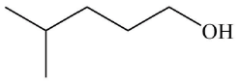
1. What is the systematic name for the molecule shown below?

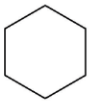
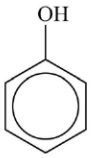
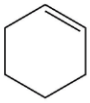
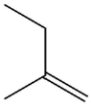
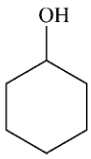


A. hexan-1-ol
B. 2-methylpentan-5-ol
C. 4-methylpentan-1-ol
D. 4-methylpentanol

Your answer ☐

[1]

2(a). The organic compounds in the table below can be termed, aliphatic, alicyclic or aromatic.

E 	**F** 	**G** 
H 	**I** 	**J** 

Identify, using letters **E**, **F**, **G**, **H**, **I**, **J**, the compound(s) which are the following types.

Each response may contain more than one letter.

aliphatic .....

alicyclic .....

aromatic .....

[3]

(b). Compound **I** has one alkyl group.

What is the general formula of alkyl groups?

[1]

(c). Compound **H** can be prepared in an elimination reaction by heating compound **J** with an acid catalyst.

A student carries out this preparation using 7.65 g of compound **J**.

The student obtains 2.05 g of compound **H**.

i. Write an equation for this reaction, using molecular formulae.

Calculate the percentage yield of compound **H**.

Give your answer to **one** decimal place.

percentage yield = ... % **[4]**

ii. Describe a simple test that the student could carry out to confirm the presence of the functional group in compound **H**.

Draw the structure of the organic product from the test.

test:

---

organic product =

[2]

3. This question looks at alkanes.

Ethane reacts with chlorine by radical substitution.

Describe fully, with equations, the mechanism for this reaction.

[5]

4. An alcohol **A** contains carbon, hydrogen and oxygen only. The alcohol is a liquid at room temperature and pressure but can easily be vaporised.

1.15 g of **A** produces 761 cm^3 of gas when vaporised, measured at 100 kPa and 366 K.

Determine the molar mass of compound **A** and draw a possible structure for **A**.

Show **all** your working.

molar mass = ... g mol^{-1}

Structure of **A**

[5]

5. Propene reacts with bromine, Br_2. In this reaction, bromine acts as an electrophile.

i. Outline the mechanism of this reaction.
Include curly arrows, relevant dipoles and the structures of the intermediate and final product(s).

[4]

ii. What does a curly arrow represent in a reaction mechanism?

[1]

6. * You are provided with three alcohols that are structural isomers: $CH_3CH_2CH_2CH_2OH$, $CH_3CH_2CHOHCH_3$ and $(CH_3)_3COH$. You do not know which is which.
You have access to normal laboratory apparatus and chemicals, Quickfit apparatus, and an infrared spectrometer.
Describe a plan that would allow you to identify the three alcohols using the same experimental set up and method.

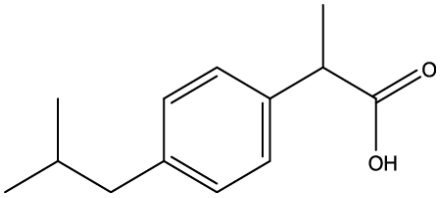
You should provide

- equations using structural formulae for any reactions
- a description of how you will identify the three alcohols from any observations and results.

[6]

7. Ibuprofen is a medicine used to relieve pain.

The structure of ibuprofen is shown below.



A standard tablet contains 200 mg of ibuprofen.

What is the amount, in moles, of ibuprofen in a standard tablet?

A. 9.62×10^{-4}
B. 9.71×10^{-4}
C. 9.62×10^{-1}
D. 9.71×10^{-1}

Your answer ☐

[1]

8. This question is about alkenes.

When alcohol **A** is heated with an acid catalyst, a reaction takes place forming alkene **B**.

The equation for this reaction is shown below as **Equation 16.1**.

$CH_3CH(CH_3)CH_2CHOHCH_3 \rightarrow CH_3CH(CH_3)CHCHCH_3 + H_2O$ **Equation 16.1**

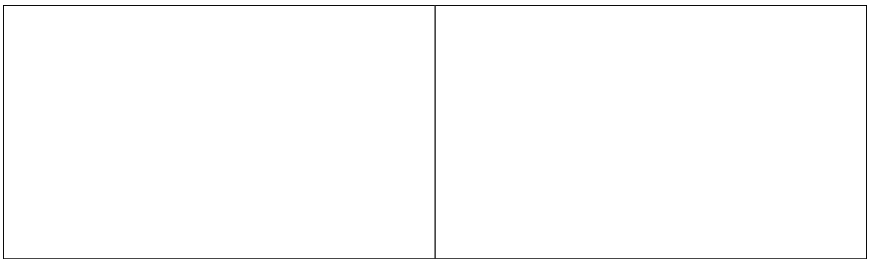
alcohol A **alkene B**

i. State the type of reaction in **Equation 16.1**.

[1]

ii. Alkene **B** has two stereoisomers.

Explain what is meant by the term *stereoisomers*, and draw the **skeletal** formulae of the two stereoisomers of alkene **B**.



[3]

iii. The reaction of **A** with an acid catalyst also forms another alkene, **C**.

Alkene **C** is a structural isomer of alkene **B**.

Suggest the structure of alkene **C**.

[1]

iv. * A student carries out the reaction in **Equation 16.1** using 9.26 g of alcohol **A**.

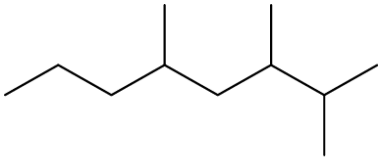
The student obtains a liquid reaction mixture containing a mixture of organic products and the acid catalyst.

The student purifies the reaction mixture to obtain the liquid alkene **B** with a percentage yield of 75.0%.

Describe a method to obtain a pure, dry sample of alkene **B** from the reaction mixture and calculate the mass of alkene **B** that the student produced.

[6]

9(a). Hydrocarbon **D** is a structural isomer of $C_{11}H_{24}$ used in aviation fuel.



hydrocarbon D

Name hydrocarbon **D**.

[1]

(b). When used in a jet engine, hydrocarbon **D** undergoes complete combustion as shown in the equation below:

$$C_{11}H_{24} + 17O_2 \rightarrow 11CO_2 + 12H_2O$$ **hydrocarbon D**

i. During a typical flight in the upper atmosphere:
- the aircraft burns 80.4 tonnes of hydrocarbon **D**
- the temperature outside the aircraft is −55 °C
- the pressure is 26.5 kPa

Calculate the volume, in m^3, of CO_2 released during a typical aircraft flight.

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

volume of CO_2 = ... m^3 **[5]**

ii. Exhaust gases from an aircraft engine contain nitrogen monoxide.

Write an equation for the formation of nitrogen monoxide in an aircraft engine.

[1]

(c). * The hydrocarbon propane can be reacted with chlorine to prepare 2-chloropropane, CH_3CHC/CH_3, by radical substitution.

Describe this reaction, including an overall equation and conditions, the mechanism with names for all steps and the limitations of this method of preparation.

[6]

10. This question is about numbers and patterns in chemistry.

This question looks at number relationships. For calculations, show your working.

i. What is the oxidation number of nitrogen in each species?

N_2O_4 ..... NO_3^- ..... NH_4^+ .....

ii. [1]

iii. What mass of $KMnO_4$ is needed to prepare a 250.0 cm^3 solution with a concentration of 0.200 mol dm^{-3} $KMnO_4$?

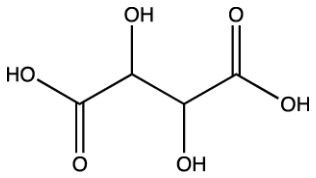
mass = ... g **[2]**

iv. What are the units of the rate constant for a reaction with an overall order of 3?

units = ... **[1]**

v. How many molecules are in 38.25 g of tartaric acid?

Give your answer to an **appropriate** number of significant figures and in standard form.



tartaric acid

number of molecules = ... **[2]**

11(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.**

methoxyethane **2-ethoxypropane**

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]

12. A student carries out a titration to determine the molar mass of an unknown acid, **A**.

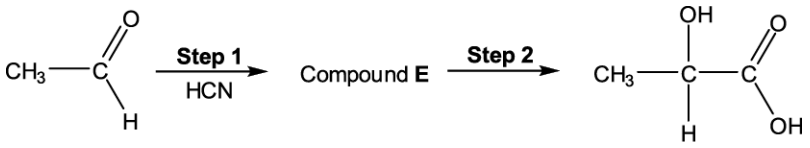
- The student dissolves 2.24 g of acid **A** in distilled water and makes the solution up to 250.0 cm^3.
- The student titrates a 25.0 cm^3 portion of this solution with 0.120 mol dm^{-3} NaOH.
- 25.25 cm^3 of 0.120 mol dm^{-3} NaOH are required to reach the end point.

The acid reacts with NaOH in a 1 : 1 molar ratio.

Calculate the molar mass of acid **A**.

molar mass of acid **A** = ... g mol^{-1} **[3]**

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



lactic acid

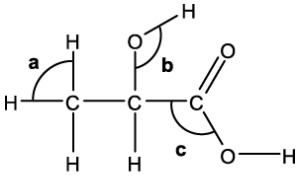
i. Draw the structure for compound **E**.

[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**.

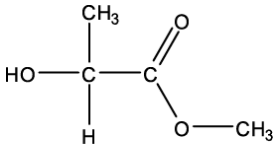
Bond angle **a**: .....

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

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

[2]

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



methyl lactate

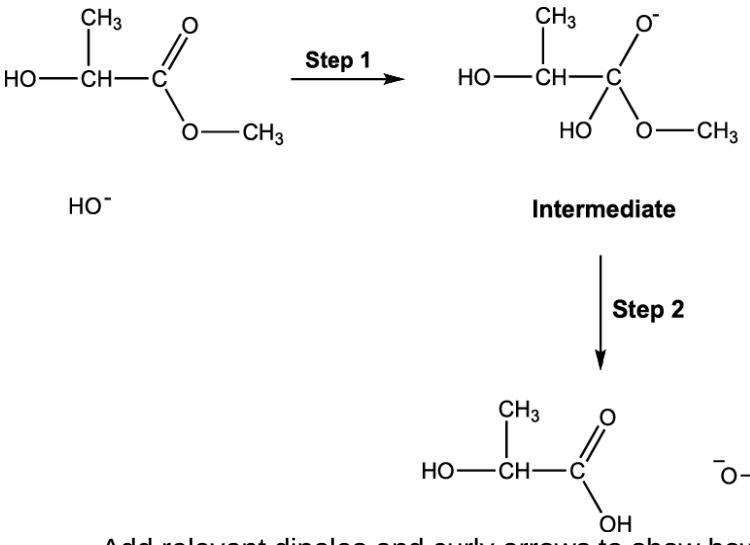
Methyl lactate can be hydrolysed by refluxing with sodium hydroxide solution.

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.

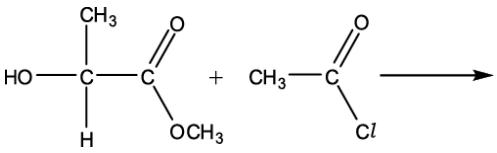


- Add relevant dipoles and curly arrows to show how the intermediate is formed in **Step 1** of the mechanism.
- Add curly arrows to show how the carboxylic acid and $^{-}OCH_3$ ion are formed from the intermediate in **Step 2** of the mechanism.

[4]

iii. Methyl lactate can also react with ethanoyl chloride.

Complete the equation for this reaction.



[2]

14(a). This question is about cyclic organic compounds.

The table shows some information about cycloalkanes.

Cycloalkane	Skeletal formula	Boiling point / °C
Cyclopropane		−33
Cyclopentane		49
Cyclohexane		81

These cycloalkanes are members of the same homologous series and have the same general formula.

i. What is meant by the term *homologous series*?

[2]

ii. State the general formula for these cycloalkanes.

[1]

iii. Explain the increase in boiling points of the cycloalkanes shown in the table.

[2]

(b). Cyclobutane is another cycloalkane.

There are several **unsaturated** isomers of cyclobutane that are alkenes.

Two of these isomers are stereoisomers.

i. Explain what is meant by the term *stereoisomers*.

_____

[1]

ii. Draw these **two** stereoisomers.

[2]

(c). In the presence of ultraviolet radiation, **cyclohexane** reacts with bromine.

A mixture of cyclic organic compounds is formed, including $C_6H_{11}Br$.

i. Complete the table below to show the mechanism of the reaction between bromine and cyclohexane to form $C_6H_{11}Br$.

Include all possible termination steps in your answer.

Step	Equation
Initiation	.....
Propagation	....
Termination	....

[5]

ii. The initiation step involves homolytic fission.

Explain why the initiation step is an example of *homolytic fission*.

[1]

(d). The reaction between cyclohexane and bromine in **(f)** also forms $C_6H_{10}Br_2$.

i. Write an equation, using molecular formulae, for the reaction of cyclohexane and bromine in the presence of ultraviolet radiation to form $C_6H_{10}Br_2$.

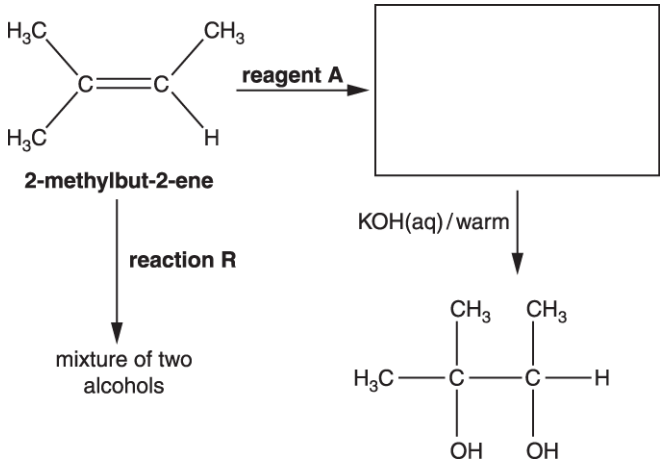
[1]

ii. Name **one** of the structural isomers of $C_6H_{10}Br_2$ formed in the reaction between cyclohexane and bromine.

[1]

15(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**.

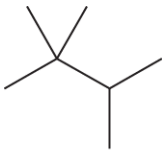
[2]

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

[2]

16(a). This question is about different alkanes present in crude oil.

Compound **A**, shown below, is one of the structural isomers of C_7H_{16}.



Compound A

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

[1]

ii. Name compound **A**.

[1]

(b). The structural isomers of C_5H_{12} have different boiling points.

Draw the **skeletal formula** of the structural isomer of C_5H_{12} with the highest boiling point.

[1]

17(a). Allyl bromide, $CH_2=CHCH_2Br$, is used in the production of polymers.

Allyl bromide is a member of a homologous series. Compounds in this series have the same general formula.

i. What is meant by the term *homologous series*?

[2]

ii. What is the general formula of the homologous series that has allyl bromide as a member?

[1]

iii. Give the systematic name for allyl bromide.

[1]

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

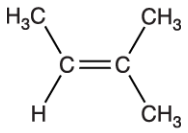
i. What does a *curly arrow* represent in mechanisms?

[1]

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

[1]

18(a). Compound **A** is an alkene.



compound **A**

The C=C bond in a molecule of compound **A** has restricted rotation because it comprises a σ bond and a π bond.

i. Describe **one** difference between the σ bond and the π bond.

[1]

ii. Explain why compound **A** does **not** have *E*/*Z* isomers.

[1]

iii. A structural isomer of compound **A** has *E*/*Z* isomers.

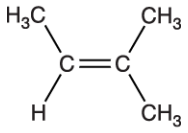
Draw the structure of the *Z* isomer and then name this isomer.

structure of *Z* isomer

name .....

[2]

(b). *Compound **A** reacts with hydrogen bromide to form a mixture of two different organic products.



compound **A**

Give the structures of the **two** possible organic products of the reaction.

Outline the mechanism, using the 'curly arrow'model, for the formation of one of the organic products from compound **A**.

Explain which of the two organic products is more likely to be formed.

[6]

19. Nitrogen forms several different oxides.

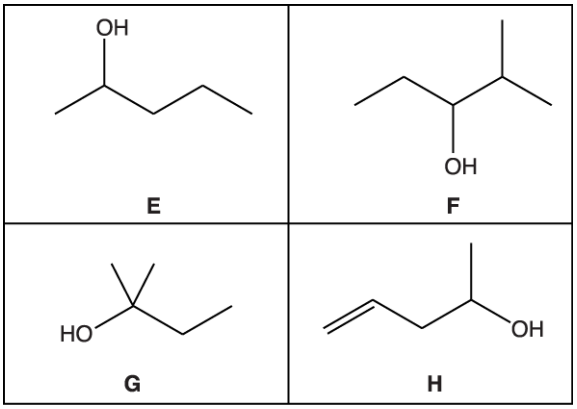
N_2O is a useful anaesthetic and NO has been linked to the depletion of ozone in the stratosphere.

NO radicals catalyse the breakdown of ozone in the stratosphere.

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

[2]

20. The skeletal formulae of four alcohols, **E**, **F**, **G** and **H**, are shown below.



Which pair of alcohols are structural isomers of each other?

A **E** and **F**

B **E** and **G**

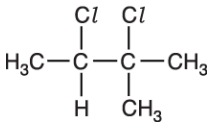
C **E** and **H**

D **F** and **G**

Your answer ☐

[1]

21. What is the name of the following compound?



A 1,2-dichloro-1,2-dimethylpropane

B 2,3-dichloro-2,3-dimethylpropane

C 2,3-dichloro-2-methylbutane

D 2,3-dichloro-3-methylbutane

Your answer ☐

[1]

22. Chlorine reacts with 1-chloropropane in the presence of ultraviolet radiation via a radical substitution mechanism.

Which equation shows a propagation step in the mechanism for this reaction?

A $Cl_2 \rightarrow \bullet Cl + \bullet Cl$

B $\bullet Cl + \bullet C_3H_6Cl \rightarrow C_3H_6Cl_2$

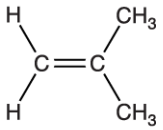
C $C_3H_7Cl + \bullet Cl \rightarrow C_3H_6Cl_2 + \bullet H$

D $\bullet Cl + C_3H_7Cl \rightarrow \bullet C_3H_6Cl + HCl$

Your answer ☐

[1]

23(a). Compound **B**, shown below, can be used to synthesise organic compounds with different functional groups.



Compound B

i. Compound **B** is a member of a homologous series.

Name the homologous series and state its general formula.

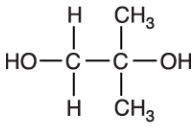
Homologous series
.....

General formula .....

ii. What reagents and conditions are needed to convert compound **B** into a saturated hydrocarbon?

[1]

(b). The structure of compound **F** is shown below.



Compound F

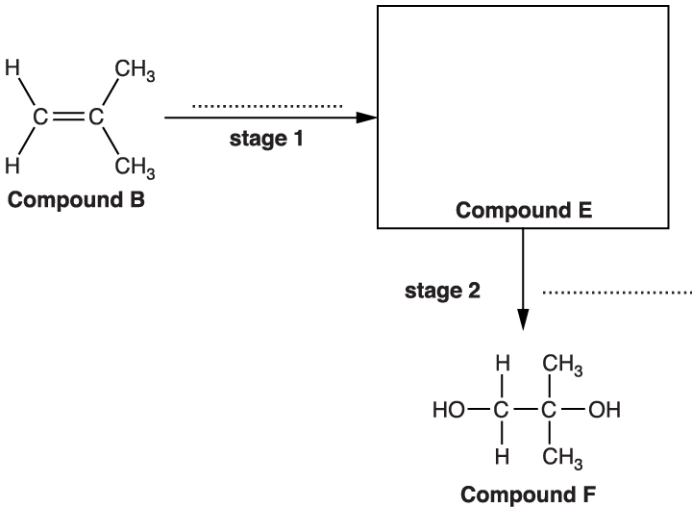
i. What is the empirical formula of compound **F**?

[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]

24. This question is about the homologous series of alcohols.

What is meant by the term *homologous series*?

[2]

25(a). The hydrocarbons present in crude oil are processed to obtain useful materials, including many fuels.

Alkanes with 6−10 carbon atoms are used in petrol.

What is the general formula of an alkane?

[1]

(b). Oil companies process alkanes into branched and cyclic hydrocarbons to promote efficient combustion in petrol.

- Draw the structure of one branched and one cyclic saturated hydrocarbon that contains **8** carbon atoms.
- Name each hydrocarbon.

Branched	**Cyclic**
name:	*name:* .....

[3]

26(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.

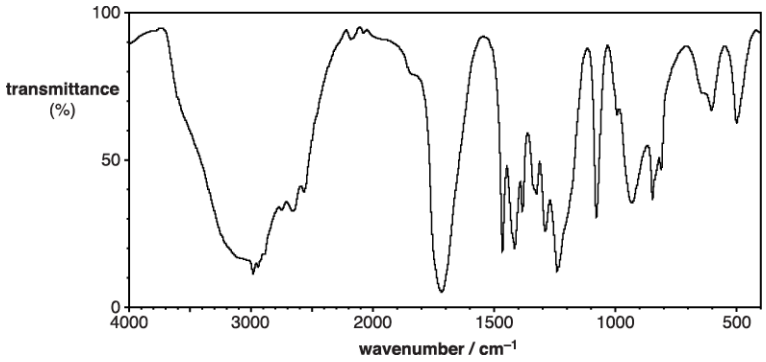
Determine the structures of the two structural isomers. Show your working.

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**.

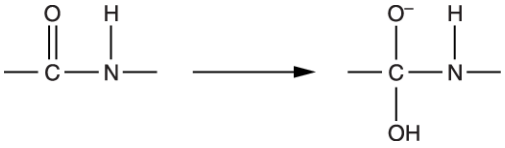
[2]

27(a). The building blocks of peptides and proteins are α-amino acids.

A tripeptide is hydrolysed to form a mixture of three different α-amino acids.

The first step of an incomplete mechanism for the alkaline hydrolysis of the tripeptide is shown below.

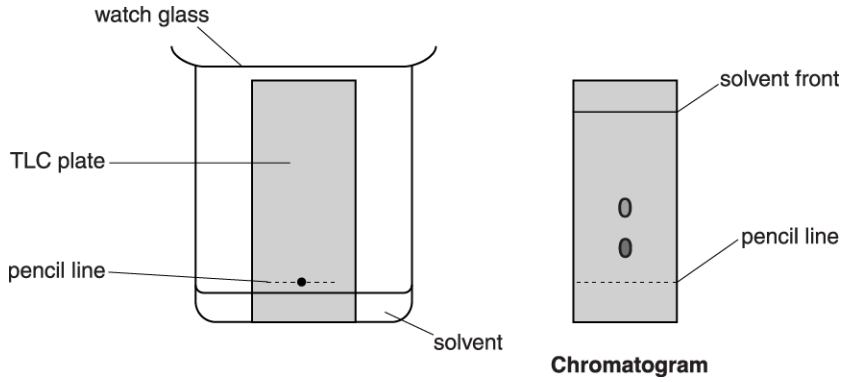
Add curly arrows and relevant dipoles to the diagram to suggest how the hydroxide ion takes part in the first step of this mechanism.



[2]

(b). The tripeptide is hydrolysed and the resulting mixture containing the three amino acids is neutralised.

A student tries to separate and identify the three amino acids in the mixture using thin-layer chromatography (TLC). The diagram below shows the apparatus for the experiment and the chromatogram produced.



Explain how the chromatogram can be used to identify amino acids.
The student thinks that there should be three spots on the chromatogram.

Suggest why there are only two spots.

[3]

(c). The three α-amino acids in the tripeptide are aspartic acid, glycine and isoleucine.

The general formula for an α-amino acid is $RCH(NH_2)COOH$.

α-amino acid	**R-group**
aspartic acid	$–CH_2COOH$
glycine	–H
isoleucine	$–CH(CH_3)CH_2CH_3$

i. Aspartic acid has an isoelectric point of 2.77.

What is meant by the term *isoelectric point*?

In your answer you should use the appropriate technical terms spelled correctly.

[1]

ii. Draw the structure of aspartic acid when it is dissolved in a solution with a high pH.

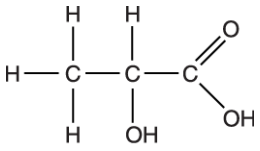
[1]

iii. Suggest a structure for the tripeptide.

On your structure, mark each chiral centre with an asterisk (*).

[2]

28. This question is about the preparation, properties and uses of lactic acid.

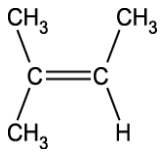


lactic acid

What is the systematic name of lactic acid?

[1]

29. A chemist reacts the following compound with hydrogen bromide, HBr.



What is the name of the **major** product?

A 2-Bromo-3-methylbutane

B 2-Bromo-2-methylbutane

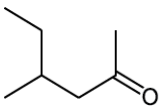
C 3-Bromo-3-methylbutane

D 3-Bromo-2-methylbutane

Your answer ☐

[1]

30. What is the systematic name of the compound below?



A 2-Ethylpentan-4-one

B 4-Ethylpentan-2-one

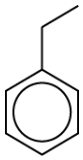
C 3-Methylhexan-5-one

D 4-Methylhexan-2-one

Your answer ☐

[1]

31. Which term(s) best describe(s) the following molecule?



1. aromatic
2. unsaturated
3. alicyclic

A 1, 2 and 3

B Only 1 and 2

C Only 2 and 3

D Only 1

Your answer ☐

[1]

32(a).

i. Define the term *homologous series*.

_____

_____

[2]

ii. What is the general formula of a member of the alcohols homologous series?

[1]

(b). 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

.....

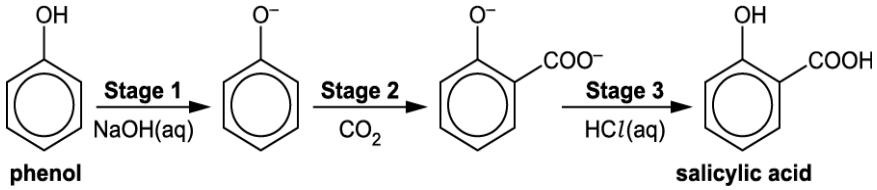
Explanation

.....

[1]

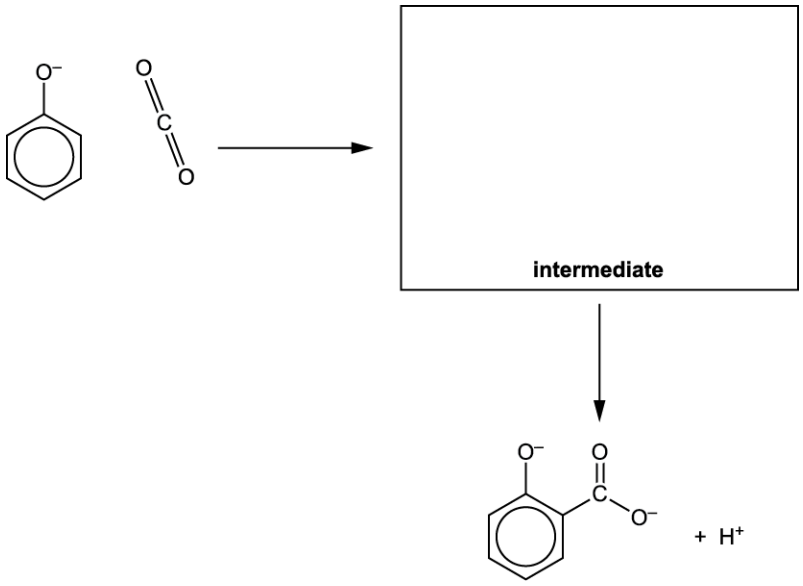
33(a). This question is about medical compounds made from salicylic acid.

Salicylic acid can be made from the reaction of phenol with carbon dioxide as shown below.



i. **Stage 2** takes place by electrophilic substitution and part of the mechanism is shown below.

Complete the mechanism by showing relevant dipoles, curly arrows and the structure of the intermediate.



[3]

ii. What type of reaction takes place during **Stage 1** and **Stage 3**?

Explain your answer.

Type of reaction .....

Explanation
.....

[2]

iii. A chemist prepares 4.83 g of salicylic acid from phenol. The percentage yield of this reaction is 45.0%.

Calculate the mass of phenol that the chemist uses. Give your answer to **three** significant figures.

mass of phenol = ... g **[3]**

(b). Aspirin is an ester of salicylic acid.

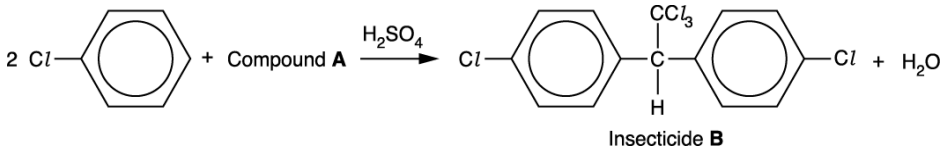
Aspirin can be prepared by reacting salicylic acid with ethanoic anhydride, $(CH_3CO)_2O$. One other organic compound also forms.

Draw **skeletal** formulae for the products of this reaction.

[2]

34. Concentrated sulfuric acid is often used to catalyse organic reactions.

An insecticide, **B**, can be made by the reaction below, using H_2SO_4 as a catalyst.



Insecticide **B**

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

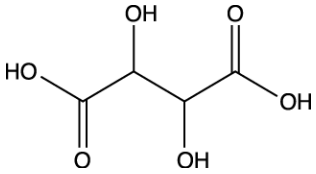
[1]

ii. Sulfuric acid is a catalyst in many reactions.

State **one** other example of an organic reaction in which sulfuric acid is a catalyst.

[1]

35. Tartaric acid, shown below, is an organic acid present in fruit juice.



i. What is the empirical formula of tartaric acid?

[1]

ii. Write the systematic name for tartaric acid.

[1]

iii. Tartaric acid reacts with 1,6-diaminohexane, $H_2N(CH_2)_6NH_2$, to form a polymer.

Draw the structure of **one** repeat unit of this polymer.

[2]

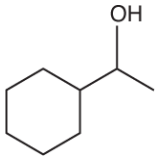
iv. The polymerisation in **(iii)** takes place in two steps.

In the first step, tartaric acid and 1,6-diaminohexane react to form a salt.

Draw the structure of this salt, showing the ions present.

[2]

36. How can the molecule below be described?



A Aromatic and alicyclic

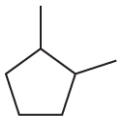
B Aliphatic and unsaturated

C Aromatic and unsaturated

D Alicyclic and saturated

Your answer ☐ **[1]**

37. What is the molecular formula of the compound below?



A C_7H_{10}

B C_7H_{12}

C C_7H_{14}

D C_7H_{16}

Your answer ☐ **[1]**

38. Ethane reacts with chlorine by radical substitution to form chloroethane.

Which radical(s) is/are present in the mechanism?

1. H•
2. Cl•
3. C_2H_5•

A 1, 2 and 3

B Only 1 and 2

C Only 2 and 3

D Only 1

Your answer ☐ **[1]**

39. Which compound(s) is a/are structural isomer(s) of $C_6H_{12}O_2$?

1. hexanoic acid
2. ethyl butanoate
3. propyl propanoate

A 1, 2 and 3

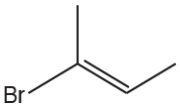
B Only 1 and 2

C Only 2 and 3

D Only 1

Your answer ☐ **[1]**

40. What is the systematic name of the compound below?



A *E*-2-bromobut-2-ene

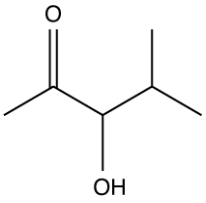
B *Z*-2-bromobut-2-ene

C *E*-1,2-dimethyl-1-bromoethene

D *Z*-1,2-dimethyl-1-bromoethene

Your answer ☐ **[1]**

41. The skeletal formula of an organic compound is shown below.



What is the molecular formula of the organic compound?

A $C_6H_{10}O_2$

B $C_6H_{11}O_2$

C $C_6H_{12}O_2$

D $C_6H_{13}O_2$

Your answer ☐ **[1]**

42. How many structural isomers have the molecular formula C_5H_{12}?

A 2

B 3

C 4

D 5

Your answer ☐ **[1]**

43(a). Compound **C**, $CH_3CH_2CH{=}CHCH_2CH_2OH$, exists as *cis* and *trans* stereoisomers.

i. Name compound **C**.

[1]

ii. Define the term *stereoisomers*.

[1]

iii. Draw the structures of the *cis* and *trans* stereoisomers of compound **C**.

cis	*trans*

[2]

(b). Compound **D**, shown below, reacts with hydrogen bromide by electrophilic addition. A mixture of two organic compounds, **E** and **F**, is formed.

compound D

i. Suggest how an HBr molecule can act as an electrophile.

[1]

ii. Draw the structures of the two organic compounds **E** and **F**.

E	**F**

[2]

iii. Outline the mechanism of the reaction between compound **D** and hydrogen bromide to form **either** compound **E** or compound **F**.
Include curly arrows and relevant dipoles.

[3]

iv. Which of **E** or **F** is the major organic product?

Explain your answer.

Major organic product

Explanation

[1]

44. 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.

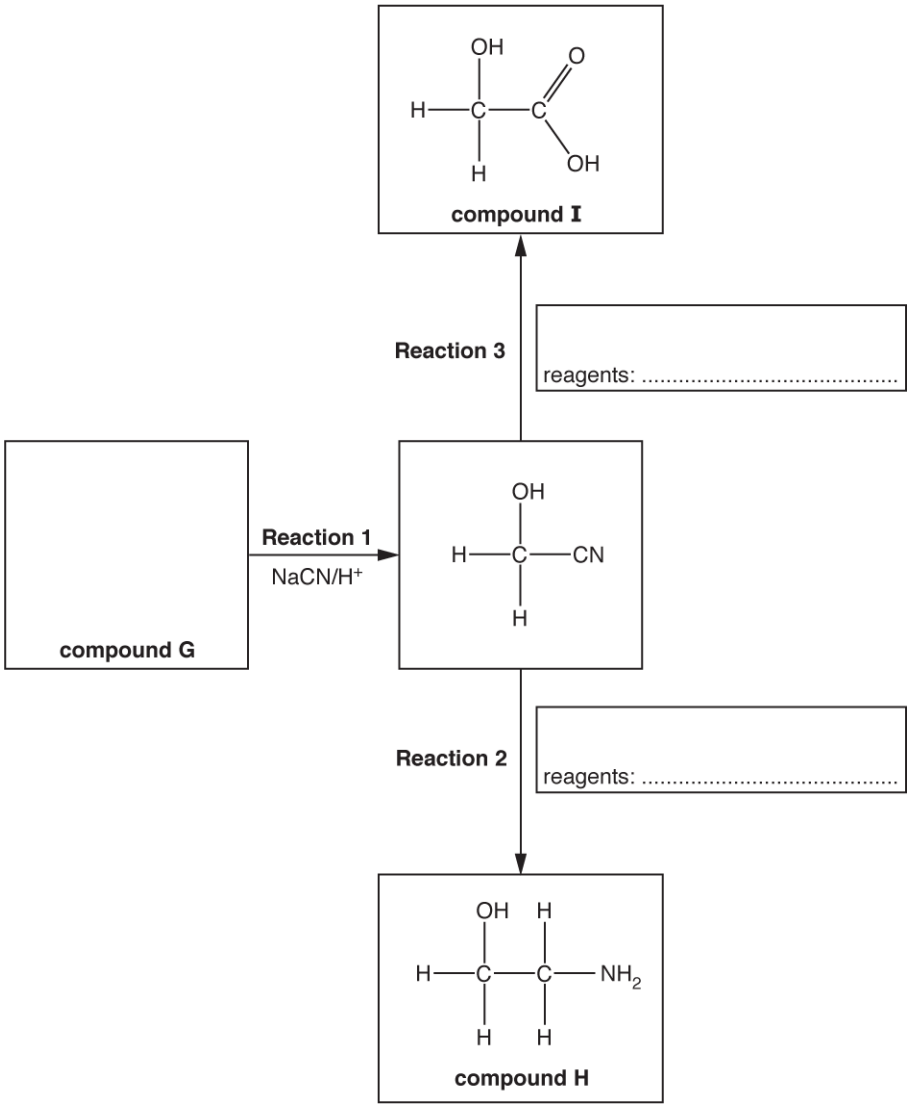
Outline the mechanism for this reaction.

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

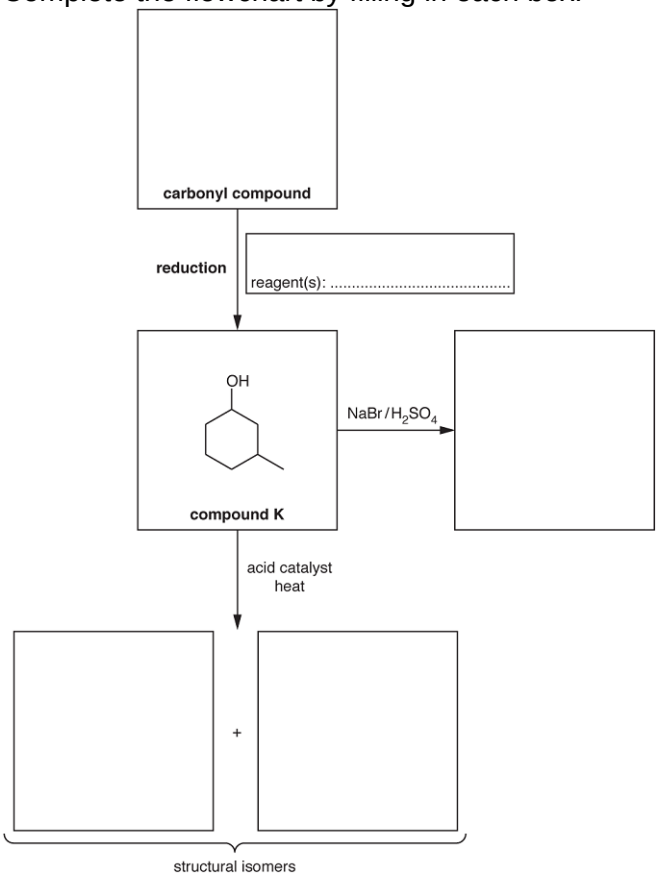
[2]

iv. 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]

45. Alcohols are important in organic synthesis and can be formed by the reduction of carbonyl compounds.

i. Complete the flowchart by filling in each box.



[5]

ii. What is the name of compound **K**?

[1]

46. Peroxycarboxylic acids are organic compounds with the COOOH functional group.

Peroxyethanoic acid, CH_3COOOH, is used as a disinfectant.

i. Suggest the structure for CH_3COOOH.
The COOOH functional group must be clearly displayed.

[1]

ii. Peroxyethanoic acid can be prepared by reacting hydrogen peroxide with ethanoic acid.
This is a heterogeneous equilibrium.

$H_2O_2(aq) + CH_3COOH(aq) \rightleftharpoons CH_3COOOH(aq) + H_2O(l)$ $\quad K_c = 0.37\ dm^3\ mol^{-1}$

A 250 cm^3 equilibrium mixture contains concentrations of 0.500 mol dm^{-3} $H_2O_2(aq)$ and 0.500 mol dm^{-3} $CH_3COOH(aq)$.

Calculate the amount, in mol, of peroxyethanoic acid in the equilibrium mixture.

amount = _____ mol **[3]**

47(a). This question is about weak acids.

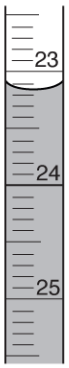
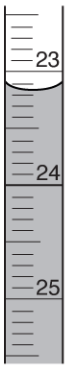
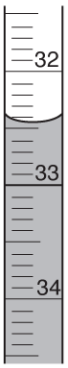
Compound **A** is a weak monobasic acid.

A student is supplied with a 250.0 cm^3 solution prepared from 2.495 g of **A**.

The student titrates 25.0 cm^3 samples of this solution with 0.0840 mol dm^{-3} NaOH in the burette.

The student carries out a trial, followed by the three further titrations. The diagrams show the initial burette readings and the final burette readings for the student's three **further** titrations.

All burette readings are measured to the nearest 0.05 cm^3.

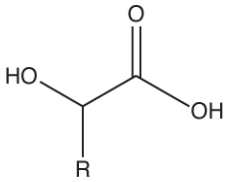
Titration 1		Titration 2		Titration 3	
Initial reading	Final reading	Initial reading	Final reading	Initial reading	Final reading
					

i. Record the student's readings and the titres in an appropriate format.

Calculate the mean titre that the student should use for analysing the results.

mean titre = _____ cm^3 **[4]**

ii. The structure of compound **A** is shown below.



compound A

Compound **A** has four optical isomers.

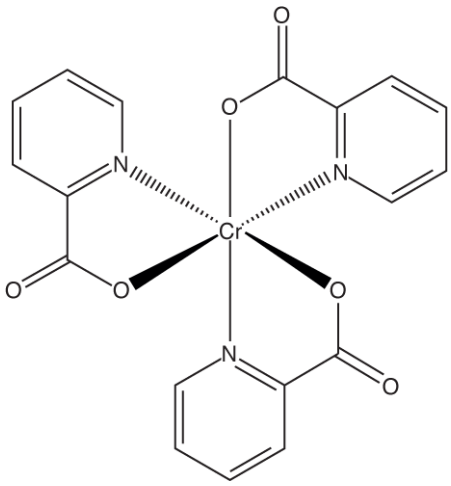
Using this information and the student's results, answer the following.

- Determine the molar mass of **A** and the formula of the alkyl group R.
- Draw the structure of compound **A** and label any chiral carbon atoms with an asterisk*.

Show all your working.

[6]

(b). Chromium (III) picolinate, shown below, is a neutral complex that can be prepared from the weak acid, picolinic acid.



Chromium(III) picolinate is used in tablets as a nutritional supplement for chromium.

i. Draw the structure of the ligand in chromium(III) picolinate.

[1]

ii. A typical tablet of chromium(III) picolinate contains 200 μg of chromium.

Calculate the mass, in g, of chromium (III) picolinate in a typical tablet.
1 μg = 10^{-6} g.

Give your answer to **three** significant figures.

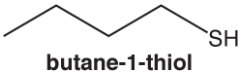
mass = g **[2]**

---

48. This question is about organic molecules that have a strong smell.

Thiols are foul-smelling, organic sulfur compounds with the functional group –SH.

Butane-1-thiol, shown below, contributes to the strong smell of skunks.



butane-1-thiol

i. Thiols are weak acids.

Write the expression for the acid dissociation constant, K_a, for butane-1- thiol.

[1]

ii. Thiols react with carboxylic acids to form thioesters.

Write an equation for the reaction of butane-1-thiol with ethanoic acid.

Use structures for all organic compounds with the functional groups clearly displayed.

[2]

iii. When beer is exposed to light, 3-methylbut-2-ene-1-thiol is formed, which gives an unpleasant smell and flavour to the beer.

Draw the **skeletal** formula for 3-methylbut-2-ene-1-thiol.

[1]

iv. Propane-1,3- dithiol reacts with carbonyl compounds in a condensation reaction to form a cyclic organic sulfur product.

Write an equation for the reaction of propane-1,3-dithiol with propanone. Use structures for organic compounds.

[2]

49(a). Propanoic acid, CH_3CH_2COOH, is a member of the homologous series of carboxylic acids.

Suggest the general formula for a carboxylic acid.

[1]

(b). 2-Chloropropanoic acid, $CH_3CHClCOOH$, can be made by reacting propanoic acid with chlorine in a radical substitution reaction.

i. State the conditions for the reaction.

[1]

ii. Write the overall equation for the reaction.

[1]

iii. The first step in the reaction mechanism involves homolytic fission of a chlorine molecule to form two chlorine radicals.

Why is this step an example of *homolytic fission*?

[1]

iv. Write **two** equations to show the propagation steps in the mechanism for this reaction.

Use dots,•, to show the unpaired electrons on radicals.

[2]

v. Draw the displayed formula of the radical formed in the first propagation step.

Use a dot,•, to show the position of the unpaired electron.

[1]

vi. Further substitution forms a mixture of organic products.

Draw the structure of an organic product formed from 2-chloropropanoic acid by further substitution.

[1]

50. An alkene **D** is a liquid at room temperature and pressure but can easily be vaporised.

When vaporised, 0.1881 g of **D** produces 82.5 cm^3 of gas at 101 kPa and 373 K.

Determine the molar mass and molecular formula of alkene **D**.

Show all your working.

molar mass = ... g mol^{-1}

molecular formula = ... **[5]**

51. Iodine monobromide, I–Br, is a polar molecule.

Heterolytic fission of the I–Br bond forms an electrophile.

State the meaning of the term *electrophile* and suggest the formula of the electrophile formed from IBr.

[2]

52. * Alcohols can be converted into alkenes in an elimination reaction.

The elimination of H_2O from pentan-2-ol forms a mixture of organic products.

Give the names and structures of all the organic products in the mixture.

Your answer should explain how the reaction leads to the different isomers.

[6]

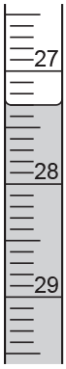
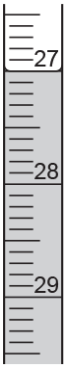
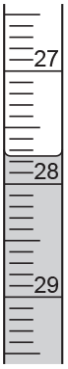
53(a). A student carries out a titration to determine the molar mass and structure of a weak acid **A**.

The student follows the method below.

- Dissolve a weighed mass of **A** in 100 cm^3 of distilled water and make the solution up to 250 cm^3 in a beaker.
- Add the solution of **A** to a burette.
- Titrate the solution of **A** with a standard solution of sodium hydroxide, NaOH.

The student carries out a trial, followed by three further titrations.
The diagram shows the initial and final burette readings for the three **further** titrations.

The student measures all burette readings to the nearest 0.05 cm^3.

Titration 1		**Titration 2**		**Titration 3**	
Initial reading	Final reading	Initial reading	Final reading	Initial reading	Final reading
					

i. Record the student's readings and the titres in the table below.

Calculate the mean titre, to the nearest 0.05 cm^3, that the student should use for analysing the results.

	Titration 1	**Titration 2**	**Titration 3**
Final reading/cm^3			
Initial reading/cm^3			
Titre/cm^3			

mean titre = _____ cm^3 **[4]**

ii. The uncertainty in each burette reading is ± 0.05 cm^3.

Calculate the percentage uncertainty for the titre in **Titration 1**.

percentage uncertainty = _____ % **[1]**

iii. The student realised that the solution of **A** had not been prepared correctly.

How should the student have made up the solution?

_____

_____

[1]

(b). A student repeats the titration to determine the molar mass and structure of **A**.

- The student prepares a 250.0 cm^3 solution from 1.513 g of **A**.
- The solution of **A** is added to the burette and titrated with 25.0 cm^3 volumes of 0.112 mol dm^{-3} NaOH(aq).
- 1 mol of **A** reacts with 2 mol of NaOH.
- The student obtains a mean titre of 27.30 cm^3.

i. Calculate the molar mass of **A** from these results.

Give your answer to the nearest whole number.

Show your working.

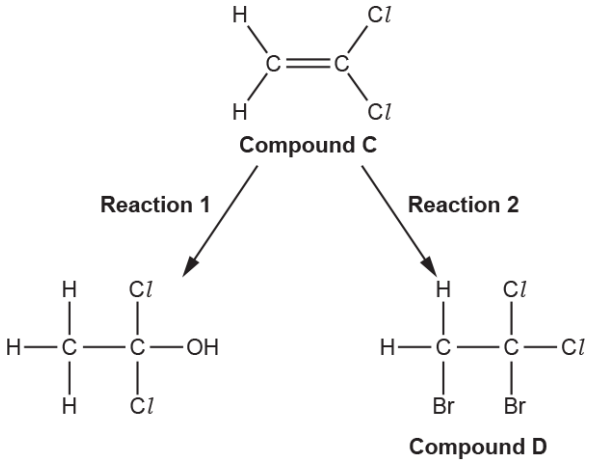
molar mass of **A** = g mol^{-1} **[4]**

ii. **A** is an organic acid, containing C, H and O only.
One molecule of **A** contains two COOH groups.

Suggest the structure of **A**.

[1]

54(a). Two reactions of compound **C** are shown in the flowchart below.



State the reagents and conditions for **reaction 1**.

[1]

(b). In **reaction 2**, compound **C** reacts with bromine to form compound **D**.

i. Give the systematic name of compound **D**.

[1]

ii. Outline the mechanism for **reaction 2**.

Include curly arrows, charges and relevant dipoles.

[3]

(c). Compound **C** forms an addition polymer **E**.

i. Write a balanced equation for this reaction.

Show displayed formulae.

[2]

ii. State **one** advantage and **one** disadvantage of using combustion as a method for the disposal of waste polymer **E**.

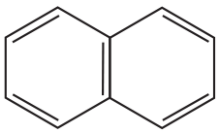
Advantage

Disadvantage

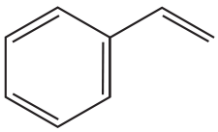
[2]

55. Which structure represents an alicyclic compound?

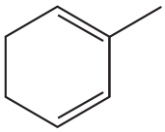
A



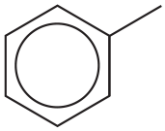
B



C



D



Your answer ☐ **[1]**

56. How many straight-chain structural isomers of $C_7H_{15}Cl$ contain a chiral carbon atom?

A 1

B 2

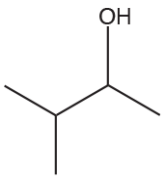
C 3

D 4

Your answer ☐ **[1]**

57. This question is about reactions of organic compounds containing carbon, hydrogen and oxygen.

A chemist investigates two reactions of alcohol **A**, shown below.



alcohol A

i. What is the systematic name of alcohol **A**?

[1]

ii. What is the structural formula of alcohol **A**?

[1]

iii. The chemist heats alcohol **A** with an acid catalyst to form a mixture containing **two** alkenes.

Draw the structures of the **two** alkenes formed in this reaction.

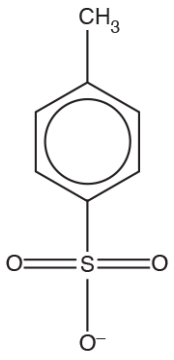
[2]

iv. The chemist heats alcohol **A** with sodium chloride and sulfuric acid.

Construct a balanced equation for this reaction.
Show structures for the organic compounds in your equation.

[2]

58. Methylbenzene reacts with sulfur trioxide, SO_3, to form **D**, shown below.

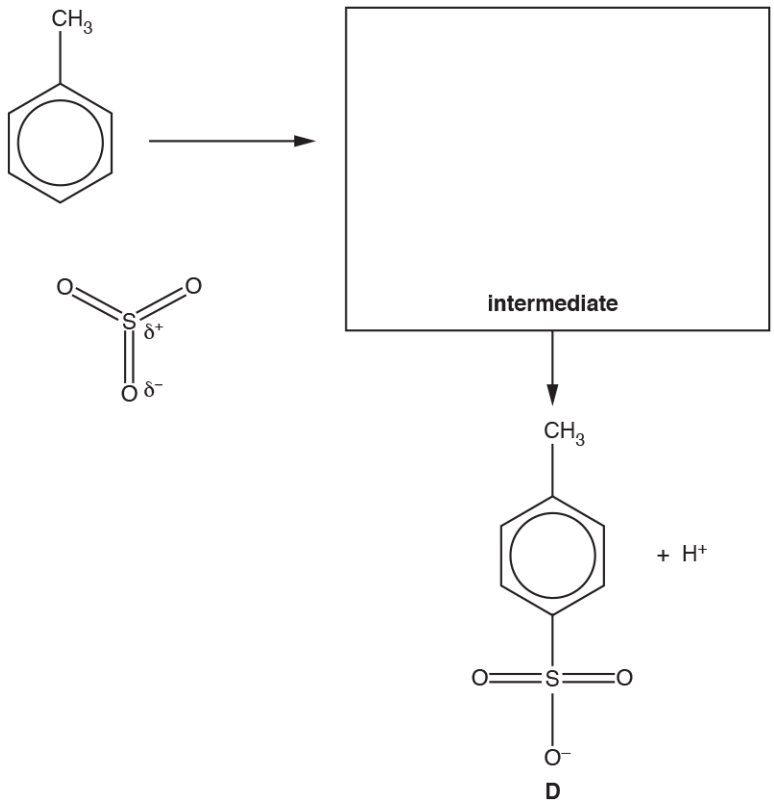


D

The electrophile in this reaction is SO_3.

Complete the mechanism for the formation of **D**.

Show curly arrows and the structure of the intermediate.



D

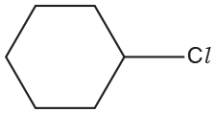
[3]

59. This question is about the hydrolysis of haloalkanes.

Chlorocyclohexane is hydrolysed with aqueous sodium hydroxide.

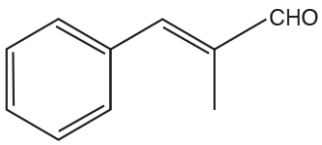
Outline the mechanism for this reaction.

Show curly arrows, relevant dipoles and the products.



[3]

60. * Methylcinnamaldehyde reacts with iodine monochloride, ICl, by electrophilic addition. The reaction produces a mixture containing two different organic products.



The electronegativity values of chlorine and iodine are given in the table below.

	Pauling electronegativity value
Cl	3.0
I	2.5

Outline the mechanism, using the 'curly arrow' model, for the formation of **one** of the organic products and explain which of the two possible organic products is more likely to be formed.

In your mechanism, you can show the phenyl group as C_6H_5. **[6]**

61. This question is about two compounds used in medicine.

Cis-platin, $PtCl_2(NH_3)_2$, is a complex of platinum which is used in cancer treatment.

i. What is the oxidation number of platinum in *cis*-platin?

[1]

ii. *Cis*-platin is prepared in a ligand substitution reaction which takes place in multiple steps.

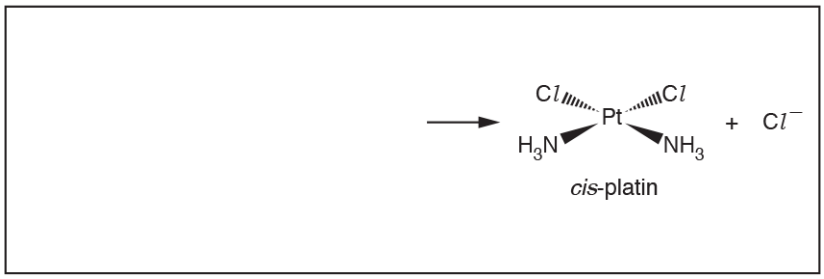
The equation for the final step forming *cis*-platin is shown below.

$$[PtCl_3(NH_3)]^- + NH_3 \rightarrow PtCl_2(NH_3)_2 + Cl^-$$

cis-platin

In the box, outline the mechanism for the formation of *cis*-platin from $[PtCl_3(NH_3)]^-$.

Use curly arrows and lone pairs where appropriate.



[2]

62. Succinic acid $(CH_2COOH)_2$ is esterified by ethanol, C_2H_5OH, in the presence of an acid catalyst to form an equilibrium mixture.

Succinic acid is esterified by ethanol, C_2H_5OH, in the presence of an acid catalyst to form an equilibrium mixture.

The equilibrium constant, K_c, for this equilibrium can be calculated using the amounts, in moles, of the components in the equilibrium mixture, using **expression 5.1**.

$$K_c = \frac{n((CH_2COOC_2H_5)_2) \times n(H_2O)^2}{n((CH_2COOH)_2) \times n(C_2H_5OH)^2}$$

Expression 5.1

A student carries out an experiment to determine the value of K_c for this equilibrium.

- The student mixes together 0.0500 mol of succinic acid and 0.150 mol of ethanol, with a small amount of an acid catalyst.
- The mixture is allowed to reach equilibrium.
- The student determines that 0.0200 mol of succinic acid are present in the equilibrium mixture.

i. Which technique could be used to determine the equilibrium amount of succinic acid?

[1]

ii. Write the equation for the equilibrium reaction that takes place.

[1]

iii. Draw the skeletal formula of the ester present in the equilibrium mixture.

[1]

iv. K_c is the equilibrium constant in terms of equilibrium concentrations.

Why can **expression 5.1** be used to calculate K_c for this equilibrium?

[1]

v. Calculate the value of K_c for this reaction.

Show your working.

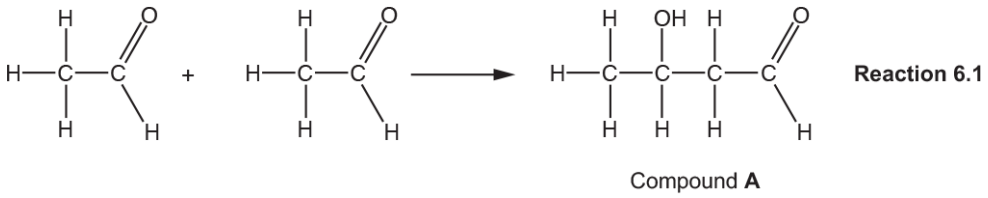
K_c =

[3]

63(a). This question is about organic reactions.

Compound **A** is formed when ethanal is mixed with OH^-(aq) ions, which act as a catalyst.

The balanced equation is shown in **reaction 6.1** below.



Reaction 6.1

Compound **A**

i. Give the systematic name for compound **A**.

[1]

ii. What type of reaction has taken place?

[1]

iii. **Reaction 6.1** takes place in two steps. OH^- ions act as a catalyst.

In **step 1**, ethanal reacts with OH^- ions to set up an acid–base equilibrium.
In **step 2**, compound **A** is formed.

- Complete the equilibrium for **step 1** and label the conjugate acid–base pairs as: **A1**, **B1** and **A2**, **B2**.

CH^3CHO + OH^- ⇌ +

- Suggest the equation for **step 2**.

[3]

iv. A similar reaction takes place when propanone, $(CH_3)_2CO$, is mixed with $OH^-(aq)$ ions.

Draw the structure of the organic product of this reaction.

[1]

(b). * Many organic reactions use electrophiles as reagents.

Explain the role of electrophiles in organic chemistry.

Your answer should include **one** reaction of an aliphatic compound and **one** reaction of an aromatic compound, including relevant mechanisms.

[6]

64. How many structural isomers of $C_6H_{14}O$ are tertiary alcohols?

A 1

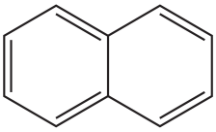
B 2

C 3

D 4

Your answer ☐ **[1]**

65. The structure of naphthalene is shown below.



What is the molecular formula of naphthalene?

A $C_{10}H_8$

B $C_{10}H_{10}$

C $C_{12}H_{10}$

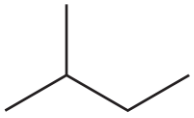
D $C_{12}H_{12}$

Your answer ☐ **[1]**

66(a). This question is about saturated hydrocarbons.

Compounds **A**, **B** and **C** are saturated hydrocarbons.

The structures and boiling points of **A**, **B** and **C** are shown below.

	Isomer	Boiling point /°C
A		36
B		28
C		9

- Use the structures to explain what is meant by the term structural isomer.
- Explain the trend in boiling points shown by **A**, **B** and **C** in the table.

[5]

(b). Compounds **A**, **B** and **C** all react with chlorine in the presence of ultraviolet radiation to form organic compounds with the formula $C_5H_{11}Cl$.

i. Name the mechanism for this reaction.

[1]

ii. Complete the table to show the number of structural isomers of $C_5H_{11}Cl$ that could be formed from the reaction of chlorine with **A** and **B**.

	A	**B**
Number of structural isomers	.....	.....

[2]

iii. The reaction of compound **A** with excess chlorine forms a compound **D**, which has a molar mass of 175.5 g mol^{-1}.

Draw a possible structure for compound **D** and write the equation for its formation from compound **A**. Use molecular formulae in the equation.

Compound D

Equation **[2]**

67(a). This question is about reactions involving alcohols.

Three reactions of an alcohol **E** are shown in **Fig. 25.1**.

i. Complete **Fig. 25.1** to show the structures of the organic products formed in the reactions.

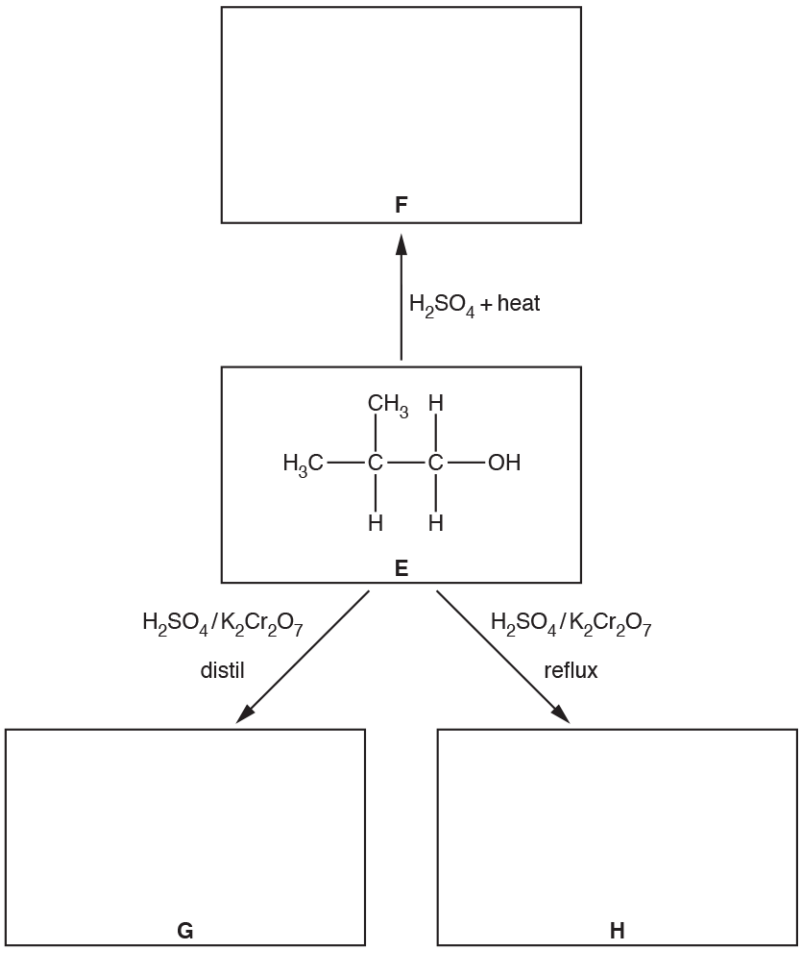


Fig. 25.1

[3]

ii. What is the systematic name of alcohol **E**?

[1]

(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]

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

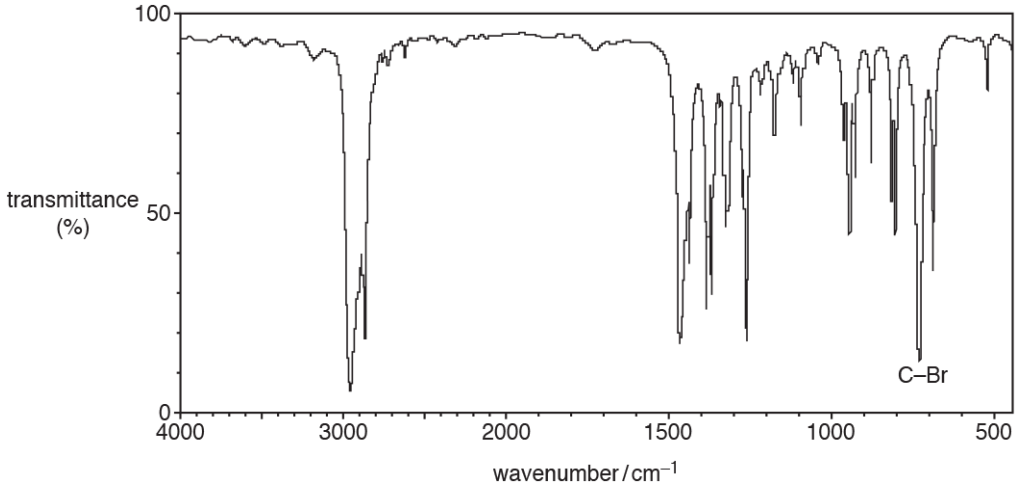
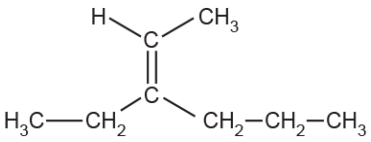


Fig. 25.2

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]

68. What is the name of the compound below?



A 3-Propylpent-2-ene

B 3-Propylpent-3-ene

C 3-Ethylhex-2-ene

D 4-Ethylhex-4-ene

Your answer ☐ **[1]**

69. This question is about reaction mechanisms.

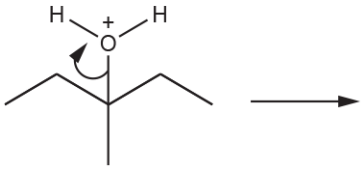
Chemists use curly arrows in reaction mechanisms.

i. What does a curly arrow show in a reaction mechanism?

_____

[1]

ii. Draw structures to show the products in the reaction mechanism below.



[2]

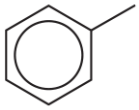
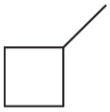
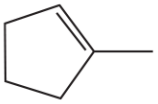
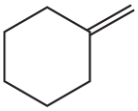
iii. Use the mechanism in **(ii)** to explain what is meant by **heterolytic fission**.

_____

_____

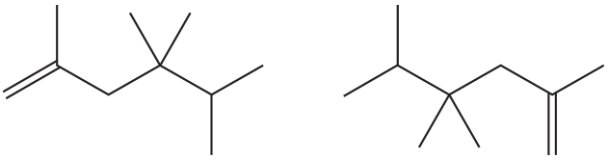
[2]

70. Which compound is unsaturated, alicyclic and contains an alkyl group?

A	
B	
C	
D	

Your answer ☐ **[1]**

71. Which statement is correct for the two structures below?



A They have the same empirical formula.

B They have different relative molecular masses.

C They are structural isomers.

D They have different functional groups.

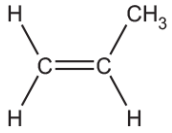
Your answer ☐ **[1]**

72(a). This question is about unsaturated hydrocarbons.

Propene reacts with bromine.

Outline the mechanism for the reaction of propene with bromine, Br_2.
The structure of propene has been provided.

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



[4]

(b). The 'alkynes' is a homologous series of hydrocarbons.

The table shows three alkynes.

Alkyne	Structural formula	Molecular formula
ethyne	$HC{\equiv}CH$	C_2H_2
propyne	$CH_3C{\equiv}CH$	C_3H_4
but-1-yne	$CH_3CH_2C{\equiv}CH$	C_4H_6

i. Explain what is meant by the term: **homologous series**.

[2]

ii. Suggest the general formula of the alkynes.

[1]

iii. Propyne reacts with bromine to form a saturated compound.

Write an equation for the reaction, showing the structure of the organic product.

[2]

iv. But-1-yne is a structural isomer of C_4H_6.

Draw the structures of **2** other structural isomers of C_4H_6.

[2]

v. Draw the structure of 2,5-dimethylhept-3-yne.

[1]

73. This question is about two different types of acid found in organic compounds, carboxylic acids and sulfonic acids, as shown in **Fig. 6.1**.

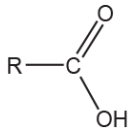
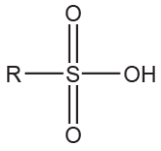
	
Carboxylic acid	Sulfonic acid

Fig. 6.1

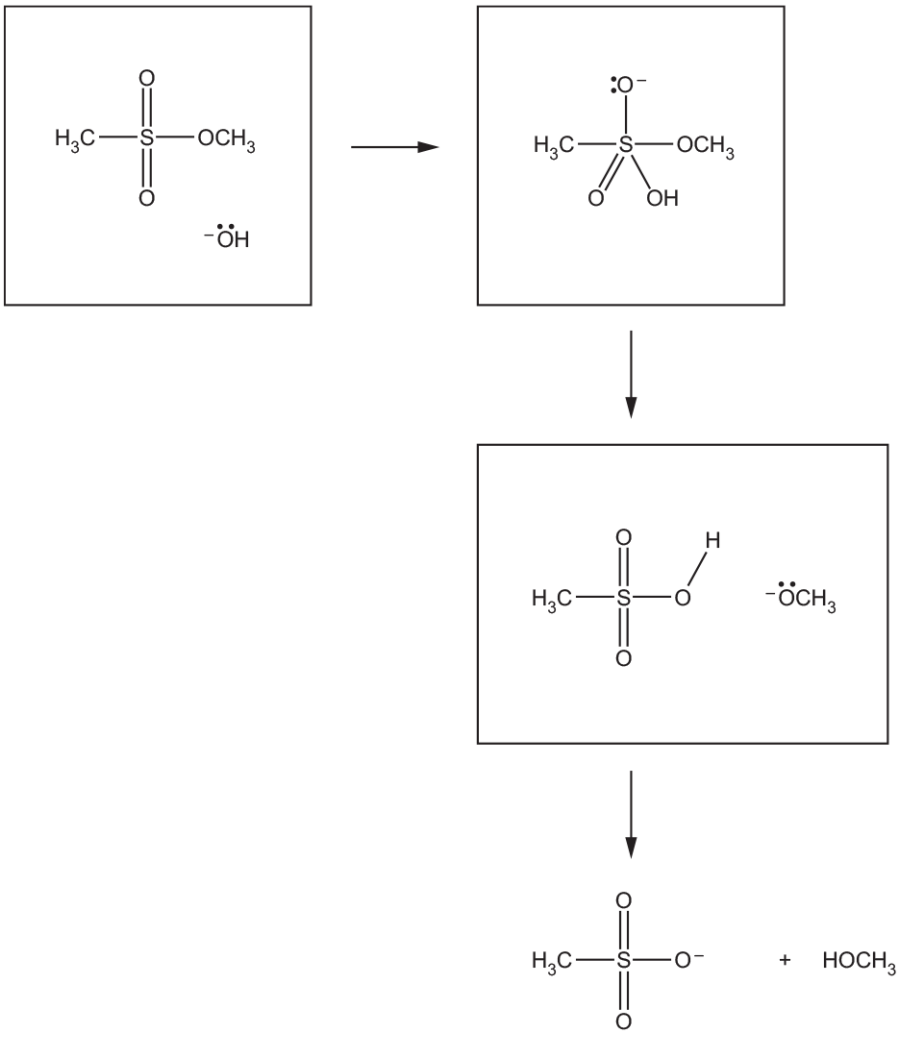
Carboxylic acids and sulfonic acids both form esters.

Sulfonic acid esters can be hydrolysed by aqueous alkali.
The equation shows the alkaline hydrolysis of a sulfonic acid ester.

$CH_3SO_2OCH_3 + OH^- \rightarrow CH_3SO_2O^- + CH_3OH$

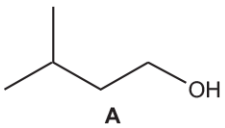
In the **3 boxes below**, add curly arrows to show the mechanism for this reaction.

In the first box, the hydroxide ion acts as a nucleophile.

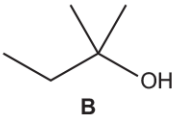


[2]

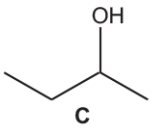
74. This question is about the alcohols **A–F** shown below.



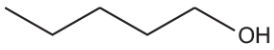
A



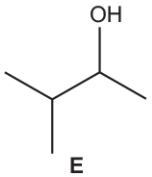
B



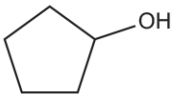
C



D



E

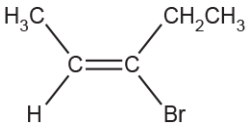


F

What is the systematic name of alcohol **B**?

[1]

75. What is the name of the compound below?



A *E*-3-bromopent-2-ene

B *E*-3-bromopent-3-ene

C *Z*-3-bromopent-2-ene

D *Z*-3-bromopent-3-ene

Your answer ☐

[1]

76. What is the structural formula of ethyl 3-methylbutanoate?

A $CH_3CH_2COOCH_2CH_2CH(CH_3)_2$

B $CH_3CH_2COOCH(CH_3)CH_2CH_3$

C $CH_3CH_2CH(CH_3)COOCH_2CH_3$

D $(CH_3)_2CHCH_2COOCH_2CH_3$

Your answer ☐ **[1]**

77. What is the number of alicyclic structural isomers of C_5H_{10}?

A 3

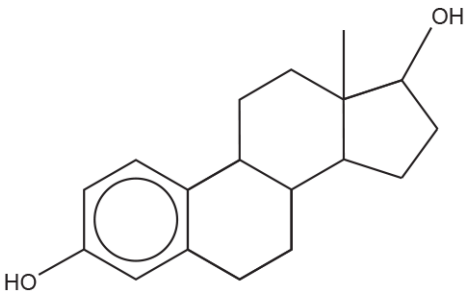
B 4

C 5

D 6

Your answer ☐ **[1]**

78. What is the molecular formula of the steroid molecule below?



A $C_{18}H_{24}O_2$

B $C_{18}H_{26}O_2$

C $C_{18}H_{28}O_2$

D $C_{18}H_{30}O_2$

Your answer ☐ **[1]**

79. The structure of hydrocarbon **A** is shown below.

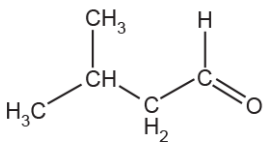
A

Hydrocarbon **A** can be reacted with bromine in the presence of ultraviolet radiation to prepare $(CH_3)_3CCHBrCH_3$.

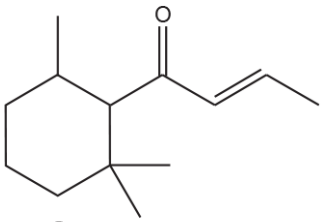
What is the systematic name for $(CH_3)_3CCHBrCH_3$?

[1]

80(a). The carbonyl compounds, **F** and **G**, shown below, contribute to the flavour of coffee.



F



G

Compound **F** is a member of a homologous series.

i. Explain the term homologous series.

[2]

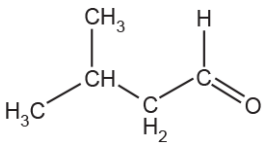
ii. Predict the molecular formula for the member of this homologous series containing 24 carbon atoms.

[1]

(b). Compound **F** reacts with HCN using NaCN(aq) and H_+(aq).

i. Outline the mechanism for the reaction of **F** with NaCN(aq) and H+(aq) and state the name of the mechanism. The structure of **F** has been provided.

Include relevant dipoles, lone pairs and the structure of the organic product.



Name of mechanism:

[5]

ii. Explain why the mechanism in **(i)** involves heterolytic fission.

[2]

81. What is the number of unsaturated isomers (structural and stereoisomers) that have the molecular formula C_4H_8?

A 3

B 4

C 5

D 6

Your answer ☐ **[1]**

82. What do curly arrows **always** show in reaction mechanisms?

A Movement of one electron.

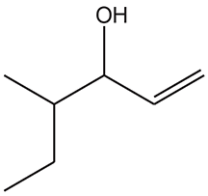
B Movement of a pair of electrons.

C Movement of a lone pair of electrons.

D Movement of the electrons in a covalent bond.

Your answer ☐ **[1]**

83. What is the systematic name of the compound below?



A 3-methylhex-5-en-4-ol

B 4-methylhex-1-en-3-ol

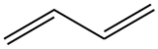
C 2-ethylpent-4-en-3-ol

D 4-ethylpent-1-en-3-ol

Your answer ☐ **[1]**

84. The 'dienes' are a homologous series of non-cyclic compounds with two double bonds.

The simplest diene is shown below.



What is the general formula of the dienes homologous series?

A C_nH_{2n+2}

B C_nH_{2n}

C C_nH_{2n-2}

D C_nH_{2n-4}

Your answer ☐ **[1]**

85. This question is about atomic structure.

Halothane, $C_2HBrClF_3$, (M_r = 197.4) is used as a general anaesthetic in medicine.

i. The systematic name for halothane is 2-bromo-2-chloro-1,1,1-trifluoroethane.

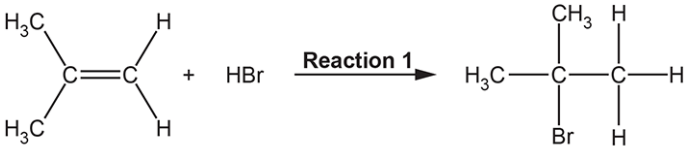
Draw the structure of a halothane molecule.

[1]

ii. What is the number of fluorine **atoms** in 7.896 g of halothane, $C_2HBrClF_3$?

number of fluorine atoms = ... **[2]**

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



Methylpropene **Compound A**

When reacting methylpropene with HBr, a small amount of compound **B** also forms.

Compound **B** is a structural isomer of compound **A**.

i. Explain the term **structural isomer**.

[1]

ii. Show the structure for compound **B**.

[1]

87. Compounds **A** and **B** are structural isomers of $(CH_3)_3COH$.

i. Compound **A** is a secondary alcohol.

What is the systematic name of compound **A**?

[1]

ii. Compound **B** is a branched primary alcohol.

Compound **B** is refluxed with acidified potassium dichromate(VI) as an oxidising agent.

Write the equation for the reaction that takes place.

Use structures for organic compounds and [O] for the oxidising agent.

[3]

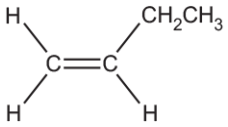
88(a). But-1-ene, $H_2C=CHCH_2CH_3$, and buta-1,3-diene, $H_2C=CH–CH=CH_2$, are unsaturated compounds used to make many organic products.

But-1-ene is reacted with hydrogen bromide, forming a mixture of two saturated organic products.

One of the organic products is formed in a much greater quantity than the other organic product.

i. Outline the reaction mechanism for the formation of this **major** organic product. The structure of but-1-ene has been provided.

Include curly arrows and relevant dipoles.



[4]

ii. Explain why one organic product is formed in a much greater quantity than the other organic product.

[2]

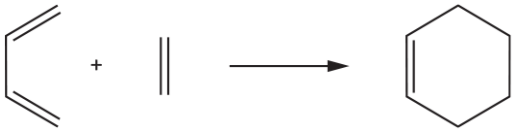
iii. Buta-1,3-diene is reacted with an excess of hydrogen bromide, forming a mixture of saturated organic products.

How many saturated organic products could be present in this mixture?

[1]

(b). 'Diels-Alder' reactions are used in the synthesis of many important organic compounds.

The Diels-Alder reaction of buta-1,3-diene with ethene is shown below.

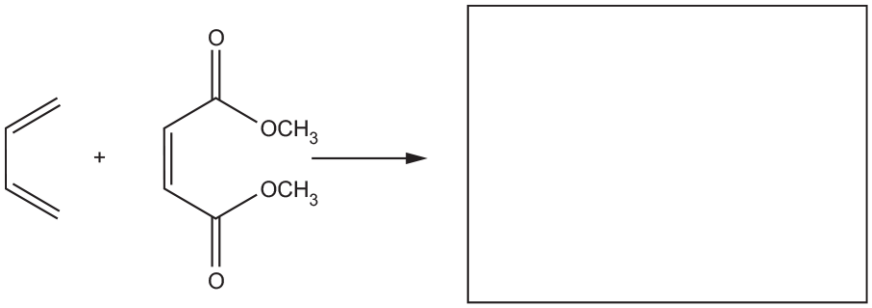


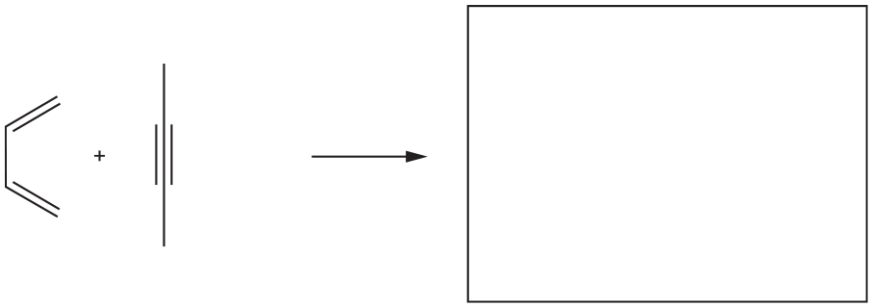
i. Add curly arrows to the diagram below to complete the mechanism for this Diels-Alder reaction.

[2]

ii. Two more Diels-Alder reactions of buta-1,3-diene are shown below.

In the boxes, draw the organic product of each reaction.

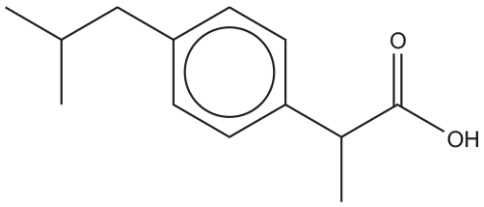




[2]

89(a). This question is about organic acids.

Ibuprofen, shown below, is used as a painkiller.



ibuprofen

i. What is the molecular formula of ibuprofen?

[1]

ii. One ibuprofen tablet contains 400 mg of ibuprofen.

Calculate the number of ibuprofen molecules in one ibuprofen tablet.

Give your answer to **3** significant figures.

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

(b). Tablets based on ibuprofen and lysine are now available from pharmacies.

These tablets are claimed to act faster than ibuprofen by being absorbed into the body more quickly than ibuprofen alone.

One type of these tablets contains a salt of ibuprofen and the amino acid lysine (R = $–(CH_2)_4NH_2$) in a 1:1 molar proportion.

i. Suggest the structure of each ion in this lysine salt of ibuprofen, including the position of any charges.

– ion	+ ion

[2]

ii. Suggest why tablets based on a salt of ibuprofen should act faster in the body than ibuprofen.

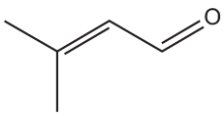
_____

_____

[1]

90. This question is about organic synthesis.

Prenal, shown below, is used in the synthesis of some pharmaceuticals.

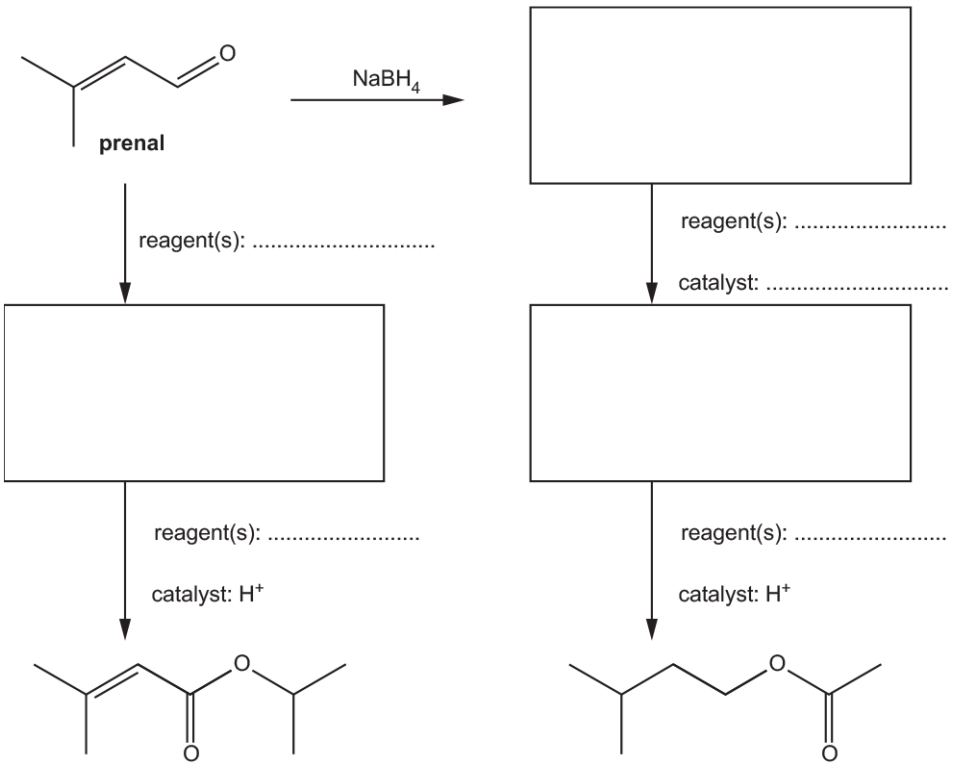


prenal

i. What is the systematic name for prenal?

[1]

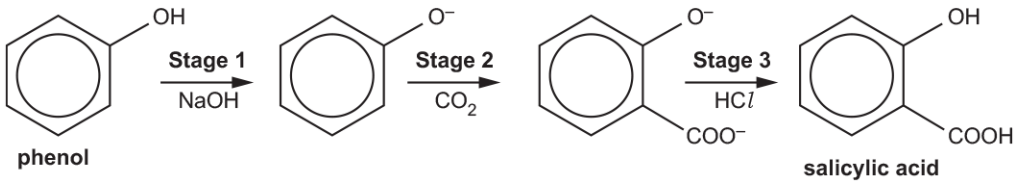
ii. Complete the flowchart below for the synthesis of two compounds starting from prenal.



[7]

91. This question is about reactions of phenol.

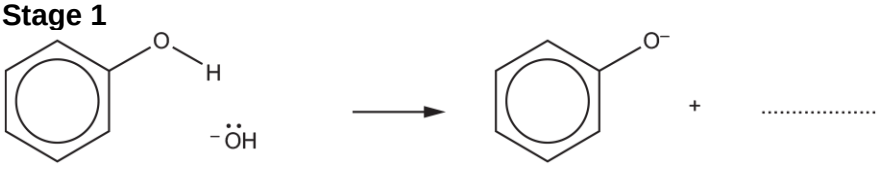
Salicylic acid can be prepared from phenol as shown below.



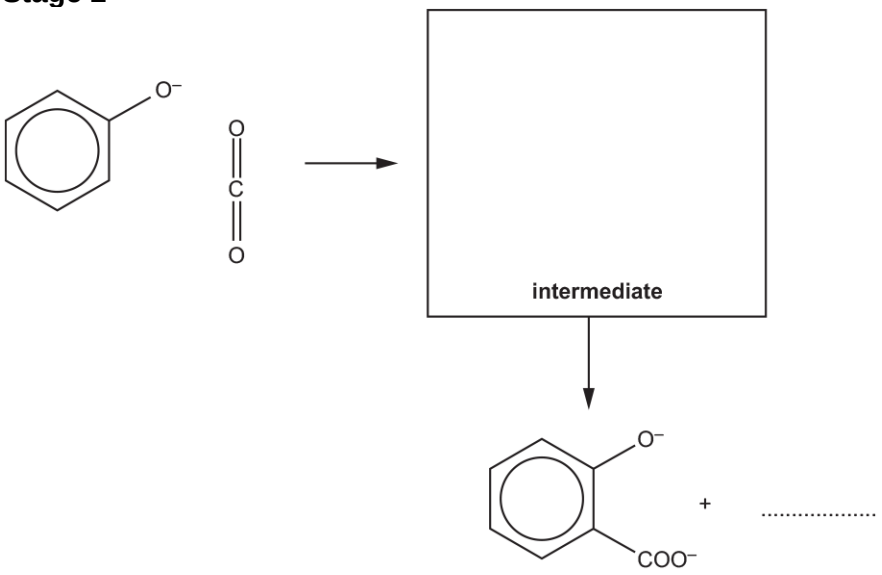
i. Complete the mechanism below for **Stage 1** and **Stage 2**.

Show curly arrows, the structure of the intermediate and the missing formulae on the dotted lines.

Stage 1



Stage 2



[6]

ii. What are the roles of ^{-}OH and CO_2 in the mechanism?

^{-}OH

CO_2

[2]

iii. Two molecules of salicylic acid can react together in the presence of an acid catalyst to form compound **B**.

Compound **B** has three rings and a molecular formula of $C_{14}H_8O_4$.

Write the equation for this reaction showing the structures of organic compounds.

[3]

92. 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]

93. This question is about carboxylic acids.

Compound **D** is a *cis* stereoisomer of an unsaturated organic acid with the general formula $C_nH_{2n-1}COOH$.

A student plans to analyse acid **D** by carrying out a titration.

A student prepares a 100.0 cm^3 solution containing 3.215 g of acid **D**.

The student titrates 25.0 cm^3 samples of the solution of **D** with 0.150 mol dm^{-3} $Ba(OH)_2(aq)$ in the burette.

1 mol $Ba(OH)_2$ reacts with 2 mol of **D**.

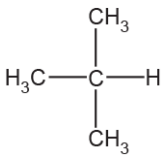
The mean titre of $Ba(OH)_2(aq)$ is 23.50 cm^3.

Analyse the titration results to determine **two** possible structures for the *cis* stereoisomer of organic acid **D**.

Structures of 2 possible cis stereoisomers of acid D

[7]

94(a). Alkane **A**, shown below, reacts with bromine in a radical substitution reaction.



Alkane A

What is meant by a **radical?**

[1]

(b). Name the type of bond breaking that occurs in a radical substitution reaction.

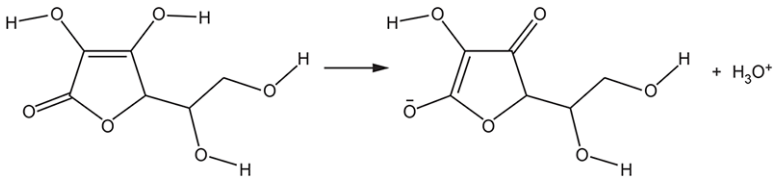
[1]

95. Vitamin C, $C_6H_8O_6$, is a weak acid (K_a = 7.94 × 10 $^{-5}$ (mol dm^{-3})), which is often referred to as ascorbic acid.

i. In aqueous solution, vitamin C donates a proton to water:

$C_6H_8O_6 + H_2O \rightleftharpoons C_6H_7O_6^- + H_3O^+$

Add curly arrows to the diagram to suggest the mechanism for this process.



[2]

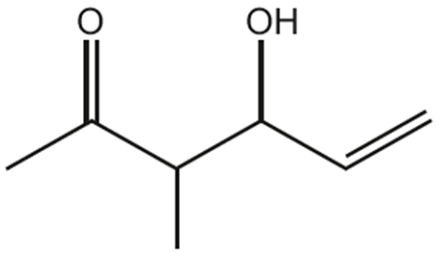
ii. The student dissolves 0.150 mol of vitamin C in water and makes the solution up to 250 cm^3 in a volumetric flask.

Calculate the pH of this solution of vitamin C.

Give your answer to **2** decimal places.

pH = ... **[3]**

96. What is the number of hydrogen atoms in **one** molecule of the compound below?



A 8

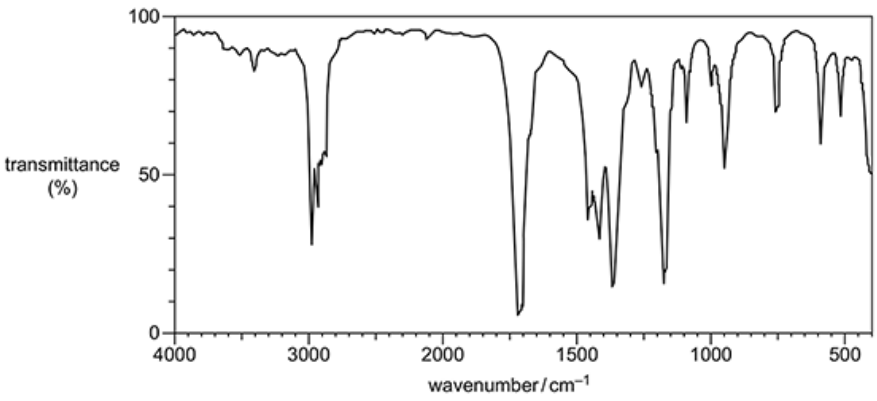
B 10

C 12

D 14

Your answer ☐ **[1]**

97. Which organic compound could have produced the infrared spectrum below?



A $CH_3COCH_2CH_3$

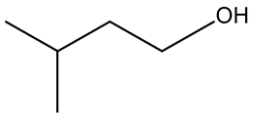
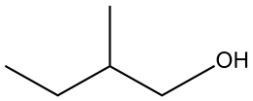
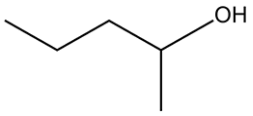
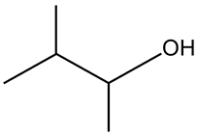
B $CH_3CH_2CHOHCH_3$

C $CH_3COCH_2CH_2OH$

D CH_3CH_2COOH

Your answer ☐ **[1]**

98. Which alcohol is likely to have fragment ions at *m*/z = 15, 29 **and** 43 in its mass spectrum?

A	
B	
C	
D	

Your answer ☐ **[1]**

99. The alkene, $(CH_3)_3CCH=CH_2$, is used to make some perfumes.

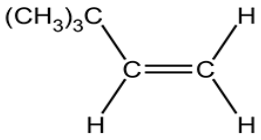
i. What is the systematic name for $(CH_3)_3CCH=CH_2$?

[1]

$(CH_3)_3CCH=CH_2$ decolourises bromine.

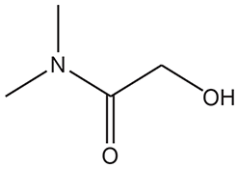
Outline the reaction mechanism for the reaction of $(CH_3)_3CCH=CH_2$ and bromine. The structure of $(CH_3)_3CCH=CH_2$ has been provided.

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



name of mechanism..... **[5]**

100. The skeletal formula of an organic compound is shown below.



Which functional groups are present?

A amide and alcohol

B amide and carboxylic acid

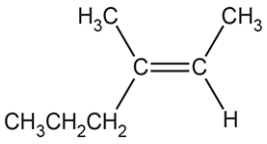
C amine and carboxylic acid

D amine, ketone and alcohol

Your answer ☐ **[1]**

101(a). This question is about unsaturated hydrocarbons.

The unsaturated hydrocarbon **A**, shown below, is reacted with bromine.



Hydrocarbon A

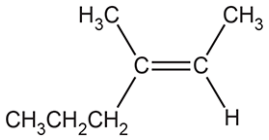
i. What is the systematic name of hydrocarbon **A**?

[1]

ii. Outline the mechanism for the reaction of hydrocarbon **A** with bromine.

The structure of hydrocarbon **A** has been provided.

Include curly arrows and relevant dipoles.



[3]

(b). Compounds **B** and **C** are **branched** hydrocarbons that are structural isomers of C_6H_{12}.

Compounds **B** and **C** both have stereoisomers.

- Compound **B** has *cis* and *trans* isomers but does **not** have optical isomers.
- Compound **C** has optical isomers but does **not** have *cis* and *trans* isomers.

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

[1]

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

[1]

iii. Draw structures for the *cis* and *trans* isomers of the branched hydrocarbon **B**.

***cis* isomer**	***trans* isomer**

[2]

iv. Draw 3D structures for the optical isomers of compound **C**.

Optical isomers	

[2]

v. Compounds **D** and **E** are two more structural isomers of C_6H_{12}.

Compounds **D** and **E** do **not** show stereoisomerism.

Table 16.1 shows NMR and infrared (IR) spectral data for **D** and **E**.

	Number of peaks in ^{1}H NMR spectrum	**Number of peaks in ^{13}C NMR spectrum**	**IR peak at 1620–1680 cm^{-1}**
D	1	1	No
E	1	2	Yes

Table 16.1

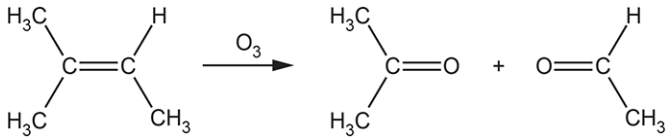
Draw the structures of **D** and **E** and explain how the spectral data in **Table 16.1** provides evidence for the structures.

D	**E**

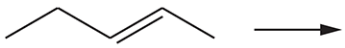
[4]

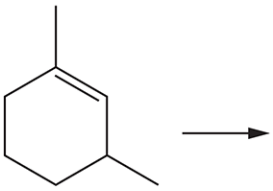
(c). 'Ozonolysis' is used in organic synthesis. Ozone breaks C=C bonds to form carbonyl compounds.

For example, the complete ozonolysis of methylbut-2-ene is shown below.



i. Draw the structures of the products you would expect from the ozonolysis of the **two** compounds below.



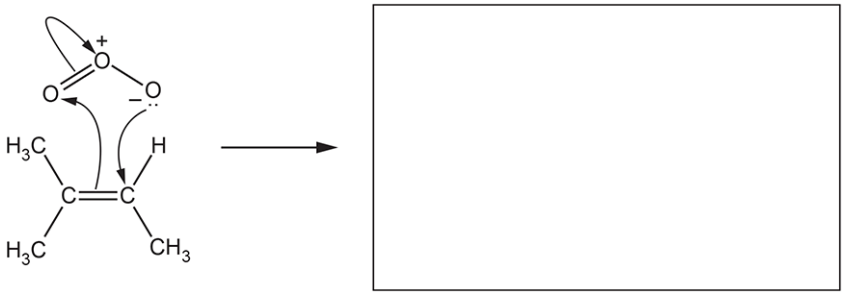


[2]

ii. The mechanism for ozonolysis takes place in several steps.

The curly arrows in the first step in the ozonolysis of methylbut-2-ene are shown below.

In the box, draw the structure(s) for the product(s) of this step.



[1]

102. This question is about an analysis of an unknown organic **Compound X**.

Some properties of **Compound X** are shown in the table.

Molecular formula	Functional groups	Chirality
$C_xH_yF_6O$	C–F C–O–C	1 chiral carbon

At a pressure of 1.07×10^5Pa at 30 °C, 1.327 g of **Compound X** is a gas with a volume of 186 cm^3.

Determine the molar mass of **Compound X** and its molecular formula.

Draw a possible structure for a molecule of **Compound X**.

molar mass ..... $gmol^{-1}$

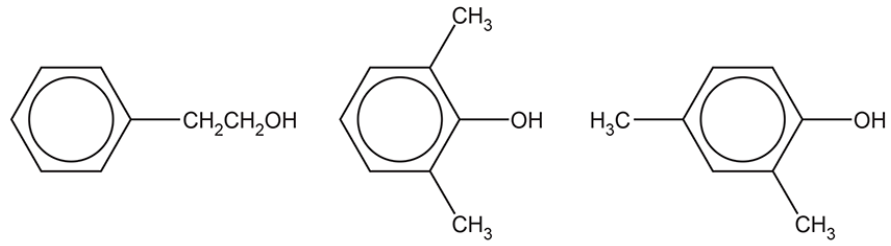
molecular formula .....

Structure of Compound X

[6]

103. This question is about the chemistry of aromatic compounds.

Compounds **J**, **K** and **L**, shown below, are structural isomers.



Compound J **Compound K** **Compound L**

i. What chemical test(s) could be used to confirm the presence of the phenol group in compounds **K** and **L**?

_____

_____

[1]

ii. A student thought that ^{13}C NMR spectroscopy could be used to distinguish between compounds **J**, **K** and **L**.

Explain, with reasoning, whether the student is correct.

[3]

iii. Compound **J** is substituted at the 2- and 4- positions by chlorine in the presence of a catalyst.

Outline the mechanism for the 4 substitution of compound **J** by chlorine in the presence of a catalyst.

Show the role of the catalyst.

[4]

104. 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]

105. 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.

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

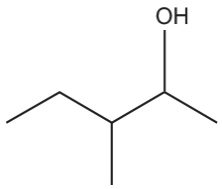
Use the curly arrow model to outline the mechanism for the alkaline hydrolysis of 2-bromopropane.

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

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

106. This question is about alkenes.

A mixture of alkenes is produced when water is eliminated from alcohol **A**.



Alcohol A

i. What is the systematic name of alcohol **A**?

[1]

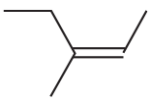
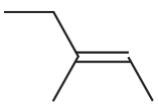
ii. Alcohol **A** is refluxed with an acid catalyst.

- A mixture of alkene isomers **B**, **C** and **D** is formed.
- Alkenes **B** and **C** show *E*/*Z* isomerism but alkene **D** does not.

Construct the equation for the formation of alkene **D** from alcohol **A**.
Show the structure of the organic product.

[2]

iii. The skeletal formulae of alkenes **B** and **C** are shown below.

	Alkene B	**Alkene C**
Skeletal formula		
Isomer	*Z*	*E*

Use the Cahn-Ingold-Prelog priority rules to explain why alkene **B** is the *Z* isomer.

[2]

107. Propyne, $CH_3C{\equiv}CH$, is a member of the alkynes homologous series with the C≡C functional group.

What is the general formula of the alkynes?

A C_nH_{2n-4}

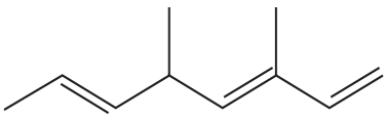
B C_nH_{2n-2}

C C_nH_{2n}

D C_nH_{2n+2}

Your answer ☐ **[1]**

108. What is the systematic name for the compound below?



A 3,5-dimethylocta-1,3,6-triene

B 3,5-dimethylocta-2,5,7-triene

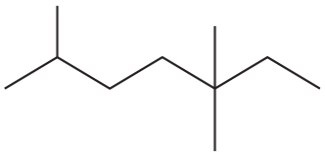
C 4,6-dimethylocta-1,3,6-triene

D 4,6-dimethylocta-2,5,7-triene

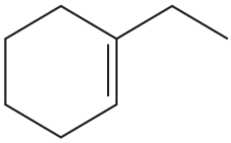
Your answer ☐ **[1]**

109. Which compound(s) is/are aliphatic?

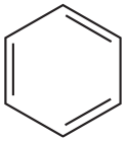
1



2



3



A 1, 2 and 3

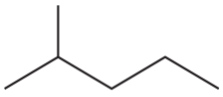
B Only 1 and 2

C Only 2 and 3

D Only 1

Your answer ☐ **[1]**

110. 2-methylpentane reacts with bromine by radical substitution.



2-methylpentane

A mixture of organic products is formed, including 3-bromo-2-methylpentane, and compounds **A** and **B**.

i. Complete the table below to show the mechanism for the formation of 3-bromo-2-methylpentane and **three** possible equations for termination.

In your equations, use **structural or skeletal formulae** and 'dots' (•) for the position of radicals.

Initiation	Equation: ..... Conditions: .....
Propagation	→ →
Termination	→ → →

[6]

ii. Organic compound **A** is formed by the substitution of **all** 14 H atoms in 2-methylpentane by Br atoms.

Write the equation, using **molecular formulae**, for the formation of compound **A** from 2-methylpentane.

[2]

iii. Organic compound **B** is formed by the substitution of **some** of the 14 H atoms in 2-methylpentane by Br atoms.

0.8649 g of compound **B** is heated until it is vaporised.

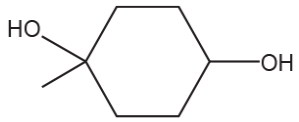
Under the conditions used:

- compound **B** has a volume of 72.0 cm^3
- the molar gas volume is 40.0 dm^3 mol^{-1}.

Determine a possible molecular formula of compound **B**.

molecular formula = ... **[3]**

111. Compound **D**, shown below, is refluxed with H_2SO_4, as an acid catalyst, to form a mixture of three isomers with the molecular formula C_7H_{10}.



Compound D

i. Draw the structures of the **three** isomers of C_7H_{10} formed from compound **D**.

[3]

ii. A student converts compound **D** into a diiodoalkane.

Suggest suitable reagents for this reaction.

[1]

112. This question is about α-amino acids.

The α-amino acid valine has the R group of $–CH(CH_3)_2$.

i. What is the systematic name of valine?

[1]

ii. Draw diagrams to show 3D structures of the optical isomers of valine.

[2]

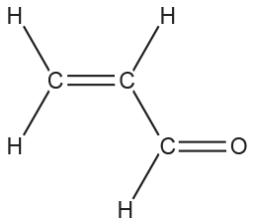
113. This question is about reactions of acrolein, $H_2C=CHCHO$.

Acrolein reacts with sodium cyanide in acidic conditions, NaCN(aq) / H^+(aq).

i. Outline the reaction mechanism for this reaction, showing the intermediate and the organic product.

The structure of acrolein has been provided.

Include curly arrows and relevant dipoles.

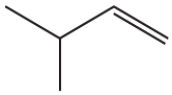
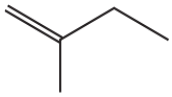


[4]

ii. Name this type of mechanism.

[1]

114. Which formula does **not** represent 3-methylbut-1-ene?

A	$CH_3CHCH_3CHCH_2$
B	$CH_2CHCH(CH_3)_2$
C	
D	

Your answer ☐ **[1]**

115. How many structural isomers have the molecular formula C_4H_9Cl?

A 2

B 3

C 4

D 5

Your answer ☐ **[1]**

116. This question is about enthalpy changes.

In a petrol engine, alkanes undergo combustion.

i. Heptane is one of the alkanes in petrol.

Write the equation for the complete combustion of heptane.

State symbols are **not** required.

[2]

ii. In a petrol engine, polluting gases such as CO and NO are formed. These are mostly removed before being emitted from the exhaust.

The equation for the removal of CO and NO is shown below.

$2CO(g) + 2NO(g) \rightarrow 2CO_2(g) + N_2(g)\ \Delta H = -746\ kJ\ mol^{-1}$

Complete the enthalpy profile diagram in **Fig. 23.1** for this reaction.

On your diagram:

- Label the enthalpy change of reaction, ΔH.
- Include the formulae of the reactants and products.
- Label the activation energy, E_a.

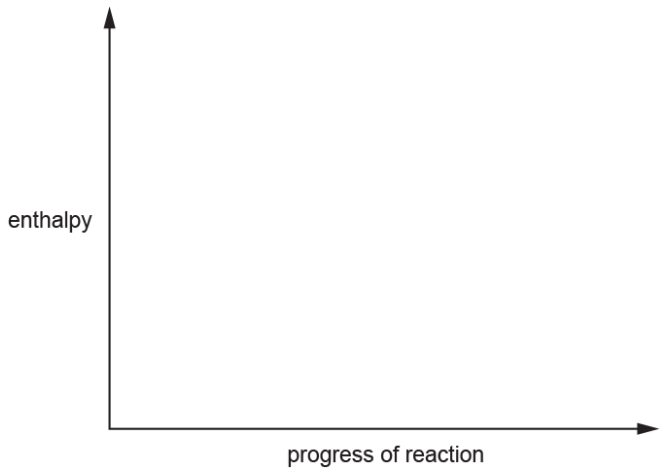


Fig. 23.1

[2]

iii. CO and NO are removed by use of a catalyst.

Explain the role of the catalyst.

Refer to your enthalpy profile diagram in **Fig. 23.1** in your answer.

[2]

117(a). This question is about hydrocarbons.

The boiling points of 2 hydrocarbons are shown below.

Hydrocarbon	Boiling point / °C
butane	0
pentane	36

Explain the difference in the boiling points of butane and pentane.

[2]

(b). Butane reacts with bromine by radical substitution to form a mixture of organic products.

The reaction needs UV radiation for the initiation stage.

Write equations for the propagation stage that follows to form 2-bromobutane.

Use skeletal formulae and 'dots' (•) to show the position of any radicals.

Propagation	→ →

118. This question is about the oxidation of two alcohols that are structural isomers of C_3H_8O.

Compare the oxidation of these two structural isomers using different reaction conditions.

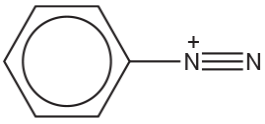
For each reaction include:

- the reaction conditions
- the functional group of any organic product
- a balanced equation.

In your equations, use [O] to represent the oxidising agent and show any organic compounds as structures.

[5]

119. The benzenediazonium ion, shown below, is stable at temperatures below 10 °C.



Benzenediazonium

Above 10 °C, the benzenediazonium ion reacts with water to form phenol.

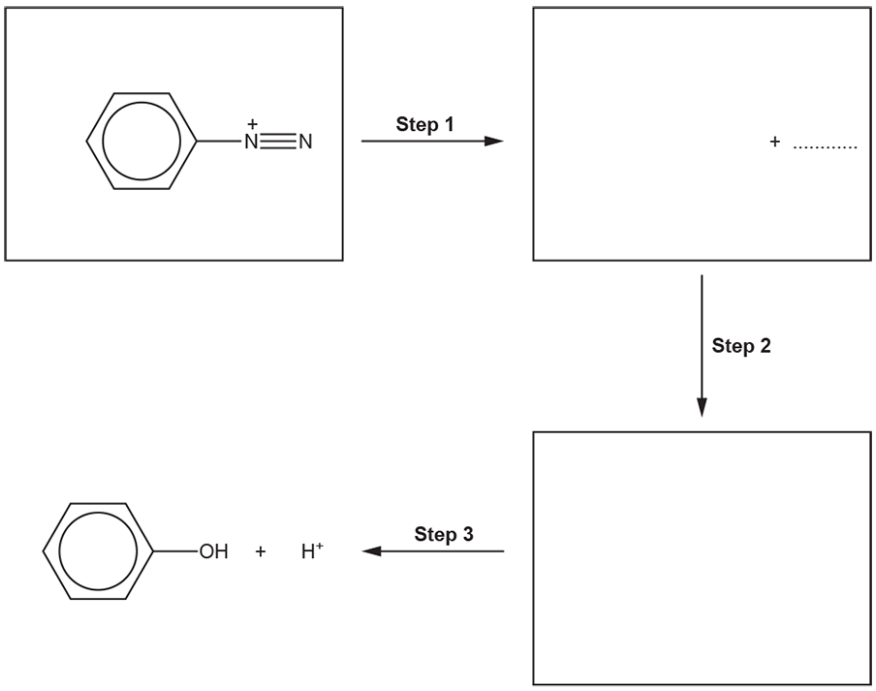
The reaction proceeds in a three-step mechanism.

Step 1 Elimination of nitrogen gas to form a carbocation.

Step 2 Nucleophilic attack by water.

Step 3 Proton loss to form the organic product.

Complete the boxes below with intermediates and curly arrows to show the mechanism for this reaction.

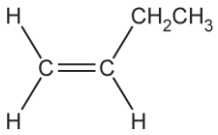


[4]

120. HBr reacts readily with alkenes.

i. Outline the mechanism for the reaction of but-1-ene with HBr to form **2-bromobutane**.

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



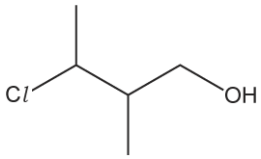
[4]

ii. During this reaction, a small amount of **1-bromobutane** is also produced.

Explain why **2-bromobutane** is the major product.

[2]

121. What is the name of the compound below?



A 1-chloro-1,2-dimethylpropan-3-ol

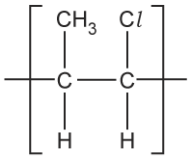
B 2-chloro-3-methylbutan-4-ol

C 3-chloro-2-methylbutan-1-ol

D 3-chloro-2,3-dimethylpropan-1-ol

Your answer ☐ **[1]**

122. The repeat unit of an addition polymer is shown below.



Which statement about this addition polymer is correct?

A Combustion produces toxic alkaline fumes.

B The addition polymer is biodegradable.

C The monomer is $H_3CCH{=}CHCl$.

D The repeat unit above is shown as a displayed formula.

Your answer ☐ **[1]**

123(a). This question is about hydrocarbons.

The hydrocarbon C_2H_6 reacts with bromine, Br_2, to form C_2H_5Br under suitable conditions.

Complete the table below to show the mechanism for the three stages of the reaction of C_2H_6 with Br_2 to form C_2H_5Br.

The equation for one of the possible reactions for termination has been completed.

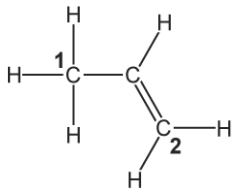
In your equations, use molecular formulae and 'dots' (·) with any radicals.

Initiation	Conditions ..... Equation ..... → .....
Propagation	**1** ..... → ..... **2** ..... → .....

Termination	**1** $Br\cdot + Br\cdot \rightarrow Br_2$ **2** ..... → ..... **3** ..... → .....

[5]

(b). Propene, C_3H_6, has different bond angles and shapes around the carbon atoms. The displayed formula of a propene molecule is shown below.



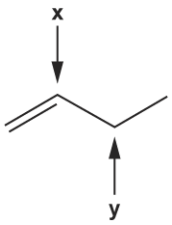
Predict the bond angles and the names of the shapes around the C atoms **1** and **2** above, and explain why the bond angles and shapes are different.

Carbon atom	Bond angle	Name of shape
1		
2		

Explanation:

[5]

124. The structure of but-1-ene is shown below.



Which row has the correct **shape** around carbon atoms labelled **x** and **y**?

	x	y
A	Tetrahedral	Pyramidal
B	Trigonal planar	Tetrahedral
C	Trigonal planar	Pyramidal
D	Pyramidal	Tetrahedral

Your answer ☐ **[1]**

125. 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 $CCl_2F_2 \rightarrow \bullet C + \bullet Cl_2F_2$

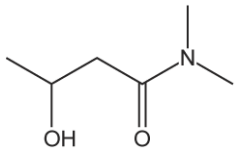
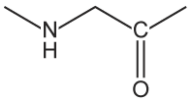
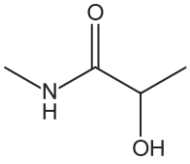
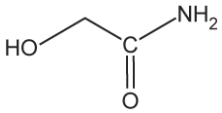
B $CCl_2F_2 \rightarrow \bullet F + \bullet CCl_2F$

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

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

Your answer ☐ **[1]**

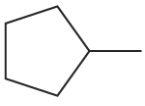
126. Which compound is a secondary amide?

A	
B	
C	
D	

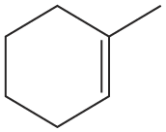
Your answer ☐ **[1]**

127(a). This question is about hydrocarbons.

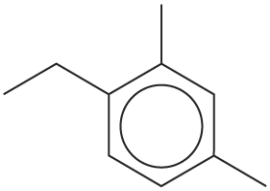
The structures of hydrocarbons **A–E** are shown below.



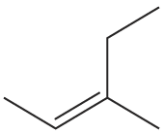
A



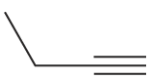
B



C



D



E

Which hydrocarbons are unsaturated?

[1]

(b). Which hydrocarbons are alicyclic?

[1]

(c). What is the systematic name of hydrocarbon **C**?

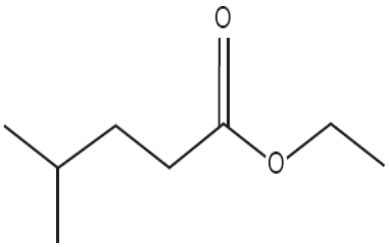
[1]

128. Alkenes and carbonyl compounds take part in addition reactions.

Describe **one** addition reaction of an alkene and **one** addition reaction of a carbonyl compound.
Include reagents and reaction mechanisms.

[6]

129. Ester **F** has the structure shown below.



Ester F

i. What is the systematic name for this ester?

[1]

ii. Ester **F** can be prepared from a carboxylic acid in two steps.

Step 1 The carboxylic acid is converted into an acyl chloride.

Step 2 The acyl chloride is converted into ester **F**.

Write equations for **Step 1** and **Step 2**.

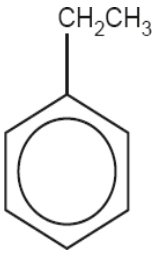
Show organic compounds as structures.

Step 1

Step 2

[4]

130. Ethylbenzene, $C_6H_5CH_2CH_3$, can be prepared by reacting benzene with chloroethane, CH_3CH_2Cl, in the presence of $AlCl_3$. The $AlCl_3$ acts as a halogen carrier.



Ethylbenzene

In the mechanism, chloroethane reacts with the halogen carrier to form a carbocation, which acts as the electrophile.

i. What is meant by the term **electrophile**?

[1]

ii. Outline the mechanism for this reaction, including the role of $AlCl_3$ as a halogen carrier.

[5]

131. This question is about the chemistry of compounds containing phosphorus.

When phosphorus(V) chloride, PCl_5, and ammonium chloride are heated together, the compound $P_3N_3Cl_6$ is formed, together with HCl gas.

$P_3N_3Cl_6$ has a cyclic structure, like the Kekulé structure of benzene.

i. Write an equation for the reaction of PCl_5 and ammonium chloride to form $P_3N_3Cl_6$.

[1]

ii. Calculate the percentage by mass of P in $P_3N_3Cl_6$.

Give your answer to **2** decimal places.

percentage by mass of P = ... % **[2]**

iii. Suggest **one** example of evidence that could show that $P_3N_3Cl_6$ has a Kekulé structure rather than a delocalised structure.

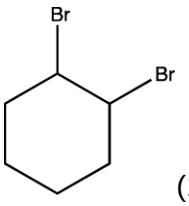
[1]

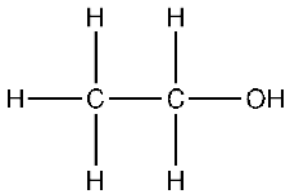
iv. In a molecule of $P_3N_3Cl_6$ all the N and Cl atoms are bonded to P atoms.
Suggest a possible structure for a molecule of $P_3N_3Cl_6$.

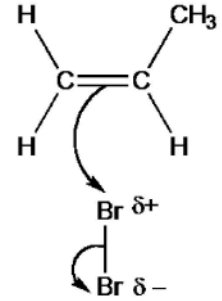
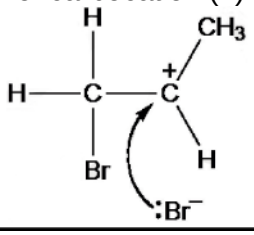
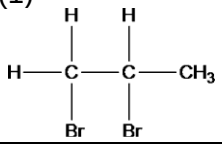
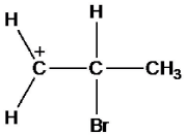
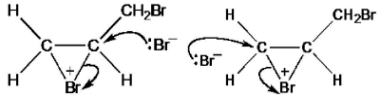
[2]

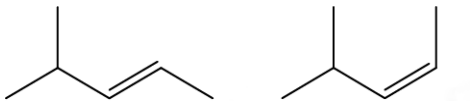
END OF QUESTION PAPER

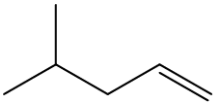
Mark scheme

Question			Answer/Indicative content	Marks	Guidance
1			C	1	
			Total	**1**	
2	a		Aliphatic = E, H, I, J (1) Alicyclic = E, H, J (1) Aromatic = F, G (1)	3	
	b		C_nH_{2n+1}	1	**do not allow** C_nH_{2n+} 1
	c	i	*Equation:* $C_6H_{12}O \rightarrow C_6H_{10} + H_2O$ (1) *Calculation:* **FIRST CHECK THE ANSWER ON THE ANSWER LINE** **IF** answer = 32.7 (%) award 3 marks theoretical yield = 7.65 / 100 = 0.0765 (mol) (1) actual yield = 2.05 / 82 = 0.025 (mol) (1) % yield = (0.025 / 0.0765) × 100% = 32.7(%) (1)	4	**ignore** state symbols **allow** $C_6H_{11}OH$ for $C_6H_{12}O$ **If there is an alternative answer, check to see if there is any ECF credit possible using working below** % yield **must** be to 1 dp **allow** theoretical and actual yield calculated in mass theoretical yield = 0.0765 × 82 = 6.273 g % yield = (2.05 / 6.273) = 32.7(%) **allow ecf** from calculated actual and theoretical yields
		ii	bromine water is decolourised (1)  (1)	2	**allow** bromine water turns colourless **ignore** 'goes clear' **allow** correct structural **OR** displayed **OR** skeletal formula **OR** mixture of the above
			Total	**10**	
3			Initiation $Cl_2 \rightarrow 2Cl\cdot$ (1) Propagation	5	

			$C_2H_6 + Cl\cdot \rightarrow C_2H_5\cdot + HCl$ (1) $C_2H_5\cdot + Cl_2 \rightarrow C_2H_5Cl + Cl\cdot$ (1) Termination $Cl\cdot + Cl\cdot \rightarrow Cl_2$ **OR** $C_2H_5\cdot + Cl\cdot \rightarrow C_2H_5Cl$ **OR** $C_2H_5\cdot + C_2H_5\cdot \rightarrow C_4H_{10}$ (1) Initiation, propagation, termination used in correct context (1)		If the structure of the ethyl radical is drawn, the lone electron must be attached to a C atom
			Total	**5**	
4			**FIRST CHECK THE ANSWER ON THE ANSWER LINE** **IF** answer = 46.0 (g mol^{-1}) award 4 marks for calculation *Rearranging ideal gas equation to make n subject* $n = \frac{pV}{RT}$(1) *Substituting all values taking into account conversion to Pa and m^3* $n = \frac{(100 \times 10^3) \times (761 \times 10^{-6})}{8.314 \times 366}$ (1) n = 0.0250 mol (1) *Calculation of M* $M = \frac{m}{n} = \frac{1.15}{0.0250} = 46.0$ (g mol^{-1})(1) *Identification of **A*** (1) 	5	**If there is an alternative answer, check to see if there is any ECF credit possible using working below**. 1st mark may be implicit in direct substitution of correct values into rearranged equation. **allow** any unambiguous structure **allow** C_2H_5OH **do not allow** C_2H_6O
			Total	**5**	
5		i	Curly arrow from double bond to Br of Br–Br (1) Correct dipole shown on Br–Br **AND** curly arrow showing breaking of Br–Br bond (1)	4	Curly arrow must start from bond and go to correct atom **do not allow** partial charges on C=C bond

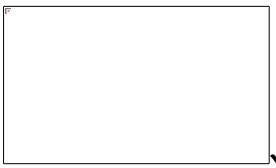
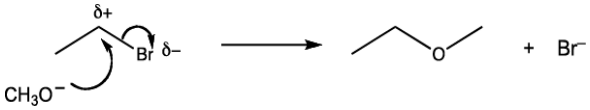
			 Correct carbocation with + charge on C with 3 bonds **AND** curly arrow from Br^- to C^+ of carbocation (1)  Correct product: (1) 		**allow** carbocation on terminal CH_2  **do not allow** δ+ on C of carbocation Curly arrow must come from a lone pair on Br^- **OR** from the negative sign of Br^- ion (then lone pair on Br^- ion does not need to be shown) **allow** formation of bromonium intermediate and curly arrows, i.e.: 
		ii	Movement of a pair of electrons	1	**allow** movement of a lone pair
			Total	**5**	
6			** Please refer to the marking instruction point 10 for guidance on how to mark this question.* **(Level 3)** Candidate provides a method for identifying the alcohols **AND** provides all supporting evidence from IR spectrum **AND** gives details of reagents and conditions and correct equations. *The explanation is detailed and well structured. The information is clearly supported by details of reactions and evidence of oxidation product.* (5–6 marks) **(Level 2)** Candidate provides a basic method **AND** provides some supporting evidence from IR spectrum **AND** gives details of reagents and conditions with some attempt at equations.	6	**Indicative scientific points may include** **Identification of alcohols** Based on recognition of alcohols as primary, secondary and tertiary (stated or implied by method). Basic procedure involves reflux followed by use of IR to identify different oxidation products. **Reactions** • stated reagents ($H^+/Cr_2O_7^{2-}$ and conditions (reflux)) • equations using [O] including structural formulae $CH_3CH_2CHOHCH_3 + [o] \rightarrow CH_3CH_2COCH_3 + H_20$ $CH_3CH_2CH_2CH_2OH + 2[o] \rightarrow CH_3CH_2CH_2COOH + H_2o$

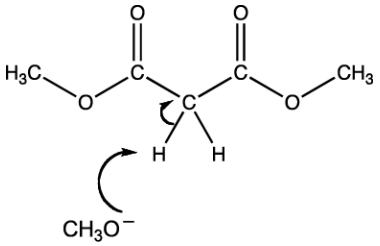
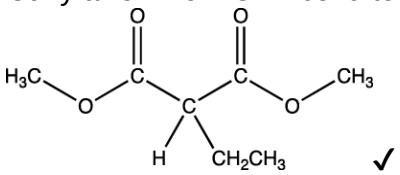
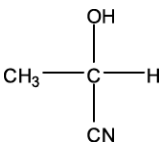
			The explanation has some structure. The information is supported by some details of reactions and evidence from IR spectrum. (3–4 marks) **(Level 1)** Candidate attempts to describe a basic method **AND** gives some supporting evidence from IR spectrum **OR** details of reagents and conditions with some attempt at equations. *The explanation is basic and lacks structure. The information is supported by limited evidence from the reactions and oxidation products and would not lead to identification.* (1–2 marks) No response or no response worthy of credit. (0 marks)		**Identification of oxidation product** • IR: carboxylic acid from broad OH absorption and C=O • IR: carbonyl / ketone from C=O and no OH • tertiary alcohol from lack of C=O and OH peak in IR **OR** no colour change in reflux.
			Total	**6**	
7			B	1	
			Total	**1**	
8		i	Elimination	1	**ALLOW** Dehydration
		ii	Same structural formula **AND** Different arrangement (of atoms) in **space OR** different **spatial** arrangement 	3	**ALLOW** have the same structure / displayed formula / skeletal formula **DO NOT ALLOW** same empirical formula **OR** same general formula Stereoisomers have the same formula or molecular formula is **not** sufficient Reference to *E*/*Z* isomerism or optical isomerism is **not** sufficient **IGNORE** names **IF** skeletal formula is not used **ALLOW** one mark if both stereoisomers of alkene **B** are shown clearly.

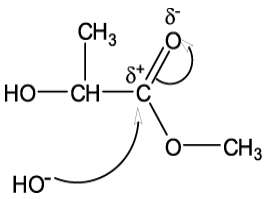
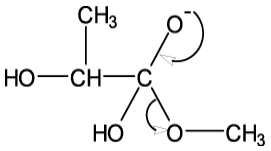
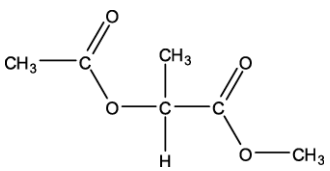
		ii i		1	**ALLOW** correct structural **OR** skeletal **OR** displayed formula **OR** mixture of the above **IGNORE** names
		i v	** Please refer to the marking instruction point 10 for guidance on how to mark this question.* **Level 3 (5–6 marks)** Outlines full details of how a pure sample of **B** is obtained from the reaction mixture. **AND** Correctly calculates mass of **B** • *Purification steps are clear, in the correct order, using appropriate scientific terms.* • *Calculation shows all relevant steps and mass given to 3 significant figures.* **Level 2 (3–4 marks)** Some details of how a sample of **B** is obtained from the reaction mixture. **AND** Attempts a calculation which is mostly correct. • *Purification steps lack detail, e.g. no drying agent or no explanation of separation, or only some scientific terms used.* • *Calculation can be followed but unclear.* **Level 1 (1–2 marks)** Few or imprecise details of how a sample of **B** is obtained from the reaction mixture. **AND** Attempts to calculate the mass of B using mole approach but makes little progress with only 1 step correct. • *Purification step is unclear with few scientific terms and little detail, e.g. just 'separate the layers and dry'.* • *Calculation is difficult to follow and lacking clarity* **0 marks** No response or no response worthy of credit.	6	**Indicative scientific points, with bulleted elements, may include:** **1. Purification** • Use of a **separating funnel** to separate organic and aqueous layers • **Drying** with an anhydrous salt, e.g. $MgSO_4$, $CaCl_2$, etc. • **Redistillation** Incorrect purification method is **NOT** worthy of credit. **2. Mass of B obtained** • $n(\mathbf{A})$ used $= \frac{9.26}{102} = 0.0908$ (mol) = theoretical $n(\mathbf{B})$ • **Actual** $n(\mathbf{B})$ obtained $= n(0.908) \times \frac{75}{100} = 0.0681$ (mol) • mass **B** = 84 × 0.0681 = **5.72 g** **CHECK** for extent of errors by **ECF** Alternative correct calculation may calculate the mass of **B** as 0.0908 × 84 = 7.63 g, followed by $7.63 \times \frac{75}{100} = 5.72$ g Calculation must attempt to calculate $n(\boldsymbol{A})$ in mol. Simply finding 75% of the initial mass of alcohol A, 9.26, is **NOT** worthy of credit.

			Total	11	
9	a		2,3,5-trimethyloctane	1	This is the **only** acceptable response
	b	i	**FIRST CHECK THE ANSWER ON THE ANSWER LINE IF** answer = 3.88×10^5 (m^3) award all five marks *Calculating moles of $C_{11}H_{24}$* $(\text{moles} = \frac{80.4 \times 10^6}{156}) = 515385$ *Use of stoichiometry to calculate moles of CO_2* $(11 \times 515385) = 5669231$ *Rearranging ideal gas equation to make V subject* **AND** *conversion to Pa and K* $V = \frac{nRT}{P} = \frac{5669231 \times 8.314 \times 218}{26.5 \times 10^3}$ 3.88×10^5 (m^3) Correct answer correctly rounded Given in standard form **AND** to 3SF	5	Allow any correctly rounded value from 515000 to calculator value of 515384.6154 Allow any correctly rounded value from 5670000 to calculator value of 5669230.769 **ALLOW ECF** from incorrect moles, pressure or temperature (in K). **Common incorrect answers are shown below** **Award 4 marks for** 3.88×10^{-1} (using 80.4 g in moles calculation) 3.88×10^8 (using 26.5 Pa as pressure)3.52×10^4 (using moles $C_{11}H_{24}$ as moles of CO_2) **DO NOT ALLOW** marking points 3, 4, and 5 for responses which have a negative value for volume of CO_2 (temperature not converted to K). i.e. max 2
		ii	$N_2 + O_2 \rightarrow 2NO$	1	**ALLOW** multiples
	c		*Please refer to the marking instruction point 10 for guidance on how to mark this question.* **Level 3 (5–6 marks)** A comprehensive description with all three scientific points explained thoroughly with few omissions.	6	**Indicative scientific points may include:** **1. Overall equation and conditions** • $C_3H_8 + Cl_2 \rightarrow C_3H_7Cl + HCl$ • Conditions: UV

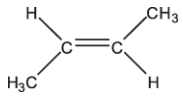
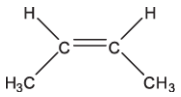
			There is a well-developed and detailed description, including correct names of all steps and radicals identified using • consistently; limitations illustrated with examples. **Level 2 (3–4 marks)** Attempts to describe all three scientific points but explanations may be incomplete. **OR** Explains two scientific points thoroughly with few omissions. *The description has some structure including names of some steps linked to correct equations and some radicals identified using •.* **Level 1 (1–2 marks)** A simple description based on at least two of the main scientific points. **OR** Explains one scientific point thoroughly with few omissions. *The description is communicated in an unstructured way, including some use of names or dots.* **0 marks** No response or no response worthy of credit.		• Initiation: $Cl_2 \rightarrow 2Cl\bullet$ **2. Propagation and termination** **Step names** / **Equation** Propagation: $C_3H_8 + Cl\bullet \rightarrow C_3H_7\bullet + HCl$; $C_3H_7\bullet + Cl_2 \rightarrow C_3H_7Cl + Cl\bullet$ Termination: $C_3H_7\bullet + Cl\bullet \rightarrow C_3H_7Cl$; $C_3H_7\bullet + C_3H_7\bullet \rightarrow C_6H_{14}$; $Cl\bullet + Cl\bullet \rightarrow Cl_2$ **3. Limitations** • Further substitution, e.g. $C_3H_6Cl_2$ • Substitution at different positions on chain, e.g. $CH_3CH_2CH_2Cl$ **IGNORE** state symbols throughout
			Total	**13**	
10		i	$N_2O_4 = +4$ **AND** $NO_3^- = +5$ **AND** $NH_4^+ = -3$ ✓	1	**ALL** 3 oxidation numbers required **DO NOT ALLOW** missing '+' or '–' **OR** oxidation numbers shown as charges e.g. N^{5+}
		ii	**FIRST CHECK THE ANSWER ON THE ANSWER LINE** **If answer = 7.9(0) (g) award 2 marks** $n(KMnO_4) = \frac{0.200 \times 250}{1000} = 0.0500$ (mol) ✓ mass of $KMnO_4 = 0.0500 \times 158.0 = 7.9(0)$ (g) ✓	2	
		iii	$dm^6\ mol^{-2}\ s^{-1}$ ✓	1	
		iv	**FIRST CHECK THE ANSWER ON THE ANSWER LINE** **If answer = 1.54×10^{23} award 2 marks**	2	

			$n(\text{tartaric acid}) = \frac{38.25}{150} = 0.255\ (\text{mol})$ ✓ number of molecules = $0.255 \times 6.02 \times 10^{23}$ $= 1.54 \times 10^{23}$ ✓ (***3 SF*** *required from least significant data*)		**ALLOW ECF** from *n*(tartaric acid) Common error: use of 148 *(missing 2H Structure)* → 1.56×10^{23}
			Total	**6**	
11	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**	4	**ALLOW** δ values ± 0.2 ppm, as a range or a value within the range

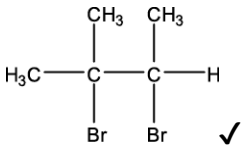
			0.5−1.9 3 Triplet ✓ 3.0−4.3 2 Quartet ✓ 0.5−1.9 6 Doublet ✓ 3.0−4.3 1 Heptet ✓		**ALLOW** multiplet for heptet
	d	i	 Curly arrow from CH_3O^- to H of CH_2 ✓ Curly arrow from C–H bond to C of CH_2 ✓  ✓	3	The curly arrow must start from **O atom** of CH_3O^- **AND** must start either from a lone pair or 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**	
12			**FIRST CHECK THE ANSWER ON THE ANSWER LINE** **IF** answer = 73.9 or 73.93 (g mol^{-1}) award 3 marks for calculation n(NaOH) = (25.25/1000) × 0.120 = 3.03 × 10^{-3} (mol) (1) n(acid in 250 cm^3 flask) = 3.03 × 10^{-3} × 10 = 3.03 × 10^{-2} (mol) (1) molar mass of unknown acid = 2.24/3.03 × 10^{-2} = 73.9 (g mol^{-1}) (1)	3	**If there is an alternative answer, check to see if there is any ECF credit possible using working below**
			Total	**3**	
13	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)
		ii i	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)
		ii i	Correct organic product:  HCl	2	**ALLOW** any combination of skeletal **OR** structural **OR** displayed formula as long as unambiguous

			Total	11	
14	a	i	(series of compounds with the) same functional group **OR** same / similar chemical properties **OR** same / similar chemical reactions ✓ each **successive/subsequent** member differing by CH_2 ✓	2	**IGNORE** references to physical properties **IGNORE** has same general formula (in question) **DO NOT ALLOW** have the same empirical formula **OR** have the same molecular formula **Examiner's Comments** Many candidates were able to score both marks by specifying the same functional group and that each successive member varies by a CH_2 group. Some responses were imprecise and referred to just members differing by CH_2 group.
		ii	C_nH_{2n} ✓	1	**Examiner's Comments** Most candidates were able to state the general formula for the cycloalkanes.
		ii i	More carbons (in ring) **OR** more (surface area of) contact **AND** **more van der Waals** forces **OR stronger van der Waals** forces ✓ More energy needed to break the intermolecular forces ✓	2	**Both answers need to be comparisons** **ALLOW** ORA throughout **ALLOW** has more electrons **OR** larger (carbon) ring **OR** higher molecular mass **IGNORE** bigger molecule **IGNORE** chain instead of ring **DO NOT ALLOW** 'more contact between atoms' **ALLOW** 'VDW' for van der Waals 'More intermolecular forces' is **not** sufficient **ALLOW** it is harder to overcome the intermolecular forces **ALLOW** intermolecular bonds / van der Waals bonds **ALLOW** more energy is needed to separate molecules **IGNORE** more energy is needed to

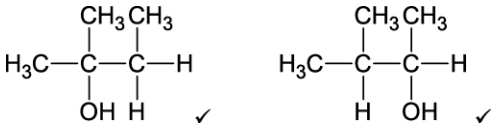
					break bonds **Examiner's Comments** This was a well answered question and many candidates could relate the difference in boiling point to the increase in points of contact and stronger van derWaals' forces. A significant number of candidates referred to the breaking of bonds rather than intermolecular forces.
	b	i	(Compounds with the) same structural formula but a different arrangement (of atoms) in space ✓	1	**ALLOW** different spatial arrangement of atoms. **DO NOT ALLOW** different displayed formula. **Examiner's Comments** Although many candidates were able to provide the correct definition, some responses did not state that stereoisomers have the same structural formula.
		ii	 ✓  ✓	2	**ALLOW** displayed **OR** skeletal formula **OR** mixture of the above. **ALLOW** structures in either order **IGNORE** molecular formula **IGNORE** structural formula **IGNORE** names **IGNORE** E/Z and cis / trans labels **ALLOW** 1 mark for a pair of E/Z isomers of an incorrect hydrocarbon structure with **four** C atoms e.g. C, or CH or CH_2 instead of CH_3 groups. **Examiner's Comments** This question required candidates to identify isomers of cyclobutane that would exhibit stereoisomerism and proved challenging for some. The more able candidates were able to provide two correct structures. A significant number of candidates suggested cyclic alkenes, which were not isomers of cyclobutane.

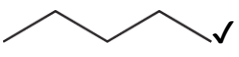
	c	i	<table><tr><th>Step</th><th>Equation</th></tr><tr><td>Initiation (1 mark)</td><td>$Br_2 \rightarrow 2Br\bullet$ ✓</td></tr><tr><td>Propagation (2 marks)</td><td>$C_6H_{12} + Br\bullet \rightarrow C_6H_{11}\bullet + HBr$ ✓ $C_6H_{11}\bullet + Br_2 \rightarrow C_6H_{11}Br + Br\bullet$ ✓</td></tr><tr><td>Termination (2 marks)</td><td>$C_6H_{11}\bullet + Br\bullet \rightarrow C_6H_{11}Br$ $C_6H_{11}\bullet + C_6H_{11}\bullet \rightarrow C_{12}H_{22}$ $Br\bullet + Br\bullet \rightarrow Br_2$ Two correct ✓ All three correct ✓✓</td></tr></table>	5	**IGNORE** state symbols **IGNORE** dots If an incorrect hydrocarbon with **six** C atoms is used: **DO NOT ALLOW** any marks for the propagation steps but **ALLOW** ECF for termination steps *(i.e. 3 max)* **Examiner's Comments** This question required candidates to apply their knowledge of the radical substitution mechanism and those who had prepared well scored full marks. A common misconception was to have hydrogen radicals being formed and reacted in propagation and termination steps.
		ii	The breaking of a (Br-Br) bond **AND** forms (two) radicals **OR** the breaking of a (Br-Br) bond **AND** one electron (from the bond pair) goes to each atom / bromine ✓	1	**ALLOW** 'the breaking of a covalent bond' **ALLOW** the splitting of the bond in bromine **ALLOW** the breaking of a covalent bond where each atom keeps one of the bonding electrons **IGNORE** particle for atom **ALLOW** one electron goes to each product / species **DO NOT ALLOW** molecule or compound for atom **IGNORE** homolytic fission equations **Examiner's Comments** This question was better attempted than in previous sessions. Although many candidates were able to identify that radicals were formed, a significant number did not refer to the breaking of the covalent bond in Br_2.
	d	i	$C_6H_{12} + 2Br_2 \rightarrow C_6H_{10}Br_2 + 2HBr$ ✓	1	**ALLOW** molecular formula only. **Examiner's Comments**

					This question proved quite difficult for the vast majority of candidates who failed to apply their knowledge of radical substitution to an unfamiliar example. The most common incorrect answer was $C_6H_{12} + Br_2 \longrightarrow C_6H_{10}Br_2 + H_2$.
		ii	1,1-dibromocyclohexane **OR** 1,2-dibromocyclohexane **OR** 1,3-dibromocyclohexane **OR** 1,4-dibromocyclohexane ✓	1	Locant numbers **MUST** lowest possible e.g. **DO NOT ALLOW** 2,4-dibromocyclohexane etc. **IGNORE** structures **Examiner's Comments** Candidates were required to name one of the dibromocyclohexane compounds that could be formed from cyclohexane and the more able candidates were able to apply their understanding of nomenclature successfully. Common incorrect responses included straight chain dibromo compounds e.g. 1,2—dibromohexane and incorrect use of locant numbers e.g. 2,3—dribromocyclohexane.
			Total	**16**	
15	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

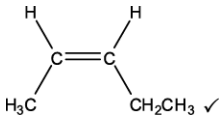
					Same formula is **not** sufficient Different arrangement of atoms is **not** sufficient **Examiner's Comments** The majority of candidates were able to explain the term structural isomers.
		iii	 ✓ ✓	2	**ALLOW** correct structural **OR** displayed **OR** skeletal formula **OR** mixture of the above **ALLOW** 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

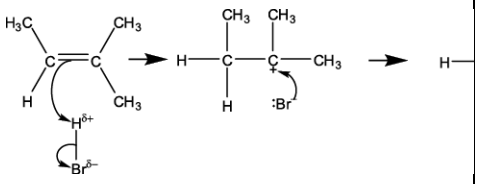
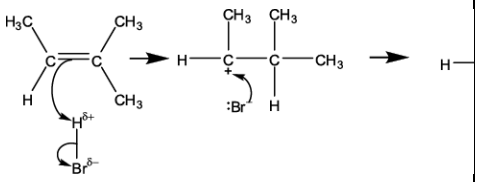
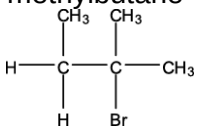
					the second mark by accurately explaining that the OH group could form hydrogen bonds with water.
			Total	**8**	
16	a	i	(compounds or molecules having the) same molecular formula but different structural formulae ✓	1	**ALLOW** different structure **OR** different displayed formula **OR** different skeletal formula for structure **DO NOT ALLOW** any reference to spatial / space Same formula is **not** sufficient (*no reference to molecular*) Different arrangement of atoms is **not** sufficient (*no reference to structure / structural*) **Examiner's Comments** Most candidates were able to define structural isomers. Some responses were imprecise with candidates stating that isomers had 'different arrangements of atoms' rather than referring to different structural formulae.
		ii	2, 2, 3-trimethylbutane ✓	1	**ALLOW** trimethylbutane as the **ONLY** alternative response **Examiner's Comments** Many candidates found this question difficult and it was common to see incorrect names for compound **A**. These included incorrect use of locant numbers e.g. 2,3,3-trimethylbutane and inappropriate nomenclature e.g. 2,2-dimethyl-3-methylbutane. A small proportion of candidates named compound **A** as heptane.
	b			1	**DO NOT ALLOW** molecular formulae **OR** structural formula **OR** displayed formula **OR** mixture of the above **Examiner's Comments** The majority of candidates were

					able to provide the skeletal formula of pentane.
			Total	**3**	
17	a	i	(series of compounds with the) same functional group **OR** same / similar chemical properties **OR** same / similar chemical reactions ✓ each **successive / subsequent** member differing by CH_2 ✓	2	**IGNORE** reference to physical properties **IGNORE** same general formula (*in question*) Differs by CH_2 is **not** sufficient (*no successive*) **DO NOT ALLOW** same empirical **OR** have the same molecular formula **Examiner's Comments** Many candidates were able to score both marks by specifying the same functional group and that each successive member varies by a CH_2 group. Some responses were imprecise and referred to just members differing by a CH_2 group.
		ii	$C_nH_{2n-1}Br$ ✓	1	**ALLOW $C_nH_{2n-1}X$ ONLY** if X is specified as Br (*question asks for bromide*) **Examiner's Comments** The most able candidates were able to determine the general formula required. Many candidates came close and stated $C_nH_{2n-1}X$, but failed to specify that X was Br.
		iii	3-bromoprop(-1-)ene ✓	1	**ALLOW** 1-bromoprop-2-ene **Examiner's Comments** Candidates were asked to give the systematic name for ally bromide. Although a fair proportion stated 3-bromopropene, 1-bromoprop-2-ene was also a common response. Either of these was allowed by the mark scheme. A common incorrect response was 1-bromoprop-3-ene. Candidates should be aware that

					the lowest possible locant numbers should be used when naming compounds.
	b	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.
			Total	**6**	
18	a	i	Any **one** from: • σ bond is between bonding atoms/nuclei **AND** π bond is above and below the bonding atoms / nuclei • σ bond has direct/head-on overlap of orbitals **AND** π bond has sideways overlap • π bond has a lower bond enthalpy / is weaker than a σ bond • σ bond has electron density between bonding atoms **AND** π bond has electron density above and below bonding atoms ✓	1	**IGNORE** the length of the σ bond and π bond **IGNORE** the type of orbital for σ bond **Examiner's Comments** The vast majority of candidates were unable to describe the difference between a σ and a π bond. The simplest answer was that the π bond was the weaker bond or the σ bond was the stronger. Many candidates attempted to describe how the two different bonds were formed. It was clear that candidates understood

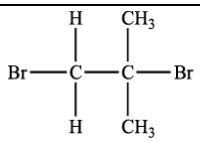
					the concept of the sideways overlap of the p orbitals to form theπ bond but were unable to describe the formation of the σ bond. A common misconception was that the σ bond could only be formed by the overlapping of the s orbitals. The best candidates were able to articulate that the σ bond results from the head on overlap of orbitals resulting in the bond forming directly between two atoms whereas the π bond results in the electron density being located above and below the plane of the bonding atoms.
		ii	One carbon atom (in double bond) is attached to two groups which are identical / the same ✓	1	**ALLOW** • One carbon atom in (double bond) is not attached to (two) different groups/groups of atoms • Right-hand carbon is attached to two groups that are the same/two methyl groups. • Two groups are the same on **right-hand side** • Three groups are the same (on the double bond) **DO NOT ALLOW** • Two groups on the same side of the double bond • *Must be right-hand side; Same side could be top or bottom)* • Functional groups **OR** molecules for groups **Examiner's Comments** This question required candidates to apply their knowledge of *E/Z* isomerism to suggest why compound A did not have *E/Z* isomers. Whilst it was clear that

					many candidates understood the concept of *E/Z* isomerism many found it difficult to apply this concept and articulate an explanation.
		iii	 ✓	1	**Mark Independently** **ALLOW** correct structural **OR** displayed **OR** skeletal formulae **OR** a combination of above as long as unambiguous **ALLOW** C_2H_5 for CH_2CH_3 **IGNORE** connectivity of alkyl groups **BUT** **.....DO NOT ALLOW** $-CH_3CH_2$
		iii	(Z-)pent-2-ene ✓	1	**DO NOT ALLOW** trans-pent-2-ene **Examiner's Comments** Most candidates were able to draw the structural isomer of compound A and provide a suitable name.
	b		*Please refer to marking instructions on page 4 of mark scheme for guidance on how to mark this question.* **Level 3 (5–6 marks)** A comprehensive description with all three scientific points explained thoroughly. *There is a well-developed and detailed description of the mechanism, including correct structures, accurately drawn curly arrows and using charges and dipoles consistently. Candidates compare tertiary and secondary carbocation stability to justify major product.* **Level 2 (3–4 marks)** Attempts to describe all three scientific points but explanations may be incomplete. **OR** Explains two scientific points thoroughly with no omissions. *The description has some structures with reasonably accurate curly arrows and some charges and dipoles identified.* **Level 1 (1–2 marks)** A simple description based on at least two of the	6	Throughout: **ALLOW** correct structural **OR** displayed **OR** skeletal formulae **OR** a combination of above if unambiguous **Indicative scientific points** **1. Two possible products of reaction** $CH_3C(CH_3)BrCH_2CH_3$ $CH_3CHBrCH(CH_3)CH_3$ **IGNORE** names where correct structures are present **2. Mechanism for formation of either product.** Curly arrow from C=C to attack the H atom of the HBr Correct dipole on H–Br Curly arrow from H–Br bond to Br Carbocation with full positive charge on carbon atom Curly

			main scientific points **OR** Explains one scientific point thoroughly with few omissions. *The description is communicated in an unstructured way, including some use of curly arrows, charges or dipoles.* **0 marks** No response worthy of credit.		arrow from negative charge on Br^- or lone pair on Br^- to carbon atom with positive charge  **or**  **3. Major organic product** Major product: 2-bromo-2-methylbutane  • Major product is formed from the most stable carbocation intermediate **OR** −Br is attached to carbon atom with the least hydrogens attached **OR** the carbon with the most $-CH_3$ groups attached **OR** the −H is attached to the carbon atom with most hydrogens attached **Examiner's Comments** The first of the six mark level of response questions required candidates to draw the mechanism of electrophilic addition, outline the two possible products and explain which one of these products would be the most likely to be formed. The most common mark for this question was five marks mainly due to candidates not being able to

					explain the formation of the major product in terms of the formation of the more stable tertiary carbocation in the intermediate stage of the mechanism. Candidate scoring five marks frequently quoted Markownikoff's rule as an explanation. Varying degrees of competence was displayed in the production of the mechanism. The correct positioning of curly arrows was a skill that the most candidates had clearly mastered with many accurate mechanisms being submitted. Weaker candidates clearly need more time to develop these skills.
			Total	**10**	
19			Propagation step 1 $NO\cdot + O_3 \rightarrow NO_2\cdot + O_2$ ✓	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.
			Propagation step 2 $NO_2\cdot + O \rightarrow NO\cdot + O_2$ ✓	1	
			Total	**2**	
20			B	1	**Examiner's Comments** Generally scored well.
			Total	**1**	
21			C	1	**Examiner's Comments** Generally scored well.
			Total	**1**	
22			D	1	**Examiner's Comments** Generally scored well.

			Total	**1**	
23	a	i	Alkene **AND** C_nH_{2n} ✓	1	**IGNORE** branched before alkene **Examiner's Comments** This part was answered very well. Most candidates identified Compound B as a member of the alkenes and showed the correct general formula of C_nH_{2n}.
		ii	Hydrogen/H_2 **AND** Ni (catalyst) ✓	1	**ALLOW** Pt **OR** Pd **OR** Rh **ALLOW** hydrogenation for hydrogen **IGNORE** any temperature and pressure stated **Examiner's Comments** A surprisingly large number of candidates answered this part poorly. Many candidates identified either hydrogen or nickel, but not both. Other common errors included steam and H_3PO_4. This was an easy question and the incorrect answers reflected that many candidates had not learnt organic reagents and conditions for the reactions in the specification.
	b	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:	3	**For structures:** **ALLOW** correct structural **OR** skeletal **OR** displayed formula **OR** mixture



✓

Stage 1: Compound **E**: Bromine/Br_2 ✓

NaOH/KOH **OR** OH^- ✓

Stage 2: *Only award if intermediate contains at least **one** halogen atom*

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

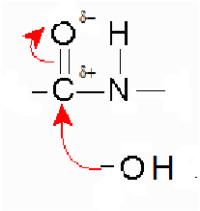
This demanding part was answered poorly by weaker candidates and was good for differentiating higher ability candidates. The mark scheme allowed some credit for using a hydrogen halide to obtain a monosubstituted haloalkane for compound E.
Surprisingly, reaction mechanism names were often given instead of reagents. Many candidates seemed to guess, sometimes

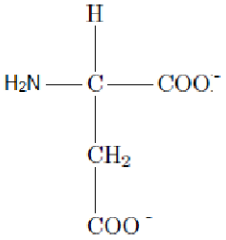
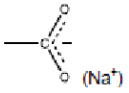
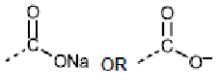
					showing the same reagents for both stages in the hope of getting a mark. Many showed an intermediate containing no halogen atom.
			Total	**6**	
24			(series of compounds with the) same functional group **OR** same / similar chemical properties / reactions ✓ each **successive / subsequent** member differs by CH_2 ✓	2	**IGNORE** reference to physical properties **IGNORE** same general formula Differs by CH_2 is **not** sufficient (*no successive*) **DO NOT ALLOW** same empirical **OR** molecular formula **Examiner's Comments** Many candidates were able to score both marks by specifying that compounds from a homologous series possess the same functional group and that each successive member varies by a CH_2 group. Some responses were imprecise and referred to just members differing by a CH_2 group, but this was less common compared to previous sessions.
			Total	**2**	
25	a		C_nH_{2n+2} ✓	1	**Examiner's Comments** Almost all candidates were able to state the general formula of an alkane correctly.
	b		structure of a branched saturated hydrocarbon with **8 C** atoms ✓ structure of a cyclic saturated hydrocarbon with **8 C** atoms ✓ Correct name for **BOTH** structures given ✓	3	**ALLOW** correct structural **OR** displayed **OR** skeletal formula **OR** mixture of the above **DO NOT ALLOW** names for

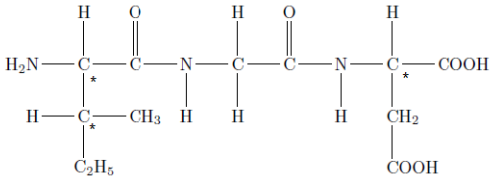
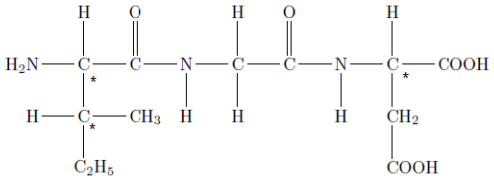
					hydrocarbons that do not have **8 C** atoms **Examiner's Comments** The majority of candidates were able to provide appropriate structures to represent a branched and cyclic alkane. Perhaps unsurprisingly, the most common responses were 2- or 3-methylheptane and cyclooctane. However, a wide range of responses was seen. In general candidates demonstrated a clear understanding of organic nomenclature and provided appropriate names for their chosen compounds. In some cases incorrect locant numbers were used. For example 2,3-dimethylcyclohexane rather than 1,2-dimethylcyclohexane.
			Total	**4**	
26	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

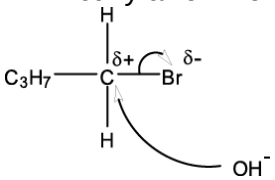
					on their merits. Please consult TL for advice on how to mark the subsequent parts of this question **Examiner's Comments** Calculation of empirical formula has always been a strength of candidates at this level. Consequently the vast majority were able to deduce the structures of the two isomers correctly. 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

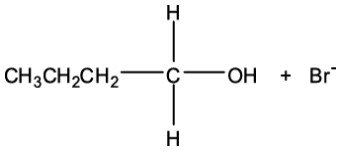
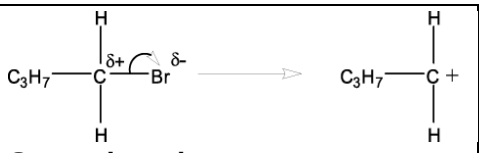
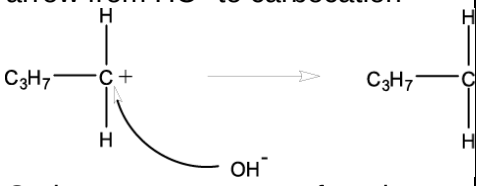
					DO NOT ALLOW missing H atom(s) in a displayed formula for one structure but **ALLOW** missing H atoms in subsequent structures
		i	***Equation for formation of G 1 mark*** $C_3H_8O + 2[O] \rightarrow C_3H_6O_2 + H_2O$ ✓		**ALLOW** correct structural **OR** displayed **OR** skeletal formula **OR** mixture 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: $CH_3CH_2COOCH_2CH_2CH_3$	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

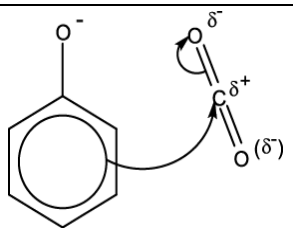
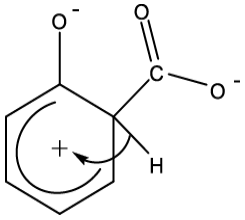
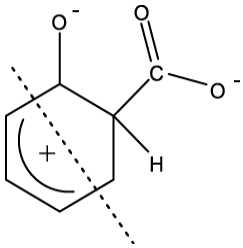
			OR Ambiguous ester: $CH_3CH_2COOC_3H_7$ ✓		**Examiner's Comments** Most candidates were able to show the structure of the ester formed from propanoic acid (**G** and propan-2-ol **(F)** correctly. Some candidates used the incorrect alcohol, propan-1-ol **(E)** and such responses received only one of the two marks available.
			Total	**13**	
27	a		 Curly arrow from OH^- to C(δ+) ✓ Dipole correct **AND** curly arrow from C=O bond to O(δ−) ✓	2	First curly arrow must come from either a lone pair on O or negative charge on O **Examiner's Comments** Some candidates lost a mark for the incorrect positioning of the curly arrow from the hydroxide ion. The mark scheme specifies that it should start at either the lone pair on the oxygen atom or the negative change on the oxygen atom.
	b		Measure distance moved by spot/distance moved by solvent ✓	2	**ALLOW** attempt at calculation of R_f value using distances measured on the chromatogram **IGNORE** explanation of how chromatography works
			Compare (R_f) value with data book values/known values ✓ Two amino acids have the same/similar R_f value **OR** similar adsorption **OR** move the same/similar distance ✓	1	**ALLOW** One spot contains two amino acids **ALLOW** Two amino acids have not separated **IGNORE** relative solubility

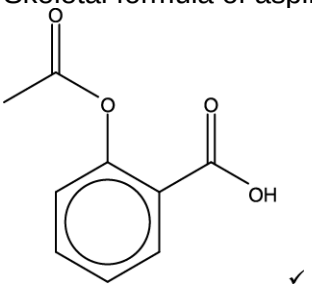
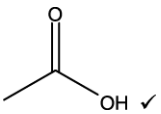
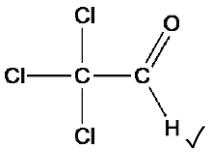
					ALLOW two of the amino acids have similar structures **Examiner's Comments** This question discriminated well with relatively few candidates able to score all three marks. Some candidates attempted to explain how the technique separates components between a mobile phase and a stationary phase which was not required by the question. There was some confusion with gas chromatography and retention times. Vague answers about all amino acids having similar structures did not score the final marking point to explain why only two spots appeared on the chromatogram.
	c	i	The **pH** at which the amino acid exists as a <u>zwitterion</u> ✓ **QWC**: **zwitterion** spelled correctly in the correct context	1	**DO NOT ALLOW** PH/ph **ALLOW** zwitter ion **Examiner's Comments** This definition had been learned by the majority of candidates.
		ii		1	**ALLOW** correct structural **OR** displayed **OR** skeletal formulae **OR** combination of above as long as unambiguous **Two** COO^- groups are required in the structure **ALLOW** $–COO^-Na^+$ **OR** –COONa  **ALLOW** delocalised carboxylate **ALLOW**  **DO NOT ALLOW** -COO-Na **OR** -O-Na (covalent bond) **Examiner's Comments**

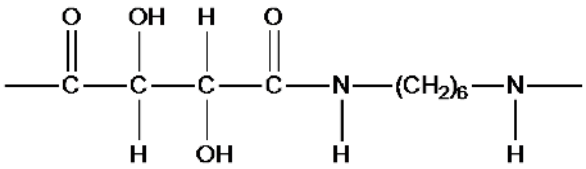
					Generally well answered but structures with only one carboxylate group were quite common and some candidates showed aspartic acid being protonated at high pH.
		ii i	**M1** structure  ✓ **M2** correct structure has three chiral centres  ✓	2	**ALLOW** correct structural **OR** displayed **OR** skeletal formulae **OR** a combination of above as long as unambiguous **ALLOW** tripeptide with the 3 amino acids in any order **ALLOW** cyclic tripeptide Isoleucine has two chiral centres, aspartic acid has one chiral centre and glycine has none. **ALL three** correct for one mark **ALLOW** chiral centres correctly identified if the three amino acids are part of a polypeptide chain **Examiner's Comments** A more challenging question with relatively few candidates able to show the position of all three chiral centres on a correct tripeptide structure. Most candidates identified the chiral centres in the amino acid backbone of aspartic acid and isoleucine and realised that glycine was not chiral, but many missed the second chiral centre in isoleucine.
			Total	**9**	
28			2(−)hydroxypropanoic acid ✓	1	**DO NOT ALLOW** 2-hydroxylpropanoic acid **IGNORE** other dashes, commas and spaces **Examiner's Comments**

					Although named correctly by the majority, errors such as 2-hydroxyl were not uncommon.
			Total	**1**	
29			**B**	1	
			Total	**1**	
30			**D**	1	
			Total	**1**	
31			**B**	1	
			Total	**1**	
32	a	i	(series of compounds with the) same functional group **OR** same/similar chemical properties/reactions ✓ each **subsequent/successive** member differing by CH_2 ✓	2	**IGNORE** reference to physical properties **IGNORE** same general formula Differs by CH_2 is **not** sufficient *(no successive)* **DO NOT ALLOW** same empirical **OR** molecular formula
		ii	$C_nH_{2n+2}O$ ✓	1	**ALLOW** $C_nH_{2n+1}OH$
	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 ✓  	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 ✓

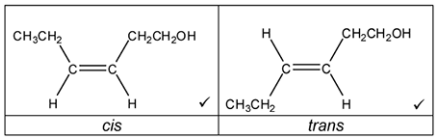
			correct organic product **AND** Br^- ✓ 		 **Second mark** Correct carbocation **AND** curly arrow from HO^- to carbocation  Curly arrow must come from lone pair on O of HO^- **OR** OH^- **OR** from minus on O of HO^- ion (no need to show lone pair if curly arrow came from negative charge) ✓ **Third mark** correct organic product **AND** Br^- ✓
		ii	Nucleophilic substitution ✓	1	
		ii i	1-iodobutane **AND** 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 ✓	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 number*) Statement **must** be comparative **ALLOW ORA** **IGNORE** C–I bond is longer **IGNORE** polarity and references to electronegativity
			Total	**8**	
33	a	i	Dipole shown on C=O bond, $C^{\delta+}$ and $O^{\delta-}$, **AND** curly arrow from the C=O bond to the $O^{\delta-}$ atom **AND** Curly arrow from π−bond to C in CO_2 ✓	3	**ANNOTATE ANSWER WITH TICKS AND CROSSES**

			 Correct intermediate ✓ Curly arrow back from C–H bond to reform π−ring ✓ 		**DO NOT ALLOW** the following intermediate:  π−ring must cover more than 1/2 of the ring **AND** 'horseshoe' in the correct orientation, *ie* gap towards C with COO^- **ALLOW** + sign anywhere inside the 'hexagon' of intermediate
		ii	Neutralisation ✓ (In Stage 1) phenol loses H^+ **AND** (In Stage 3) carboxylate ion gains H^+ ✓	2	**ALLOW** acid-base **ALLOW** both Stage 1 **AND** Stage 3 involve proton transfer
		iii	**FIRST CHECK THE ANSWER ON THE ANSWER LINE** **IF** answer = 7.31 (g) award 3 marks **actual** n(salicylic acid) produced = $\frac{4.83}{138}$ = 0.035(0) (mol) ✓ **theoretical** n(phenol) = n(salicylic acid) = 0.035(0) × $\frac{100}{45.0}$ = 0.0778 (mol) ✓	3	**ANNOTATE ANSWER WITH TICKS AND CROSSES** **ALLOW ECF** at each stage **ALLOW 3 SF** up to calculator value correctly rounded for intermediate values 100 **ALLOW** expected mass compound **E** = 4.83 × $\frac{100}{45.0}$ = 10.733 (g) **ALLOW** Mass phenol reacted =

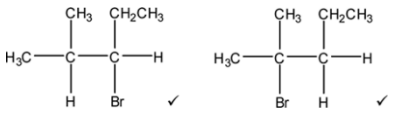
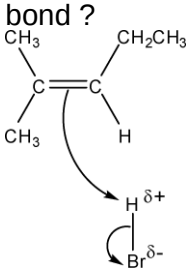
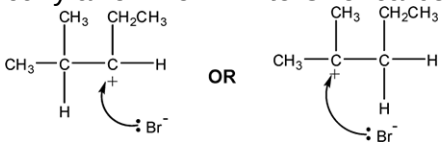
			Mass of phenol = 0.0778 × 94.0 = 7.31 (g) ✓		0.035 × 94.0 = 3.29 (g) **ALLOW** Mass of phenol used = $3.29 \times \frac{100}{45.0} = 7.31$ (g) **Note:** 1.48 g would get 2 marks *(use of 45.0/100 instead of 100/45.0)* 7.30 g would get 2 marks *(use of 0.0777 for moles phenol)*
	b		Skeletal formula of aspirin  ✓ Skeletal formula of ethanoic acid 	2	**IF** skeletal formulae are not used **ALLOW** one mark if both the structures of aspirin **AND** ethanoic acid are correct **IGNORE** names
			Total	**10**	
34		i		1	**ALLOW** any combination of skeletal **OR** structural **OR** displayed formula as long as unambiguous
		ii	Any **organic** reaction in which sulfuric acid is a catalyst e.g: Elimination of (H_2O from) alcohols Nitration of benzene Esterification Hydrolysis of esters/amides	1	The answer needs to refer to the reaction: i.e. 'Elimination', 'hydrolysis' are insufficient but 'Esterification' describes the reaction **DO NOT ALLOW** oxidation for alcohols/ aldehydes
			Total	**2**	

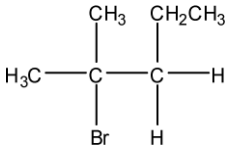
35		i	$C_2H_3O_3$ ✓	1	
		ii	2,3− dihydroxybutanedioic acid ✓	1	**ALLOW** 2,3−dihydroxybutane−1,4−dioic acid **ALLOW** absence of hyphens or extra hyphen or space, e.g. 2,3−dihydroxy butanedioic acid **ALLOW** full stops or spaces between numbers e.g. 2.3 dihydroxybutanedioic acid
		iii	 Correct amide link ✓ Rest of structure ✓	2	**ALLOW** any combination of skeletal **OR** structural **OR** displayed formula as long as unambiguous 'End bonds' **MUST** be shown **IGNORE** brackets **IGNORE** *n*
		iv	$[H_3N^+(CH_2)_6NH_3^+]$ $[^-OOC(CHOH)_2COO^-]$ **OR** $[H_3N(CH_2)_6NH_3]^{2+}$ $[OOC(CHOH)_2COO]^{2-}$ Positive ion correct ✓ Negative ion correct ✓	2	**ALLOW** correct structural **OR** displayed **OR** skeletal formulae **OR** a combination of above as long as unambiguous **ALLOW** charge either on N atom or NH_3^+ Negative charge must be on COO^- **ALLOW**$[H_2N(CH_2)_6NH_3^+]$ $[^-OOC(CHOH)_2COOH]$
			Total	**6**	
36			D	1	**Examiner Comments:** This question was answered well by over 85% of candidates. Candidates failing to score a mark here often provided an answer which indicated that the compound was unsaturated rather than saturated.
			Total	**1**	
37			C	1	**Examiner Comments** The vast majority of candidates were able to determine the molecular formula of the compound on what proved to be one of the

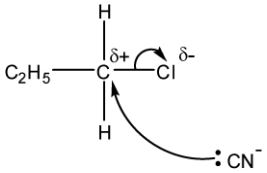
					easiest of the multiple choice questions.
			Total	**1**	
38			C	1	**Examiner Comments** Once the Candidates had realised that hydrogen radicals do not appear in the mechanism for a radical substitution reaction of an alkane, the answer C was given. Almost 90% of candidates scored this mark.
			Total	**1**	
39			A	1	**Examiner Comments** This question proved accessible to the full range of abilities with many, having drawn all three structures out on their paper and converted these structures to molecular formulae, selecting the correct answer A.
			Total	**1**	
40			A	**1**	**Examiner's Comments** Able candidates who approached this question correctly (based on priority) obtained the correct answer. Some candidates seemed to look for the same group (CH_3) on the same side (*cis*), and incorrectly identified the compound as answer option B, the Z isomer.
			Total	**1**	
41			C	**1**	**Examiner's Comments** Most successful candidates showed rough working at the side with the formula displayed.
			Total	**1**	
42			B	**1**	**Examiner's Comments** Most candidates correctly identified the correct number of isomers. However, about a third of

					candidates gave the incorrect answer C, perhaps trying to use an ethyl branch.
			Total	**1**	
43	a	i	Hex-3-en-1-ol ✓	**1**	**ALLOW** Hex-3-ene-1-ol **ALLOW** 1-hydroxyhex-3-ene as this is unambiguous Hex-3-enol is **not** sufficient **IGNORE** lack of hyphens, or addition of commas **Examiner Comments** Naming the organic molecule, hex-3-en-1-ol, proved difficult for all but the most able candidates. Candidates are not expected to know the priority of the alkene and hydroxyl groups in naming conventions so the answers given in the marking scheme were accepted to treat all candidates fairly.
		ii	Same structural formula **AND** Different arrangement (of atoms) **in space OR** different **spatial** arrangement (of atoms) ✓	**1**	**ALLOW** have the same structure/displayed formula/skeletal formula **DO NOT ALLOW** same empirical formula **OR** same general formula **IGNORE** same molecular formula Reference to *E*/*Z* isomerism or optical isomerism is **not** sufficient **Examiner Comments** Stereoisomers is one of a declining number of definitions candidates are expected to recall from the new specification. Surprisingly 35% of candidates failed to score this mark. The most common errors were the use of molecular formula rather than structural formula or giving the definition for structural isomerism.
		ii i		**2**	**ALLOW** any combination of skeletal **OR** structural **OR** displayed formula as long as unambiguous

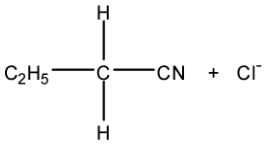
					ALLOW one mark if both stereoisomers of compound **C** are shown but in the incorrect columns **ALLOW** one mark for correct stereoisomers of compound **C** in correct columns where – CH_2CH_2OH is represented as – C_2H_5O or – C_2H_4OH **DO NOT ALLOW** incorrect connectivity e.g. – CH_3CH_2 on first occasion but allow **ECF** in second structure. **Examiner Comments** Even those candidates who were not be able to define stereoisomerism, clearly understood how to draw the cis and trans isomers of hex-3-en-1-ol. Excellent structures were seen in the vast majority of cases. The most common error was the failure to place the -OH group on the correct carbon within the structure leading to only one mark being awarded. Candidates should be encouraged either to give displayed or structural formulae for cis and trans isomers rather than combining atoms, leading to groups such as $–C_2H_5O$ or – C_2H_4OH being attached to the double bond. These were credited the second time they were given in the question but penalised on their first occurrence.
	b	i	(The H atom of HBr) accepts a pair of electrons ✓	**1**	**Examiner Comments** The specification states in learning outcome 4.1.3(g) that the definition and use of the term electrophile (an electron pair acceptor) is expected. This was tested in the context of electrophilic addition in alkenes. Half of the candidates gave a perfect answer, leaving half of candidates not gaining any credit. Answers indicating “accepting electrons“ rather than an electron pair were not credited, neither did

					answers which discussed the attack of the alkene or an electrophile being electron loving or seeking.
		ii	 ✓ ✓	**2**	**ALLOW** correct structural **OR** displayed **OR** skeletal formulae **OR** a combination of above as long as unambiguous **ALLOW** in either order
		ii i	Curly arrow from C=C bond to H of H–Br ? Correct dipole shown on H–Br **AND** curly arrow showing the breaking of H–Br bond ?  --- Correct carbocation **AND** curly arrow from Br^- to C^+ of carbocation ? 	**3**	**ANNOTATE ANSWER WITH TICKS AND CROSSES** **ALLOW** any combination of skeletal **OR** structural **OR** displayed formula as long as unambiguous **DO NOT ALLOW** partial charges shown on C=C double bond (the second marking point) **DO NOT ALLOW** d+ on C of carbocation 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) **Examiner Comments** This was a well answered question with the vast majority of candidates displaying their knowledge of the addition of an unsymmetrical molecule to an unsymmetrical alkene and the production of two isomeric products. There were no common errors, rather those candidates who did not score a mark omitted the question or gave structures with an incorrect number of carbon atoms.

		iv	 2-bromo-2-methylpentane **AND** (the) **carbocation** intermediate (in the formation of 2-bromo-2-methylpentane) is more stable (than the carbocation in the formation of the other product) ✓	**1**	**Note:** the correct product and explanation are **both** required for the mark The major product may be identified by its • corresponding letter (**E** or **F**) from the table in **(d)(ii)** • correct structure • correct name **DO NOT ALLOW** product comes from the more stable **secondary or primary** carbocation **IGNORE** explanations based on Markownikoff's rule. **Examiner Comments** On the whole candidates answered this question well, with many giving clear and accurate mechanisms to gain all three marks. In poorer scoring mechanisms, the main errors were around the drawing of arrows. Candidates must recognise that an arrow should start either at the negative charge or from the middle of a lone pair in the final step of an addition mechanism Good answers to this question indicated the major organic product and related this to the intermediate being the most stable carbocation. Weaker answers discussed the stability of the product rather than the intermediate and did not include any comments about the carbocation.
			Total	**11**	
44		i	curly arrow from $^{-}$CN to carbon atom of C−C*l* bond ✓ Dipole shown on C–C*l* bond, $C^{\delta+}$ and $Cl^{\delta-}$, **AND** curly arrow from C−C*l* bond to C*l* 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*⁻✓

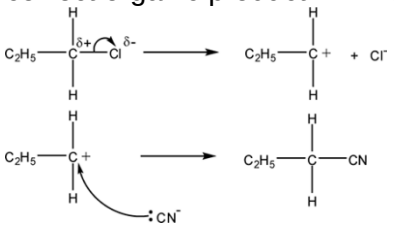


IGNORE NaCl

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 ✓

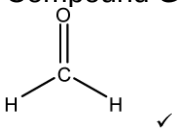
Correct carbocation **AND** curly arrow from
^{-}CN to carbocation. Curly arrow must come from lone pair on C of ^{-}CN **OR** CN^{-}
OR from minus sign on C of ^{-}CN ion (then lone pair on CN^{-} does not need to be shown) ✓
correct organic product **AND** Cl^{-} ✓



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 Cl^{-} ion. The placing of curly arrows, dipoles and lone pairs of electrons are important when communicating by mechanisms.

ii

Compound **G**



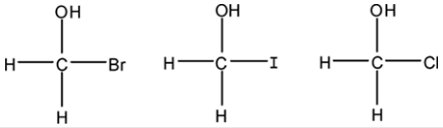
✓

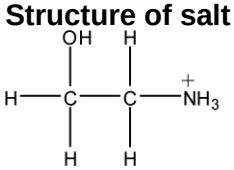
Reagents

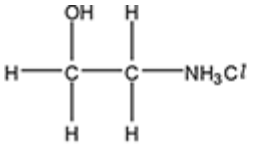
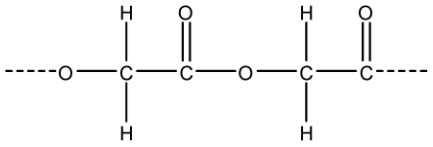
3

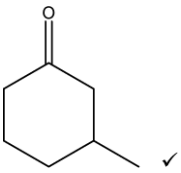
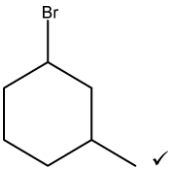
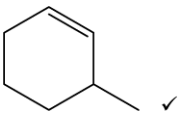
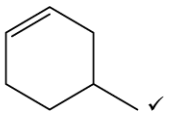
ALLOW any combination of skeletal **OR** structural **OR** displayed formula as long as unambiguous

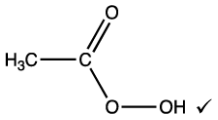
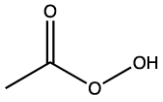
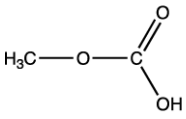
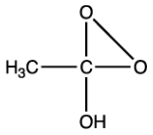
IGNORE name(s)
ALLOW



			Reaction 2: H_2 **AND** Ni ✓ **Reaction 3:** Correct formula of an aqueous acid e.g. HCl(aq)/H_2SO_4(aq) ✓		**ALLOW** any suitable metal catalyst e.g. Pt **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 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**  *i.e.* charges **not** requir **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	 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**	
45		i	**Starting material from reduction reaction**  ✓ **Reagent for reduction** $NaBH_4$ ✓ **Product from reaction with NaBr/H_2SO_4**  ✓ **Structural isomers**  ✓  ✓	**5**	**ALLOW** any combination of skeletal **OR** structural **OR** displayed formula as long as unambiguous Watch for missing methyl groups **IGNORE** H^+ / acid or H_2O or ethanol **ALLOW** sodium borohydride **OR** sodium tetrahydridoborate **ALLOW** $LiAlH_4$ **ALLOW** in either order **Examiner Comments** There were many good answers to this synthesis question with about 40% of the cohort scoring full marks. The structure of the carbonyl and the reagent needed for reduction were well known by a majority of candidates however some reacted the alcohol group with sodium bromide to obtain $-O^-Na+$ for the second structure.

					Weaker candidates did not realise that an alcohol could be dehydrated and thus failed to be awarded the final two marks.
		ii	3-methylcyclohexanol ✓	**1**	**ALLOW** 3-methylcyclohexan-1-ol **ALLOW** 1-methylcyclohexan-3-ol **IGNORE** lack of hyphens, or addition of commas **Examiner Comments** Just over half of candidates managed to name the structure as 3-methylcyclohexanol. The most common errors included 3-methylphenol, 3-methylcyclichexanol and 3-methylhexanol.
			Total	**6**	
46		i	 **ALLOW** skeletal **OR** displayed formula **OR** mixture of the above as long as non-ambiguous, e.g. 	**1**	**ALLOW**  **OR**  Structure must include OH as part of COOOH group **ALLOW** $-O^{-}$ H^{+} in structure **Examiner's Comment:** This part was attempted well, with many providing a structure containing the correct COOOH functional group. The mark scheme did allow alternatives provided that the three O atoms were bonded to the C atom, e.g. H_3C-O-COOH
		ii	**FIRST CHECK THE ANSWER ON THE ANSWER LINE** **IF** answer = 0.023(125) (mol) award 3 marks for calculation ..... ***K_c expression*** $(K_c =) \frac{[CH_3COOOH]}{[H_2O_2]\,[CH_3COOH]}$ ✓ **[CH_3COOOH]**	**3**	**If there is an alternative answer, check for any ECF credit** ..... **ALLOW** $0.37 = \frac{[CH_3COOOH]}{0.500 \times 0.500}$ **ALLOW ECF** but **ONLY** if 0.37 **AND** 0.5 × 0.5 have been used

= 0.37 × 0.500 × 0.500 = 0.0925 (mol dm^{-3}) ✓

Subsumes K_c expression

$n(CH_3COOOH)$

$= 0.0925 \times \frac{250}{1000} = 0.023(125)$ (mol) ✓

Common errors

0.076 **2 marks**

Use of $[CH_3COOOH]^2$

0.675 **2 marks**

Use of 0.5 for $[H_2O]$ on K_c

0.169 **2 marks**

Inverted K_c

0.338 **1 mark**

Inverted K_c AND 0.5 for $[H_2O]$

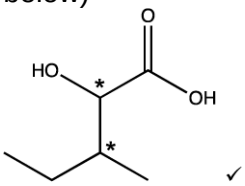
5.78×10^{-3} **2 marks**

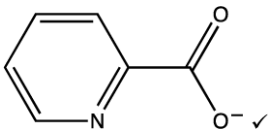
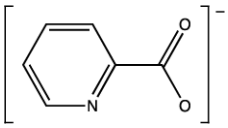
$\times \frac{250}{1000}$ *before* $[CH_3COOOH]$

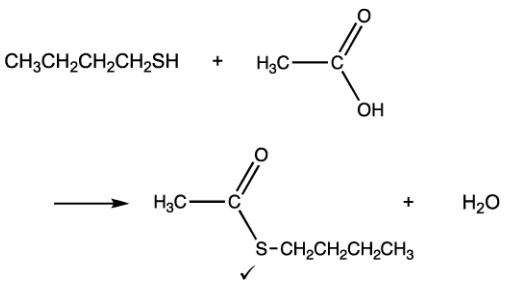
Examiner's Comment:
Many candidates obtained the correct answer but water was often seen in the K_c expression. Candidates then assigned arbitrary values to the concentration of the water, often the same as CH_3COOH, unity, or even 55.6 from 1000/18. The mark scheme allowed some credit by use of error

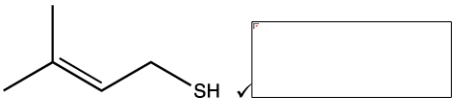
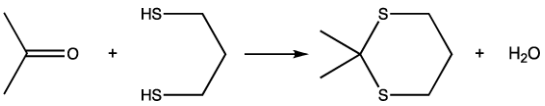
					carried forwards. Answer: 0.023 mol
			Total	**4**	
47	a	i	***Burette readings*** Final (reading) /cm^3 23.15 45.95 32.45 Initial (reading) /cm^3 0.60 23.15 10.00 ✓ Titre / cm^3 22.55 22.80 22.45 ✓ ***Titres*** • Correct titration results recorded with initial and final readings, clearly labeled **AND** all readings recorded to two decimal places with last figure either 0 or 5 • Correct subtractions to obtain final titres to 2 DP ***Units*** • Units of cm^3 for initial, final and titres ✓ ***Mean titre*** • mean titre = $\frac{22.55 + 22.45}{2}$ = 22.50 **OR** 22.5 cm^3 ✓ *i.e. using concordant (consistent) titres*	**4**	Table **not** required **ALLOW** initial reading before final reading **ALLOW ECF** **ALLOW** units with each value **ALLOW** brackets for units, i.e. (cm^3) **ALLOW ECF** from incorrect concordant titres **Examiner's Comment:** This question should have been four straightforward marks, but it was actually found very challenging by candidates. Most read the scales correctly but then did not present their findings clearly, often scattering unlabelled numbers around, omitting units with absence

					of any heading linking them to the burettes. 0.60 was very often shown as 0.6 and 22.80 as 22.8. Candidates were expected to take the mean of their closest titres but a significant number took an average of all three titres instead. The mark scheme allowed for a mean titre obtained from incorrect titres. Candidates need to appreciate the importance of communicating their results in a clear and comprehensive way with headings and units, and showing numerical values to the accuracy of the apparatus used.
		ii	**ALLOW 3SF** or more throughout **IGNORE** trailing zeroes, e.g. **ALLOW** 0.084 for 0.0840 ..... $n(\text{NaOH}) = 0.0840 \times \frac{22.50}{1000} = 1.89 \times 10^{-3}$ (mol) ✓ n(**A**) in 250 cm^3 = $10 \times 1.89 \times 10^{-3} = 1.89 \times 10^{-2}$ (mol) ✓ $M(\text{A}) = \frac{2.495}{1.89 \times 10^{-2}} = 132$ (g mol^{-1}) ✓ M(alkyl group) (= 132 – 75) = 57 ✓ R = C_4H_9 ✓ **ALLOW** alkyl group in drawn structure with straight chain or branch (es) in wrong position, e.g. for R = C_4H_9, $CH_3CH_2CH_2CH_2$ **OR** $(CH_3)_3C$ Structure with chiral carbon atoms identified (see *	**6**	**ALLOW ECF** from incorrect mean titre in **4a(i)** e.g. From 22.60 cm^3 (mean of all 3 titres in **(i)**, n(NaOH) = 1.8984 × 10^{-3} (mol) **ALLOW ECF** from incorrect n(NaOH) **ALLOW ECF** from incorrect n(**A**) **ALLOW ECF** from incorrect M(**A**) – 75 **ALLOW ECF** for alkyl group closest to calculated M(alkyl group), e.g. for M = 45, **ALLOW** C_3H_7 (43) **ALLOW** correct structural **OR** skeletal **OR** displayed formula **OR**

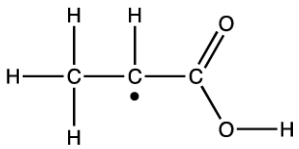
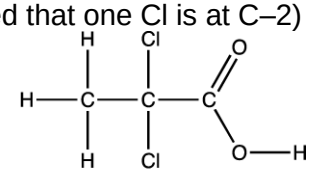
			below)  ✓		mixture of the above as long as non-ambiguous **IGNORE** poor connectivity to OH groups *Given in question* ..... **Common error for 4 marks max** *25.00 instead of 22.50 and scaling by × 10* 2.10×10^{-3} → 2.10×10^{-2} ✓ → 118.81 ✓ → 43.81 ✓ → C_3H_7 ✓ *25.00 instead of 22.50 and scaling by* $\times \frac{250}{22.50}$ 2.10×10^{-3} → 2.33×10^{-2} ✓ → 106.93 ✓ → 31.93 ✓ → C_2H_5 ✓ No structure with 2 chiral centres possible . **Examiner's Comment:** Most candidates made some headway with this problem. Candidates were expected to process their mean titre from 4(a)(i) in a conventional titration calculation to arrive at a molar mass of 132 g mol^{-1}. From there, candidates could determine a C_4H_9 alkyl group and draw the structure of compound A with two chiral carbon atoms. Most candidates scored some marks but processing beyond the molar mass proved to be difficult for weaker candidates. Some candidates showed a structure with a linear C_4H_9 group which contains one chiral carbon atom. A common error was use of 25.0 cm^3, instead of the titre, as the volume of NaOH, obtaining an initial value of 2.10×10^{-3} mol. The mark scheme allowed processing of this value to be credited using error carried forwards. Some candidates omitted to scale their

					initial value by a factor of ×10, obtaining a molar mass of over 1000 g mol^{-1}, e.g. 1320 instead of 132. A large range of marks was seen and the question discriminated extremely well.
	b	i	 ✓	**1**	**ALLOW** brackets around structure with negative charge outside, i.e.  **ALLOW** ring (Kekulé structure) **Examiner's Comment:** Most candidates identified the skeleton of the ligand. However, this was often drawn without the minus sign on the COO^- or with an additional minus sign on the nitrogen.
		ii	**FIRST CHECK THE ANSWER ON THE ANSWER LINE** **If answer = 1.61 × 10^{-3} award 2 marks** *M* = 418(.0) (g mol^{-1}) **OR** *n*(Cr) = 3.85 × 10^{-6} (mol) ✓ Mass = 3.85 × 10^{-6} × 418.0 = 1.61 × 10^{-3} g ✓	**2**	**Note:** $\frac{200 \times 10^{-6}}{52.0} = 3.85 \times 10^{-6}$ (at least 3 SF) **ALLOW ECF** from incorrect *M* **OR** *n*(Cr) **ALLOW 3 SF** up to calculator value correctly rounded **For 5a(i)–(iv) IGNORE** poor connectivity to SH groups *Given in question* **Examiner's Comment:** Most candidates calculated the amount of chromium correctly as 3.85 × 10^{-6} mol. The second mark required this value to be multiplied by the molar mass of the complex. Success here was dependent on obtaining the correct molar mass of 418 g mol^{-1}. Candidates scored better

					here than in 4(c)(i). Answer: 1.61×10^{-3} g
			Total	**13**	
48		i	$K_a = \frac{[H^+]\,[C_4H_9S^-]}{[C_4H_9SH]}$ ✓ *Square brackets required*	**1**	**ALLOW** correct structural **OR** skeletal **OR** displayed formula **OR** mixture of the above as long as non- ambiguous **Examiner's Comment:** This part was very well answered. Candidates responded with either near molecular formulae, such as C_4H_9SH, structural formulae or with skeletal formulae. Some candidates made careless errors such as omitting the negative charge or showing $[H^+]^2$ as numerator rather than $[C_4H_9S^-]$ $[H^+]$.
		ii	 Structure of thioester ✓ Complete equation ✓	**2**	**ALLOW** correct skeletal **OR** displayed formula **OR** mixture of the above as long as non-ambiguous **ALLOW** C_4H_9SH **ALLOW** CH_3COOH Thioester functional group **must** be fully displayed, **OR** as a skeletal formula but allow SC_4H_9 in thioester **Examiner's Comment:** In this part, candidates were expected to apply their knowledge and understanding of esterification to thiols and thioesters. Over half the candidates obtained a correct structure of the thioester. Most of these candidates constructed a balanced equation although some omitted the water product. Common errors included formation of a conventional ester and H_2S,

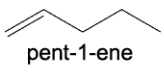
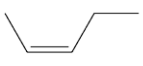
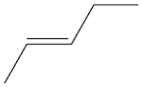
					and retaining the O atom from the OH in the carboxyl group to form –COOS–. As with 4(b)(i), structural and skeletal formulae were used. Candidates are less likely to omit H atoms if the skeletal formula is used.
		iii	 ✓	**1**	**IF** correct **skeletal** formula is shown, **IGNORE** displayed formula in a second structure **Examiner's Comment:** Just over half the candidates drew the correct structure, displaying a good understanding of interpreting organic nomenclature when drawing a structure. Common errors included omission of the CH_2 adjacent to the terminal –SH group and placing the branch or double bond in wrong positions. Some candidates spoilt an otherwise good response by showing a structural formula or a mixture of skeletal and structural formulae.
		iv	 Reactants ✓ Products **AND** balanced equation ✓	**2**	**ALLOW** correct structural **OR** skeletal **OR** displayed formula **OR** mixture of the above as long as non-ambiguous **Examiner's Comment:** In this part, candidates were expected to apply their knowledge and understanding of condensation to an entirely new context. One mark was allocated for the reactants and this was usually scored. The second mark for the novel cyclic compound and water was much more difficult, aimed at stretch and challenge. A significant number of candidates interpreted the information to obtain a correct cyclic structure but this mark was

					the domain of the most able candidates.
			Total	**6**	
49	a		$C_nH_{2n}O_2$ **OR** $C_nH_{2n+1}COOH$ ✓	**1**	**Examiner's Comment:** The correct response; $C_nH_{2n}O_2$ or $C_nH_{2n+1}COOH$, was presented by a good proportion of candidates but many incorrect alternatives were seen.
	b	i	Ultraviolet (radiation)/UV ✓	**1**	**ALLOW** sunlight **IGNORE** temperature **Examiner's Comments** Most candidates scored this mark.
		ii	$CH_3CH_2COOH + Cl_2 \rightarrow CH_3CHClCOOH + HCl$ ✓	**1**	**ALLOW** $C_2H_5COOH + Cl_2 \rightarrow C_2H_4ClCOOH + HCl$ **ALLOW** $C_3H_6O_2 + Cl_2 \rightarrow C_3H_5ClO_2 + HCl$ **Examiner's Comments** Many candidates could write the overall equation but there was some confusion with propagation steps and some equations contained radicals or missed out HCl as a product.
		iii	one electron from the bond (pair) goes to each atom / chlorine/radical ✓	**1**	**ALLOW** the breaking of a covalent bond where each atom keeps one of the bonding electrons **IGNORE** particle for atom **ALLOW** one electron from the bond goes to each product / species **DO NOT ALLOW** molecule or compound for atom **IGNORE** homolytic fission equations **Examiner's Comments** Homolytic fission is described in the specification in terms of each bonding atom receiving one

					electron from the bonded pair forming two radicals. A large proportion of candidates failed to match the essential points in this definition.
		iv	*Propagation step 1* $Cl\cdot + CH_3CH_2COOH \rightarrow CH_3CHCOOH\cdot + HCl$ ✓ *Propagation step 2* $CH_3CHCOOH\cdot + Cl_2 \rightarrow CH_3CHClCOOH + Cl\cdot$ ✓	**2**	**ALLOW** 1. $Cl\cdot + C_3H_6O_2 \rightarrow C_3H_5O_2\cdot + HCl$ 2. $C_3H_5O_2\cdot + Cl_2 \rightarrow C_3H_5ClO_2 + Cl\cdot$ **ALLOW** dot at any position on the radical **ALLOW** 1 mark if both equations correct but any dots omitted from radicals **Examiner's Comments** Generally well answered. Candidates took note of the instruction in the question and it was very rare to see radicals without their unpaired electron.
		v	 ✓	**1**	Dot shown in correct position **ALLOW** –OH **Examiner's Comments** Unfortunately, candidates who were not able to attempt equations for the propagation steps in part (iv) were then unable to suggest the structure of the radical formed in the first step. Many candidates did not present a fully displayed formula. However, formulae showing –OH were given credit in this question.
		vi	Any structure with two or more Cl atoms on alkyl chain (provided that one Cl is at C–2)  e.g.✓	**1**	**ALLOW** correct structural **OR** skeletal **OR** displayed formula **OR** mixture of the above **DO NOT ALLOW** $C_3H_4Cl_2O_2$ **ALLOW** further substitution into any or all of the 4 positions occupied by H atoms in the alkyl

					group, provided that at least one Cl is at C–2 **Examiner's Comment:** Generally well answered but it was clear from some of the structures drawn that some candidates did not understand what is meant by further substitution.
			Total	**8**	
50			**FIRST check the molar mass on answer line MUST be derived from *pV = nRT*,** **Award 4 marks for calculation for:** • **answer = 70** • **OR answer that rounds to 69.9 OR 70.0** --- *Rearranging ideal gas equation to make n subject* $n = \frac{pV}{RT}$ ✓ *Substituting all values including conversion to Pa and m³* $n = \frac{(101 \times 10^3) \times (82.5 \times 10^{-6})}{8.314 \times 373}$ ✓ $n = 2.68693073 \times 10^{-3}$ (unrounded) → 2.69×10^{-3} (mol) (rounded to 3 SF) ✓ *Calculation of molar mass, M* $M = \frac{m}{n} = \frac{0.1881}{2.68693073 \times 10^{-3}} = 70(.0)$ (g mol⁻¹) $\rightarrow \frac{0.1881}{2.69 \times 10^{-3}} = 69.9$ (g mol⁻¹) ✓ *Molecular formula of* **D** C_5H_{10} ✓ --- **IF** candidate has failed to derive suitable value of *n*, **ALLOW** value of *M* from 0.1881 **AND** 24000	**5**	**FULL ANNOTATIONS MUST BE USED** --- **If there is an alternative answer, check to see if there is any ECF credit possible using working below** 1st mark may be implicit by direct substitution of correct values below into rearranged equation. **ONLY award this mark if *n* has been derived from correct rearranged ideal gas equation** **ALLOW 3 SF up to calculator value, correctly rounded** **NOTE: ALLOW** 69.9 → 70.0 **AND** 70 (**2 SF**) *Calculator from unrounded: 70.00552634* **ALLOW** any unambiguous structure **ALLOW ECF** provided that formula given is an alkene and matches *M* calculated from 0.1881 **AND** *pV = nRT*

			with alkene closest to calculated value for last 2 marks **See Guidance column.**		---------- $M = \frac{0.1881}{82.5/24000}$ **OR** $\frac{0.1881}{3.4375 \times 10^{-3}}$ = 54.72 **OR** 54.7 **OR** 55 ✓ **ALLOW** 54.68 from use of 3.44×10^{-3} From **54.72, ONLY ALLOW** = C_4H_8 ✓ **Examiner's Comments** Most candidates realised the need to use the ideal gas equation. The equation was usually rearranged correctly, with substituted values for *p*, *V*, *R* and *T* being added. Pressure and volume were not always converted correctly into Pa and m^3, creating problems for subsequent parts. Many candidates attempted to convert from cm^3 to m^3 by multiplying by 10^{-3} rather than 10^{-6}. Candidates usually obtained a value for *n*, although those who had struggled with unit conversion obtained values that differed by powers of 10. Finally, candidates needed to derive the molar mass using their value of *n* and the mass of the alkene. Some candidates over-rounded their value of *n*, introducing an error in calculating the molar mass. Surprisingly, an appreciable number of candidates wrote their value of *n* on the answer line rather than the molar mass indicated by the answer prompt. This suggested that some candidates do not understand the term molar mass. Candidates who had obtained a molar mass of 70.0 usually determined that the alkene had the

					formula C_5H_{10}. Answer: 70.0 g mol^{-1}
			Total	**5**	
51			Electron pair acceptor (1) I^+ (1)	2	
			Total	**2**	
52			** Please refer to the marking instruction point 10 for guidance on how to mark this question.* **(Level 3)** Applies knowledge of elimination reactions to provide the correct names and structures of all three alkenes. **AND** Full, detailed explanation of formation of both types of isomers linked to the reaction, with clear understanding of both types of isomerism. *The explanations show a well-developed line of reasoning which is clear and logically structured. The information presented is relevant to the compounds drawn / named.* (5–6 marks) **(Level 2)** Applies knowledge of elimination reactions to provide the correct name and structure for pent-1-ene. **AND** Correct structures of stereoisomers of pent-2-ene but full names missing or incorrect. **AND** Explanation of formation of at least one type of isomers in some detail. *The explanations show a line of reasoning presented with some structure. The information presented is in the most-part relevant to the compounds drawn / named.* (3–4 marks) **(Level 1)** Applies knowledge of elimination reactions to name and draw the structures of organic products. Either name **OR** structure should be correct for two compounds. **AND** Attempts to explain formation of one type of	6	**Indicative scientific points may include:** • the elimination can produce a double bond in either the 1- or the 2- position (through combination of the hydroxyl group with a hydrogen from either the 1st or the 3rd carbon) • this leads to the formation of structural isomers (pent-1-ene and pent-2-ene) • pent-2-ene exhibits stereoisomerism / *E*/*Z* isomerism / *cis–trans* isomerism because it has two different groups attached to each carbon atom • there are two possible isomers of pent-2-ene and three in total. **Names and structures of alkenes**  pent-1-ene  *Z* or *cis*-pent-2-ene  *E* or *trans*-pent-2-ene

<table>
<tr><td></td><td></td><td></td><td>isomer.
The information about isomerism is basic and communicated in an unstructured way. The relationship to the compounds drawn / named may not be clear.
(1–2 marks)

(0 marks)
No response or no response worthy of credit.</td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td>Total</td><td>6</td><td></td></tr>
<tr><td>53</td><td>a</td><td>i</td><td>
<table>
<tr><td>Final reading/ cm^3</td><td>27.30</td><td>27.00</td><td>27.75</td></tr>
<tr><td>Initial reading/ cm^3</td><td>0.45</td><td>0.60</td><td>1.25</td></tr>
<tr><td>Titre/cm^3</td><td>26.85</td><td>26.40</td><td>26.50</td></tr>
</table>

Initial and final readings
All burette readings (×6) correct ✓

Titres recorded to two decimal places with the last figure either 0 or 5
Correct subtractions to obtain final titre values ✓

Mean titre calculated from concordant results
Correct mean titre = 26.45 (cm^3) ✓

Mean titre recorded to accuracy of burette
Final answer recorded to two decimal places with the last figure either 0 or 5 ✓</td><td>4</td><td>ANNOTATE ANSWER WITH TICKS AND CROSSES ETC

ALLOW missing zeroes for burette readings
i.e. 0.6 for 0.60
27 OR 27.0 for 27.00

ALLOW ECF from incorrect burette readings

IF MEAN IS CALCULATED FROM ECF, IT MUST BE FROM CLOSEST TITRES

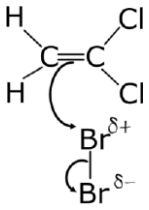
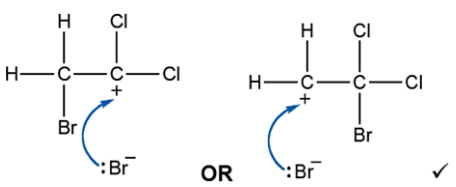
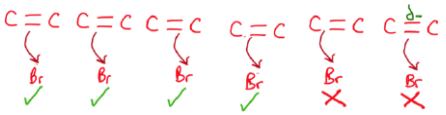
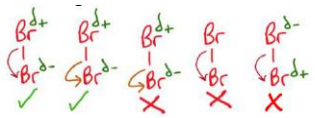
ALLOW ecf from incorrect mean
DO NOT ALLOW 26.5 cm^3
Question asks for nearest 0.05 cm^3

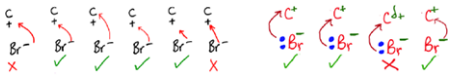
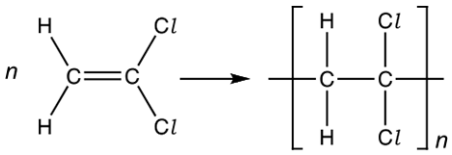
<u>Examiner's Comments</u>

Most candidates were able to accurately record the burette readings and made the correct subtractions. Despite the examination question requesting the mean titre to be recorded to the accuracy of the burette, many candidates did not do this. A common error was taking a mean of all three readings instead of only the concordant results; this led the candidates to give an answer of 26.58 which lost them 2 marks.</td></tr>
</table>

		ii	$\frac{2 \times 0.05}{26.85} \times 100 = 0.37(2)$ (%) ✓	1	**ALLOW** 0.4 up to full calculation display of 0.372439478 **ALLOW ECF FOR CORRECT CALCULATION FROM 1 (c) (i) OR USE OF ANY TITRE** **Examiner's Comments** A good attempt by many candidates but some did not know how to calculate this or did not multiply by 2.
		iii	Use a (250 cm^3) **volumetric** flask (instead of a beaker)✓	1	**IGNORE** graduated flask **Examiner's Comments** Although there were some excellent descriptions of the correct processes, such as inverting the apparatus to ensure mixing and then making the solution up to the mark, many candidates could not name a volumetric flask.
	b	i	**FIRST CHECK ANSWER ON ANSWER LINE** If answer = 118 (g mol^{-1}) award 4 marks If answer = 108 (g mol^{-1}) award 3 marks *n*(NaOH) $= 0.112 \times \frac{25.0}{1000} = 0.00280$ (mol) ✓ *n*(**A**) in 25.0 cm^3 $= \frac{0.00280}{2} = 0.00140$ (mol) ✓ **n**(**A**) in 250 cm^3 $= 0.00140 \times \frac{250.0}{27.30} = 0.0128$ (mol) ✓ Molar mass, *M*(**A**) to nearest whole number. $= \frac{1.513}{0.0128} = 118$ (g mol^{-1}) ✓	4	**ANNOTATE ANSWER WITH TICKS AND CROSSES ETC** Throughout: **IGNORE** trailing zeroes in intermediate working, e.g. For *n*(NaOH) **ALLOW** 0.0028 for 0.00280 **ALLOW ECF** from incorrect *n*(NaOH) **ALLOW ECF** from incorrect *n*(A) **OR** *n*(NaOH) **ALLOW** 3 sig fig up to full calculator display correctly rounded (0.012820512) **ALLOW ECF** from incorrect *n*(NaOH) **Possible ECFs for 3 marks** 1.513 ÷ (0.00140 × 250/25) = 108 1.513 ÷ 0.00140 = **1081**

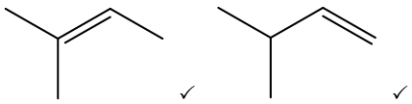
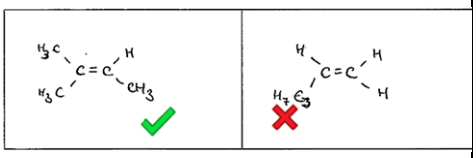
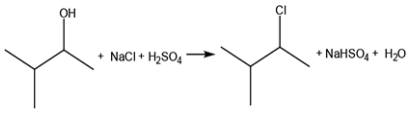
					No ÷2 for n(**A**) • Molar mass **A** = 59 (g mol^{-1}) Using mean titre of 26.45 cm^3 from **1c(i)** • Molar mass **A** = 114 (g mol^{-1}) Using 27.3 × 0.112 in M1 and then 25.0 in M3 • Molar mass **A** = 99 (g mol^{-1}) **Examiner's Comments** Although there were some excellent descriptions of the correct processes, such as inverting the apparatus to ensure mixing and then making the solution up to the mark, many candidates could not name a volumetric flask.
		ii	Structure of dicarboxylic acid $HOOCCH_2CH_2COOH$ **OR** $HOOCCH(CH_3)COOH$ ✓ **STRUCTURE MUST MATCH *M*$_r$** from answer to 1 d) i) (within 10 AMU)	1	**ALLOW** correct structural **OR** skeletal **OR** displayed formulae **OR** a combination **ALLOW** incorrect connectivity e.g -HO **ALLOW ECF** from incorrect molar mass in **(d)(i)** but only if 2 × COOH possible and M_r is a close match to **(d) (i) within 10 AMU** **Examiner's Comments** Most candidates that obtained a sensible value for the previous question managed to draw a creditable structure. Allowing error carried forward meant that feasibly derived structures could be credited a mark.
			Total	**11**	
54	a		steam **AND** Acid/H^+ (catalyst) ✓	1	**Examiner's Comments**

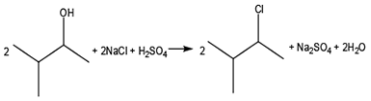
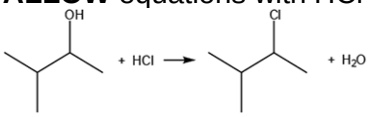
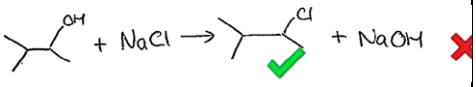
					Many candidates knew the answer to this question but forgot that water must be in the gaseous state. There were numerous responses stating nickel as the catalyst, but most knew that an acid catalyst was required.
	b	i	1,2-dibromo-1,1-dichloroethane✓	1	**Examiner's Comments** This question was generally well answered, although some candidates made careless mistakes such as not writing -di or writing 1,2-dibromo-1-dichloroethane
		ii	 **1st curly arrow (from ANY alkene)** Curly arrow from double bond to Br of Br–Br ✓ **DO NOT ALLOW** partial charge on C=C **2nd curly arrow** Correct dipole on Br Br **AND** curly arrow for breaking of Br–Br bond ✓ **3rd curly arrow** **Correct carbocation** with + charge on C with 3 bonds **AND** curly arrow from Br^- to C^+ of carbocation ✓ **DO NOT ALLOW** δ+ on C of carbocation 	3	**ANNOTATE ANSWER WITH TICKS AND CROSSES ETC** **For curly arrows, ALLOW straight or snake-like arrows and small gaps (see examples):** **1st curly arrow** must • go to a Br atom of Br–Br • **AND** • start from, **OR** be traced back to **any point across width** of C=C  **2nd curly arrow** must • start from, **OR** be traced back to, **any part of** $^{\delta+}Br–^{\delta-}$ bond • **AND** go to $^{\delta-}$  **3rd curly arrow** must

			i.e. ALLOW carbonium + on either C atom **DO NOT ALLOW** half headed or double headed arrows but allow **ECF** if seen more than once		• go to the C^+ of carbocation • **AND** start from, **OR** be traced back to • **any point across width** of lone pair on :Br^- **OR** start from – charge on Br– ion •  *(Lone pair **NOT** needed if curly arrow shown from – charge on Br^-)* **Examiner's Comments** Many candidates gained all three marks on this question and the diagrams were clear and easy to read. Lower ability candidates had incorrect dipoles or curly arrows that could not be traced back to the correct origin. Candidates should be encouraged to consider what the arrows mean rather than memorising mechanisms with no understanding.
c	i		 Correct polymer with side links and brackets ✓ Equation balanced with *n* ✓ **TAKE CARE** of '*n*' position on both sides of equation.	2	**For repeat unit,** • displayed formula required • 'side bonds' required on either side of repeat unit from C atoms • **ALLOW** section containing more than one repeat unit **DO NOT ALLOW ECF** from incorrect repeat unit *n* on LHS at any height to the left of the formula *n* on RHS must be subscript **Examiner's Comments**

					Most candidates correctly drew the repeat unit and were credited with one mark, but many placed the *n* position in the wrong place on the left-hand side of the equation or forgot to write it in at all.
		ii	**Advantage (1 mark)** Energy production / (energy) used to produce electricity ✓ **Disadvantage (1 mark)** Formation of HCl/products of combustion cause acid rain **OR** Formation of CO_2/gases that cause global warming / greenhouse gases **OR** Formation of CO✓	2	**ALLOW** reduced use of fossil fuels **ALLOW** less landfill / less harm to wildlife **ALLOW** chlorine/Cl **OR** Cl_2 **ALLOW** toxic/poisonous waste products **Examiner's Comments** With all the media interest in plastic pollution this question was answered well, although many gave the answer 'quick and efficient' as an advantage which was not credited. Candidates should beware of vague statements such as these. Many wrote 'harmful' instead of toxic, or 'bad for the environment' instead of being specific about the environmental issue.
			Total	**9**	
55			**C**	**1**	**Examiner's Comments** Many candidates correctly identified C as the alicyclic compound. B and D proved good distractors and were seen in approximately equal proportions.
			Total	**1**	
56			**B**	**1**	**ALLOW** 2 (This is the number of straight chain isomers with a chiral C atom) **Examiner's Comments** This question proved difficult.

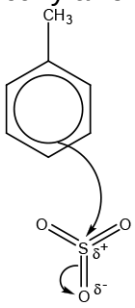
					Candidates who drew out the different isomers of chloroheptane were able to identify B as the correct response.
			Total	**1**	
57		i	3-methylbutan-2-ol ✓	**1**	**IGNORE** lack of hyphens or addition of commas **ALLOW** 3-methylbutane-2-ol **DO NOT ALLOW** 2-methylbutan-3-ol **OR** 3-methylbut-2-ol **OR** 3-methbutan-2-ol **OR** 3-methybutan-2-ol **OR** 3-methlybutan-2-ol **Examiner's Comments** The majority of candidates were able to correctly name alcohol A as 3-methylbutan-2-ol. A significant number of responses used incorrect numbering and suggested 2-methylbutan-3-ol as the name.
		ii	$(CH_3)_2CHCHOHCH_3$ ✓	**1**	**ALLOW** brackets around OH e.g. $(CH_3)_2CHCH(OH)CH_3$ **ALLOW** any unambiguous structural formula e.g. $CH_3CH(CH_3)CHOHCH_3$ $CH_3CH(CH_3)CH(CH_3)OH$ **Examiner's Comments** Most candidates were able to show a correct structural formula of alcohol A.

		iii	One mark for each correct structure. 	**2**	**ALLOW** any combination of skeletal **OR** structural **OR** displayed formula as long as unambiguous **ALLOW** in either order **Examiner's Comments** Many candidates correctly identified the two alkenes formed as 2-methylbut-2-ene and 3-methybut-1-ene. Stronger responses used skeletal formula to show the structures clearly. Some candidates preferred to use chemical symbols to represent the atoms present and although this approach is valid, lower ability responses did not show sufficient detail as demonstrated in Exemplar 1. **Exemplar 1**  In this response the alkene 2-methylbut-2-ene has been correctly identified and one mark credited. However, the attempt to show 3-methylbut-1-ene does not score. This is because C_3H_7 has been used instead of $CH(CH_3)_2$. Candidates should be encouraged to show every carbon atom when drawing a structure as the use of ambiguous formulae is not sufficient to gain credit.
		iv	 Correct haloalkane ✓ Correctly balanced equation ✓	**2**	**ALLOW** any combination of skeletal **OR** structural **OR** displayed formula as long as unambiguous **ALLOW** H^+ for H_2SO_4 **ALLOW** equations forming Na_2SO_4

					 **ALLOW** equations with HCl  **DO NOT ALLOW** equations that form NaOH **Examiner's Comments** This question proved difficult for candidates. Although many candidates were able to identify the correct organic product, only the higher ability candidates were able to construct an appropriate balanced equation. A common error was to omit the role of the acid; this is shown in Exemplar 2 below. Lower ability candidates appeared not to recognise this reaction and suggested an alkoxide salt, rather than a haloalkane as the organic product. **Exemplar 2**  This type of response was seen frequently by examiners. The candidate has drawn the correct structure of the haloalkane formed and scores the first mark. However, the response fails to recognise that the reaction occurs under acidic conditions and omits the sulfuric acid from the equation.
			Total	**6**	
58			Curly arrow from π-bond to S in SO_3	**3**	**ANNOTATE 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

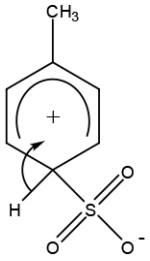
AND

curly arrow from the S=O bond to O atom ✓

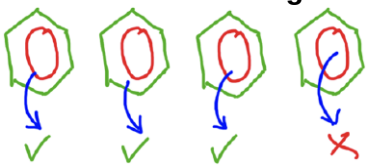


Correct intermediate ✓

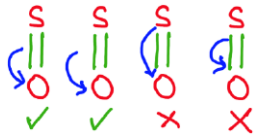
Curly arrow from C-H bond to reform π-ring ✓



- go to the S of SO_3
  AND
- start from, **OR** close to **circle of benzene ring**



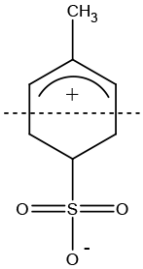
2nd curly arrow must start from, **OR** be traced back to, **any part of** S=O bond and go to O



ALLOW 2nd curly arrow from S=O to any O in SO_3

Intermediate must have correct SO_3^- structure fully displayed

DO NOT ALLOW the following intermediate:



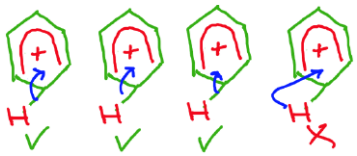
π-ring must cover more than half of the benzene ring structure
AND
the correct orientation, i.e. gap towards C with SO_3^-

ALLOW + sign anywhere inside the 'hexagon' of the intermediate.

DO NOT ALLOW mark for intermediate if CH3 is missing

curly arrow must start from, **OR**

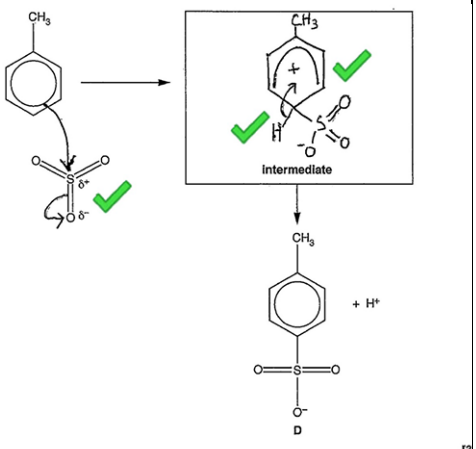
be traced back to, **any part of** C-H bond and go inside the 'hexagon'



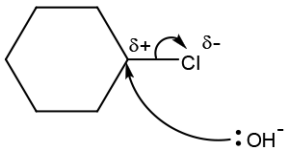
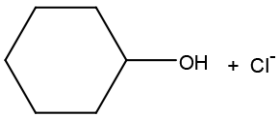
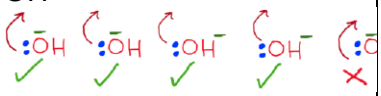
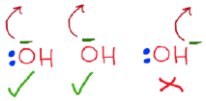
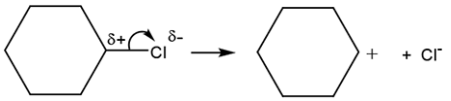
Examiner's Comments

This question required candidates to apply their understanding of electrophilic substitution to the reaction of methylbenzene with sulfur trioxide. Examiners were encouraged by the quality of responses to this question. Most candidates secured full marks in this part. Some candidates did not show the curly arrow for the breaking of the S=O bond, while others omitted the methyl group from the intermediate. Exemplar 4 shows an excellent response.

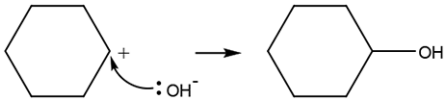
Exemplar 4



This response demonstrates an excellent example for candidates to follow. Curly arrows are drawn accurately, with each arrow touching the bond it starts from. The intermediate has been drawn clearly, using all the space

					provided. The 'horseshoe' has been drawn accurately over five of the carbon atoms with the positive charge shown neatly in the centre.
			Total	**3**	
59			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



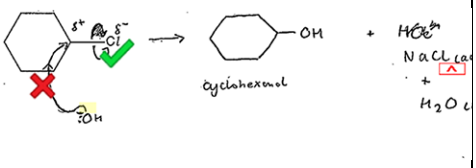
Curly arrow must come from lone pair on O of HO^- OR OH^-
OR from minus on O of HO^- ion
(no need to show lone pair if curly came from negative charge) ✓

Third mark
Correct organic product **AND** Cl^- ✓

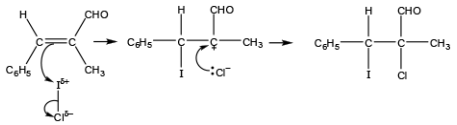
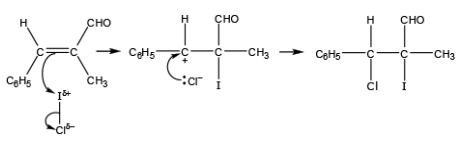
Examiner's Comments

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

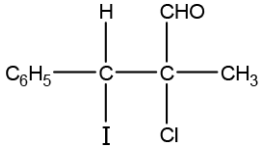


This response demonstrates the two most common errors seen in this part. The first marking point cannot be credited as the curly arrow from the hydroxide ion does not involve either the lone pair or minus sign on the O atom. The organic product is correct but the chloride ion produced by the heterolytic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

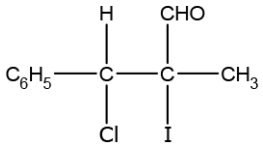
					only scores one mark for the correct partial charges and curly arrow on the C-Cl bond. Candidates are encouraged to practice drawing mechanisms so as to avoid costly errors during examinations.
			Total	**3**	
60			*Please refer to marking instructions on page 5 of mark scheme for guidance on how to mark this question.* **Level 3 (5–6 marks)** An outline of the mechanism for the formation of either product which is mostly correct. **AND** Major and minor products identified with a correct explanation of which product is most/least likely to be formed. *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)** An outline of the mechanism for the formation of either product but with a few omissions/errors. **AND** Identifies major/minor product correctly **OR** Explanation of which product is most/least likely to be formed. *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)** A basic outline of the mechanism for the formation of either product is attempted. **OR** Basic explanation of which of the products is most/least likely to be formed. *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.*	**6**	**Please check all of page 23 which is included with this response. If this page is blank please annotate with SEEN** Throughout: **ALLOW** correct structural **OR** displayed **OR** skeletal formulae **OR** a combination of above if unambiguous **Indicative scientific points:** **<u>Mechanism for formation of either product.</u>** • Curly arrow from C=C to attack the I atom of the I-Cl • Correct dipole on I-Cl • Curly arrow from I-Cl bond to Cl • Carbocation with full positive charge on carbon atom • Curly arrow from negative charge on Cl^- or lone pair on Cl^- to carbon atom with positive charge  **OR** 

Organic products

- Major/most likely product



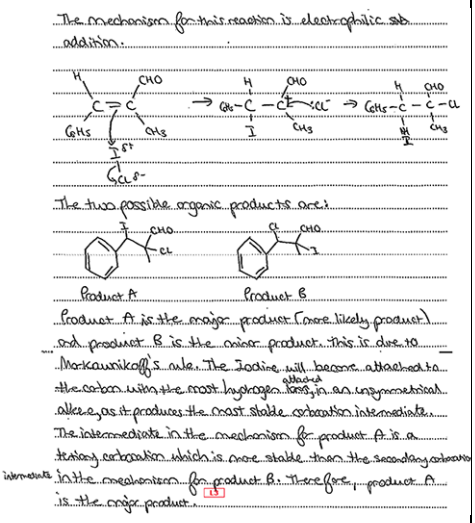
- Minor/least likely product

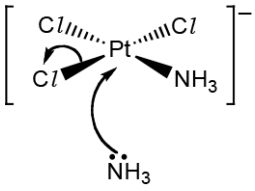


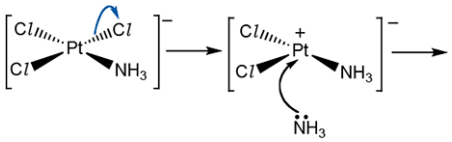
- Major/most likely product is formed from the most stable carbocation intermediate **OR** – C*l* is attached to carbon atom with the least hydrogens attached **OR** the carbon with the most –C atoms attached **OR** the – I is attached to the carbon atom with most hydrogens attached

Examiner's Comments

This question was marked using a level of response mark scheme. Most candidates gave an answer worthy of at least level two (3-4 marks) by providing a suitable mechanism and identifying the major product. The strongest candidates identified both products and were able to describe which

					was most likely. Such responses received level 3 (5-6 marks) as shown in Exemplar 9. Lower ability candidate responses seemed to ignore the reference to electrophilic addition in the question and tried reacting IC/ with either the benzene ring or the aldehyde group. **Exemplar 9**  This response starts with a clear outline of the electrophilic addition mechanism showing correct partial charges and accurately drawn curly arrows. The structures of the two possible organic products are shown and the most likely product

					to be formed is identified correctly. Notice that the candidate has labelled these structures as 'Product A' and 'Product B' and refers to the labels later in the response. This is a good strategy, which enables the candidate to provide a clear and easy to follow answer. The response concludes with a detailed explanation, referring to carbocation stability to justify why product A is most likely to be formed. This response therefore satisfies the Level 3 criteria. The response is logically structured with a well-developed line of reasoning and was therefore credited the upper mark within the level and achieved six marks.
			Total	**6**	
61		i	+2 **Sign required**	1	**ALLOW** 2+ **OR** +II **ALLOW** Pt^{2+} **Examiner's Comments** Almost all candidates responded with the correct oxidation number of +2. Incorrect responses were 0 (the overall charge of the complex), +4 or 2 (with no sign). Candidates are reminded on the importance of the sign in assigning oxidation numbers.
		ii	 Curly arrow from lone pair on NH_3 to Pt ✓ $[PtCl_3(NH_3)]^-$ drawn with 1 Pt, 3 Cls and 1 NH_3 **AND** Curly arrow from **any** Pt C*l* bond in the complex ✓ **ALLOW** S_N1 mechanism:	2	For $[PtCl_3(NH_3)]^-$: • **IGNORE** dipoles • **IGNORE** absence of – charge • **IGNORE** – charge shown on atoms **ALLOW** any 4 coordinate shape for $[PtCl_3(NH_3)]^-$, |



Mark curly arrows as above for S_N2
Requires + on platinum intermediate

e.g.

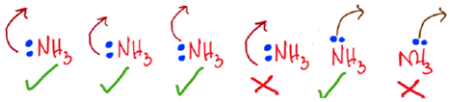
tetrahedral;

1st curly arrow must

go to Pt

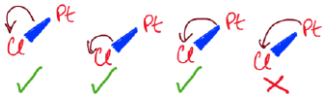
AND

- start from, **OR** be traced back to **any point across width** of lone pair on N of NH_3



DO NOT ALLOW charge on NH_3 nucleophile, e.g. NH_3^-

2nd curly arrow must start from, **OR** be traced back to, **any part of** Pt–Cl bond and go to one of the 3 Cl atoms



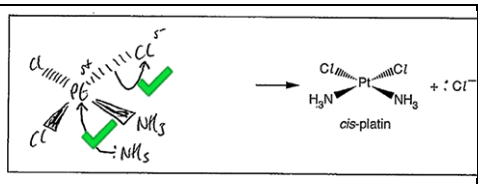
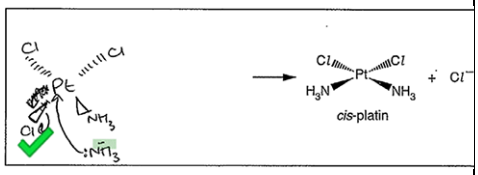
Examiner's Comments

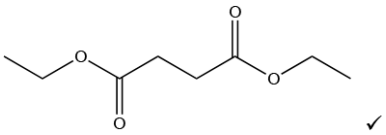
This part required candidates to apply their knowledge and understanding of the nucleophilic substitution mechanism in a novel context.

This part discriminated extremely well with able candidates drawing the correct initial complex and showing precisely positioned curly arrows, dipoles and the role of the NH_3 lone pair, as shown in Exemplar 7.

Lower ability candidates often showed imprecise curly arrows or placed a negative charge on NH_3, as shown in Exemplar 8.

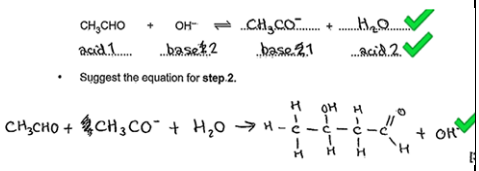
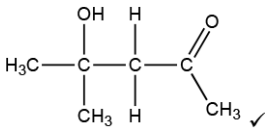
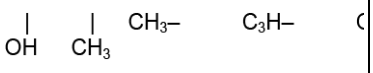
Exemplar 7

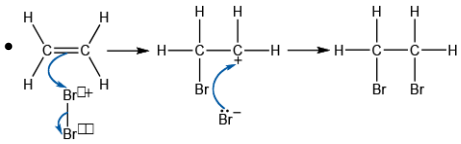
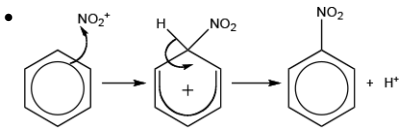
					 **Exemplar 8** 
			Total	**3**	
62		i	Titration ✓	1	**IGNORE** type of titration **Examiner's Comments** Candidates found this part difficult and only higher ability candidates identified that a titration could easily determine the concentration of succinic acid. The answers seen covered most of the techniques encountered in the course. Candidates should consider the information provided in a practical context to arrive at an informed response rather than what sometimes seemed to be a guess.
		ii	$(CH_2COOH)_2 + 2C_2H_5OH \rightleftharpoons (CH_2COOC_2H_5)_2 + 2H_2O$ ✓	1	**ALLOW** → instead of ⇌ sign **ALLOW** molecular formulae or hybrid formulae *Structures provided on QP* e.g. $C_4H_6O_4 + 2C_2H_6O \rightleftharpoons C_8H_{14}O_4 + 2H_2O$ **Examiner's Comments** Candidates were required to derive the equation from which the supplied K_c expression had been written. Overall, this part was answered well but some candidates struggled

					with the brackets or used CH_2COOH_2 for succinic acid.
		ii i	 ✓	1	**IGNORE** displayed formulae **Examiner's Comments** This part discriminated extremely well with many candidates finding it difficult to convert the bracketed structural formula into a skeletal formula. Common errors were drawing of the mono-ester or omitting a carbon atom in the centre of the structure. Even when incorrect, most attempted answers were skeletal formulae.
		i v	Volume cancels **OR** Same number of moles on each side of equation ✓	1	**ALLOW** units cancel **ALLOW** (sum of) balancing numbers/coefficients on each side of equation are the same **OR** same number of (moles of) reactants and products **IGNORE** volume is the same; K_c has no units **Examiner's Comments** Many candidates did not seem to realise that the supplied equation used moles, not concentrations. Those who did often stated that the mole representation could be used because the volume was the same for all. Of those who went on to state that the volume would cancel, only a few explained why that was true in this particular case. This challenging part discriminated very well. The best responses showed the units as n/V in the expression and showed that the volumes cancel.
		v	**Moles of equilibrium products** ***1 mark***	3	

			$n((CH_2COOC_2H_5)_2)$ = 0.0300 (mol) **AND** $n(H_2O)$ = 0.0600 (mol) ✓ **Moles of C_2H_5OH** ***1 mark*** n(**C_2H_5OH**) = 0.150 − 0.060 = 0.0900 (mol) ✓ **K_c calculated** ***1 mark*** $= \frac{0.03 \times 0.06^2}{0.02 \times 0.09^2} = 0.667$ **OR** 0.67 ✓ **NOTE**: 0.02 must be used for n(succinic acid)		**ALLOW ECF** **ALLOW** 0.66, 0.666, etc. (**2 SF** and more) *Treated as meaning 0.6 recurring* **ALLOW** 2/3 **IGNORE** any units **Examiner's Comments** Overall, this part discriminated well with many candidates obtaining the correct answer of 0.67. Common errors included a one significant figure answer of 0.6 or 0.7 and 0.375, by using 0.12 mol instead of 0.09 mol for the moles of ethanol. Many successful answers were well-presented and included a table of initial and final values. This gave a systematic way of deriving the equilibrium moles.
			Total	**7**	
63	a	i	3-hydroxybutanal ✓	1	**ALLOW** 3-hydroxybutan-1-al **IGNORE** lack of hyphens or addition of commas **ALLOW** 4-oxobutan-2-ol **OR** 1-oxobutan-3-ol **DO NOT ALLOW** • 3-hydroxybutal • 3-hydroxylbutanal **Examiner's Comments**

					Most candidates made good attempts at the name, the difficulty being that hydroxyl group needed to be shown as a hydroxy- prefix, rather than the suffix -ol. Common errors included 2-hydroxybutanal (counting the carbon chain from the wrong end) and 2- or 3-hydroxybutanoic acid (reading the aldehyde group as a carboxylic acid).
		ii	Addition ✓	1	**IGNORE** nucleophilic **OR** electrophilic **OR** radical **DO NOT ALLOW** addition–elimination, condensation, polymerisation **Examiner's Comments** This part was answered well with most choosing nucleophilic addition. Credit was given just for 'addition'.
		ii i	**ALLOW** any formula provided that number and type of atoms and charge are correct, e.g. For CH_3CHO, **ALLOW** CH_3COH, C_2H_4O, etc. **Step 1**: • Correct equation ✓ One correct acid–base pair ✓ • i.e. A1 and B1 **OR** A2 and B2 $CH_3CHO + OH^- \rightleftharpoons {}^-CH_2CHO + H_2O$ **OR** $CH_3CHO + OH^- \rightleftharpoons CH_3CO^- + H_2O$ ✓ **A1 B2 B1 A2** **OR A2 B1 B2 A1**	3	Throughout, **IGNORE** 'connectivity in any formula or structures shown. Examples in Answer column and in 6a(iv) guidance below **Step 1: ALLOW** H^+ transfer from OH^-, i.e. $CH_3CHO + OH^- \rightleftharpoons CH_3CH_2O^+ + O^{2-}$ ✓ **B2 A1 A2 B1** **OR B1 A2 A1 B2** **Step 2:**

			Step 2: $CH_3CHO + {}^-CH_2CHO + H_2O \rightarrow$ $CH_3CHOHCH_2CHO + OH^-$ ✓ For $^-CH_2CHO$: **ALLOW** CH_2CHO^-; CH_3CO^-; $C_2H_3O^-$ For $CH_3CHOHCH_2CHO$, **ALLOW** $C_4H_8O_2$		$CH_3CHO + CH_3CH_2O^+ + O^{2-} \rightarrow$ $CH_3CHOHCH_2CHO + OH^-$ ✓ For $CH_3CH_2O^+$: **ALLOW** CH_3CHOH^+, $C_2H_5O^+$ **Examiner's Comments** This novel question linked together acid–base equilibria with a multi-step process. Many candidates completed an equation to generate acid–base pairs, which were then usually assigned correctly. The final equation was challenging but the highest ability candidates were able to combine together all the information with their earlier responses to arrive at the correct equation. See Exemplar 15. **Exemplar 15** 
		iv		1	**ALLOW** correct structural **OR** displayed **OR** skeletal formulae **OR** a combination of above as long as unambiguous For connectivity, **ALLOW**  *(Connectivity not being assessed)* **Examiner's Comments** This part was one of the most challenging on the paper. Candidates needed to link the

					earlier information for combining two ethanal molecules to derive the product for combining two propanone molecules. Despite the challenge, the highest ability candidates were able to come up with the correct structure.
	b		*Refer to marking instructions on page 5 of mark scheme for guidance on marking this question.* **Level 3 (5–6 marks)** Describes, in detail, electrophilic reactions and mechanisms of one aliphatic **AND** one aromatic compound. *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, in detail, an electrophilic reaction and mechanism of one aliphatic **OR** one aromatic compound. **OR** Describes electrophilic reactions and mechanisms of one aliphatic **AND** one aromatic compound, with few omissions/errors. *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 electrophilic reactions of one aliphatic **AND** one aromatic compound. **OR** Attempts to describe an electrophilic reaction and mechanism of one aliphatic **OR** one aromatic compound, 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.	6	**Indicative scientific points may include:** **<u>Explanation of role of electrophiles in organic chemistry</u>** **<u>Reaction of aliphatic compound and mechanism</u>** • Suitable reaction, e.g. ethene and Br_2 • *May be shown within mechanism* • Mechanism, e.g.  **<u>Reaction of aromatic compound and mechanism</u>** • Suitable reaction, e.g. benzene + Cl_2 ; HNO_3 • *May be shown within mechanism* • Mechanism, e.g.  **Examples of a detailed description (NOT INCLUSIVE)**

- Electrophile as electron pair acceptor
- Types and names of mechanisms
- Equations for generation of electrophile and regeneration of catalyst
- Accurately positioned and directed curly arrows and charges/ dipoles included
- Explanation of major and minor product from electrophilic addition

Examiner's Comments

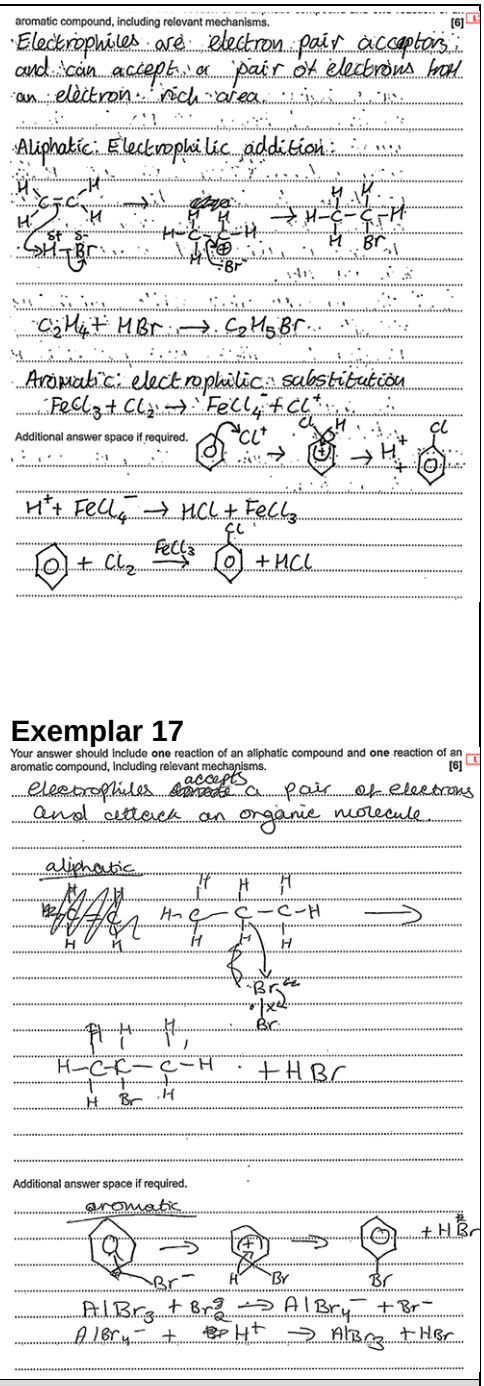
Overall, this part was answered well.

Good answers were well organised, showing clear mechanisms with precisely positioned curly arrows.

Most candidates included a clear definition of an electrophile and were able to select appropriate reactions. Most candidates were familiar with the mechanisms for electrophilic addition and electrophilic substitution. Mechanisms of an alkene with HBr or Br2 and benzene with NO_2^+ or Br^+ were the most commonly seen. Most candidates showed the role of a catalyst in electrophilic substitution.

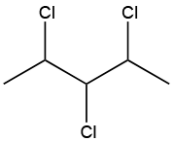
Common errors/omissions were the direction of the curly arrow from the aromatic ring to the electrophile, the position of the curly arrow when H^+ is lost from an aromatic intermediate, and not

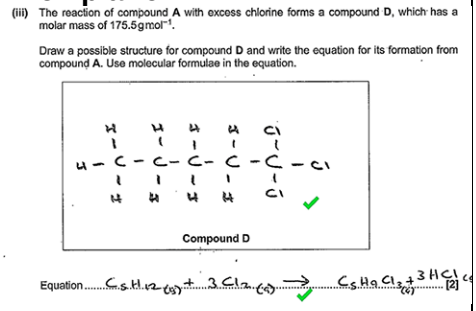
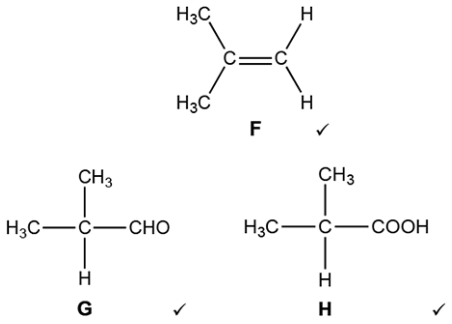
					showing the lone pair when Br^- attacks a carbocation. Some answers lacked detail and gave only two mechanisms with minimal supporting words. Lower ability candidates described nucleophilic addition or substitution as one of their mechanisms or had curly arrows going in the wrong direction. A few candidates answered in prose without including equations or diagrams. Candidates are advised that mechanisms must always be communicated in the usual diagrammatic way. Exemplar 16 is a very clear and concise response showing all the key features of electrophilic addition and electrophilic substitution, including the role of the $FeCl_3$ catalyst. Curly arrows are precisely positioned, with correct use of lone pairs and charges. The candidate has demonstrated excellent knowledge and understanding. The response in Exemplar 17 is clearly at a different level. The candidate has chosen an alkane rather than an alkene and has used curly arrows and charges incorrectly. This candidate appears to have been poorly prepared. **Exemplar 16**

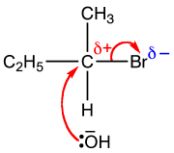
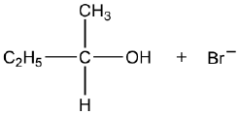
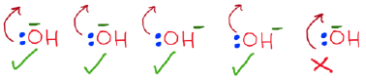
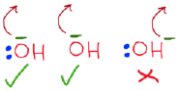
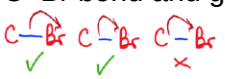
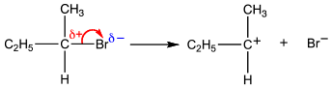
					
			Total	**12**	
64			**C**	**1**	**ALLOW** 3 **Examiner's Comments** The responses showed a reasonably even split across all options with relatively few correct responses of C. A good route to success here is to draw out the possibilities.
			Total	**1**	

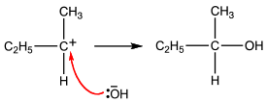
65			**A**	**1**	**Examiner's Comments** Many candidates added H atoms to the structure to aid their choice. Most candidates selected the correct response of A, with a sizeable number selecting B (by adding two H atoms where the two rings join).
			Total	**1**	
66	a		**Structural isomers:** *1 mark* Different structural formulae AND same molecular formula ✓ **Common molecular formula:** *1 mark* C_5H_{12} for all 3 hydrocarbons ✓ **Boiling point and branching:** *1 mark* Boiling point decreases with more branching	**5**	For 'structural': **ALLOW** different structure **OR** different displayed/ skeletal formula **DO NOT ALLOW** any reference to spatial/space/3D Same formula is **not** sufficient (no 'molecular') Different arrangement of atoms is **not** sufficient (no 'structure'/'structural') **ALLOW** 5 carbons and 12 hydrogens **ALLOW** for 2 marks: Different structural formulae **AND** same molecular formula ✓ of C_5H_{12} ✓ **Comparisons** needed throughout **ORA** throughout **ALLOW** comparison between any alcohols, e.g. **A** is least branched and has highest b pt **C** is most branched and has lowest b pt **ALLOW** induced dipole(−dipole) interactions **IGNORE** van der Waals'/vdw forces **ALLOW** SA for surface area

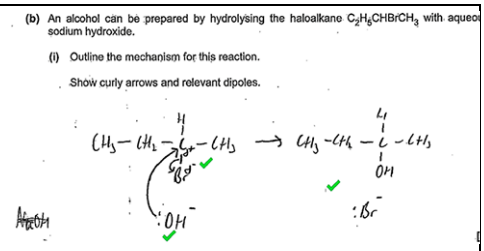
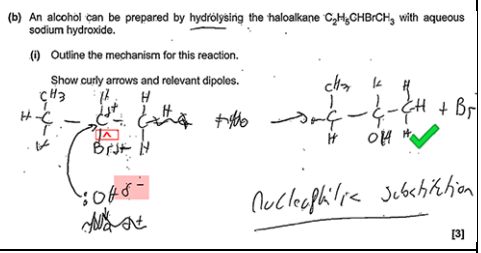
			OR more methyl/alkyl groups/side chains **OR** shorter carbon chain ✓ **Branching and London forces:** *1 mark* *Could be seen anywhere within response* More branching gives less (surface) contact **AND** fewer/weaker London forces ✓ **Energy and intermolecular forces:** *1 mark* Less energy to break London forces/ intermolecular forces/intermolecular bonds/ ✓		**ALLOW** 'harder to overcome intermolecular forces**ALLOW** more energy to separate the molecules **IGNORE** just 'bonds'***intermolecular/London forces*** *required* **Examiner's Comments** This question discriminated well and resulted in a full range of marks. Most candidates were aware that structural isomers have different structural formulae but the same molecular formulae. It was common though for candidates to refer to different arrangements of atoms in space, clearly confusing with stereoisomerism. The best candidates used the structures (as in the question) to show that the common molecular formula was C5H12. Candidates were expected to link the amount of surface contact between molecules with induced dipole–dipole forces or London forces. 'Contact' or the name of the intermolecular forces was often omitted. Finally, candidates were expected to link the amount of branching to the strength of the intermolecular forces and the energy needed to change state. Lower ability candidates often let themselves down by being unable to construct a well-reasoned response. There was often a gulf between the clear responses of able candidates and those of lower ability candidates.
	b		Enter text here.	Enter text here.	Enter text here.
		i	Radical substitution ✓	**1**	**ALLOW** Free radical substitution **Examiner's Comments**

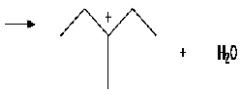
					Most candidates identified this reaction as radical substitution.
		ii	<table><tr><th>A</th><th>B</th></tr><tr><td>3 ✓</td><td>4 ✓</td></tr></table>	**2**	**Examiner's Comments** Most candidates achieved at least one mark, particularly for isomer **A**. Successful candidates often drew structures of the isomers alongside the table to help with their response.
		ii i	**Structure of D** Structure of a trichloro isomer of **A**, e.g.  ✓ **ALLOW** any trichloro isomer of A **CHECK** carefully **Equation** $C_5H_{12} + 3Cl_2 \rightarrow C_5H_9Cl_3 + 3HCl$ ✓ **Molecular formulae required** **NO ECF** from incorrect structure of **D**	**2**	**ALLOW** correct structural **OR** displayed **OR** skeletal formula **OR** mixture of the above (as long as unambiguous) **IGNORE** molecular formula **ALLOW** multiples, e.g. $2C_5H_{12} + 6Cl_2 \rightarrow 2C_5H_9Cl_3 + 6HCl$ **Examiner's Comments** Many candidates correctly drew the structure of compound D but comparatively few were able to construct a correct equation. For this equation, candidates needed to apply their knowledge and understanding of monosubstitution of alkanes to substitution of three H atoms by three Cl atoms. This task proved to be one of the most difficult questions on this paper. The exemplar shows an excellent response. The candidate has drawn a trisubstituted structure that fits the molar mass of 175.5 g mol^{-1} and a correct equation for its

					formation. Many attempts at this equation showed H2 as the second product rather than HCl. **Exemplar 6** 
			Total	**10**	
67	a	i	 	**3**	**ALLOW** correct structural **OR** displayed **OR** skeletal formulae **OR** mixture of the above (as long as unambiguous) **IGNORE** molecular formula **ALLOW** CH_3- **ALLOW** 1 mark for **G AND H** combined is structures are correct but in wrong boxes **Examiner's Comments** Part (i) discriminated extremely well and rewarded the well-prepared candidate. Compound F proved to be the most difficult option, with a large variety of responses, many appearing to be guesses. Candidates were much more successful with compounds **G** and **H**, although these were sometimes shown in reverse order. A significant number of candidates drew structures containing C=C or C=O bonds in which the carbon atom had five bonds. Candidates should check drawing of organic structures carefully to ensure that all carbon atoms have four bonds. There were some good responses

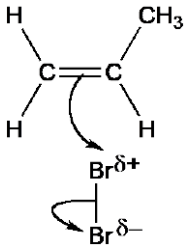
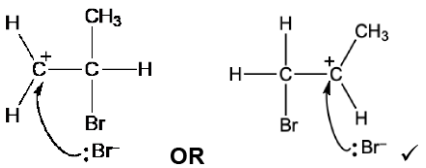
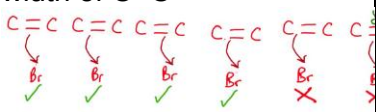
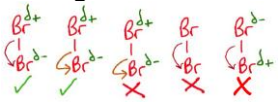
					for part (ii), with many clearly shown and correct systematic names.
		ii	2-methylpropan−1−ol ✓ *Both numbers required*	**1**	**IGNORE** absence of hyphen or use of dots or commas as separators **DO NOT ALLOW** 2−methylprop−1−ol **OR** 2−methpropan−1−ol **OR** 2−methypropan−1−ol
	b	i	**ANNOTATE ANSWER WITH TICKS AND CROSSES** --- **Curly arrows 2 marks** 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^+/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^- ✓ 	**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^-  • **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

			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		 Use curly arrow criteria in guidance above **Examiner's Comments** 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**

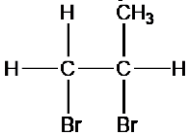
					 **Exemplar 8** 
		ii	**Disappearance** of peak at 500-800 cm^{-1} **OR** C–Br peak ✓ Appearance of peak at 3200-3600 cm^{-1} **OR alcohol** O–H peak	**2**	**ALLOW** value within range 500–800 $cmcm^{-1}$ **ALLOW** value within range 3200–3600 $cmcm^{-1}$ **DO NOT ALLOW** responses that only describe the spectrum shown **Examiner's Comments** 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	**9**	
68			**C**	1 (AO 1.2)	**Examiner's Comments**

					The majority of candidates were able to select 3-ethylhex-2-ene (C) as the correct name of the compound. A common incorrect response was D.
			Total	**1**	
69		i	Movement of an electron **pair** ✓	1 (AO 1.1)	For electron pair, **ALLOW** lone pair **OR** bonding pair **OR** 2 electrons **Examiner's Comments** Most candidates were able to state that a curly arrow shows the movement of a pair of electrons. However, many candidates gave responses that lacked precision, such as 'movement of electrons'. Such responses did not receive credit as the number of electrons was not specified.
		ii	 Correct carbon skeleton ✓ '+' charge on correct carbon skeleton ✓	2(AO 3.1 ×2)	**ALLOW** any combination of skeletal **OR** structural **OR** displayed formula as long as unambiguous **IGNORE** any other products **Examiner's Comments** This demanding question required candidates to apply their knowledge of curly arrows to an unfamiliar intermediate. Examiners were impressed by the number of good responses and many candidates were able to draw an organic product with the correct carbon skeleton. The best responses demonstrated candidates' flair for the subject and these recognised that a carbocation would be formed rather than an alkane.
		ii i	**Heterolytic** one (bonded) atom/O receives both/2 electrons ✓ **Fission**	2(AO 1.2)(AO 1.1)	**ALLOW** 2 electrons go to one (bonded) atom/O **IGNORE** formation of ions/radicals For O atom,

			Breaking of a **covalent** bond **OR** breaking of C-O bond ✓		**ALLOW** species **DO NOT ALLOW** element **OR** molecule 'Bond breaking' is **not** sufficient *(no reference to covalent)* **Examiner's Comments** Many candidates were able to describe the meaning of 'heterolytic', referring to both electrons going to the O atom. However, only some candidates described 'fission' and a significant proportion of these referred only to 'bond breaking'. The best responses correctly stated that fission is the breaking of a covalent bond. Candidate are encouraged to read questions carefully and take notice of words that appear in bold type as these often communicate what is expected in a question.
			Total	**5**	
70			**C**	1 (AO1.2)	**Examiner's Comments** Unsaturated, alicyclic and alkyl are all terms that are introduced in AS Chemistry and about two-thirds of candidates recognised that option C met the three criteria. From the annotations on scripts, most candidates ruled out the saturated option B. A sizeable number of candidates selected either the aromatic option A, or structure D which does not possess an alkyl group. It is important that candidates learn the terms introduced in the specification Section 4.1.1, Basic concepts in organic chemistry.
			Total	**1**	
71			**A**	1 (AO1.2)	**Examiner's Comments** Although the two structures were

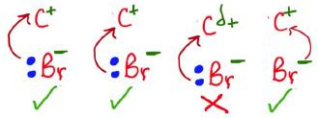
					the same molecule drawn in two different configurations, many candidates identified the structures as being structural isomers (C), rather than A.
			Total	**1**	
72	a		 **1st curly arrow** Curly arrow from double bond to Br of Br–Br ✓ **DO NOT ALLOW** partial charge on C=C **2nd curly arrow** Correct dipole on Br–Br **AND** curly arrow for breaking of Br–Br bond ✓ **3rd curly arrow** **Correct carbocation** with + charge on C with 3 bonds **AND** curly arrow from Br^- to C^+ of carbocation **DO NOT ALLOW** δ^+ on C of carbocation  ✓ *i.e.* ***ALLOW*** *carbonium + on either C atom*	4 (AO1.2) (AO1.2) (AO2.5) (AO2.5)	**ANNOTATE ANSWER** **For curly arrows, ALLOW straight or snake-like arrows and small gaps (see examples)** -------- **1st curly arrow** must • go to a Br atom of Br–Br **AND** • start from, OR be traced back to any point across width of C=C  **2nd curly arrow must** • start from, **OR** be traced back to, **any part of** $^{\delta+}$Br–Br$^{\delta-}$ bond • **AND** go to Br $^{\delta-}$  **3rd curly arrow must** • go to the C^+ of carbocation **AND** • start from, **OR** be traced back to **any point across width** of lone pair on $:Br^-$

Correct product to match mechanism ✓



DO NOT ALLOW half headed or double headed arrows but allow **ECF** if seen more than once

- **OR** start from – charge on Br^- ion



*(Lone pair **NOT** needed if curly arrow shown from – charge on Br^-)*

ALLOW bromonium ion

ALLOW any combination of skeletal **OR** structural **OR** displayed formula as long as unambiguous

NOTE: For a mechanism with HBr, **ALLOW** all marks **EXCEPT** for final product

Examiner's Comments

This question rewarded the well-prepared candidate and discriminated well. Conversely, many mechanisms showed little resemblance to the accepted mechanism for electrophilic addition.

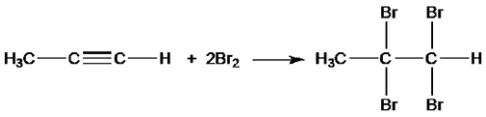
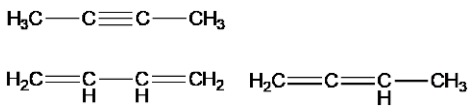
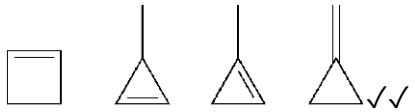
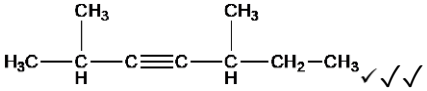
Mechanisms were often seen showing curly arrows going in the wrong direction and between the wrong bonds and atoms, with incorrect charges and dipoles, and partial charges used where full charges were required.

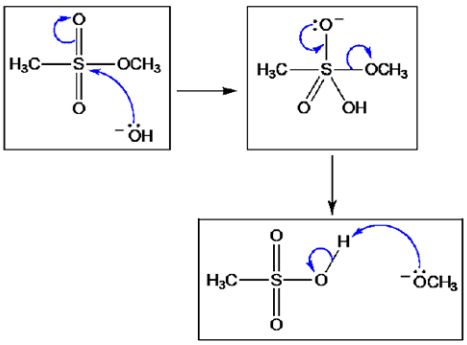
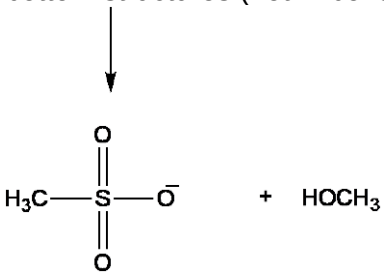
AfL

Writing mechanisms is an important skill in organic chemistry and candidates should learn and practice their writing.

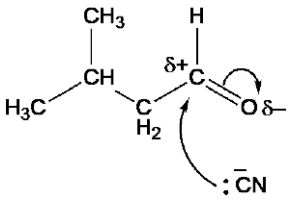
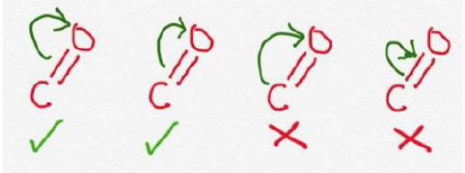
Our organic chemistry delivery

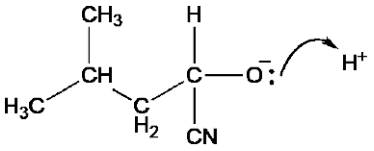
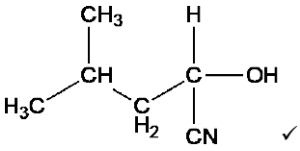
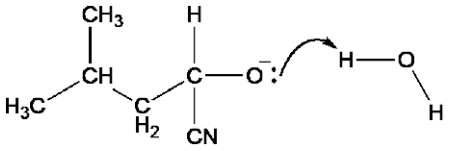
					guide contains links to some useful resources which can help students with their knowledge of mechanisms: https:/teachcambridge.org/item/c814aaeb-3e14-4ad8-b691-120110623bb8
	b	i	(series of organic compounds with the) same functional group **OR** same/similar reactions / chemical properties ✓ each successive member differs by CH_2 ✓	2 (AO1.1 ×2)	**IGNORE** reference to physical properties **IGNORE** same general formula **DO NOT ALLOW** same empirical **OR** molecular formula Differs by CH_2 is **not** sufficient (*no successive*) **ALLOW** differs by CH_2 each time **AW** **Examiner's Comments** Many candidates were aware that members of a homologous series have the same functional group and react in similar ways. A second mark was available for stating that the formula of successive members increases by CH_2. It is important to stress 'successive' in communicating this information.
		ii	C_nH_{2n-2} ✓	1 (AO3.2)	**ALLOW** $C_nH_{2(n-1)}$ **Examiner's Comments** This part required candidates to apply their understanding of a 'general formula' in a novel context. Many candidates analysed the provided formulae for the alkynes homologous series to derive the correct general formula of C_nH_{2n-2}. There was no real pattern in the incorrect responses which usually contained a mixture of numbers for the H atom, e.g. C_nH_{2n}, C_nH • n+1 .

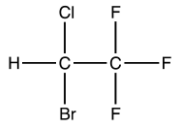
		ii i	 Left-hand side, i.e. Reactants, balanced with $2Br_2$ ✓ Right-hand side, i.e. Product ✓	2 (AO2.5) (AO2.6)	**ALLOW** any combination of skeletal **OR** structural **OR** displayed formula as long as unambiguous **ALLOW** C_3H_4 for $H_3CC{\equiv}CH$ *Questions asks only for structure of product* **ALLOW** $H_3CCBr_2CHBr_2$ **OR** $H_3CCBr_2CBr_2H$ **Examiner's Comments** Although attempted by most candidates, comparatively few responses could be credited. The key to success was again to use the information provided: the formation of a saturated compound. The commonest response seen showed addition of 1 Br_2 molecule to form the unsaturated $CH_3CBr{=}CHBr$ instead of the saturated $CH_3CBr_2{-}CBr_2$ by addition of 2 Br_2. This question was one of the most difficult on the exam paper.
		iv	Any **2** structures from:  	2 (AO3.2 ×2)	**ALLOW** any combination of skeletal **OR** structural **OR** displayed formula as long as unambiguous **Examiner's Comments** Most candidates achieved 1 of the available 2 marks for drawing the structure of but-2-yne, $CH_3C{\equiv}CCH_3$. The structure of but-1-yne was then usually drawn in the other box despite it being provided already in the table at the start of part (c). A variety of creditworthy structures were seen, including $H2C{=}CH{-}CH{=}CH_2$, cyclobutene and isomers of methylcyclopropane.
		v		1 (AO2.5)	**ALLOW** any combination of skeletal **OR** structural **OR** displayed formula as long as unambiguous

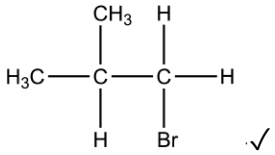
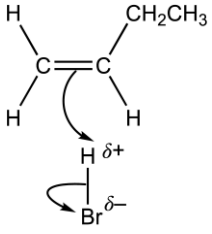
					Examiner's Comments It was encouraging to see the many correct structures drawn from the unfamiliar 2,5-dimethylhept-3-yne. Most candidates positioned the C≡C group and the two substituted CH_3 groups correctly. The commonest error was showing a main stem with 6, rather than 7 C atoms.
			Total	**12**	
73			 6 curly arrows correct ✓✓✓✓ 5 curly arrows correct ✓✓✓ 4 curly arrows correct ✓✓ 3 curly arrows correct ✓	4 (AO 3.1×4)	**IGNORE** any added charges **OR** dipoles. *Marks solely for curly arrows* **IGNORE** any curly arrows on bottom structures (not in boxes):  **Examiner's Comments** Most candidates showed a good understanding and appreciation of drawing curly arrows. It must be stressed that curly arrows that do not start from a lone pair, negative charge or a bond cannot be credited. Lower-attaining candidates often drew imprecisely positioned curly

					arrows, curly arrows in the wrong direction or to the wrong atoms. For their response to be credited with marks, candidates should position curly arrows to ensure credit when outlining reaction mechanisms.
			Total	**4**	
74			2-methylbutan-2-ol ✓	1 (AO1.2 ×1)	**Examiner's Comments** Nomenclature in organic chemistry takes lots of practice. Approximately half of the candidates did not score this mark. It was more challenging as they needed to work with skeletal structures but evidence of drawing out displayed formula was often seen.
			Total	**1**	
75			**A**	1 (AO1.2)	
			Total	**1**	
76			**D**	1 (AO1.2)	
			Total	**1**	
77			**C**	1 (AO2.5)	ALLOW 5
			Total	**1**	
78			**A**	1 (AO2.2)	
			Total	**1**	
79			2-bromo-3,3-dimethylbutane ✓	1 (AO1.2)	**IGNORE** lack of hyphens or addition of commas **ALLOW** 3,3-dimethyl-2-bromobutane **DO NOT ALLOW** methy for methyl

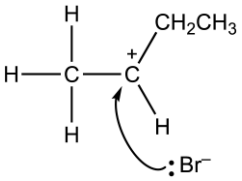
					methly for methyl brom for bromo **Examiner's Comments** **Misconception** Many candidates either reversed the order of the locant numbers for the bromo/dimethyl substituents or did not recognise the need for two locant numbers for the dimethyl group (e.g. 3,3 – often reported as just 3 dimethyl).
			Total	**1**	
80	a	i	(series of organic compounds with the) same functional group **OR** same/similar chemical properties/reactions ✓ each **successive/subsequent** member differs by CH_2 ✓	2 (AO1.1 ×2)	**IGNORE** reference to physical properties **IGNORE** same general formula **DO NOT ALLOW** same empirical **OR** molecular formula Differs by CH_2 is **not** sufficient (*no successive*)
		ii	$C_{24}H_{48}O$ ✓	1 (AO2.1)	
	b	i	**Mechanism** ***3 marks***  Curly arrow from ^-CN to C atom of C=O ✓ Dipole shown on C=O bond, $C^{\delta+}$ and $O^{\delta-}$, **AND** curly arrow from C=O bond to O atom ✓	5 (AO1.2) (AO1.2) (AO2.5) (AO2.5) (AO2.5) (AO1.1)	**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) Curly arrow from C=O bond must start from, OR be traced back to, any part of C=O bond and go to O  --- **ALLOW** curly arrow to H atom of H_2O, i.e.

			 Curly arrow from lone pair **OR** – charge on O^- of **correct** intermediate to H^+ ✓ --- **Product** ***1 mark***  ✓ --- **Name of mechanism** ***1 mark*** Nucleophilic addition ✓		 **IGNORE** attempt to draw curly arrow showing breaking of H–O in H_2O **IGNORE** lack of dipole on H_2O
		ii	**Heterolytic** One (bonded) atom/O receives both/2 electrons ✓ **Fission** Breaking of a **covalent** bond ✓	2 (AO1.2)	**ALLOW** 2 electrons go to one (bonded) atom/O **DO NOT ALLOW** both pairs of electrons go to O **IGNORE** formation of ions/radicals For O atom, **ALLOW** species **DO NOT ALLOW** element or molecule **ALLOW** π bond in C=O breaks **IGNORE** breaking of C=O bond (no reference to only one bond breaking) 'Bond breaking' is **not** sufficient *(no reference to covalent)* **<u>Examiner's Comments</u>** Candidates often referred to NaCN and HCN in their responses.

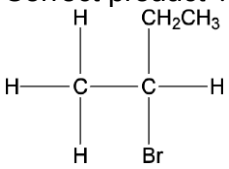
					Candidates who identified the correct bond breaking often then incorrectly wrote that the oxygen atom gained the lone pair of electrons.
			Total	**10**	
81			**B**	1 AO2.5	**ALLOW** 4
			Total	**1**	
82			**B**	1 AO1.1	
			Total	**1**	
83			**B**	1 AO1.2	
			Total	**1**	
84			**C**	1 AO2.2	
			Total	**1**	
85		i	 ✓	1 AO2.5	**ALLOW** any combination of skeletal **OR** structural **OR** displayed formula as long as unambiguous, e.g. $CF_3CHClBr$
		ii	FIRST, CHECK ANSWER IF answer = 7.224×10^{22}, award 2 marks --- $n(C_2HBrClF_3) = \frac{7.896}{197.4}$ **OR** 0.04(00) (mol) ✓ F atoms = $3 \times 0.0400 \times 6.02 \times 10^{23}$ $= 7.224 \times 10^{22}$ ✓ Minimum **3** SF required	2 AO2.2 ×2	**Alternative approaches** n(F atoms) = $\frac{7.896}{197.4} \times 3 = 0.12$ ✓ F atoms = $0.12 \times 6.02 \times 10^{23}$ $= 7.224 \times 10^{22}$ ✓ **OR** 3 mol F atoms $= 3 \times 6.02 \times 10^{23} = 1.806 \times 10^{24}$ ✓ F atoms = $1.806 \times 10^{24} \times 0.04$ $= 7.224 \times 10^{22}$ ✓ **OR** Mass F in 7.896 g $= \frac{57}{197.4} \times 7.896 = 2.28$ (g) ✓ F atoms = $\frac{2.28}{19} \times 6.02 \times 10^{23}$ $= 7.224 \times 10^{22}$ ✓ **ALLOW ECF** from incorrect $n(C_2HBrClF_3)$ **ALLOW** use of 6.022×10^{23} **OR** 6.023×10^{23}

					---------- **Common error** 2.408 × 10^{22} **OR** 2.41 × 10^{22} → 1 mark No × 3 1.806 × 10^{24} → 1 mark No $n(C_2HBrClF_3)$
			Total	**3**	
86		i	Same **molecular** formula **AND** Different **structural** formulae ✓	1 AO1.1	Same formula is **not** sufficient (*no reference to molecular*) Different arrangement of atoms is not sufficient (*no reference to structure/structural*) For structural formulae, **ALLOW** structure/displayed/skeletal formulae
		ii	 ✓	1 AO2.5	**ALLOW** any combination of skeletal **OR** structural **OR** displayed formula as long as unambiguous
			Total	**2**	
87		i	Butan-2-ol	1 (AO1.2)	
		ii	$(CH_3)_2CHCH_2OH + 2[O] \rightarrow (CH_3)_2CHCOOH + H_2O$ **B** as reactant: $(CH_2)_2CHCH_2OH$ ✓ $(CH_3)_2CHCOOH$ as product ✓ Correct equation with 2[O] and H_2O ✓	3 (AO2.5 × 2) (AO2.6)	**ALLOW** any combination of skeletal **OR** structural **OR** displayed formula as long as unambiguous If structure of **B** is a different primary or secondary alcohol, **ALLOW ECF** for product and equation
			Total	**4**	
88	a	i	 Curly arrow from C=C bond to H of H–Br ✓ **DO NOT ALLOW** partial charge on C=C Correct dipole shown on H–Br **AND** curly arrow showing breaking of H–Br bond ✓	4 (AO1.2 ×2) (AO2.5 ×2)	**NOTE**: curly arrows can be straight, snake like, etc. but **NOT** double headed or half headed arrows **1st curly arrow must** • go to the H atom of H–Br **AND**

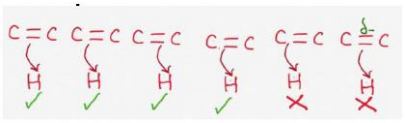
Correct carbocation
AND curly arrow from Br^- to C^+ of carbocation ✓
DO NOT ALLOW δ+ on C of carbocation



Correct product ✓

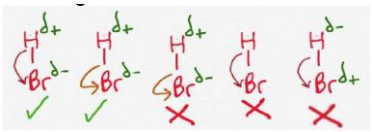


- start from, **OR** be traced back to **any point across width** of C=C



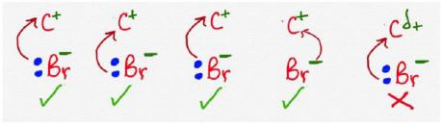
2nd curly arrow must

- start from, **OR** be traced back to **any part of** $^{\delta+}H–Br^{\delta-}$ bond
  AND
- go to $Br^{\delta-}$



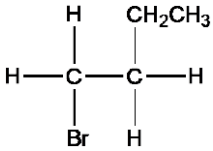
3rd curly arrow must

- go to the C+ of carbocation
  AND
- start from, **OR** be traced back to any point across width of lone pair on $:Br^-$
- **OR** start from – charge of Br^- ion



*(Lone pair **NOT** needed if curly arrow shown from – charge of Br^- ion)*

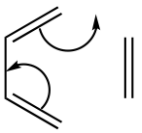
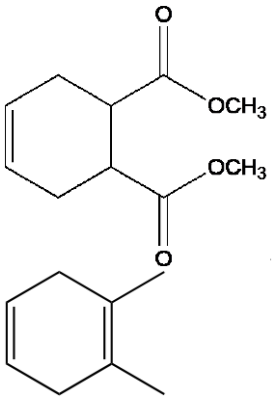
ALLOW ECF for product from incorrect carbocation, i.e.

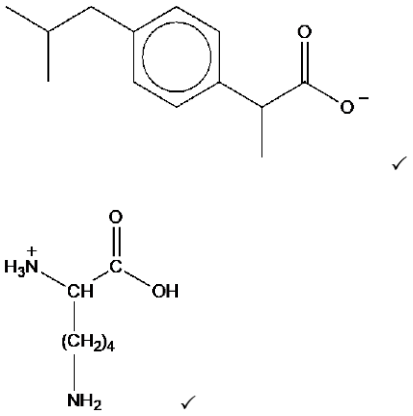
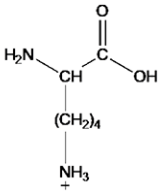
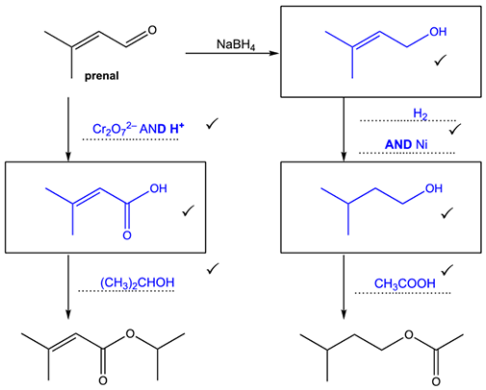
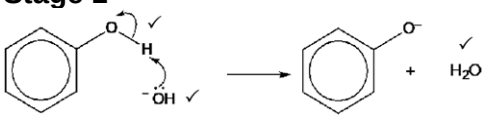


IF Br_2 is used instead of HBr contact your Team Leader

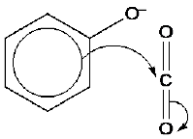
Examiner's Comments

					This was answered well by students. Many candidates included correct dipoles and charges. Curly arrows were frequently well-positioned. Few candidates attempted to make the minor product.
		ii	(major product forms from) most/more stable intermediate/carbocation ✓ (major product forms from a) secondary carbocation **OR** carbocation bonded to more C atoms / more alkyl groups **OR** carbocation bonded to fewer H atoms ✓	2 (AO1.1) (AO1.2)	For carbocation, **ALLOW** carbonium ion or cation **IGNORE** descriptions of the major/minor product in terms of Markownikoff's rule e.g. H atom joins to C with most H **IGNORE** references to stability of the product --- **ALLOW ORA**, i.e. (minor product forms from) least/less stable intermediate/carbocation ✓ (minor product forms from a) primary carbocation **OR** carbocation bonded to less C atoms / less alkyl groups **OR** carbocation bonded to more H atoms ✓ **Examiner's Comments** **Misconception** Some candidates explained the formation of the major organic product in terms of the stability of the product, rather than referring to the stability of the intermediate. Many responses also stated Markownikoff's rule – rather than explaining their response.
		iii	3 ✓	1 (AO1.2)	

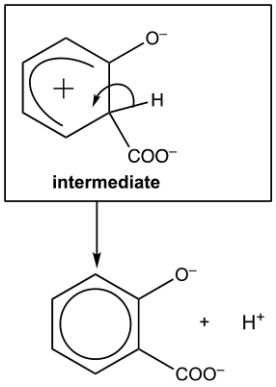
	b	i	 1 mark for each curly arrow ✓✓	2 (AO2.5 ×2)	**IGNORE** any dipoles shown **NOTE**: curly arrows can be straight, snake-like, etc. but **NOT** half headed or double headed arrows **Curly arrow** from C=C bond must start from, **OR** be traced back to, **Lower left: any part of** C=C bond and go to C–C **Upper left: any part of** C=C bond and go to gap between C=C and C=C **Examiner's Comments** Many candidates did not apply their knowledge of curly arrows to this unfamiliar context. Those that scored a mark often did so for the top curly arrow but missed the requirement of the second curly arrow.
		ii		2 (AO3.2 ×2)	**Examiner's Comments** Many candidates did not correctly answer this question with products being given that had too few carbon atoms.
			Total	**11**	
89	a	i	$C_{13}H_{18}O_2$ ✓	1 (AO2.1)	**ALLOW** C, H and O in any order
		ii	**FIRST CHECK ANSWER ON THE ANSWER LINE** **If answer = 1.17 × 10_{21} award 3 marks** *M*(ibuprofen) = 206 ✓ *n*(ibuprofen) = $\frac{400 \div 1000}{206}$ = 1.94×10^{-3} (mol) ✓ Number of molecules = $1.94 \times 10^{-3} \times 6.02 \times 10^{23}$ = 1.17×10^{21} to **3 SF** ✓	3 (AO2.2 × 3)	**ALLOW ECF** from **(c)(i)** Calculator: $1.941747573 \times 10^{-3}$ **ALLOW ECF** from *n*(ibuprofen) **3 SF** essential

	b	i		2 (AO3.2 × 2)	**IGNORE** small slip in carbon chains  **ALLOW**
		ii	More soluble in water ✓	1 (AO3.1)	**Answer must be a comparison** **ALLOW** dissolve faster/quicker **IGNORE** absorbed more quickly (given in question)
			Total	**7**	
90		i	3-methylbut-2-enal ✓	1 (AO1.2)	**IGNORE** lack of hyphens, or addition of commas
		ii		7 (AO1.2 ×4) (AO2.5 ×3)	**ALLOW** any combination of skeletal **OR** structural **OR** displayed formula as long as unambiguous **ALLOW** names of reagents and catalyst For oxidation, **ALLOW** $K_2Cr_2O_7$ for $Cr_2O_7^{2-}$ **ALLOW** H_2SO_4 for H^+ For left hand side esterification **IGNORE** C_3H_7OH **IF** esterification is given instead of hydrogenation contact your Team Leader
			Total	**8**	
91		i	**Stage 1**  1 mark for each curly arrow as shown. **Stage 2** Curly arrow from π-ring to C in CO_2 **AND**	6 (AO1.1) (AO1.2) (AO2.5) (AO2.5) (AO2.5	**ANNOTATE WITH TICKS AND CROSSES** **NOTE**: curly arrows can be straight, snake-like, etc. but **NOT** double headed or half headed arrows **Curly arrow** from OH^- must

curly arrow from the C=O bond to O atom ✓

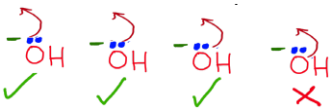


Correct intermediate ✓ Curly arrow from C–H bond to reform π-ring
AND H^+ formed ✓

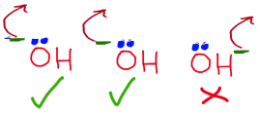


)
(AO1.2
)

- go to the H of O–H
  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



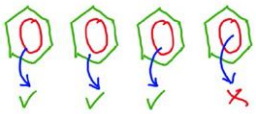
Curly arrow from O–H bond must start from, **OR** be traced back to, **any part of** O–H bond and go to O

IGNORE dipoles on O-H bond

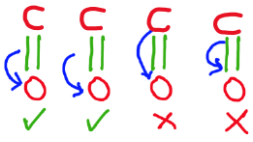
IGNORE Na^+

1st curly arrow must

- go to the C of CO_2
  AND
- start from, **OR** close to **circle of benzene ring**

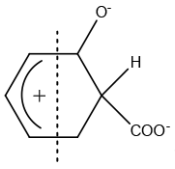
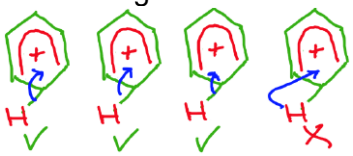
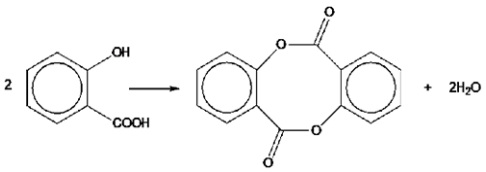


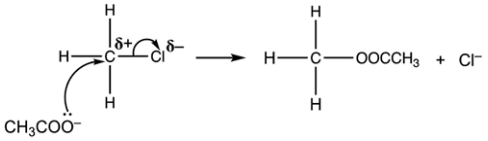
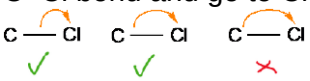
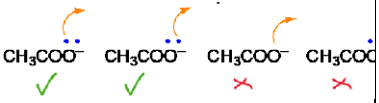
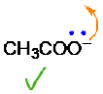
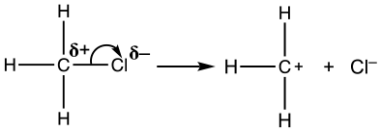
2nd curly arrow must start from, **OR** be traced back to, **any part of** C=O bond and go to O



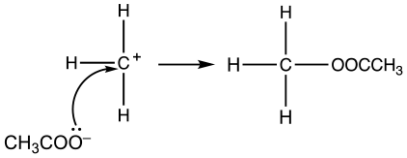
ALLOW 2nd curly arrow from C=O to any O in CO_2

DO NOT ALLOW the following intermediate:

					 π-ring must cover more than half of the benzene ring structure **AND** the correct orientation, *i.e.* gap towards C with CO_2^- **ALLOW** + sign anywhere inside the 'hexagon' of the intermediate. **DO NOT ALLOW** mark for intermediate if phenolic O– is missing **curly arrow** must start from, **OR** be traced back to, **any part of** C-H bond and go inside the 'hexagon'  **Examiner's Comments** Candidates who answered this question well had clear mechanisms. Too often positioning of curly arrows was ambiguous.
		ii	OH^- : base ✓ CO_2: electrophile **OR** electron pair acceptor ✓	2 (AO2.1 ×2)	**ALLOW** alkali **IGNORE** 'nucleophile', 'donates electron pair' **IGNORE** lone pair acceptor (*No lone pair involved*)
		iii	 One ester link in organic product ✓ Correct structure of organic product ✓ Correct equation **AND** balanced ✓	3 (AO3.1) (AO3.2) (AO2.6)	**Examiner's Comments** Candidates who found this question difficult often did not recognise the functional groups present in the reacting molecule. Those that identified an esterification reaction often then did not balance the equation.
			Total	**11**	

92			**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⁻** Curly arrow from CH_3COO^- to C atom of C–X bond ✓ --- **Products** Correct organic product **AND** X^- ✓	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 • 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) ✓

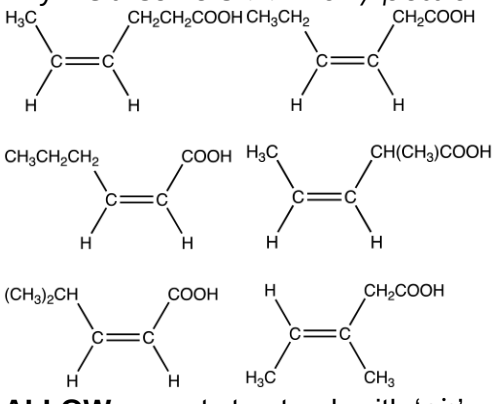
Third mark
Correct organic product **AND** Cl^- ✓

Examiner's Comments

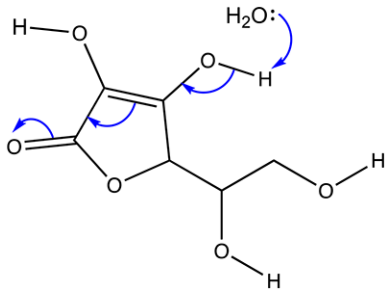
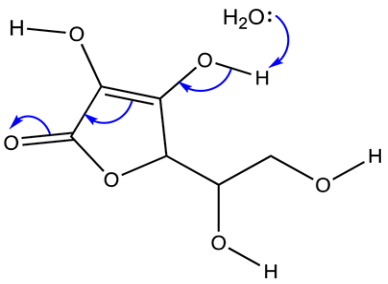
Candidates were required to apply their knowledge of nucleophilic substitution of haloalkanes to outline a similar mechanism for an unfamiliar nucleophile.

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**	
93			$n(Ba(OH)_2) = 0.150 \times \frac{23.50}{1000}$ $= \mathbf{3.525} \times \mathbf{10^{-3}}$ (mol) ✓ n(**D**) in 25.0 $cm^3 = 2 \times 3.525 \times 10^{-3}$ $= \mathbf{7.05} \times \mathbf{10^{-3}}$ (mol) ✓ n(**D**) in 100 $cm^3 = 7.05 \times 10^{-3} \times \frac{100}{25.0}$ $= \mathbf{0.0282}$ (mol) ✓ **Molar mass** (**D**) $= \frac{3.215}{0.0282} = \mathbf{114}$ (g mol^{-1}) ✓ **Formula**: = C_5H_9COOH **OR** C_nH_{2n-1}: $M(C_5H_9) = 114 - 45 = 69$ ✓ *If not stated, could be credited from structure* ***cis* stereoisomers.** The drawn stereoisomers must have • Different groups attached to each C atom of C=C • Each C of C=C has the same group on the same side Any 2 *cis* isomers ✓✓ *Many possibilities*, e.g.  **ALLOW** correct structural, with '*cis*' part displayed **OR** skeletal **OR** displayed formula **OR** mixture of above as long as non-ambiguous **ALLOW** side chains as molecular formula, e.g. C_3H_7 for $(CH_3)_2CH$ **OR** $CH_3CH_2CH_2$ e.g. $C_3H_5O_2$ for CH_2CH_2COOH	7 (AO2.8 ×4) (AO3.2 ×1) (AO3.2 ×2)	**Use ECF throughout** Intermediate values for working to **at least 3 SF**. **TAKE CARE** as value written down may be truncated value stored in calculator. Depending on rounding, either can be credited. --- **ALLOW** Mass **D** in 25.0 $cm^3 = \frac{3.215}{4} = 0.80375$ g **Molar mass** (**D**) $= \frac{0.80375}{7.05 \times 10^{-3}} = 114$ **COMMON ERRORS:** *Up to Molar mass = 114 (1st 4 marks)* $M = 456 \rightarrow$ 3/4 marks (mol in 100 cm_3 omitted) $M = \frac{3.215}{7.05 \times 10^{-3}} = 456$ $M = 228 \rightarrow$ 3/4 marks (*No × 2 for n(D)*) $3.525 \times 10^{-3} \times \frac{100}{25.0} = 0.0141$ $M = \frac{3.215}{0.0141} = 228$ $M = 100.8 \rightarrow$ 3/4 marks *23.50 instead of 25.00 and scaling by* $\times \frac{100}{23.50}$ $25.0 \times \frac{0.150}{1000} = 3.75 \times 10^{-3}$ X $\rightarrow 2 \times 3.75 \times 10^{-3} = 7.5 \times 10^{-3}$ ✓

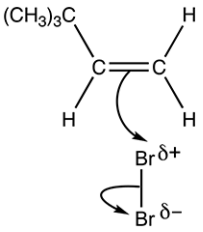
			IGNORE poor connectivity to all groups		→ $7.5 \times 10^{-3} \times \frac{100}{23.50} = 0.0319$ ✓ → $\frac{3.215}{0.0319}$ → 100.8 ✓ **THEN ALLOW ECF** for carboxylic acid closest to calculated *M*(alkyl group) but must be C_nH_{2n-1} e.g. For ***M(alkyl)* = 100**, **ALLOW** C_4H_7 (55) For ***M(alkyl)* = 411**, **ALLOW** $C_{29}H_{57}$ (405) **OR** $C_{30}H_{59}$ (419) **THEN** judge *cis* isomers with closest match **ALLOW** 1 mark for 2 *trans* isomers shown instead of 2 *cis* isomers ***ECF*** *for Same error made twice.* **Examiner's Comments** As with Question 2, candidates had more success with the mole calculation in (b) than the descriptive response in (a). Most candidates followed a set procedure to show that the molar mass of the acid was 114, and to then show that the formula must be C_5H_9COOH. Correct cis stereoisomers were seen more rarely. One structure was often repeated in both boxes and the structures seen sometimes had C or H atoms missing. When errors were made with the calculation, these usually stemmed from the scaling up by a factor of 4 in going from 25 cm^3 to 100 cm^3. Some candidates omitted this stage, obtaining a molar mass value of 456. Others scaled up by a factor of 10 to 250 cm^3, obtaining a molar mass of 45.6. Both errors made it very difficult to make further progress. If candidates get into this situation, they are advised to check back through their calculation – it should be obvious

					that there is a critical error somewhere in the working.
			Total	**7**	
94	a		A species with an unpaired electron ✓	1 (AO1.1)	**DO NOT ALLOW:** species with **one** electron
	b		Homolytic (fission) ✓	1 (AO1.1)	
			Total	**2**	
95		i	 3 **OR** 4 curly arrows correct → 2 marks ✓ ✓ 1 curly arrow correct → 1 mark ✓	2 (2 ×AO3.2)	**IGNORE incorrect curly arrows** **IGNORE** 'double' curly arrows such as:  **H_2O Curly arrow** must • start from, **OR** be traced back to **any point across width** of lone pair on H_2O**:** **<u>Examiner's Comments</u>** This novel mechanism assessed a candidate's understanding of curly arrows, and four curly arrows were needed. One mark was available for one correct curly arrow, usually from the H_2O: or from the C=O. 2 marks were given for three or four correct curly arrows. The two curly arrows within the ring structure proved to be the most difficult. The question discriminated extremely well: many candidates were able to secure one mark with the most able being given both marks. A candidate showing all four curly arrows correctly demonstrated an

					excellent understanding of curly arrows.
		ii	**FIRST CHECK ANSWER ON THE ANSWER LINE** **If answer = 2.16 award 3 marks** --- [Vitamin C] = 0.150 × 4 = 0.600 (mol dm^{-3}) ✓ *0.6 seen anywhere* $[H^+] = \sqrt{(K_a \times [\text{Vitamin C}])}$ $= \sqrt{(7.94 \times 10^{-5} \times 0.600)}$ $= 6.90 \times 10^{-3}$ (mol dm^{-3}) ✓ pH = -log $[H^+]$ = -log 6.90×10^{-3} = 2.16 ✓ **2 DP required**	3 (2 ×AO2.4) (1 ×AO1.2)	**For $[H^+]$** **ALLOW ECF** from incorrect [vitamin C] for pH **ALLOW ECF ONLY** if $[H^+]$ has been derived from K_a **AND** [vitamin C] --- **COMMON ERRORS** pH = 4.32 2/3 calculation marks *No square root of* $(7.94 \times 10^{-5} \times 0.600)$ pH = 2.46 2/3 calculation marks *No ×2 4* $(7.94 \times 10^{-5} \times 0.150)$ pH = 2.76 2/3 calculation marks *÷ 4* $(7.94 \times 10^{-5} \times 0.0375)$ pH = 4.92 1/3 calculation mark *No square root AND 0.150* pH = 5.53 1/3 calculation mark *No square root AND 0.0375* **Examiner's Comments** Most candidates had learnt a standard method for calculating the pH of a weak acid. with the correct answer of 2.16 being seen on very many scripts. Success required conversion of 0.150 moles of vitamin C in 250 cm^3 to its concentration as 0.600 mol^{-3}, calculation of $[H^+]$ using $[H^+] = \sqrt{(K_a \times [HA])}$ and determination of pH using -log$[H^+]$. Common errors usually resulted from one mistake and could still be rewarded with 2 of the available 3 marks. Examples are shown below. • pH = 4.32 *No square root of* $(7.94 \times 10^{-5} \times 0.600)$ • pH = 2.46 *No conversion of 0.150 mol to 0.600 mol* $dm^{-3} \rightarrow (7.94 \times 10^{-5} \times 0.150)$

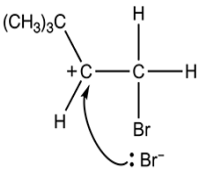
					• pH = 2.76 ÷ 4 instead of × 4 for concentration → (7.94 × 10^{-5} × 0.0375) **AfL** pH calculations are common in A Level Chemistry There are four different types, and it is essential that the standard methods for determination of $[H^+]$ in the calculations are **learnt**: • pH of strong acids • pH of weak acids, using K_a and [HA] • pH of strong bases, using Kw and $[OH^-]$ • pH of buffers, using K_a and $[HA]/[A^-]$ It is extremely likely that at least one of these types of pH calculation will feature in at least one of the A Level units.
			Total	**5**	
96			**C**	1(AO1.2)	**ALLOW** 12 **Examiner's Comments** Most candidates selected the correct response. Where an error had been made, it was usually option B, the result of ignoring the two tertiary H atoms.
			Total	**1**	
97			**A**	1(AO2.5)	**Examiner's Comments** Candidates found this question hard with many selecting C or D instead of the correct option, B. Candidates appeared to have assigned the C–H absorption at 3000 cm^{-1} to an O–H group (from

					an alcohol or carboxylic acid). Candidates should appreciate that this C–H absorption will be present in any organic compound possessing a C–H group (that is, nearly all organic compounds).
			Total	**1**	
98			**C**	1(AO2.5)	**Examiner's Comments** Compared to Question 19, candidates had more success with this question. Most drew out all the bonds in each structure, a good approach that should allow the candidate to identify the compound that would produce the three peaks.
			Total	**1**	
99		i	3,3-dimethylbut-1-ene ✓ **CARE**: Look for **di**methyl	1 (AO1.2 ×1)	**IGNORE** lack of hyphens, or addition of commas or spaces **ALLOW** full stops or spaces between numbers e.g. 3.3 dimethyl but-1-ene **DO NOT ALLOW** meth **OR** methy **Examiner's Comments** Candidates had difficulty in naming this compound correctly as 3,3-dimethylbut-1-ene. Many counted an incorrect number of carbons in the chain, numbered substituents from the wrong end (e.g. 1,1,1-) or used insufficient numbering (e.g. 3-dimethyl). Hex-1-ene was a common incorrect answer, presumably as there are six carbon atoms and one C=C double bond in the alkene
		ii	**ANNOTATE ANSWER WITH TICKS AND CROSSES**	5 (AO1.2) (AO1.2) (AO2.5) (AO2.5)	**For curly arrows, ALLOW straight or snake-like arrows and small gaps (see examples):** **1st curly arrow** must • go to a Br atom of Br–Br **AND** • start from, **OR** be traced back to **any point across width** of C=C



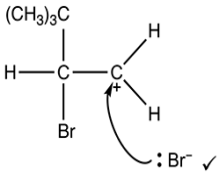
or

1st curly arrow (from ANY alkene)
Curly arrow from double bond to Br of Br–Br ✓
DO NOT ALLOW partial charge on C=C
2nd curly arrow
Correct dipole on Br–Br
AND curly arrow for breaking of Br–Br bond ✓
3rd curly arrow
Correct carbocation with + charge on C with 3 bonds
AND curly arrow from Br^- to C^+ of carbocation
DO NOT ALLOW δ+ on C of carbocation

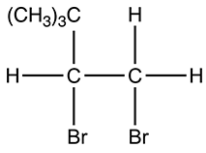


or

OR



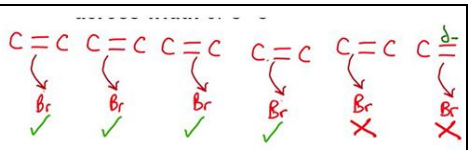
i.e. ***ALLOW*** *carbonium + on either C atom*
Correct product to match mechanism/intermediate ✓



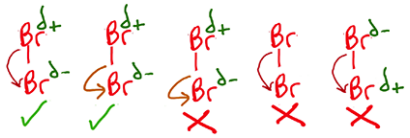
or

DO NOT ALLOW half headed or double headed arrows but allow **ECF** if seen more than once
Name of mechanism: Electrophilic addition ✓

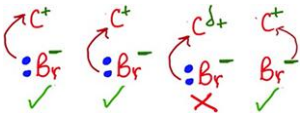
(AO1.1)



2nd curly arrow must
• start from, **OR** be traced back to, **any part** of $^{\delta+}Br–Br^{\delta-}$ bond
• **AND** go to $Br^{\delta-}$



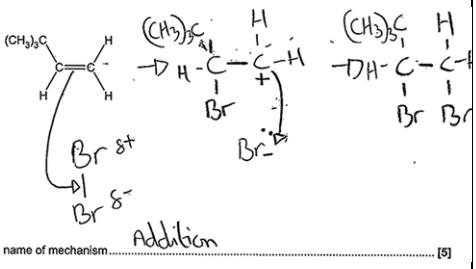
IGNORE connectivity of CH_3 groups in carbocation and product and **ALLOW** C_4H_9
3rd curly arrow must
• go to the C^+ of carbocation
AND
• start from, **OR** be traced back to **any point across width** of lone pair on $:Br^-$ • **OR** start from – charge on Br^- ion



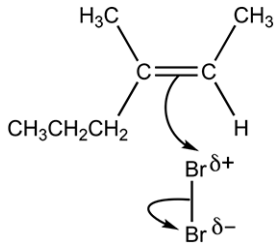
(Lone pair NOT needed if curly arrow shown from – charge on Br⁻)
ALLOW bromonium ion
ALLOW any combination of skeletal **OR** structural **OR** displayed formula as long as unambiguous
NOTE: For a mechanism with HBr, ALLOW all marks EXCEPT for final product mark

Examiner's Comments

Many candidates answered the mechanism proficiently. However, many mistakes were seen with the direction of arrows, and confusing δ+/ δ– and +/– charges. In the intermediate carbocation, the C=C was often left intact and δ– used on the bromide ion attacking the intermediate. Some less successful

					responses did not position curly arrows accurately. One common error was showing one or more C atoms missing from the $(CH_3)C$ groups. Candidates should take great care when drawing organic structures to make sure that all groups have been drawn accurately. Exemplar 1  name of mechanism ..... [5] This exemplar has been included to emphasise the importance of accurately placed curly arrows and use of charges. It was only possible to award this response 1 out of 5 marks. With a few improvements, this response could easily have been 5/5. The start of the first curly arrow has been placed accurately starting from the C=C double bond but the arrow should have finished at the $Br^{\delta+}$: 0 marks The Br–Br dipole is correct but there is no curly arrow showing it breaking: 0 marks The intermediate carbocation is correct but the curly arrow should have been shown from a lone pair on the Br^- ion to the + charge of the carbocation: 0 marks The product is correct: 1 mark The reaction type is addition but the name of the mechanism is electrophilic addition: 0 marks

					Assessment for learning Reactions mechanisms are the organic chemist's way of communicating electron transfers in organic chemistry. Candidates must use curly arrows, dipoles and charges 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	**6**	
100			A	1 (AO1.1)	**Examiner's Comments** Most candidates correctly selected A. The most common incorrect response was option D as candidates had misinterpreted the amide group as a ketone and an amine.
			Total	**1**	
101	a	i	3-methylhex-2-ene ✓	1 (AO1.2)	**IGNORE** lack of hyphens, or addition of commas **DO NOT ALLOW** 3-methyhex-2-ene OR 3-methhex-2-ene OR 3-methlyhex-2-ene OR 3-methylhexan-2-ene **IGNORE** references to *E*/*Z* or *cis*/*trans*
		ii	**ANNOTATE ANSWER WITH TICKS AND CROSSES**	3 (AO1.2 ×1) (AO2.5 ×2)	**ALLOW** any combination of skeletal **OR** structural **OR** displayed formula as long as unambiguous **IGNORE** connectivity of

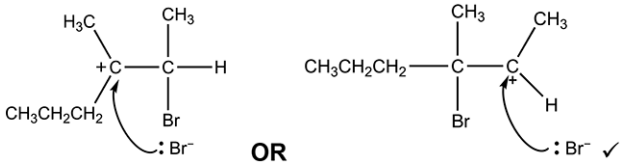


Curly arrow from C=C bond to $Br^{\delta+}$ of Br–Br

AND

Correct dipole on Br–Br
AND
curly arrow for breaking of Br–Br bond ✓

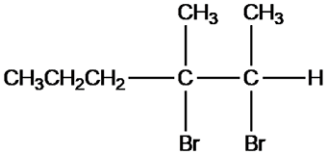
Correct carbocation to match mechanism
AND curly arrow from Br^- to C^+ of carbocation



OR

i.e. ALLOW *carbonium + on either C atom*

Correct product to match mechanism ✓



$CH_3CH_2CH_2$ and CH_3 groups in carbocation and product
ALLOW C_3H_7 for $CH_3CH_2CH_2$

DO NOT ALLOW half headed or double headed arrows but allow **ECF** if seen more than once

DO NOT ALLOW use of HBr but ECF for subsequent use

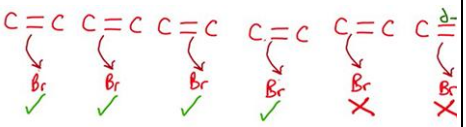
For curly arrows, ALLOW straight or snake-like arrows and small gaps (see examples):

DO NOT ALLOW partial charge on C=C

1st curly arrow must

• go to a Br atom of Br–Br

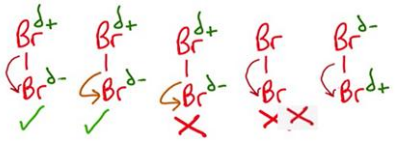
AND
start from, **OR** be traced back to **any point across width** of C=C

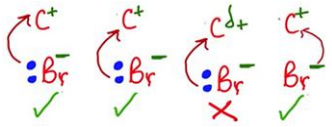


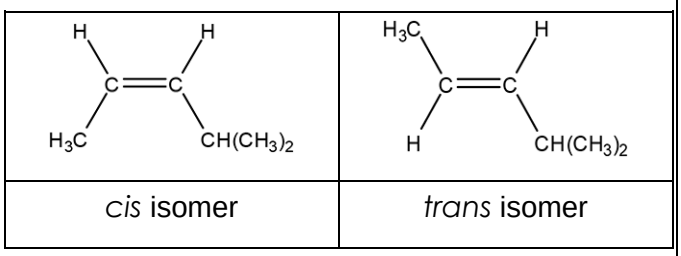
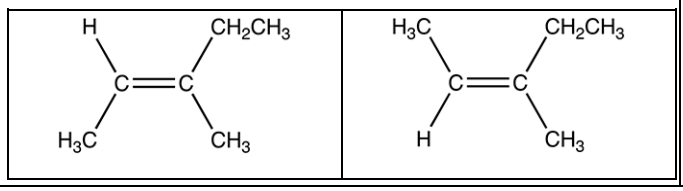
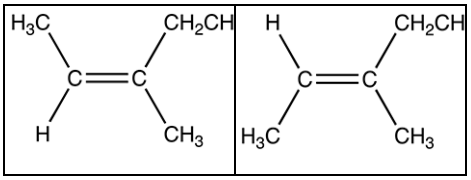
2nd curly arrow must

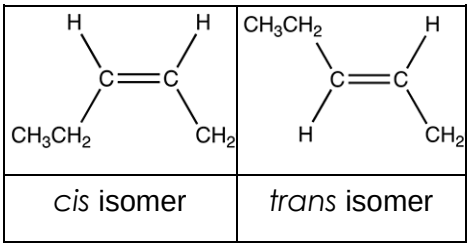
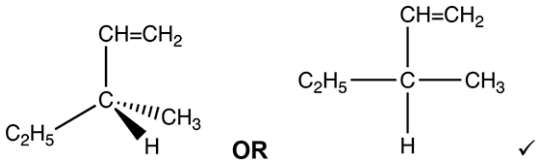
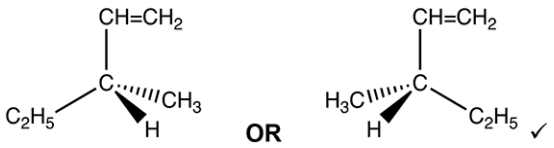
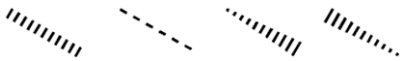
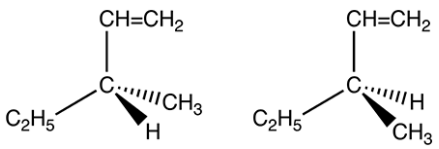
• start from, **OR** be traced back to, **any part of** $^{\delta+}$Br–Br$^{\delta-}$ bond

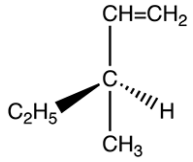
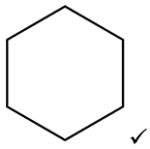
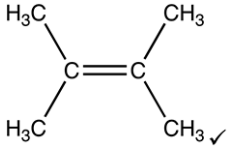
• **AND** go to Br $^{\delta-}$

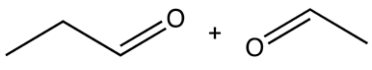
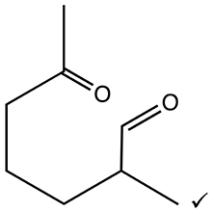
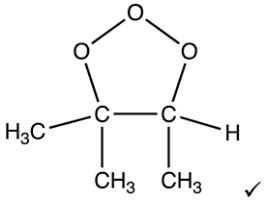


					3rd curly arrow must • go to the C^+ of carbocation **AND** • start from, **OR** be traced back to **any point across width** of lone pair on $:Br^-$ • **OR** start from – charge on Br^- ion  *(Lone pair **NOT** needed if curly arrow shown from – charge on Br^-)* **ALLOW** bromonium ion (Contact TL) **Examiner's Comments** The majority of candidates were able to correct name hydrocarbon **A** as 3-methylhex-2-ene. A number of responses used incorrect numbering or suggested 3-methylhexan-2-ene as the name. Candidates are familiar with the mechanism for the bromination of hydrocarbons. So, the majority of candidates scored 3 marks. Common errors included the use of HBr rather than Br_2 or putting a dipole on the carbon-carbon double bond.
	b	i	Same **molecular** formula **AND** Different **structural** formulae ✓	1 (AO1.1)	Same formula is **not** sufficient *(no reference to molecular)*

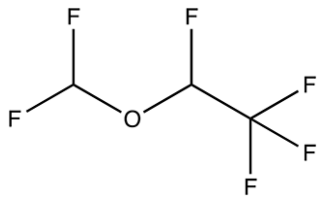
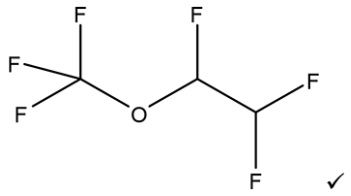
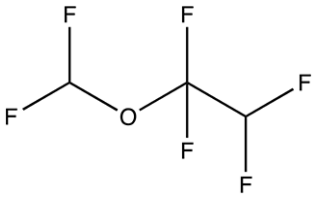
			OR Both have the **molecular** formula C_6H_{12} **AND** Different **structural** formulae ✓		Different arrangement of atoms is **not** sufficient *(no reference to structure/structural)* For 'structural formulae', **ALLOW** structure/displayed/skeletal formulae/functional groups **DO NOT ALLOW** any reference to spatial/space
		ii	Same structural formula **AND** Different arrangement (of atoms) in **space** **OR** different **spatial** arrangement (of atoms) ✓	1 (AO1.1)	**ALLOW** structure/displayed/skeletal formula **DO NOT ALLOW** same empirical formula **OR** same general formula **IGNORE** same molecular formula Reference to *E*/*Z* isomerism or optical isomerism is **not** sufficient
		ii i	Correct identification of *cis* **AND** *trans* isomers of 4-methylpent-2-ene ✓✓  *cis* isomer | *trans* isomer **OR** Identification of 3-methylpent-2-ene as *cis* **AND** *trans* isomers ✓✓  	2 (AO1.2) (AO2.5)	**ALLOW** any combination of skeletal **OR** structural **OR** displayed formula as long as unambiguous C_3H_7 is **not** sufficient (could be unbranched) **ALLOW** one mark if *cis* **AND** *trans* isomers of 4-methylpent-2-ene are in the wrong boxes **ALLOW** the isomers of 3-methylpent-2-ene in either box 

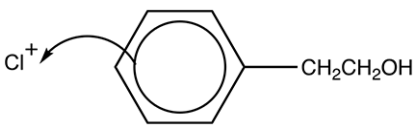
			<table><tr><td>*cis* isomer</td><td>*trans* isomer</td></tr></table>		<table><tr><td>*cis* isomer</td><td>*trans* isomer</td></tr></table> *Ambiguity with cis/trans identification system* **ALLOW** one mark for correct identification of *cis* **AND** *trans* isomers of unbranched C_6H_{12} e.g.  *cis* isomer *trans* isomer
		iv	Correct groups attached to chiral carbon of compound C seen **once** e.g.  ✓ Two **3D structures** of compound C that are mirror images with correct connectivity in both  ✓	2 (AO2.5 ×2)	**ALLOW** any combination of skeletal **OR** structural **OR** displayed formula as long as unambiguous For C_2H_5–, ALLOW CH_3CH_2– For –$CH{=}CH_2$, ALLOW –C_2H_3 OR –$CHCH_2$ For bond into paper accept:  **ALLOW** two 3D structures with 2 groups swapped e.g.  **DO NOT ALLOW** a bond angle of

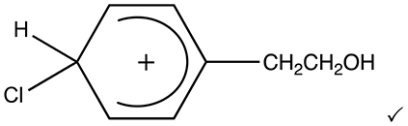
					180° e.g. 
		v	 ✓	 ✓	**ALLOW** 1 mark for structures if shown in wrong boxes. **CHECK** table 16.1 for annotations that may be worthy of credit
			D	**E**	
			Two of the following for **D** ✓ • All H are equivalent/in the same chemical environment/ the same type • All C are equivalent/ in the same chemical environment/ the same type • No C=C present Two of the following for **E** ✓ • All H are equivalent/ in the same chemical environment/ the same type • 2 C environments • C=C present	4 (AO2.5 ×2) (AO2.2 ×2)	**Examiner's Comments** The majority of candidates were able to correctly define a structural isomer. This definition was well known by candidates with the majority of responses given the mark. Some candidates omitted the reference to structural formula. This question required candidates to link their knowledge of *cis* and *trans* isomers with branched hydrocarbons. Higher ability candidates were able to do this. The majority of candidates scored 1 mark for correctly drawing *cis* and *trans* isomers of an unbranched hydrocarbon. This question discriminated well. Candidates were required to identify the groups around a chiral carbon This question discriminated

					well. Candidates were required to identify the groups around a chiral carbon and then draw the two corresponding optical isomers. Incorrect responses frequently had incorrect connectivity around the chiral carbon, bond angles of 180° or 2D structures. Most candidates were able to correctly draw the structure of D and E. Many candidates did not explain their answers in terms of the number of different hydrogen and carbon environments or the presence/absence of a carbon-carbon double bond.
	c	i	 **BOTH** structures required for ✓ 	2 (AO3.1 ×1) (AO3.2 ×1)	**ALLOW** any combination of skeletal **OR** structural **OR** displayed formula as long as unambiguous
		ii		1 (AO3.2)	**ALLOW** any combination of skeletal **OR** structural **OR** displayed formula as long as unambiguous **Examiner's Comments** Most candidates were able to score 1 mark for correctly drawing the structures of the two aldehyde products of the first reaction. The

					second reaction proved more challenging, with most candidates incorrectly drawing two products. Few candidates were given this mark. A common error was to produce multiple products (rather than a ring structure) or to put positive/negative charges on the oxygen atoms within the ring structure.
			Total	**17**	
10 2			**FIRST CHECK ANSWER LINES** **If M=168(.0) Award 4 marks for calculation providing unit conversions are correct** **----------** ***Use of ideal gas equation*** $pV = nRT$ ***OR*** $n = \frac{pV}{RT}$ ✓ ***SI Unit conversions AND substitution into*** $n = \frac{pV}{RT}$: • *R = 8.314* ***OR*** *8.31* • $V = 186 \times 10^{-6}$ • *T in K: 303 K* *e.g.* $\frac{1.07 \times 10^5 \times 186 \times 10^{-6}}{8.314 \times 303}$ ✓ ***Calculation of n*** $n = 7.90 \times 10^{-3}$ (mol) ✓ ***Calculation of M*** $M = \frac{1.327}{7.90 \times 10^{-3}} = 168(.0)$ ✓ ***Molecular formula***	6 (AO1.2 ×1) (AO2.4 ×3) (AO2.5 ×2)	**ALLOW ECF throughout** **ALLOW** calculator value of 167.968115 (using 8.314) for M **ALLOW** calculator value of 167.8873033 (using 8.31) for M Calculator value of *n*: from 8.314 = $7.900308915 \times 10^{-3}$ from 8.31 = $7.904111711 \times 10^{-3}$ **ALLOW** ECF that matches M but the formula MUST contain F_6O **----------** **Use of 24 dm³**: e.g. $n = \frac{186.0}{24000} = 7.75 \times 10^{-3}$ **No mark** *(calculation much simpler)* $M = \frac{1.327}{7.75 \times 10^{-3}} = 171(.2)$ ✓

			$C_3H_2F_6O$ ✓ ***Structure***  **OR**  ✓		**ECF** $C_3H_5F_6O$ ✓ **ECF** **ALLOW** ECF for a feasibile chemical structure that matches M **AND** contains F_6O **AND** has a chiral carbon **DO NOT ALLOW**  *no chiral carbon* **Examiner's Comments** This question proved difficult and discriminated well. Higher ability candidates correctly used SI units and showed each step of their calculation and then using this to correctly identify a structure of compound X. Candidates frequently used the wrong interconversions and gave structures that lacked a chiral centre. A small number of candidates used molar gas volume rather than PV=nRT for their calculation.
			Total	**6**	

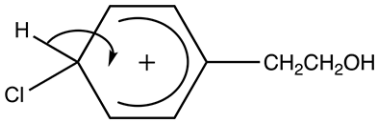
10 3		i	Indicator **AND** observation of acidity **AND** No reaction with carbonate ✓	1 (AO1.2 ×1)	**ALLOW** (Add) bromine **AND** white precipitate ✓ **ALLOW** (Add) $FeCl_3$ **AND** violet/purple colour ✓
		ii	Compound **J** has **6** peaks/environments/types of carbon ✓ Compound **K** has **5** peaks/environments/types of carbon ✓ Compound **L** has **8** peaks/environments/types of carbon ✓	3 (AO3.2 ×3)	**IGNORE** any numbers shown on structures **IGNORE** chemical shifts
		ii i	**ANNOTATE ANSWER WITH TICKS AND CROSSES** **Action of catalyst 1 mark** Formation of electrophile: $Cl_2 + AlCl_3 \rightarrow Cl^+ + AlCl_4^-$ **AND** Regeneration of catalyst: $H^+ + AlCl_4^- \rightarrow AlCl_3 + HCl$ ✓ --- **Electrophilic attack 1 mark** Curly arrow from π-bond to Cl^+ ✓  **Correct intermediate only 1 mark**	4 (AO1.2 ×2) (AO2.5 ×2)	**ALLOW** use of $FeCl_3$ or other halogen carriers ($AlBr_3$) --- **For curly arrows, ALLOW straight or snake-like arrows and small gaps (see examples):** --- **1st curly arrow** must • start from, **OR** close to **circle of benzene ring** **AND** • go to Cl^+

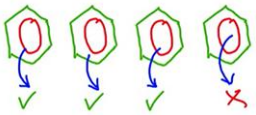


✓

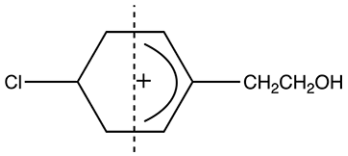
Reforming benzene ring **1 mark**

Curly arrow from C–H bond to reform π-ring ✓





DO NOT ALLOW the following intermediate:

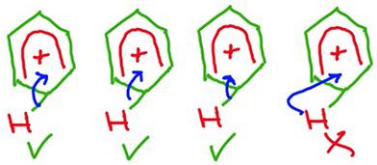


π-ring must cover more than half of benzene ring
AND
correct orientation, *i.e.* gap towards C with Cl

ALLOW + sign anywhere inside the 'hexagon' of intermediate

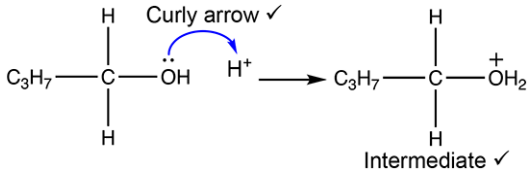
DO NOT ALLOW intermediates substituted at positions 3 or 5
IGNORE intermediates substituted at position 2
OR di-substituted at positions 2,4

Curly arrow must start from, **OR** be traced back to, **any part of** C–H bond and go inside the 'hexagon'



Examiner's Comments

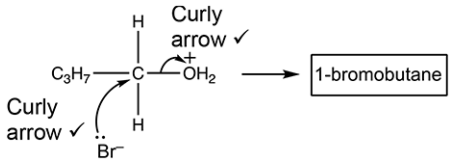
Few candidates knew the test for a phenol group. Frequent incorrect responses involved the production

					of a gas with a carbonate or stating that bromine water is decolourised but failing to state that a white precipitate is also formed. A significant number of candidates also stated that the reaction with sodium hydroxide confirms the presence of the phenol group. This question proved challenging to candidates with few scoring all 3 marks. Where no marks were given, this was frequently because candidates did not state the number of carbon environments in compounds J, K and L. Candidates who were given 1 or two marks frequently stated the incorrect number of peaks that would be observed. This question required candidates to apply their knowledge of the mechanism of electrophilic substitution. Examiners were encouraged by the number of excellent responses to this question, with the majority of candidates securing 3 out of 4 marks. Common errors included the omission of HCl as product from the regeneration of the catalyst or candidates attempting to substitute at the 2 position.
			Total	**8**	
10 4			**Step 1** The oxygen atom of the alcohol group accepts a proton to form a positively-charged intermediate. ***2 marks***  	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

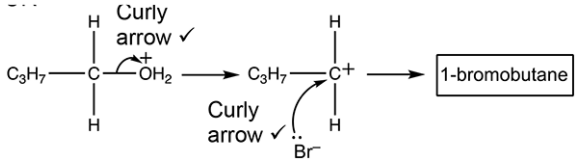
Step 2 Bromide ions react with the intermediate by nucleophilic substitution to form 1-bromobutane.

2 marks

2 possible routes:
EITHER



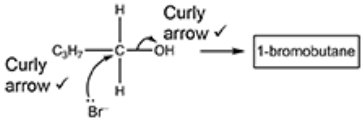
OR



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 $C_3H_7CH_2\text{-}O^+H_2$ is **not** shown, **ALLOW** intermediate mark for carbocation: $C_3H_7CH_2^+$
ALLOW 2 marks max for mechanism without positively charge intermediate, i.e.

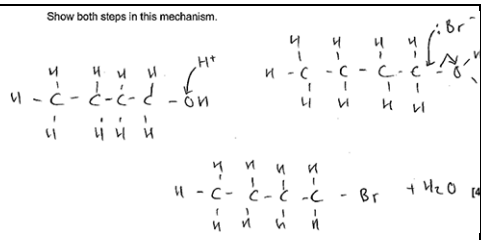


If in doubt, contact Team Leader

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



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.

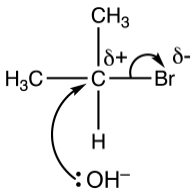
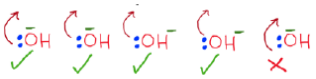
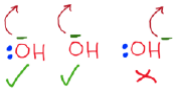
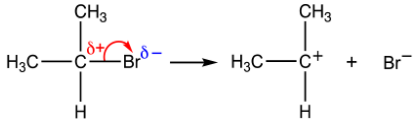
Assessment for learning

In organic chemistry mechanisms, a curly arrow shows the movement of an electron pair and demonstrates the direction of electron flow in organic reactions.

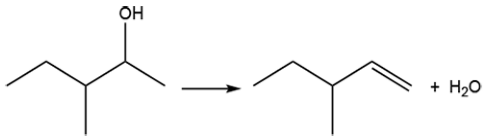
A curly arrow must start from:

- 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**.

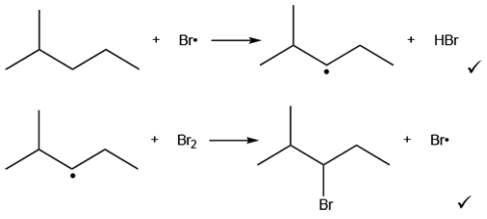
In Q3b, curly arrows start

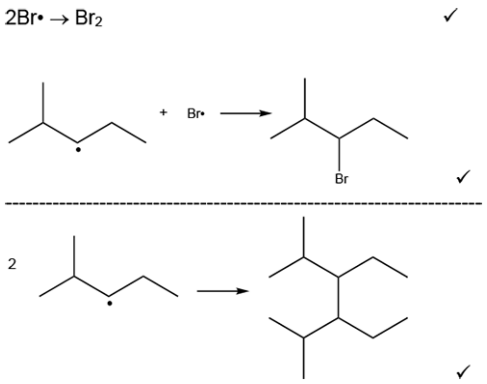
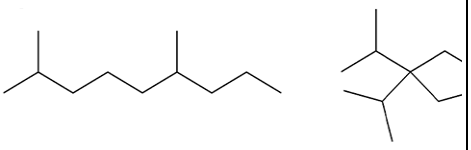
					• from a lone pair on the alcohol OH and a Br^- ion • from a C-O bond A curly arrow will **not** originate from a + charge.
			Total	**4**	
10 5			**Mechanism** Curly arrow from OH– to C atom of C−Br bond in 2-bromopropane✓ Dipole shown on C–Br bond, $C^{\delta+}$ and $Br^{\delta-}$, **AND** curly arrow 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_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 ✓ 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) ✓ **Examiner's Comments** 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.
			Total	**3**	
10 6		i	3-methylpentan-2-ol ✓	1 (AO 2.1)	**IGNORE** lack of hyphens or addition of commas **ALLOW** 3-methylpentane-2-ol **DO NOT ALLOW** 2-methylpentan-3-ol 3-methylpent-2-ol 3-methpentan-2-ol 3-methypentan-2-ol 3-methlypentan-2-ol **Examiner's Comments**

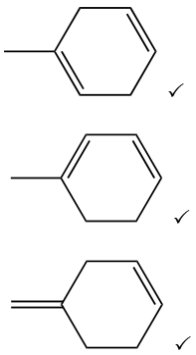
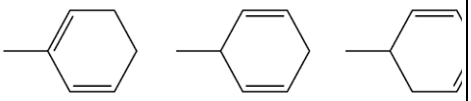
					A significant number of candidates lost the mark for missing -an- in their answer i.e. 3-methylpent-2-ol. Others lost the mark for incorrect spelling of methyl.
		ii	 Correct structure of organic product ✓ Balanced equation ✓	2 (AO 2.7 × 2)	**ALLOW** any combination of skeletal **OR** structural **OR** displayed formula as long as unambiguous **DO NOT ALLOW** additional reactants such as H^+ or [O] in the equation. **ALLOW** incorrect isomer 3-methylpent-2-ene for balancing mark. **Examiner's Comments** Most candidates did not score either mark here, despite the structures for B and C being given in the table below for (iii). Many thought this was oxidation, showing [O] in equations and giving a carbonyl product. Many had alkenes but still with the -OH present. Some attempted to use structural or displayed formulae but errors were made in giving the correct number of H atoms. For those that did have the correct structure, they often did not give an equation, added the acid as a reactant , or missed off the water as a product.
		iii	Priority groups on same side ✓ High(est) priority groups are CH_3CH_2 and CH_3 **OR** Low(est) priority groups are CH_3 and H ✓	2 (AO 3.1 × 2)	**ALLOW** suitable alternatives to 'priority' e.g. Groups with highest atomic number or more important groups etc. **ALLOW** priority groups are both on the top **IGNORE** references to relative mass of groups, Ar, Mr,

					ALLOW identification by name e.g. ethyl and methyl, or by circling on the structure. **IF** 'priority' is not mentioned **ALLOW** 1 mark for CH_3CH_2 and CH_3 are on same side **OR** H and CH_3 are on same side **Examiner's Comments** Many responses made no reference to 'priority' and/or discussed alkene C, suggesting that they didn't read the question fully. Candidates often struggled to find the right language to express themselves, such as reference to 'functional groups' or 'molecules' rather than priority groups. Lots discussed using *M*r to assign priority with only a few stating correctly that it is atomic number that is used for CIP rules. Many, despite stating that priority groups are on the same side, didn't identify these groups so didn't get the second mark.
			Total	**5**	
107			**B**	1 (AO2.1)	
			Total	**1**	
108			**A**	1 (AO1.2)	**Examiner's Comments** This question was well answered. Some candidates used the strategy of numbering the C atoms in the structure to aid the deduction of the correct systematic name. D was the most common incorrect response by numbering from left to right.
			Total	**1**	
109			**B**	1 (AO1.2)	**Examiner's Comments** Few students gained marks on this

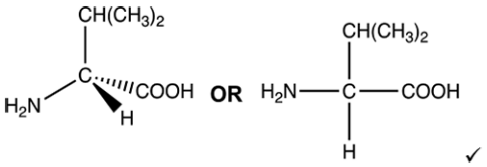
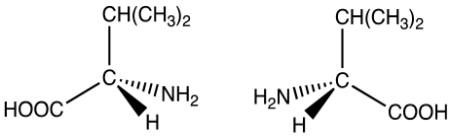
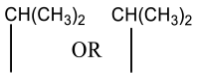
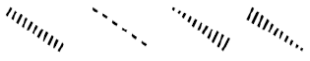
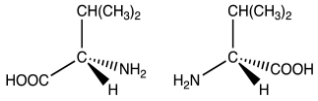
					question. The distinction between aliphatic and aromatic compounds was not well understood with many candidates giving D as their response. It is evident that there is confusion that a molecule can be both alicyclic and aliphatic. Alternatively, candidates may have believed that a cyclic compound with a double bond is aromatic. **Misconception** A molecule is either aromatic, if it contains a benzene ring, or aliphatic. Aliphatic molecules which contain a ring can also be described as alicyclic. This OCR article offers clarification for classification of organic compounds.
			Total	**1**	
11 0		i	**Initiation** $Br_2 \rightarrow 2Br\bullet$ **AND** ultraviolet / UV ✓ **Propagation**  ✓ **Termination**	6 (AO1.1) (AO2.5) (AO2.5) (AO2.5) (AO3.1)	**DOT REQUIRED** throughout **IGNORE** temperature and pressure **ALLOW ECF** for use of Cl• (from Cl2) in subsequent propagation and termination steps **ALLOW** any combination of skeletal **OR** structural **OR** displayed formula as long as unambiguous **ALLOW** 1 mark for propagation for 2 'correct' equations but with dot omitted or in wrong position **DO NOT ALLOW ECF** from incorrect radical intermediate for termination steps **Examiner's Comments**

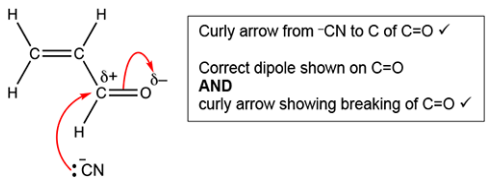
					Many candidates tackled this question confidently, especially when using skeletal formula following the format of the structure given in the question. Over half the candidates scored 5 or 6 marks. Only the highest attaining candidates were able to provide all three correct termination steps. Many lost a mark for the combination of the two alkyl radicals, typically either by simply joining the ends of the chains or by missing the connecting C-C bond.  Those that attempted to use structural formula often lost marks due to missing Hs. Other common errors included the incorrect positioning of the radical dot, most typically on the terminal carbon, addition of Br in the first propagation step or use of molecular formula. Lower attaining candidates were often able to score a mark for the initiation step and the termination step involving two Br radicals. However, for some this was not a well-known mechanism, with attempts to break up the chain or form hydrogen radicals or charged species. Errors were also seen with correct balancing of equations such as truncated C chains or extra Br atoms added.
		ii	C_6Br_{14} ✓ Correct balanced equation $C_6H_{14} + 14\ Br_2 \rightarrow C_6Br_{14} + 14\ HBr$ ✓	2 (AO2.6 ×2)	**ALLOW** 1 mark for correct balanced equation using any combination of skeletal **OR** structural **OR** displayed formula **Examiner's Comments**

					Most responses gained at least 1 mark for this question giving the correct molecular formula of C_6Br_{14}. However many hadn't assimilated that when a hydrogen atom is substituted in an alkane it requires one mole of a halogen and produces one mole of the hydrogen halide. So many gave this incorrect equation instead: $C_6H_{14} + 7Br_2 \rightarrow C_6Br_{14} + 7H_2$. Some lost marks for C_5H_{14} or for use of structural formulae.
		iii	$n(\mathbf{B}) = \frac{72.0}{40000}$ **OR** $\frac{0.072}{40}$ **OR** $1.8(0) \times 10^{-3}$ (mol) ✓ $M(\mathbf{B}) = \frac{0.8649}{1.8(0) \times 10^{-3}} = 480.5$ ✓ Molecular formula = $C_6H_9Br_5$ ✓	3 (AO2.2 ×2) (AO3.2)	**ALLOW 2SF** up to calculator value **ALLOW ECF** from incorrect *n*(**B**) **ALLOW ECF** from incorrect *M*(**B**) from *n*(**B**) --- **COMMON ERROR** $n(\mathbf{B}) = \frac{72.0}{24000} = 3 \times 10^{-3}$ (mol) × $M(\mathbf{B}) = \frac{0.8649}{3 \times 10^{-3}} = 288.3$ .....✓ Molecular formula = $C_6H_{12}Br_2$ **OR** $C_6H_{11}Br_3$ ✓ **ALLOW ECF** for viable molecular formula with C_6 but must be derived from a calculated value for *M*(**B**) **Examiner's Comments** Overall, this question was well answered with over half of candidates gaining all 3 marks. The use of a different molar volume confused some candidates. Some attempted to use PV=nRT or different combinations of the figures given with varying degrees of success. Lower attaining candidates typically struggled with unit conversions and were unable

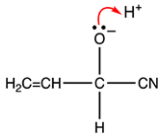
					to make use of the units to help them work out the methodology to use.
			Total	**11**	
11 1		i		3 (AO2.5 ×3)	**ALLOW** any combination of skeletal **OR** structural **OR** displayed formula as long as unambiguous **<u>Examiner's Comments</u>** Lots struggled here with just under half of candidates gaining no credit. Only the strongest responses recognised that a carbon-carbon double bond could be formed external to the ring from the methyl branch. A common error was repeating one of the first two isomers as a mirror or rotated image and so lost a mark - candidates need to be able to recognise same structures (especially using skeletal formula) Lower scoring candidates didn't recognise this reaction would result in the elimination of water. So, it was common to see responses with three structures still containing the OH group or ketones (possible oxidation products), despite the molecular formula C_7H_{10} being provided twice in the question. Some candidates attempted to give structural isomers of C_7H_{10} that would not form from this reaction (see below) including those with smaller rings and even unsaturated straight chain compounds. Some even gave benzene structures.  This question was particularly problematic to mark if previous

					structures drawn were then rubbed out. **Drawing structures in exams** Please remind candidates to draw structures clearly in black ink. If incorrect cross them out and redraw them. Drawing in pencil then rubbing out often leads to extra lines showing when exam papers are scanned making it appear that structures are incorrect.
		ii	NaI / KI **AND** H_2SO_4 ✓	1 (AO1.2)	**ALLOW** HI **ALLOW** NaI / KI **AND** H_3PO_4 **OR** HNO_3 **IGNORE** Conc or dilute **Examiner's Comments** Many candidates were unable to provide reagents and conditions for this reaction. Iodo- seemed unfamiliar to some with responses including NaBr or HBr suggesting substitutions with Br are more familiar. The most common errors were to use iodide with no acid or to use iodine, sometimes in conjunction with other reagents such as AlI_3 or FeI_3.
			Total	**4**	
11 2		i	2-amino-3-methylbutanoic acid **OR** 3-methyl-2-aminobutanoic acid ✓	1 (AO1.2)	**IGNORE** lack of hyphens, extra hyphens, or addition of commas **DO NOT ALLOW** the following for methyl: methy, meth, methly **DO NOT ALLOW** the following for amino: amine, amin **Examiner's Comments** Over half of candidates were unable to give the systematic name of valine, despite many being able to draw out a structure in the

					following question. A minority of candidates did not attempt the question. The best strategy was to use displayed formula, find the longest chain which included the COOH and label this as C number 1 to make sure of correct numbering. Common errors included 2-amino-3,3-dimethylpropanoic acid or 3-amino-2-methylbutanoic acid. Many candidates did not know how to name the amine functional group with errors including, amine, N-, nitro-, nitrile, etc. Some simply attempted to name the R group alone, e.g. '2-methylethyl- or 'dimethyl'.
		ii	Correct groups attached to chiral C of valine seen **once** e.g.  Two **3D structures** of valine that are mirror images with correct connectivity in both ✓ 	2 (AO1.1) (AO1.2)	**ALLOW** any combination of skeletal **OR** structural **OR** displayed formula as long as unambiguous **IGNORE** connectivity for the first marking point but must be correct for the second mark. **ALLOW** bond to any part of the CH of the $CH(CH_3)_2$ group e.g. **ALLOW**  Each structure must have four central bonds with **at least two wedges.** For bond into paper accept:  **ALLOW** two 3D structures with 2 groups swapped e.g.  **ALLOW** R or C_3H_7 to be shown for

					$CH(CH_3)_2$ for second mark only. **ALLOW ECF** for second mark for small slips such as missing H e.g. $C(CH_3)_2$ **Examiner's Comments** Most candidates (more than half) were able to score both marks here, on what was a well-practised question from previous examination series. Most were able to identify the correct chiral carbon, with four different groups attached, and draw a 3-D representation of the two optical isomers with correct connectivity. Some candidates inadvertently drew the same structure (e.g. switched groups and gave a mirror image) so if not drawn in a standard way it needed extra checking. Some lost the second mark due to incorrect connectivity or use of C_3H_7. Some attempted to write formulae out as literal mirror images, e.g. $_2(_3HC)C$ and need to be told that this isn't necessary as can sometime lead to connectivity errors.
			Total	**3**	
11 3		i	**NOTE**: curly arrows can be straight, snake-like, etc. but **NOT** double headed or half headed arrows --- **Nucleophilic attack** *2 marks*  ---	4 (AO1.2 ×2) (AO2.5 ×2)	**ANNOTATIONS MUST BE USED** --- **1st curly arrow must** • go to the C atom of C=O **AND** • start from, **OR** be traced back to any point across width of lone pair on C of ⁻ **:**CN **OR :**CN^- • **OR** start from – charge on C of ⁻CN (then lone pair on CN^- does not need to be shown)

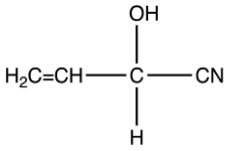
Intermediate *1 mark*



Correct intermediate
AND curly arrow from O^- to H^+ ✓

DO NOT ALLOW δ– on O of intermediate
IGNORE connectivity of H_2C=CH–

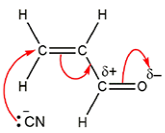
Product *1 mark*



Correct product ✓

Possible alternative 1,4 (conjugate) addition can be credited as follows (not in specification):

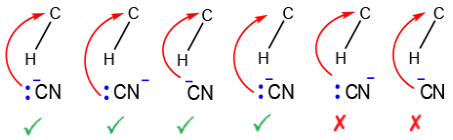
Nucleophilic attack *2 marks*



Curly arrow from $^-$CN to C of CH_2 of C=C ✓

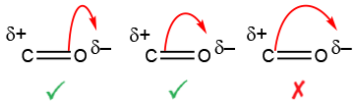
Curly arrow from C=C to C-C
AND
curly arrow showing breaking of C=O ✓

Intermediate *1 mark*



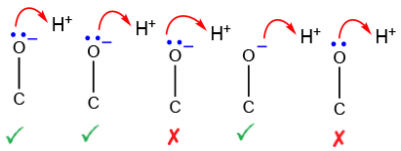
2nd curly arrow must

- start from, **OR** be traced back to any part of $^{\delta+}$C=O $^{\delta-}$ bond
  AND
- go to $O^{\delta-}$ (across width of $O^{\delta-}$)

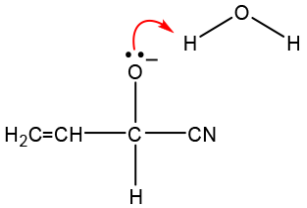


3rd curly arrow must

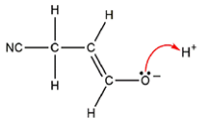
- go to H^+
  AND
- start from, **OR** be traced back to any point across width of lone pair on $:O^-$
- **OR** start from – charge of O^- of intermediate (then lone pair on O^- does not need to be shown)



NOTE: For arrow to H^+
ALLOW arrow to H of H_2O
i.e.



IGNORE attempt to draw curly

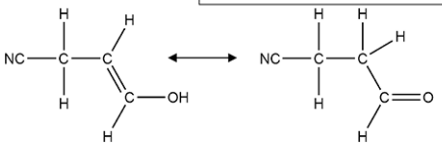


Correct intermediate
AND curly arrow from O^- to H^+ ✓

DO NOT ALLOW δ– on O of intermediate

Product *1 mark*

Either tautomer as correct product ✓



arrow showing breaking of H–O in H_2O

IGNORE lack of dipole on H_2O

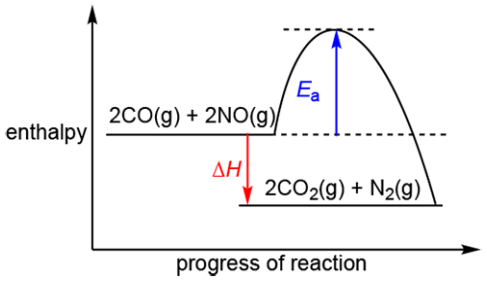
IGNORE absence of OH^- as 2nd product
Otherwise this more difficult mechanism could cost 2 marks

Product mark can only be given here if clear from mechanism that there is nucleophilic attack of CH_2 in C=C.
Same product could be seen with an attempt at electrophilic addition across C=C.

Examiner's Comments

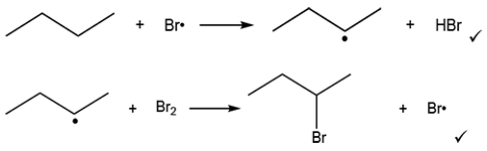
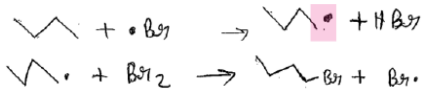
There were many excellent examples of precisely drawn mechanisms for the reaction of acrolein with sodium cyanide in acidic conditions and so most candidates gained at least 3 marks. The importance of accuracy when drawing curly arrows needs to be emphasised when teaching mechanisms - arrows must start at lone pairs or negative charges or come from bonds. Many candidates lost marks due to incorrect arrows. Common errors included the use of NaCN or HCN rather than the cyanide ion, the first curly arrow coming from the N of CN-, omission of partial charge across the C=O double bond and addition of partially charges to hydrogen or oxygen. Lower scoring responses often included an intermediate and/or product containing sodium. Some

					attempted electrophilic addition using HCN across the double bond. A few gained some credit for the mechanism for a competing reaction with nucleophilic addition on CH_2 of C=C. This is not covered in the A Level specification and no candidates scored full marks for this alternative.
		ii	Nucleophilic addition ✓	1 (AO1.1)	**IGNORE** just 'addition' **Examiner's Comments** Most candidates were able to recall the correct response here, especially for those more confident with drawing out the mechanism. The most common incorrect response was nucleophilic substitution. Some suggested reduction or nucleophilic addition elimination. Misspellings of 'nucleophilic' were often seen.
			Total	**5**	
11 4			**D**	1 (AO 1.2)	**Examiner's Comments** Most candidates showed a good understanding of organic nomenclature to obtain the correct option of D. Candidates who drew out the structures for options A and B were able to easily eliminate them. Those trying to interpret the A and B options without drawing out the structures were often less successful.
			Total	**1**	
11 5			**C**	1 (AO 2.5)	**ALLOW 4** **Examiner's Comments** As with Question 15, the strategy of drawing out structures was more likely to lead to success with the correct option of C. Despite this, less than half of candidates obtained the correct response with many missing one of the isomers and opting for option B.

			Total	1	
11 6		i	$C_7H_{16} + 11O_2 \rightarrow 7CO_2 + 8H_2O$ Correct species ✓ Balanced ✓	2 (AO2.6 ×2)	**ALLOW** multiples **IGNORE** state symbols For heptane formula, **ALLOW** any combination of skeletal **OR** structural **OR** displayed formula as long as unambiguous **ALLOW 1 mark** for balanced combustion equation for a different alkane (**ECF**) e.g. $C_6H1_4 + 9½O_2 \rightarrow 6CO_2 + 7H_2O$ **Examiner's Comments** Most candidates were able to construct a balanced equation for the combustion of heptane. Most were aware that CO_2 and H_2O would be the products although some generated CO, C_6H_{12} or unusual compounds such as $C_7H_{14}O$. The hardest part was the formula of heptane itself with use of hexane instead being a common error; candidates who made this error were given 1 mark, provided that their equation was balanced.
		ii	 **Reactants, products and Δ*H*** **2CO + 2NO** on LHS **AND** **2CO₂ + N₂** on RHS **AND**	2 (AO2.1) (AO1.2)	**ANNOTATE ANSWER WITH TICKS AND CROSSES ETC** **IGNORE** state symbols **Δ*H* DO NOT ALLOW –Δ*H*** **DO NOT ALLOW** double headed arrow on Δ*H* **ALLOW** Δ*H* arrow even with small gap at the top and bottom, i.e. line does not quite reach reactant or product line.

			ΔH labelled with products **below** reactants **AND** **Arrow downwards** ✓ ***E_a (independent of ΔH)*** curve with arrow from reactants to top of curve **AND** E_a labelled ✓ **IF** endothermic diagram shown, **ALLOW ECF** for E_a using MS criteria		**ALLOW** –746 for ΔH ***E_a*** **ALLOW** AE **OR** A_E **ALLOW 2** arrowheads at **each** end of E_a line **OR** no arrowhead **BUT DO NOT ALLOW** arrowhead down E_a line must reach maximum (or near to maximum) on curve **<u>Examiner's Comments</u>** Most candidates obtained 1 or 2 of the available marks, the commonest errors being use of a doubleheaded arrow for ΔH or a – ΔH label. Some candidates showed endothermic profiles and these could create issues with positioning of the ΔH and E_a arrows. Generally, positioning of ΔH and E_a arrows was imprecise and candidates are advised to start and finish the positions of their arrows accurately. The mark scheme did allow for some leeway but positioning of arrows could generally be improved.
		iii	Catalyst lowers activation energy **OR** Catalyst increases rate without itself changing ✓ Reaction proceeds via a different route/pathway **OR** More molecules/particles exceed activation energy ✓	2 (AO1.2 ×2)	**ALLOW** 2nd labelled curve on profile diagram in **23(a)(ii)** with lower activation energy/E_c with catalyst **ALLOW** E_c needs less energy to start reaction **ALLOW** E_c curve is lower than E_a curve

					IGNORE 'shorter route' for alternative route **IGNORE** more successful collisions **Examiner's Comments** Almost all candidates knew that a catalyst lowered activation energy and most were aware that an alternative pathway was made possible by a catalyst.
			Total	**6**	
11 7	a		*Each marking point is independent* **Chain length: interaction between molecules** Chain length (in pentane) is longer **AND** more (surface) contact **OR** greater surface area/SA✓ **London forces: strength and energy** **Stronger / more** London forces **OR more energy to break** London forces ✓	2 (AO1.1 ×2)	**Comparisons** needed throughout **ORA** throughout **Assume the following for longer chain** • larger/bigger molecule • more C (and H) • more atoms • more electrons **BUT** 'branching' is a **CON** **IGNORE** comments about packing **ALLOW** induced dipole(–dipole) interactions for London forces **IGNORE** van der Waals'/vdw forces **Examiner's Comments** Most candidates were given 1 or 2 marks, with some omitting the idea of surface area or surface contact. Most candidates identified London forces or induced dipole interactions as the relevant intermolecular force. A few candidates gave a general comment in terms of 'intermolecular' forces without specifying the type of intermolecular forces.

					There has been a general improvement in candidate responses to this type of question with fewer candidates than in previous exams suggesting the breaking of hydrogen bonds or covalent bonds.
	b		**Skeletal formulae required**  	2 (AO3.1 ×2)	**ALLOW** 1 mark (**ECF**) for 2 'correct' equations with dot omitted or incorrectly positioned **ALLOW** 1 mark for forming 1-bromobutane with dots correct for 1-bromobutane e.g.  **No credit for responses using molecular formulae for organic structures** **Examiner's Comments** This question discriminated very well at the top end of the ability range, but many ignored the instruction to use skeletal formula and obtained no marks as a result. Of those that did use skeletal formula, many placed the dot on the wrong carbon atom or produced 1- brombutane, rather than 2-bromobutane, stated in the question. A mark was still available by ECF for misplaced or absent dots or formation of 1-brombutane with dots. This question was aimed to be demanding and so it proved to be.
			Total	**4**	
118					**ANNOTATE WITH TICKS AND CROSSES**

Correct structural isomers of C_3H_8O *1 mark*

$CH_3CH_2CH_2OH$ **AND** $CH_3CHOHCH_3$ ✓

Reaction conditions *1 mark*

Distillation for aldehyde

AND reflux for carboxylic acid **OR** ketone ✓

Functional group of organic product *2 marks*

$CH_3CH_2CH_2OH$ → aldehyde

OR

$CH_3CHOHCH_3$ → carboxylic acid ✓

$CH_3CHOHCH_3$ → ketone ✓

One correct equation *1 mark*

$CH_3CH_2CH_2OH + [O] \rightarrow CH_3CH_2CHO + H_2O$

OR

$CH_3CHOHCH_3 + [O] \rightarrow CH_3COCH_3 + H_2O$

OR

$CH_3CH_2CH_2OH + 2[O] \rightarrow CH_3CH_2COOH + H_2O$ ✓

Throughout,
ALLOW any combination of skeletal **OR** structural **OR** displayed formula as long as unambiguous

IF functional group is NOT given,

ALLOW propanal / RCHO

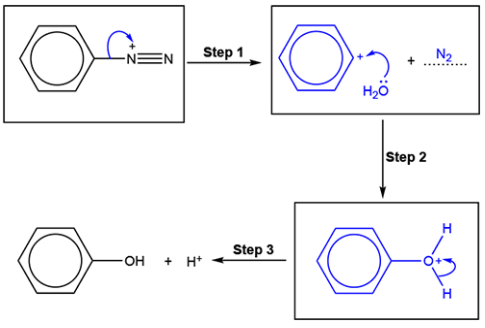
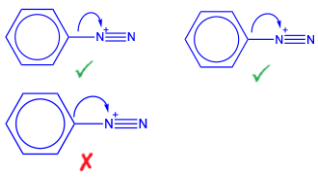
ALLOW propanoic acid / RCOOH

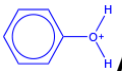
ALLOWpropanone / ..... RCOR

IGNORE small slips in formulae (assessed in equation)

Examiner's Comments

There were some excellent responses to this question which discriminated extremely well. Unfortunately, there were a significant number of incorrect responses and some less successful candidates had clearly struggled to recall and apply this important material. The identification of the isomers was usually correct, as was the identification of the oxidation products from the primary and secondary alcohols, and the conditions required to produce the organic products. The equation proved to be the hardest

					requirement with the H_2O by-product often being omitted or H_2 shown instead. A general point applies to organic structures. Some candidates did not show the structures of the isomers and attempted this question using the molecular formula of C_3H_8O supplied in the question for both alcohol isomers and no structural formulae. It was then impossible to know which isomer was being reacted and this could cost the candidate a significant number of marks. It is essential in organic chemistry to use unambiguous formulae which can be any combination of skeletal, structural or displayed. Unless a question specifies that a molecular formula is required, candidates should assume that an unambiguous formula is required.
			Total	**5**	
11 9			**Mechanism**:  **M1**: Curly arrow from C–N bond to N^+ ✓ **M2**:  **AND** N_2 ✓ **M3**: Curly arrow from lone pair of O of H_2O to C^+ ✓	4 (AO 3.2 ×4)	**ANNOTATE ANSWER TICKS AND CROSSES** --- **NOTE**: Curly arrows can be straight, snake-like, etc. but **NOT** half arrows **1st curly arrow** must start from, **OR** be traced back to, **any part of** C–N^+ bond and go to N **OR** + of N^+  **2nd curly arrow** must • start from, **OR** be traced back to **any point across width** of lone pair on O of H_2O

M4  **AND** Curly arrow from O–H bond to O+ ✓

For all marks, treat additional curly arrows as CON

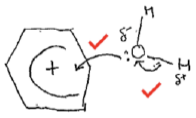
ALLOW M3 shown in bottom box

IGNORE partial charges
ALLOW M3 AND M4 combined
e.g.

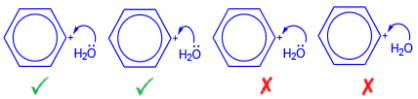
For  **DO NOT ALLOW M2** for carbocation

BUT

ALLOW for M3 and/or M4 by ECF, e.g.

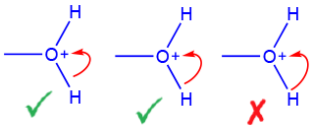


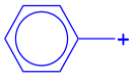
- go to the C or + of C^+ of $C_6H_5^+$



3rd curly arrow must

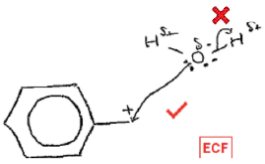
- start from '–' **of O–H** of $–OH_2^+$
- go to O or + of O^+



For  **DO NOT ALLOW M2** for carbocation

BUT

ALLOW for M3 and/or M4 by ECF, e.g.



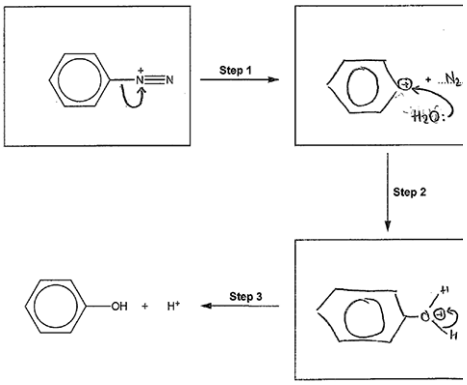
Examiner's Comments

This question required candidates to apply their understanding of organic mechanisms to an unfamiliar reaction. The stem to the question includes important information and clues that should have guided candidates towards this unfamiliar mechanism, with the prompts for the three steps being critical. Many responses fell back to the familiar mechanism for electrophilic substitution, an

approach that could not be credited.

This question discriminated very well but many candidates scored few marks.

Exemplar 1

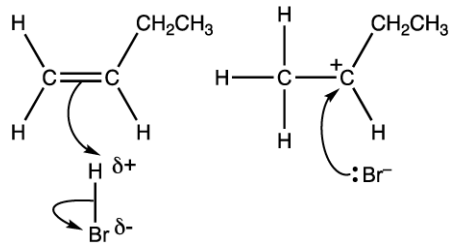


This response has been included to show a candidate with an excellent understanding of the meaning of curly arrows and the importance of charges and dipoles. The prompts in the question are followed and the candidate has been given all four marks.

Notice how the curly arrows start either from a bond or from a lone pair. The candidate has also realised that the addition of H_2O produces a positively charged oxonium ion. Many candidates omitted the '+' charge or showed the curly arrow for loss of a proton going to a H atom rather than the O atom of water.

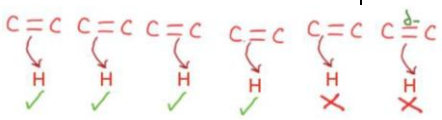
Assessment for learning

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

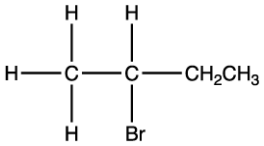
					demonstrates the direction of electron flow in organic reactions. A curly arrow must start from: • A lone pair or negative charge and go to an atom to show where a bond **forms** • A bond to show where a bond **breaks**. In Question 2 (c), curly arrows: • start from a C–N bond to form the intermediate carbocation by elimination of N_2 • go from a lone pair on the water O atom to the + charge of the carbocation • go from an O–H bond to the + charge on the oxonium ion, losing a proton H^+ in the process.
			Total	**4**	
120		i	 **1st curly arrow (from ANY alkene)** Curly arrow from double bond to H of H–Br ✓ **DO NOT ALLOW** partial charge on C=C **2nd curly arrow** Correct dipole on H–Br **AND** curly arrow for breaking of H–Br bond ✓ **3rd curly arrow** Correct carbocation with + charge on C	4	**Throughout**, **ALLOW** any combination of skeletal **OR** structural **OR** displayed formula as long as unambiguous **For curly arrows,** **ALLOW straight or snake-like arrows and small gaps (see examples)** **DO NOT ALLOW** half headed or double headed arrows but allow **ECF** if seen more than once **1st curly arrow** must • go to a H atom of H-Br • **AND** • start from, **OR** be traced back to **any point across width** of C=C

AND curly arrow from Br^- to C+ of carbocation ✓

DO NOT ALLOW δ+ on C of carbocation

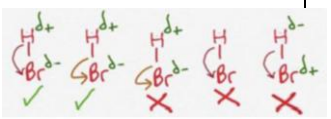


Correct product (***independent mark***) ✓



2nd curly arrow must

- start from, **OR** be traced back to, **any part of** $^{\delta+}H–Br^{\delta-}$ bond
- **AND** go to $Br^{\delta-}$



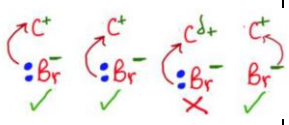
ALLOW ECF for 2nd and 3rd curly arrow marking points if used Br_2 instead of HBr

3rd curly arrow must

- go to the C^+ of carbocation

AND

- start from, **OR** be traced back to **any point across width** of lone pair on $:Br^-$
- **OR** start from - charge on Br^- ion

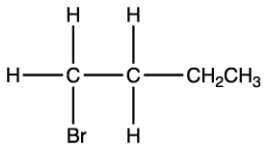


*(Lone pair **NOT** needed if curly arrow shown from - charge on Br^-)*

IGNORE connectivity of alkyl groups in carbocation and product

IF drawn both intermediates and products with no labelling **ALLOW** 3rd curly arrow mark **BUT NOT** product mark, unless clearly labelled as'2-bromobutane' or 'major' product

ALLOW ECF for product from incorrect carbocation. e.g. 1-bromobutane:



Examiner's Comments

Approximately half of candidates scored all 4 marks. Very few scored no marks as they were able to give the correct structure of the named product (2-bromobutane). The most common reasons for losing marks included:

- Adding dipoles to C=C
- Missing dipoles on H-Br or reversed dipole on H-Br (i.e. δ+ Br)
- Missing charge on bromide ion or adding δ-
- Arrows the wrong way round or not coming from a bond or lone pair (or negative charge for bromide ion)

Some attempted a radical mechanism.

OCR Support

					For ideas on teaching this topic please look at our Topic Exploration Pack: Electrophilic Addition and Markownikoff's rule: https:/teachcambridge.org/item/b4220e86-bc04-492c-b354-8103687ce594
		ii	(major product forms from) most/more stable intermediate/carbocation ✓ major product forms from a) secondary carbocation **OR** carbocation bonded to more C atoms / more alkyl groups **OR** carbocation bonded to fewer H atoms ✓	2	**ALLOW** carbonium ion for carbocation **IGNORE** descriptions of the major/minor product in terms of Markownikoff's rule e.g. H atom joins to C with most H **IGNORE** references to stability of the product **ALLOW ORA** **Examiner's Comments** Over half of candidates didn't gain any credit for their response here. Answers often focused on Markownikoff's rule, i.e. adding H to C with most H atoms already attached, or described the stability of the product. Students need more support in understanding that the more stable carbocation will be formed in preference and result in forming more product. Many referred to the 'secondary haloalkane' being more stable, rather than the 'secondary carbocation'. Some stated that 2-bromobutane is a 'secondary carbocation', showing some misunderstanding about the terminology used here. **OCR Support** We have a useful PowerPoint Presentation for teaching about

					Markownikoff's rule and carbocation stability: https:/ocr.org.uk/Images/250388-markownikoff-s-rule-presentation.ppt
			Total	**6**	
12 1			**C**	1	**Examiner's Comments** About half the candidates correctly chose C. Options A and B were incorrectly chosen by many candidates, presumably by counting from the left or not first identifying the longest carbon chain. This question proved to be an excellent discriminator.
			Total	**1**	
12 2			**C**	1	**Examiner's Comments** This question proved to be an excellent discriminator with most above average candidates choosing monomer (option C).
			Total	**1**	
12 3	a		**CORRECT DOTS REQUIRED FOR ALL MARKS** **Initiation** ultraviolet / UV **AND** $Br_2 \rightarrow 2Br\cdot$ **OR** $Br_2 \rightarrow Br\cdot + Br\cdot$ **OR** Br–Br → 2Br·, etc ✓ **Propagation** **1** $C_2H_6 + Br\cdot \rightarrow C_2H_5\cdot + HBr$ ✓ **2** $C_2H_5\cdot + Br_2 \rightarrow C_2H_5Br + Br\cdot$ ✓	5	**ALLOW** any combination of skeletal **OR** structural **OR** displayed formula as long as unambiguous **DO NOT ALLOW** charged formulae **IGNORE** position of dots within a formula **DO NOT ALLOW** if reagents also present, e.g..steam **ALLOW** $\cdot CCH_5$ for $C_2H_5\cdot$ **ALLOW** $C_2H_5C_2H_5$ for C_4H_{10} ✓

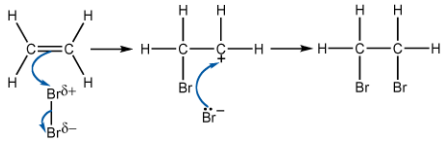
			Termination In either order: $C_2H_5\cdot + C_2H_5\cdot \rightarrow C_4H_{10}$ **OR** $2C_2H_5\cdot \rightarrow C_4H_{10}$ ✓ $C_2H_5\cdot + Br\cdot \rightarrow C_2H_5Br$ ✓		**Examiner's Comments** This question was answered extremely well with most candidates obtaining the full 5 marks. It was encouraging to see the widespread correct use of dots to indicate radicals, with relatively few omissions. Of the three steps, initiation and termination were answered better than the equations for propagation.
	b		<table><tr><th>Carbon atom</th><th>Bond angle</th><th>Name of shape</th></tr><tr><td>1</td><td>109.5</td><td>tetrahedral</td></tr><tr><td>2</td><td>120</td><td>trigonal planar</td></tr></table> **2 OR 3** correct ✓ **4** correct ✓ ***Number of electron pairs*** In **C1**/109.5°, **4** bonded pairs/bonding regions/bonds ✓ In **C2**/120°, **3** bonded regions/bonds ✓ **Electron pair repulsion** Electron pairs/bonded pairs repel (as far apart as possible) ✓ ***Electron pairs/bonded pairs essential***	5	**ALLOW** 109−110 for **C1** **ALLOW** 118−122 for **C2** **ALLOW** planar triangle **ALLOW** table responses if in wrong columns **IGNORE** areas of electron density **For bonded pairs** **ALLOW** bp, **bonded** groups, **bonded** atoms ***Bonded/bonding*** *essential* **For C2, ALLOW** • 3 bonded areas/environments • 3 bonded pairs/groups/atoms • 2 bonded pairs and 1 double bond • 2 bonded pairs and 1 bonded region **DO NOT ALLOW** 'atoms repel' **IGNORE** • electrons repel • bonds repel

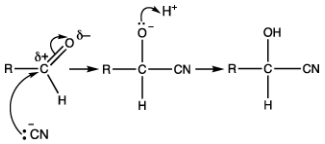
			DO NOT ALLOW 'bonded atoms' for this mark		• electron region **OR** electron density • lone pairs repel more *irrelevant here* • shapes, even if wrong **Examiner's Comments** The bond angles and shapes rewarded the well-prepared candidates, with many being given both available marks for this part of the question. This part discriminated very well. For the explanation, most candidates identified 4 and 3 for C1 and C2, but candidates often linked 4 and 3 to atoms, rather than to electron pairs or bonded pairs for C1 and to bonding regions for C2. A mark was available for stating that 'electron pairs repel', but this important fact was often omitted despite being the main principle that determines molecular shapes. The question discriminated well, giving a good spread of marks across the five available. **Misconception** Many students think that molecular shapes are determined solely by lone pairs or by repulsion between bonded atoms. The principle behind molecular shapes is called electron pair repulsion theory because it is based on repulsion between electron pairs, which may be bonded pairs or lone pairs, but **not** atoms.
			Total	**10**	

12 4			**B**	1	**Examiner's Comments** A large majority of candidates were able to correctly identify shape at x as being trigonal planar and y as being tetrahedral. The most common incorrect responses seen were for getting one of these incorrect i.e. D incorrect for x or C incorrect for y.
			Total	**1**	
12 5			**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**	
12 6			**C**	1	**Examiner's Comments** More than three quarters of candidates were able to identify C as being the secondary amide, with many annotating each structure with the correct functional group. Some gave B, i.e. a secondary amine not amide, and a few gave A, i.e. tertiary amide not secondary.
			Total	**1**	
12 7	a		B, C, D **AND** E only ✓	1	**ALLOW** letters in any order **Examiner's Comments** Over half the candidates found this question challenging an did not score the mark here. The most common error was to omit Structure C, but some also omitted

					Structure E. This suggested that many candidates may only apply the term 'unsaturated' to alkenes. It also highlights a potential lack of understanding of the delocalised ring in benzene and the relationship to the Kekulé structure.
	b		A **AND** B only ✓	1	**ALLOW** letters in any order **Examiner's Comments** Most candidates were able to correctly identify the alicyclic compounds. Some candidates also included Structure C showing some confusion between terms alicyclic and aromatic. This was also noted in last year's paper on Question 13. **Misconception** A molecule is either aromatic, if it contains a benzene ring, or aliphatic. Aliphatic molecules which contain a ring can also be described as alicyclic. OCR have previously offered clarification for classification of organic compounds.
	c		1-ethyl-2,4-dimethylbenzene ✓	1	**ALLOW** other unambiguous names using smallest numbering. e.g. **ALLOW** 1,3-dimethyl-4-ethylbenzene 2,4-dimethylethylbenzene ethyl-2,4-dimethylbenzene 2,4-dimethyl-1-ethylbenzene

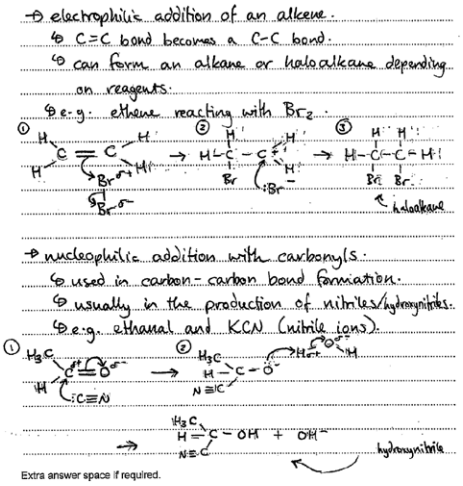
					IGNORE alphabetical order of methyl and ethyl **IGNORE** lack of hyphens, extra hyphens, full stops instead of commas, extra spaces **DO NOT ALLOW** 1,5-dimethyl-2-ethylbenzene **OR** 1,3-dimethyl-6-ethylbenzene *Needs smallest numbers* **DO NOT ALLOW** the following for dimethyl: dimethy, dimeth, dimethly, dimethanyl **DO NOT ALLOW** the following for ethyl: ethy, eth, ethly, ethanyl **<u>Examiner's Comments</u>** This question appeared to be equally challenging for candidates. Common errors included names without the lowest possible numbering. The methyl group was given on the top which could have influenced candidates to start counting from there – more practice is needed to help with naming simple aromatics. Other common errors included:1-ethyl-2,4-methylbenzene (missing di-) and 1-ethyl-2,3-dimethylbenzene (miss counting groups).
			Total	**3**	
12 8			*Refer to marking instructions on page 5 of mark scheme for guidance on marking this question.* **Level 3 (5-6 marks)** Describes addition reactions including the mechanisms of **one** alkene **AND one** carbonyl compound **AND** some additional details *There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.*	6	**Indicative scientific points may include:** **<u>Reaction of alkene and mechanism</u>** • Suitable reaction, e.g. alkene and Br_2 **OR** X_2 **OR** HX **OR** H_2O **OR** H_2 **OR** polymerisation *May be shown within mechanism* • Mechanism, e.g.

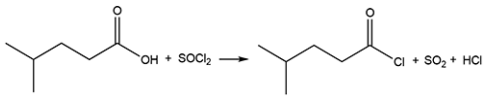
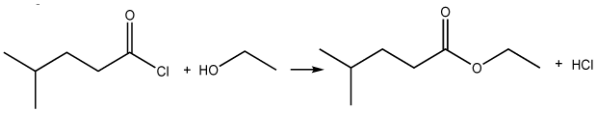
			Level 2 (3-4 marks) Describes an addition reaction including the mechanism of **one** alkene **OR one** carbonyl compound **AND** some additional details **OR** Describes addition reactions including an attempt to give the mechanisms of **one** alkene **AND one** carbonyl compound *There is a line of reasoning presented with some structure. The information presented is relevant and supported by some evidence.* **Level 1 (1-2 marks)** Selects suitable reagents for addition reactions of **one** alkene **AND one** carbonyl compound. **OR** Attempts to describe an addition reaction including an attempt to give the mechanism of **one** alkene **OR one** carbonyl compound. *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.*		 **ALLOW** mechanism for H_2 **AND** H_2O to be shown as electrophilic addition even though incorrect - consider impact on communication statement. **ALLOW** suitable non-specification alternative e.g. HCN **Additional details (NOT INCLUSIVE)** • Electrophilic addition • Systematic names of reactants and/or products • Details of functional group interconversion e.g. alkene to dibromo • Details on reagents required e.g. - H_2 with Ni Catalyst - $H_2O(g)$ with H_3PO_4 catalyst • Explanation of major and minor product from electrophilic addition of HX with unsymmetrical alkene • Explanation of carbocation intermediate stability • Heterolytic fission **<u>Reaction of carbonyl compound and mechanism</u>** Suitable reactions, e.g. • Aldehyde or ketone and HCN **OR** H^- e.g. RCHO +

					HCN → RCH(OH)CN *May be shown within mechanism* • Mechanisms, e.g.  **OR** H_2O instead of H^+ for 2nd stage **ALLOW** suitable non-specification alternative e.g. H_2O, NH_3, 1° amine **IGNORE** reactions with carboxylic acids (or derivatives) i.e. addition-elimination mechanism (condensation reaction) **Additional details (NOT INCLUSIVE)** • Nucleophilic addition • Systematic names of reactants and/or products • Details of functional group interconversion e.g. aldehyde to hydroxynitrile • In reduction, aldehydes form 1° alcohols and ketones form 2° alcohols • Details on reagents required e.g. - formation of hydroxynitriles with $NaCN/H^+(aq)$ - formation of alcohols with $NaBH_4$ • Heterolytic fission

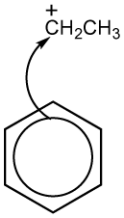
					Aspects of the **communication statement** being met might typically include: • Curly arrows starting from lone pairs / negative charges / bonds. • All reactants and intermediates have relevant charges and dipoles. • Mechanisms given are chemically feasible for the reactions. • No additional incorrect reactants have been included. **Examiner's Comments** A very good proportion of candidates scored all 6 marks, giving well-drawn mechanisms with some additional details such as mechanism names, functional group interconversions or other additional reaction information. Some attempted to 'describe' the mechanism using only words rather than drawing it out with a conventional curly arrow mechanism. Candidates may need more clarity on what 'describe' means in an organic chemistry context. Equally, a few gave just the mechanisms with no additional details, limiting themselves to Level 2. Candidates were usually more confident with the addition to alkenes using an electrophilic addition mechanism. Some gave additional details about major and minor products, although not always relevant as for a symmetrical alkene. Some represented the addition of

					hydrogen or water to alkenes via an electrophilic addition mechanism. While not correct it showed an understanding of mechanisms and a correct addition reaction for alkenes, so credit was given. Some candidates included incorrect reagents for reactions, such as acid catalysts with addition of a hydrogen halide, or incorrect conditions, such as the requirement for ultraviolet light on addition of a halogen. The addition to carbonyl compounds was not always as well-described. Some candidates struggled to identify carbonyl compounds, selecting carboxylic acids or their derivatives, with attempts at addition-elimination mechanism i.e. condensation reactions. Some gave incorrect reagents for carbonyls, including H_2O and HBr. However, some used off-specification reactions such as the addition of H_2O to form a geminal diol which was given but as the mechanism differs from the nucleophilic addition mechanism taught in this specification, full credit was rarely achieved. Some also considered oxidation of aldehyde or ketone to be an addition reaction. Most who presented a correct mechanism for addition to a carbonyl used the reaction with cyanide rather than reduction with $NaBH_4$. Common errors included arrows coming from the N of CN^-, a lack of putting dipoles on carbonyl bonds, missing charges on O in intermediates or showing the wrong direction of arrows. **OCR support**

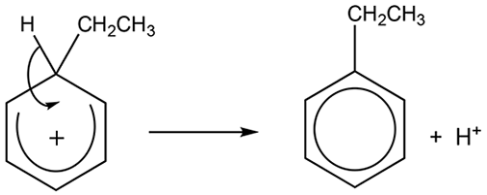
					The OCR Guide to Level of Response questions can be found on Teach Cambridge and can be used to help your students better understand this type of question. Exemplar 1  Level 3 – 6 marks Two correct addition mechanisms have been shown, one for an alkene and one for a carbonyl compound. Additional details include the names of the mechanisms, names of the functional groups in the products, and the fact that a C-C bond is formed in the second mechanism. All curly arrows, charges and dipoles are correctly positioned so this response was also given the communication mark.
			Total	**6**	
12 9		i	ethyl 4-methylpentanoate ✓	1	**ALLOW** one word: ethyl4-methylpentanoate **OR** more words, e.g. ethyl 4-methyl pentanoate **DO NOT ALLOW** 1-ethyl-4-methylpentanoate **IGNORE** lack of hyphens, extra hyphens, full stops instead of

					commas, extra spaces **DO NOT ALLOW** the following for methyl:methy, meth, methly, methanyl **DO NOT ALLOW** the following for ethyl:ethy, eth, ethly, ethanyl **Examiner's Comments** Candidates found this difficult, with less than half gaining the mark. The most common error was incorrectly numbering the methyl group due to counting from the wrong end, giving ethyl-2-methylpentanoate.
		ii	**Step 1**  **Step 2**  $SOCl_2$ used in **Step 1** ✓ Acyl chloride: $(CH_3)_2CHCH_2CH_2COCl$ correct ✓*Seen anywhere* **Step 1** correct equation ✓ **Step 2** correct equation ✓	4	**ALLOW** any combination of skeletal **OR** structural **OR** displayed formula as long as unambiguous e.g. $(CH_3)_2CHCH_2CH_2COOH + SOCl_2 \rightarrow (CH_3)_2CHCH_2CH_2COCl + SO_2 + HCl$ $(CH_3)_2CHCH_2CH_2COCl + C_2H_5OH \rightarrow (CH_3)_2CHCH_2CH_2COOC_2H_5 + HCl$ **DO NOT ALLOW** incorrect connectivity on OH **BUT ALLOW ECF** on subsequent structures **ALLOW** suitable non-specification alternatives for step 1 e.g. PCl_3, PCl_5, $COCl_2$ e.g. $3(CH_3)_2CHCH_2CH_2COOH + PCl_3 \rightarrow 3(CH_3)_2CHCH_2CH_2COCl + H_3PO_3$ $(CH_3)_2CHCH_2CH_2COOH + PCl_5 \rightarrow (CH_3)_2CHCH_2CH_2COCl + POCl_3 + HCl$ $(CH_3)_2CHCH_2CH_2COOH + COCl_2 \rightarrow (CH_3)_2CHCH_2CH_2COCl + HCl + CO_2$ **Examiner's Comments** This question differentiated between candidates well with the full range of marks seen. Some couldn't identify the correct reagent to use to form an acyl chloride i.e. $SOCl_2$, so lost 2 marks for the first step. Use of HC*l* as an alternative was common. A significant number

					used $SOCl_2$ but struggled to balance the equation. Many made errors with structures used, for example missing the CH_3 side chain, adding CH_3 to 3-position instead 4, inserting an additional CH_2 group or using a much easier structure, e.g. ethanoic acid. None of these structures were given marks as they would not form Ester F. Some used R- instead to simplify, for which credit was given, but only if it was clear what structure R represented. Another common error was to include an additional O in the acyl chloride group i.e. COOC*l* not COC*l*. The most common error made in Step 2 was to omit the formation of HC*l* or to use H_2O instead. A few lost the final mark for a connectivity error on ethanol i.e. $OHCH_2CH_3$.
			Total	**5**	
13 0		i	**ALLOW correct Kekulé representation of benzene throughout question 21** An electron pair acceptor ✓	1	**ALLOW** gains an electron pair / lone pair **Examiner's Comments** Most candidates were able to give the correct definition here. A common error was omission of 'pair' of electrons. Manyalso described that electrophiles are 'species attracted to areas of high electron density'or words to that effect, either alongside the accepted definition gaining credit or as the sole definition not gaining a mark.
		ii	**Generation of electrophile** $AlCl_3 + CH_3CH_2Cl \rightarrow CH_3CH_2^+ + AlCl_4^-$ ✓ **Electrophilic substitution**	5	**ANNOTATE ANSWER WITH TICKS AND CROSSES** **ALLOW** any combination of skeletal **OR** structural **OR** displayed formula as long as unambiguous **ALLOW** C_2H_5Cl **AND** $C_2H_5^+$ **ALLOW** positive charge anywhere on CH_2CH_3 e.g. $CH_2CH_3^+$



Curly arrow from π-bond to $^{+}CH_2CH^3$ ✓



Correct intermediate ✓

Curly arrow from C–H bond to reform π-ring **AND** H^+ as product ✓

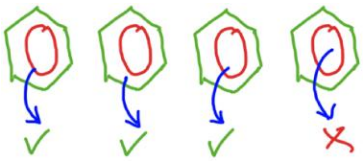
Regeneration of catalyst

$H^+ + AlCl_4^- \rightarrow AlCl^3 + HCl$ ✓

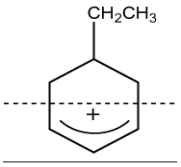
NOTE: curly arrows can be straight, snake-like, etc.
but **NOT** double headed or half headed arrows

1st curly arrow must

- start from, **OR** close to **circle of benzene ring AND**
- go to anywhere on $^{+}CH_2CH^3$



DO NOT ALLOW the following intermediate:



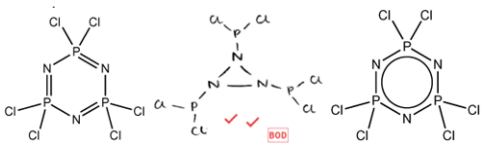
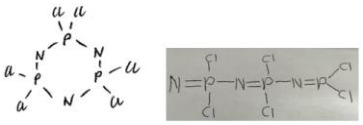
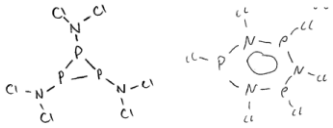
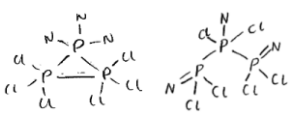
π-ring should cover approximately 4 of the 6 sides of the benzene ring structure
AND
'horseshoe' the right way, *i.e.* gap towards C with CH_2CH_3
ALLOW + sign anywhere inside the 'hexagon' of intermediate

Examiner's Comments

Most candidates were well prepared for this question, with over half of candidates gaining all 5 marks. A significant number of candidates showed halogenation, generating Cl^+ as an electrophile, instead ofalkylation. Others attempted to substitute the ethylbenzene ring rather than

					benzene. Further commonerrors included incorrect connectivity in the ethyl group on the intermediate, curly arrows coming fromhydrogen atoms rather than C-H bond to reform the π-ring and omission of an H^+ ion at the end ofmechanism.
			Total	**6**	
13 1		i	$3PCl_5 + 3NH_4Cl \rightarrow P_3N_3Cl_6 + 12HCl$ ✓	1	**ALLOW** multiples **IGNORE** state symbols, even if wrong **Examiner's Comments** This question again required candidates to construct an equation. Candidates were provided with the formula of all species reactants and products except for that of ammonium chloride. Candidates are expected to know that the ammonium ion is NH_4^+ but many incorrect equations showed NH_3Cl. About half the candidates were able to construct a correctly balanced equation with the '12' balancing number for HCl being the hardest part. This links back to the 'assessment for learning' callout added to Question 4 (b) (ii) in this report. As with other questions requiring equations to be written, this question differentiated very well. Writing formulae and balancing equations are fundamentals for mastering chemistry and candidates are advised to practise these skills throughout the course. **Assessment for learning**

					The specification states the following. ***Formulae and equations*** ***2.1.2(a)*** *the writing of formulae of ionic compounds from ionic charges, including:* i. *prediction of ionic charge from the position of an element in the periodic table* ii. *recall of the names and formulae for the following ions: NO_3^-, CO_3^{2-}, SO_4^{2-}, OH^-, NH_4^+, Zn^{2+} and Ag^+* This section will be studied at the start of the two-year course and form the backbone for chemical literacy. For success in chemistry, the common ions should be learnt.
		ii	**FIRST, CHECK THE ANSWER ON ANSWER LINE IF % by mass = 26.72, award 2 marks IF % by mass = 26.7, award 1 mark** ---------- ---------- M_r of $P_3N_3Cl_6$ = 348(.0) ✓ % by mass of P = $\frac{31.0 \times 3}{348} \times 100 = 26.72$ ✓ **2 DP required**	2	**ALLOW** 1 mark total for 26.7 *Question asks for 2 DP* **ALLOW** ECF from incorrect M_r **ALLOW** 1 mark for 8.91 (omission of ×3): $\frac{31.0}{348} \times 100 = 8.91$ **Examiner's Comments** In contrast to equation writing, candidates found this simple calculation far easier with the majority obtaining both marks for 26.72. Common incorrect percentages were 26.7 (wrong number of decimal places) and 8.91 (using 31 rather than 3 × 31 for the numerator).

		ii i	(P-N) bond lengths are different ✓ **OR** enthalpy change of hydrogenation is more exothermic (than delocalised structure) **OR** reacts with bromine/electrophiles/by addition	1	**Throughout, ORA** for delocalised structure **IGNORE** C-C bond lengths are different **IGNORE** hydration **ALLOW** decolourises bromine (without a catalyst/halogen carrier) **IGNORE** more reactive without example **IGNORE** alternating single and double bonds **<u>Examiner's Comments</u>** About half the candidates suggested a range of creditworthy responses with 'different bond lengths' and 'decolorises bromine' being the most common.
		i v	Structure shown with molecular formula $P_3N_3Cl_6$ **1st mark** • Each P bonded to 2 Cl atoms • Each P bonded to N **AND** Cl • Each N has *at least* 2 bonds • Each Cl has 1 bond ✓ **2nd mark (dependent on 1st mark)** • Each N has 3 bonds • Each P has 3 **OR** 5 bonds ✓ **IGNORE** charges Examples for 2 marks 	2	1st mark *Meets criteria for 1st mark*  **ZERO** marks  *N bonded to Cl*  *N atom(s) with 1 bond only*

					Examiner's Comments This was another question where valuable information: *'all N and Cl atoms are bonded to P atoms'* had been provided. Many of the structures seen ignored this information with chlorine often been shown bonded to a nitrogen atom. Nitrogen atoms were often shown with 1 bond only and chlorine atoms in the ring structure with 2 or more bonds. Most structures contained 6 or 3-membered rings. This was a difficult question, requiring candidates to use the supplied information to come up with realistic structures that met chemical bonding rules. Only about a quarter of candidates could be given any mark. The Kekulé theme in Questions 4 (c) (i) - (iv) should have prompted candidates that a Kekulé structure was likely here. Several other structures were allowed providing that they met normal chemistry bonding rules
			Total	**6**	