drawn arrows and partial charges. Although many candidates wrote out the correct organic product, many wrote NaI instead of I^- which lost them the final mark. **Exemplar 4**  This candidate scored all 3 marks. The lone pair of electrons on the oxygen and partial charges on the C-I bond are clearly marked on the diagram and the arrows are precisely drawn. Connectivity is good on the organic product and I^- identified as the additional product.
		ii	**Time** for **precipitate** to appear ✓	1(AO3.3)	Time **AND** precipitate required *Question asks for measurement* **<u>Examiner's Comments</u>** The question asked for the measurement AND observation, many

					students did not answer both parts and therefore did not gain any marks. “How fast” and “how long” were not given as they did not detail the measurement.
		iii	C–I bond is weaker (than C–Br bond) **OR** C–I bond has a lower bond enthalpy (than C–Br bond) ✓ Carbon – halogen **bond breaks** ✓	2(AO3.2)	**For 2 marks,** **ALLOW** C–I is broken more easily (than C–Br) as the bond is weaker There must be a **comparison** between C–Br and C–I bonds **Examiner’s Comments** Answers were too vague to be given in most cases. Candidates referred to bonds being broken or overcome, but did not specify C-I bonds breaking, or discussed iodine and bromine in terms of reactivities.
			Total	**6**	
34			**B**	1 (AO1.2)	**Examiner’s Comments** Many candidates correctly chose B, with A being seen as the expected main distractor. Fewer than half the candidates scored this mark.
			Total	**1**	
35	a	i	**FIRST, CHECK THE ANSWER ON ANSWER LINE** **IF atom economy = 46.1(%) award 2 marks** -- Atom economy $= \frac{M_r \text{ of } (CH_3)_2CHCH_2CH_2OH}{M_r\,(CH_3)_2CHCH_2CH_2OH + M_r\,NaBr} \times 100$ **OR** $= \frac{88}{190.9} \times 100$ ✓ = 46.1(%)✓	2 (AO1.2×1) (AO2.2×1)	**ALLOW** $\frac{M_r\,(CH_3)_2CHCH_2CH_2OH}{M_r\,(CH_3)_2CHCH_2CH_2Br + M_r\,NaOH} \times 100$ **ALLOW** 46% up to calculator value (46.09743321) **ALLOW ECF** from incorrect M_r values **Examiner’s Comments** Most candidates were able to recall the formula to calculate atom economy, however a number made errors in working out M_r values. However, some left this blank or just gave an answer without any working.
		ii	**ANNOTATE ANSWER WITH TICKS AND CROSSES** -- **Curly arrows 2 marks**	3 (AO2.5×1)	**1st curly arrow** must - go to the C of C–Br **AND**

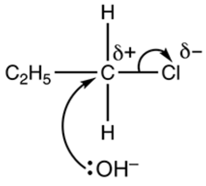
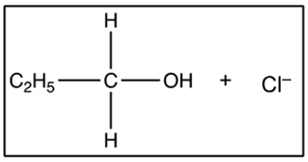
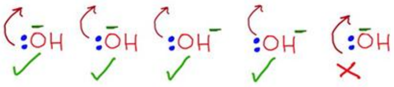
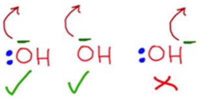
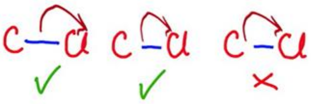
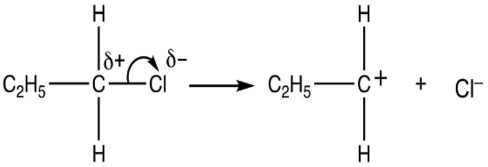
			curly arrow from OH– to C atom of C−Br bond ✓ dipole shown on C–Br bond, $C^{\delta+}$ and $Br^{\delta-}$, **AND** curly arrow from C−Br bond to Br atom ✓  **IGNORE** incorrect R groups for curly arrow marks **IGNORE** presence of Na+ but OH– needed i.e. Na+OH–can be allowed if criteria met --- **Products** **1 mark** correct organic product AND Br– ✓  **IGNORE** presence of Na^+ but Br^- needed i.e. Na^+Br^-can be allowed **BUT** NaBr does **NOT** show Br– **NOTE:** curly arrows can be straight, snake-like, etc. but **NOT** double headed or half headed arrows	(AO1.1×1) (AO2.5×1)	• start from, **OR** be traced back to **any point across width** of lone pair on O of OH–  • **OR** start from – charge **on O** of ^-OH ion  *(Lone pair **NOT** needed if curly arrow shown from O–)* **2nd curly arrow** must start from, **OR** be traced back to, **any part of** C–Br bond and go to Br  -- **ALLOW** S_N1 mechanism for 2 curly arrow marks **First mark** Dipole shown on C–Br bond, $C^{\delta+}$ and $Br^{\delta-}$, **AND** curly arrow from C−Br bond to Br atom ✓  **Second mark** Curly arrow from OH– **AND** to correct carbocation  Use curly arrow criteria in guidance above **Examiner's Comments** Mechanisms were often seen showing curly arrows going in the wrong direction and between the wrong bonds and atoms, charges and dipoles were often incorrect, and partial changes used where full charges were required. Writing mechanisms is an important skill in organic chemistry so it is vital that time is spent practising writing

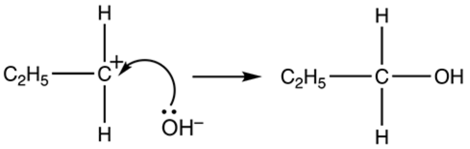
					them out and fully understanding the significance of the curly arrow.
		iii	Nucleophilic substitution ✓	1 (AO1.1×1)	**Examiner's Comments** Many candidates gave the correct mechanism here, with common incorrect responses being other types of mechanism, substitution only, or isomerism.
	b		Rate slower with chloroalkane **ORA** ✓ C–C*l* bond is stronger than C–Br bond **OR** C–C*l* bond has greater bond enthalpy **OR** more energy needed to break C–C*l* bond ✓	2 (AO3.1×1) (AO2.5×1)	**IGNORE** reference to bond polarity **Examiner's Comments** Very few candidates gained both marks here. It was not enough here to just state faster/slower without specifying which haloalkane they were referring to. It was also important to specify the C-X bond not just vague reference to the chlorine or bromine bond. Many described the difference in bond polarity so had the wrong order. Some were more general and discussed the reactivity of bromine and chlorine themselves.
			Total	**8**	
36			**B**	1 (AO2.3)	
			Total	**1**	
37			**B**	1 AO1.1	
			Total	**1**	
38		i	Alcohol **C**  ✓ Reagent **AND** product NaOH **AND** NaBr **OR** KOH **AND** KBr **OR** OH– **AND** Br^- ✓	2 AO2.5×2	**ALLOW** Reagent: H^2O/water **AND** Product: HBr
		ii		2 AO3.3×2	**For condenser label, ALLOW** 'condenser' **OR** water in **AND** water out (May be implied by connection to tap and sink).

			 **1st mark:** **Labelled condenser** above a flask ✓ **2nd mark:** *Only available if 1st mark has been awarded* Flask **AND** heat labelled ✓		
			Total	**4**	
39			**C**	1 (AO1.2)	
			Total	**1**	
40			**A**	1 (AO1.2)	
			Total	**1**	
41			**Formation of C*l*•** $CClF_3 \rightarrow CF_3\bullet + Cl\bullet$ ✓ **Breakdown of O_3** $Cl\bullet + O_3 \rightarrow \bullet ClO + O_2$ ✓ $\bullet ClO + O \rightarrow Cl\bullet + O_2$ ✓	3 (AO2.5) (AO1.1×2)	**IGNORE** dots for formation C*l*•, i.e. **ALLOW** $CClF_3 \rightarrow CF_3 + Cl$ **DO NOT ALLOW** ECF Dots **required** in this equation **IGNORE** $O + O_3 \rightarrow 2O_2$ **ALLOW 1 mark** if both equations are correct by atom but dot(s) missing or incorrect
			Total	**3**	
42			**Mechanism:**  **NOTE:** Can be any C–X bond, e.g. C–Cl, C–Br, C–I but must be consistent. **Curly arrow on C–X** Dipole shown on C–X bond of CH_3X, $C^{\delta+}$ and $X^{\delta-}$ **AND** curly arrow from C−X bond to X atom ✓ **Curly arrow from CH3COO⁻**	3 (AO2.5) (AO1.2) (AO2.5)	ANNOTATE ANSWER TICKS AND CROSSES --- **NOTE:** Curly arrows can be straight, snake-like, etc. but **NOT** double headed or half headed arrows **1st curly arrow** must start from, **OR** be traced back to, **any part** of C–Cl bond and go to Cl  **2nd curly arrow** must

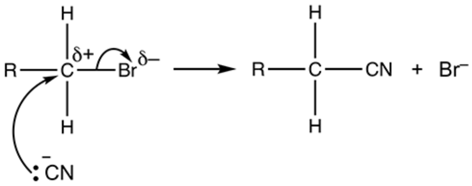
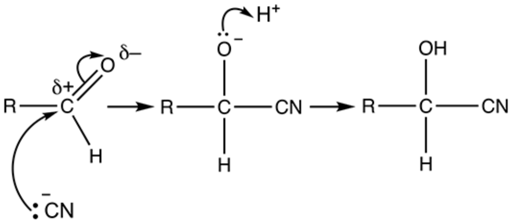
			Curly arrow from CH_3COO^- to C atom of C–X bond ✓ -- **Products** Correct organic product **AND** X^- ✓		- go to the C of C–Cl **AND** - start from, **OR** be traced back to **any point across width** of lone pair on O of CH_3COO^-  - **OR** start from '–' **on O** of CH_3COO^- ion  *(Lone pair **NOT** needed if curly arrow from O–)* --- If CH_3COOH used instead of CH_3COO^-, **ALLOW** X^- **OR** HX as 2nd product **ALLOW** S_N1 mechanism **First mark** Dipole shown on C–Cl bond, $C^{\delta+}$ and $Cl^{\delta-}$, **AND** curly arrow from C−Cl bond to Cl atom ✓  **Second mark** Correct carbocation **AND** curly arrow from CH_3COO^- to carbocation  Curly arrow must be from lone pair on O of CH_3COO^- **OR** from minus on O of CH_3COO^- ion (no need to show lone pair if curly came from – charge) ✓ **Third mark** Correct organic product **AND** Cl^- ✓

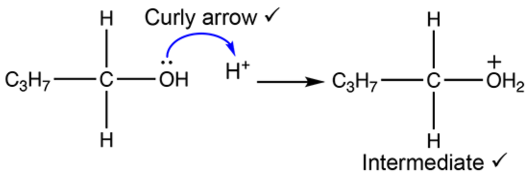
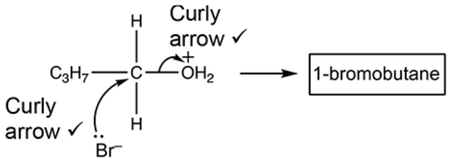
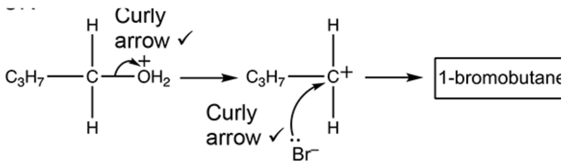
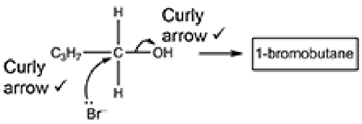
					Examiner's Comments Candidates were required to apply their knowledge of nucleophilic substitution of haloalkanes to outline a similar mechanism for an unfamiliar nucleophile. Most candidates were able to show a correct curly arrow for breaking the C–X bond, with a dipole shown. The role of the unfamiliar ethanoate ion proved to be much more difficult, with curly arrows not starting from either a lone pair or the – charge. A mark was given for the correct products but the halide ion was often omitted. This question discriminated extremely well. Higher-attaining candidates provided clear mechanisms and were commonly given all 3 marks. Many candidates could not work out where to start, beyond breaking the C–X bond. It was common to see reactants and products with the wrong number of carbon atoms, and the structure of ethyl methanoate instead of methyl ethanoate being shown as the product. When confronted with a question set in a novel context, candidates are advised to apply knowledge and understanding from reactions that they have studied – here the reaction of a haloalkane with a OH– ion.
			Total	**3**	
43			**B**	1(AO1.1)	**Examiner's Comments** Most candidates selected the correct option, B. The main distractors were A (confusing which C–X bondis stronger) and C (confusing which effect of bond strength and polarity is dominant for this reaction).
			Total	**1**	
44			Curly arrow from HO^- to C atom of C-Cl bond ✓	3 (AO1.2) (AO1.2)	**ANNOTATE ANSWER WITH TICKS AND**

			Dipole shown on C-Cl bond, $C^{\delta+}$ and $Cl^{\delta-}$ **AND** curly arrow from C-Cl bond to Cl atom ✓  or **IGNORE** presence of Na^+ but OH^- needed i.e. Na^+OH^-can be allowed if criteria met **DO NOT ALLOW** H_2O instead of OH^- Correct organic product **AND** Cl^- ✓ or  **IGNORE** presence of Na^+ but Cl^- needed i.e. Na^+Cl^- can be allowed **BUT** NaCl does **NOT** show Cl^-	(AO2.5 ×1)	**CROSSES** **NOTE**: curly arrows can be straight, snake-like, etc. but **NOT** double headed or half headed arrows **1st curly arrow** must • go to C of C-Cl **AND** · start from, **OR** be traced back to **any point** Cl **across width** of lone pair on O of OH^-  • **OR** start from - charge **on O** of ^-OH ion  *(Lone pair **NOT** needed if curly arrow shown from O^-)* **2nd curly arrow** must start from, **OR** be traced back to, **any part of** C-Cl bond and go to Cl  **ALLOW ECF** $NaCl^-$**ONLY** from $NaOH^-$ **ALLOW** S_N1 mechanism **First mark** Dipole shown on C-Cl bond, $C^{\delta+}$ and $Cl^{\delta-}$, **AND** curly arrow from C-Cl bond to Cl atom ✓  **Second mark** Correct carbocation **AND** curly arrow from HO^- to carbocation

					 Curly arrow must come from lone pair on O of HO$^-$ **OR** OH$^-$ **OR** from minus on O of HO$^-$ ion (no need to show lone pair if curly came from negative charge) ✓ **Third mark** Correct organic product **AND** Cl$^-$ ✓ **Examiner's Comments** Although a simpler mechanism than electrophilic addition in Question 21 (a)(ii), candidate responses here were less successful. Many candidates weren't able to identify the OH$^-$ ion attacking the carbon atom and the curly arrow often did not originate from an O lone pair or the negative charge. Candidates often omitted the dipole on the C–Cl bond or did not include a curly arrow. Candidates were expected to show both the resulting alcohol and Cl$^-$ as products. Many tried to incorporate Na into their organic structure. Organic mechanisms are a key concept in organic chemistry and it is essential for candidates to learn all the mechanisms in preparation for examinations. **Assessment for learning** Reactions mechanisms are the organic chemist's way of communicating electron transfers in organic chemistry. It is essential that curly arrows, dipoles and charges are used appropriately and accurately. AS Chemistry includes three important reaction mechanisms: electrophilic addition, nucleophilic substitution and radical substitution. This paper includes two of these in

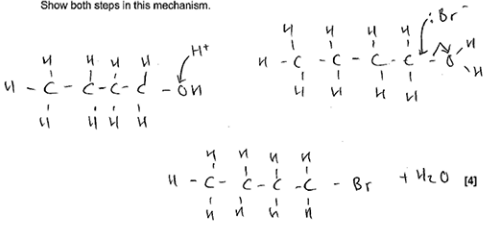
					Questions 21 (a) (i) and 26 (a). It is essential that candidates learn these three mechanism types.
			Total	**3**	
45			B	1 (AO1.1)	**Examiner's Comments** The majority of candidates identified B as the correct answer.
			Total	**1**	
46			B	1 (AO1.1)	**Examiner's Comments** Candidates found this multiple choice question challenging. While some identified B as the correct answer, many candidates selected C.
			Total	**1**	
47			A	1 (AO1.1)	**Examiner's Comments** Many candidates did not identify CH_3NH_2 as a nucleophile and selected option B.
			Total	**1**	
48			**Level 3 (5–6 marks)** Describes, in detail, reactions of **two** aliphatic compounds that form a C–C bond **AND** mechanisms for the **two** aliphatic reactions. *There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.* **Level 2 (3–4 marks)** Describes a reaction of **one** aliphatic compound that forms a C–C bond with few omissions/errors. **AND** mechanism for **one** aliphatic reaction. **OR** Describes reactions of **two** compounds	6 (AO1.2×4) (AO2.5×2)	**Indicative scientific points may include:** **Reactions of aliphatic compounds and mechanisms** • Haloalkane, RX and CN^- → RCN + X^- Reagents: NaCN and ethanol Reaction: Nucleophilic substitution Mechanism:

			that forms a C–C bond **AND** attempts a mechanism for **one** of the reactions *There is a line of reasoning presented with some structure. The information presented is relevant and supported by some evidence.* **Level 1 (1–2 marks)** Selects suitable reagents for reactions of **two** compounds that form a C–C bond. **OR** Attempts to describe a reaction and mechanism of **one** compound that forms a C–C bond, with omissions/errors. *There is an attempt at a logical structure with a line of reasoning. The information is in the most part relevant.* **0 marks** *No response or no response worthy of credit*.		 • Aldehyde or ketone and HCN e.g. $RCHO + HCN \rightarrow RCH(OH)CN$ Reagents: NaCN and H^+ Reaction: Nucleophilic addition Mechanism:  OR H_2O instead of H^+ for 2nd stage **If alternative reactions are shown contact your TL e.g. radical substitution, polymerisation** **<u>Examiner's Comments</u>** This question differentiated well. Candidates who were given Level 3 (5-6 marks) understood the term aliphatic and were able to provide two different mechanisms that produced a C-C bond. The most common responses seen involved the nucleophilic substitution of a halogenoalkane and a cyanide ion and the nucleophilic addition of a carbonyl with a cyanide ion. Some candidates offered radical

					substitution mechanisms, detailing initiation, propagation and termination steps, with the termination step producing a C-C bond. Candidates who scored Level 2 (3-4 marks) frequently detailed a reaction involving aromatic compounds or polymerisation of alkenes for which they were unable to give a mechanism.
			Total	**6**	
49			**Step 1** The oxygen atom of the alcohol group accepts a proton to form a positively-charged intermediate. ***2 marks***  **Step 2** Bromide ions react with the intermediate by nucleophilic substitution to form 1-bromobutane. ***2 marks*** *2 possible routes:* **EITHER**  OR  	4 (AO3.2 ×4)	**ALLOW** any combination of skeletal **OR** structural **OR** displayed formula as long as unambiguous For $CH_3CH_2CH_2$, **ALLOW** $CH_3(CH_2)_2$, C_3H_7 **IGNORE** dipoles --- **ALLOW** curly arrow to H of H-O-SO_3H **OR** H-Br **IGNORE** absence of curly arrow from H-O or from H-Br + charge **MUST** be on O of intermediate **Curly arrow** must • start from, **OR** be traced back to **any point across width** of lone pair on :Br$^-$ **OR** :OH **OR** start from - charge on Br$^-$ *(Lone pair* ***NOT*** *needed if curly arrow shown from - charge on Br-)* **IGNORE** final products: 1-bromobutane and H_2O **IF** $C_3H_7CH_2$-O^+H_2 is **not** shown, **ALLOW** intermediate mark for carbocation: $C_3H_7CH_2^+$ **ALLOW** 2 marks max for mechanism without positively charge intermediate, i.e.  **If in doubt, contact Team Leader** **Examiner's Comments**

This question is one of two on this paper assessing understanding of unfamiliar organic reaction mechanisms. The stem to the question includes important information and clues that should have then guided candidates towards this unfamiliar mechanism (which is related to the familiar nucleophilic substitution of haloalkanes). The two prompts for Step 1 and Step 2 are critical but many candidates did not use these, instead inventing their own mechanisms. However, there were many successful responses seen that gained the full 4 marks.

Exemplar 2

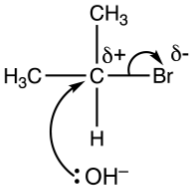
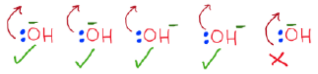
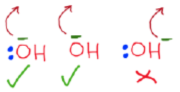

Show both steps in this mechanism.

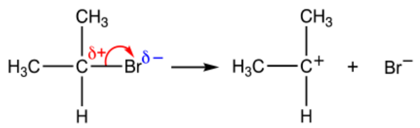
Exemplar 2 illustrates a limited appreciation of what curly arrows mean and the importance of charges and dipoles. Step 1 is an attempt to show the alcohol OH group accepting a proton, but a curly arrow shows the movement of an electron pair. It cannot travel from a + charge to a lone pair. The intermediate shown does contain the correct atoms but the + charge has been omitted from the O atom.

Marks were given for the curly arrow from the Br^- lone pair and from the C-O bond. However, the candidate has drawn the bonds with very short lines making it all too easy for a curly arrow to be shown imprecisely. This response was given 2/4 marks.

Assessment for learning

In organic chemistry mechanisms, a curly arrow shows the movement of an electron pair and demonstrates the

					direction of electron flow in organic reactions. A curly arrow must start from: • A lone pair or negative charge and go to an atom to show where a bond **forms** • A bond to show where a bond **breaks**. In Q3b, curly arrows start • from a lone pair on the alcohol OH and a Br$^-$ ion • from a C-O bond A curly arrow will **not** originate from a + charge.
			Total	**4**	
50	a		**Mechanism** Curly arrow from OH– to C atom of C−Br bond in 2-bromopropane✓ Dipole shown on C–Br bond, C$^{\delta+}$ and Br$^{\delta-}$, **AND** curly arrow from C−Br bond to Br atom ✓  **Name** nucleophilic substitution ✓ **NOTE**: Curly arrows can be straight, snake-like, etc. but **NOT** double headed or half headed arrows	3 (AO 1.2) (AO 2.1) (AO 1.1)	**1st curly arrow** must • go to the C of C–Br **AND** • start from, **OR** be traced back to **any point across width** of lone pair on O of OH$^-$  • **OR** start from – charge **on O** of $^-$OH ion  *(Lone pair **NOT** needed if curly arrow shown from O$^-$)* **2nd curly arrow** must start from, **OR** be traced back to, **any part of** C–Br bond and go to Br  -- **ALLOW** S$_N$1 mechanism for 2 curly arrow marks **First mark**

<table>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Dipole shown on C–Br bond, $C^{\delta+}$ and $Br^{\delta-}$,
AND curly arrow from C−Br bond to Br atom ✓

Second mark
Curly arrow from OH^- AND to correct carbocation ✓

Curly arrow must come from lone pair on O of HO^- OR OH^-
OR from minus on O of HO– ion (no need to show lone pair if curly came from negative charge) ✓

<u>Examiner’s Comments</u>

Just under half the candidates gained all 3 marks for this mechanism. Marks were often lost for incorrect positioning or a missing arrow for the breaking of the C-Br bond. Dipoles were often added to the hydroxide ions. Some also showed the lone pair for OH- going to the C-Br bond and not to the $C^{\delta+}$.

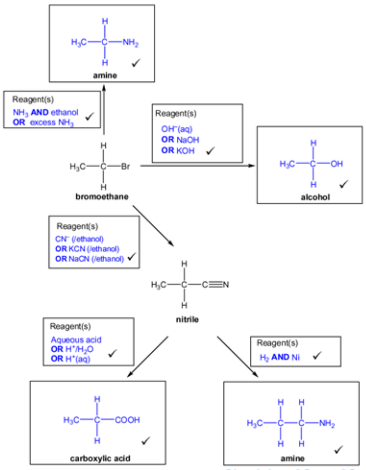
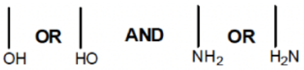
A range of spellings of nucleophilic were seen, including: nucleophilic, nucleophilic, nucleophilic, and nucleophilic. It is important to promote good literacy in science, including meanings and spellings of technical language.</td>
</tr>
<tr>
<td></td>
<td>b</td>
<td>i</td>
<td>
<table>
<tr><th><i>Haloalkane</i></th><th><i>Formula</i></th><th><i>Colour</i></th><th></th></tr>
<tr><td><i>2-bromopropane</i></td><td>AgBr</td><td>cream</td><td>✓</td></tr>
<tr><td><i>2-iodopropane</i></td><td>AgI</td><td>yellow</td><td>✓</td></tr>
</table>
</td>
<td>2
(AO 1.1 x 2)</td>
<td>ALLOW 1 mark if correct formula for both OR correct colour for both

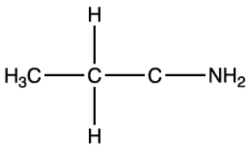
<u>Examiner’s Comments</u>

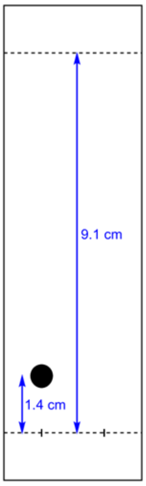
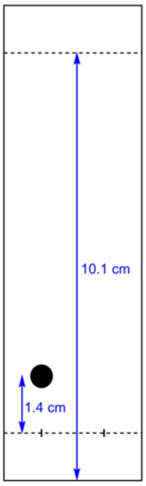
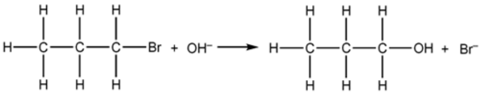
The majority of candidates scored both marks. Some scored 1 mark only mainly for correct colours of the precipitates but with incorrect formulae. Common errors included $AgBr_2$ and AgI_2, giving the formula of the</td>
</tr>
</table>

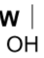
			Formula **AND** colour required for each mark		haloalkane or formulae involving a halogen and a nitrate ion.
		ii	AgI **OR** yellow (precipitate forms first) **AND** C–I bond is weaker (than C–Br bond) ✓	1 (AO2.3)	**ALLOW** (precipitate from) 2-iodopropane **ALLOW** ECF from incorrect formula or colour ppt from 3(d)(ii) **ALLOW** C–I bond has a lower bond enthalpy **OR** C–I bond is longer **ORA** **IGNORE** references to bond length, polarity and electronegativity **<u>Examiner's Comments</u>** Most responses did not gain credit here. Some recognised that AgI would form first but then gave an incorrect reason (such as 'held by weaker London forces') or their answers lacked detail (e.g., 'weaker bonds' without specifying which bonds). Many said AgBr because Br is more reactive or more electronegative.
			Total	**6**	
51			**D**	1 (AO 2.7)	**<u>Examiner's Comments</u>** Candidates find it difficult to identify an intermediate within a synthesis and less than half selected the correct option, D.
			Total	**1**	
52			**D**	1	**<u>Examiner's Comments</u>** Most correctly identified the colour of the precipitate as yellow, D. The most common incorrect response was brown, A, possibly linking to the colour of iodine.
			Total	**1**	

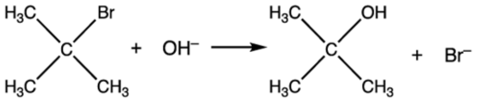
53			**A**	1	**Examiner's Comments** Most candidates gave the incorrect response D as their answer. Ultraviolet radiation does cause bonds in CFC molecules to break, and candidates may have been influenced by Question 8. However it is not a valid scientific reason for global warming. It suggests candidates may be confused about global warming verses the depletion of the ozone layer. This question was looking for candidates to link global warming to infrared active molecules i.e. C-H bond in methane. Just under a fifth of candidates gave the correct answer A. **Misconception** Many candidates believed there was a link between ultraviolet radiation and global warming. This is a topical issue so can be explored by looking at a range of resources including current news reports or exploring the United Nations resources.
			Total	**1**	
54			**C**	1	**Examiner's Comments** Most candidates correctly identified C as the correct initiation step forming a chlorine radical. A few gave B which forms an ·F radical instead. It is always good to discuss the reason why the C-C*l* bond will break but C-F won't in the presence of ultraviolet light.
			Total	**1**	
55				9	**ALLOW** any combination of skeletal **OR** structural **OR** displayed formula as long as unambiguous

			 Check has 3C not 2C		**DO NOT ALLOW** structure if H(s) are missing from **ONE** structural/displayed formula… **BUT ALLOW** any further omissions as **ECF** **ALLOW** any vertical bond to the OH **OR** NH_2  **DO NOT ALLOW** OH−, **OR** NH_2- but **ALLOW ECF** for subsequent use in this part **ALLOW** names of reagents e.g. ethanolic ammonia, if no formulae given **DO NOT ALLOW** other additional reagents **IGNORE** Conditions **For bromoethane to amine:** **IF** a secondary / tertiary amine is given **ALLOW** one mark for a correct structure **AND** one mark for an appropriate reagent to produce the amine shown. **For bromoethane to alcohol:** **ALLOW** H_2O **IGNORE** ethanol (as a solvent) **For bromoethane to nitrile:** **DO NOT ALLOW** HCN **OR** CN^- / H^+ **DO NOT ALLOW** H_2O / (aq) **For nitrile to carboxylic acid:** **ALLOW** any mineral acid **IGNORE** dilute/concentrated **For nitrile to amine:** **ALLOW** suitable non-specification alternative e.g. $LiAlH_4$, H_2 with Pd or Pt **Examiner's Comments** This question was well-answered with around a half of candidates scoring 8

					or 9 marks. The full range of marks was seen across the whole cohort. The most common reasons for losing marks were for the addition of extra, contradictory reagents or for missing hydrogens from structures. **Bromoethane to amine:** The amine structure was mostly correct with a few adding an extra hydrogen to the amine i.e. $CH_3CH_2NH_3$. Most gave the correct reagent as NH_3 but some omitted either ethanol or excess, so did not score here. **Bromoethane to alcohol:** The alcohol structure was usually correct. However, many lost the reagent mark here for the addition of acid/ H^+/H_2SO_4 alongside the hydroxide. **Bromoethane to nitrile:** A suitable cyanide was often used, but again many included an acid catalyst or aqueous conditions (aq) so lost the mark here. Ideally candidates would react in ethanol to prevent hydrolysis of the haloalkane. **Nitrile to carboxylic acid:** Most gave the correct carboxylic acid structure, while occasionally ethanoic acid was given instead of propanoic acid. Most identified the need for acid as a reagent but some omitted water or (aq). **Nitrile to amine:** H_2 was often seen as the reagent but sometimes without a catalyst. Many gave an incorrect structure here either with a missing C (i.e. ethylamine) or missing hydrogens on the first carbon i.e. 

					OCR support A useful resource for teaching about organic synthetic routes including functional groups, reagents and two-step processes can be found in the Topic Exploration pack on Teach Cambridge.
			Total	**9**	
56		i	$R_f \sim \frac{1.4}{\mathbf{9.1}}$ in cm **OR** $\frac{14}{\mathbf{91}}$ in mm = **0.15** ✓ *Working required* ***Check for ~ 9.1 as denominator*** 	1	**ALLOW** 0.12 - 0.18 (i.e. ±0.03) **DO NOT ALLOW** $\frac{1.4}{\mathbf{10.1}}$ = 0.14 ***10.1*** *measured from bottom of plate to solvent front*  **Examiner's Comments** Candidates are well versed with calculating an R_f value, with nearly all candidates obtaining a value in the acceptable range of 0.12-0.18.
		ii	$CH_3CH_2CH_2Br + OH^- \rightarrow CH_3CH_2CH_2OH + Br^-$ Correct balanced equation **ALLOW** OH- above the arrow	1	**ALLOW** any combination of skeletal **OR** structural **OR** displayed formula as long as unambiguous **DO NOT ALLOW Missing H atoms** **DO NOT ALLOW** H_2O and HBr

			DO NOT ALLOW if a **CON** reagent is present, e.g. an acid For OH- and Br- **ALLOW** KOH and KBr **OR** NaOH and NaBr **BUT DO NOT ALLOW** K-OH *implies covalent bond*		*Question asks for **alkaline** hydrolysis* **DO NOT ALLOW** C_3H_7, i.e. C_3H_7Br **OR** C_3H_7OH *Structure asked for in Question* **IGNORE** connectivity, e.g. **ALLOW**  **BUT DO NOT ALLOW —HO** **<u>Examiner's Comments</u>** This question was answered well by candidates, with most showing correct structures for the organic reactant and its product, propan-1-ol, and skeletal formulae mostly used. The question asked for an equation for alkaline hydrolysis and candidates were expected to use an alkali. Acceptable answers would include NaOH/KOH and NaBr/KBr, or OH^- and Br^-. Equations including H_2O and HBr were not given a mark, a common error for alkaline hydrolysis.
		iii	**Difference** propan-1-ol/product/bottom spot is smaller **OR** 1-chloropropane/reactant/top spot bigger ✓ **Reasons** propan-1-ol/product/bottom spot is smaller C-Cl bond is stronger than C-Br **AND**	3	**FULL ANNOTATIONS MUST BE USED** **ALLOW ECF and ORA throughout** -- **IGNORE** references to halogens as elements: *i.e.* chlorine is less reactive than bromine etc. **DO NOT ALLOW** chloride, bromide **DO NOT ALLOW** 1-chloropropane has larger bond enthalpy *C-Cl bond required* **IGNORE** 1-chloroproane has different R_f value **IGNORE** 'as a control' **OR** 'as a

			1-chloropropane reacts slower/is less reactive ✓ **Use of propan-1-ol** shows **formation** of propan-1-ol **OR** shows when reaction has **finished** **OR** monitors **course/progress** of reaction ✓		comparison' .... with no further explanation **Examiner's Comments** This novel question assessed whether candidates realised why chemists used TLC when carrying out organic reactions. A good response would identify the following key features after 20 minutes: • The C-C*l* bond energy is greater than C-Br and so the reaction would be slower. • The haloalkane spot would be larger and the propan-1-ol spot smaller. • The propan-1-ol is spotted on the chromatogram to monitor the progress of the reaction. The question differentiated very well between candidates, but many did not seem to know where to start with many candidates not scoring any marks. This suggested that candidates recognised chromatography as a technique but did not appreciate its relevance in organic chemistry. Some candidates referred to pigments, recalling their early chromatography experiments in finding the colours in ink.
			Total	**5**	
57		i	 Structure of **BOTH** organic compounds ✓ ***DO NOT ALLOW*** *if H(s) are missing* OH^- on left **AND** Br^- on right ✓ **ALLOW** NaOH/KOH with NaBr/KBr	2	**ALLOW** any combination of skeletal **OR** structural **OR** displayed formula as long as unambiguous **IGNORE** state symbols **ALLOW** OH^- **AND** Br^- in a balanced mechanism **ALLOW** OH^- over the arrow for LHS of equation **DO NOT ALLOW** unbalanced charges, e.g. OH^- with Br **DO NOT ALLOW** H_2O AND HBr

					question specifies aqueous alkali. **DO NOT ALLOW** 2nd mark if a CON reagent is present, e.g. an acid **Examiner's Comments** This question discriminated very well. Most candidates were given a first mark by showing correct structures for the organic reactant and its product, 2-methylpropan-2-ol. The question asked for an equation for alkaline hydrolysis and candidates were expected to use an alkali. Acceptable responses would include NaOH/KOH and NaBr/KBr, or OH^- and Br^-. Equations including H_2O and HBr were not given marks, a common error for alkaline hydrolysis. Candidates are advised to carefully read the requirements in the question. For the most successful responses, candidates often underline these to draw their attention.
		ii	**Rates of hydrolysis of all 3 haloalkanes** Fastest RI > RBr > RCl slowest ✓ **Bond enthalpies/strength of bonds for any one RX** Strongest: C−Cl > C−Br > C−I weakest ✓ **MUST** refer to C−X bond in some way	2	**IGNORE** reactivity of halogens **ALLOW** unambiguous comparison of two haloalkanes e.g. RI is fastest **AND** RCl is slowest **ALLOW** C−Cl is strongest bond **ALLOW** R−Cl, etc **BUT NOT** RCl > RBr > RI *no bonds* **DO NOT ALLOW** just ‘strongest bond enthalpy iodine has weakest bond **Examiner's Comments** Candidates found this question difficult. Many fell into a trap of their own making by comparing the relative reactivities of the halogens chlorine, bromine and iodine and it was common to see responses claiming that a chloroalkane has the fastest rate and that an iodoalkane has the slowest

					rate. Only the most successful candidates related a correct order of reactivity to the different strengths of the carbon–halogen bond.
			Total	**4**	