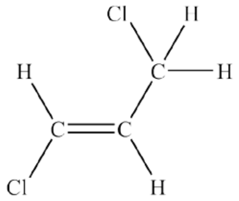
Alkenes OCR Questions Part 1

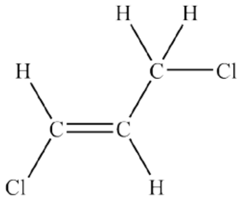
1. Three of the following displayed formulae represent the same isomer of $C_3H_4Cl_2$ but one structure represents a different isomer, **X**.

Which displayed formula represents **X**?

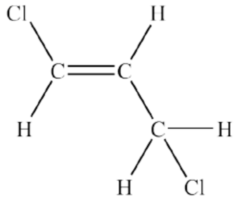
A



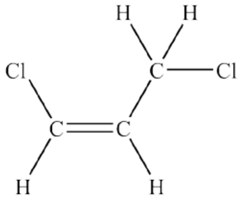
B



C



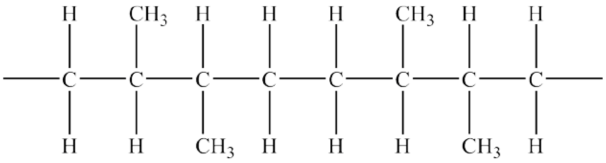
D



Your answer ☐

[1]

2. A section of a polymer chain is shown below.



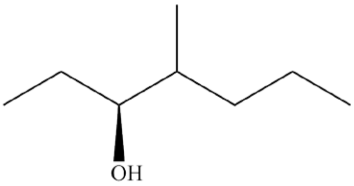
Identify the monomer that would give rise to this section of addition polymer.

A. *E*-But-2-ene
B. *Z*-But-2-ene
C. Methylpropene
D. Propene

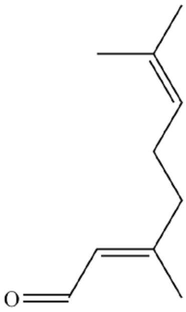
Your answer ☐

[1]

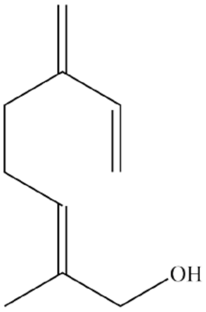
3. The organic compounds labelled **A** to **E** below are all produced by living organisms.



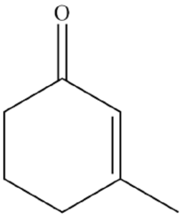
A



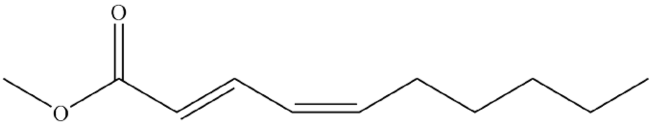
B



C



D



E

Compound **D** reacts readily with hydrogen chloride in an addition reaction. Two products are formed in this reaction, but one of the products is formed in much greater amounts than the other.

i. Draw the structure of **both** possible addition products of this reaction.

product 1

product 2

[2]

ii. State and explain which of the two possible products will be formed in greater amounts. Include a diagram of the intermediate in the mechanism of this reaction in your answer.

[2]

iii. 4.125 g of compound **D** is reacted with an excess of hydrogen chloride. The mixture of products contains 95% by mass of one product and 5% by mass of the other product.

Calculate the mass of each product formed.

[2]

4. Every year, two million tonnes of ethanol are produced worldwide by hydration of ethene obtained from crude oil.

$$C_2H_4(g) + H_2O(g) \rightleftharpoons C_2H_5OH(g) \qquad \Delta H = -45\ \text{kJ mol}^{-1}$$

This reaction is typically carried out using a catalyst at 300 °C and 6000 kPa.

The catalyst allows the reaction to reach equilibrium more quickly at the given temperature and pressure.

i. State the catalyst used in this reaction.

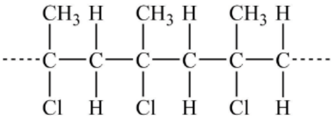
[1]

ii. Outline how a catalyst increases the rate of a chemical reaction.

[2]

5. This question looks at organic halogen compounds.

A section of a halogenated polymer is shown.



i. Draw the structure of the monomer that could be used to make this polymer.

[1]

ii. Combustion of this polymer produces HCl, which is a toxic gas.

Describe how HCl is removed from the waste gases produced.

[1]

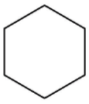
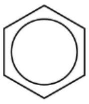
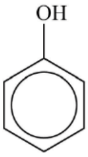
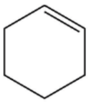
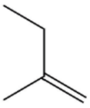
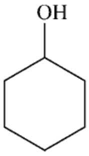
iii. Polymers made from natural foods such as corn starch are replacing halogenated polymers.

An advantage of this is that these polymers do not produce toxic gases on combustion.

State **one** other advantage of using polymers made from natural foods.

[1]

6(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]

7(a). 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]

(b). Pent-1-ene, $CH_3CH_2CH_2CH{=}CH_2$, is an alkene with molecular formula C_5H_{10}.

i. Pent-1-ene does **not** show stereoisomerism.
Explain why.

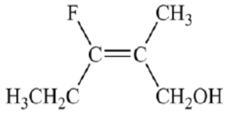
[1]

ii. A structural isomer of pent-1-ene shows *cis*—*trans* stereoisomerism.
Draw structures for the *cis* and *trans* isomers of this structural isomer of pent-1-ene.

cis isomer	*trans* isomer

[2]

(c). The following molecule shows *E/Z* isomerism**.**



Use the Cahn—Ingold—Prelog priority rules to identify whether this alkene is an *E* or *Z* stereoisomer.

Explain how you came to your decision.

[1]

8. How many stereoisomers are there of $CH_3CH = CHCH(OH)CH_2CH = CH_2$?

A. 2
B. 4
C. 6
D. 8

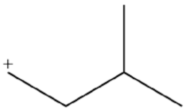
Your answer ☐

[1]

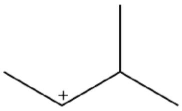
9. Hydrogen bromide reacts with 3-methylbut-1-ene.

What is the structure of the major intermediate formed in the mechanism?

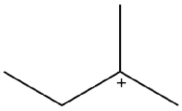
A



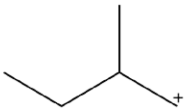
B



C



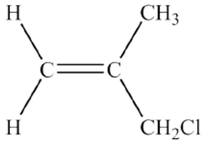
D



Your answer ☐

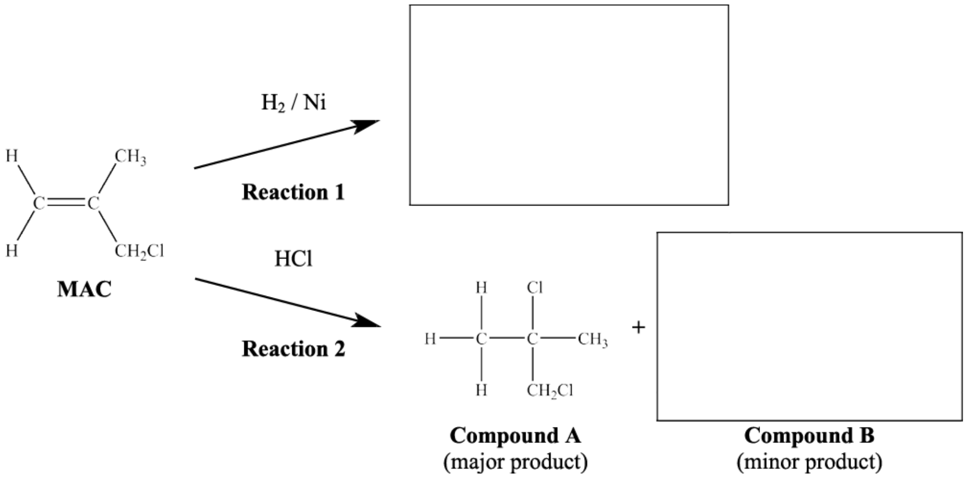
[1]

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



MAC

The flowchart below shows some reactions of MAC.



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

[2]

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

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

Use curly arrows and show relevant dipoles.

[3]

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

[1]

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

Draw the structure of the organic product of this reaction.

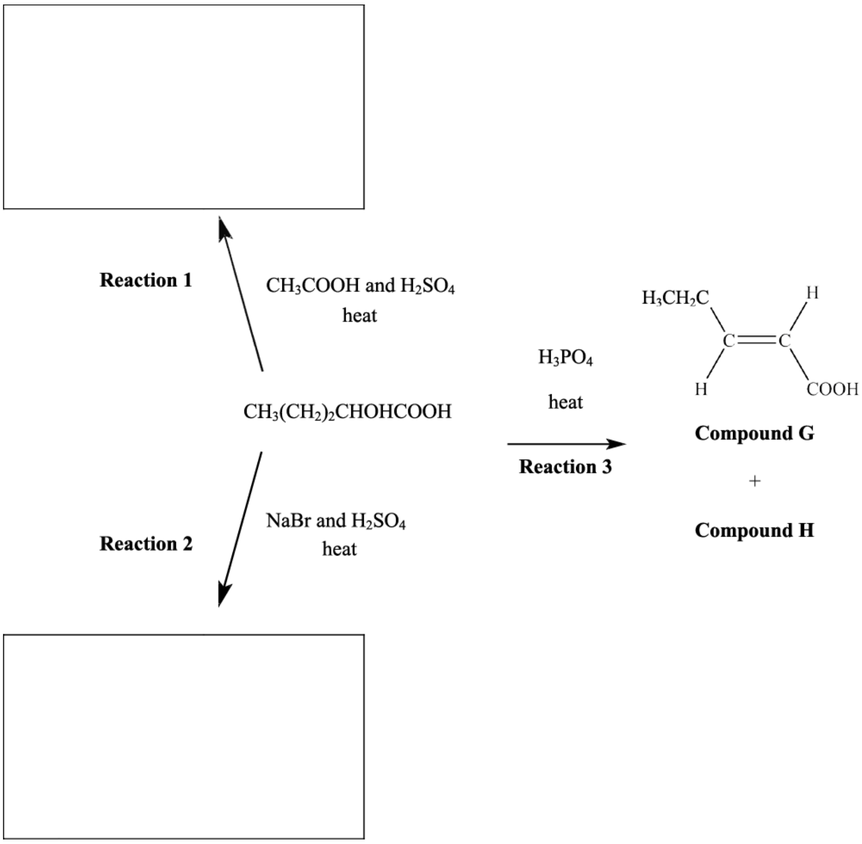
State what you would **observe** in this reaction and identify the compound responsible for the observation.

[2]

11. α-Hydroxy acids (AHAs) are naturally occurring acids often used as cosmetics.

The flowchart below shows some reactions of an AHA, $CH_3(CH_2)_2CHOHCOOH$.

i. Fill in the boxes to show the organic products of **Reactions 1** and **2**, clearly showing the relevant functional groups.



[2]

ii. Give the **full** systematic name for compound **G**.

[1]

iii. Compound **H** is a stereoisomer of compound **G**.

- Suggest a structure for compound **H**.
- Draw the repeat unit of the addition polymer that can be formed from compound **H**.

Compound H

addition polymer

[2]

iv. The addition polymer in (**iii**) is used widely in industry. Increasingly, waste polymers are being processed as a more sustainable option than disposal.

Apart from recycling, state **two** methods for usefully processing waste polymers.

[2]

12(a). 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**.

$CH_3CH(CH_3)CH_2CHOHCH_3$ → $CH_3CH(CH_3)CHCHCH_3 + H_2O$ **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]

(b). Alkenes can be used to make polymers.

i. Phenylethene, $C_6H_5CHCH_2$, undergoes addition polymerisation.

Write a balanced equation for the addition polymerisation of phenylethene.

You should show the structures of the monomer and polymer clearly.

[2]

ii. Waste polymers are often put into landfill sites.

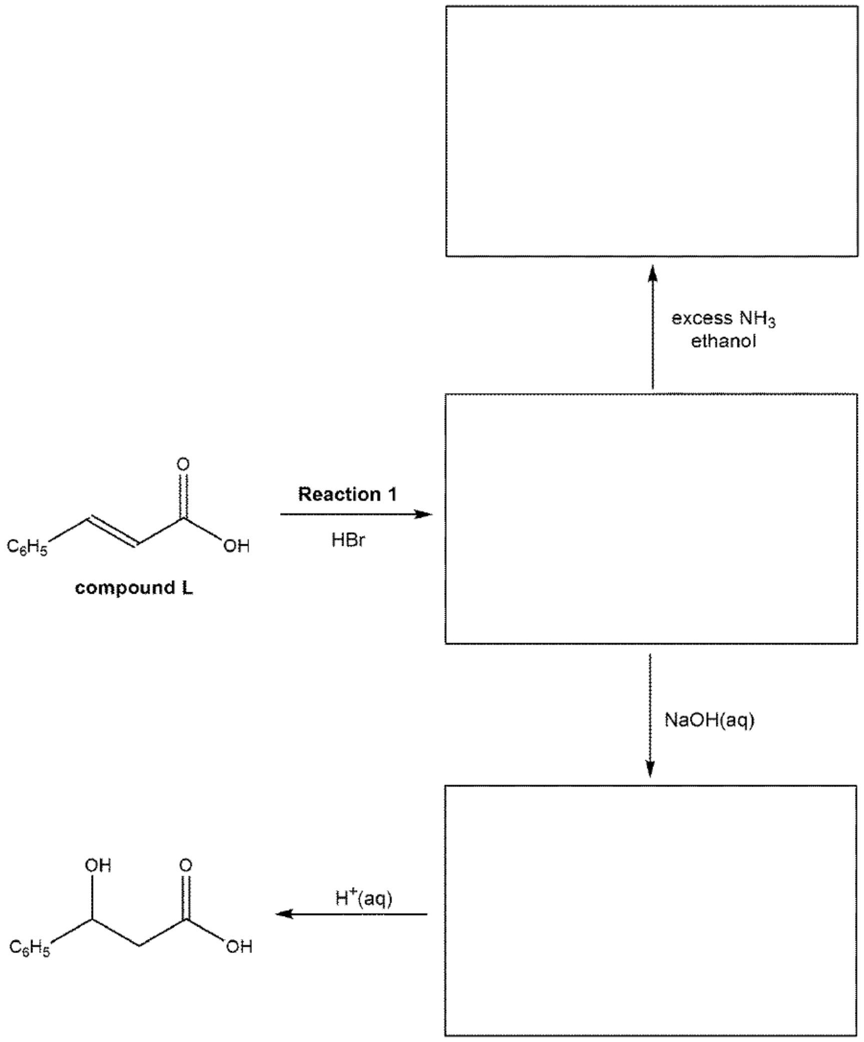
State **one** way of processing waste polymers usefully, other than landfill and recycling.

[1]

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

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

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



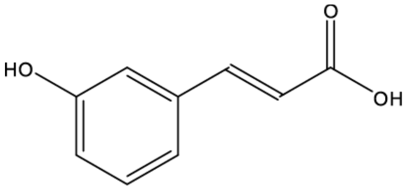
[3]

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

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

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

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



compound M

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

[1]

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

[2]

14. Information about a monobasic organic acid **D** is shown below.

- **D** reacts by both electrophilic substitution and electrophilic addition.
- The molecular formula of **D** is $C_xH_yO_2$.
- The mass spectrum of **D** has a molecular ion peak at *m/z* = 148.
- The ^{13}C NMR spectrum of **D** contains seven peaks.

Determine and draw a possible structure for **D**.

Explain your reasoning from the evidence provided.

[5]

15(a). Compound **F** has the molecular formula C_4H_8.

Compound **F** is reacted with steam in the presence of an acid catalyst, to form a mixture of three alcohols, **G**, **H** and **I**.

Compound **G** is oxidised with acidified potassium dichromate(VI) to form compound **J**.

Compound **J** reacts with Tollens' reagent to form compound **K**.

Compounds **H** and **I** are optical isomers.

Draw the structures of the compounds **F**, **G**, **H**, **I**, **J** and **K**.

[6]

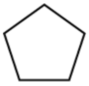
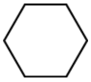
(b). Explain, with reference to a suitable chemical test, how compound **J** could be identified.

Your answer should **not** include spectroscopy.

[3]

16(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

In the absence of ultraviolet radiation, **cyclopropane** undergoes an addition reaction with bromine.

Suggest the structure of the organic product formed in this reaction.

[1]

(b). Petrol contains both **cyclohexane**, C_6H_{12}, and hexane.

Cyclohexane can be prepared from hexane.

i. Construct the equation for this reaction.

[1]

ii. Suggest **one** advantage of adding cyclohexane to hexane in petrol.

[1]

(c). 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]

17(a). Chloroethene, CH_2CHCl, can be polymerised to form poly(chloroethene).

Write an equation, using displayed formulae, to show the formation of this polymer.

[2]

(b). Incineration of plastics containing poly(chloroethene) produces waste gases that can damage the environment.

Incineration carried out in the presence of oxygen produces carbon dioxide, carbon monoxide and hydrogen chloride as waste gases and one other non-toxic product.

i. Write an equation for the incineration of the monomer, chloroethene, with oxygen.

[1]

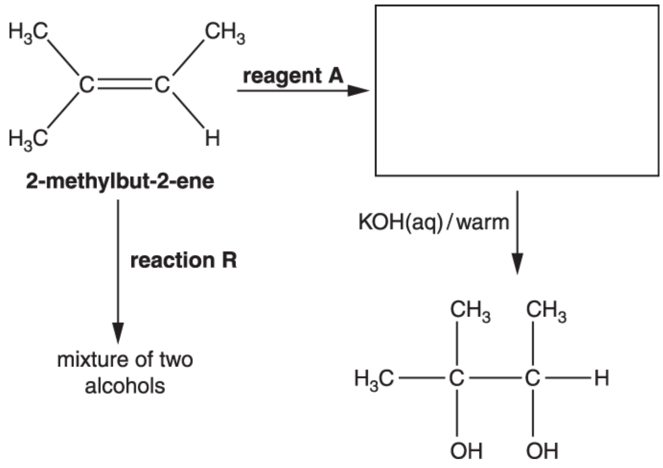
ii. Chemists have developed ways of removing hydrogen chloride from these waste gases. Sodium hydrogencarbonate, $NaHCO_3(s)$, is frequently used in industry for this purpose.

Explain how sodium hydrogencarbonate removes hydrogen chloride.

[1]

18(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]

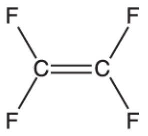
iii. Draw the two structural isomers of $C_5H_{12}O$ formed in **reaction R**.

[2]

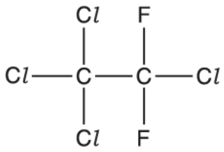
iv. Suggest why 2-methylbut-2-ene is less soluble in water than either of the structural isomers formed.

[2]

19(a). This question is about the compounds shown below.



B



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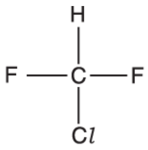
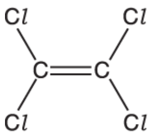
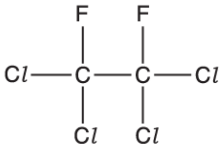


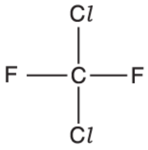
D



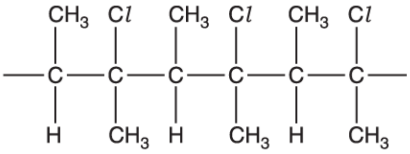
E



F



G



H

Which compound, **B** to **H**, could be used to make the polymer PTFE?

[1]

(b). Polymer **H** can be disposed of by combustion. One environmental problem is the production of toxic gases, such as CO.

i. Draw the structure of the monomer needed to produce polymer **H**.

[1]

ii. Give the formula of an acidic toxic gas that could form during combustion of polymer **H**.

[1]

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

Part of the C=C double bond in allyl bromide is called a π-bond.

Draw a labelled diagram to show the formation of the π-bond.

[2]

(b). Allyl bromide, $CH_2{=}CHCH_2Br$, reacts with bromine, Br_2.

i. Outline the mechanism of this reaction.

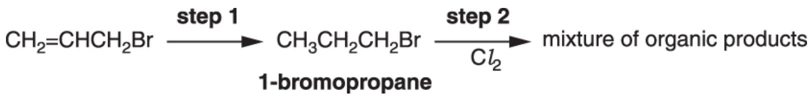
Include curly arrows, relevant dipoles and the structures of the intermediate and final product(s).

[4]

ii. Name the type of mechanism.

[1]

(c). Allyl bromide is reacted as shown below.



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

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

[1]

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

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

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

[5]

iii. Radical substitution produces a mixture of organic products.

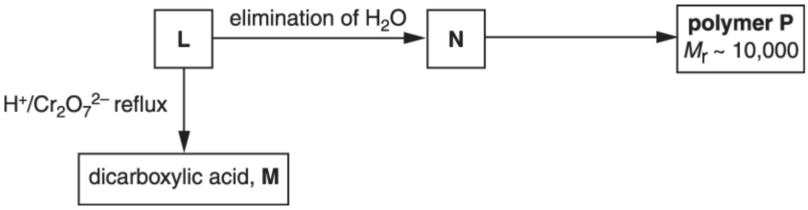
Suggest **two** reasons why.

[2]

Alkenes OCR Questions Part 1

21(a). L, **M**, **N** and P are straight-chain organic compounds containing C, H and O only.

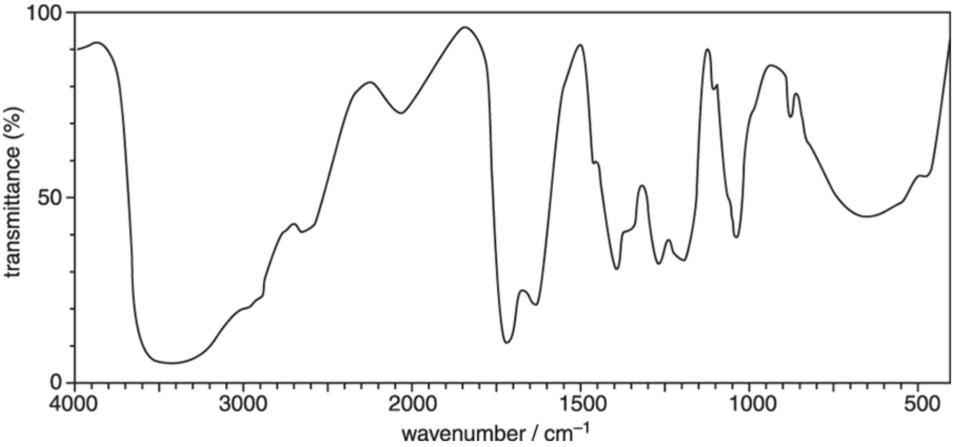
The flowchart shows reactions involving these compounds.



Analysis of compound **L** shows the following.

- Percentage composition by mass: C, 40.00%; H, 6.67%; O, 53.33%.
- Relative molecular mass of 90.0.
- The infrared spectrum below.

IR spectrum of **L**



Calculate the empirical and molecular formulae of compound **L**.

Show your working.

[3]

(b). Analyse the information and spectrum to determine the structures of **L** and **M**.

Include an equation for the reaction of **L** to form **M**.

[5]

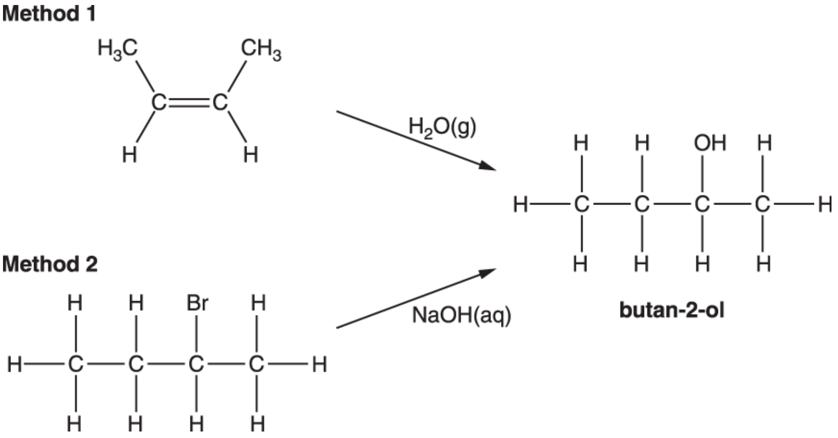
(c). Determine the structures of compounds **N** and **P**.

Estimate the number of repeat units in polymer **P** and write the equation for the formation of **P** from **N**.

[4]

Alkenes OCR Questions Part 1

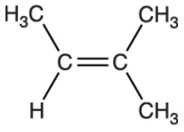
22. Butan-2-ol can be prepared using two different methods.



State the catalyst required for **Method 1**.

[1]

23(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.

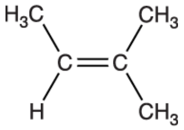
Draw the structure of the *Z* isomer and then name this isomer.

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]

24. Which compound has non-polar molecules?

A *E*-1,2-dichlorobut-2-ene

B *E*-2,3-dichlorobut-2-ene

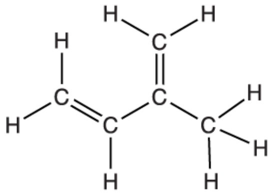
C *Z*-2,3-dichlorobut-2-ene

D *Z*-1,4-dichlorobut-2-ene

Your answer ☐

[1]

25. The displayed formula for a hydrocarbon is shown below.



How many σ and π bonds are present in a molecule of this hydrocarbon?

	σ bonds	**π bonds**
A	2	4
B	10	2
C	10	4
D	12	2

Your answer ☐

[1]

26. A reaction sequence is shown below:

Step 1 $CH_3CH{=}CHCH_3$ + HBr → $CH_3CH_2CHBrCH_3$

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

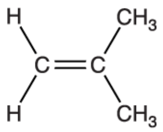
Which type of reaction mechanism is involved in each step?

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

Your answer ☐

[1]

27(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 ....

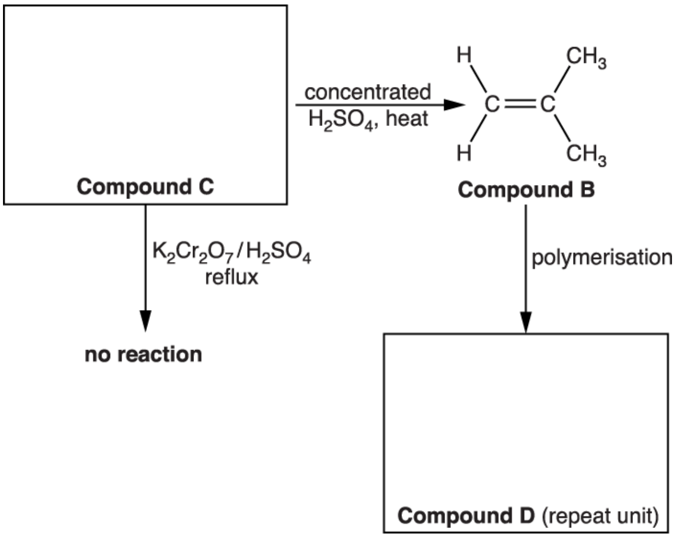
   General formula ....

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

[1]

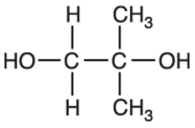
(b). Some reactions involving compound **B** are shown in the flowchart below.

Complete the flowchart, showing the structures of organic compounds **C** and **D**.



[2]

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



Compound F

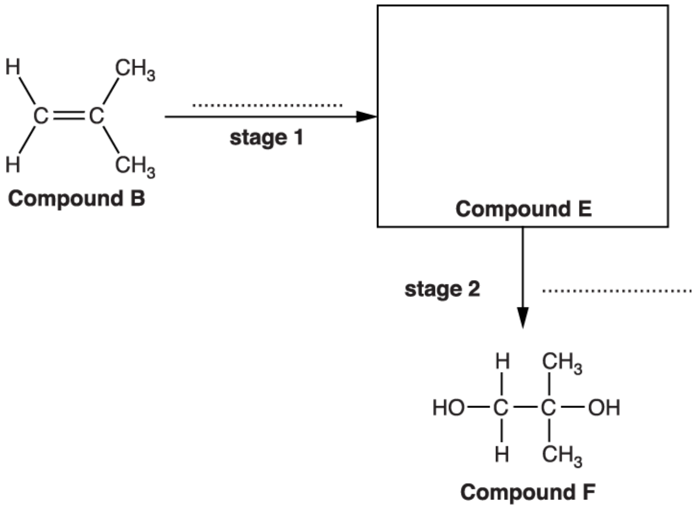
i. What is the empirical formula of compound **F**?

[2]

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

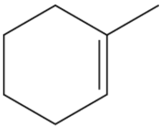
The synthesis first prepares compound **E**, as shown in the flowchart.

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



[3]

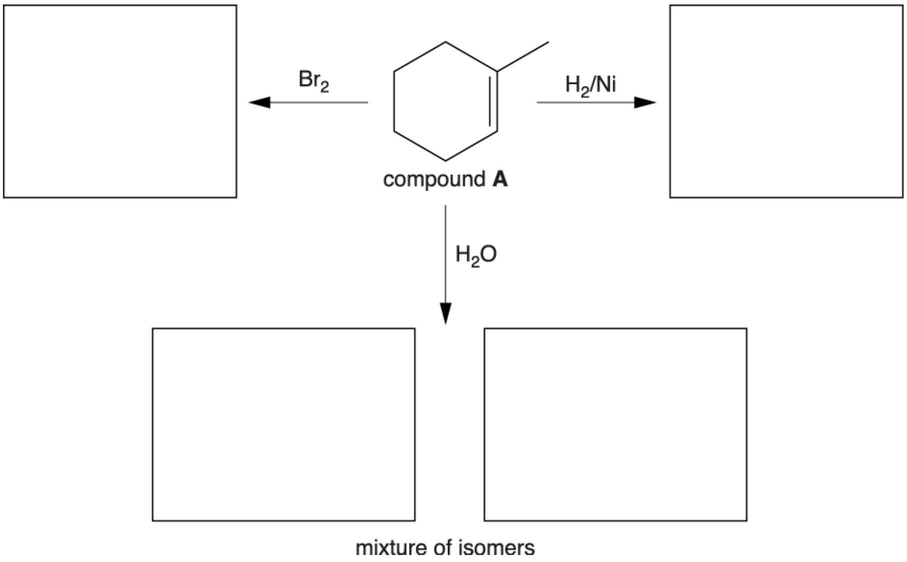
28. Compound **A** is an unsaturated hydrocarbon that can be used as the starting material for the production of organic compounds.



compound **A**

The flowchart shows three **addition** reactions of compound **A**.

i. In the boxes below, show the structures of the organic products formed in the reactions.



[4]

ii. What are the essential conditions for the reaction of compound **A** with H_2O?

[2]

iii. Using curly arrows, outline the mechanism for the reaction of compound **A** with Br_2.

[3]

iv. Name the mechanism in part **(iii)**.

[1]

29(a). Hex-2-ene shows *E*/*Z* isomerism.

i. Draw the skeletal formulae of *E*-hex-2-ene and *Z*-hex-2-ene.

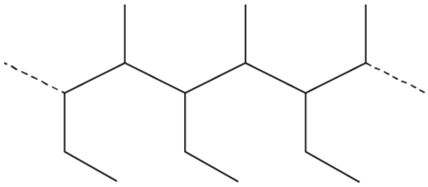
E-hex-2-ene	*Z*-hex-2-ene

[2]

ii. State and explain the features of a hex-2-ene molecule that lead to *E* and *Z* isomers.

[2]

(b). A section of a polymer that can be made from an unsaturated hydrocarbon **B** is shown below.



i. Add brackets to the section of the polymer to show **one** repeat unit.

[1]

ii. Draw the structure of hydrocarbon **B**.

[1]

iii. The polymer has a relative molecular mass of 50,000.

Calculate the number of monomer molecules required to make one molecule of the polymer.

number of monomer molecules = ... **[1]**

30. Stearic acid, oleic acid and linoleic acid are examples of naturally occurring fatty acids.

Traditional name	Structure	Systematic name
Stearic acid	$C_{17}H_{35}COOH$	Octadecanoic acid
Oleic acid	$C_{17}H_{33}COOH$	Octadec-9-enoic acid
Linoleic acid	$C_{17}H_{31}COOH$	Octadeca-9,12-dienoic acid

Partial hydrogenation of linoleic acid may result in the formation of *trans*-octadec-12-enoic acid.

i. Draw the **skeletal** formula of *trans*-octadec-12-enoic acid.

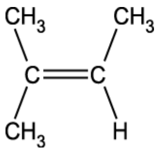
[2]

ii. Some fatty acids show *cis-trans* isomerism because there is restricted rotation about a C=C double bond.

State **one** other feature of these molecules that enables them to show *cis-trans* isomerism.

[1]

31. 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]

32. What is the number of sigma bonds in a benzene molecule?

A 3

B 6

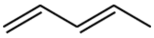
C 9

D 12

Your answer ☐

[1]

33. The compound shown below reacts with hydrogen chloride gas at room temperature and pressure to form a saturated compound.



What volume of hydrogen chloride reacts with 0.25 mol of the compound?

A 6 cm^3
B 12 cm^3
C 6 dm^3
D 12 dm^3

Your answer ☐

[1]

34. A student plans the two-step synthesis below.

$HOCH_2CH{=}CHCH_2OH$ → **intermediate** → $HOOCCH_2COCOOH$

Which compound could be the student's intermediate?

A $HOOCCH{=}CHCOOH$
B $HOCH_2CH_2CHICOOH$
C $HOCH_2CH_2CH(OH)CH_2OH$
D $HOCH_2CH(OH)CH(OH)CH_2OH$

Your answer ☐

[1]

35. Which bond angle(s) is/are present in a molecule of but-2-en-1-ol?

1. 120°
2. 109.5°
3. 104.5°

A 1, 2 and 3

B Only 1 and 2

C Only 2 and 3

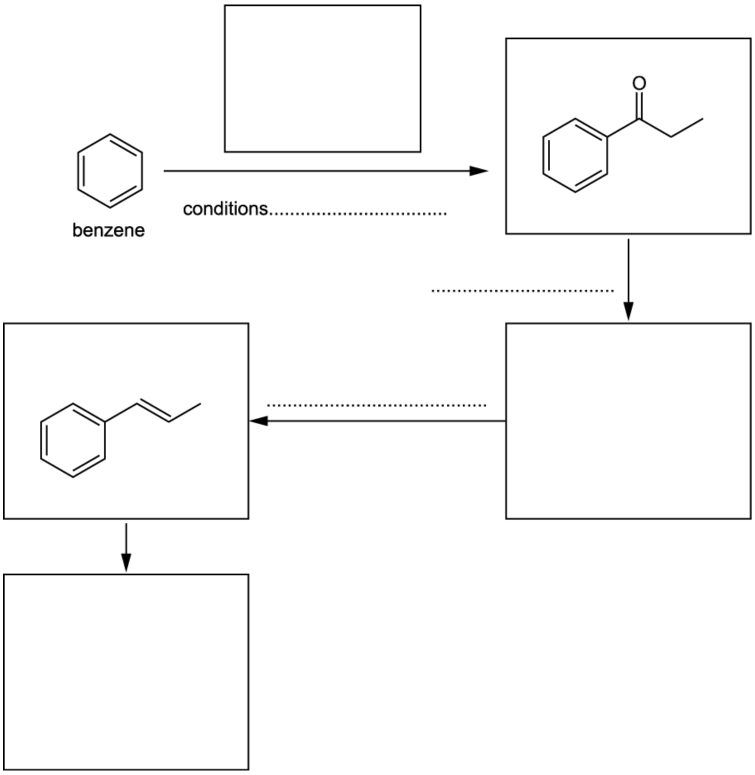
D Only 1

Your answer ☐

[1]

36(a). This question is about the synthesis of a polymer.

The flowchart below shows the synthesis of polymer **I** starting from benzene.
Draw the structures of the missing compounds in the boxes and add the missing reagents on the dotted lines.



repeat unit of polymer **I**

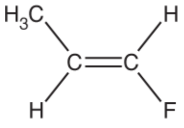
[6]

(b). Polymer **I** cannot be disposed of in landfill sites as it is not biodegradable.

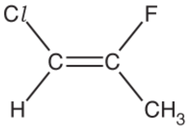
Suggest **one** way of processing waste polymer **I** other than landfill and recycling.

[1]

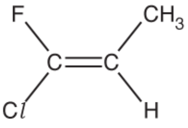
37. Which molecule is a *Z*-isomer?



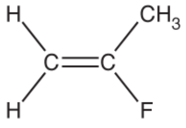
A



B



C



D

Your answer ☐ **[1]**

38. Which type of reaction has the greatest atom economy?

A Substitution

B Hydrolysis

C Elimination

D Addition

Your answer ☐ **[1]**

39. Which alcohol reacts with an acid catalyst to form *E* and *Z* stereoisomers?

A pentan-3-ol

B pentan-1-ol

C 2-methylbutan-2-ol

D 2,2-dimethylpropan-1-ol

Your answer ☐ **[1]**

40(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). The C=C group in an alkene contains a p-bond.

Complete the diagram below to show how p-orbitals are involved in the formation of a p-bond.

[1]

(c). 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?

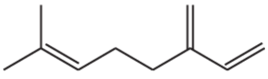
Explain your answer.

Major organic product

Explanation

[1]

(d). Myrcene, $C_{10}H_{16}$, is a naturally occurring hydrocarbon containing more than one carbon-carbon double bond.



myrcene

i. Reaction of 204 mg of myrcene with hydrogen gas produces a saturated alkane.

Calculate the volume of hydrogen gas, in cm^3 and measured at RTP, needed for this reaction.

Show your working.

volume = ... cm^3 **[2]**

ii. ß-Carotene is a naturally occurring unsaturated hydrocarbon found in carrots.
A ß-carotene molecule contains 40 carbon atoms, has two rings, and a branched chain.

0.0200 mol of ß-carotene reacts with 5.28 dm^3 of hydrogen gas to form a saturated hydrocarbon.

Using molecular formulae, construct a balanced equation for this reaction.

Include relevant calculations and reasoning.

Equation .... **[4]**

41. Cyclohexene is reacted with bromine to prepare the organic compound **F**.

Give the structure of compound **F** and outline the mechanism for this reaction.

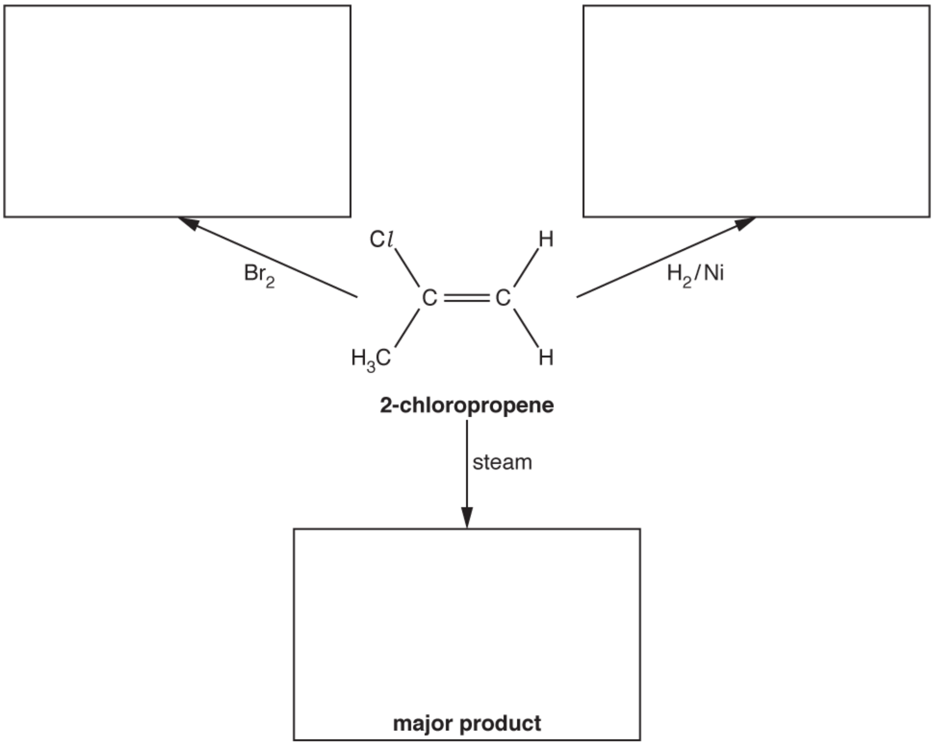
Include curly arrows, charges and relevant dipoles.

[4]

42(a). This question is about 2-chloropropene, C_3H_5Cl.

Three reactions of 2-chloropropene are shown in the flowchart below.

i. Complete the flowchart to show the organic products formed in the reactions.



[3]

ii. The reaction of 2-chloropropene with steam requires a catalyst.

State a suitable catalyst for this reaction.

[1]

(b). 2-chloropropene can be polymerised to form poly(2-chloropropene).

i. Write a balanced equation for the formation of this polymer.
The equation should include the structure of the repeat unit of the polymer.

[2]

ii. After their useful life, waste polymers can be disposed of by combustion.

State **one** particular problem with disposal of poly(2-chloropropene) by combustion.

[1]

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

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

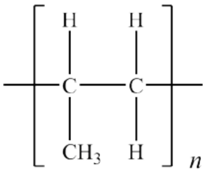
State the meaning of the term *electrophile* and suggest the formula of the electrophile formed from IBr.

[2]

44(a). A large proportion of the world's output of organic chemicals is used to make addition polymers. These polymers have a variety of uses.

Poly(propene) is used to make packaging, textiles and rope.

A repeat unit for poly(propene) is shown below.



i. Explain why poly(propene) is a *saturated* hydrocarbon.

[1]

ii. State the bond angle around each carbon atom in poly(propene).

[1]

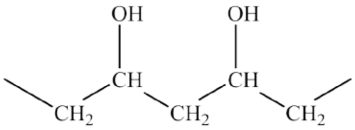
iii. After polymers have been used for packaging, the waste polymers need to be processed to save resources, for example, by recycling.

Describe **two** other ways in which waste poly(propene) can be processed in a sustainable way.

[2]

(b). Poly(ethenol) is used to make soluble laundry bags.

A section of the structure of poly(ethenol) is shown below.



i. Draw a structure to represent one repeat unit of poly(ethenol).

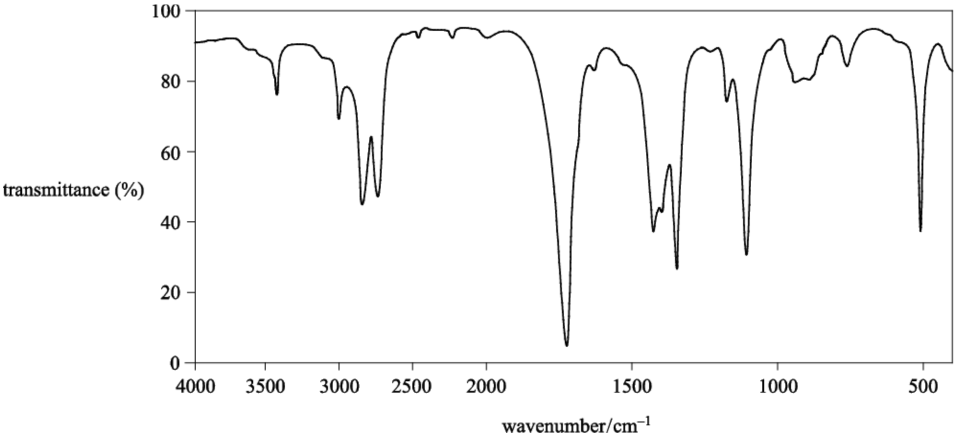
[1]

ii. Poly(ethenol) is not manufactured from ethenol.

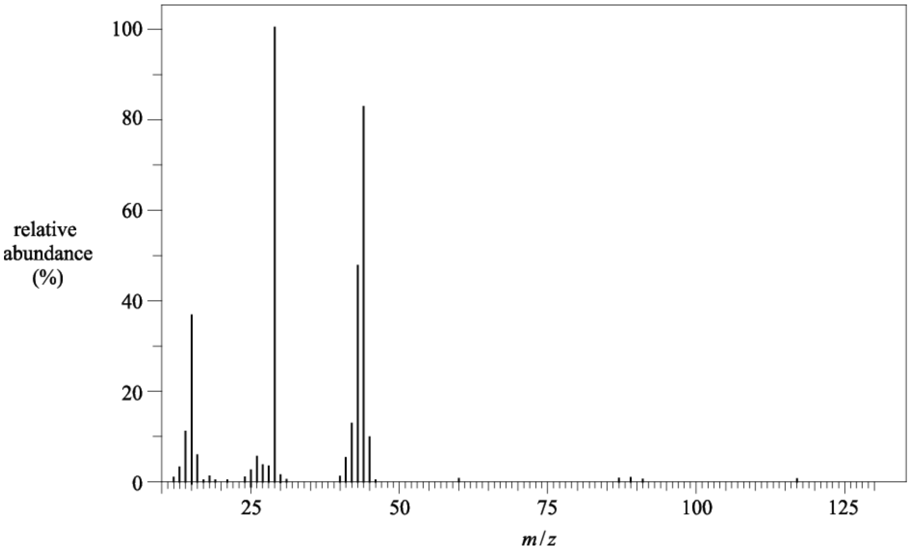
Ethenol is unstable and it forms a more stable structural isomer.

Analysis of the structural isomer gave the following data.

Infrared spectrum



Mass spectrum



Use **all** the data to show that the isomer is **not** ethenol.

Identify the structural isomer of ethenol.

In your answer you should make clear how your explanation is linked to the evidence.

[4]

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

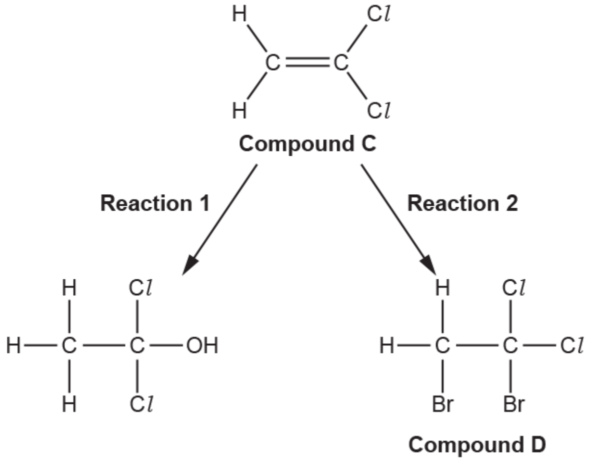
The elimination of H_2O from pentan-2-ol forms a mixture of organic products.

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]

46(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

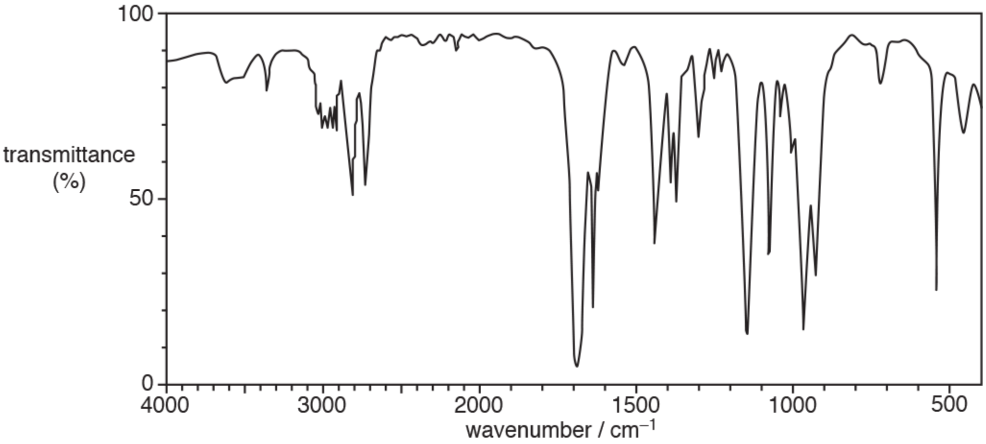
[2]

47. * Compound **F** is a *trans* stereoisomer which is a useful intermediate in organic synthesis.

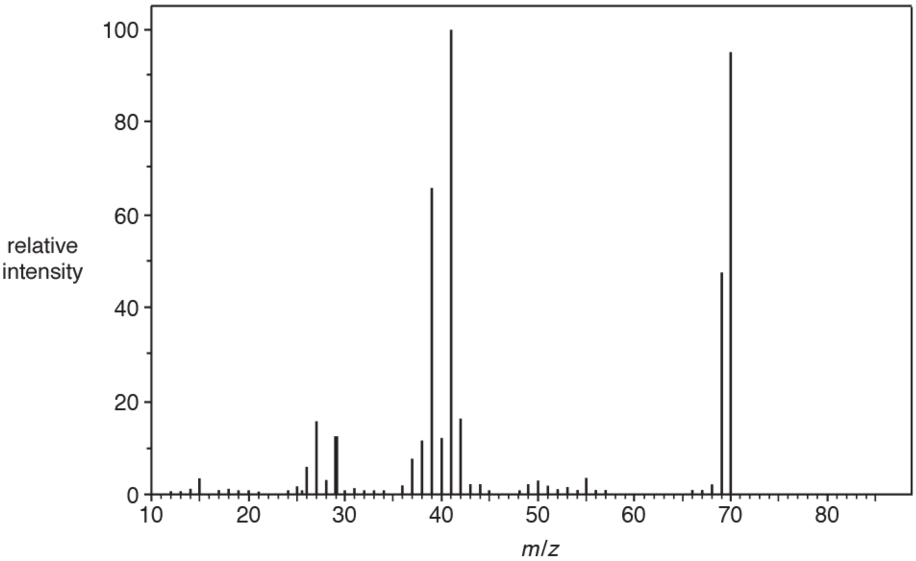
The results of elemental and spectral analysis of compound **F** are shown below.

Percentage composition by mass: C, 68.6 %; H, 8.6 %; O, 22.8 %.

Infrared spectrum



Mass spectrum



In the mass spectrum, the peak with the greatest relative intensity is caused by the loss of a functional group from the molecular ion of compound **F**.

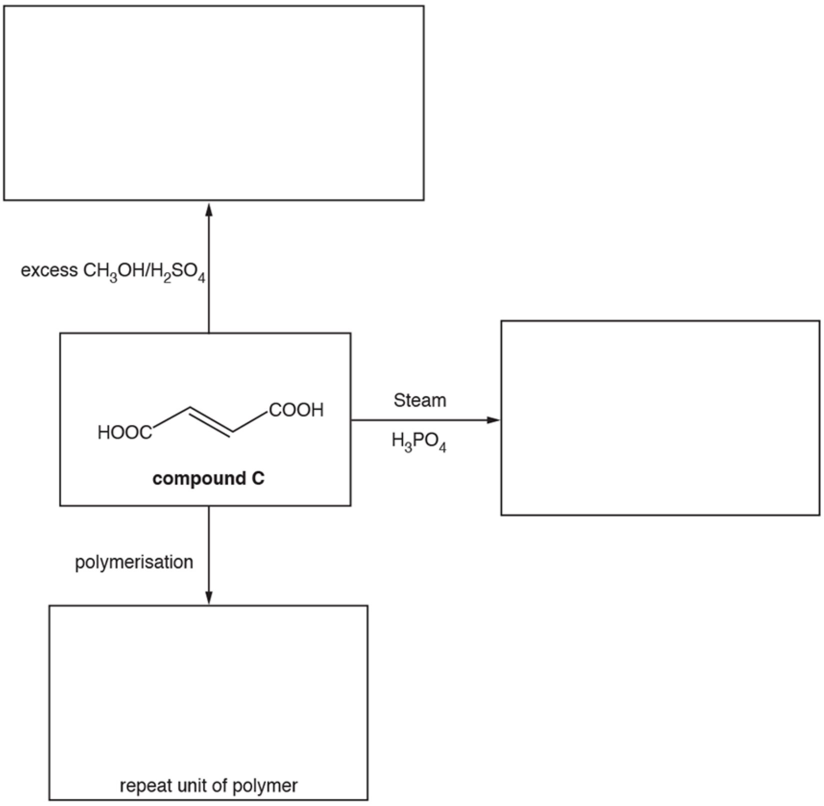
Determine the structure of compound **F**.

Explain your reasoning and show your working.

[6]

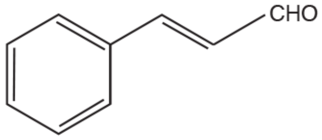
48. The flowchart below shows some reactions of compound **C**.

In the boxes, draw the organic products of these reactions.

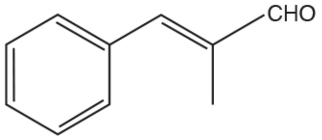


[3]

49(a). Cinnamaldehyde and methylcinnamaldehyde are naturally occurring organic compounds.



cinnamaldehyde



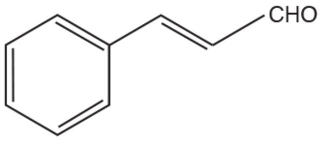
methylcinnamaldehyde

Methylcinnamaldehyde is an *E* stereoisomer.

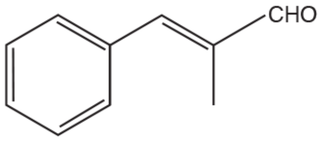
Explain this statement in terms of the Cahn-Ingold-Prelog (CIP) rules.

[2]

(b). A student plans to carry out some chemical tests on both cinnamaldehyde and methylcinnamaldehyde.



cinnamaldehyde



methylcinnamaldehyde

i. Suggest a suitable chemical test to confirm that both compounds contain an unsaturated carbon chain.

   Your answer should include the reagent and observations.

[1]

ii. Describe a chemical test to confirm that both compounds contain an aldehyde functional group.

   Your answer should include the reagent and observations.

[1]

iii. Describe a chemical test to confirm that cinnamaldehyde and methylcinnamaldehyde contain a carbonyl group.

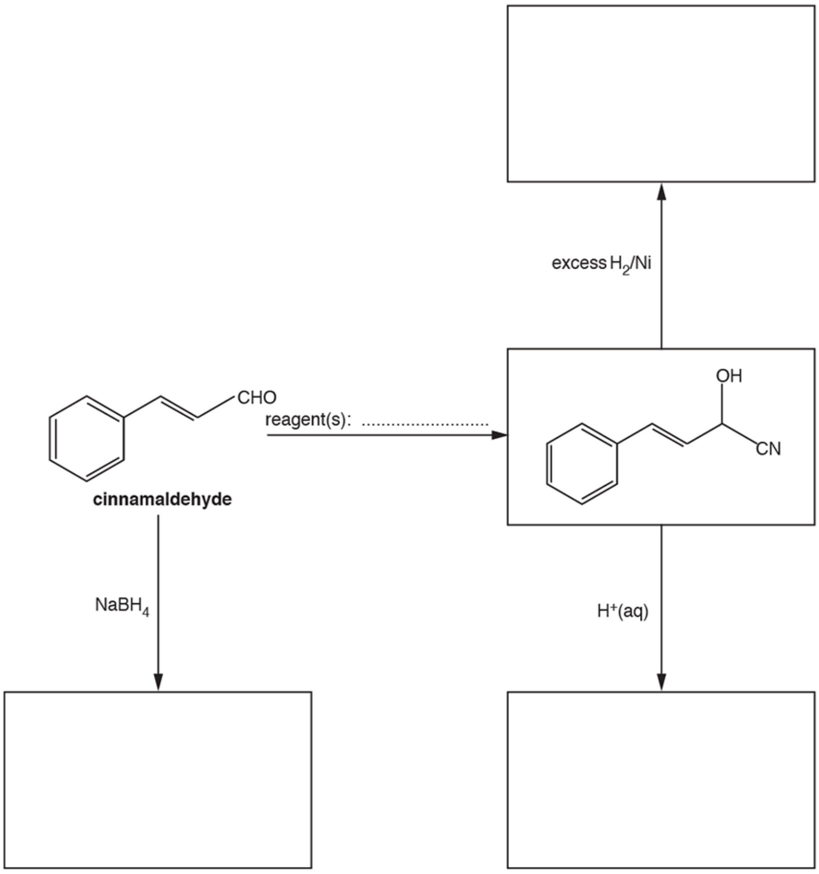
How could the products of this test be used to distinguish between the two compounds?

Your answer should **not** include spectroscopy.

[3]

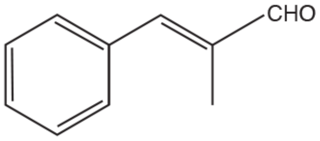
(c). The flowchart below shows some reactions starting with cinnamaldehyde.

Draw the structures of the missing organic compounds in the boxes and add the missing reagent(s) on the dotted line.



[5]

(d). * 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
C*l*	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]**

50. * 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]

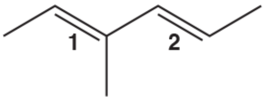
51. A student reacts pent-2-ene with bromine in the laboratory.

Which compound is formed?

A 1,1-dibromopentane
B 1,2-dibromopentane
C 2,2-dibromopentane
D 2,3-dibromopentane

Your answer ☐ **[1]**

52. The molecule below has two double bonds, labelled **1** and **2**.



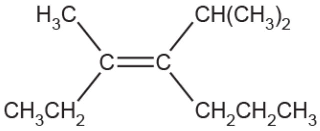
The arrangement around each double bond can be identified as *E* or *Z*.

Which row in the table is correct for double bond **1** and double bond **2**?

	Double bond 1	**Double bond 2**
A	*E*	*Z*
B	*Z*	*E*
C	*E*	*E*
D	*Z*	*Z*

Your answer ☐ **[1]**

53. The structure of a stereoisomer is shown below.



Which term correctly describes this stereoisomer?

A *cis-*

B *trans-*

C *E-*

D *Z-*

Your answer ☐ **[1]**

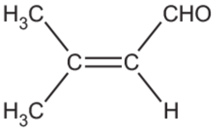
54. Which types of bonds are broken and formed in the reaction of ethene and bromine?

	Types of bond broken	**Types of bond formed**
A	σ	π
B	π	σ
C	σ and π	π
D	σ and π	σ

Your answer ☐ **[1]**

55(a). This question is about unsaturated aldehydes and alcohols.

3-Methylbut-2-enal, shown below, is used as a food flavouring.



3-methylbut-2-enal

3-Methylbut-2-enal is reacted with hydrogen bromide, forming a mixture of two organic products.

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

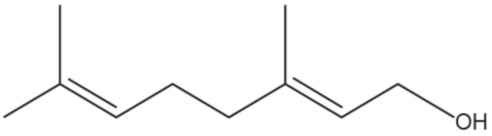
i. Outline the reaction mechanism for the formation of **one** of the organic products.
Include curly arrows and relevant dipoles.

[4]

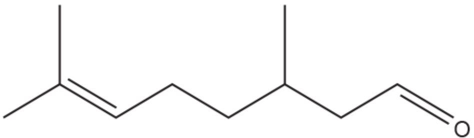
ii. Explain why one of the organic products forms in a much greater quantity than the other organic product.

[2]

(b). Geraniol and citronellal, shown below, are isomers present in ‘citronella oil’, used as an insect repellent.



Geraniol



Citronellal

- Geraniol and citronellal are structural isomers of each other.
- They also show stereoisomerism.

i. Describe how the observations from a chemical test would distinguish between geraniol and citronellal.

[2]

ii. What is the molecular formula of geraniol?

[1]

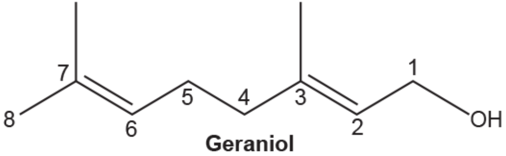
iii. Explain why geraniol and citronellal are structural isomers of each other.

[1]

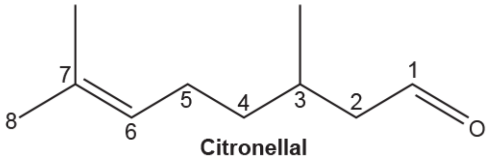
iv. Explain the term **stereoisomerism.**

[1]

v. The structures of geraniol and citronellal are repeated below with the carbon atoms numbered.



Geraniol



Citronellal

Explain the types of stereoisomerism shown by geraniol and citronellal.

In your answer,
- refer to the numbered carbon atoms in the structures above
- draw diagrams clearly showing any stereoisomers.

Geraniol stereoisomers

Citronellal stereoisomers

[4]

56. What is the best description for the bonding between the carbon atoms in an ethene molecule?

A One σ-bond and one π-bond

B One π-bond

C Two σ-bonds

D Two π-bonds

Your answer ☐ **[1]**

57. Which statement about an electrophile is correct?

A It is an electron pair acceptor.

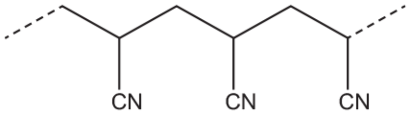
B It is a proton donor.

C It is a negative ion.

D It is a species with an unpaired electron.

Your answer ☐ **[1]**

58. A section of a polymer is shown below.



Which monomer could form this polymer?

A $CH_3CH(OH)CN$

B $HOCH_2CH_2CN$

C $H_2C{=}CHCN$

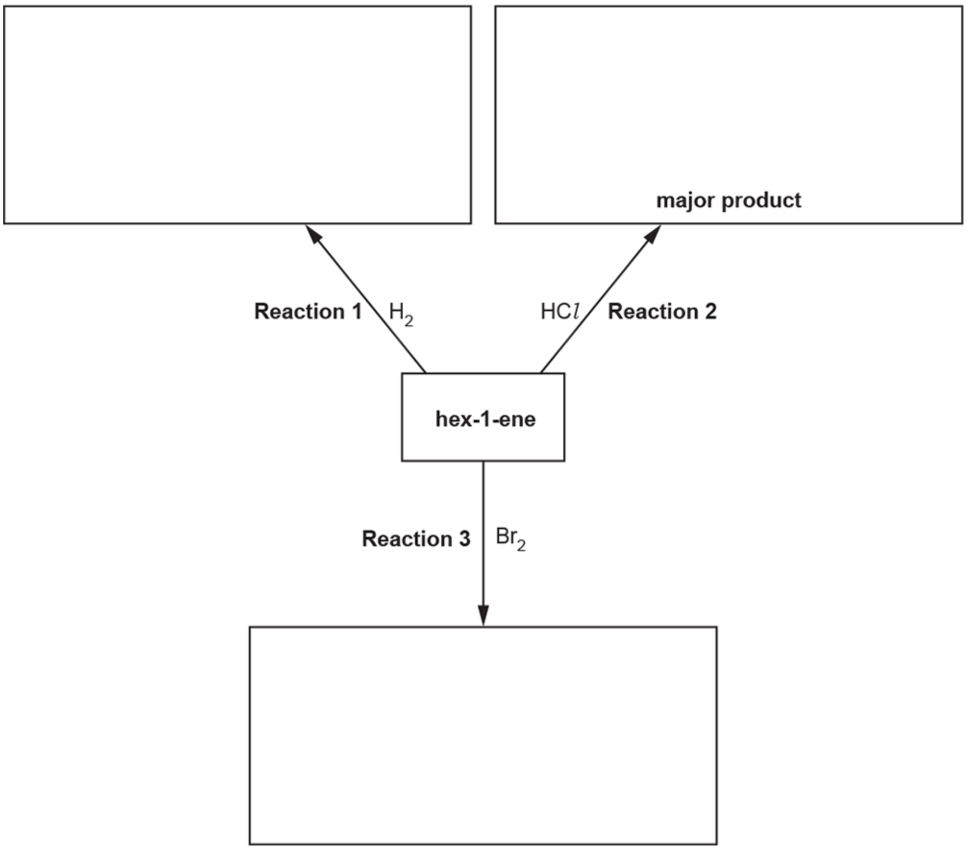
D $NCCH{=}CHCN$

Your answer ☐ **[1]**

59. This question is about hex-1-ene, $CH_3CH_2CH_2CH_2CH{=}CH_2$.

Hex-1-ene is reacted with H_2, HC*l* and Br_2 as shown in the flowchart below.

i. Complete the flowchart to show the structures of the organic products of these reactions.



[3]

ii. State the catalyst needed in **reaction 1.**

[1]

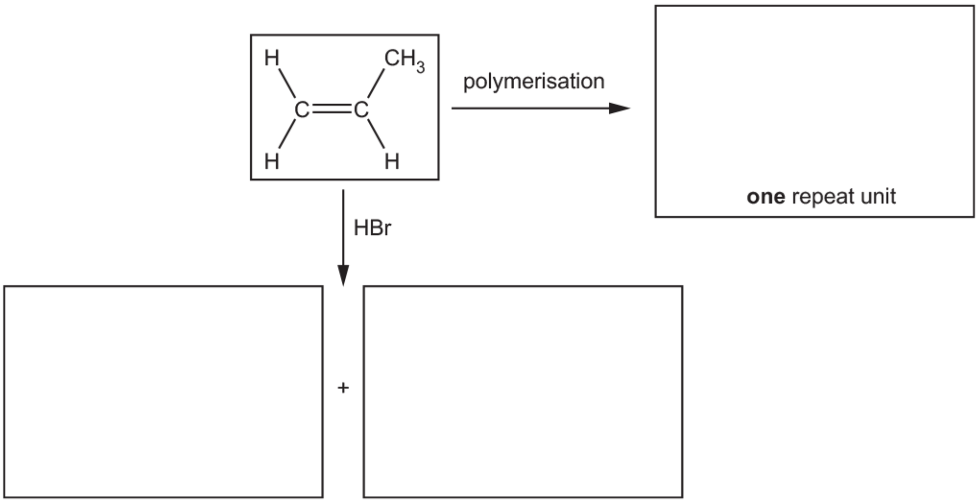
iii. What would you observe in **reaction 3**?

[1]

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

Two reactions of propene are shown below.

In the boxes, show the structures of the organic products of the reactions.

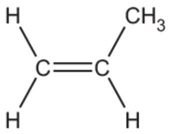


[3]

(b). 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]

(c). The ‘alkynes’ is a homologous series of hydrocarbons.

The table shows three alkynes.

Alkyne	**Structural formula**	**Molecular formula**
ethyne	HC≡CH	C_2H_2
propyne	$CH_3C≡CH$	C_3H_4
but-1-yne	$CH_3CH_2C≡CH$	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.

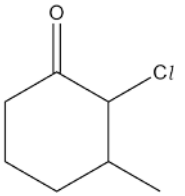
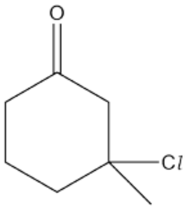
[2]

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

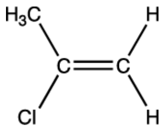
[1]

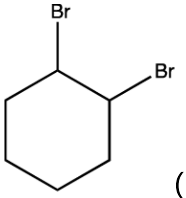
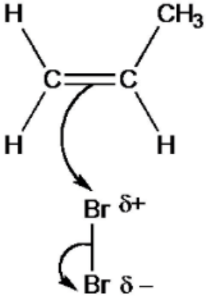
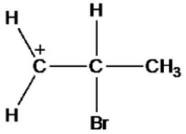
END OF QUESTION PAPER

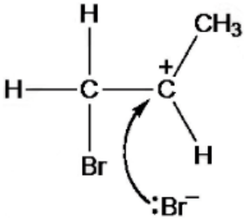
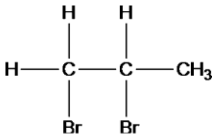
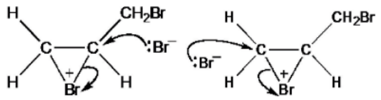
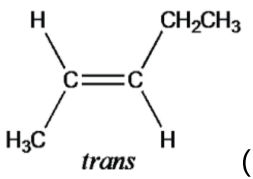
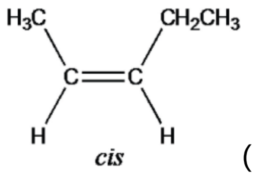
Mark scheme

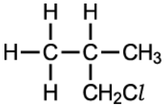
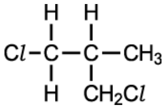
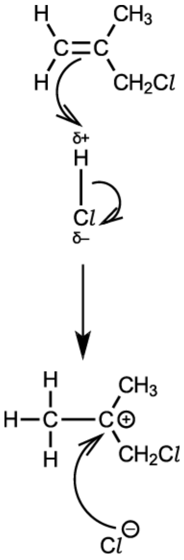
1			D	1	
			Total	**1**	
2			D	1	
			Total	**1**	
3		i	 (1)  (1)	2	**allow** any unambiguous structure or formula. **allow ecf** on the second structure for hydrogen atom errors if candidate tries to convert to a displayed / structural formula, but the carbon skeleton must be correct.
		ii	correct structure of either possible carbocation intermediate shown (1) the tertiary halogenoalkane (which will be labelled as either product 1 or product 2) is identified as the one formed in greater amounts … because the carbocation more stable on C3 than C2 *owtte* (1)	2	If both carbocations are drawn, only one needs to be correct to score the mark. **allow ecf** from **(i)** for correct justification of product formed in greater amount based on incorrect structures.
		iii	*Amount of **D** that reacts* M(**D**: $C_7H_{16}O$) = 110 (g mol^{-1}) **AND** $n(C_7H_{16}O) = \frac{4.125}{110} = 0.0375$ (mol) (1) *Masses of two products formed*	2	

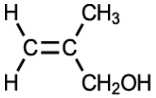
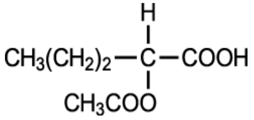
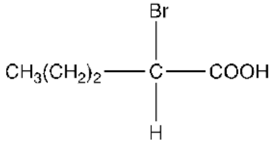
		iii	M(product: $C_7H_{17}OCl$) = 146.5 (g mol^{-1}) **AND** Mass of 95% product = $0.0375 \times \frac{95}{100} \times 146.5 = 5.22$ g **AND** Mass of 5% product = $0.0375 \times \frac{5}{100} \times 146.5 = 0.27$ g (1)		**allow** mass of both products = 0.0375 × 146.5 = 5.49 g Mass of 95% product = $\frac{95}{100} \times 5.49 = 5.22$ g Mass of 5% product = $\frac{5}{100} \times 5.49 = 0.27$ g **allow** 'product 1' and 'product 2' if linked to **correct** mass given labelling in **(i)** and reasoning in **(ii)** (**allow ecf** from **(ii)**).
			Total	**6**	
4		i	phosphoric acid / H_3PO_4	1	if both name and formula are given, the formula must be correct, but **allow** minor errors in an attempt at the name
		ii	(allows the reaction to proceed via a route with) lower activation energy … (1) … so that a greater proportion of molecules exceed the activation energy (1)	2	**allow** a sketch of an energy profile diagram as long as the catalysed and uncatalysed E_a are both labelled **allow** 'more molecules exceed the activation energy' **allow** a sketch of a Boltzmann distribution as long as both axes and both E_a values are labelled
			Total	**3**	

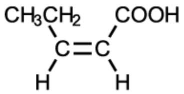
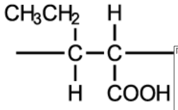
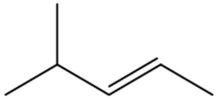
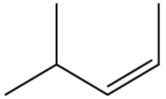
5		i	Structure of 2-chloropropene 	1	**allow** any unambiguous structure **allow** $CH_3CCl = CH_2$ (Double bond must be shown)
		ii	HCl gas is passed through alkali / carbonate	1	
		iii	Reduces the dependency on finite resources **OR** Biodegradable **OR** Photodegradable	1	**allow** crude oil **OR** petroleum **OR** fossil fuels for ‘finite resources’ **allow** ‘rots naturally’
			Total	**3**	
6	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

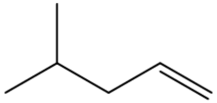
					% yield = (2.05 / 6.273) = 32.7(%) **allow ecf** from calculated actual and theoretical yields
		ii	bromine water is decolourised (1)  (1)	2	**allow** bromine water turns colourless **ignore** ‘goes clear’ **allow** correct structural **OR** displayed **OR** skeletal formula **OR** mixture of the above
			Total	**10**	
7	a	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)  Correct carbocation with + charge on C with 3 bonds **AND** curly arrow from Br^- to C^+ of carbocation (1)	4	Curly arrow must start from bond and go to correct atom **do not allow** partial charges on C=C bond **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)

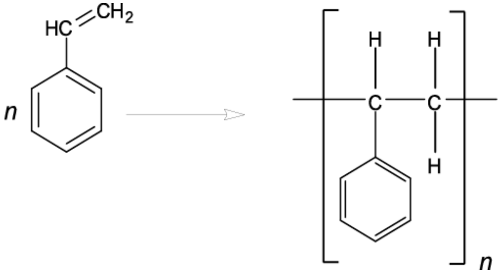
			 Correct product: (1) 		**allow** formation of bromonium intermediate and curly arrows, i.e.: 
		ii	Movement of a pair of electrons	1	**allow** movement of a lone pair
	b	i	One of the carbons of the C=C has two of the same groups attached / has two hydrogen atoms attached (so it can't show 2 different stereoisomers)	1	**allow** a stereoisomer must have 2 different groups attached to each carbon of the C=C double bond
		ii	1 mark each correct DIAGRAM  (1)  (1)	2	**allow** correct skeletal **OR** displayed formula **OR** mixture **but** must clearly show arrangement around C=C
	c		*E* isomer **AND** F takes priority over the carbon on the left hand side (as it has a higher atomic number) **AND** CH_2OH takes priority over the CH_3 group on the right hand side	1	*E* with no explanation is insufficient
			Total	**9**	

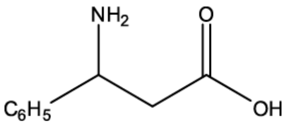
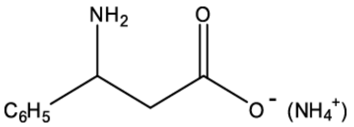
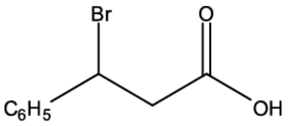
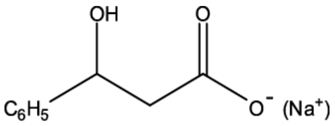
8			B	1	
			Total	**1**	
9			B	1	
			Total	**1**	
10		i	From **Reaction 1** =  compound **B** = 	2	**ALLOW** correct structural **OR** displayed **OR** skeletal formulae **OR** a combination of above as long as unambiguous
		ii	 Curly arrow from $C{=}C$ to attack the H atom Correct dipole on $\mathrm{H{-}C}l$ **AND** curly arrow from bond to $\mathrm{C}l$ Correct carbocation / carbonium ion with full	3	**ALLOW** correct structural **OR** displayed **OR** skeletal formulae **OR** a combination of above as long as unambiguous. Curly arrow must start from covalent bonds and not atoms. **DO NOT ALLOW** any other partial charges *e.g.* shown on double bond. **DO NOT ALLOW** $C^{\delta+}$ for charge on carbonium ion. Curly arrow from $\mathrm{C}l^{-}$ can start from the negative charge or the lone pair. **DO NOT ALLOW** delta negative, *i.e.* $\mathrm{C}l^{\delta-}$.

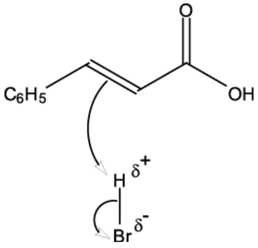
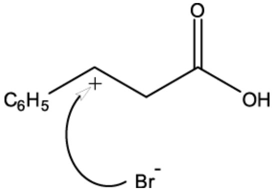
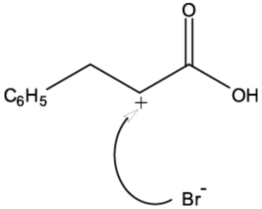
			positive charge shown **AND** correct curly arrow from negative charge of Cl^- to correct carbon atom **OR** correct curly arrow from lone pair of Cl^- to correct carbon atom		
		iii	because the intermediate / carbocation in the formation of compound **B** is less stable (than the intermediate in the formation of compound **A**)	1	
		iv	 (Formation of) white precipitate / solid / suspension **AND** (ppt is) silver chloride / AgC*l*	2	**ALLOW** correct structural **OR** displayed **OR** skeletal formulae **OR** a combination of above as long as unambiguous.
			Total	**8**	
11			Enter text here.		
		i	**Product from reaction 1**:  $CH_3(CH_2)_2-\underset{CH_3COO}{\overset{H}{C}}-COOH$ **Product from reaction 2**:  $CH_3(CH_2)_2-\underset{H}{\overset{Br}{C}}-COOH$	2	**ALLOW** correct structural **OR** displayed **OR** skeletal formulae **OR** a combination of above as long as unambiguous.
		ii	(*E*)-pent-2-enoic acid	1	**ALLOW** “*E*” with or without brackets

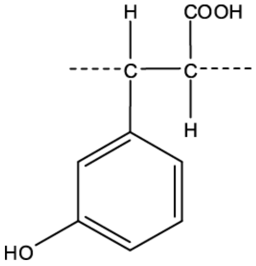
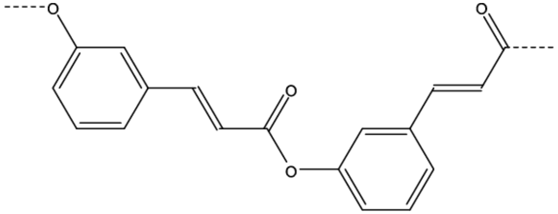
		iii	compound **H** =  addition polymer = 	2	**ALLOW** correct structural **OR** displayed **OR** skeletal formulae **OR** a combination of above as long as unambiguous. 'End bonds' **MUST** be shown (solid or dotted) **IGNORE** brackets and / or *n*
		iv	combustion for energy production use as an organic feedstock for the production of plastics and other organic chemicals	2	
			Total	**7**	
12	a	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.

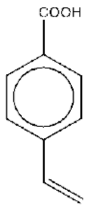
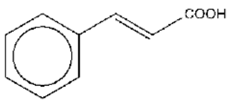
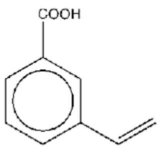
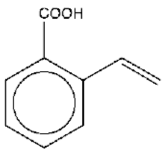
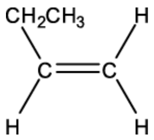
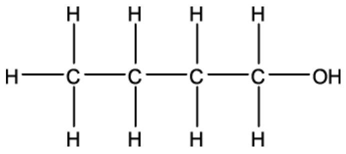
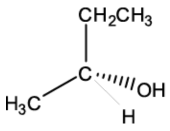
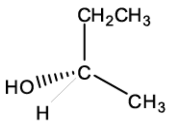
		iii		1	**ALLOW** correct structural **OR** skeletal **OR** displayed formula **OR** mixture of the above **IGNORE** names
		iv	** Please refer to the marking instruction point 10 for guidance on how to mark this question.* **Level 3 (5–6 marks)** Outlines full details of how a pure sample of **B** is 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.	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 =

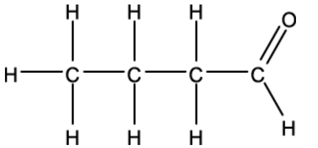
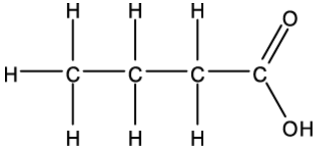
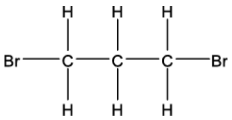
			AND Attempts to calculate the mass of B using mole approach but makes little progress with only 1 step correct. - *Purification step is unclear with few scientific terms and little detail, e.g. just 'separate the layers and dry'.* - *Calculation is difficult to follow and lacking clarity* **0 marks** No response or no response worthy of credit.		7.63 g, followed by $7.63 \times \frac{75}{100} = 5.72$ g Calculation must attempt to calculate *n*(***A***) in mol. Simply finding 75% of the initial mass of alcohol A, 9.26, is **NOT** worthy of credit.
	b	i	 Correct polymer with side links Balanced equation for formation of correct polymer - correct use of *n* in the equation and brackets	2	**ALLOW** any combination of skeletal **OR** structural **OR** displayed formula as long as unambiguous *n* on LHS can be at any height to the left of formula **AND** *n* on the RHS must be a subscript (essentially below the side link)
		ii	Use as an organic feedstock **OR** Combustion for energy production	1	**ALLOW** the production of plastics or monomers or new polymers Combustion alone is **not** sufficient
			Total	**14**	

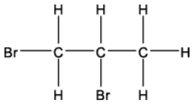
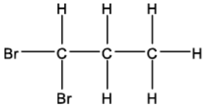
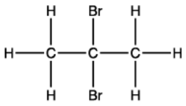
13	a			3	**ALLOW** any combination of skeletal **OR** structural **OR** displayed formula as long as unambiguous
			Product from NH_3/ethanol		**ALLOW**
					
					ALLOW ECF from 2-bromo compound as product from Reaction 1
			……………………………………………………		……………………………………………………
			Product from Reaction 1		**DO NOT ALLOW** 2-bromo compound *(inconsistent with final product shown)*
					
			……………………………………………………		……………………………………………………
			Product from NaOH(aq)		**DO NOT ALLOW ECF** from 2-bromo compound as product from Reaction 1 *(inconsistent with final product shown)*
					
	b				**ANNOTATE ANSWER WITH TICKS AND CROSSES**
			Curly arrow from C=C bond to H of H-Br		

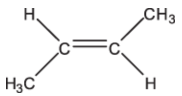
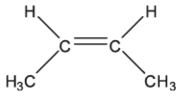
					ALLOW any combination of skeletal **OR** structural **OR** displayed formula as long as unambiguous
			Correct dipole shown on H–Br **AND** curly arrow showing the breaking of H-Br bond 		**DO NOT ALLOW** partial charges shown on C=C double bond
			Correct carbocation **AND** curly arrow from Br^- to C^+ of carbocation 		**DO NOT ALLOW** δ+ on C of carbocation **ALLOW** formation of the 2-bromo isomer 
			Electrophilic addition		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)

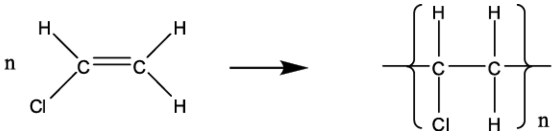
	c	i		1	**ALLOW** any combination of skeletal **OR** structural **OR** displayed formula as long as unambiguous 'End bonds' **MUST** be shown (do not have to be dotted) **IGNORE** brackets **IGNORE** *n*
		ii	 Ester link Rest of structure	2	**ALLOW** any combination of skeletal **OR** structural **OR** displayed formula as long as unambiguous 'End bonds' **MUST** be shown (do not have to be dotted)
			Total	**10**	
14			Electrophilic substitution means benzene ring Electrophilic addition means alkene / C=C Isomer of $C_9H_8O_2$ containing C=C, benzene ring **AND** COOH Correct isomer:	5	Concluded using data provided and conclusions from 1st two marks. **ALLOW** 1 mark for:

			 **OR**  justification in terms of number of carbon environments		 **OR**  (does not gain final justification mark)
			Total	**5**	
1 5	a		**F–K** clearly identified **Compound F:**  **Compound G:**  **Compounds H and I:**   **Compound J:**	6	**ANNOTATE ANSWER WITH TICKS AND CROSSES** **ALLOW** any combination of skeletal **OR** structural **OR** displayed formula as long as unambiguous **IGNORE** names **H** and **I** can be identified either way round

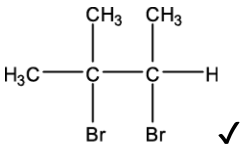
			 **Compound K:** 		
	b			3	**NOTE: (b)** is marked completely independently of **(a)**
			(Add) 2,4-dinitrophenylhydrazine **AND** orange/yellow/red precipitate		ALLOW errors in spelling **ALLOW** 2,4(−)DNP **OR** 2,4(−)DNPH **ALLOW** Brady's reagent or Brady’s Test **ALLOW** solid **OR** crystals **OR** ppt as alternatives for precipitate
			Take melting point of crystals		**Mark second and third points independently of response for first marking point**
			Compare to known values		**DO NOT ALLOW** 2nd and 3rd marks for taking and comparing boiling points **OR** chromatograms
			Total	**9**	
1 6	a		 ✓	1	**ALLOW** correct structural **OR** displayed **OR** skeletal formula **OR** mixture of the above (as long as unambiguous) **ALLOW** structure of 1,2-isomer

					 **IGNORE** molecular formula **DO NOT ALLOW**, structure of 1,1-isomer **OR** 2,2-isomer  **Examiner's Comments** Candidates generally struggled with this question which required application of knowledge. Common incorrect responses included products of a substitution reaction e.g. 1,2- dibromocyclopropane.
	b	i	$C_6H_{14} \rightarrow C_6H_{12} + H_2$ ✓	1	**ALLOW** correct structural **OR** displayed **OR** skeletal formula **OR** mixture of the above (as long as unambiguous) **ALLOW** any correct multiple **IGNORE** state symbols **Examiner's Comments** Most candidates were able to provide the correct equation.
		ii	Cyclohexane will burn more efficiently ✓	1	**KEY IDEA IS COMBUSTION OR BURNING** **Assume 'it' refers to cyclohexane** **ALLOW ORA** for hexane

					ALLOW cyclohexane allows smoother burning **OR** promotes more efficient combustion **OR** increases octane number **OR** reduces knocking **OR** less likely to produce pre-ignition **OR** burns better **OR** easier to burn **OR** combusts more easily **OR** improves combustion **OR** burns more cleanly **DO NOT ALLOW** cyclohexane ignites more easily **IGNORE** cyclohexane increase volatility of fuel **IGNORE** reference to boiling points **IGNORE** cyclohexane gives a better fuel **Examiner's Comments** The importance of cyclohexane to the petroleum industry was well known.
	c	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

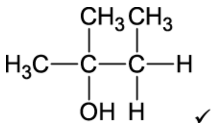
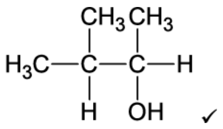
					ALLOW 1 mark for a pair of E/Z isomers of an incorrect hydrocarbon structure with **four** C atoms e.g. C, or CH or CH_2 instead of CH_3 groups. **Examiner's Comments** This question required candidates to identify isomers of cyclobutane that would exhibit stereoisomerism and proved challenging for some. 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.
			Total	**6**	
17	a		 Correct polymer with side links ✓ Balanced equation for formation of correct polymer - correct use of *n* in the equation and brackets ✓	2	**Displayed formulae MUST be used to award each mark** *n* on LHS can be at any height to the left of formula **AND** *n* on the RHS must be a subscript (essentially below the side link) **Examiner's Comments** The majority of candidates were able to show the displayed formula for the correct polymer. Surprisingly, many candidates failed to score the second mark because they did not consider balancing the equation on the left-hand side by inserting an *n* before the chloroethene monomer.

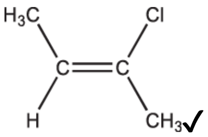
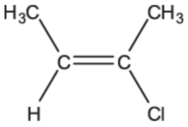
	b	i	$CH_2CHCl + 2O_2 \rightarrow CO + CO_2 + HCl + H_2O$ ✓	1	**ALLOW** any other correctly balanced equation with the same reactants and products **ALLOW** C_2H_3Cl for CH_2CHCl **Examiner's Comments** The stronger candidates were able identify that the other non-toxic product was water and therefore could to provide a suitable equation for this unfamiliar question. A significant number of candidates found this question difficult and it was common to see equations where hydrogen had been stated as the other product. A smaller proportion of candidates attempted to balance the equation using only the three products stated in the question.
		ii	Sodium hydrogencarbonate neutralises HCl ✓	1	**Assume that 'it' refers to sodium hydrogencarbonate but** **DO NOT ALLOW** other chemicals e.g. sodium **ALLOW** $NaHCO_3$ is a base **ALLOW** forms a salt or sodium chloride or NaCl **ALLOW** equation to show formation of NaCl from $NaHCO_3$ and HCl even if not balanced. **IGNORE** reacts **Examiner's Comments** The examiners expected candidates to recognise that sodium hydrogencarbonate would neutralise the acidic gas and most candidates communicated this well. Responses such as 'sodium hydrogencarbonate is a base' and '$NaHCO_3$ forms a salt' were accepted. Weaker candidates often used less precise language

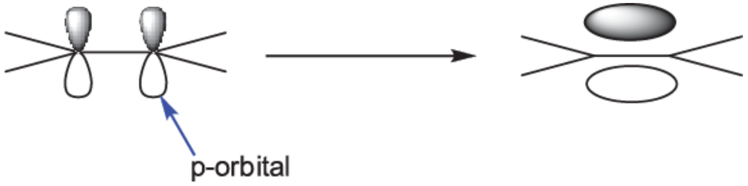
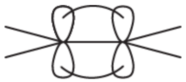
					and responses such as ‘$NaHCO_3$ reacts with the HC*l*’ did not receive credit.
			Total	**4**	
18	a		 ✓	1	**ALLOW** correct structural **OR** displayed **OR** skeletal formula **OR** mixture of the above **DO NOT ALLOW** molecular formula **ALLOW** dichloro or diiodo compound instead of the dibromo 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

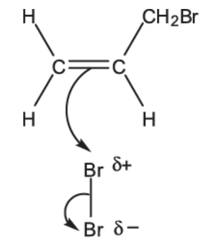
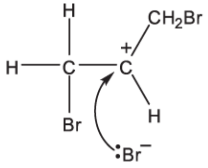
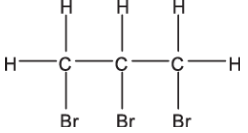
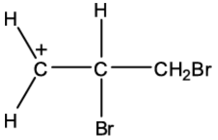
					mark in part (b), as this was essentially dependant on part (a).
	b		Reagent **A**: correct halogen✓ e.g. Br_2 / bromine	1	**ALLOW** Cl_2 if dichloro compound drawn **ALLOW** I_2 if diiodo compound drawn **IGNORE** state symbols Answer must match box from **(a)** to score **Examiner's Comments** This 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**	
19	a		**B** ✓	1	**ALLOW** CF_2CF_2 **OR** C_2F_4 **OR** tetrafluoroethene **Examiner's Comments** The majority of candidates were able to identify **B** as the monomer required to make PTFE.
	b	i		1	**ALLOW** correct structural **OR** displayed **OR** skeletal **OR** mixture of the above **ALLOW** *E* isomer  **Examiner's Comments** The monomer of polymer **H** was correctly identified by the majority of the cohort. However, a small proportion of candidates simply drew the repeat unit of **H.**
		ii	HCL ✓	1	**DO NOT ALLOW** Cl_2 **IGNORE** names **IGNORE** nitrogen oxides / NO_x **Examiner's Comments** Most candidate were able to provide the formula of HCl. Common incorrect answers included ClO and Cl_2.
			Total	**3**	

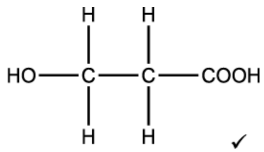
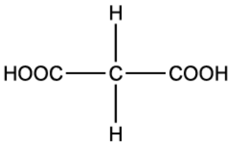
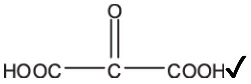
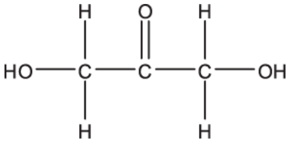
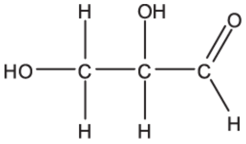
20	a		 **First mark** diagram on left with p-orbitals labelled **OR** unlabelled diagram **AND** the statement: (sideways) overlap of p orbitals ✓ **Second mark** (labelled) diagram on right showing π-bond ✓	2	**Note**: A diagram is required for **each** mark **DO NOT ALLOW** C=C in one diagram but **ALLOW ECF** for subsequent use in another diagram. The bonds shown in the diagram are **required** **ALLOW ECF** for missing bonds in second diagram **IGNORE** any atoms joined to the bonds **ALLOW** a diagram where the p-orbitals are linked for second mark.  e.g. **Examiner's Comments** Most candidates produced reasonable diagrams to illustrate the formation of a π-bond. A common mistake was showing a C=C group rather a C—C bond in the centre of each structure. Omission of the peripheral bonds was also frequently seen. Although over half of the cohort received some credit in this part it was clear that many candidates found this question difficult. Only the most able scored both marks.
	b	i	Curly arrow from double bond to Br of Br–Br ✓	4	**ANNOTATE ANSWER WITH TICKS AND CROSSES ETC** Curly arrow **must** start from bond and go to correct atom **DO NOT ALLOW** any other partial charges

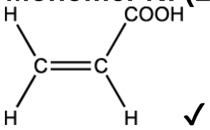
			Correct dipole shown on Br–Br **AND** curly arrow showing breaking of Br–Br bond ✓  Correct carbocation with + charge on C with 3 bonds **AND** curly arrow from Br^- to C^+ of carbocation ✓  Correct product: ✓ 		e.g. shown on double bond **ALLOW** carbocation on terminal CH_2  **DO NOT ALLOW** δ+ on 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) **Examiner's Comments** There were many excellent attempts at this mechanism and it is clearly well understood by candidates at this level. Consequently the majority of candidates scored three or four marks. In some cases the placement of the curly arrow from the C=C group was the cause for a candidate to only score three marks. Curly arrows should be drawn accurately. Where an arrow is expected to come from a bond, candidates are encouraged to start the arrow touching the bond.

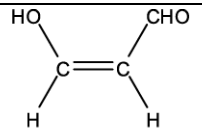
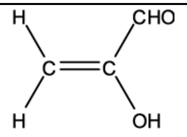
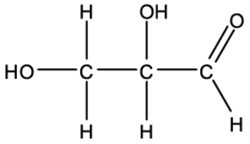
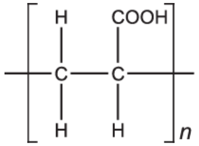
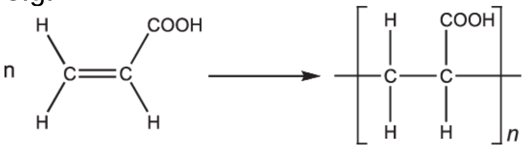
		ii	Electrophilic addition ✓	1	**Examiner's Comments** The name of this mechanism was also well known by most candidates.
	c	i	H_2 **AND** Ni (catalyst) ✓	1	**ALLOW** name or formula for each **IGNORE** any stated temperature and pressure **Examiner's Comments** To score the mark in this question candidates had to state that both hydrogen and nickel were required for step 1. It was often the case that only one of these was stated. Although hydrogen was often seen as a reagent it was common to see an incorrect catalyst, such as H_2SO_4.
		ii	(Initiation) $Cl_2 \rightarrow 2Cl$ **AND** UV ✓ (Propagation) $C_3H_7Br + Cl \rightarrow C_3H_6Br + HCl$ ✓ $C_3H_6Br + Cl_2 \rightarrow C_3H_6BrCl + Cl$ ✓ (Termination) Two from the three termination equations below ✓ $2Cl \rightarrow Cl_2$	5	**ANNOTATE ANSWER WITH TICKS AND CROSSES ETC** **DO NOT ALLOW** any ECF in this question **IGNORE** references to temperature **THROUGHOUT, ALLOW** correct molecular formulae **OR** structural **OR** displayed **OR** skeletal **OR** mixture of the above **IGNORE** dots **IGNORE** state symbols **IGNORE** one incorrect termination equation

			$C_3H_6Br + Cl \rightarrow C_3H_6BrCl$ $2C_3H_6Br \rightarrow C_6H_{12}Br_2$ names of steps initiation, propagation and termination linked to one correct equation for each step in this mechanism✓		**Examiner's Comments** This question required candidates to apply their knowledge of the radical substitution mechanism to form a bromochloroalkane. Examiners were encouraged by the number of excellent attempts and it is clear that candidates had prepared well for this type of question. Consequently most candidates scored four or five marks. A common reason for a candidate only scoring four marks was the omission of UV radiation as an essential condition.
		iii	further substitution **OR** produces different termination products **OR** More than one termination step✓ substitution at different positions along chain ✓	2	**IGNORE** mixture of organic products (*in question*) **ALLOW** dichloro / multichloro / dibromo / multibromo compounds formed **OR** an example of a further substitution product **OR** an example of a different termination product **ALLOW** more than one hydrogen (atom) can be replaced **ALLOW** radicals react with each other to form other products **ALLOW** forms different structural isomers **ALLOW** a hydrogen (atom) on a different carbon (atom) can be replaced **Examiner's Comments** Candidates often found it difficult to provide clearly written explanations for this question. The majorly of responses focused on further substitution or the idea of different termination steps. Only the best candidates

					recognised that chlorination of 1-bromopropane would produce a mixture of structural isomers.
			Total	**15**	
21	a		Mole ratio C : H : O is 3.33 : 6.67 : 3.33 ✓ Empirical formula is CH_2O ✓ Molecular formula is $C_3H_6O_3$ **AND** use of 90 **OR** 3 + 30 ✓	3	**ALLOW** $\frac{40.00}{12.0} : \frac{6.67}{1.0} : \frac{53.33}{16.0}$ **ALLOW** mass of C = 0.400 × 90 **or** 36 **AND** mass of H = 0.06677 × 90 **or** 6 **AND** mass of O = 0.5333 × 90 **or** 48 **Examiner's Comments** Almost all candidates were able to correctly calculate the empirical formula of **L**. Although the majority also deduced the correct molecular formula, not all included their working. A small, but significant, proportion of candidates omitted this part of the question. Candidates are advised to show all working when required.
	b		**Evidence of carboxylic acid (1 mark)** **IR:** 1550–1800 cm^{-1} **AND** C=O / carbonyl **AND** 2300–3700 cm^{-1} **AND** O–H in carboxylic acid ✓ **Evidence of alcohol (1 mark)** (broad) 3200–3700 cm^{-1} linked to O–H in alcohol **OR** (is a primary) alcohol as oxidised (to a COOH)	5	**ANNOTATE ANSWER WITH TICKS AND CROSSES ETC** **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} (broad) O–H within range 3200–3550 cm^{-1} **For ALL structures:** **ALLOW** correct structural **OR** skeletal **OR** displayed

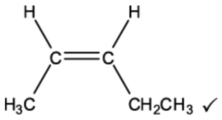
			OR is an alcohol as it forms a carboxylic acid **OR** is an alcohol as water is eliminated. ✓ **Identifications (2 marks)** **L**:  ✓ **M**:  ✓ **Equation (1 mark)** $C_3H_6O_3 + 2[O] \rightarrow C_3H_4O_4 + H_2O$ ✓		formula **OR** mixture of the above **IGNORE** names .... **FOR M: ALLOW 1 mark for**  $HOOC-\overset{\overset{O}{\|}}{C}-COOH$ ✓ **AS ECF from L as either**  **OR**  **Equation:** $C_3H_6O_3 + 4[O] \rightarrow C_3H_2O_5 + 2H_2O$ ✓ .... **ALLOW** correct structural **OR** displayed **OR** skeletal formula **OR** mixture of the above in equation

					Examiner's Comments This question allowed candidates to demonstrate their knowledge and problem solving skills to tie together all the evidence provided. It was common to see candidates identify the ranges of the characteristic peaks for a carboxylic acid in the IR spectrum but a significant proportion did not identify the relevant bond that each peak referred to. Many candidates interpreted the flowchart given at the start of the question to comment on the presence of an alcohol group in **L**, and using their molecular formula from part (a), deduced structures for both **L** and **M**. The strongest candidates were also able to provide a correctly balanced equation for the formation of **M**. The most common incorrect structure for **L** was 1,3-dihydroxypropanone, however, error carried forward marks were awarded to candidates who provided the corresponding dicarboxylic acid as the oxidation product **M**.
	c		**Monomer N: (1 mark)**  ✓	4	**For ALL structures:** **ALLOW** correct structural **OR** skeletal **OR** displayed formula **OR** mixture of the above **IGNORE** names **ALLOW 1 mark for either**

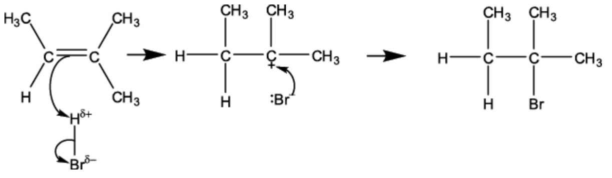
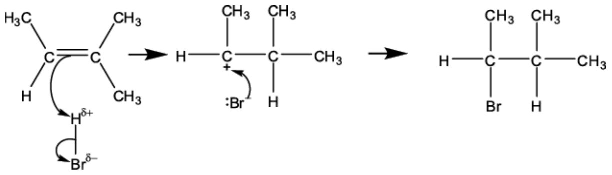
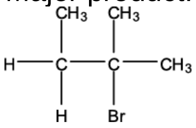
					 **OR**  **AS ECF from L:**  ....
			Polymer P: (1 mark) Section showing at least one repeat unit of a polymer formed from **N** with side links ✓ e.g. 		**For P: ALLOW ECF** from an alkene with molecular formula $C_3H_4O_2$ **ALLOW** one or more repeat units but has to have a whole number of repeat units **ALLOW** repeat unit with no brackets and absence of *n*
			Repeat units (1 mark) $n = 10000/72 = 139$ ✓		**MUST** be a whole number. **ALLOW** 138 **OR** 140 ....
			Equation (1 mark) Balanced equation for formation of P from **N**✓ e.g. 		**For equation, ALLOW** molecular **OR** structural **OR** skeletal **OR** displayed formulae **OR** mixture of the above e.g. **ALLOW** $nC_3H_4O_2 \rightarrow (C_3H_4O_2)_n$

					n on LHS can be at any height to the left of formula **AND** *n* on the RHS must be a subscript (essentially below the side link if displayed / skeletal formula is used) **ALLOW** use of calculated value for *n* in equation e.g. $139C_3H_4O_2 \rightarrow (C_3H_4O_2)_{139}$ **Examiner's Comments** This was a very demanding question and the strongest candidates were able to identify both **N** and **P** in addition to calculating the number of repeat units the polymer. However, not all included the polymerisation equation. Some candidates who were unable to deduce a correct structure for **L** in part (b) approached this part as a 'fresh start'. Using both the molecular formula from (a) and the information in the flowchart worked out the molecular formula of **N** and built a response from there.
			Total	**12**	
2 2			Acid ✓	1	**ALLOW** H^+ / named mineral acid / H_2SO_4 / H_3PO_4 **DO NOT ALLOW** 'weak acid' e.g. ethanoic acid **IGNORE** pressure **IGNORE** temperature **Examiner's Comments** This question was answered well and the majority of candidates identified a suitable catalyst for the

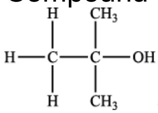
					hydration of an alkene. A common incorrect response was nickel.
			Total	**1**	
23	a	i	Any **one** from: • σ bond is between bonding atoms/nuclei **AND** π bond is above and below the bonding atoms / nuclei • σ bond has direct/head-on overlap of orbitals **AND** π bond has sideways overlap • π bond has 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**

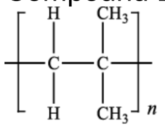
					• One carbon atom in (double bond) is not attached to (two) different groups/groups of atoms • Right-hand carbon is attached to two groups that are the same/two methyl groups. • Two groups are the same on **right-hand side** • Three groups are the same (on the double bond) **DO NOT ALLOW** • Two groups 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

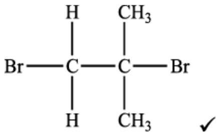
					unambiguous **ALLOW** C_2H_5 for CH_2CH_3 **IGNORE** connectivity of alkyl groups **BUT** ....**DO NOT ALLOW** $-CH_3CH_2$
		iii	(Z-)pent-2-ene ✓	1	**DO NOT ALLOW** trans-pent-2-ene **Examiner's Comments** Most candidates were able to draw the structural isomer of compound A and provide a suitable name.
	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)**	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 arrow from negative charge on Br^- or lone pair on Br^- to carbon atom with positive charge

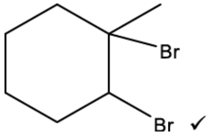
			A simple description based on at least two of the main scientific points **OR** Explains one scientific point thoroughly with few omissions. *The description is communicated in an unstructured way, including some use of curly arrows, charges or dipoles.* **0 marks** No response worthy of credit.		 **or**  **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**

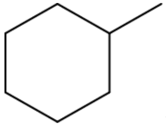
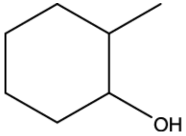
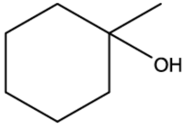
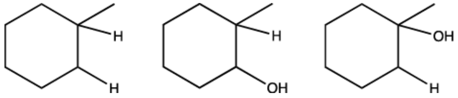
					The first of the six mark level of response questions required candidates to draw the mechanism of electrophilic addition, outline the two possible products and explain which one of these products would be the most likely to be formed. The most common mark for this question was five marks mainly due 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**	
24			B	1	**Examiner's Comments** Candidates struggled with this very different polarity question. The majority of candidates are clearly used to applying symmetry to much simpler molecules.
			Total	**1**	
25			D	1	**Examiner's Comments** B was a common incorrect answer with the sigma bond not counted as part of a double bond.
			Total	**1**	

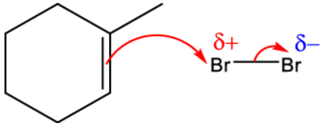
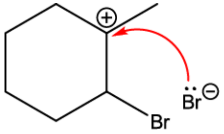
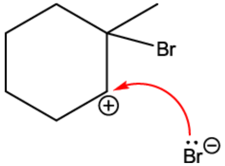
26			B	1	**Examiner's Comments** Generally scored well.
			Total	**1**	
27	a	i	Alkene **AND** C_nH_{2n} ✓	1	**IGNORE** branched before alkene **Examiner's Comments** This part was answered very well. Most candidates identified Compound B as a member of the alkenes and showed the correct general formula 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		Compound C:  ✓ **CARE**: Tertiary alcohol	2	**For structures:** **ALLOW** correct structural **OR** skeletal **OR** displayed formula **OR** mixture of the above ***Connectivity***

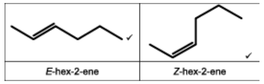
			Compound **D**: (repeat unit)  ✓		**IGNORE** connectivity of bonds to CH_3 e.g. **ALLOW** CH_3- **ALLOW any** vertical bond to OH, e.g. **ALLOW** OH **OR** OH | | **DO NOT ALLOW** OH– **DO NOT ALLOW** more than one repeat unit **REQUIRED:** Side links (dotted lines fine) **NOT REQUIRED:** Brackets and ‘*n*’ **Examiner's Comments** This part was answered well. If a mark was lost, it was almost always due to compound C, especially at the low scoring end of the range. Many struggled with the structure of a tertiary alcohol or omitted H atoms from the structure. Compound D was generally drawn correctly by candidates of all abilities. If the mark was not credited, it was usually due to not removing the double bond, or drawing more than one repeat unit.
	c	i	C_2H_5O ✓	1	**ALLOW** elements in any order

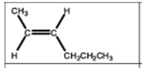
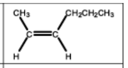
					DO NOT ALLOW any other answer **Examiner's Comments** This part was answered well by most candidates. Some candidates however wrote the molecular rather than the empirical formula, or attempted to show the empirical formula as C_2H_4OH instead of C_2H_5O.
		ii	Compound E:  ✓ **Stage 1**: Compound **E**: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

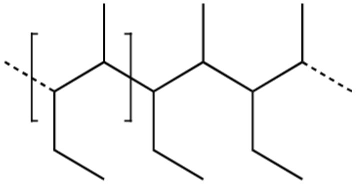
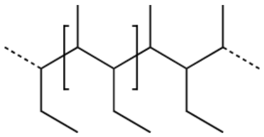
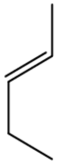
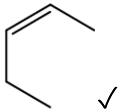
					1 mark Intermediate: $CH_3C(CH_3)_2Br$ **OR** $BrCH_2CH(CH_3)_2$ **AND** Reagent: NaOH **Examiner's Comments** This demanding part was answered poorly by weaker candidates and was good for differentiating higher ability candidates. The mark scheme allowed some credit for using a hydrogen halide to obtain a monosubstituted haloalkane for compound E. Surprisingly, reaction mechanism names were often given instead of reagents. Many candidates seemed to guess, sometimes showing the same reagents for both stages in the hope of getting a mark. Many showed an intermediate containing no halogen atom.
			Total	**8**	
28		i	**Product from Br_2** 	4	**ALLOW** correct structural **OR** displayed **OR** skeletal formula **OR** mixture of the above **IGNORE** names **WATCH** for missed methyl stick **ALLOW** added H shown,

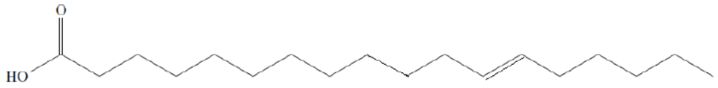
			Product from H_2/Ni  ✓ **Mixture of isomers from H_2O**  ✓  ✓		i.e.  **ALLOW** in either order **Examiner's Comments** Most of the candidates were able to show correct structures for all four organic products. The majority of these candidates used skeletal formulae. A small proportion of responses included incomplete structures. These included a missing Br atom on the product from the reaction of compound **A** with Br_2 or a missing methyl group. Candidates should be advised to check structures carefully, especially when using skeletal formulae.
		ii	Steam **OR** temperature ≥ 100°C ✓ acid (catalyst) ✓	2	**ALLOW** $H_2O(g)$ **IGNORE** pressure **IGNORE** High temperature / reflux **ALLOW** H^+ / named mineral acid / H_2SO_4 / H_3PO_4 **DO NOT ALLOW** 'weak acid' e.g. ethanoic acid **Examiner's Comments** Most candidates were able to state that an acid catalyst

					was required for the reaction of compound **A** with H_2O. However, although many candidates recognised the need for the reaction to be heated only the strongest responses referred to temperatures above 100 °C. It was not uncommon to see vague responses that simply referred to a high temperature. Candidates should be encouraged to give precise conditions for the hydration reaction of an alkene.
		iii	Curly arrow from double bond to Br of Br–Br ✓ Correct dipole shown on Br–Br **AND** curly arrow showing breaking of Br−Br bond ✓  .... Correct carbocation with + charge on C **AND** curly arrow from Br^- to C^+ of carbocation ✓  **OR**  	3	**ANNOTATE ANSWER WITH TICKS AND CROSSES** Curly arrow **must** start from bond and go to correct atom **DO NOT ALLOW** any other partial charges e.g. shown on C=C bond **DO NOT ALLOW** δ+ on C of carbocation. **IF** C atoms are displayed **IGNORE** missing bonds to H atoms Curly arrow must come from a lone pair on Br^-

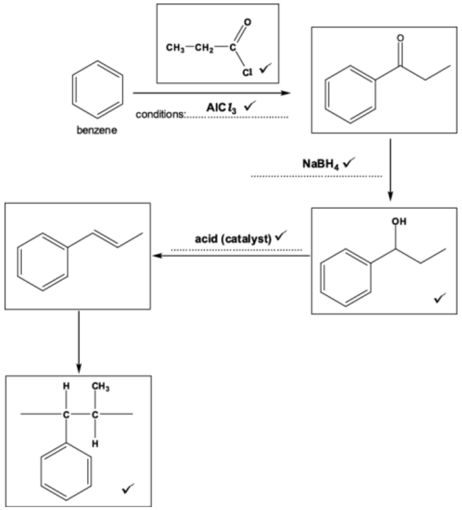
			Note: ‘+’ and ‘−’ are fine for charge (circles used for clarity)		**OR** from the negative sign of Br^- ion (then lone pair on Br^- ion does not need to be shown) **Examiner's Comments** The mechanism of the reaction of compound **A** with Br_2 was well known and consequently the majority of candidates scored all three marks. A common reason for scoring only two marks was inaccurate placement of the curly arrow from the bromide ion to the carbocation intermediate. This arrow should start from either a lone pair or the minus sign of the bromide ion.
		iv	electrophilic addition ✓	1	**Examiner's Comments** Most of the candidates were able to name the mechanism correctly. However it was not uncommon to see incorrect responses which included electrophilic substitution and nucleophilic addition.
			Total	**10**	
29	a	i	 *E*-hex-2-ene *Z*-hex-2-ene	2	**ALLOW** 1 mark if skeletal formulae of both *E* and *Z* hex-2-ene are shown but in the incorrect columns **IF** correct unambiguous structural **OR** displayed **OR** mixture of formulae are shown **ALLOW** 1 mark if both stereoisomers are in the correct columns e.g the following scores 1 mark

					 *E*-hex-2-ene  *Z*-hex-2-ene **IF** the skeletal formula of *E* hex-3-ene is shown in the first box **ALLOW** 1 mark for the skeletal formula of *Z* hex-3-ene as **ECF** **Examiner's Comments** It was anticipated that most candidates would be able to provide the skeletal formulae for the *E* and *Z* isomers of hex-2-ene but this proved not to be the case. A large number of responses displayed the C=C group and gave structural formulae for the side chains, while others confused *E* and *Z*, placing the isomers in the incorrect columns. A number of candidates opted to use an ambiguous formula and it was not uncommon to see C_3H_7 attached to a C=C group. Candidates should be made aware of the importance of showing each C atom when a question requires structural detail.
		ii	(carbon-carbon) double bond does not rotate **OR** has restricted rotation ✓ Each carbon atom of the double bond attached to (two) different groups / atoms ✓	2	**Examiner's Comments** Most candidates recognised that the C=C group had restricted rotation which resulted in *E/Z* isomerism. However, many struggled to explain that each C atom in the C=C group was bonded to different groups with sufficient clarity.

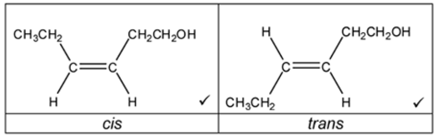
	b	i	 One repeat unit shown ✓ *(could be any of the three repeat units shown)*	1	**ALLOW** repeat unit at any point along the section provided that it works, e.g.  **Examiner's Comments** The majority of candidates were able to use brackets to show the repeat of the polymer shown. A number of candidates placed brackets inaccurately, often intersecting carbon atoms in the backbone.
		ii	Structure of pent-2-ene:  **OR**  ✓	1	**ALLOW** correct structural **OR** displayed **OR** skeletal formula **OR** mixture of the above (as long as unambiguous) **Examiner's Comments** Candidates found this part more difficult than part **(c)(i)**. Many candidates correctly drew the structure of pent-2-ene as hydrocarbon **B** but a wide range of other responses was seen. Two common incorrect responses were the structures of either 2-methylpent-2-ene or 2-methylpentane.
		iii	(50,000/70 =) 714 **OR** 715 ✓	1	**MUST** be a whole number **Examiner's Comments** Many candidates were able to use the repeat unit identified in **(c)(i)** or the monomer in **(c)(ii)** to determine the number of monomer molecules in the polymer.

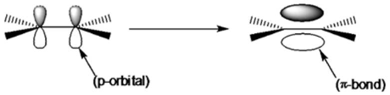
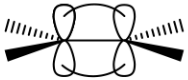
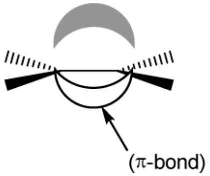
			Total	**7**	
30		i	**M1** Correct structure of a mono unsaturated fatty acid with 18 C ✓ **M2** Correct position of double bond (12) in a mono unsaturated fatty acid **AND** trans arrangement ✓	1	Must be skeletal formula for M1  **DO NOT ALLOW** cis isomer for M2 **Examiner's Comments** Well answered by the majority of candidates. Incorrect chain length and putting the double bond in the wrong position were the most common errors.
		ii	**Each** carbon atom in the double bond is attached to (two) different group**s**/atoms ✓	1	**ALLOW Each** carbon atom of the double bond is attached to a H atom **DO NOT ALLOW** functional group for group **DO NOT ALLOW** the carbon atoms are attached to different groups **IGNORE** two of the substituent groups are the same **Examiner's Comments** Many candidates failed to score the mark for this simple definition with reference to the carbon atoms in the double bond a common omission.
			Total	**3**	
31			**B**	1	

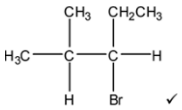
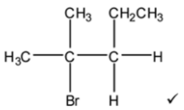
			Total	**1**	
32			**D**	1	
			Total	**1**	
33			**D**	1	
			Total	**1**	
34			**C**	1	
			Total	**1**	
35			**A**	1	
			Total	**1**	
36	a		One mark for each correct structure/reagent/condition as shown below	6	**ANNOTATE ANSWER WITH TICKS AND CROSSES** **ALLOW** any combination of skeletal **OR** structural **OR** displayed formula as long as unambiguous **IGNORE** names of organic compounds *(question asks for structures)* **ALLOW** aluminium(III) chloride **OR** aluminium trichloride **ALLOW** $FeCl_3$ **OR** Fe as halogen carrier in first step.

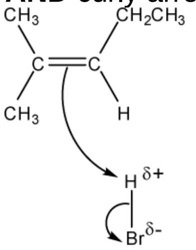
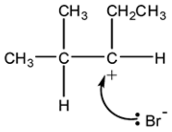
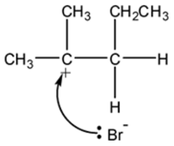
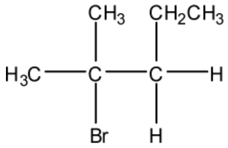
					**ALLOW** sodium borohydride **OR** sodium tetrahydridoborate **IGNORE** [H] for reducing agent in second step **ALLOW** H^+ / H_2SO_4 / H_3PO_4 / named mineral acid for reagent in third step
	b		Use as an organic feedstock ✓ **OR** Combustion for energy production ✓	1	**ALLOW** the production of plastics or monomers or new polymers Combustion alone is **not** sufficient
			Total	**7**	
37			B	1	**Examiner Comments** Those candidates who had clearly learned and understood the principles of the Cahn-Ingold-Prelog rules applied these successfully to this question arriving at the correct answer, B. All other answer options were equally distracting.

			Total	**1**	
38			D	1	**Examiner Comments** This was a fairly easy question and the vast majority of candidates knew that addition, with 100% atom economy based on only one product being formed, had the highest atom economy of the four reaction types listed. Candidates who failed to score this mark randomly choose one of the other distractors.
			Total	**1**	
39			A	**1**	**Examiner's Comments** Candidates found this question challenging, with only the more able candidates obtaining the correct alcohol. Answer option C was a common incorrect answer.
			Total	**1**	
40	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.
		iii		**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

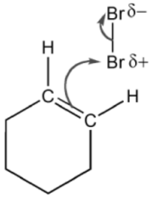
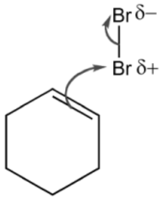
					structures were seen in the vast majority of cases. The most common error was the failure to place the -OH group on the correct carbon within the structure leading to only one mark being awarded. Candidates should be encouraged either to give displayed or structural formulae for cis and trans isomers 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		 Two p-orbitals shown as a “dumb-bell” added to structure on left. **AND** *p*-bond on structure on right ✓	**2**	**DO NOT ALLOW** C=C in diagram **DO NOT ALLOW** overlapping p orbitals on left hand side in the diagram. **DO NOT ALLOW** a diagram that contains four lobes on the right hand side. e.g.  **IGNORE** any atoms joined to the bonds **Note:** labels are **not** required **ALLOW** the following diagram to show the *p*-bond 

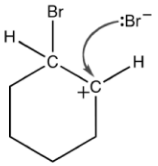
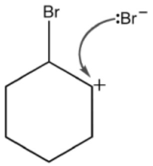
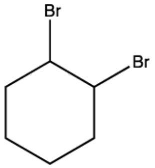
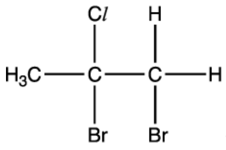
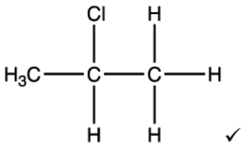
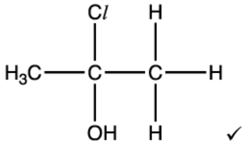
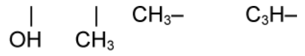
					Examiner Comments Over half of candidates completing this question did not score a mark. The answer required the drawing of two p-orbitals on the left hand diagram and a pi-bond, a lobe of electron density above and below the plane of the carbon atoms, on the right hand diagram. Many candidates produced unexpected diagrams, some where the pi-bonds extended beyond even the remaining groups attached to the double bond. Others placed p-orbitals in the left hand diagram so that they were on the end of the molecule or showed four lobes merging in the right hand diagram. This clearly is an area for teachers' attention in the coming academic year.
	c	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	 $H_3C-C(CH_3)(H)-C(CH_2CH_3)(Br)-H$ ✓  $H_3C-C(CH_3)(Br)-C(CH_2CH_3)(H)-H$ ✓	**2**	**ALLOW** correct structural **OR** displayed **OR** skeletal formulae **OR** a combination of above as long as unambiguous **ALLOW** in either order
		iii	Curly arrow from C=C bond to H of H–Br ?	**3**	**ANNOTATE ANSWER WITH TICKS AND CROSSES**

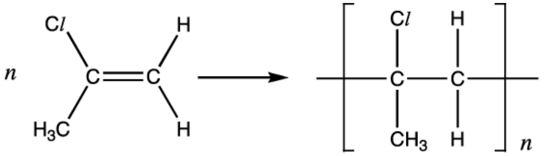
			Correct dipole shown on H–Br **AND** curly arrow showing the breaking of H–Br bond ?  --- Correct carbocation **AND** curly arrow from Br^- to C^+ of carbocation ?  **OR** 		**ALLOW** any combination of skeletal **OR** structural **OR** displayed formula as long as unambiguous **DO NOT ALLOW** partial 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		**1**	**Note:** the correct product and explanation are **both** required for the mark The major product may be identified by its

			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) ✓		• 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.
	d	i	n(myrcene) = $\frac{204 \times 10^{-3}}{136.0}$ = $1.5(0) \times 10^{-3}$ (mol) ✓ Volume of H_2 = $3 \times 1.5(0) \times 10^{-3} \times 24000$ = 108 (cm^3) ✓	**2**	Correct working **required** for the first marking point. **ALLOW ECF** from incorrect moles of myrcene i.e. *n*(myrcene) × 3 × 24000

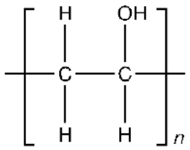
					Common incorrect answers $108000\ cm^3$ = 1 mark (not converted to g) $12 cm^3$ = 1 mark (divided by 3) $36\ cm^3$ = 1 mark (not multiplied by 3) **IGNORE** Calculations based on $pV = nRT$ **Examiner Comments** The best answers first converted 204 mg into g and then divided this value by the molar mass of myrcene. Candidates then linked this to presence of three double bonds and calculated correctly the moles of hydrogen required to produce the saturated alkene. Finally the moles were multiplied by $24000\ cm^3$ to provide an answer in cm^3. Candidates who worked in mg could not access the first mark however the subsequent mark was awarded as error carried forward. Answer = $108\ cm^3$
		ii	**Amount of hydrogen** $n(H_2) = \frac{5.28}{24.0} = 0.22(0)$ (mol) ✓ **Number of double bonds** $= \frac{0.220}{0.0200} = 11$ ✓ **Formula of saturated product** $C_{40}h_{78}$ **Equation** $C_{40}H_{56} + 11H_2 \longrightarrow C_{40}H_{78}$ ✓	**4**	**ALLOW** Evidence of $n(H_2) = \frac{5.28}{24.0}$ if 0.22 is not seen Evidence for 11 double bonds could come from $11H_2$ in equation Formula could be shown as the product of an equation **ALLOW ECF** from $C_{40}H_{82}$ and $C_{40}H_{80}$ **only** i.e. $C_{40}H_{60} + 11H_2 \longrightarrow C_{40}H_{82}$ $C_{40}H_{58} + 11H_2 \longrightarrow C_{40}H_{80}$

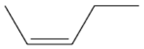
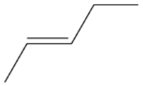
					Examiner Comments The most common score on this question was two, with candidates being able to calculate the moles of hydrogen gas and relate this to the replacement of eleven double bonds. Frequently candidates calculated the formula of the saturated hydrocarbon to be $C_{40}H_{82}$ by applying the general formula C_nH_{2n+2} to a compound containing 40 carbon atoms. The best Candidates were able to adjust this formula to account for the presence of the two rings and were then able to write the correct equation for the hydrogenation
			Total	**18**	
4 1			Curly arrow from double bond to Br of Br–Br ✓ Correct dipole shown on Br–Br **AND** curly arrow showing breaking of Br–Br bond ✓   **OR** Correct carbocation with + charge on C with 3 bonds **AND** curly arrow from Br$^-$ to C$^+$ of carbocation ✓	**4**	**ANNOTATE ANSWER WITH TICKS AND CROSSES ETC** Curly arrow **must** start from bond and go to correct atom **DO NOT ALLOW** any other partial charges e.g. shown on double bond **DO NOT ALLOW** missing H on displayed formulae (penalise once only) **DO NOT ALLOW** δ+ on C of carbocation. Curly arrow must come from a lone pair on Br$^-$ **OR** from

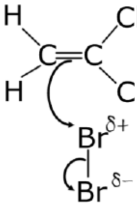
			 **OR**  Correct product:  ✓		the negative sign of Br^- ion (then lone pair on Br^- ion does not need to be shown) **IGNORE** wording if diagrams are correct Maximum of two marks for mechanism based on incorrect structure of cyclohexene **Examiner's Comment:** The precise setting out of a reaction mechanism was a skill that a good number of candidates have mastered with many accurate mechanisms being drawn. Others need more time to develop these skills; many errors being made with the position of dipoles and curly arrows. Despite making errors in the mechanism, many achieved one mark for drawing a correct final structure.
			Total	**4**	
42	a	i	 ✓  ✓  ✓	**3**	**ALLOW** structural **OR** displayed **OR** skeletal formula **OR** mixture of the above (as long as unambiguous) For connectivity, **ALLOW**  $\underset{\text{OH}}{\vert}$ $\underset{\text{CH}_3}{\vert}$ $CH_3–$ $C_3H–$ **DO NOT ALLOW** OH— **Examiner's Comments** This part was generally well answered with the majority

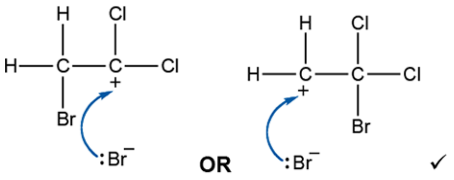
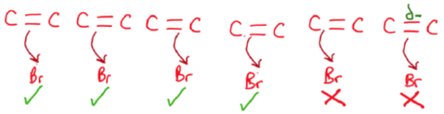
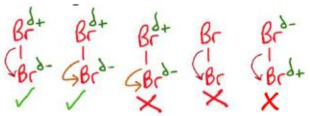
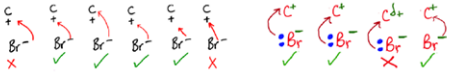
					of candidates scoring two or three marks. The most common errors were the omission of the C*l* atom from each structure, or identifying the minor product instead of the major product from the reaction with steam. For addition products of an alkene, candidates are advised to copy the alkene but with a single rather than a double bond, then to add the reagent across where the double bond was. This might have prevented the omission of the C*l* atom on so many of the structures seen.
		ii	H^+/acid/H_2SO_4/H_3PO_4 ✓	**1**	**ALLOW** HCl **IGNORE** (aq) **OR** ‘dilute’ **OR** concentrated **Examiner’s Comments** Most candidates correctly identified an acid catalyst, with the most common response being phosphoric acid. Common mistakes were nickel, zinc and acidified dichromate.
	b	i	 Correct repeat unit (*n* and brackets not required) ✓ Equation balanced with *n* ✓ **TAKE CARE** of ‘*n*’ position on both sides of equation.	**2**	**For monomer,** **ALLOW** correct molecular **OR** structural **OR** displayed **OR** skeletal formula **OR** mixture of the above (as long as unambiguous) **For repeat unit,** **DO NOT ALLOW** molecular formula **NOTE**: ‘side bonds’ **ARE** required on either side of repeat unit from C atoms **ALLOW** section of polymer containing more than one repeat unit

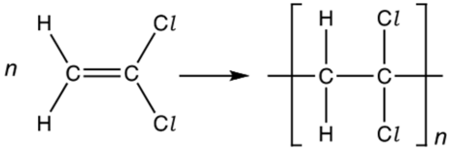
					NO ECF from incorrect repeat unit **Examiner's Comments** The majority of candidates correctly drew the repeat unit but only afew wrote a full equation, balanced with *n*. The most common error was omission of the '*n*' before the monomer. Candidates are reminded of the importance of balancing equations.
		ii	Formation of HCl/hydrochloric acid/ **OR** chlorine ✓	**1**	**ALLOW** Cl or Cl_2 for chlorine **IGNORE** toxic waste products *Response must reflect chlorine in some way* **Examiner's Comments** Most candidates realised that the combustion would produce toxic/harmful gases, but the majority either incorrectly identified the problem gas as CO_2/CO or did not identify the gas at all. Others referred to ozone damage and global warming. Good responses referred to the formation of chlorine compounds such as hydrogen chloride.
			Total	**7**	
43			Electron pair acceptor (1) I^+ (1)	2	
			Total	**2**	
44	a	i	(because) molecule contains only single C–C bonds (1)	1	**allow** no multiple bonds / no double or triple bonds **allow** contains single bonds only
		ii	109.5°	1	

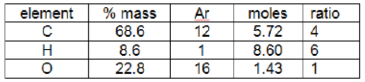
		iii	Combustion for energy production (alternative to fossil fuels) (1) Use as an organic feedstock (1)	2	
	b	i	 (1)	1	
		ii ii	***Evidence against ethenol:*** No infrared absorption between 3200 and 3600 cm^{-1} from O–H (1) ***Evidence for isomer:*** Infrared absorption between 1640 and 1750 cm^{-1} indicates C=O (1) Mass spectrum: fragmentation peak at m/z = 29 suggests CHO$^+$ **OR** fragmentation peak at m/z = 15 suggests CH$_3$ (1) ***Identification:*** Ethanal / CH$_3$CHO (1)	4	**ignore** molecular ion peak at m/z confirms molecular mass of 44 g mol^{-1}
			Total	**9**	
45			** 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*	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

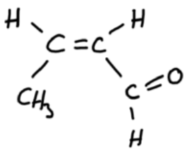
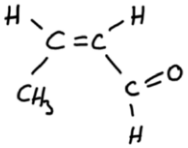
			clear and logically structured. The information presented is relevant to the compounds drawn / named. (5–6 marks) **(Level 2)** Applies knowledge of elimination reactions to provide the correct name and structure for pent-1-ene. **AND** Correct structures of stereoisomers of pent-2-ene but full names 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 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.		- 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

			Total	**6**	
4 6	a		steam **AND** Acid/H$^+$ (catalyst) ✓	1	<u>**Examiner's Comments**</u> 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	<u>**Examiner's Comments**</u> 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	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

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

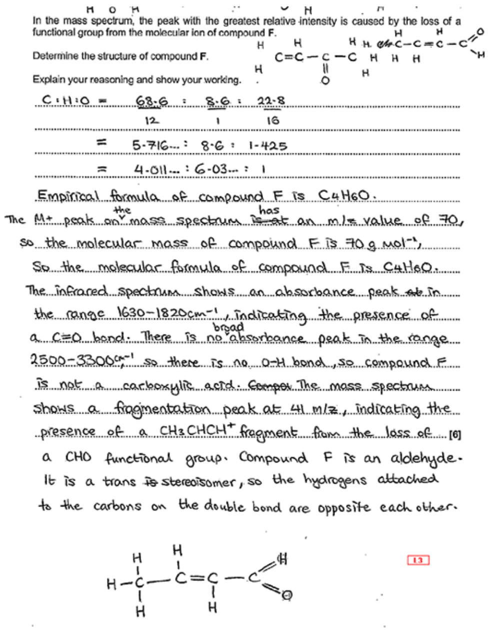
					Examiner's Comments Many candidates gained all three marks on this question and the diagrams were clear and easy to read. Lower ability candidates had incorrect dipoles or curly arrows that could not be traced back to the correct origin. Candidates should be encouraged to consider what the arrows mean 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)**	2	**ALLOW** reduced use of fossil fuels

<table>
<tr><th></th><th></th><th></th><th></th><th></th><th></th></tr>
<tr><td></td><td></td><td></td><td>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✓</td><td></td><td>**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.</td></tr>
<tr><td></td><td></td><td></td><td>**Total**</td><td>**9**</td><td></td></tr>
<tr><td>47</td><td></td><td></td><td>*Please refer to the marking instructions on page 5 of the mark scheme for guidance on how to mark this question.*
Level 3 (5-6 marks)
A comprehensive description including most of the evidence to justify the correct structure of **F** (accept *cis* or *trans*).
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)
The candidate attempts all three scientific points, but explanations are incomplete.
OR
Explains two scientific points thoroughly with few omissions.</td><td>6</td><td>**LOOK AT THE SPECTRA** for labelled peaks
Indicative scientific points may include:
Empirical formula
• empirical formula = C_4H_6O
<table>
<tr><th>element</th><th>% mass</th><th>Ar</th><th>moles</th><th>ratio</th></tr>
<tr><td>C</td><td>68.6</td><td>12</td><td>5.72</td><td>4</td></tr>
<tr><td>H</td><td>8.6</td><td>1</td><td>8.60</td><td>6</td></tr>
<tr><td>O</td><td>22.8</td><td>16</td><td>1.43</td><td>1</td></tr>
</table>**IR and spectra and molecular formula**
• infrared absorption; 1630–1820 cm^{-1}, due to C=O (aldehyde/ketone/carbonyl group)</td></tr>
</table>

			AND an attempt at a feasible structure based on deduction from correct molecular formula *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)** The correct empirical formula **AND** a simple description based on at least one of the main scientific points. **OR** The candidate explains one scientific point thoroughly with few omissions. *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.		• molar mass = 70 g mol^{-1} (mass spectrum molecular ion peak *m/z* = 70) • molecular formula = C_4H_6O **<u>Functional groups, structure and stereochemistry</u>** • alkene / C=C • aldehyde / −CHO ($C_3H_5^+$ fragment) • mass spectrum; peak at 41 due to $C_3H_5^+$ (loss of CHO) • *E/Z or cis-trans* isomer: *E/Z or cis-trans* isomer:  *cis*  *trans (correct structure)* **<u>Examiner's Comments</u>** This question was a good discriminator. Most candidates were able to deduce the empirical formula and the C=O peak on the IR spectrum. However, many mistook the C-H peaks around 3000 cm^{-1} for an alcohol O-H peak or assumed from the empirical formula that it was an alcohol so made the spectra 'fit' their hypothesis. At AS, the exposure of candidates to IR and MS spectra is not as comprehensive as in the second year of A Level and this was evident. There was very little annotation of the spectra and candidates

should be encouraged to do this as it is helpful to them in their deductions (and to the examiners for crediting marks). Analysis of the IR spectrum was much more detailed than the mass spectrum. Most candidates just referred to the molecular ion peak and made no attempt, or an incorrect attempt, at discerning the peak at 41. Those that did quickly realised what the structure was and gained 5 or 6 marks. Some candidates, despite ascertaining that a *trans* stereoisomer should be drawn, drew the *cis* version instead.

Exemplar 5



In the mass spectrum, the peak with the greatest relative intensity is caused by the loss of a functional group from the molecular ion of compound **F**.

Determine the structure of compound **F**.

Explain your reasoning and show your working.

$C:H:O = \frac{68.6}{12} : \frac{8.6}{1} : \frac{22.8}{16}$

$= 5.716... : 8.6 : 1.425$

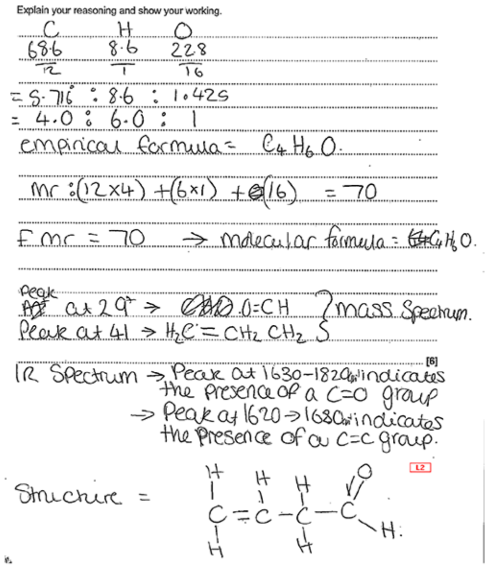
$= 4.011... : 6.03... : 1$

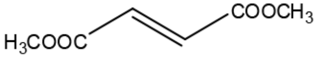
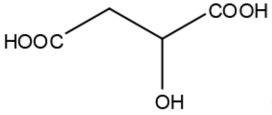
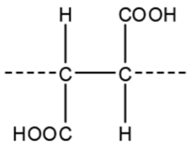
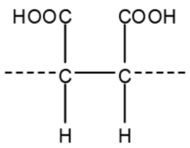
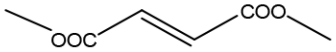
Empirical formula of compound F is C_4H_6O.

The M+ peak on the mass spectrum ~~is at~~ has an m/z value of 70, so the molecular mass of compound F is 70 g mol^{-1}, So the molecular formula of compound F is C_4H_6O. The infrared spectrum shows an absorbance peak ~~at~~ in the range 1630–1820 cm^{-1}, indicating the presence of a C=O bond. There is no broad absorbance peak in the range 2500–3300 cm^{-1}, so there is no O-H bond, so compound F is not a carboxylic acid. ~~Compou~~ The mass spectrum shows a fragmentation peak at 41 m/z, indicating the presence of a CH_3CHCH^+ fragment from the loss of **[6]** a CHO functional group. Compound F is an aldehyde. It is a trans ~~is~~ stereoisomer, so the hydrogens attached to the carbons on the double bond are opposite each other.

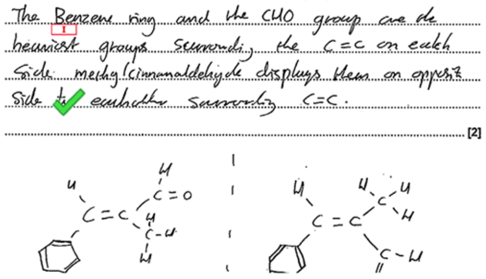
13

This candidate has very logically worked through all the information provided and has come up with the correct

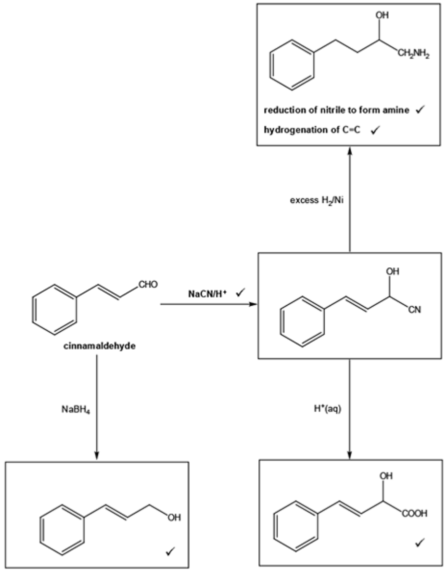
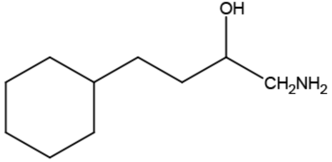
					structure from the deductions. **Exemplar 6**  Explain your reasoning and show your working. C H O 68.6/12 8.6/1 22.8/16 = 5.716 : 8.6 : 1.425 = 4.0 : 6.0 : 1 empirical formula = C_4H_6O. Mr : (12×4) + (6×1) + ~~O~~(16) = 70 F Mr = 70 → molecular formula : ~~C4~~ C_4H_6O. ~~At~~ Peak at 29 → ~~CHO~~ O=CH } mass Spectrum. Peak at 41 → $H_2C=CH_2CH_2$ } [6] IR Spectrum → Peak at 1630–1820 cm⁻¹ indicates the presence of a C=O group → Peak at 1620 → 1680 cm⁻¹ indicates the presence of a C=C group. Structure = L2 Like most candidates, the crucial information about F being a *trans* isomer was not picked up so they drew the double bond in the wrong place.
			Total	**6**	
48			**Product from excess CH_3OH/H_2SO_4**	**3**	**ALLOW** any combination of skeletal **OR** structural **OR** displayed formula as long as unambiguous e.g

			 ✓ **Product from steam, H_3PO_4**  ✓ **Repeat unit of polymer C**  **OR**  ✓		 **IGNORE** connectivity in each product **ALLOW** the *E* or *Z* isomer as product from excess CH_3OH/H_2SO_4 'End bonds' MUST be shown (do not have to be dotted) **IGNORE** brackets **IGNORE** *n* **ALLOW** more than one repeat unit but has to be a whole number of repeat units **<u>Examiner's Comments</u>** The majority of candidates were able to identify at least one product from the reactions of compound C. The polymerisation reaction appeared to be the most familiar, although some candidates attempted to draw a condensation polymer using the carboxylic acid groups rather than the alkene. The reaction of C with excess methanol was also well attempted. However, a significant number of candidates used chemical symbols to show their product. A proportion of these did not show the H atoms of the alkene group, showing only C=C in the centre of the structure. Candidates are advised to use the type of

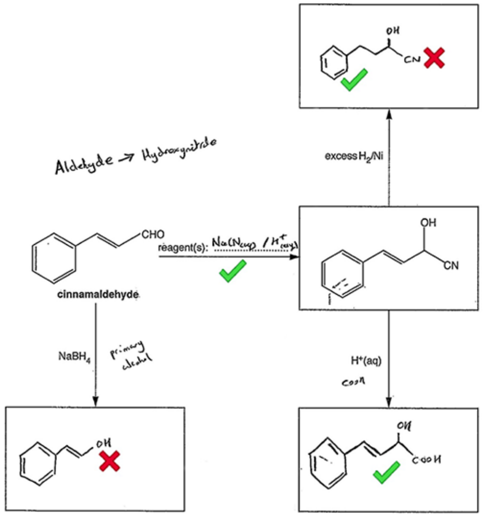
					formulae given in a question as this will reduce the potential for error or omissions. The product from the hydration of C appeared to be the hardest to deduce. Many candidates recognised this reaction would produce an alcohol, but often included two OH groups – one on each C from the double bond – in their structure. Other candidates confused this reaction with hydrogenation and formed a saturated product from C.
			Total	**3**	
49	a		priority groups/atoms are on different/opposite sides ✓ High(est) priority groups are C_6H_5 **AND** CHO **OR** Lowest priority groups are H and CH_3 ✓	**2**	**ALLOW** suitable alternatives to 'priority' e.g. groups with highest atomic number or more important groups etc. **ALLOW** high priority groups are diagonal(ly across) **IGNORE** references to relative mass of groups, A_r, M_r, **ALLOW** identification by name e.g aldehyde for CHO phenyl/benzene group for C_6H_5 alkyl for CH_3 **ALLOW** response in terms that O has higher priority than H in context of $–CH_3$ and –CHO **IF** 'priority' is not mentioned **ALLOW** 1 mark for 'C_6H_5 and CHO are on different sides' **OR** H and CH_3 are on different sides

					Examiner's Comments Many candidates explained that methylcinnamaldehyde is an *E* isomer as the highest priority groups are on opposite sides, but only the highest ability candidates applied the CIP rules to identify the highest priority groups as C_6H_5 and CHO. A common misconception was to refer to the molecular mass of the groups instead of priority as in Exemplar 7. **Exemplar 7**  The Benzene ring and the CHO group are de heaviest groups surrondi, the C=C on each side. methyl(cinnamaldehyde displays them on opposit side to ✓ eachother surroundy C=C. [2] This response uses the mass of the benzene and CHO groups to attempt to justify their priority. This was ignored by the mark scheme as the CIP rules use atomic number to determine the highest priority groups. However, this response does clearly communicate that these two groups are on different sides of the carbon-carbon double bond so scored one mark.
	b	i		**1**	**Note:** both reagent and observation are required

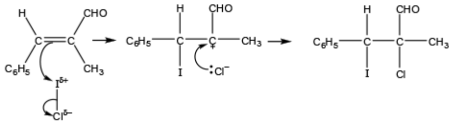
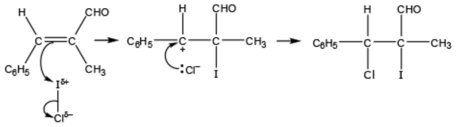
			Bromine/ Br_2 **AND** goes colourless/decolourised ✓		**ALLOW** bromine water/ $Br_2(aq)$ **Examiner's Comments** Almost all candidates were able to correctly describe the use of bromine as a test for an unsaturated chain.
		ii	Tollens' (reagent) **AND** Silver (mirror/precipitate/ppt/solid) ✓	**1**	**Note:** both reagent and observation are required for the mark. **ALLOW** ammoniacal silver nitrate **OR** Ag^+/NH_3 **ALLOW** black ppt **OR** grey ppt **Examiner's Comments** Almost all candidates were able to correctly describe the use of Tollens' reagent as a test for an aldehyde functional group.
		iii	(Add) 2,4-dinitrophenylhydrazine **AND** orange/yellow/red precipitate ✓ Take melting point (of crystals) ✓ Compare to known values/database ✓	**3**	**ALLOW** errors in spelling **ALLOW** 2,4(-)DNP **OR** 2,4(-)DNPH **ALLOW** Brady's reagent or Brady's Test **ALLOW** solid **OR** crystals **OR** ppt as alternatives for precipitate **Mark second and third points independently of response for first marking point** **DO NOT ALLOW** 2nd and 3rd marks for taking and comparing boiling points **OR** chromatograms **Examiner's Comments**

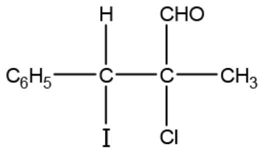
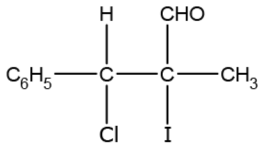
					The use of 2,4-dinitrophenylhydrazine as a test for the carbonyl group is well known by candidates at this level. The majority of the cohort correctly identified this test and the subsequent analysis of the melting point of the products as a method of identifying each compound. Lower ability candidate responses made reference to analysis of the boiling points of the cinnamaldehyde and methylcinnamaldehyde as a means of identification.
	c		Marks for each correct structure/reagent shown below  	**5**	**ANNOTATE WITH TICKS AND CROSSES** **ALLOW** any combination of skeletal **OR** structural **OR** displayed formula as long as unambiguous For reaction with excess H_2/Ni **IGNORE** hydrogenation of benzene ring i.e. the following structure scores two marks  **ALLOW** KCN/H^+ **ALLOW** HCN **ALLOW** H_2SO_4 or HNO_3 or HC*l* for H^+ **<u>Examiner's Comments</u>** This question proved difficult and although the majority of candidates scored in some parts, only the very best

					responses secured all five marks. More detailed feedback is discussed with Exemplar 8. **Exemplar 8**

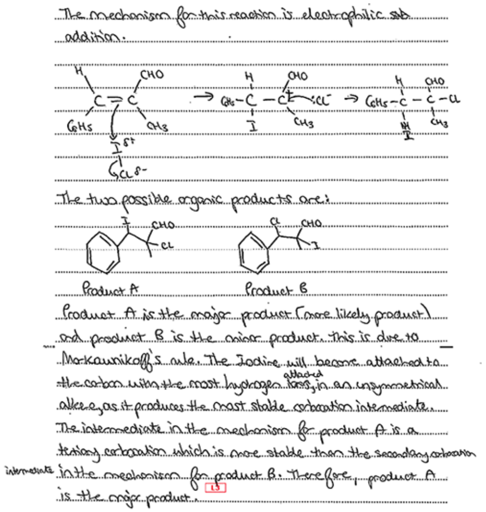
					 Cinnamaldehyde was the starting point for this flowchart of reactions. The most frequently scored mark was correct identification of the reagents required for the formation of the hydroxynitrile. This response uses NaCN/H^+. Other candidates used HCN which was also acceptable. The flowchart shows two different reactions of this hydroxynitrile. The first is the reaction with excess hydrogen in the presence of Ni. Most candidates scored one mark for their product. As in this exemplar, the double bond was often reacted to form a saturated chain. Some candidates identified that the CN group would also react but instead of writing CH_2NH_2 they replaced the CN group with just NH_2, effectivity removing a carbon atom from the chain. The second

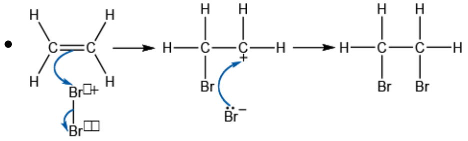
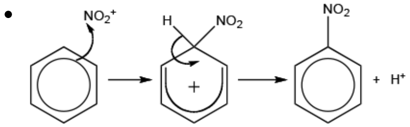
					reaction of the hydroxynitrile is acid hydrolysis of the CN group. This response identifies the correct carboxylic acid. However, this reaction seemed unfamiliar to many candidates and a range of incorrect responses were frequently seen. The final reaction is the reduction of cinnamaldehyde with $NaBH_4$. Many candidates recognised this reaction, but as can be seen in this response the alcohol group is shown on the incorrect carbon atom. This was a common error. Candidates are advised to number carbon atoms present if provided with a complex structure, such as cinnamaldehyde. Numbering will ensure that each carbon is considered when drawing reaction products and would minimise errors, such as those demonstrated in the reduction product.
	d		*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)**	**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:** **Mechanism for formation of either product.** • Curly arrow from C=C to attack the I atom of the I-Cl • Correct dipole on I-C*l*

			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.*		• Curly arrow from I-C*l* bond to C*l* • 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**  **<u>Organic products</u>** • Major/most likely product

					 $C_6H_5-CH(I)-C(Cl)(CHO)-CH_3$ • Minor/least likely product  $C_6H_5-CH(Cl)-C(I)(CHO)-CH_3$ • 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 **<u>Examiner's Comments</u>** 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

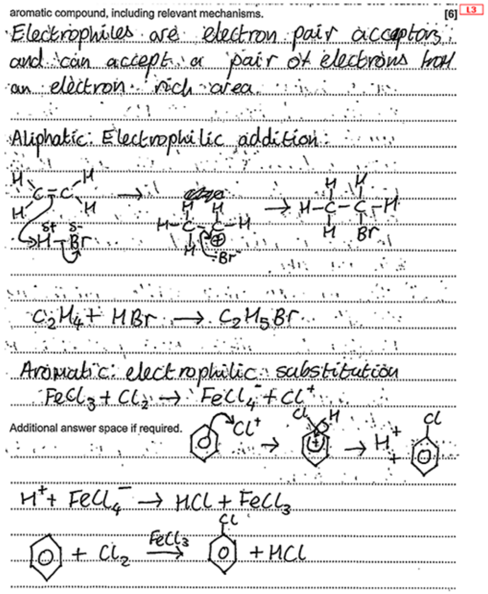
					reference to electrophilic addition in the question and tried reacting IC*l* with either the benzene ring or the aldehyde group. **Exemplar 9**

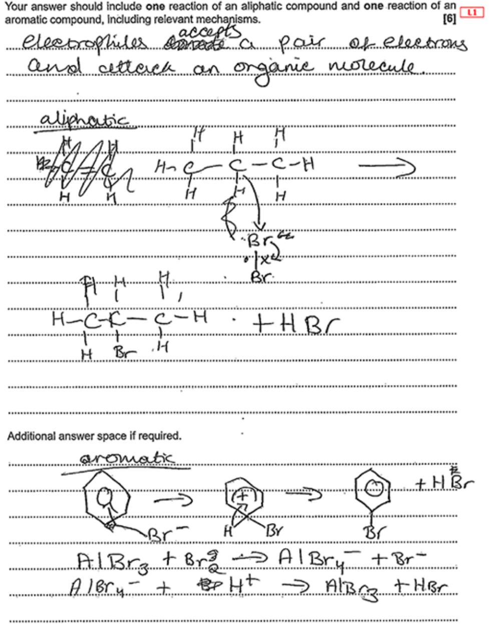
					 The mechanism for this reaction is electrophilic ~~sub~~ addition. The two possible organic products are: Product A Product B Product A is the major product (more likely product) and product B is the minor product. This is due to Markownikoff's rule. The Iodine will become attached to the carbon with the most hydrogen ~~ions~~ attached, in an unsymmetrical alkene, as it produces the most stable carbocation intermediate. The intermediate in the mechanism for product A is a tertiary carbocation which is more stable than the secondary carbocation intermediate in the mechanism for product B. Therefore, product A is the major product. L3 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	**18**	

5 0			*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.*	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)**

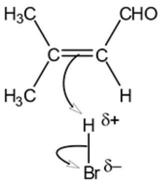
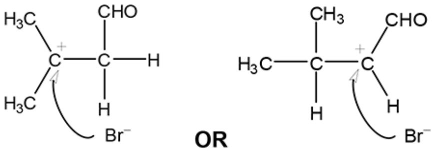
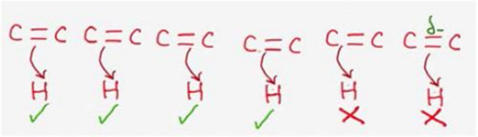
			0 marks	No response or no response worthy of credit.		- Electrophile as electron pair acceptor - Types and names of mechanisms - Equations for generation of electrophile and regeneration of catalyst - Accurately positioned and directed curly arrows and charges/ dipoles included - Explanation of major 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,

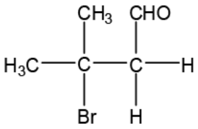
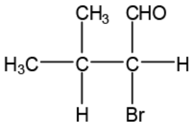
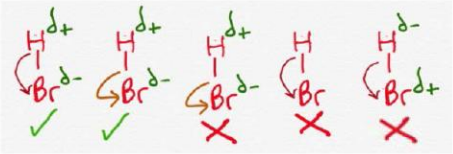
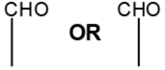
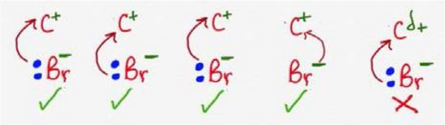
					the position of the curly arrow when H^+ is lost from an aromatic intermediate, and not showing the lone pair when Br_- attacks a carbocation. Some answers lacked detail and gave only two mechanisms with minimal supporting words. Lower ability candidates described nucleophilic addition or substitution 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**

					 aromatic compound, including relevant mechanisms. [6] L3 Electrophiles are electron pair acceptors, and can accept a pair of electrons from an electron rich area. Aliphatic: Electrophilic addition: $C_2H_4 + HBr \longrightarrow C_2H_5Br$ Aromatic: electrophilic substitution $FeCl_3 + Cl_2 \rightarrow FeCl_4^- + Cl^+$ Additional answer space if required. $H^+ + FeCl_4^- \rightarrow HCl + FeCl_3$

					Exemplar 17  Your answer should include **one** reaction of an aliphatic compound and **one** reaction of an aromatic compound, including relevant mechanisms. [6] L1 electrophiles ~~donate~~ accepts a pair of electrons and attack an organic molecule. aliphatic + HBr Additional answer space if required. aromatic + HBr $AlBr_3 + Br_2 \rightarrow AlBr_4^- + Br^-$ $AlBr_4^- +$ ~~Br~~ $H^+ \rightarrow AlBr_3 + HBr$
			Total	**6**	
5 1			**D**	**1**	**<u>Examiner's Comments</u>** Most candidates chose the correct option of D but a sizeable number chose B and C, the other options containing a ‘2’ in their names. The best strategy here is to draw out the carbon skeleton of pent-2-ene from which it is clear that bromine atoms must be added at carbon positions 2 and 3.
			Total	**1**	
5 2			**C**	**1**	**<u>Examiner's Comments</u>** This was a difficult question but higher ability

					candidates selected the correct option of C. The main discriminator was B, which identifies the 1 double bond as *Z*. CIP analysis is required to show that the double bond is *E*. This is a good 'hard' example for illustrating *E*/Z isomerism.
			Total	**1**	
53			**C**	1 (AO 1.2)	**ALLOW** E (This is the correct term) **<u>Examiner's Comments</u>** This question proved difficult. Many candidates identified that this structure is an E stereoisomer (C) but a significant number of responses selected D. Candidates are encouraged to draw out the groups to determine the first point of difference when applying the Cahn Ingold Prelog (CIP) priority rules. ⓘ **OCR support** OCR has a worksheet which can help support students' understanding of Cahn Ingold Prelog priority rules, available here: http:/www.ocr.org.uk/Images/208569-cip-rules-activity.doc.
			Total	**1**	
54			**D**	1 (AO 2.5)	**<u>Examiner's Comments</u>** This is a demanding question. The best responses

					drew the first step of the mechanism near the table. This showed both the π bond in ethene and the σ bond in bromine breaking in addition to a σ bond forming between carbon and bromine atoms. Although many candidates correctly selected D, option B was a good distractor and was the most commonly seen incorrect response.
			Total	**1**	
5 5	a	i	**ANNOTATE ANSWER WITH TICKS AND CROSSES**  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 ✓ Correct carbocation **AND** curly arrow from Br– to C+ of carbocation ✓ **DO NOT ALLOW** $\delta+$ on C of carbocation  -- Correct product ✓	4 (AO 1.2) (AO 1.2)	**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** • 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**

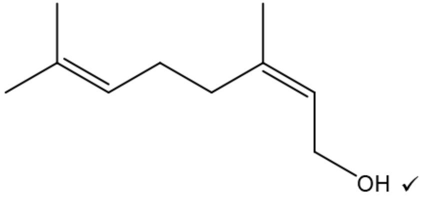
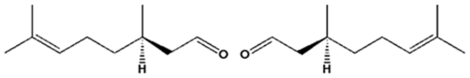
			 **OR** 	(AO 2.5) (AO 2.5)	• go to $Br^{\delta-}$  **IGNORE** connectivity of CHO and CH^3 groups in carbocation and product e.g. **ALLOW**  **ALLOW** COH for CHO (*reaction does not involve this group*) **3rd curly arrow must** • go to the C+ of carbocation **AND** • start from, **OR** be traced back to **any point across width** of lone pair on $:Br^-$ • **OR** start from – charge of Br^- ion 

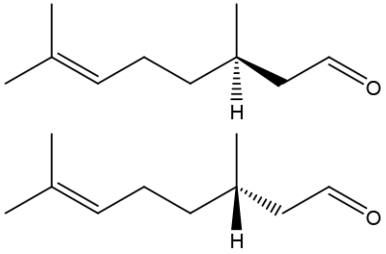
					(*Lone pair **NOT** needed if curly arrow shown from – charge of Br^- ion*) **IF** Br_2 is used instead of HBr contact your Team Leader **Examiner's Comments** Candidates were very familiar with this electrophilic addition mechanism, so the majority of candidates scored three or four marks. Common errors included inaccurate curly arrows from either the carbon-carbon double bond or the bromide ion or the omission of key detail such as the partial charges on HBr or the charge on the bromide ion.
		ii	(major product forms from) most/more stable intermediate/carbocation ✓ (major product forms from a) tertiary carbocation **OR** carbocation bonded to more C atoms / more alkyl groups **OR** carbocation bonded to no H atoms ✓	2 (AO 1.1) (AO 1.2)	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) secondary carbocation **OR** carbocation bonded to fewer C atoms / more alkyl groups **OR** carbocation bonded to H atoms ✓ --------------------- -----------------------------

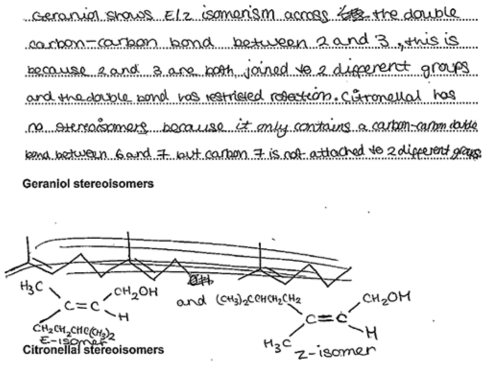
					Examiner's Comments This question required candidates to apply their knowledge of Markownikoff's rule to explain the formation of a major product in the reaction in part (a)(i). The majority of candidates recognised that the stability of the intermediate was responsible for one of the products being formed in a greater quantity, and most scored at least one mark. The best responses recognised that, in the context of the reaction in (a)(i), a tertiary carbocation would form the major product. Other response talked more generally about the major product (without identifying that the tertiary carbocation in the mechanism is responsible)). Lower ability candidates focused their response on the stability of the product and did not discuss the intermediate at all. **OCR support** A topic exploration pack on electrophilic addition and Markownikoff's rule, including activities to assess student understanding, is available here: http:/www.ocr.org.uk/Images/336551-electrophilic-addition-and-markownikoff-s-rule.doc
	b	i	Tollens' (reagent) ✓ Silver (mirror/precipitate/ppt/solid) with citronellal/the aldehyde ✓	2(AO 1.2×2)	**ALLOW** ammoniacal silver nitrate **OR** Ag^+/NH_3 **ALLOW** black ppt **OR** grey ppt

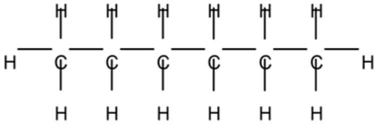
					IGNORE references to acidified dichromate reacting with **both** compounds --- **ALLOW** 2,4-DNP/2,4-DNPH **ALLOW** Brady's reagent ✓ Yellow/orange/red precipitate with citronellal/aldehyde/carbonyl group ✓ --- **IF** other reagents are seen, contact your Team Leader **Examiner's Comments** Almost all candidates were able to describe a suitable test to distinguish between geraniol and citronellal and most scored both marks. The most common choice was to use Tollens' reagent to identify the aldehyde group in citronellal by the formation of a silver mirror. Other candidates opted for 2,4-dinitrophenylhdrazine to differentiate the carbonyl compound from the alcohol.
		ii	$C_{10}H_{18}O$ ✓	1(AO 1.2)	**DO NOT ALLOW** $C_{10}H_{17}OH$ **Examiner's Comments** Many candidates were able to determine the correct molecular formula of geraniol as $C_{10}H_{18}O$. A small but significant proportion of the candidates gave a structural formula, showing each C atom in turn, rather than grouping atoms of the same element together. Candidates are encouraged to practice giving different types of formulae for a range of organic compounds to make sure that each type is understood, and to check

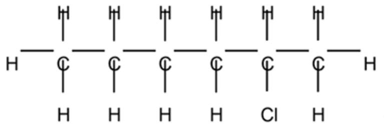
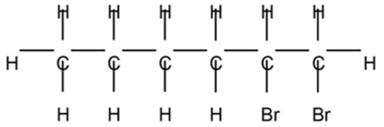
					to ensure they are providing the type of formula that the question is asking for.
		iii	Same **molecular** formula **AND** Different **structural** formulae ✓ **OR** Both (geraniol and citronellal) have the molecular formula $C_{10}H_{18}O$ **AND** Different **structural** formulae ✓	1 (AO 1.1)	Same 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/ functional groups **DO NOT ALLOW** any reference to spatial/space **ALLOW ECF** from incorrect molecular formula in **(b)(ii)**
		iv	Same structural formula **AND** Different arrangement (of atoms) in space **OR** different spatial arrangement (of atoms) ✓	1 (AO 1.1)	**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 **Examiner's Comments** Most candidates were able to explain the term stereoisomerism succinctly. However, a significant number of candidates referred to stereoisomers as having the same molecular formula, rather than being more precise and stating that they are compounds with the same structural formula.

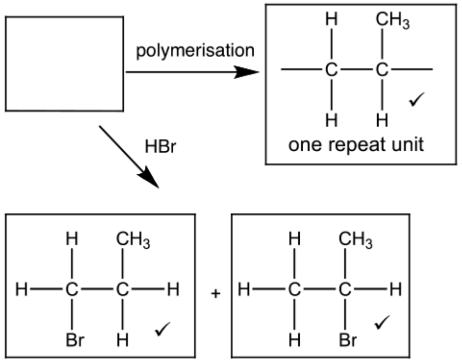
		v	**Geraniol:** (Carbon-carbon) double bond at carbon-2(,3) **AND** *E* **OR** *Z* ✓ Structure of *Z* geraniol (*E* isomer is shown in question)  OH ✓ **Citronellal:** chiral/asymmetric C at carbon-3 **OR** carbon-3 is bonded to 4 different groups **AND** optical isomerism ✓ Two 3D structures of citronellal that are mirror images ✓ e.g. 	4 (AO 1.2) (AO 2.5) (AO 1.2)	**ANNOTATE ANSWER WITH TICKS AND CROSSES ETC** **CHECK** diagrams of citronellal and geraniol for annotations that may be worthy of credit **DO NOT ALLOW** isomerism at C=C at carbon 6(,-7) **ALLOW** identification of carbon-2(,3) from correct *Z* geraniol isomer if not stated in text or diagram **IGNORE** *cis* **OR** *trans* isomerism (*none of the substituent groups attached to the C=C are the same*) **IGNORE** geometric **ALLOW** type of isomerism from *E/Z* labels, even if incorrectly assigned In geraniol, **ALLOW** C_6H_{11} **OR** R to represent alkenyl chain **ALLOW** CH_3O to represent CH_2OH **ALLOW** identification of carbon-3 from 3D structure citronellal if not stated in text or diagram **IGNORE** connectivity of groups around chiral C In citronellal, **ALLOW** C_6H_{11} **OR** R to represent alkenyl chain **ALLOW** C_2H_3O to represent CH_2CHO **IF** structural formula of alkenyl chain is used

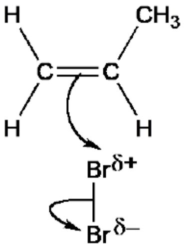
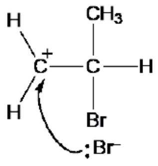
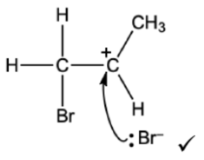
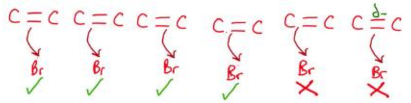
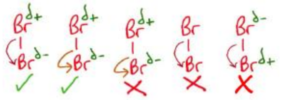
				(AO 2.5)	**IGNORE one** small slip in one/both isomers e.g.$(CH_3)_2CHCH_2CH_2$ (*missing carbon-7*) **ALLOW** two 3D structures with 2 groups swapped e.g.  **<u>Examiner's Comments</u>** This question, which discriminated well, required candidates to apply their knowledge of stereoisomerism to geraniol and citronellal. The majority of responses focused on *E/Z* isomerism, as shown in Exemplar 2. Many candidates were able to show the structure of the *Z* isomer of geraniol and scored at least one mark. Stronger responses were able to explain this type of isomerism as the result of the carbon-carbon double bond between carbon atoms 2 and 3. Common errors included attributing *E/Z* isomerism to the double bond between carbon atoms 6 and 7 or use of *cis/trans* to describe the isomers (the latter of which was ignored by the mark scheme as it does not apply to geraniol). The best responses also identified the chiral carbon atom in citronellal and were able to show the optical isomers appropriately.

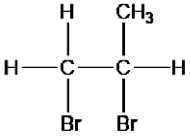
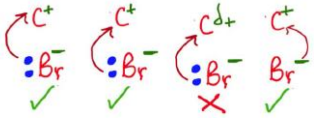
					Exemplar 1  Geraniol shows E/Z isomerism across ~~[illegible]~~ the double carbon-carbon bond between 2 and 3, this is because 2 and 3 are both joined to 2 different groups and the double bond has restricted rotation. Citronellal has no stereoisomers because it only contains a carbon-carbon double bond between 6 and 7 but carbon 7 is not attached to 2 different groups. Geraniol stereoisomers Citronellal stereoisomers This response identifies that geraniol has E/Z isomers and provides a correct explanation with reference to the carbon-carbon double bond between carbon atoms 2 and 3. So marking points one and two were given. The candidate recognises that the double bond between carbon atoms 6 and 7 would not cause isomerism in both compounds. Unfortunately this response overlooks the chiral carbon in citronellal and incorrectly states that it has are no stereoisomers. This question highlights the challenge of a linear specification, where content from different modules may be assessed within the same question. Candidates are likely to encounter these two types of stereoisomerism in different years of their course. They should therefore be encouraged to make links between the different modules to help develop their understanding.
			Total	**15**	
56			**A**	1 (AO1.1)	**<u>Examiner's Comments</u>** Candidates answered this question well with over two-

					thirds choosing the correct option A. Option D was the most common incorrect response suggesting that candidates are uncertain about the nature of a C=C double bond.
			Total	**1**	
57			**A**	1 (AO1.1)	
			Total	**1**	
58			**C**	1 (AO1.2)	**Examiner's Comments** This part discriminated well. Although most candidates did select C as the correct structure, many were diverted into selecting option D, the other alternative containing a double C=C bond. In identifying a monomer for an addition polymer, candidates are advised to identify the repeat unit and then to replace the single C–C bond with a double bond to give the monomer.
			Total	**1**	
59		i	**Product with H_2**  ✓ **Product with HCl**	3(AO1.2x3)	**ALLOW** any combination of skeletal **OR** structural **OR** displayed formula as long as unambiguous **ALLOW** part molecular formulae but not full **Examiner's Comments** Most candidates answered this question well and achieved full marks. The most common errors were to put the chlorine on the wrong carbon, or to put both bromines on the same carbon.

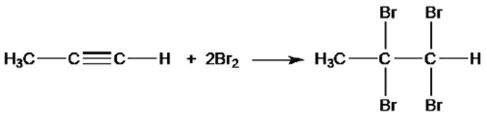
			 ✓ **Product with Br_2**  ✓		
		ii	Nickel/Ni ✓	1(AO1.2)	**ALLOW** Pt **OR** Pd **OR** Rh **Examiner's Comments** Most candidates correctly stated nickel, although it was spelled incorrectly a lot of the time, which was ignored. "Acid" was the most common incorrect answer
		iii	(orange to) colourless **OR** bromine is decolourised ✓	1(AO1.2)	**ALLOW** 'it decolourises / turns colourless' **IGNORE** colour change **Examiner's Comments** Many candidates wrote the colour change the wrong way around, or thought that a gas would be evolved, or wrote "clear" instead of "colourless". A large proportion merely stated what type of reaction it was, rather than what they would observe.
			Total	**5**	

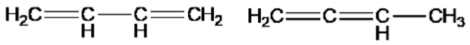
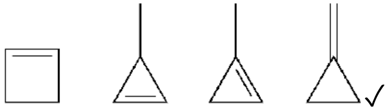
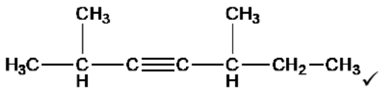
60	a			3 (AO2.5×3)	**ALLOW** any combination of skeletal **OR** structural **OR** displayed formula as long as unambiguous **For repeat unit,** • ‘side bonds’ required on either side of repeat unit from C atoms • **DO NOT ALLOW** > one repeat unit **IGNORE** brackets • **IGNORE** *n* **ALLOW** in either order **<u>Examiner’s Comments</u>** This part was generally well-answered with well-prepared candidates scoring all three marks. The most common errors resulted from the products of reaction with HBr. The same structure was often drawn, reversed in one of the boxes. Candidates should take care to check that the atoms in a structure have the correct number of bonds. Some candidates added HBr across the C=C double bond but left the C=C bond intact in their final structures, showing carbon atoms with 5 bonds instead of 4.

	b		 **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  **OR** 	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**

			*i.e. **ALLOW** carbonium + on either C atom* **Correct product to match mechanism** ✓  **DO NOT ALLOW** half headed or double headed arrows but allow **ECF** if seen more than once		- 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 **<u>Examiner's Comments</u>** 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
	c	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** **<u>Examiner's Comments</u>** 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 .
		iii	 $H_3C-C\equiv C-H + 2Br_2 \longrightarrow H_3C-CBr_2-CBr_2-H$ 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: $H_3C-C\equiv C-CH_3$  $H_2C=CH-CH=CH_2$ $H_2C=C=CH-CH_3$  ✓✓	2 (AO3.2×2)	**ALLOW** any combination of skeletal **OR** structural **OR** displayed formula as long as unambiguous **<u>Examiner's Comments</u>** 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	 $H_3C-CH(CH_3)-C\equiv C-CH(CH_3)-CH_2-CH_3$ ✓✓✓	1 (AO2.5)	**ALLOW** any combination of skeletal **OR** structural **OR** displayed formula as long as unambiguous **<u>Examiner's Comments</u>** 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	**15**	