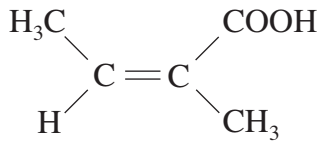
Examiner only

SECTION A

Answer **all** *the questions in the spaces provided.*

1. *(a)* Angelic acid, (2-methylbut-2-enoic acid), is the traditional name for a compound produced by some plants as a defence against attack by beetles.



angelic acid

(i) This acid is one of a pair of stereoisomers.
Explain what is meant by the term stereoisomer. [1]

.....

.....

.....

(ii) Draw the **skeletal** formula of the **other** stereoisomer of angelic acid. [1]

(iii) The ethyl esters of these unsaturated acids have uses in the perfume industry.
State the reagent(s) and the condition(s), apart from heating, that are needed to produce ethyl angelate from angelic acid. [2]

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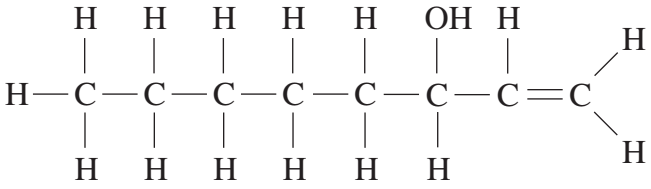
(b) Oct-1-en-3-ol, which shows optical isomerism, can be used as a mosquito repellent.



oct-1-en-3-ol

(i) Explain what is meant by a chiral centre. Indicate the location of a chiral centre on the formula above by using an asterisk (*). [2]

.....

.....

(ii) State how the two enantiomers of oct-1-en-3-ol affect the plane of polarised light. [1]

.....

(iii) State what is meant by a racemic mixture and how its solution would affect the plane of polarised light. [2]

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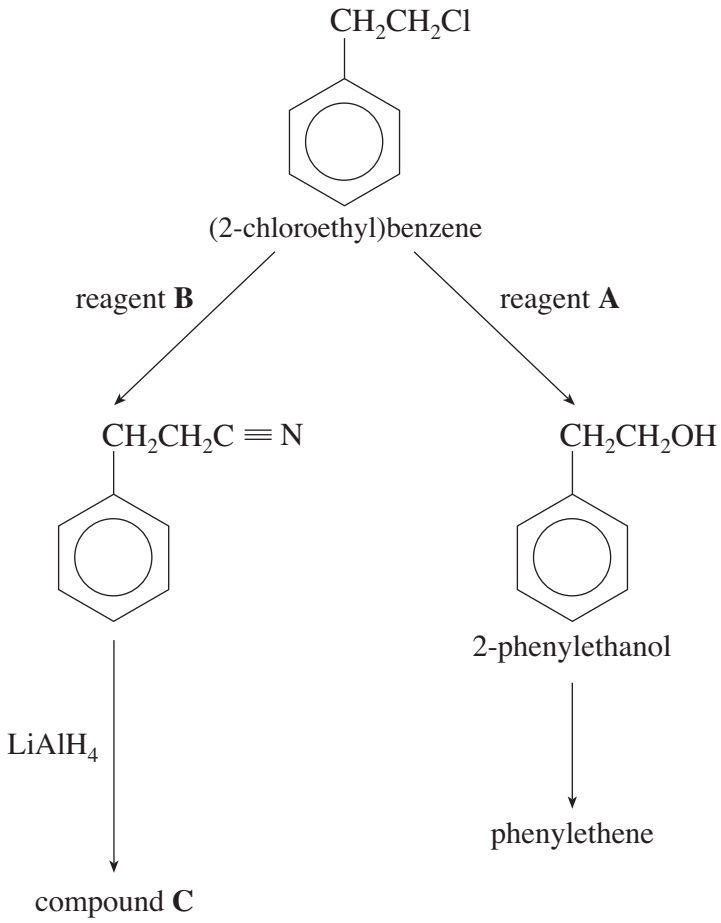
2. *(a)* (2-Chloroethyl)benzene is the starting material for the production of a number of other compounds.



(i) State the name of reagent **A**. ..... [1]

(ii) State the name of reagent **B**. ..... [1]

(iii) Name the type of reaction that occurs when phenylethene is produced from 2-phenylethanol. [1]

.....

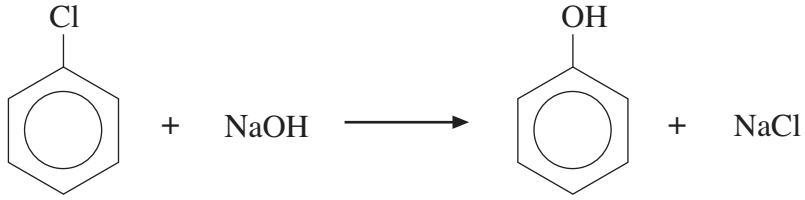
(iv) Give the displayed formula of compound **C**. [1]

SECTION B

Answer **both** *questions in the separate answer book provided.*

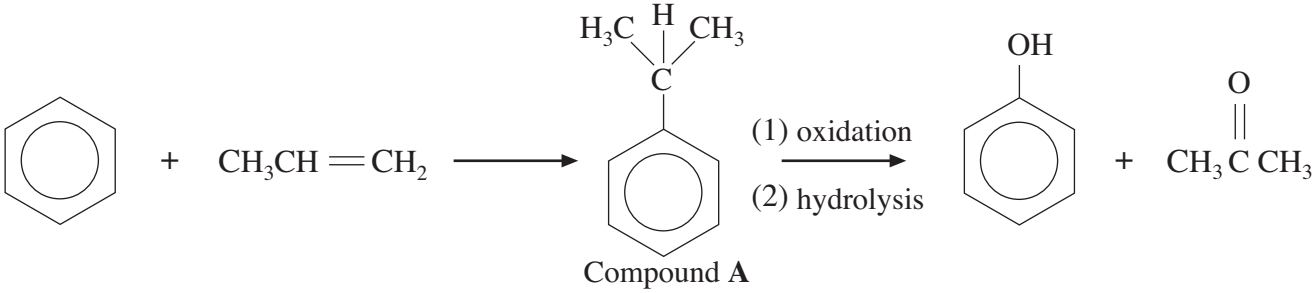
4. *(a)* Chlorobenzene, C_6H_5Cl, is an important industrial chemical. It can be made in the laboratory by reacting benzene and chlorine in the presence of an iron or iron(III) chloride catalyst.
Give the mechanism for this electrophilic substitution reaction. [4]

(b) One method for making phenol is by reacting chlorobenzene with aqueous sodium hydroxide, but at a pressure of 200 atmospheres.



Explain why it is difficult to react chlorobenzene with sodium hydroxide. [3]

(c) Most phenol is now produced from benzene and propene in a three-stage reaction.



(i) State the name of compound **A**. [1]

(ii) Explain why the atom economy of this reaction to make phenol is poor. [2]

(iii) Using the Data Sheet, describe how an infrared spectrum of a sample of phenol produced in this process would indicate that traces of propanone were also present. [2]

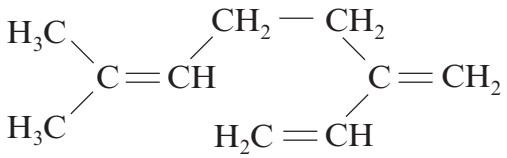
(iv) At room temperature phenol is a solid. A sample of phenol was dissolved in ethanol and then a few drops of the solution were added to some iron(III) chloride solution. State what was seen and why ethanol is a suitable solvent to use for this reaction. [2]

Examiner only

SECTION A

Answer **all** *questions in the spaces provided.*

1. *(a)* Terpenes are the primary constituents of the essential oils of many types of plants and flowers.
An example is myrcene, one of the most important chemicals used in the perfume industry because of its pleasant odour. It has the structure shown below.



(i) State the molecular formula of myrcene. [1]

.....

(ii) Draw the **skeletal** formula of myrcene. [1]

(iii) Myrcene reacts with hydrogen to form a saturated hydrocarbon in the same way as alkenes of general formula C_nH_{2n}.

I. Explain what is meant by the term *saturated* hydrocarbon. [1]

.....

.....

II. Using molecular formulae write an equation for this reaction. [1]

.....

Examiner only

2. *(a)* Explain the difference in structure between *primary* and *secondary* alcohols. [1]

.....

.....

(b) Quantitative analysis of an alcohol shows that its percentage composition by mass is C 68.1%, H 13.7% and O 18.2%. It has a relative molecular mass of 88.1.

Calculate the empirical formula of the alcohol and show that its molecular formula is the same as the empirical formula. [3]

.....

.....

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(c) The following compounds have the same molecular formula, $C_5H_{10}O$.

A $CH_3CH_2COCH_2CH_3$ **B** $CH_3CH_2CH_2CH_2CHO$

C $CH_3CH_2CHCHCH_2OH$ **D** $CH_2CHCH_2CH(OH)CH_3$

(i) Draw the structure of an isomer of **B** that is also an aldehyde. [1]

(ii) I. State which **one** of the compounds **A–D** exhibits E-Z (trans-cis) isomerism. [1]

.....

II. Draw the structures of **both** isomers. [1]

SECTION B

Answer **both** *questions in the separate answer book provided.*

4. *(a)* The reaction between but-1-ene and hydrogen bromide produces a mixture of **three** isomers.

(i) Draw the displayed formula of each of the three isomers. [3]

(ii) Outline how each of the isomers can be distinguished from one another. [3]

(QWC) [1]

(b) (i) Ethylamine can be produced by the reaction of ammonia with chloroethane.

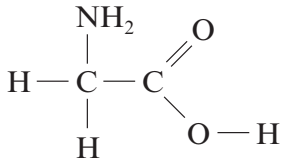
I. Write an equation for this reaction. [1]

II. Classify the type of reaction taking place. [1]

(ii) Phenylamine cannot be prepared in this way. Name the starting material and reagent(s) used to prepare phenylamine in a laboratory. [2]

(iii) Give one chemical test, including reagent(s), condition(s) and expected observations, which would distinguish between ethylamine and phenylamine. [3]

(c) Amino acids also contain an amine group. The simplest amino acid, aminoethanoic acid (glycine) has the formula



(i) Draw the displayed formula of 2-aminopropanoic acid (alanine). [1]

(ii) A dipeptide can be formed by reacting two amino acids. Draw the displayed formulae of the two different dipeptides which can be made by combining glycine and alanine. [2]

(iii) Proteins are natural polypeptides. Explain briefly what is meant by primary, secondary and tertiary protein structure. [3]

Total [20]

(iv) Another terpene, α-farnasene, is responsible for the characteristic odour of green apples.
A 0.100 mol sample of α-farnasene reacted with 8.96 dm^3 of hydrogen to form a saturated hydrocarbon $C_{15}H_{32}$.
(1 mole of gas molecules occupy 22.4 dm^3 under these conditions.)

Calculate how many double bonds there are in each molecule of α-farnasene. [2]

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Examiner only

SECTION A

Answer **all** *questions in the spaces provided.*

1. *(a)* Complete the following passage by inserting suitable words or formulae where required. [3]

Nitrobenzene, an aromatic yellow oil, has the molecular formula ..... .

However, in blue light, this compound appears black because .....

..... .

The ^{1}H NMR spectrum of nitrobenzene is produced as a result of interactions between the spin of the nuclei and an applied magnetic field. This spectrum is seen as a number of peaks because the protons causing the spectrum are not ..... .

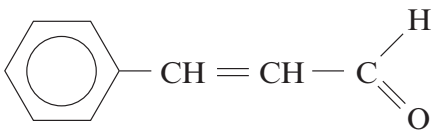
(b) Benzene reacts with chloromethane in the presence of a catalyst giving methylbenzene as the main organic product.

(i) Give the equation for this reaction. [1]

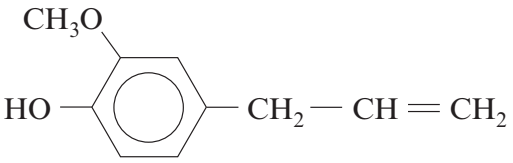
(ii) State the name of a catalyst that can be used. [1]

.....

(c) The smell and flavour of cinnamon oil is largely due to cinnamaldehyde (3-phenylpropenal) and, to a smaller extent, eugenol.



cinnamaldehyde



eugenol

(i) Explain why only cinnamaldehyde, and not eugenol, is able to have E-Z isomers. [1]

.....

.....

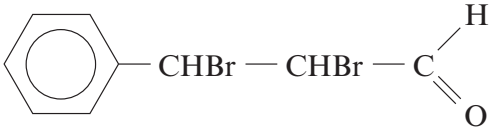
.....

(ii) Giving the reagent and an observation, state a chemical test that gives a positive result with eugenol but not with cinnamaldehyde. [2]

Reagent .....

Observation .....

(iii) Cinnamaldehyde reacts with bromine to give the chiral compound **C**.



compound **C**

Both compound **C** and cinnamaldehyde can be used to illustrate stereoisomerism. State what is meant by *stereoisomerism.* [1]

.....

.....

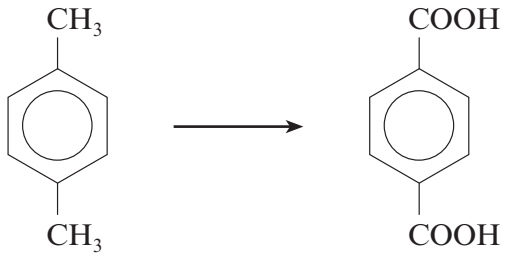
.....

Total [12]

(ii) The two isomers are separated by recrystallisation from ethanol, in which the 2-isomer is much more soluble.
Use the information provided to state and explain how you would know when the 4-isomer is no longer contaminated with traces of the 2-isomer. [2]

(iii) In an experiment 8.10 g of N-phenylethanamide (M_r 135) produced 6.48 g of pure 4-nitro-N-phenylethanamide (M_r 180).
Calculate the percentage yield of 4-nitro-N-phenylethanamide. [3]

(c) One stage in the preparation of the polyester PET is the oxidation of 1,4-dimethylbenzene to benzene-1,4-dioic acid.



This is carried out in the laboratory by refluxing 1,4-dimethylbenzene and an alkaline solution (containing sodium hydroxide) of an oxidising agent **G**, giving an intermediate product, which is then acidified.

(i) State the name of oxidising agent **G**. [1]

(ii) Explain why it is then necessary to acidify the intermediate product to give the required acid. [1]

(d) The polyester PET is produced by reacting benzene-1,4-dioic acid and ethane-1,2-diol.
Draw the formula of the repeating unit found in PET and state why this reaction is described as condensation polymerisation. [2]

Total [20]

Examiner only

SECTION A

Answer **all** *questions in the spaces provided.*

1. *(a)* Nitrobenzene, $C_6H_5NO_2$, is a yellow oily liquid.

(i) Give the general name of a group responsible for colour in organic compounds. [1]

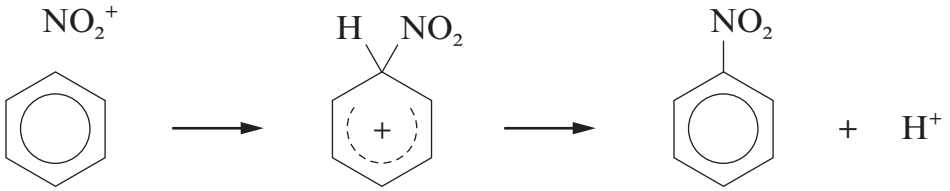
.....

(ii) State why nitrobenzene is yellow in white light. [1]

.....

(b) Nitrobenzene is produced from benzene by reaction with the nitronium ion (nitryl cation), NO_2^+.

(i) Complete the mechanism below by the use of the curly arrows (↷) [1]



(ii) During this reaction to produce nitrobenzene small quantities of 1,3-dinitrobenzene are produced.
Give the **empirical** formula of 1,3-dinitrobenzene. [1]

.....

(iii) In this reaction the nitronium ion is produced from nitric and sulfuric acids.

$$HNO_3 + 2H_2SO_4 \longrightarrow NO_2^+ + H_3O^+ + 2HSO_4^-$$

Use this equation to state why the sulfuric acid is acting as an acid. [1]

.....

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(c) Explain why benzene compounds tend to react by electrophilic **substitution** rather than undergo electrophilic addition. [2]

(QWC) [1]

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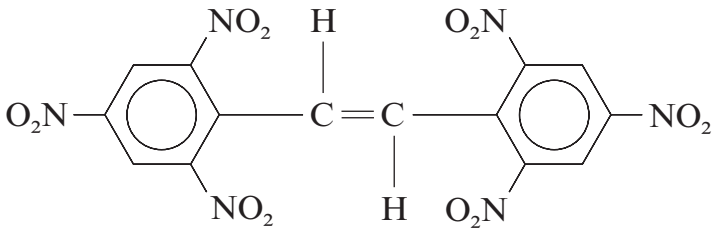
(d) Many explosives contain nitro-groups. The explosive hexanitrostilbene (HNS)



hexanitrostilbene

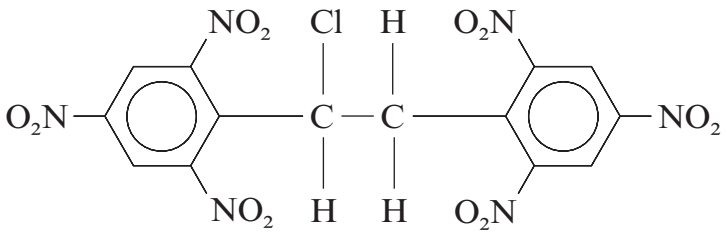
has been used to separate different sections in space rockets and for seismic experiments on the Moon.

(i) HNS is the E-isomer of a pair of E-Z isomers. State why HNS has both E- and Z-isomers. [1]

.....

.....

(ii) The manufacture of HNS is believed to proceed via compound **R**.



compound **R**

I Compound **R** contains a chiral centre. Identify the chiral centre in the formula of compound **R** by using an asterisk (*). [1]

II Compound **R** exists as two enantiomers. Explain what is meant by the term *enantiomers* and how these affect plane-polarised light. [2]

.....

.....

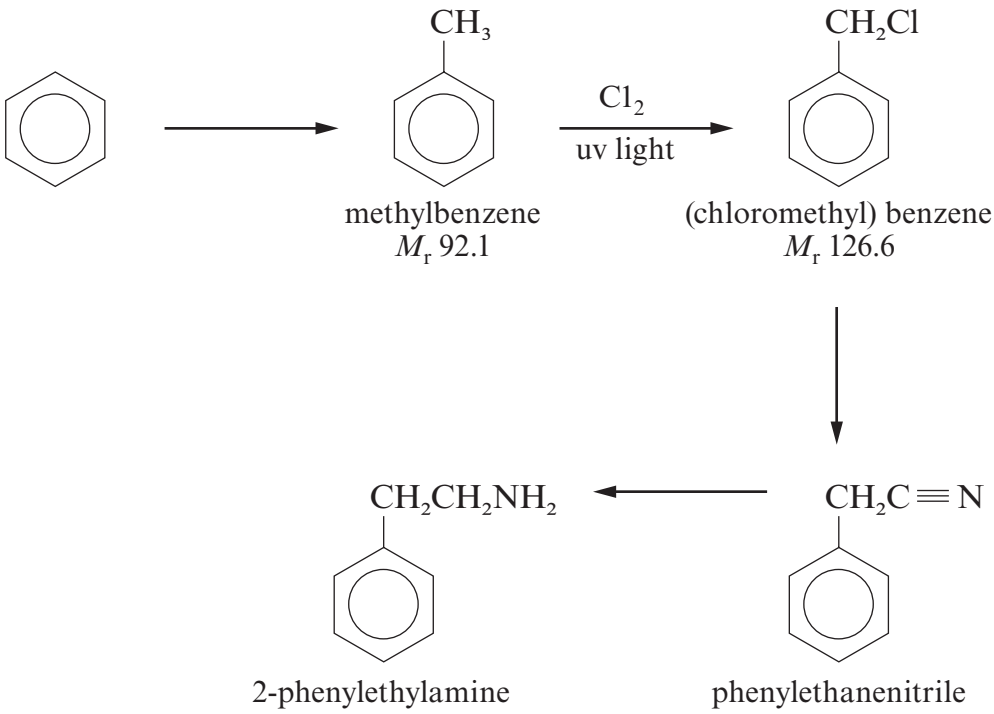
.....

III State the type of reaction that occurs when compound **R** is converted to HNS by the use of a suitable base. [1]

.....

Total [13]

5. *(a)* 2-Phenylethylamine, present in chocolate, can be made from benzene in four stages.



(i) Give the equation, and the name of a suitable catalyst, for the Friedel-Crafts alkylation of benzene leading to methylbenzene. [2]

(ii) (Chloromethyl)benzene is produced by passing chlorine gas into methylbenzene in the presence of ultraviolet light. In practice the substitution by chlorine can proceed further giving (dichloromethyl)benzene and (trichloromethyl)benzene.
In order to prevent further chlorination the reaction is stopped when the increase in mass corresponds to (chloromethyl)benzene being produced.
You should assume that the other product, gaseous hydrogen chloride, is lost from the mixture.
In an experiment the following results were obtained.

Mass of flask	+	product	=	158.4 g
Mass of flask	+	methylbenzene	=	148.0 g
Mass of flask			=	120.4 g

Show that the increase in mass corresponds to the conversion of all the methylbenzene into (chloromethyl)benzene. [4]

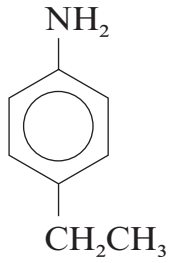
(iii) State the names of the reagents necessary to convert

I (chloromethyl)benzene to phenylethanenitrile, [1]

II phenylethanenitrile to 2-phenylethylamine. [1]

(b) Explain why 2-phenylethylamine is a base. [2]

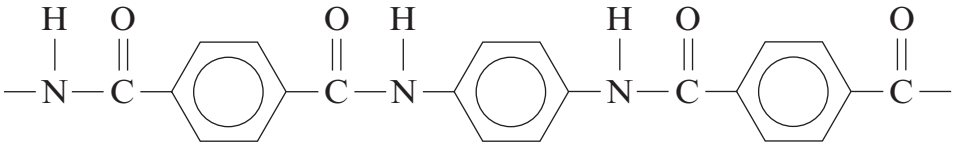
(c) State how both 2-phenylethylamine and its isomer 4-ethylphenylamine react with nitric(III) (nitrous) acid at 5°C.



4-ethylphenylamine

In **each** case you should state the type of compound produced and any relevant observations. [3]

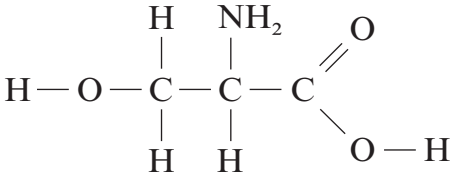
(d) Kevlar ® is a polyamide that is used in bullet-proof vests.



Kevlar ®

Give the formula of two starting materials that can be reacted together to give Kevlar ®. [2]

(e) Silk is a naturally occurring material composed of polymerised serine molecules. Serine is an α-amino acid.



serine

(i) Give the **systematic name** of serine, which is a derivative of propanoic acid. [1]

(ii) Hydrogen bonding is largely responsible for the solubility of serine in water. Explain what is meant by hydrogen bonding, using serine to illustrate your answer. [3]

(QWC) [1]

Total [20]

Section B Total [40]

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SECTION A

Answer **all** *questions in the spaces provided.*

1. *(a)* The formulae of some compounds are shown below.

$CH_3CH_2NH_2$	$CH_3CH_2CONH_2$	$CH_3CHCHCHO$
A	**B**	**C**
$CH_3CH(OH)CH_2CH_3$	CH_2CHCH_3	$CH_3CH_2COCH_2CH_3$
D	**E**	**F**

Each letter may be used once, more than once or not at all, to answer the questions below.

Give the letter of the compound which

(i) is most basic, [1]

.....

(ii) forms yellow crystals when warmed with iodine in alkaline solution, [1]

.....

(iii) forms a silver mirror when warmed with Tollens' reagent, [1]

.....

(iv) exhibits E-Z isomerism. [1]

.....

(b) (i) Butylamine is one of the compounds responsible for the smell of rotting fish. It can be prepared in the laboratory from 1-chlorobutane.

Classify the reaction mechanism when butylamine is prepared in this way. [1]

.....

(ii) Explain why phenylamine, an aromatic amine, cannot be prepared from chlorobenzene using a similar reaction to that in part (i). [2]

.....

.....

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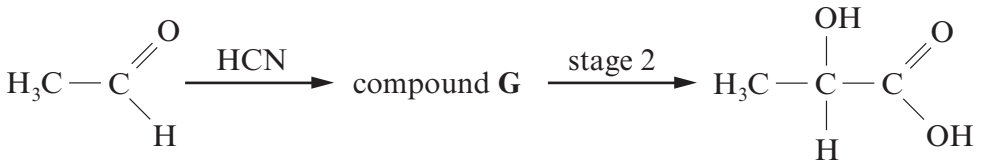
2. *(a)* Lactic acid is a naturally-occurring compound that shows optical activity.
Lactic acid can be prepared from ethanal in the laboratory in a two stage process.



lactic acid

However, a sample prepared in this way was found to be optically inactive.

(i) Explain what is meant by a 'compound that shows optical activity'. [1]

.....

.....

(ii) Draw diagrams to show the two optical isomers of lactic acid. [1]

(iii) Give the displayed formula for compound **G**. [1]

(iv) State the reagent(s) and condition(s) needed for stage 2. [1]

.....

(v) Explain why the sample prepared in the laboratory was optically inactive. [2]

.....

.....

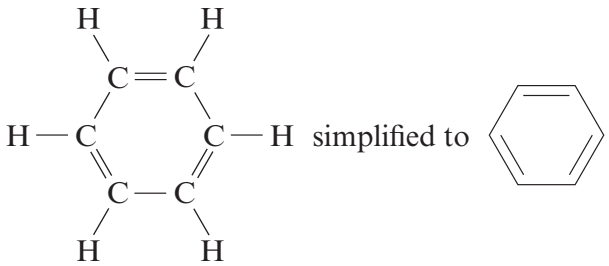
.....

3. *Read the passage below and then answer the questions in the spaces provided.*

Benzene

Benzene, C_6H_6, is a colourless, highly flammable liquid with a sweet smell, but it is carcinogenic. The word "benzene" derives historically from "gum benzoin", an aromatic resin known to European pharmacists and perfumers since the 15th century.

Discovering the structure of benzene proved to be quite difficult. Benzene was first isolated and identified by Michael Faraday in 1825 from the oily residue derived from the production of illuminating gas. However, it was not until 1865 that Kekulé proposed this structure for benzene.

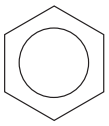


However this structure fails to explain why benzene does not react like an alkene. Ethene reacts readily with bromine as follows:

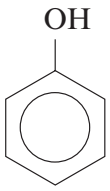
$$CH_2 = CH_2 + Br_2 \longrightarrow CH_2Br\,CH_2Br$$

In contrast, benzene needs far more stringent conditions to react with bromine.

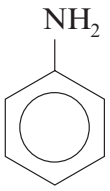
It was around 1930 that the structure of the benzene ring was finally confirmed using X-ray diffraction. It was shown that all the carbon-carbon bonds were of the same length. To account for this, it was proposed that three pairs of electrons were not localised in particular double bonds, but were shared equally amongst all six carbons. These electrons were said to be delocalised giving benzene great stability (delocalisation energy of benzene). The structure of benzene is therefore usually represented as:



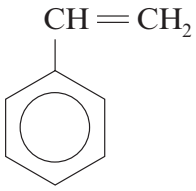
An understanding of the structure of benzene was crucial to early chemists since benzene is the parent molecule of all arene or 'aromatic' compounds and a huge variety of compounds are derived from benzene. Simple benzene derivatives include:



phenol



phenylamine



phenylethene

In the 19th and early 20th centuries, benzene was used as an after-shave lotion because of its pleasant smell, but today benzene is used to make other chemicals.

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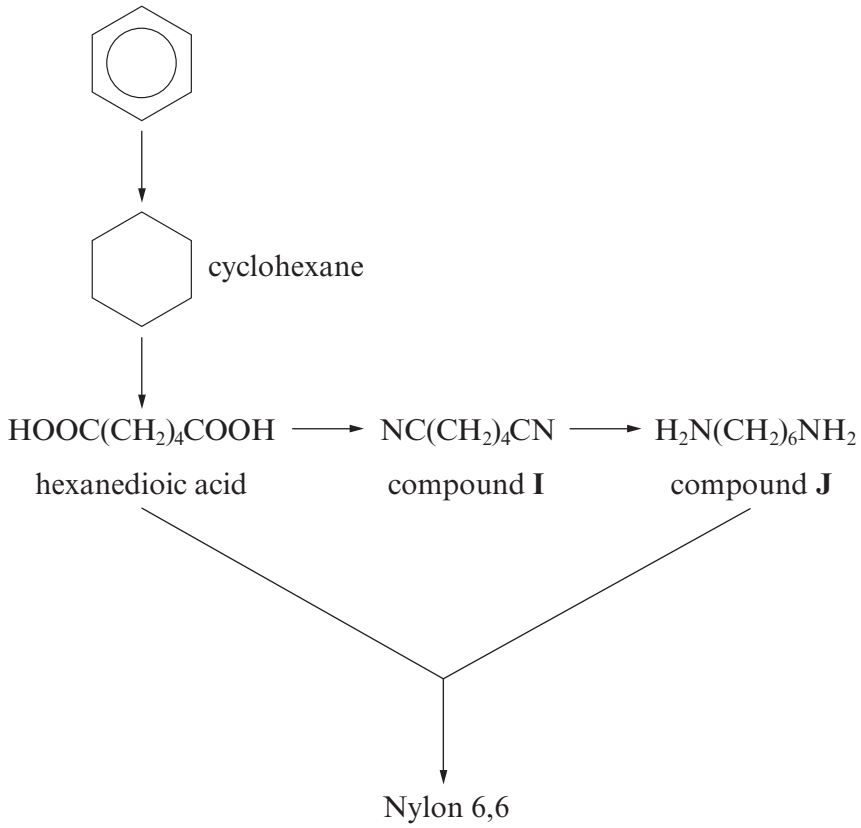
One of its most widely-produced derivatives is cyclohexane, which is used in the manufacture of Nylon 6,6 as shown in the scheme below:



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– End of passage –

(a) Benzene reacts with bromine *(line 12)* in the presence of an iron(III) bromide catalyst to form bromobenzene.

(i) Classify the reaction mechanism. [1]

.....

(ii) Draw the mechanism for this reaction. [3]
(The mechanism is similar to that for the chlorination of benzene.)

Examiner only

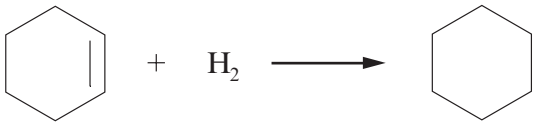
(b) (i) Explain what is meant by the *delocalisation energy* of benzene *(line 17)*. [1]

.....

.....

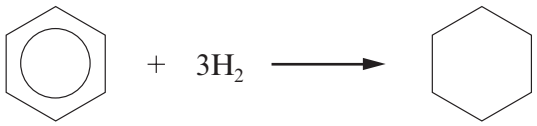
.....

(ii) Given that the enthalpy change of hydrogenation of cyclohexene is $-120\,kJ\,mol^{-1}$ and that the enthalpy change of hydrogenation of benzene is $-208\,kJ\,mol^{-1}$, calculate the delocalisation energy of benzene. [2]



$\Delta H^{\ominus} = -120\,kJ\,mol^{-1}$

cyclohexane



$\Delta H^{\ominus} = -208\,kJ\,mol^{-1}$

benzene

.....

.....

.....

$\Delta H^{\ominus}$ = ... $kJ\,mol^{-1}$

(c) Use the information in the passage to give a reason why benzene is no longer used in after-shave lotion. [1]

.....

(d) In the production of Nylon 6,6 *(line 28)* each of the repeating units requires **two** molecules of benzene; one for the formation of hexanedioic acid and one for the formation of compound **J**.

(i) Draw the **skeletal** formula of hexanedioic acid. [1]

(ii) Name the type of reaction occurring when compound **I** is converted to compound **J**. [1]

.....

(iii) State the name of compound **J**. [1]

.....

5. This question concerns isomers with molecular formula $C_5H_{10}O_2$.

(a) Isomers **P**, **Q**, **R** and **S** all react with aqueous sodium carbonate to produce carbon dioxide.

Isomer **P** is a straight-chain compound.

Isomer **Q** contains a chiral carbon centre.

Isomer **R** has only two peaks in its NMR spectrum, both of which are singlets.

Draw the displayed formulae for all **four** isomers. [4]

(b) Isomer **T** is a neutral, sweet-smelling compound and is formed by the reaction between compounds **X** and **Y** in the presence of concentrated sulfuric acid.

Compound **X** has an absorption in its infrared spectrum at 1750 cm^{-1} and a broad absorption around 3000 cm^{-1}.

Compound **Y** can be formed directly from ethanal.

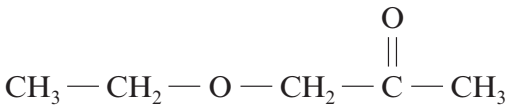
(i) Use **all** the information given to name compounds **X** and **Y**, giving your reasoning. Draw the displayed formula for isomer **T**. [4]

QWC [2]

(ii) I. State the reagent needed to form compound **Y** from ethanal. [1]

II. State the role of sulfuric acid in the formation of **T**. [1]

(c) Isomer **U** has the structural formula shown below.



List the peaks which would be found in the NMR spectrum of isomer **U**. Identify which protons are responsible for each peak, giving the approximate chemical shift (ppm) and the splitting of the peak. [4]

(d) Explain which one of isomers **P**, **T** and **U** would have the highest boiling temperature. [3]

QWC [1]

Total [20]

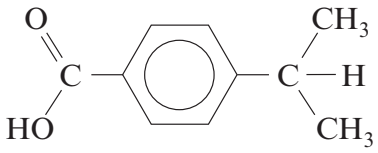
Section B Total [40]

Examiner only

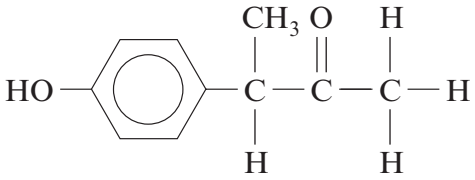
SECTION A

Answer **all** *questions in the spaces provided.*

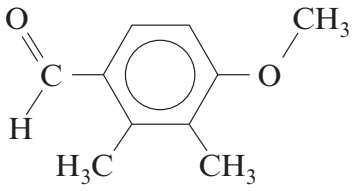
1. This question focuses on the chemistry of some of the many compounds which share the molecular formula $C_{10}H_{12}O_2$. Four compounds with this formula are shown below.



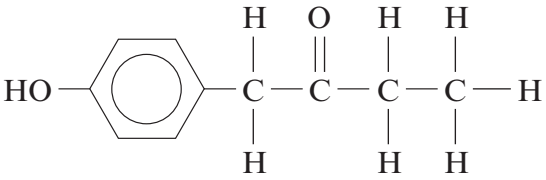
compound **W**



compound **X**



compound **Y**



compound **Z**

(a) Draw an **ester** which is an isomer of the compounds above. [1]

(b) Only one of the compounds shown can exhibit optical isomerism.

(i) Identify which compound can exhibit optical isomerism. ..... [1]

(ii) Indicate the chiral centre in this molecule by labelling it with an asterisk (*). [1]

(iii) State how the two enantiomers of this compound can be distinguished. [1]

.....

.....

.....

Examiner only

SECTION A

Answer **all** *questions in the spaces provided.*

1. *(a)* From the information given, draw the displayed formula of each compound.
In parts (i)-(iii) the compounds consist of molecules that have **three** carbon atoms.
In part (iv) the compound has **four** carbon atoms.

(i) A compound that is oxidised to a ketone [1]

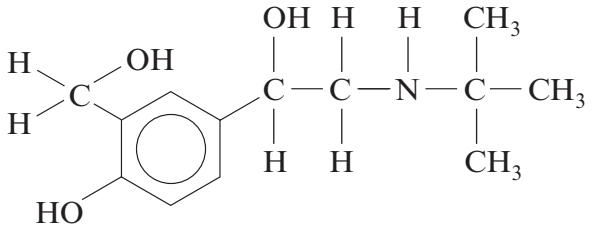
(ii) A neutral sweet-smelling compound [1]

(iii) An α-amino acid [1]

(iv) A hydrocarbon that exhibits E–Z isomerism [1]

Examiner only

(b) The active compound in Ventolin® inhalers used by asthma sufferers is salbutamol, which shows optical isomerism.



salbutamol

(i) Indicate a chiral centre in this molecule by labelling it with an asterisk (*). [1]

(ii) State how the optical isomers of salbutamol could be distinguished from each other. [1]

.....

.....

(iii) Suggest a reason why only one optical isomer of salbutamol is used as a pharmaceutical. [1]

.....

(iv) Draw the displayed formula of the likely organic product formed when salbutamol is refluxed with acidified $K_2Cr_2O_7$. [2]

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SECTION B

Answer **both** *questions in the separate answer book provided.*

4. *(a)* Today there are thousands of different polymers and they are used in a wide range of applications.

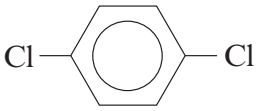
Describe the formation of **one** synthetic polymer and **one** natural polymer, both made by condensation polymerisation.

Your answer should include

- the names or structures of the starting materials required for both polymers,
- a structure which shows the repeating unit for the synthetic polymer,
- a structure which shows the relevant linkage in the natural polymer. [5]

QWC [1]

(b) **F** and **G** are two organohalogen compounds.



(chloromethyl) benzene

F **G**

Compound **F** is used in the manufacture of plasticizers and perfumes and behaves as a chloroalkane. Compound **G** is used as a pesticide and as a deodorant.

(i) Draw the displayed formula of compound **F**. [1]

(ii) Name compound **G**. [1]

(iii) State the reagent(s) and condition(s) needed to substitute a chlorine atom into a benzene ring. [2]

(iv) Describe how you could use a chemical test to distinguish between compounds **F** and **G**. Give the expected result for **each** compound and an explanation for any difference in their behaviour. [6]

QWC [1]

(c) Benzenediazonium chloride can be prepared as follows.
Phenylamine is dissolved in excess hydrochloric acid and the solution cooled to 5 °C.
Aqueous sodium nitrate(III), $NaNO_2$, is added gradually until in excess, keeping the temperature at approximately 5 °C.

(i) State why the temperature is kept under 10 °C. [1]

(ii) Give the displayed formula of the compound that forms when benzenediazonium chloride reacts with naphthalene-2-ol in alkaline conditions. [1]

(iii) State what is meant by the term *chromophore*. [1]

Total [20]

Examiner only

(iv) 2-Methylpropene can be polymerised to give poly(2-methylpropene). Draw the repeating unit of the polymer. [1]

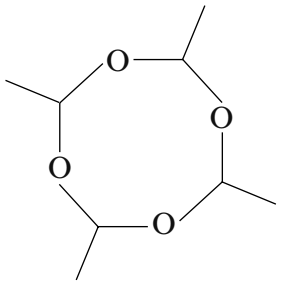
(v) Write the displayed formula of any isomer of tertiary butanol that contains a chiral centre. Identify the chiral centre by an asterisk (*). [2]

(vi) The main alcoholic compound of the fake vodka is ethanol. This can be oxidised to give ethanal.

I State the reagent(s) used to oxidise ethanol to ethanal in the laboratory. [1]

.....

II Ethanal can be polymerised to 'metaldehyde', $(CH_3CHO)_4$, which is used to kill slugs.



Use the Data Sheet to describe how the infrared spectrum of 'metaldehyde' will differ from the infrared spectrum of its monomer, ethanal, giving the absorption values and the bonds involved. Reference to C—H bonds is not required. [2]

.....

.....

.....

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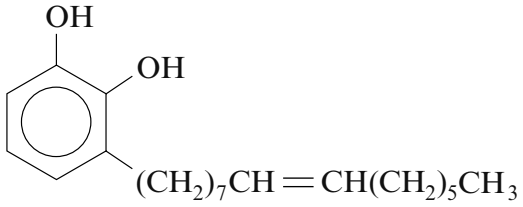
Examiner only

(d) 'Urushiol' is a yellow liquid that is found in the plant poison ivy. It causes an allergic skin rash. Urushiol is not a single compound but a mixture of phenolic compounds that have long saturated or unsaturated alkyl groups bonded to the benzene ring.
It contains, for example, the following compound.



(i) Suggest a catalyst that could be used in the hydrogenation of the unsaturated alkyl side chain. [1]

.....

(ii) By analogy with carboxylic acids, explain why 1,2-dihydroxybenzene is soluble in water but urushiol is not. [2]

.....

.....

.....

Total [12]

Examiner only

(d) Acids **A** and **B** are formed by dehydration and by decarboxylation (where the compound is heated with sodalime). Give any other decarboxylation reaction of your choice, stating the organic starting material and the organic product of your chosen reaction. [2]

.....

.....

(e) On heating to 130 °C, acid **C** *(line 15)* decomposes to give only propanone and carbon dioxide. Give the equation for this reaction. [1]

.....

(f) Give the **displayed** formula of the product formed when acid **C** is reduced by lithium tetrahydridoaluminate(III) (lithium aluminium hydride). [1]

(g) The boiling temperatures of limonene and citral, both present in lemon oil, are 177 °C and 228 °C respectively. State a method by which these two liquids can be separated. [1]

.....

(h) Limonene occurs in some substances as a single enantiomer and in others as a racemic mixture.

(i) State what is meant by the term *enantiomer.* [1]

.....

.....

(ii) State what is meant by the term *racemic mixture.* [1]

.....

.....

Total [15]

Total Section A [40]

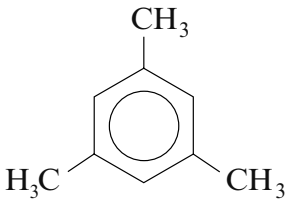
SECTION B

Answer **both** *questions in the separate answer book provided.*

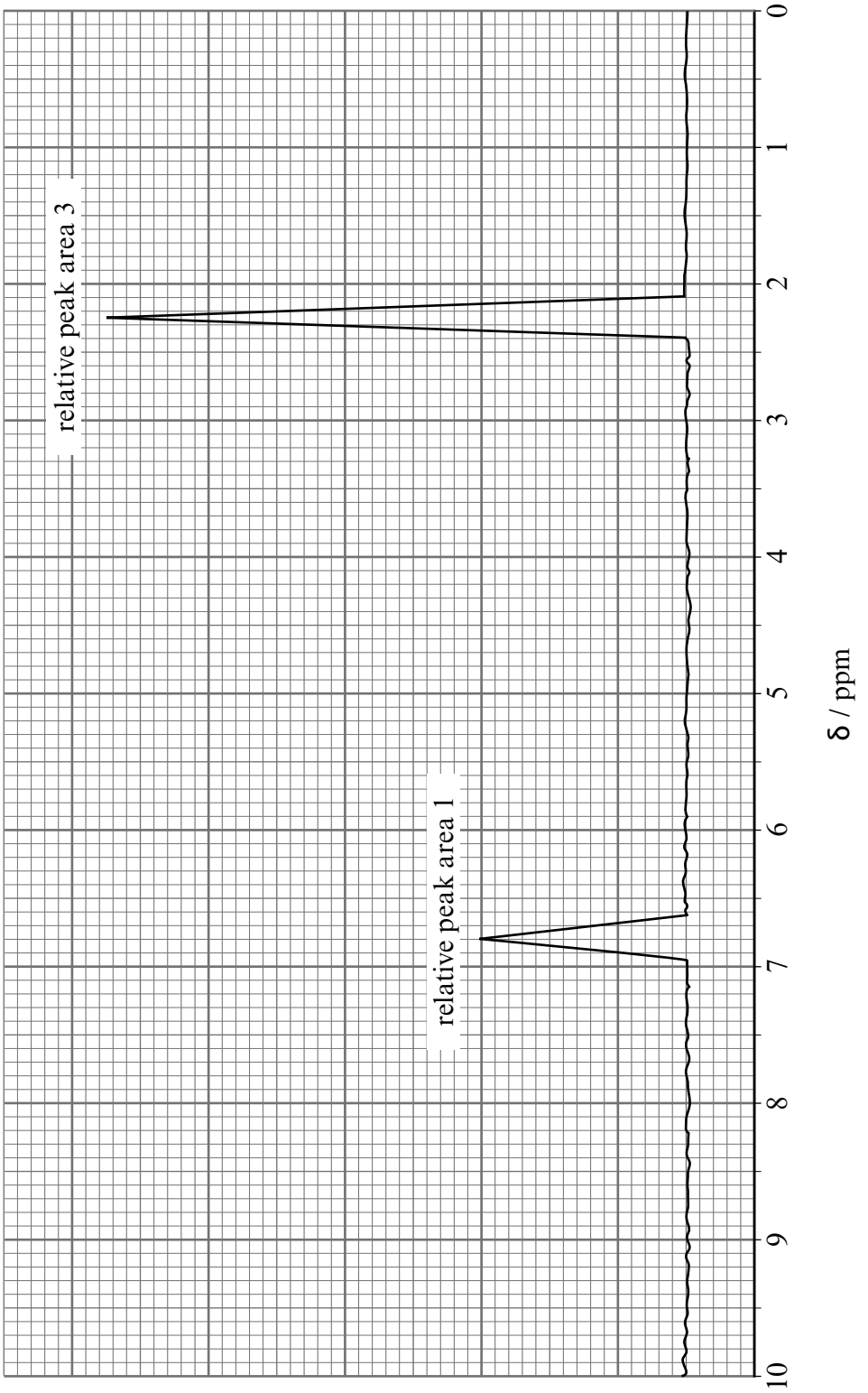
4. *(a)* Describe the structure and bonding in benzene and explain why it is susceptible to electrophilic substitution reactions. [6]
QWC [2]

(b) Methylbenzene can be made by the Friedel-Crafts alkylation of benzene.
Give the equation for this reaction and name a catalyst that can be used. [2]

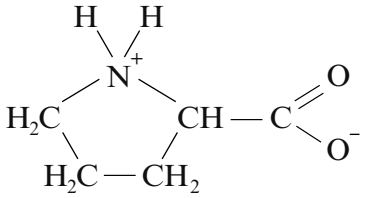
(c) 1,3,5-Trimethylbenzene (mesitylene) is also an alkylbenzene.



(i) The NMR spectrum of mesitylene is shown opposite.
Use the chemical formula to help you explain the peaks in this spectrum, including the relative peak areas and the absence of splitting. [3]


relative peak area 3
relative peak area 1
0
1
2
3
4
5
6
7
8
9
10
δ / ppm

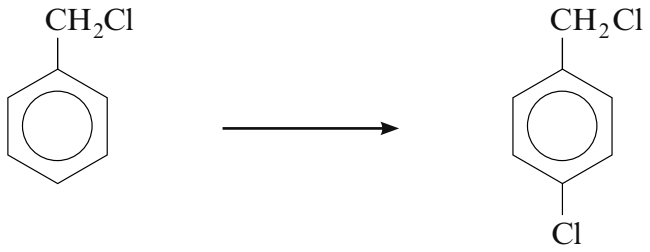
(b) Proline is a cyclic α-amino acid. In an aqueous solution of pH 6.3, proline exists largely as its zwitterion form.



(i) Write the structural formula of proline in its non-zwitterion form. [1]

(ii) Proline forms two different dipeptides when it reacts with aminoethanoic acid. Give the structural formula of **one** of these dipeptides. [1]

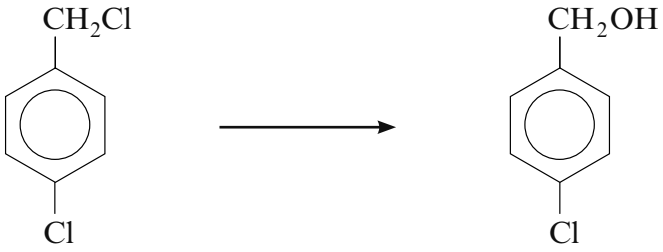
(c) (i) (Chloromethyl)benzene, $C_6H_5CH_2Cl$, reacts with chlorine in the presence of a catalyst to produce a mixture of isomers, **one** of which is 1-(chloromethyl)-4-chlorobenzene.



The mechanism of this electrophilic substitution reaction is similar to the reaction of benzene with chlorine. Give the mechanism for the reaction to produce the 4-isomer.

Your mechanism should show any necessary polarisation, curly arrows, the structure of the intermediate and how the catalyst is regenerated so that it can be used again. [4]

(ii) A student made (4-chlorophenyl)methanol by refluxing 1-(chloromethyl)-4-chlorobenzene (shown in (i)) with aqueous sodium hydroxide.
He obtained a 72% yield.



He wrote an outline of his method as follows.

- Place 0.1 mol of the chloro-compound in a flask and add some sodium hydroxide solution of concentration 2 mol dm^{-3}.
- Reflux this mixture using an electrical heater.

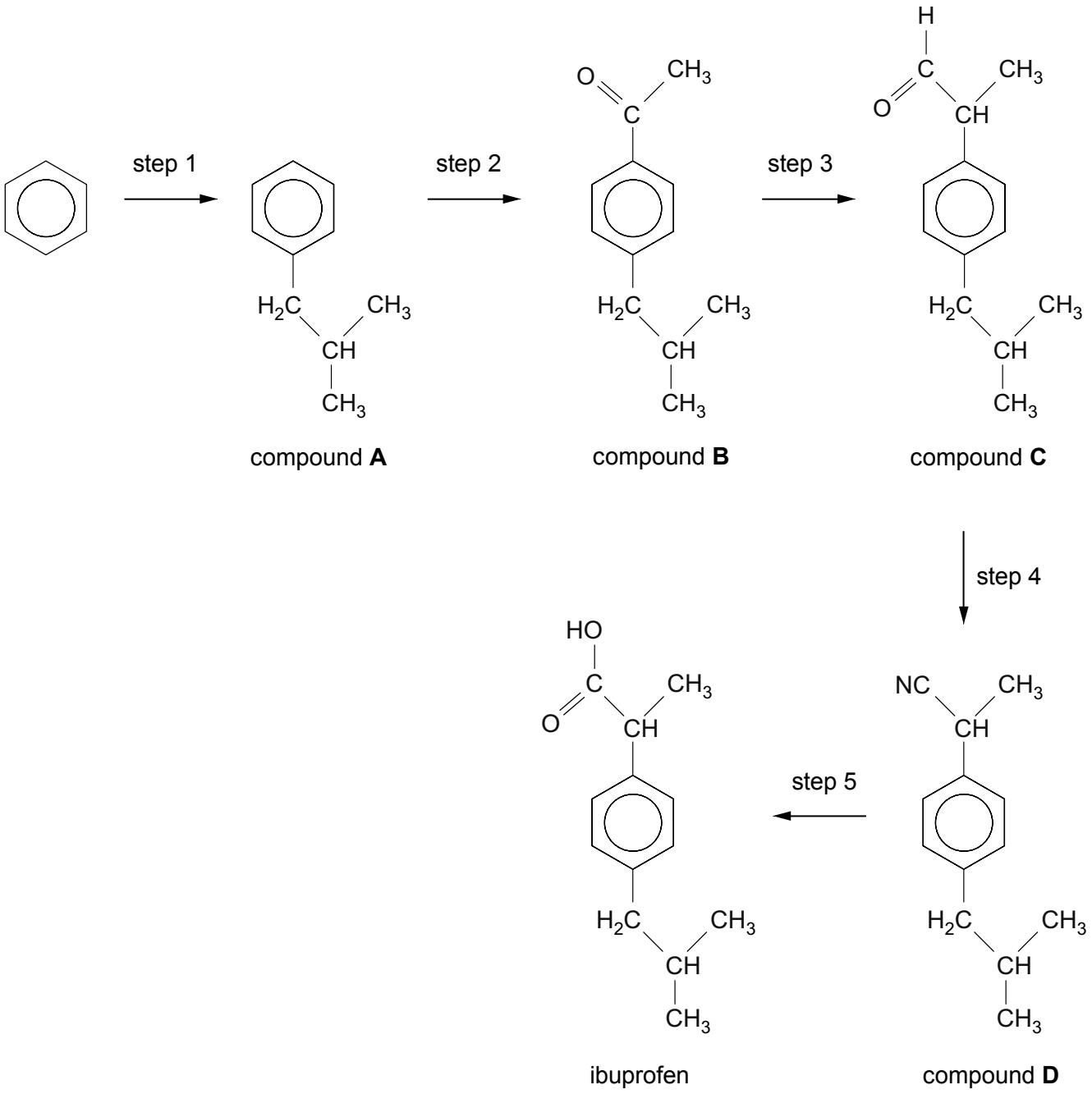
Suggest **two** other details that you would need to know before you could test the reliability and validity of his method. [2]

SECTION B

Answer **both** *questions in the separate answer book provided.*

4. Ibuprofen is a common drug taken as an analgesic and anti-inflammatory treatment.

A possible route to the synthesis of ibuprofen is shown below.



(a) Step 1 is a Friedel-Crafts alkylation reaction. Give the reagent(s) and condition(s) required for this step. [3]

(b) Compounds **B** and **C** can be analysed using chemical tests.

(i) Give a chemical test that would give a positive result for **both** compound **B** and compound **C**. Include reagent(s) and the observation(s) expected for a positive result. [2]

(ii) Give a chemical test that would give a positive result for compound **C** but **not** for compound **B**. Include reagent(s) and the observation(s) for both compounds. [2]

(c) Compound **C** shows optical isomerism. Discuss this statement.
Your answer should include:

- What is meant by optical isomerism.
- What feature of compound **C** allows it to exhibit optical isomerism.
- Diagrams to show the two optical isomers of compound **C**.
- How the two optical isomers of compound **C** can be distinguished. [4]

QWC [1]

(d) Give the reagent(s) and condition(s) required for step 5 and classify the reaction that occurs. [3]

(e) A student investigating alternative methods of producing ibuprofen suggests that it would be better to convert compound **C** into ibuprofen in a one-step process. Discuss whether this is correct.
Your answer should include:

- The reagent(s) and condition(s) for a reaction expected to convert compound **C** directly into ibuprofen.
- Why it is generally better to use one step rather than two or more steps when producing a desired compound.
- A suggestion of why a two-step process is chosen for the synthesis of ibuprofen from compound **C** rather than a one-step process. [4]

QWC [1]

Total [20]

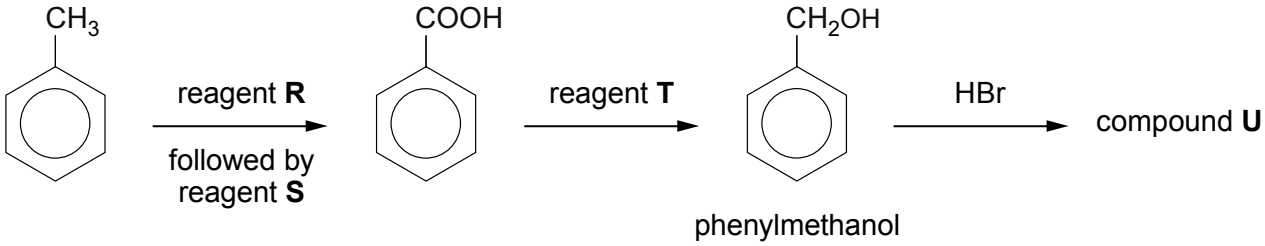
Examiner only

(ii) This preparation of phenylethanone also gives small traces of an impurity. This impurity has a molecular formula $C_{10}H_{10}O_2$ and reacts in a similar way to phenylethanone when it is treated with 2,4-dinitrophenylhydrazine. It does not react with Tollens' reagent. Suggest a displayed formula for this impurity, giving a reason for your choice. [2]

.....

.....

(d) Methylbenzene can be oxidised to benzoic acid by heating it strongly with an alkaline solution of reagent **R** followed by treatment with reagent **S**. The benzoic acid can then be used to produce a number of other compounds. A reaction sequence is shown below.



(i) State the name of reagent **R**. ..... [1]

(ii) State the name of reagent **S**. ..... [1]

(iii) State the name of reagent **T**. ..... [1]

(iv) Give the displayed formula of the organic compound **U**. [1]

(e) State and explain how the infrared spectrum of benzoic acid would differ from that of phenylmethanol. [2]

.....

.....

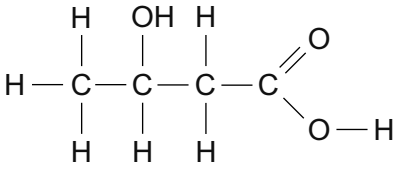
.....

Total [12]

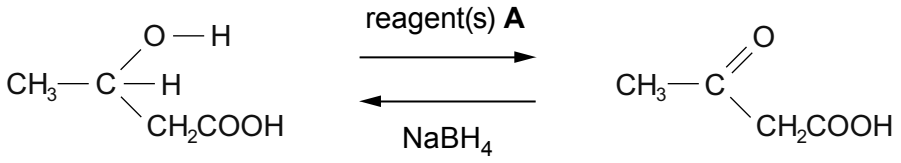
Examiner only

2. 3-Hydroxybutanoic acid is a white solid that can react as a carboxylic acid and an alcohol.

(a) Indicate the position of any chiral centre in the formula of 3-hydroxybutanoic acid by use of an asterisk (*). [1]



(b) The acid can be oxidised to an oxoacid by using reagent(s) **A**. This oxoacid can then be reduced back to the hydroxyacid by sodium tetrahydridoborate(III), $NaBH_4$.



3-oxobutanoic acid

(i) State the name(s) of reagent(s) **A**. [1]

.....

(ii) The reduction of the oxoacid gives 3-hydroxybutanoic acid, which is present as a racemic mixture.

I State what is meant by the term *racemic mixture*. [1]

.....

.....

II State the effect (if any) that a racemic mixture has on the plane of polarised light. [1]

.....

.....