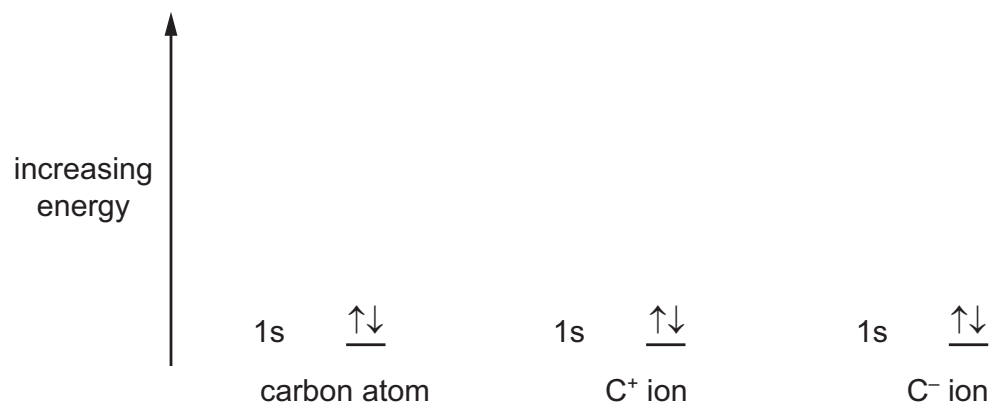


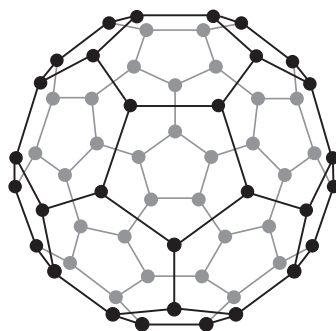
1. Question part 1/2 | 9701 Feb-March 2016 P4 V2 Q1

- 1 (a) Complete the diagrams to show the energies of the electrons in a carbon atom, a C^+ ion and a C^- ion.



[2]

- (b) One of the simple molecular allotropes of carbon is buckminsterfullerene, C_{60} .



buckminsterfullerene

- (i) What is the hybridisation of the carbon atoms in C_{60} ?

..... [1]

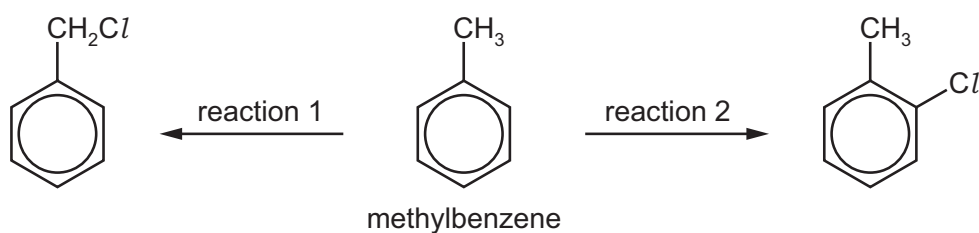
- (ii) C_{60} reacts with an excess of hydrogen to form a single product, C_{60}H_x .

Using your answer to (i), suggest a suitable value for x .

..... [1]

1. Question part 2/2 | 9701 Feb-March 2016 P4 V2 Q1

(c) Methylbenzene can undergo different reactions to form the products shown below.



(i) Give the reagents and conditions for these two reactions.

reaction 1

reaction 2

[2]

(ii) Name the mechanism of reaction 1.

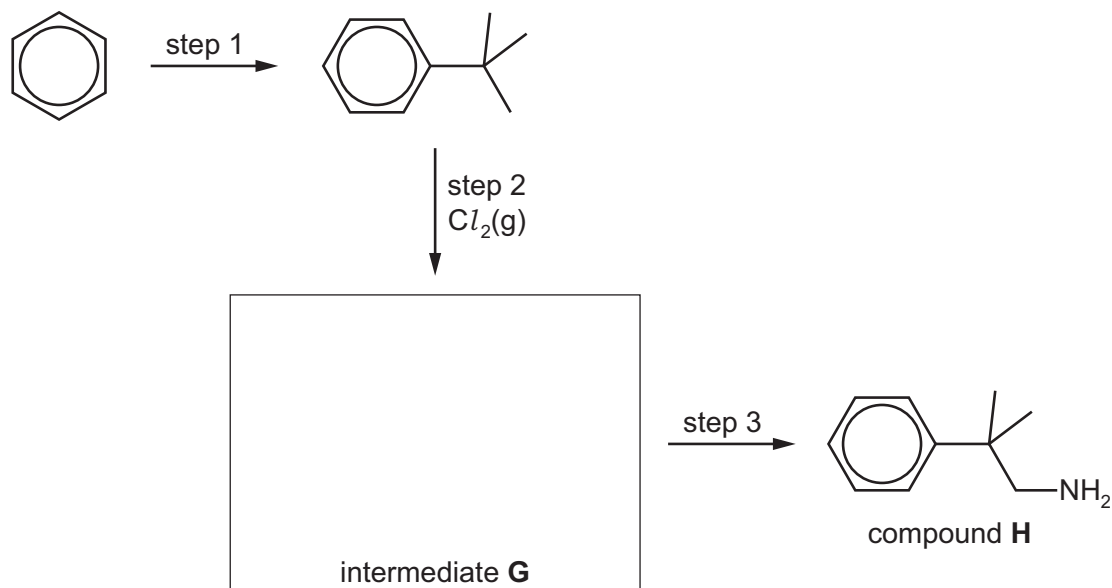
..... [1]

(iii) Draw the structure of the product obtained if reaction 1 is carried out using an excess of chlorine.

[1]

[Total: 8]

- 5 (a) Compound **H** can be synthesised from benzene as shown.



- (i) State the reagents and conditions needed for step 1.

reagents

conditions

[2]

- (ii) Step 2 takes place in the presence of chlorine gas.

State the conditions for this reaction.

..... [1]

- (iii) Draw the structure of intermediate **G** in the box.

[1]

- (iv) State the reagents and conditions needed for step 3.

reagents

conditions

[2]

- (b) Write an equation to show how compound **H**, $\text{C}_{10}\text{H}_{13}\text{NH}_2$, behaves as a base.

..... [1]

- (c) Compare the relative basicities of ammonia, phenylamine and compound **H**. Explain your answer.

.....

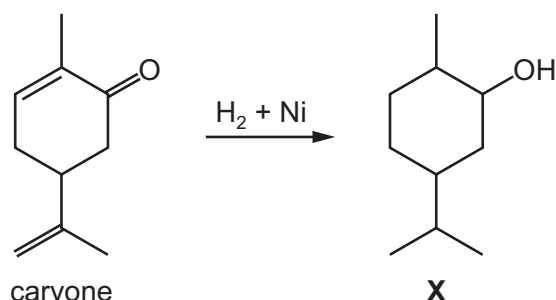
.....

..... [2]

[Total: 9]

3. Question part 1/2 | 9701 May-June 2017 P4 V3 Q4

- 4 Carvone occurs in spearmint and a stereoisomer of carvone occurs in caraway seeds. Treating either isomer with hydrogen over a nickel catalyst produces a mixture of isomers with the structural formula **X**.



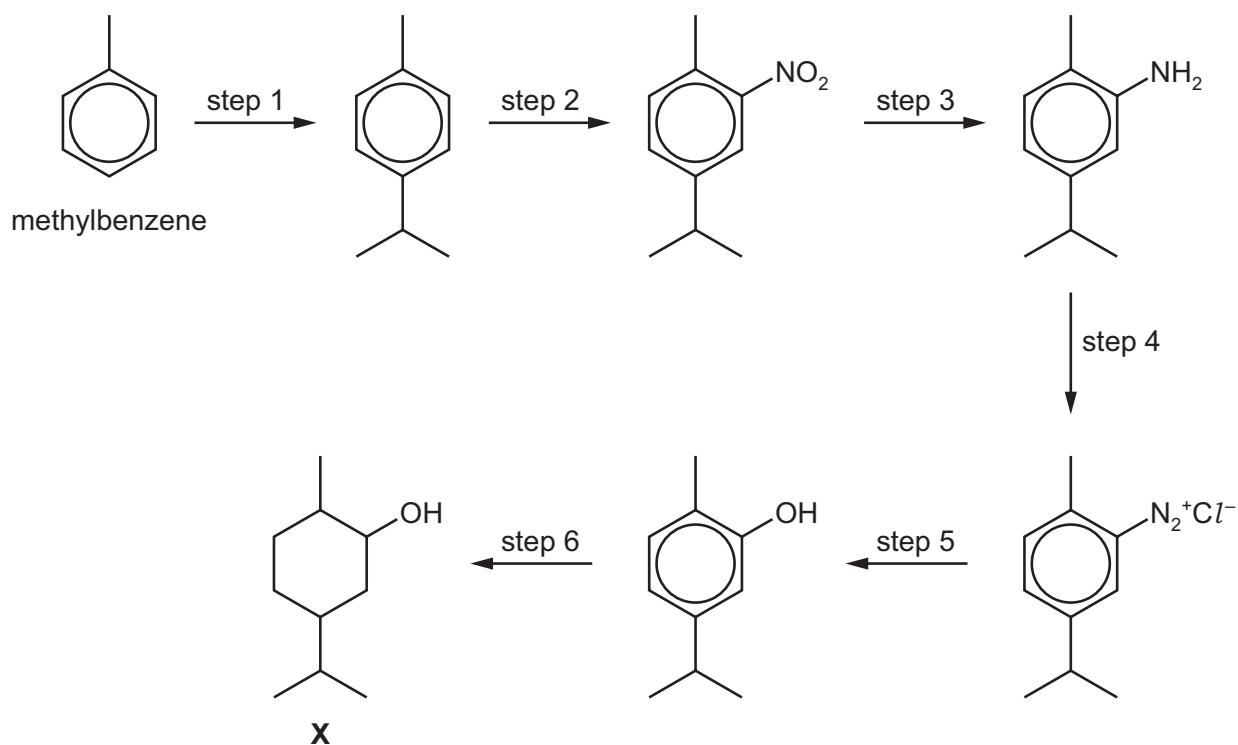
- (a) (i) State the type of stereoisomerism carvone can show. Explain your answer.

.....
 [1]

- (ii) Write an equation, using molecular formulae, for this conversion of carvone to **X**.

..... [2]

X can be synthesised from methylbenzene by the following route.



(b) (i) Name the mechanism in step 1.

..... [1]

(ii) What type of reaction is occurring in the following steps?

step 3

step 5 [2]

(iii) Suggest reagents and conditions for each of the following steps.

step 1

step 2

step 3

step 4 [6]

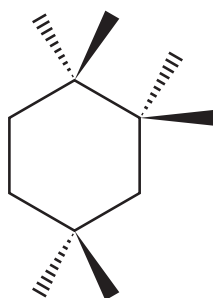
(c) During step 6, hydrogen is added to the benzene ring to produce the cyclohexane ring in **X**. The six hydrogen atoms are all added to the **same side** of the benzene ring.

(i) State the reagents and conditions needed for this reaction.

..... [1]

(ii) Complete the part structure to show the structure of the isomer of **X** that would most likely be obtained during this reaction.

X



[2]

[Total: 15]

9701 Chemistry Paper 4 - Hydrocarbons

Topical questions | 34 questions

4. Question part 1/3 | 9701 Oct-Nov 2017 P4 V2 Q7

- 7 (a) Calcium carbide, CaC_2 , reacts readily with water, forming ethyne, C_2H_2 , and a sparingly soluble white ionic compound.

(i) Write an equation for the reaction of CaC_2 with water.

..... [1]

(ii) Draw a 'dot-and-cross' diagram for the carbide ion, C_2^{2-} . Show outer electrons only.

[1]

(b) Ethyne is the simplest member of the alkyne homologous series.



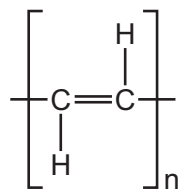
ethyne

Propyne, C_3H_4 , and butyne, C_4H_6 , are the next two members of the series.

Deduce the general formula for the alkynes.

..... [1]

(c) Ethyne can be polymerised into poly(acetylene), which is a conducting polymer.



poly(acetylene)

(i) Suggest why this polymer conducts electricity.

.....
..... [1]

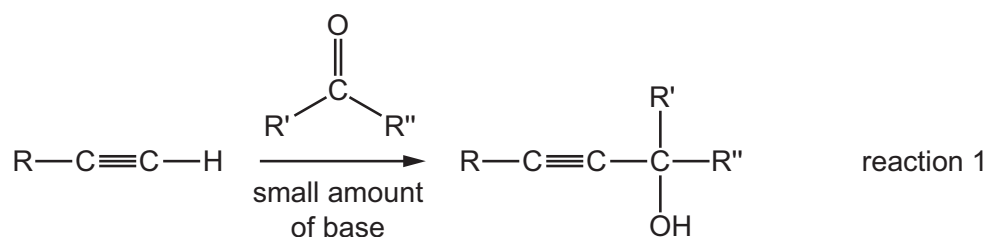
(ii) State the empirical formula of poly(acetylene).

..... [1]

(iii) By reference to a physical or chemical property, suggest **one** advantage of a conducting polymer when compared with metals.

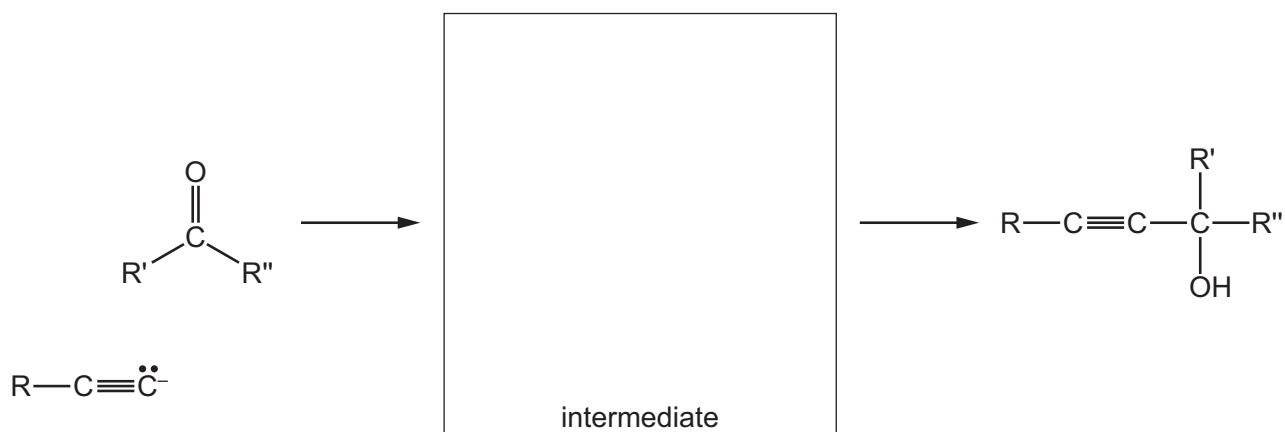
..... [1]

(d) Alkynes can react with carbonyl compounds under basic conditions as shown in reaction 1.



- (i) The first step of the mechanism of reaction 1 involves the alkyne anion reacting with the carbonyl compound.

Complete the first step of the mechanism and draw the intermediate for this reaction. Include all relevant dipoles, charges and curly arrows.

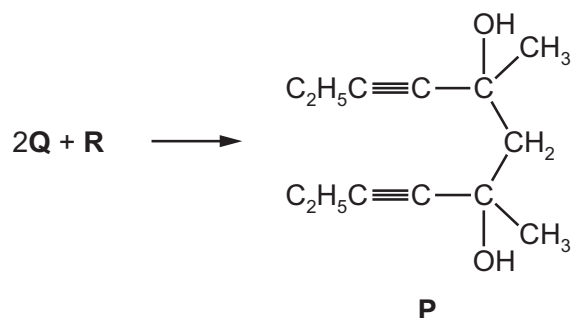


[3]

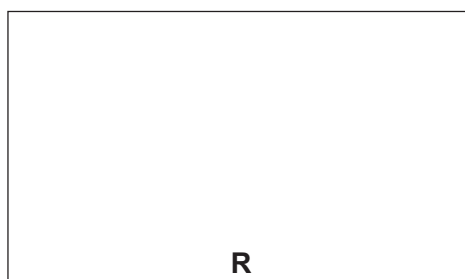
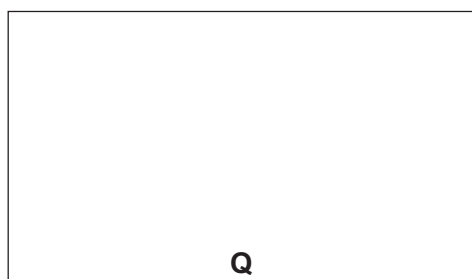
- (ii) Suggest the name of the mechanism in reaction 1.

..... [1]

(iii) An alkyne, **Q**, and a carbonyl compound, **R**, react together to form compound **P** as shown.



Use reaction 1 to suggest the structures of **Q** and **R**.



[2]

(e) A series of twelve separate experiments is carried out as shown in the table.

Complete the table by writing in **each** box a tick (✓) if a reaction occurs, or a cross (✗) if no reaction occurs.

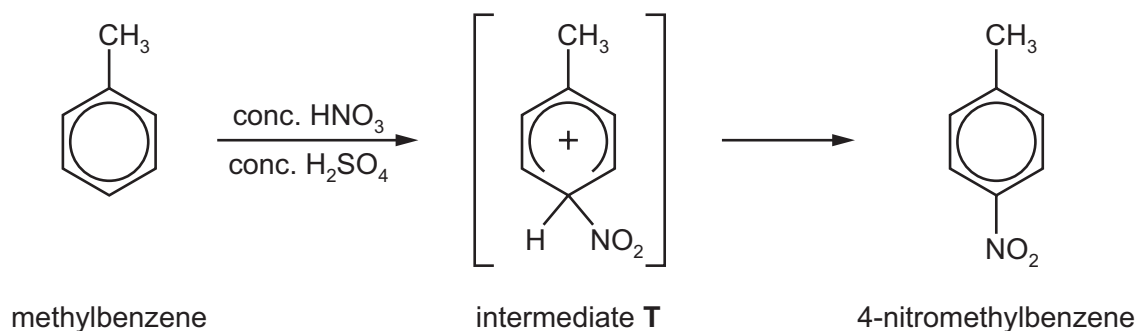
	CH ₃ CHO	HCO ₂ H	CH ₃ COCH ₃	HO ₂ CCO ₂ H
hot, acidified MnO ₄ ⁻ (aq)				
alkaline I ₂ (aq)				
warm Tollens' reagent				

[4]

[Total: 16]

5. Question part 1/4 | 9701 Oct-Nov 2017 P4 V3 Q6

- 6 (a) 4-nitromethylbenzene can be prepared via an electrophilic substitution reaction as shown.



- (i) This reaction also forms an isomer of 4-nitromethylbenzene as a by-product.

Draw the structure of this by-product.

[1]

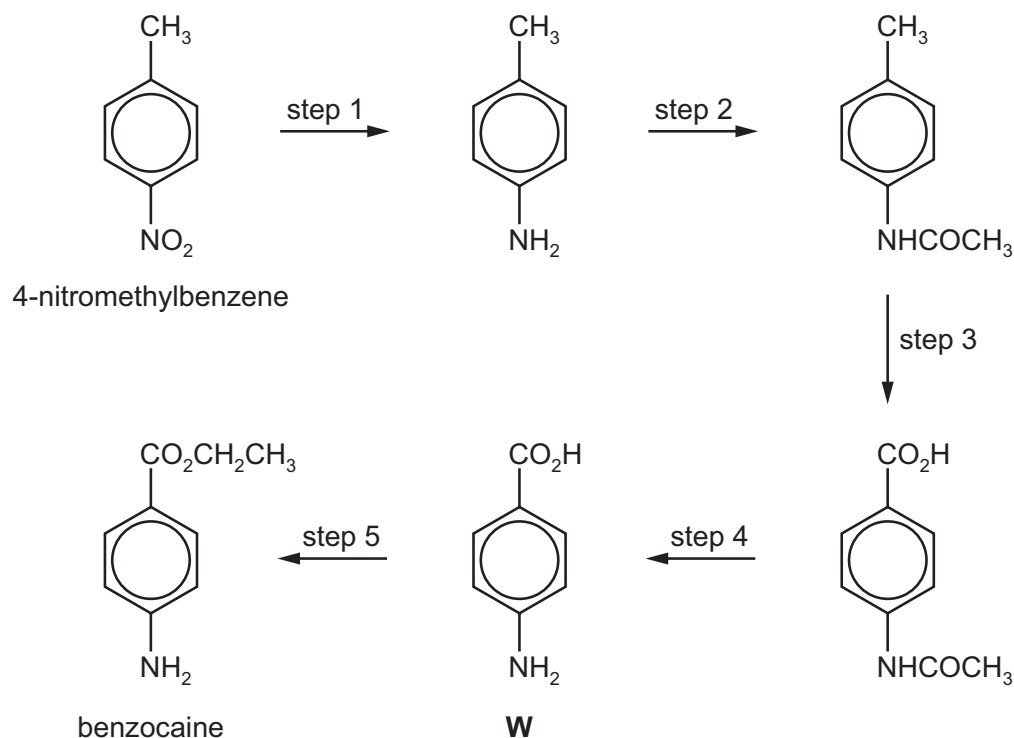
- (ii) Write an equation for the reaction between HNO_3 and H_2SO_4 that forms the electrophile for this reaction.

..... [1]

- (iii) Describe how the **structure and bonding** of the six-membered ring in intermediate T differs from that in methylbenzene.

.....
.....
.....
..... [3]

- (b) Benzocaine is used as a local anaesthetic. It can be synthesised from 4-nitromethylbenzene by the route shown.



- (i) Give the systematic name of compound **W**.

..... [1]

- (ii) Suggest the reagents and conditions for steps 1–5.

step 1

step 2

step 3

step 4

step 5

[6]

- (c) Suggest how the basicity of benzocaine would compare to that of ethylamine. Explain your answer.

.....

.....

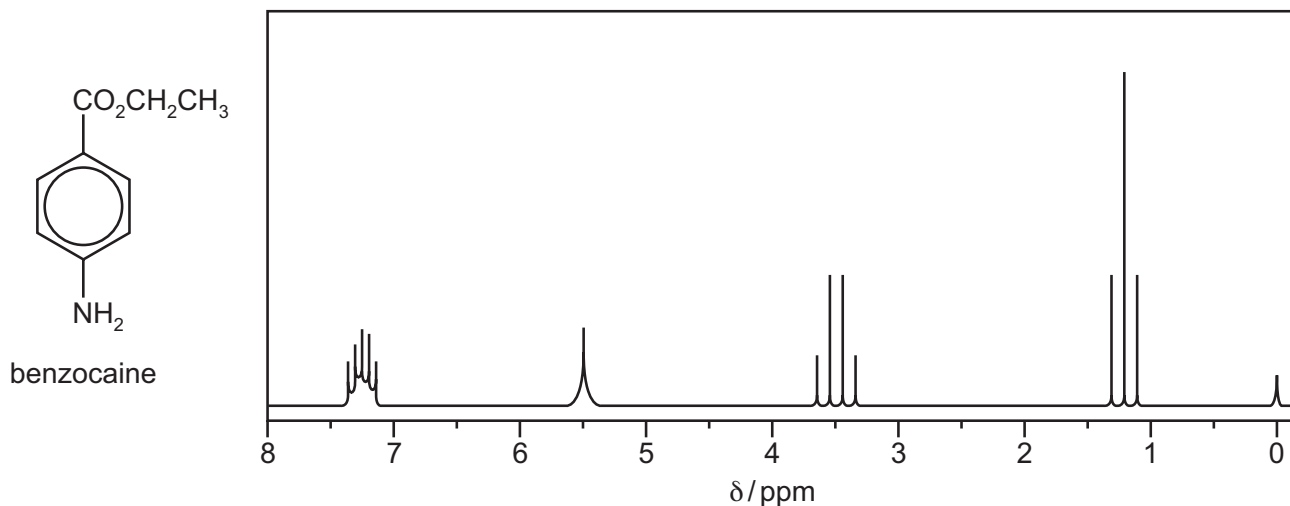
..... [2]

(d) A sample of benzocaine, shown below, was analysed by proton NMR and carbon-13 NMR spectroscopy.

(i) Predict the number of peaks that would be seen in the carbon-13 NMR spectrum.

..... [1]

(ii) Benzocaine was dissolved in CDCl_3 and the proton NMR spectrum of this solution was recorded.



Suggest why CDCl_3 and not CHCl_3 is used as the solvent when obtaining a proton NMR spectrum.

..... [1]

(iii) Use the *Data Booklet* and the spectrum in (d)(ii) to complete the table for the proton NMR spectrum of benzocaine. The actual chemical shifts, δ , for the four absorptions have been added.

δ/ppm	group responsible for the peak	number of ^1H atoms responsible for the peak	splitting pattern
1.2			
3.5			
5.5			
7.1–7.4			multiplet

[4]

(iv) Explain the splitting pattern for the absorption at $\delta 1.2\text{ ppm}$.

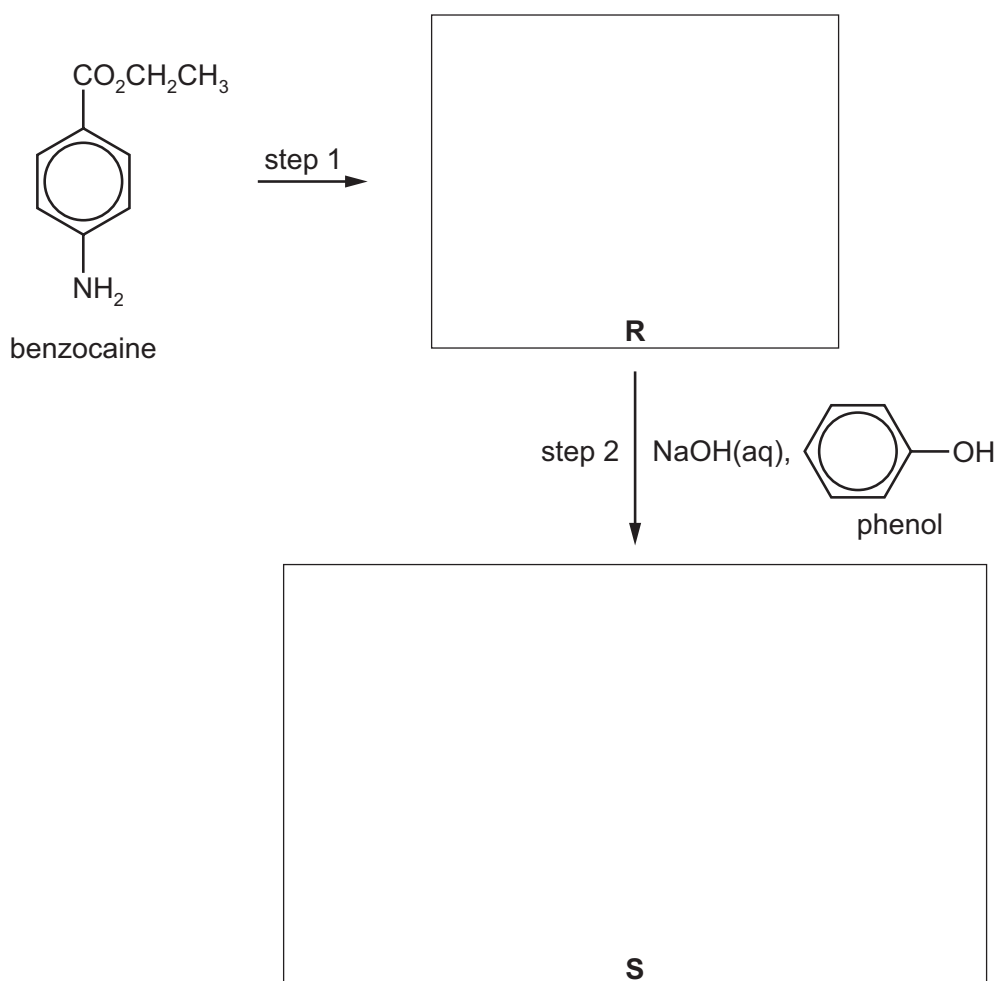
..... [1]

- (v) The proton NMR spectrum of benzocaine dissolved in D_2O was recorded.

Suggest how this spectrum would differ from the spectrum in (d)(ii).
Explain your answer.

.....
..... [1]

- (e) Benzocaine can also be used to synthesise the dyestuff **S** by the following route.



- (i) Suggest the reagents used for step 1.

..... [1]

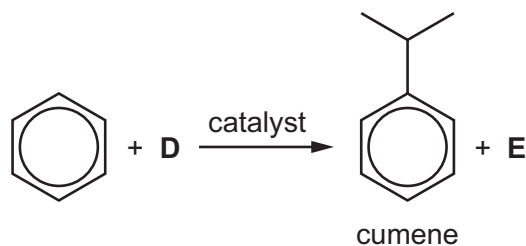
- (ii) Suggest structures for compounds **R** and **S** and draw them in the boxes.

[2]

[Total: 25]

6. Question part 1/3 | 9701 May-June 2018 P4 V1 Q6

- 6 (a) Benzene reacts with **D** in the presence of a suitable catalyst to give cumene and non-organic product **E**. This is an electrophilic substitution reaction.



- (i) Name the reactant **D** and the non-organic product **E**.

D

E

[2]

- (ii) Give the name of the type of aromatic electrophilic substitution reaction taking place.

..... [1]

- (b) Cumene undergoes substitution reactions with chlorine to give several different isomeric products with the formula $C_9H_{11}Cl$. The substitution can occur in the aromatic ring or in the side-chain of cumene.

- (i) Describe the conditions that are used to ensure substitution takes place only in the **aromatic ring**.

..... [1]

- (ii) Draw the structures of the **two** major isomeric products of the reaction, formula $C_9H_{11}Cl$, when substitution takes place in the aromatic ring.

[1]

9701 Chemistry Paper 4 - Hydrocarbons

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6. Question part 2/3 | 9701 May-June 2018 P4 V1 Q6

- (iii) Describe the conditions that are used to ensure substitution takes place only in the **side-chain**.

..... [1]

- (iv) Draw the structures of **two** isomeric products of the reaction, formula $C_9H_{11}Cl$, when substitution takes place in the side-chain.

[1]

- (c) Complete the following table to show the structures of the organic products formed when cumene reacts with each reagent.

reagent	structure of organic product
hot $KMnO_4(aq)$	
$H_2 + Ni$, high pressure	

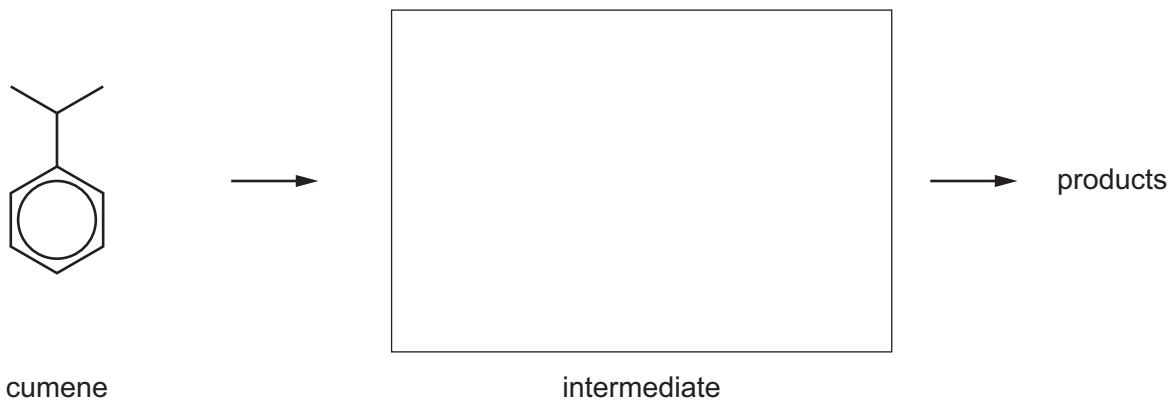
[2]

6. Question part 3/3 | 9701 May-June 2018 P4 V1 Q6

- (d) Cumene can be nitrated using a mixture of concentrated nitric and sulfuric acids. The mechanism for this reaction is similar to the mechanism for the nitration of benzene.

Complete the mechanism for this reaction.

- Include all relevant charges and curly arrows showing the movement of electron pairs.
- Draw the structure of the intermediate.
- You do not need to draw the products.

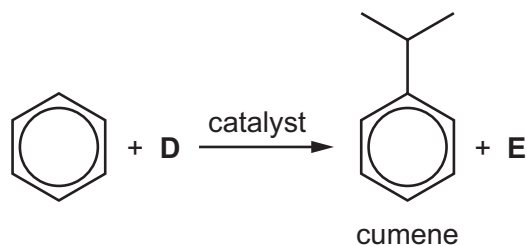


[4]

[Total: 13]

7. Question part 1/3 | 9701 May-June 2018 P4 V3 Q6

- 6 (a) Benzene reacts with **D** in the presence of a suitable catalyst to give cumene and non-organic product **E**. This is an electrophilic substitution reaction.



- (i) Name the reactant **D** and the non-organic product **E**.

D

E

[2]

- (ii) Give the name of the type of aromatic electrophilic substitution reaction taking place.

..... [1]

- (b) Cumene undergoes substitution reactions with chlorine to give several different isomeric products with the formula $C_9H_{11}Cl$. The substitution can occur in the aromatic ring or in the side-chain of cumene.

- (i) Describe the conditions that are used to ensure substitution takes place only in the **aromatic ring**.

..... [1]

- (ii) Draw the structures of the **two** major isomeric products of the reaction, formula $C_9H_{11}Cl$, when substitution takes place in the aromatic ring.

[1]

9701 Chemistry Paper 4 - Hydrocarbons

Topical questions | 34 questions

7. Question part 2/3 | 9701 May-June 2018 P4 V3 Q6

- (iii) Describe the conditions that are used to ensure substitution takes place only in the **side-chain**.

..... [1]

- (iv) Draw the structures of **two** isomeric products of the reaction, formula $C_9H_{11}Cl$, when substitution takes place in the side-chain.

[1]

- (c) Complete the following table to show the structures of the organic products formed when cumene reacts with each reagent.

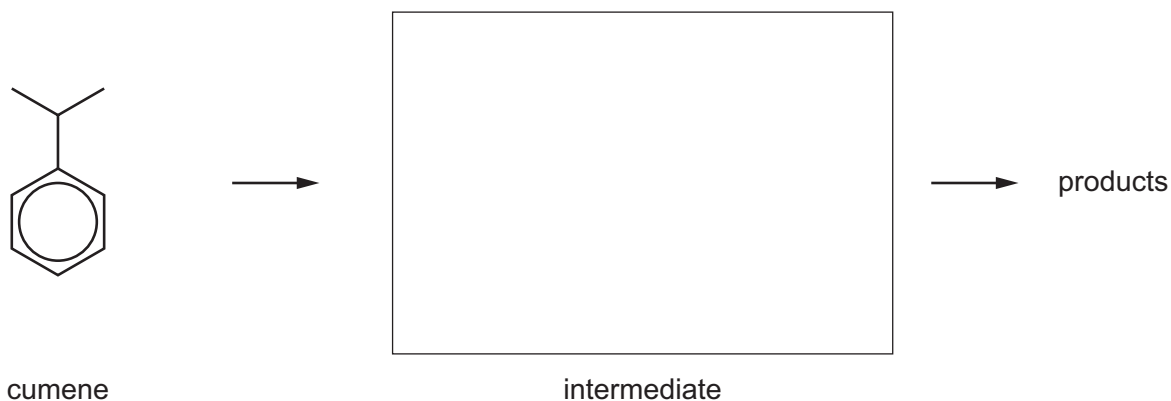
reagent	structure of organic product
hot $KMnO_4(aq)$	
$H_2 + Ni$, high pressure	

[2]

- (d) Cumene can be nitrated using a mixture of concentrated nitric and sulfuric acids. The mechanism for this reaction is similar to the mechanism for the nitration of benzene.

Complete the mechanism for this reaction.

- Include all relevant charges and curly arrows showing the movement of electron pairs.
- Draw the structure of the intermediate.
- You do not need to draw the products.



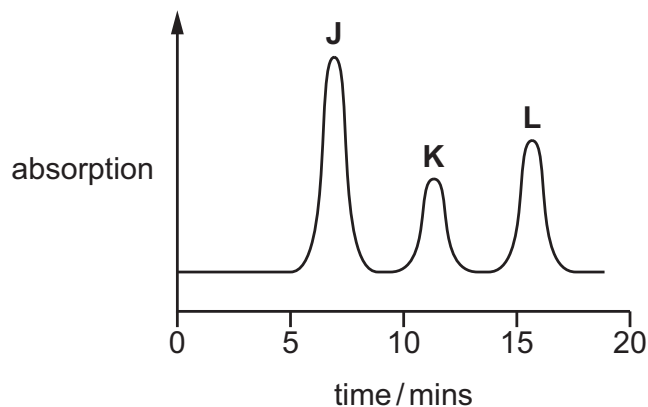
[4]

[Total: 13]

8. Question part 1/3 | 9701 Oct-Nov 2018 P4 V2 Q1

- 1 (a) An alkene, a carboxylic acid and a ketone, all of similar volatility, are mixed together. The mixture is then analysed by gas chromatography.

The gas chromatogram produced is shown.



The separation of the three compounds depends on their relative solubilities in the liquid stationary phase. The liquid stationary phase is an alkane.

- (i) Complete the table to suggest which compound in the mixture is responsible for each peak **J**, **K** and **L**. Explain your answer by reference to the intermolecular forces of each compound.

peak	organic compound	explanation
J		
K		
L		

A student calculates the areas underneath the three peaks in the chromatogram.

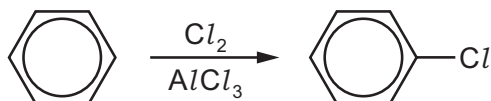
peak	J	K	L
area/mm ²	46	18	28

- (ii) The area underneath each peak is proportional to the mass of the respective compound.

Calculate the percentage **by mass** in the original mixture of the compound responsible for peak **K**.

% of mixture responsible for peak **K** = ... [1]

- (b) Chlorobenzene can be prepared from benzene as shown.



Aluminium chloride, AlCl_3 , catalyses this reaction.

- (i) Write an equation to show how AlCl_3 generates the electrophile needed in this reaction.

..... [1]

- (ii) Draw the mechanism of the reaction between this electrophile and benzene to form chlorobenzene. Include all relevant curly arrows and charges.

[4]

- (iii) Write an equation to show how the catalyst is regenerated.

..... [1]

9701 Chemistry Paper 4 - Hydrocarbons

Topical questions | 34 questions

8. Question part 3/3 | 9701 Oct-Nov 2018 P4 V2 Q1

- (c) (i) Catalysts can be heterogeneous or homogeneous.

Explain what is meant by a *homogeneous catalyst*.

.....

..... [1]

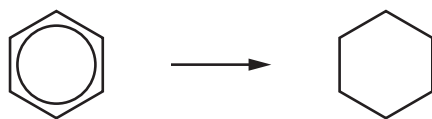
- (ii) Complete the table by placing **one** tick (✓) in **each row** to indicate the mode of action of the catalyst in each reaction.

	heterogeneous	homogeneous
Rh in the removal of NO ₂ from exhaust gases of cars		
Fe ³⁺ in the I ⁻ /S ₂ O ₈ ²⁻ reaction		

[1]

[Total: 11]

- 7 (a) Benzene can be converted into cyclohexane.



- (i) For this reaction name the type of reaction and identify the reagent and conditions needed.

type of reaction

reagent and conditions

[2]

- (ii) State the bond angles in benzene and cyclohexane.

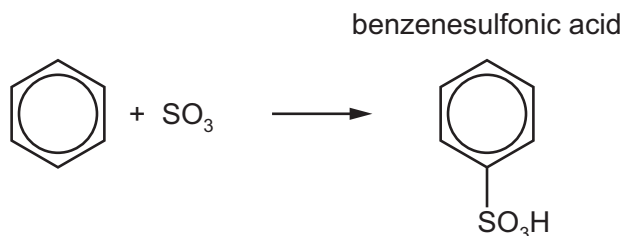
bond angle in benzene bond angle in cyclohexane

Explain your answers.

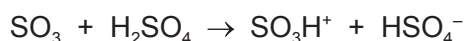
.....

[2]

- (b) When benzene reacts with SO_3 , benzenesulfonic acid is produced.



The mechanism of this reaction is similar to that of the nitration of benzene. Concentrated H_2SO_4 is used in an initial step to generate the SO_3H^+ electrophile as shown.



- (i) Draw a mechanism for the reaction of benzene with SO_3H^+ ions. Include all necessary curly arrows and charges.



[3]

- (ii) Write an equation to show how the H_2SO_4 catalyst is reformed.

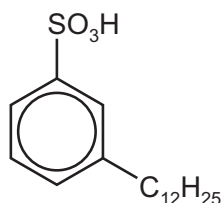
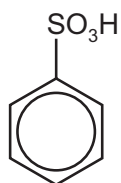
..... [1]

9. Question part 2/2 | 9701 May-June 2019 P4 V1 Q7

- (c) 3-dodecylbenzenesulfonic acid can be prepared from benzenesulfonic acid.

benzenesulfonic acid

3-dodecylbenzenesulfonic acid

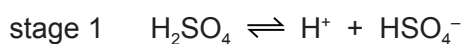


Suggest the reagents and conditions and name the mechanism for this reaction.

reagents and conditions

mechanism [2]

- (d) When concentrated sulfuric acid is added to water, dissociation takes place in two stages.



K_{a2} is the acid dissociation constant for stage 2.

- (i) Write the expression for the acid dissociation constant K_{a2} .

$$K_{a2} =$$

[1]

- (ii) H_2SO_4 is considered a strong acid whereas HSO_4^- is considered a weak acid.

Suggest how the magnitude of the acid dissociation constant for stage 1 compares to K_{a2} .

..... [1]

- (e) Benzoic acid, $\text{C}_6\text{H}_5\text{CO}_2\text{H}$, is a weak acid. A solution of $0.0250 \text{ mol dm}^{-3}$ benzoic acid has a pH of 2.90.

Calculate the K_a of benzoic acid.

$$K_a = \dots\dots\dots \text{mol dm}^{-3}$$

[2]

[Total: 14]

10. Question part 1/3 | 9701 May-June 2019 P4 V2 Q6

- 6 (a) By reference to the formation of σ and π bonds, describe and explain the shape of a benzene molecule, C_6H_6 .

.....

.....

.....

.....

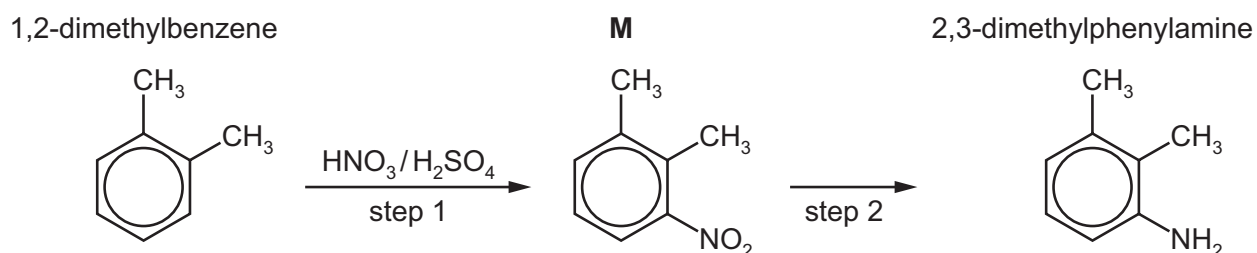
.....

.....

.....

..... [3]

- (b) 2,3-dimethylphenylamine can be prepared from 1,2-dimethylbenzene in two steps as shown.

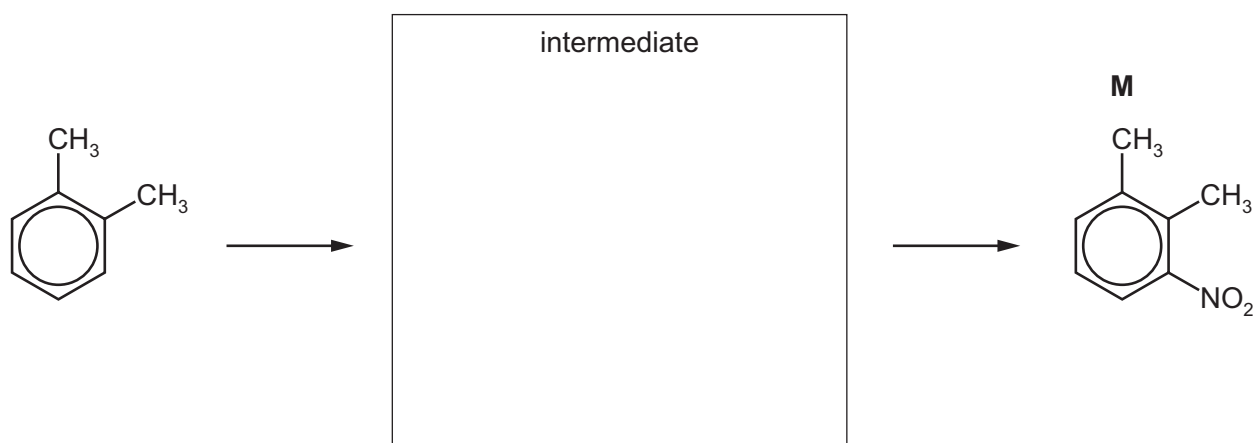


Step 1 is catalysed by H_2SO_4 .

- (i) Write an equation to show how H_2SO_4 generates the electrophile during step 1.

..... [1]

- (ii) Draw the mechanism of the reaction between this electrophile and 1,2-dimethylbenzene to form **M**. Include all relevant curly arrows and charges.



[3]

10. Question part 2/3 | 9701 May-June 2019 P4 V2 Q6

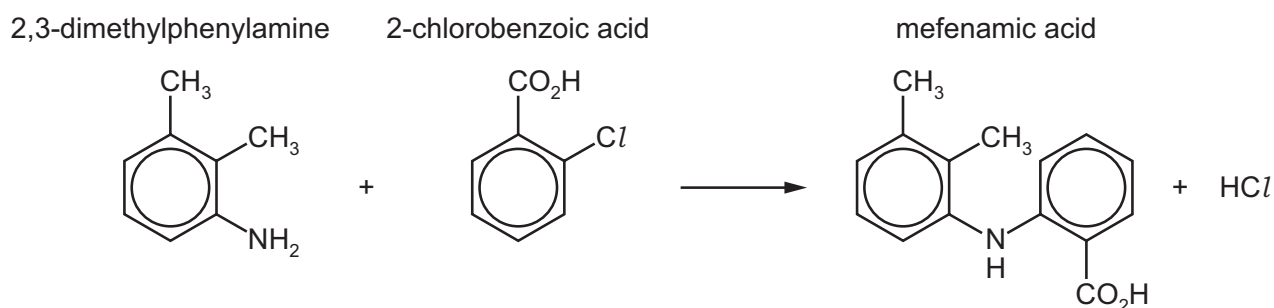
(iii) Write an equation to show how the H_2SO_4 catalyst is reformed.

..... [1]

(iv) For step 2, suggest the reagents and conditions and name the *type of reaction*.

- reagents and conditions
 - type of reaction
- [2]

(c) The drug mefenamic acid can be made using 2,3-dimethylphenylamine in an excess of 2-chlorobenzoic acid.



(i) Deduce the molecular formula of mefenamic acid.

..... [1]

(ii) Name the functional groups, apart from the benzene ring, in mefenamic acid.

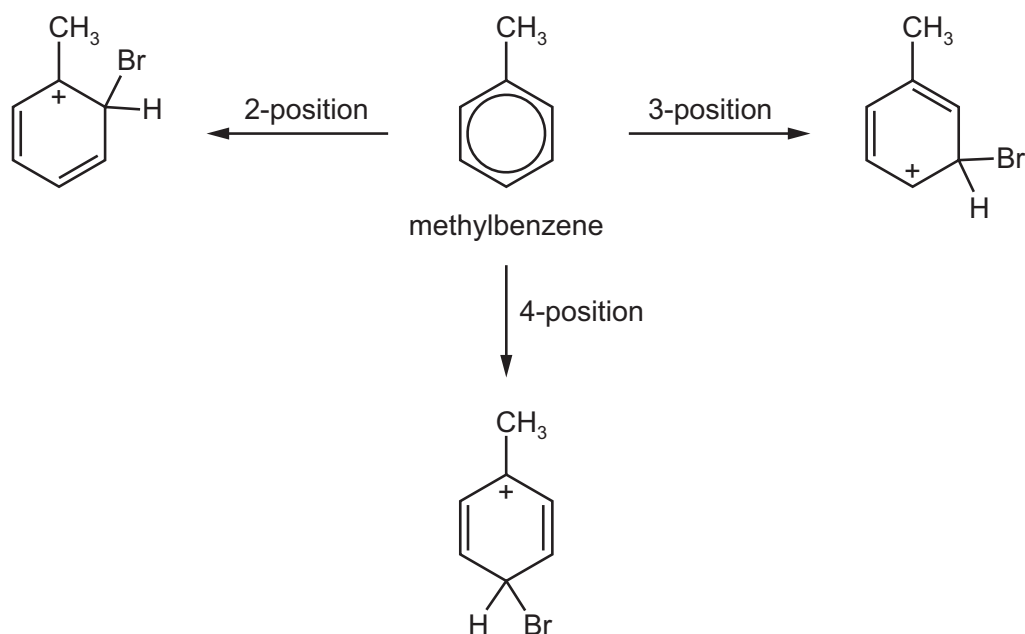
..... [1]

(iii) Calculate the maximum mass of mefenamic acid that could be formed from 5.00g of 2,3-dimethylphenylamine in this reaction. Give your answer to **three** significant figures.

mass of mefenamic acid = ... g [2]

10. Question part 3/3 | 9701 May-June 2019 P4 V2 Q6

- (d) The position of substitution in the electrophilic substitution of arenes can be explained based on the stability of the intermediate cations formed in the first step. The example given involves the bromination of methylbenzene.



Use this information and your knowledge about the stability of cations to suggest why the CH_3 group directs incoming electrophiles to the 2- and 4-positions in preference to the 3-position.

.....

.....

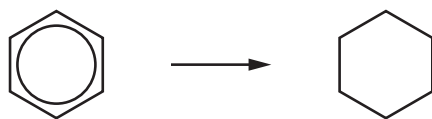
.....

..... [2]

[Total: 16]

11. Question part 1/2 | 9701 May-June 2019 P4 V3 Q7

- 7 (a) Benzene can be converted into cyclohexane.



- (i) For this reaction name the type of reaction and identify the reagent and conditions needed.

type of reaction

reagent and conditions

[2]

- (ii) State the bond angles in benzene and cyclohexane.

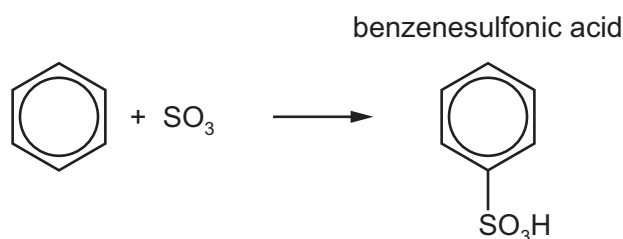
bond angle in benzene bond angle in cyclohexane

Explain your answers.

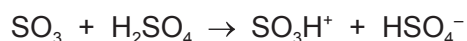
.....

[2]

- (b) When benzene reacts with SO_3 , benzenesulfonic acid is produced.



The mechanism of this reaction is similar to that of the nitration of benzene. Concentrated H_2SO_4 is used in an initial step to generate the SO_3H^+ electrophile as shown.



- (i) Draw a mechanism for the reaction of benzene with SO_3H^+ ions. Include all necessary curly arrows and charges.



[3]

- (ii) Write an equation to show how the H_2SO_4 catalyst is reformed.

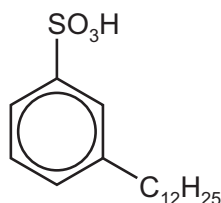
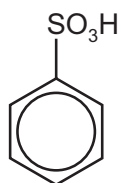
..... [1]

11. Question part 2/2 | 9701 May-June 2019 P4 V3 Q7

- (c) 3-dodecylbenzenesulfonic acid can be prepared from benzenesulfonic acid.

benzenesulfonic acid

3-dodecylbenzenesulfonic acid



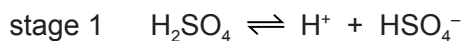
Suggest the reagents and conditions and name the mechanism for this reaction.

reagents and conditions

mechanism

[2]

- (d) When concentrated sulfuric acid is added to water, dissociation takes place in two stages.



K_{a2} is the acid dissociation constant for stage 2.

- (i) Write the expression for the acid dissociation constant K_{a2} .

$$K_{a2} =$$

[1]

- (ii) H_2SO_4 is considered a strong acid whereas HSO_4^- is considered a weak acid.

Suggest how the magnitude of the acid dissociation constant for stage 1 compares to K_{a2} .

..... [1]

- (e) Benzoic acid, $\text{C}_6\text{H}_5\text{CO}_2\text{H}$, is a weak acid. A solution of $0.0250 \text{ mol dm}^{-3}$ benzoic acid has a pH of 2.90.

Calculate the K_a of benzoic acid.

$$K_a = \dots\dots\dots \text{mol dm}^{-3}$$

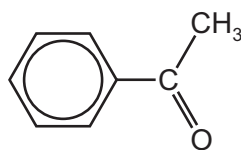
[2]

[Total: 14]

12. Question part 1/3 | 9701 Oct-Nov 2019 P4 V3 Q4

- 4 Phenylethanone is an important chemical with many uses.

phenylethanone



- (a) Phenylethanone can be synthesised using benzene as one of the starting materials.

Identify the other reagents used and describe any essential reaction conditions.

.....
..... [2]

- (b) Phenylethanone is treated separately with three reagents.

Complete the table, for each reagent, to give the structural formula of one organic product formed and the name of the mechanism involved. If there is no reaction you should write 'no reaction'.

reagent	organic product	name of mechanism
chlorine gas at 10 °C in the presence of ultra-violet light		
a mixture of concentrated nitric and sulfuric acids at 50 °C		
bromine water		

[5]

12. Question part 2/3 | 9701 Oct-Nov 2019 P4 V3 Q4

(c) Phenylethanone reacts with HCN in the presence of a small amount of NaCN.

(i) Name the mechanism of this reaction.

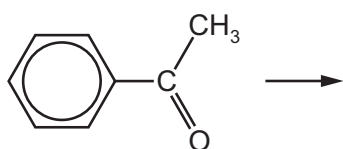
..... [1]

(ii) Draw the mechanism of this reaction below. Include all relevant charges, dipoles, lone pairs and curly arrows. Your mechanism should show the catalytic role of CN^- ions.

phenylethanone

intermediate

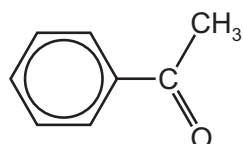
product



[4]

(d) Phenylethanone can be used as a starting material to make phenylethene in a two-step synthesis.

phenylethanone

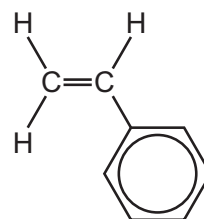


step 1

D

step 2

phenylethene



(i) Draw the structure of compound **D** in the box.

[1]

(ii) Identify a suitable reagent for step 1.

..... [1]

(iii) Identify a suitable reagent for step 2.

..... [1]

9701 Chemistry Paper 4 - Hydrocarbons

Topical questions | 34 questions

12. Question part 3/3 | 9701 Oct-Nov 2019 P4 V3 Q4

(iv) State the number of peaks in the C-13 NMR spectrum of **phenylethene**.

..... [1]

(v) Suggest C-13 chemical shift ranges expected for the different types of carbon environment in **phenylethanone**.

.....

.....

..... [2]

[Total: 18]

13. Question part 1/2 | 9701 May-June 2020 P4 V1 Q5

- 5 (a)** Benzene reacts with bromine in the presence of an aluminium bromide catalyst, $AlBr_3$, to form bromobenzene. This is a substitution reaction. No addition reaction takes place.

(i) Explain why no addition reaction takes place.

.....
..... [1]

$AlBr_3$ reacts with bromine to generate an electrophile, Br^+ .

- (ii)** Draw the mechanism of the reaction between benzene and Br^+ ions. Include all relevant arrows and charges.

[3]

- (iii)** Write an equation to show how the $AlBr_3$ catalyst is reformed.

..... [1]

- (b)** Suggest why bromination of phenol occurs more readily than bromination of benzene.

.....
.....
.....
.....
..... [2]

9701 Chemistry Paper 4 - Hydrocarbons

Topical questions | 34 questions

13. Question part 2/2 | 9701 May-June 2020 P4 V1 Q5

- (c) (i) There are four different carbocations with the same formula, $C_4H_9^+$. One structure is given in the table.

Suggest the structural formulae of the three other carbocations.

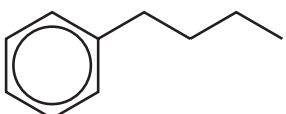
structure 1	structure 2	structure 3	structure 4
$CH_3CH_2CH_2CH_2^+$			

[3]

- (ii) Benzene reacts with each of these carbocations in separate Friedel-Crafts alkylation reactions.

In each reaction an organic compound with formula $C_{10}H_{14}$ is formed. The number of peaks observed in the carbon-13 NMR spectrum of each compound is given.

Suggest the structures for the three other compounds.

	
number of peaks in carbon-13 NMR = 8	number of peaks in carbon-13 NMR = 6
number of peaks in carbon-13 NMR = 7	number of peaks in carbon-13 NMR = 8

[4]

[Total: 14]

9701 Chemistry Paper 4 - Hydrocarbons

Topical questions | 34 questions

14. Question part 1/2 | 9701 May-June 2020 P4 V3 Q5

- 5 (a)** Benzene reacts with bromine in the presence of an aluminium bromide catalyst, $AlBr_3$, to form bromobenzene. This is a substitution reaction. No addition reaction takes place.

(i) Explain why no addition reaction takes place.

.....
..... [1]

$AlBr_3$ reacts with bromine to generate an electrophile, Br^+ .

- (ii)** Draw the mechanism of the reaction between benzene and Br^+ ions. Include all relevant arrows and charges.

[3]

- (iii)** Write an equation to show how the $AlBr_3$ catalyst is reformed.

..... [1]

- (b)** Suggest why bromination of phenol occurs more readily than bromination of benzene.

.....
.....
.....
.....
..... [2]

9701 Chemistry Paper 4 - Hydrocarbons

Topical questions | 34 questions

14. Question part 2/2 | 9701 May-June 2020 P4 V3 Q5

- (c) (i) There are four different carbocations with the same formula, $C_4H_9^+$. One structure is given in the table.

Suggest the structural formulae of the three other carbocations.

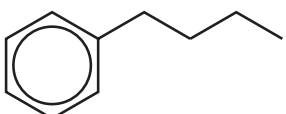
structure 1	structure 2	structure 3	structure 4
$CH_3CH_2CH_2CH_2^+$			

[3]

- (ii) Benzene reacts with each of these carbocations in separate Friedel-Crafts alkylation reactions.

In each reaction an organic compound with formula $C_{10}H_{14}$ is formed. The number of peaks observed in the carbon-13 NMR spectrum of each compound is given.

Suggest the structures for the three other compounds.

	
number of peaks in carbon-13 NMR = 8	number of peaks in carbon-13 NMR = 6
number of peaks in carbon-13 NMR = 7	number of peaks in carbon-13 NMR = 8

[4]

[Total: 14]

15. Question part 1/3 | 9701 Oct-Nov 2020 P4 V1 Q8

8 Benzene, C_6H_6 , can be obtained from crude oil.

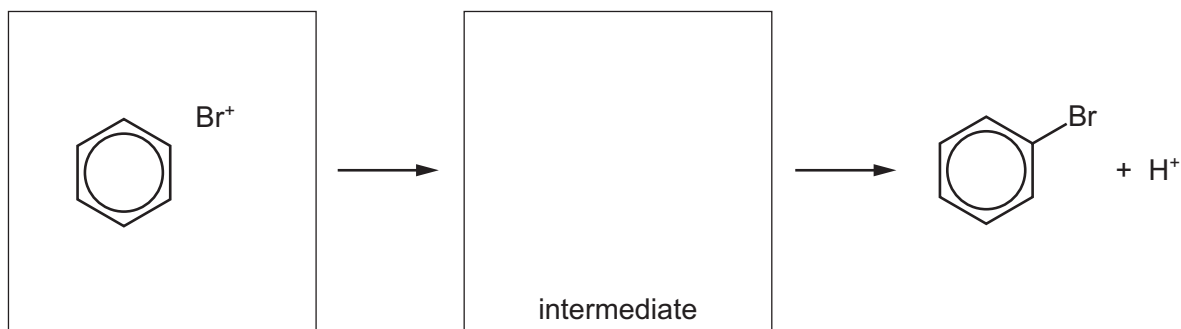
(a) Benzene reacts with bromine, in the presence of a suitable catalyst, forming bromobenzene as one product.

(i) Give the name or formula of the other product of this reaction.

..... [1]

(ii) In the presence of the catalyst, bromine can be considered to form the electrophile Br^+ .

Complete the mechanism by which benzene reacts with Br^+ , using curly arrows to show the movement of electron pairs.



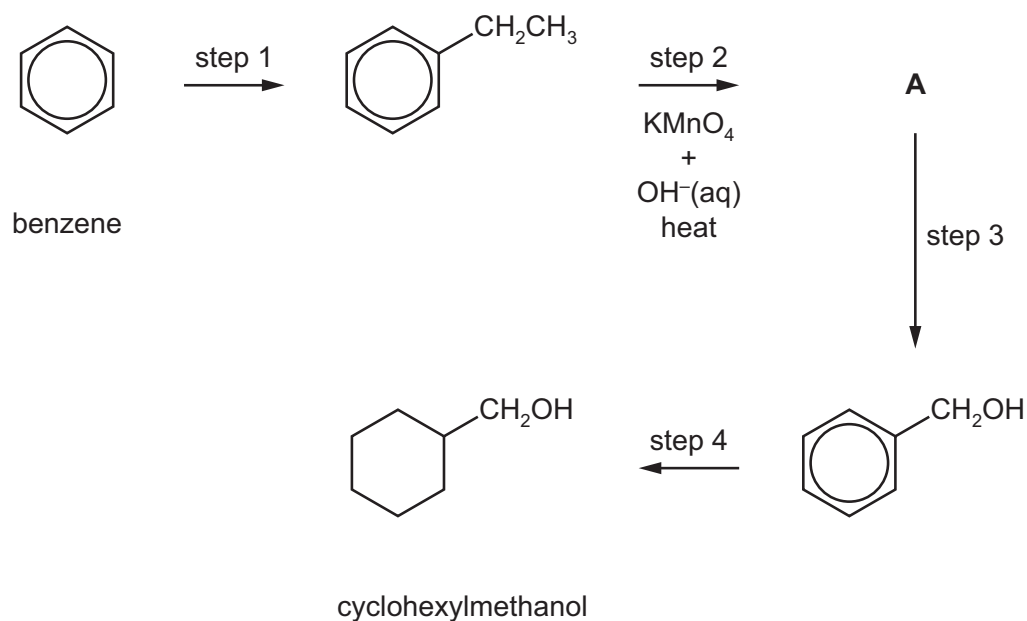
[2]

(iii) Name this mechanism.

..... [1]

15. Question part 2/3 | 9701 Oct-Nov 2020 P4 V1 Q8

- (b) Benzene can be used as a starting material in the synthesis of cyclohexylmethanol, $\text{C}_6\text{H}_{11}\text{CH}_2\text{OH}$, as outlined below.



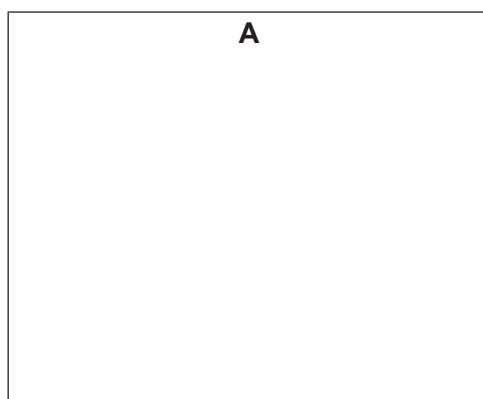
- (i) Identify a suitable reagent and a suitable catalyst for step 1.

reagent

catalyst

[2]

- (ii) Draw the structure of **A**.



[1]

9701 Chemistry Paper 4 - Hydrocarbons

Topical questions | 34 questions

15. Question part 3/3 | 9701 Oct-Nov 2020 P4 V1 Q8

(iii) Identify suitable reagents for steps 3 and 4.

step 3

step 4

[2]

(iv) Deduce the number of peaks in the carbon-13 NMR spectrum of cyclohexylmethanol.

..... [1]

[Total: 10]

16. Question part 1/3 | 9701 Oct-Nov 2020 P4 V2 Q7

7 (a) Describe the structure of a benzene molecule, C_6H_6 .

Your answer should include:

- the shape of the molecule
- the relative lengths of the C–C bonds
- bond angles
- the hybridisation of the carbon atoms
- the overlap between orbitals that produces each type of bond present.

.....

.....

.....

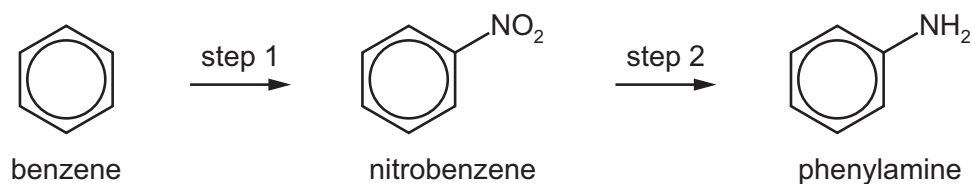
.....

.....

.....

..... [4]

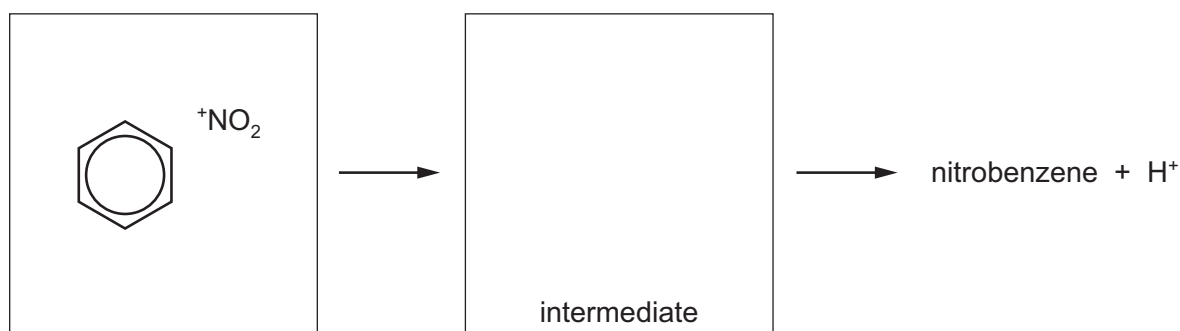
(b) Benzene can be used as a starting material to produce phenylamine by a two-step synthesis.



(i) Step 1 is the reaction of benzene with NO_2^+ ions.

Complete the mechanism and draw the intermediate of step 1.

Include all relevant charges and curly arrows to show the movement of electron pairs.



[2]

(ii) State the name of the mechanism in (b)(i).

..... [1]

Topical questions | 34 questions

(iii) Identify the reagents needed to produce NO_2^+ ions.

..... [2]

..... [2]

(i) Write an equation for this reaction. You may use structural or displayed formulae.

..... [1]

..... [1]

[1]

.....

.....

.....

.....

[3]

16. Question part 3/3 | 9701 Oct-Nov 2020 P4 V2 Q7

(e) 1,3-diaminopropane, $\text{H}_2\text{NCH}_2\text{CH}_2\text{CH}_2\text{NH}_2$, can be used to make polyamides.

(i) Identify **one** compound that would react with 1,3-diaminopropane to form a polyamide.

..... [1]

(ii) Draw a section of the polymer chain formed from 1,3-diaminopropane and the compound you chose in (e)(i).

Your answer should:

- include four monomer residues (two of each type of monomer)
- show the amide link fully displayed
- clearly identify **one** repeat unit of this polymer.

[2]

[Total: 20]

17. Question part 1/3 | 9701 Oct-Nov 2020 P4 V3 Q8

8 Benzene, C_6H_6 , can be obtained from crude oil.

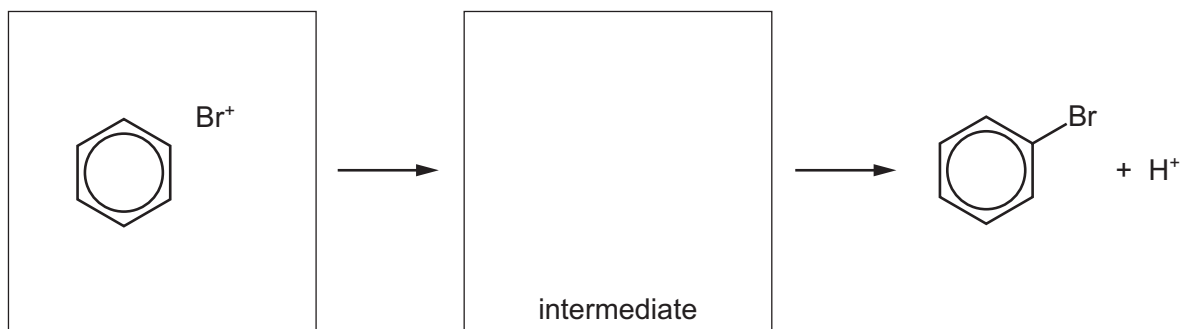
(a) Benzene reacts with bromine, in the presence of a suitable catalyst, forming bromobenzene as one product.

(i) Give the name or formula of the other product of this reaction.

..... [1]

(ii) In the presence of the catalyst, bromine can be considered to form the electrophile Br^+ .

Complete the mechanism by which benzene reacts with Br^+ , using curly arrows to show the movement of electron pairs.



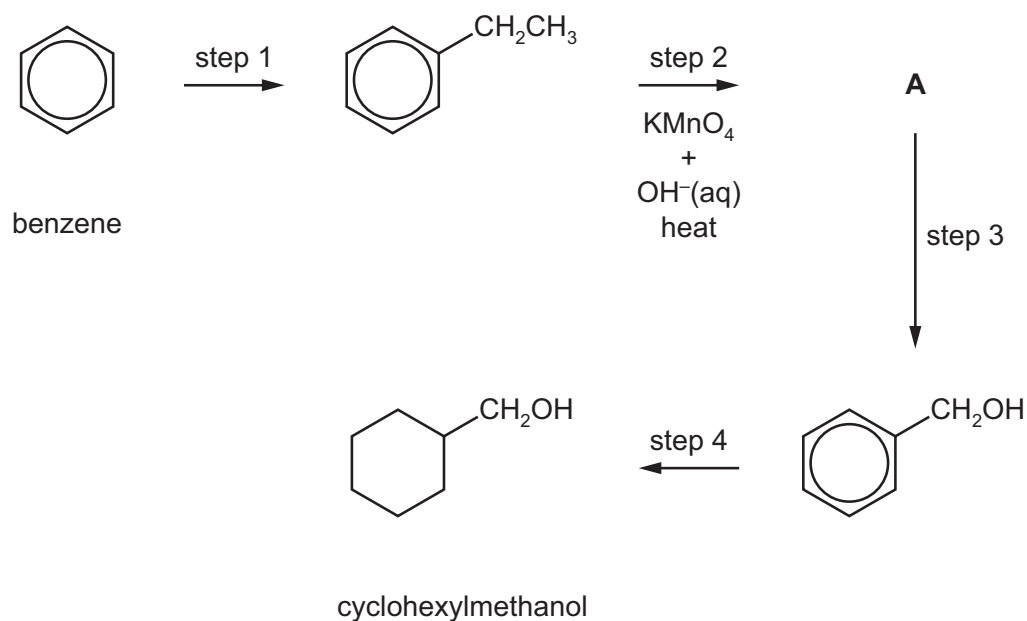
[2]

(iii) Name this mechanism.

..... [1]

17. Question part 2/3 | 9701 Oct-Nov 2020 P4 V3 Q8

- (b) Benzene can be used as a starting material in the synthesis of cyclohexylmethanol, $\text{C}_6\text{H}_{11}\text{CH}_2\text{OH}$, as outlined below.



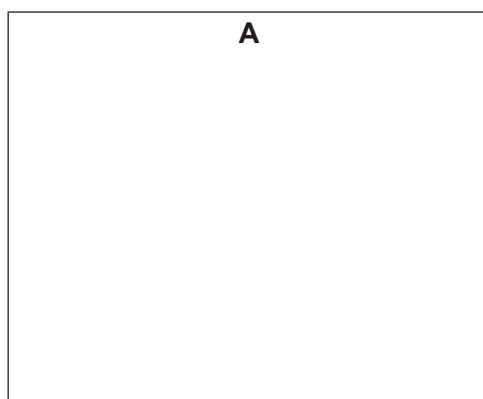
- (i) Identify a suitable reagent and a suitable catalyst for step 1.

reagent

catalyst

[2]

- (ii) Draw the structure of **A**.



[1]

9701 Chemistry Paper 4 - Hydrocarbons

Topical questions | 34 questions

17. Question part 3/3 | 9701 Oct-Nov 2020 P4 V3 Q8

(iii) Identify suitable reagents for steps 3 and 4.

step 3

step 4

[2]

(iv) Deduce the number of peaks in the carbon-13 NMR spectrum of cyclohexylmethanol.

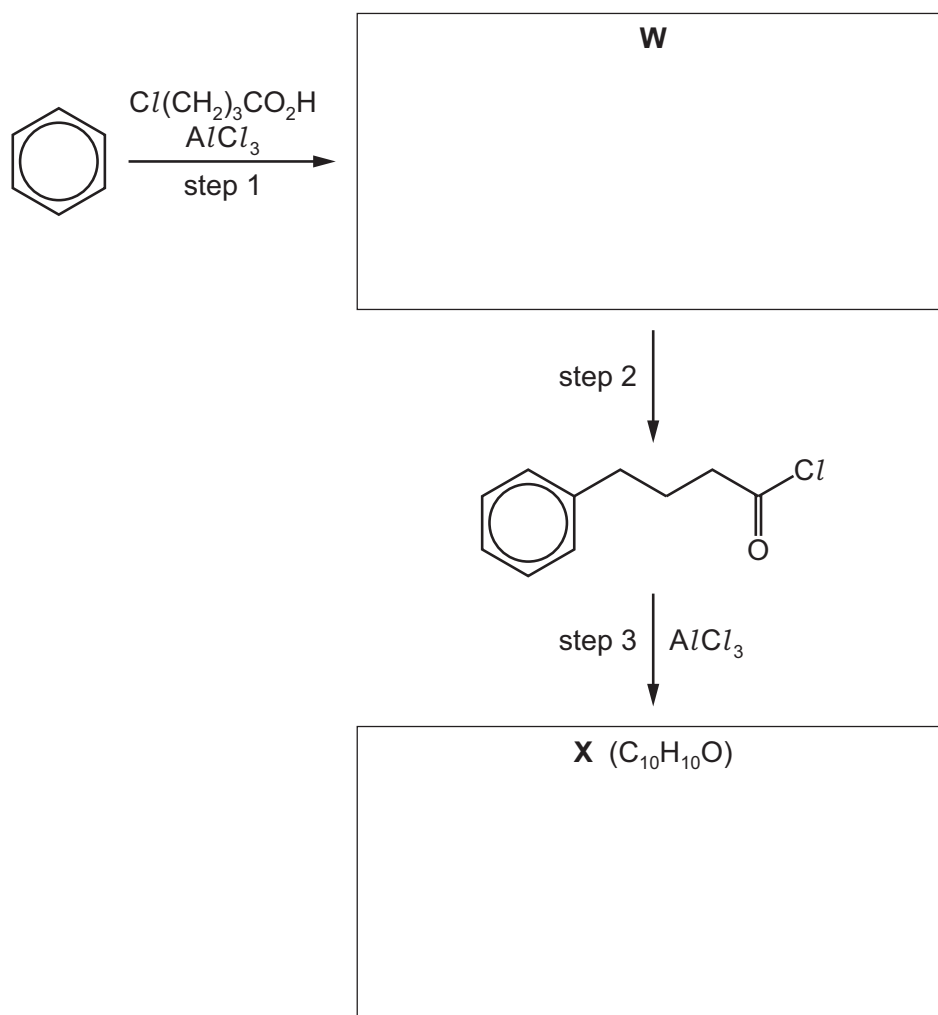
..... [1]

[Total: 10]

isomer 1 three peaks in ^{13}C NMR	isomer 2 four peaks in ^{13}C NMR
isomer 3 five peaks in ^{13}C NMR	isomer 4 six peaks in ^{13}C NMR

[4]

(b) A three-step synthesis of **X** ($C_{10}H_{10}O$) from benzene is suggested as shown.



- (i) Step 1 is the alkylation of benzene by electrophilic substitution.
Use $R-Cl$ to represent $Cl(CH_2)_3CO_2H$.

Write an equation for the formation of an electrophile from $R-Cl$ and $AlCl_3$.

..... [1]

- (ii) Deduce and draw the structures of **W** and **X** in the boxes. [2]

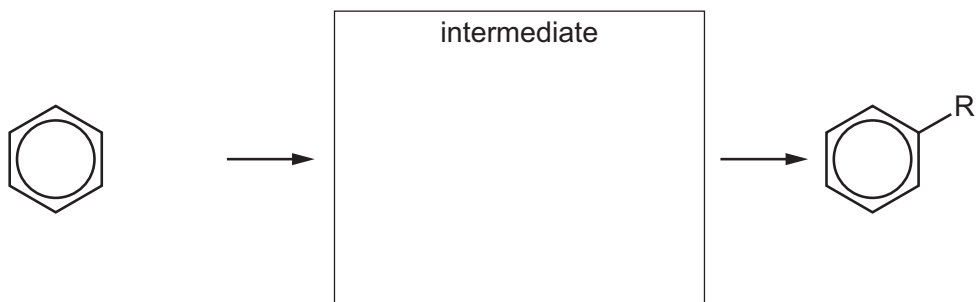
- (iii) Suggest the reagents and conditions for step 2.

..... [1]

- (iv) Complete the mechanism for the reaction of benzene with the electrophile formed in (b)(i).

Include all relevant charges and curly arrows showing the movement of electron pairs.

Draw the structure of the intermediate.



[3]

[Total: 11]

19. Question part 1/3 | 9701 May-June 2022 P4 V2 Q6

- 6 (a) The reagent and conditions required for the nitration of benzene, benzoic acid and phenol are shown in Table 6.1.

Table 6.1

compound	reagents and conditions for nitration
benzene	concentrated HNO_3 , 50°C , concentrated H_2SO_4 catalyst
benzoic acid	concentrated HNO_3 , 100°C , concentrated H_2SO_4 catalyst
phenol	dilute $\text{HNO}_3(\text{aq})$, 20°C

Concentrated HNO_3 reacts with concentrated H_2SO_4 to generate the electrophile NO_2^+ .

- (i) Complete Fig. 6.1 to show the mechanism of the reaction between benzene and NO_2^+ . Include all relevant curly arrows and charges.

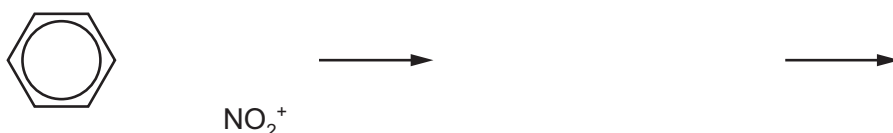


Fig. 6.1

[3]

- (ii) Write an equation to show how H_2SO_4 is regenerated.

..... [1]

- (b) Draw the major products from the mononitration of benzoic acid and of phenol.

major product from benzoic acid

major product from phenol

[2]

9701 Chemistry Paper 4 - Hydrocarbons

Topical questions | 34 questions

19. Question part 2/3 | 9701 May-June 2022 P4 V2 Q6

- (c) Compare the relative ease of nitration of benzene, benzoic acid and phenol.
Explain your reasoning; include reference to the structures of the three compounds in your answer.

..... > >
easiest least easy

.....

.....

.....

.....

.....

[4]

19. Question part 3/3 | 9701 May-June 2022 P4 V2 Q6

- (d) The azo compound Congo Red is used as an acid–base indicator and can be made by the route shown in Fig. 6.2.

In step 3 of this synthesis, compound **Y** reacts with compound **Z**. Compound **Z** is made from compound **X**. Assume that the SO_3^-Na^+ groups do not react.

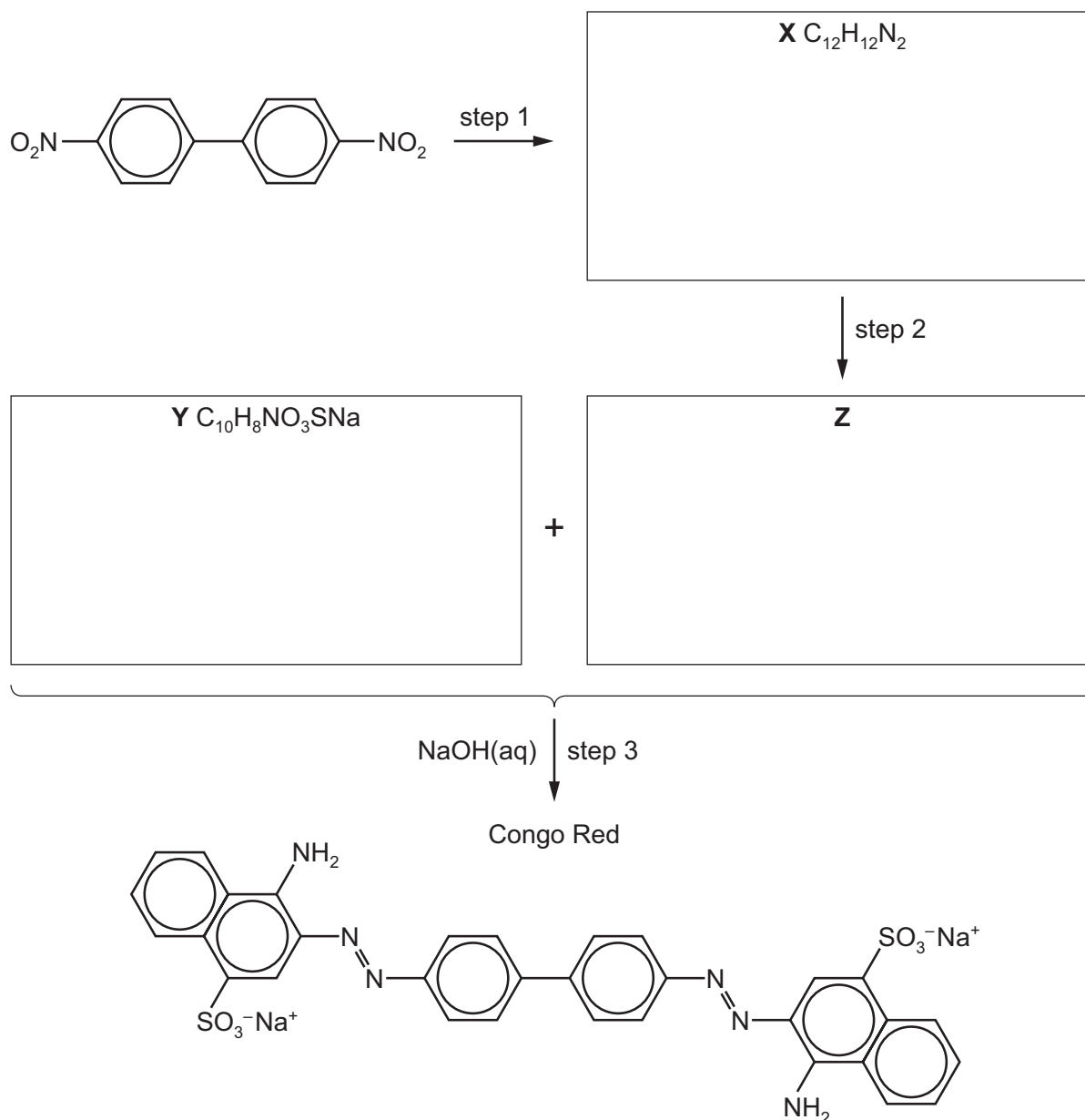


Fig. 6.2

- (i) Suggest structures for compounds **X**, **Y** and **Z** and draw them in the boxes in Fig. 6.2. [3]
- (ii) Give the reagents and conditions for step 1 and step 2.

step 1

step 2

[3]

[Total: 16]

8 Benzene, C_6H_6 , is an aromatic molecule.

(a) State the C–C–C bond angle and the hybridisation shown by the carbon atoms in benzene.

bond angle

hybridisation

[1]

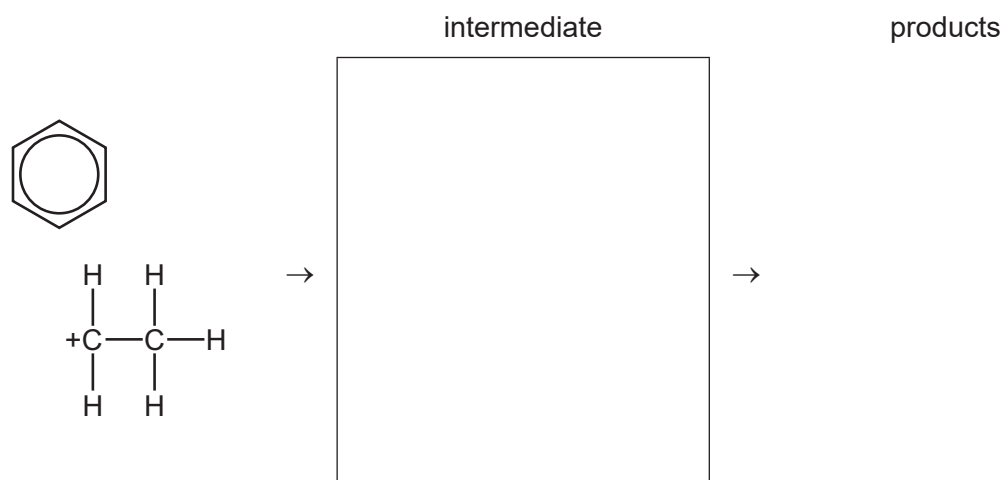
(b) Benzene reacts with chloroethane in the presence of a catalyst. The reaction mechanism is called electrophilic substitution.

(i) The first step in the reaction is the generation of the $^+CH_2CH_3$ electrophile.

Write an equation for the reaction that generates this electrophile.

..... [1]

(ii) Describe the mechanism for the reaction between benzene and the $^+CH_2CH_3$ electrophile. Include all relevant curly arrows and charges.



[3]

9701 Chemistry Paper 4 - Hydrocarbons

Topical questions | 34 questions

20. Question part 2/2 | 9701 Oct-Nov 2022 P4 V1 Q8

- (c) Chlorobenzene and chloroethane have different reactivities in nucleophilic substitution reactions.

- (i) Identify a suitable reagent to illustrate this difference in reactivity.

The reagent chosen should give **visibly** different results with chlorobenzene and chloroethane.

..... [1]

- (ii) Write equations to describe any reactions that occur.

[1]

- (iii) Explain the difference in the reactivities of chlorobenzene and chloroethane in nucleophilic substitution reactions.

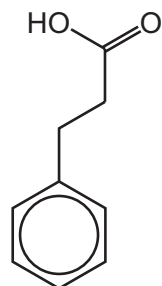
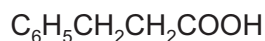
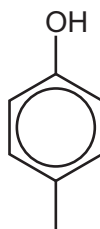
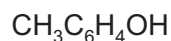
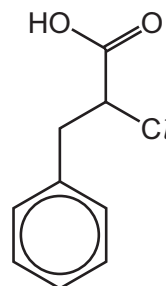
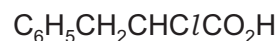
.....

..... [1]

[Total: 8]

21. Question part 1/3 | 9701 Oct-Nov 2022 P4 V2 Q7

- 7 (a) The structural and displayed formulae of three aromatic compounds, **A**, **B** and **C**, are shown in Fig. 7.1.

**A****B****C****Fig. 7.1**

Compare the relative acidities of **A**, **B** and **C**.

..... > >
 most acidic least acidic

Explain your answer.

.....

 [3]

- (b) Methylbenzene, $\text{C}_6\text{H}_5\text{CH}_3$, can be made from benzene by an electrophilic substitution reaction.

- (i) Identify a compound that reacts with benzene to form methylbenzene.
 Identify the catalyst used.

compound

catalyst

[1]

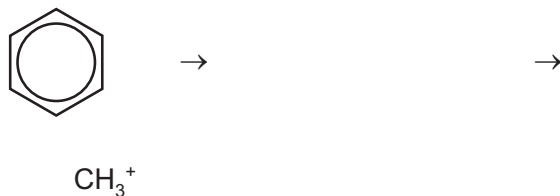
- (ii) The first step in the reaction is the generation of the CH_3^+ electrophile.

Write an equation for the reaction that generates this electrophile.

..... [1]

21. Question part 2/3 | 9701 Oct-Nov 2022 P4 V2 Q7

- (iii) Describe the mechanism for the reaction between benzene and the CH_3^+ electrophile. Include all relevant curly arrows and charges.



[3]

- (iv) Identify a suitable reagent to oxidise methylbenzene to benzoic acid, $\text{C}_6\text{H}_5\text{COOH}$.

Write an equation for this reaction using [O] to represent one atom of oxygen from the oxidising agent.

reagent

equation

[2]

- (v) Methylbenzene and benzoic acid are both nitrated with a mixture of concentrated nitric acid and sulfuric acid to give mononitrated products. The structural formulae of these products are $\text{CH}_3\text{C}_6\text{H}_4\text{NO}_2$ and $\text{HOOC}\text{C}_6\text{H}_4\text{NO}_2$ respectively.

Draw the structures of these two products.

[1]

(c) A reaction scheme is shown in Fig. 7.2.

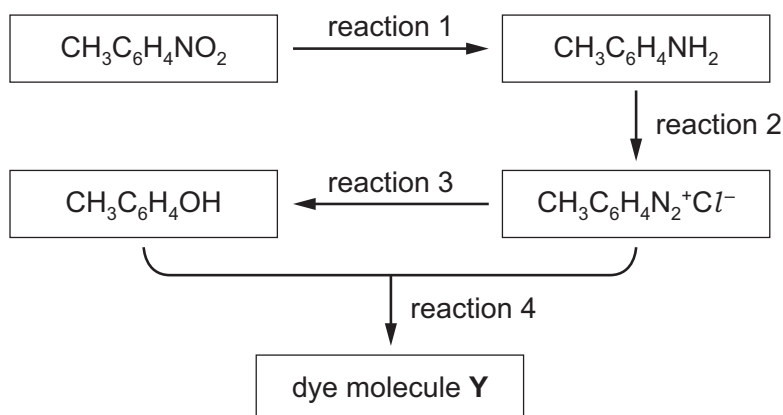


Fig. 7.2

- (i) Describe the reagents and conditions to produce $\text{CH}_3\text{C}_6\text{H}_4\text{N}_2^+\text{Cl}^-$ from $\text{CH}_3\text{C}_6\text{H}_4\text{NH}_2$ in reaction 2.

reagents

conditions

[1]

- (ii) Describe how $\text{CH}_3\text{C}_6\text{H}_4\text{OH}$ can be produced from $\text{CH}_3\text{C}_6\text{H}_4\text{N}_2^+\text{Cl}^-$ in reaction 3.

..... [1]

- (iii) Draw the structure of the dye molecule **Y** formed when $\text{CH}_3\text{C}_6\text{H}_4\text{N}_2^+\text{Cl}^-$ and $\text{CH}_3\text{C}_6\text{H}_4\text{OH}$ react together in reaction 4. Describe the conditions for this reaction.

structure

conditions

[2]

[Total: 15]

8 Benzene, C_6H_6 , is an aromatic molecule.

(a) State the C–C–C bond angle and the hybridisation shown by the carbon atoms in benzene.

bond angle

hybridisation

[1]

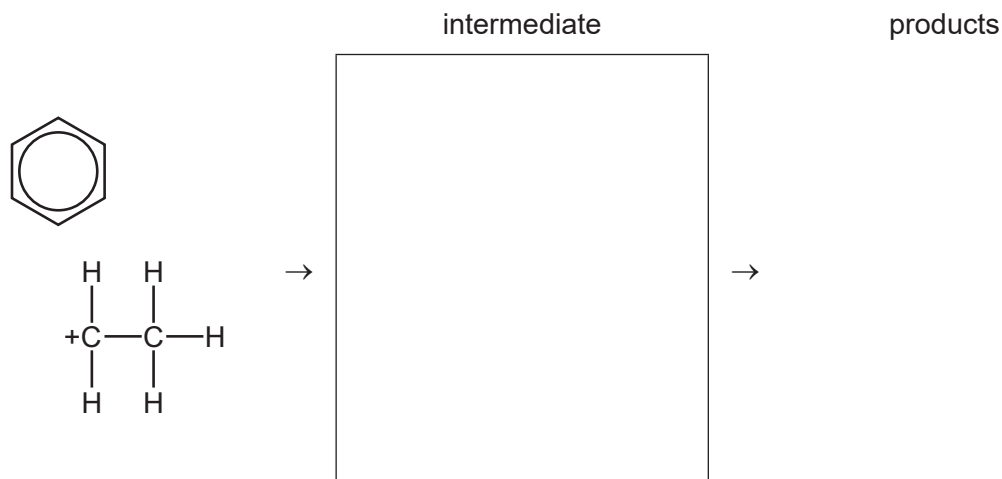
(b) Benzene reacts with chloroethane in the presence of a catalyst. The reaction mechanism is called electrophilic substitution.

(i) The first step in the reaction is the generation of the $^+\text{CH}_2\text{CH}_3$ electrophile.

Write an equation for the reaction that generates this electrophile.

..... [1]

(ii) Describe the mechanism for the reaction between benzene and the $^+\text{CH}_2\text{CH}_3$ electrophile. Include all relevant curly arrows and charges.



[3]

9701 Chemistry Paper 4 - Hydrocarbons

Topical questions | 34 questions

22. Question part 2/2 | 9701 Oct-Nov 2022 P4 V3 Q8

- (c) Chlorobenzene and chloroethane have different reactivities in nucleophilic substitution reactions.

- (i) Identify a suitable reagent to illustrate this difference in reactivity.

The reagent chosen should give **visibly** different results with chlorobenzene and chloroethane.

..... [1]

- (ii) Write equations to describe any reactions that occur.

[1]

- (iii) Explain the difference in the reactivities of chlorobenzene and chloroethane in nucleophilic substitution reactions.

.....

..... [1]

[Total: 8]

23. Question part 1/2 | 9701 May-June 2023 P4 V1 Q4

- 4 (a) State the hybridisation of the carbon atoms and the C–C–H bond angle in benzene, C_6H_6 . Explain how orbital overlap leads to the formation of σ and π bonds in benzene.

.....

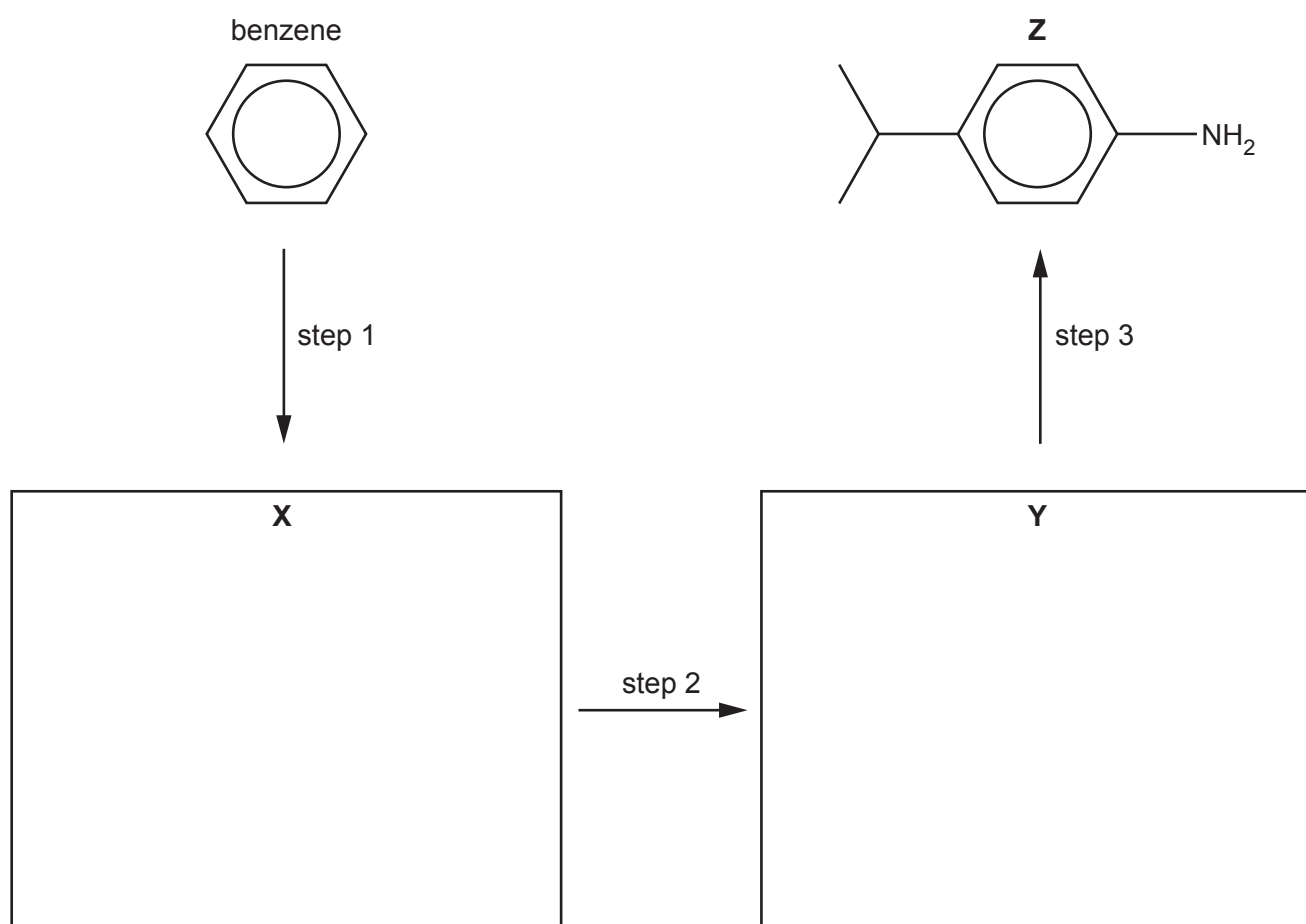
.....

.....

.....

..... [3]

- (b) Compound **Z** can be synthesised from benzene in three steps by the route shown in Fig. 4.1.

**Fig. 4.1**

- (i) Draw structures for **X** and **Y** in Fig. 4.1. [2]
- (ii) Give the reagents and conditions for steps 1, 2 and 3.

step 1

step 2

step 3

[3]

- (c) Compound **W** is an isomer of **Z**.

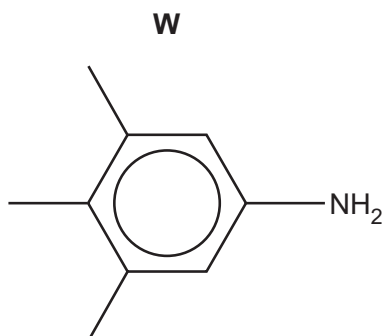


Fig. 4.2

Give the systematic name of **W**.

..... [1]

- (d) Complete Table 4.1 to show the number of peaks observed in the carbon-13 NMR spectrum for **W** and **Z**.

Table 4.1

compound	number of peaks observed
W	
Z	

[1]

[Total: 10]

- 5 (a) Methylbenzene can undergo different reactions, as shown in Fig. 5.1.

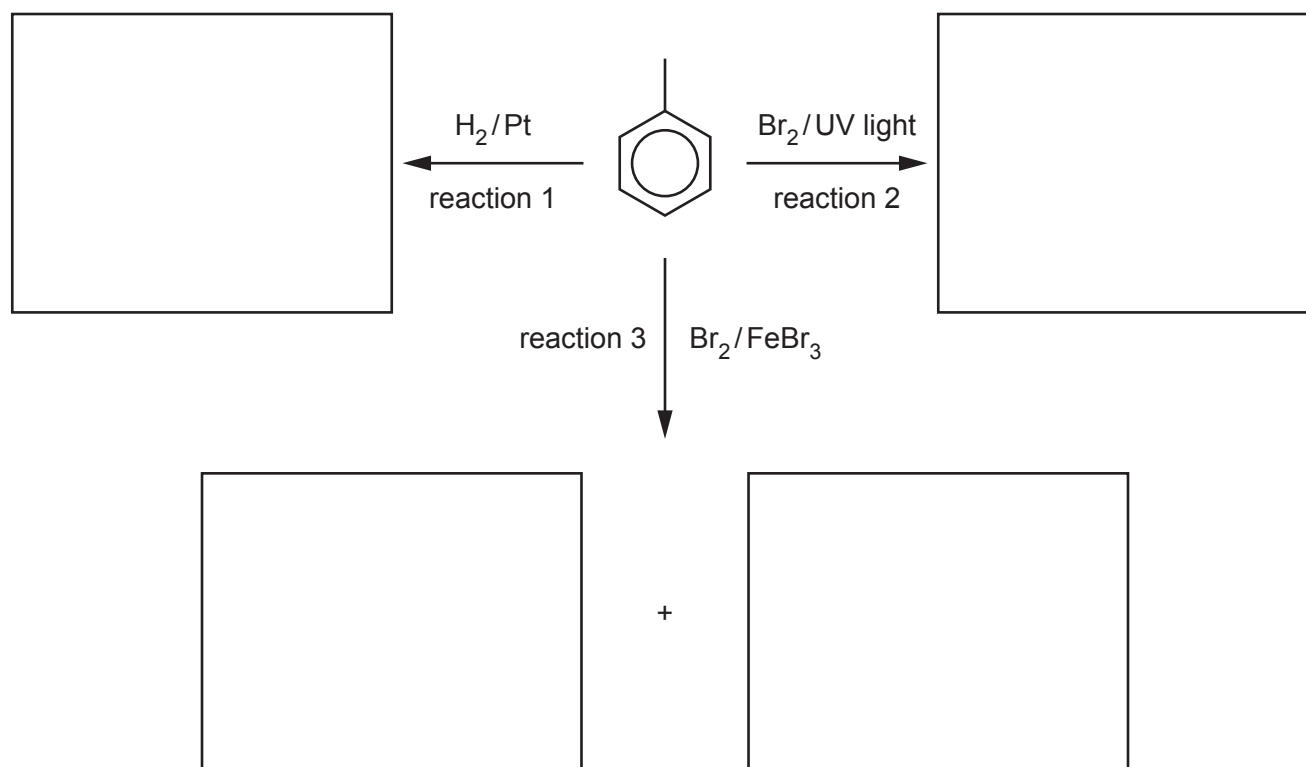


Fig. 5.1

- (i) Draw structures in Fig. 5.1 for the possible organic products of the three reactions shown. [3]

- (ii) Complete Table 5.1.

Table 5.1

	type of reaction	mechanism
reaction 1		
reaction 2		

[2]

- (b) When methylbenzene reacts with an electrophile, a substitution reaction occurs. No addition reaction takes place under these conditions.

Explain why no addition reaction takes place.

.....
 [1]

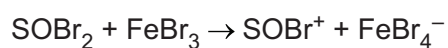
- (c) The reaction of methylbenzene with thionyl bromide, SOBr_2 , in the presence of an iron(III) bromide catalyst, FeBr_3 , is shown in Fig. 5.2.



Fig. 5.2

The mechanism of this reaction is similar to that of the bromination of benzene.

The first step of the mechanism generates the SOBr^+ electrophile, as shown.



- (i) The reaction of methylbenzene with SOBr^+ ions is shown in Fig. 5.3. Complete the mechanism in Fig. 5.3.

Include all relevant curly arrows and charges.

Draw the structure of the organic intermediate.

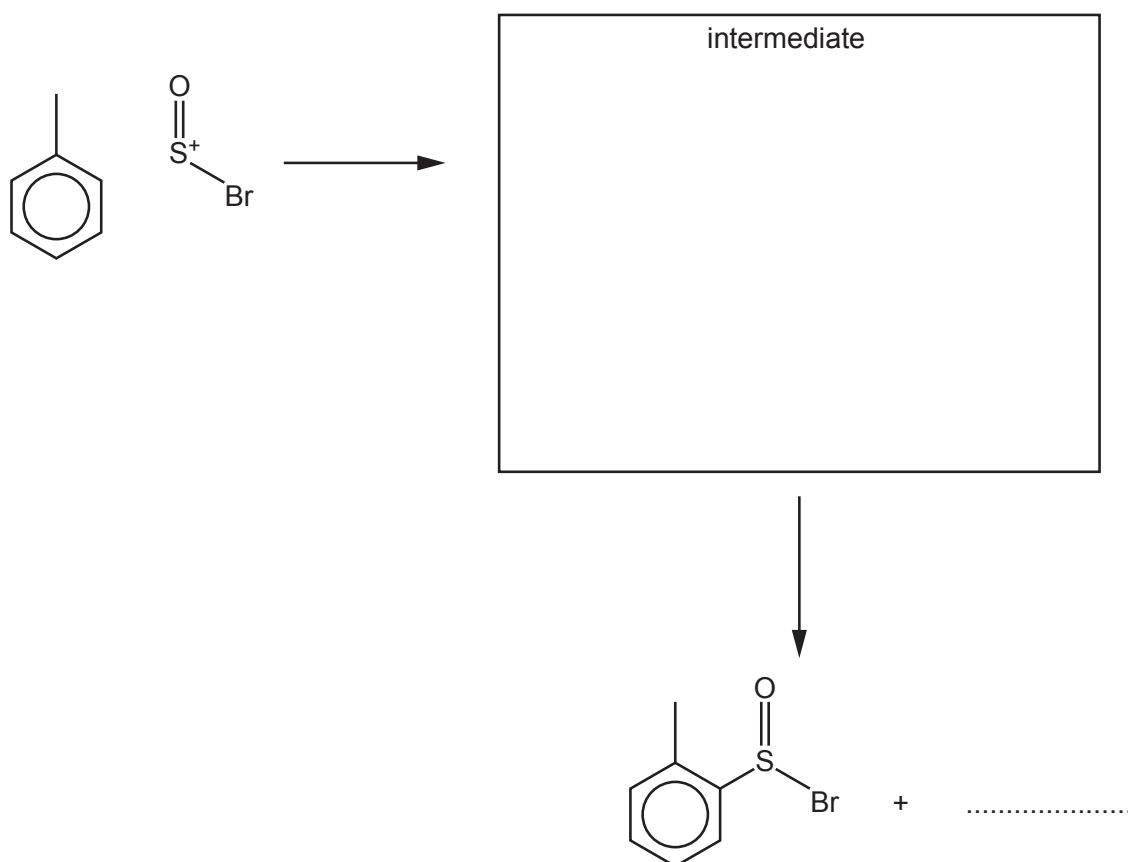


Fig. 5.3

- (ii) The reaction shown in Fig. 5.2 produces a small amount of a by-product, **P**, with the molecular formula $C_{14}H_{14}OS$.

Suggest a structure for by-product **P**.

[1]

- (d) Acyl bromides, $RCOBr$, can be synthesised by the reaction of a carboxylic acid and $SOBr_2$.

This is a similar reaction to the synthesis of acyl chlorides using $SOCl_2$.

- (i) Give an equation for the reaction between ethanoic acid and $SOBr_2$.

..... [1]

- (ii) Suggest the relative ease of hydrolysis of acyl bromides, $RCOBr$, acyl chlorides, $RCOCl$, and alkyl chlorides, RCI .

Explain your answer.

..... > >
easiest to hydrolyse hardest to hydrolyse

.....
.....
.....
.....
.....

[3]

[Total: 14]

25. Question part 1/2 | 9701 May-June 2023 P4 V3 Q4

- 4 (a) State the hybridisation of the carbon atoms and the C–C–H bond angle in benzene, C_6H_6 . Explain how orbital overlap leads to the formation of σ and π bonds in benzene.

.....

.....

.....

.....

..... [3]

- (b) Compound **Z** can be synthesised from benzene in three steps by the route shown in Fig. 4.1.

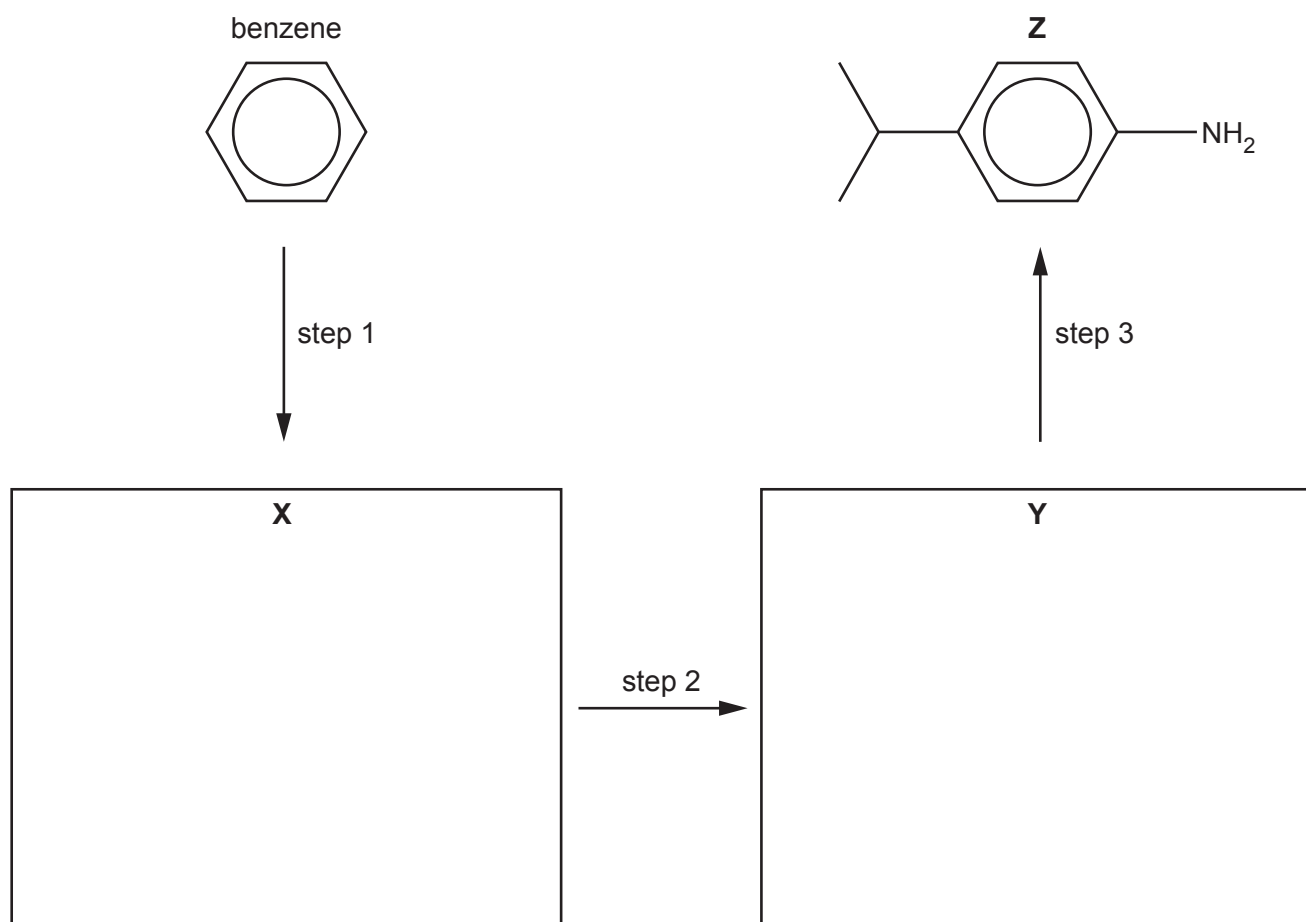


Fig. 4.1

- (i) Draw structures for **X** and **Y** in Fig. 4.1. [2]
- (ii) Give the reagents and conditions for steps 1, 2 and 3.

step 1

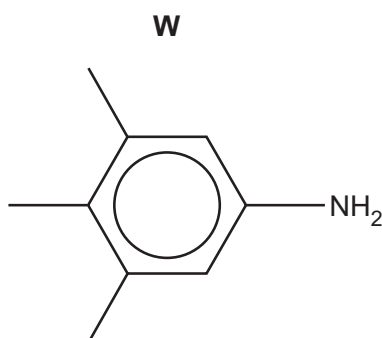
step 2

step 3

[3]

25. Question part 2/2 | 9701 May-June 2023 P4 V3 Q4

- (c) Compound **W** is an isomer of **Z**.



Give the systematic name of **W**.

..... [1]

- (d) Complete Table 4.1 to show the number of peaks observed in the carbon-13 NMR spectrum for **W** and **Z**.

Table 4.1

compound	number of peaks observed
W	
Z	

[1]

[Total: 10]

- 7 Benzene can be used to make benzoic acid in the two-step process shown in Fig. 7.1.

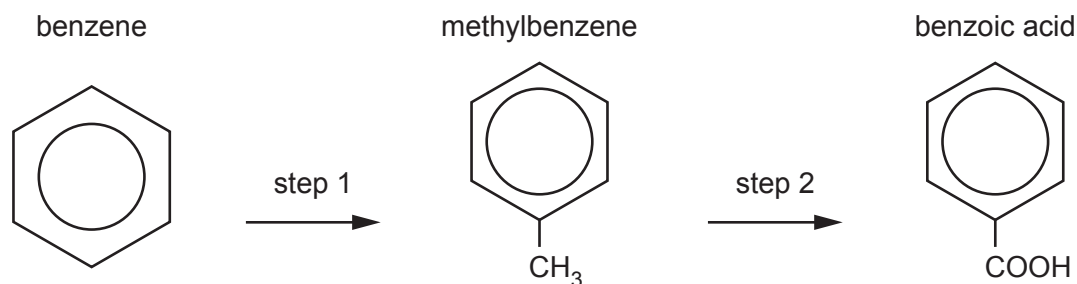


Fig. 7.1

- (a) Give the reagents and conditions for step 1 and step 2.

step 1

step 2

[2]

- (b) Methylbenzene and benzoic acid each have five different peaks in the carbon (^{13}C) NMR spectrum.

Table 7.1

hybridisation of the carbon atom	environment of carbon atom	example	chemical shift range / ppm
sp^3	alkyl	CH_3- , $-\text{CH}_2-$, $-\text{CH}<$, $>\text{C}<$	0–50
sp^3	next to alkene/arene	$-\text{C}=\text{C}$, $-\text{C}-\text{Ar}$	25–50
sp^3	next to carbonyl/carboxyl	$\text{C}-\text{COR}$, $\text{C}-\text{O}_2\text{R}$	30–65
sp^3	next to halogen	$\text{C}-\text{X}$	30–60
sp^3	next to oxygen	$\text{C}-\text{O}$	50–70
sp^2	alkene or arene	$>\text{C}=\text{C}<$, 	110–160
sp^2	carboxyl	$\text{R}-\text{COOH}$, $\text{R}-\text{COOR}$	160–185
sp^2	carbonyl	$\text{R}-\text{CHO}$, $\text{R}-\text{CO}-\text{R}$	190–220
sp	nitrile	$\text{R}-\text{C}\equiv\text{N}$	100–125

Use Table 7.1 to complete the two sentences to suggest descriptions of these two spectra.

The carbon (^{13}C) NMR spectrum of methylbenzene:

- has peak(s) in the chemical shift range of and
- has peak(s) in the chemical shift range of

The carbon (^{13}C) NMR spectrum of benzoic acid:

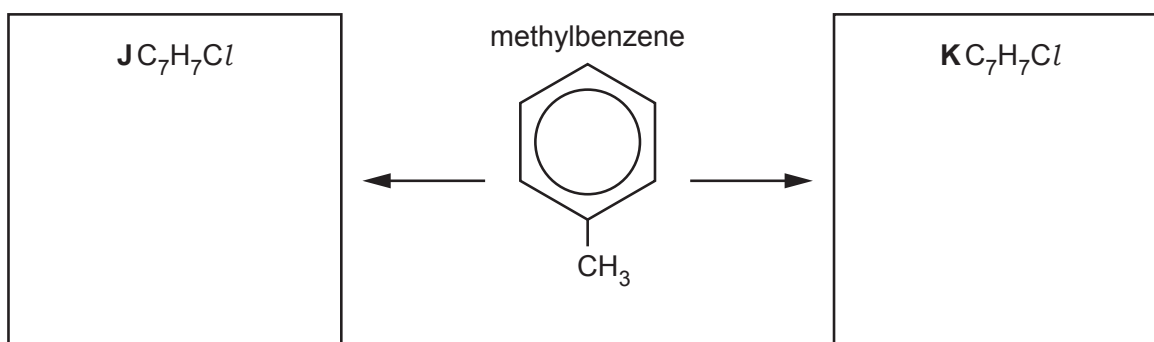
- has peak(s) in the chemical shift range of and
- has peak(s) in the chemical shift range of

[2]

(c) (i) When treated with Cl_2 under suitable conditions, methylbenzene forms compound **J**.

When treated with Cl_2 under **different** conditions with **different** reagents, methylbenzene forms compound **K**.

Suggest and draw structures of compounds **J** and **K** in the boxes. The molecular formula of each compound is given.



State the reagents and conditions required to form each product.

to form compound **J**

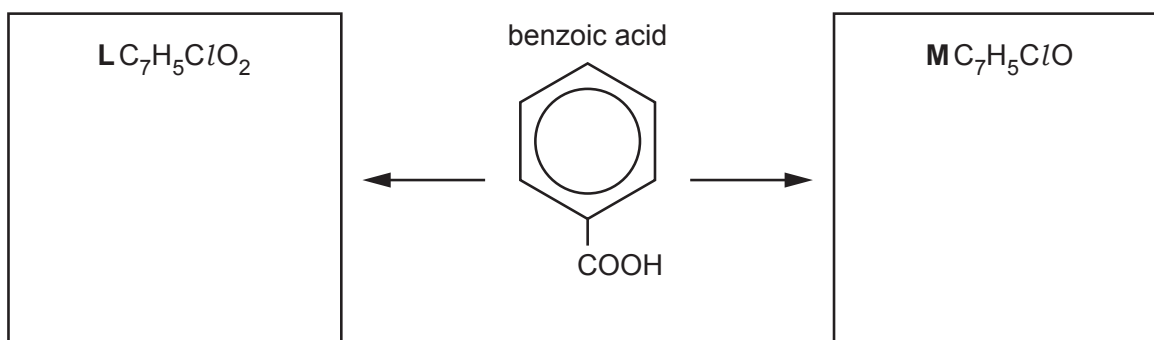
to form compound **K**

[4]

(ii) When treated with a chlorine-containing reagent under suitable conditions, benzoic acid forms compound **L**.

When treated with a **different** chlorine-containing reagent under **different** conditions, benzoic acid forms compound **M**.

Suggest and draw structures of compounds **L** and **M** in the boxes. The molecular formula of each product is given.



State the reagents and conditions to form compound **M** from benzoic acid.

..... [3]

[Total: 11]

- 6 (a) (i) State what is meant by partition coefficient, K_{pc} .

.....

 [1]

- (ii) The partition coefficient, K_{pc} , for a compound, **X**, between carbon disulfide, CS_2 , and water is 10.5.

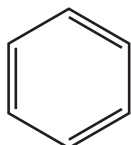
1.85 g of **X** is dissolved in water and made up to 100.0 cm^3 in a volumetric flask.
 40.0 cm^3 of this aqueous solution is shaken with 25.0 cm^3 of CS_2 .
 The mixture is left to reach equilibrium.

Calculate the mass of **X**, in g, extracted into the CS_2 layer.

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

- (b) The compound C_6H_6 has many structural isomers. Four suggested structures of C_6H_6 are shown in Fig. 6.1.

Kekulé benzene



Dewar benzene



Ladenburg benzene



delocalised benzene

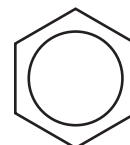


Fig. 6.1

Using Fig. 6.1, complete Table 6.1 to predict the number of carbon atoms that have sp , sp^2 and sp^3 hybridisation in Kekulé benzene, Dewar benzene and Ladenburg benzene.

Table 6.1

C_6H_6 structure	sp hybridised	sp^2 hybridised	sp^3 hybridised
Kekulé benzene			
Dewar benzene			
Ladenburg benzene			

[2]

(c) Describe the shape of delocalised benzene.

Include the geometry of each carbon, the C-C-H bond angle and the type of bond(s) between the carbon atoms and between the carbon and hydrogen atoms.

.....

.....

.....

.....

..... [2]

(d) Suggest why Dewar benzene and Ladenburg benzene are unstable isomers of C_6H_6 .

.....

..... [1]

(e) Complete Table 6.2 to predict the number of peaks in the proton (^1H) NMR spectrum for Dewar benzene, Ladenburg benzene and delocalised benzene.

Table 6.2

	number of peaks
Dewar benzene	
Ladenburg benzene	
delocalised benzene	

[1]

- (f) The reaction of phenylethanone with 1,4-dibromobutane, $\text{BrCH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{Br}$, in the presence of FeBr_3 is shown in Fig. 6.2.

phenylethanone

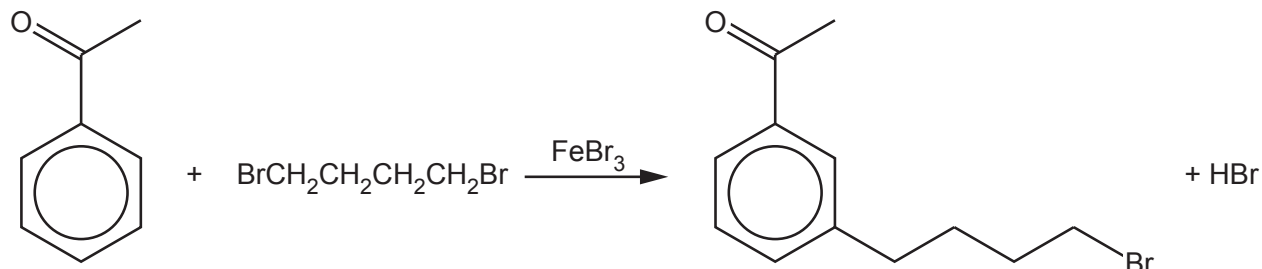


Fig. 6.2

The mechanism of this reaction is similar to that of the alkylation of benzene.

- (i) Construct an equation for the formation of the electrophile, $\text{BrCH}_2\text{CH}_2\text{CH}_2\text{CH}_2^+$.

..... [1]

- (ii) Complete the mechanism in Fig. 6.3 for the reaction of phenylethanone with $\text{BrCH}_2\text{CH}_2\text{CH}_2\text{CH}_2^+$ ions.

Include all relevant curly arrows and charges.
Draw the structure of the organic intermediate.

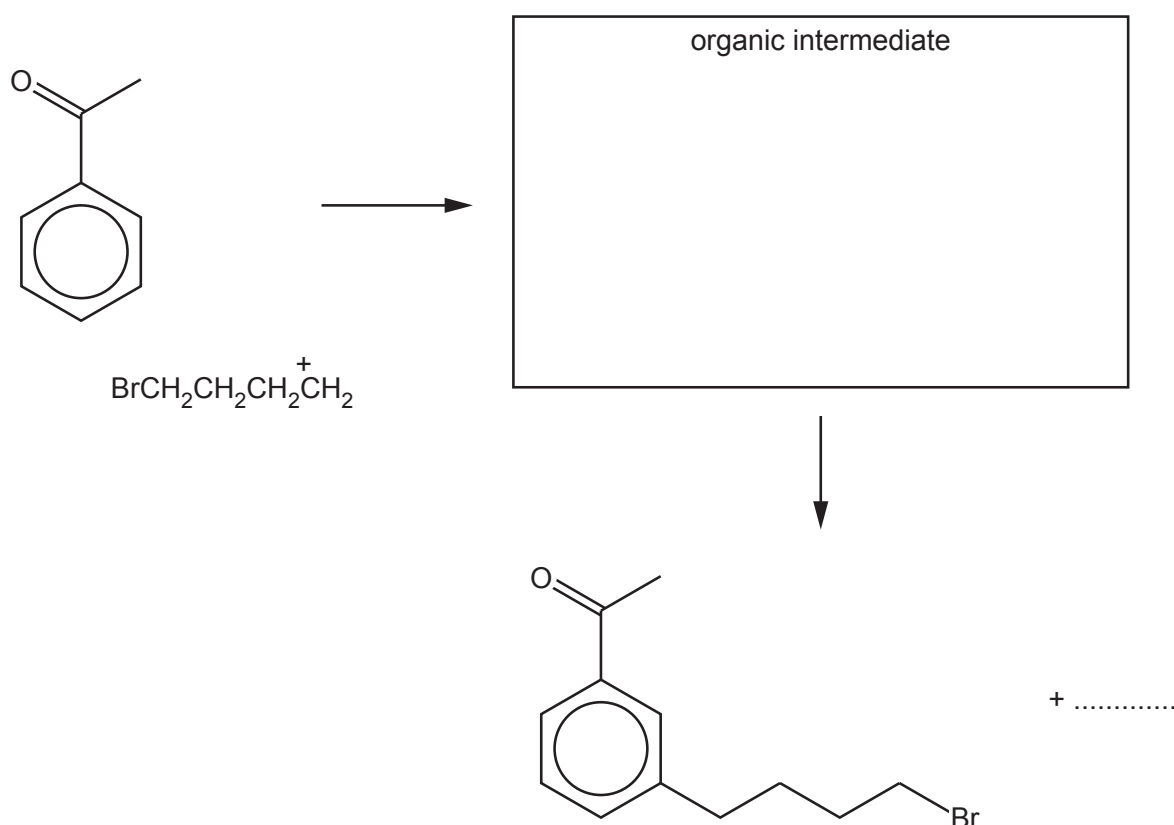


Fig. 6.3

9701 Chemistry Paper 4 - Hydrocarbons

Topical questions | 34 questions

27. Question part 4/4 | 9701 May-June 2024 P4 V3 Q6

- (iii) The reaction shown in Fig. 6.2 forms small amounts of two by-products, **Y** ($\text{C}_{20}\text{H}_{22}\text{O}_2$) and **Z** ($\text{C}_{12}\text{H}_{14}\text{O}$).

Suggest structures for **Y** and **Z** in the boxes in Fig. 6.4.

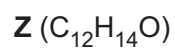
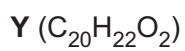


Fig. 6.4

[2]

[Total: 15]

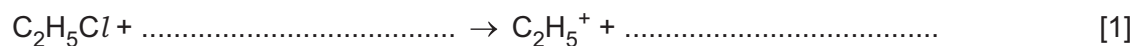
9701 Chemistry Paper 4 - Hydrocarbons

Topical questions | 34 questions

28. Question part 1/4 | 9701 Oct-Nov 2024 P4 V1 Q6

- 6** Benzene, C_6H_6 , reacts with chloroethane, $\text{C}_2\text{H}_5\text{Cl}$, in the presence of a suitable catalyst to form ethylbenzene, $\text{C}_6\text{H}_5\text{C}_2\text{H}_5$. In the presence of the catalyst, the ion C_2H_5^+ is formed. This ion reacts with benzene.

- (a)** Complete the equation for the reaction of $\text{C}_2\text{H}_5\text{Cl}$ with this catalyst to form C_2H_5^+ as one product.



- (b)** Ethylbenzene reacts with more $\text{C}_2\text{H}_5\text{Cl}$, forming a mixture containing 1,2-diethylbenzene and 1,4-diethylbenzene.

- (i)** Draw the structures of 1,2-diethylbenzene and 1,4-diethylbenzene.



[1]

- (ii)** Explain why there is very little 1,3-diethylbenzene in the product mixture.

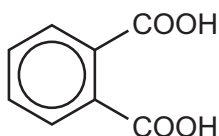
.....
..... [1]

28. Question part 2/4 | 9701 Oct-Nov 2024 P4 V1 Q6



(c) 1,2-diethylbenzene can be oxidised to benzene-1,2-dioic acid, $\text{C}_6\text{H}_4(\text{COOH})_2$.

benzene-1,2-dioic acid



(i) State the reagent and conditions used for this reaction.

..... [1]

(ii) Complete the overall equation for this reaction.

An atom of oxygen from the oxidising agent is represented as [O].

All of the atoms in the two ethyl groups are fully oxidised in this reaction.

..... + ... [O] $\rightarrow$ $\text{C}_6\text{H}_4(\text{COOH})_2$ + ... + ...
(1,2-diethylbenzene)

[2]

(iii) Predict the number of peaks in the carbon-13 NMR spectrum of benzene-1,2-dioic acid.

..... [1]

28. Question part 3/4 | 9701 Oct-Nov 2024 P4 V1 Q6



- (d) The proton (^1H) NMR spectra of ethylbenzene, $\text{C}_6\text{H}_5\text{C}_2\text{H}_5$, in CDCl_3 and of benzene-1,2-dioic acid, $\text{C}_6\text{H}_4(\text{COOH})_2$, in CDCl_3 are shown. They have **not** been identified.

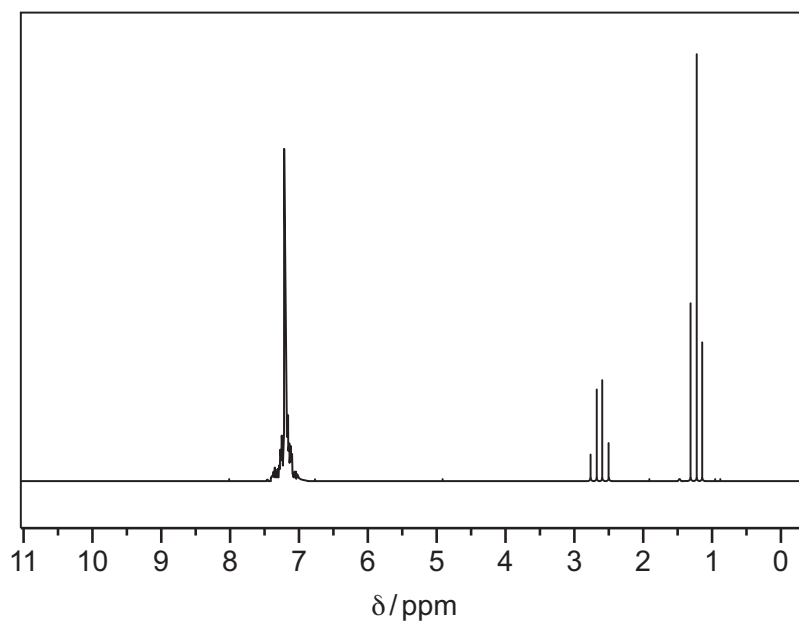


Fig. 6.1

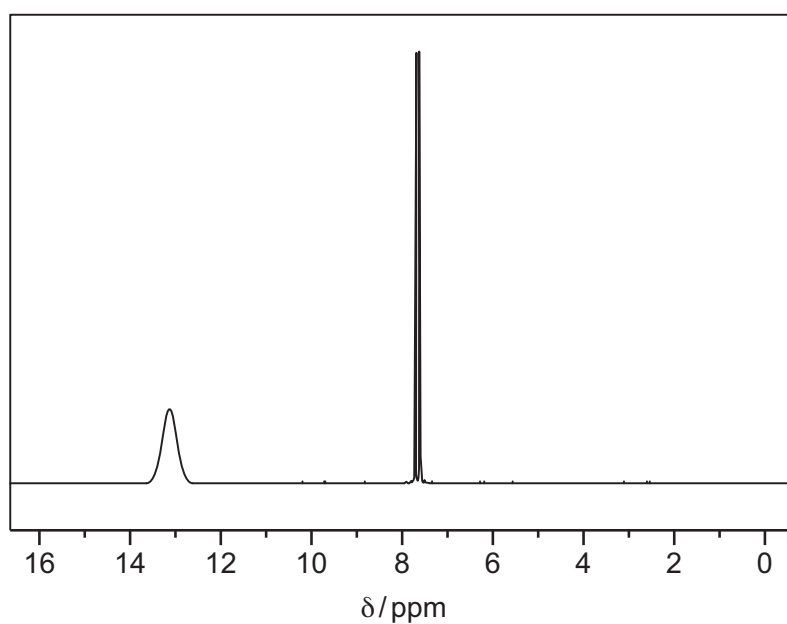


Fig. 6.2

- (i) Explain the use of CDCl_3 , instead of CHCl_3 , as the solvent when obtaining these spectra.

..... [1]

28. Question part 4/4 | 9701 Oct-Nov 2024 P4 V1 Q6



(ii) Identify the substance shown by the spectrum in Fig. 6.1, and complete Table 6.1.

substance

Table 6.1

	peak at $\delta = 1.2$	peak at $\delta = 2.6$
name of splitting pattern		
group responsible for peak		
explanation of splitting pattern		

[3]

(iii) Identify the substance shown by the spectrum in Fig. 6.2, and complete Table 6.2.

substance

Table 6.2

	peak at $\delta = 7.8$	peak at $\delta = 13.1$
group responsible for peak		

[1]

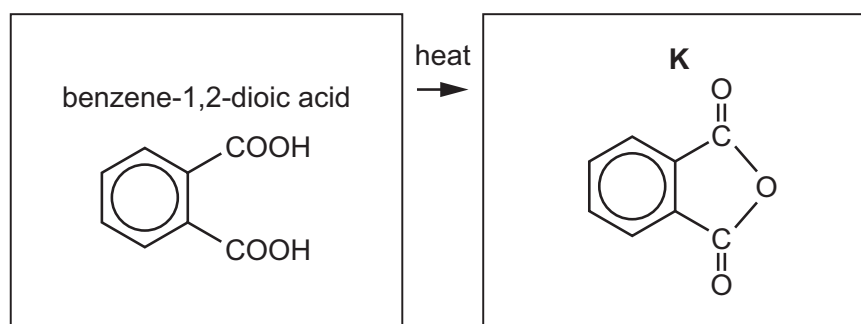
(iv) When D_2O is used as a solvent, the spectrum obtained is different from the spectrum in Fig. 6.2.

Describe this difference and explain your answer.

.....

.....

..... [1]

(e) Benzene-1,2-dioic acid can be used to produce **K**.

Suggest the name of this type of reaction.

..... [1]

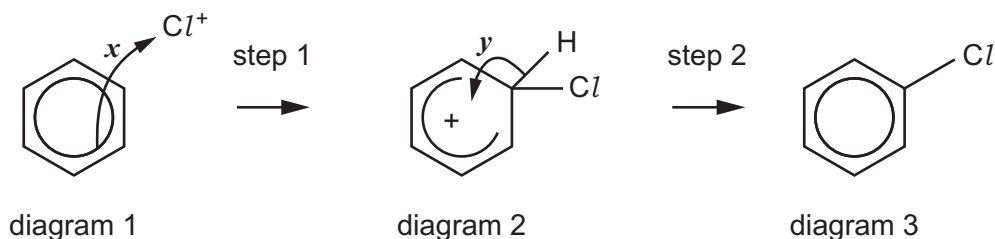
[Total: 14]

- 7 Benzene reacts with chlorine gas to form chlorobenzene. This reaction can be described as the reaction between benzene molecules and Cl^+ ions. The Cl^+ ions are formed by adding a suitable catalyst to the chlorine gas.

(a) Give the name or formula of a catalyst that can be used for this reaction.

..... [1]

(b) The mechanism for this reaction is shown.



(i) The movement of a pair of electrons is represented by x in diagram 1.

- State where this pair of electrons is **before** step 1 takes place.

.....

- State where this pair of electrons is **after** step 1 has taken place.

.....

[2]

(ii) The movement of another pair of electrons is represented by y in diagram 2.

- State where this pair of electrons is **before** step 2 takes place.

.....

- State where this pair of electrons is **after** step 2 has taken place.

.....

[2]

(c) There are six carbon atoms in diagram 2.

State how many of these carbon atoms are sp hybridised, sp^2 hybridised, and sp^3 hybridised.

sp hybridised

sp^2 hybridised

sp^3 hybridised

[1]



(d) Complete the equation for this reaction between benzene and chlorine.



(e) The mechanism for this reaction is electrophilic substitution.

Complete the following sentence. Write formulae in the gaps provided.

During this reaction, the electrophile is and a atom
in benzene is substituted by a atom.

[1]

(f) Chloroethane reacts with NaOH(aq). Chlorobenzene does not.

(i) Name the mechanism of the reaction that chloroethane undergoes with NaOH(aq), and identify the major organic product that is formed.

mechanism

major organic product
[1]

(ii) Explain the difference in reactivity of chloroethane and chlorobenzene when treated with NaOH(aq).

.....
.....
..... [2]

[Total: 11]

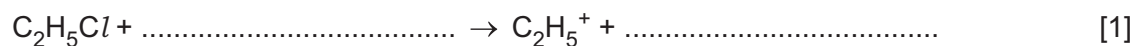
9701 Chemistry Paper 4 - Hydrocarbons

Topical questions | 34 questions

30. Question part 1/4 | 9701 Oct-Nov 2024 P4 V3 Q6

- 6** Benzene, C_6H_6 , reacts with chloroethane, $\text{C}_2\text{H}_5\text{Cl}$, in the presence of a suitable catalyst to form ethylbenzene, $\text{C}_6\text{H}_5\text{C}_2\text{H}_5$. In the presence of the catalyst, the ion C_2H_5^+ is formed. This ion reacts with benzene.

- (a)** Complete the equation for the reaction of $\text{C}_2\text{H}_5\text{Cl}$ with this catalyst to form C_2H_5^+ as one product.



- (b)** Ethylbenzene reacts with more $\text{C}_2\text{H}_5\text{Cl}$, forming a mixture containing 1,2-diethylbenzene and 1,4-diethylbenzene.

- (i)** Draw the structures of 1,2-diethylbenzene and 1,4-diethylbenzene.



[1]

- (ii)** Explain why there is very little 1,3-diethylbenzene in the product mixture.

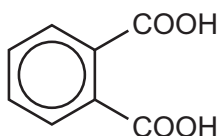
.....
..... [1]

30. Question part 2/4 | 9701 Oct-Nov 2024 P4 V3 Q6



(c) 1,2-diethylbenzene can be oxidised to benzene-1,2-dioic acid, $\text{C}_6\text{H}_4(\text{COOH})_2$.

benzene-1,2-dioic acid



(i) State the reagent and conditions used for this reaction.

..... [1]

(ii) Complete the overall equation for this reaction.

An atom of oxygen from the oxidising agent is represented as [O].

All of the atoms in the two ethyl groups are fully oxidised in this reaction.

..... + ... [O] $\rightarrow$ $\text{C}_6\text{H}_4(\text{COOH})_2$ + ... + ...
(1,2-diethylbenzene)

[2]

(iii) Predict the number of peaks in the carbon-13 NMR spectrum of benzene-1,2-dioic acid.

..... [1]

30. Question part 3/4 | 9701 Oct-Nov 2024 P4 V3 Q6



- (d) The proton (^1H) NMR spectra of ethylbenzene, $\text{C}_6\text{H}_5\text{C}_2\text{H}_5$, in CDCl_3 and of benzene-1,2-dioic acid, $\text{C}_6\text{H}_4(\text{COOH})_2$, in CDCl_3 are shown. They have **not** been identified.

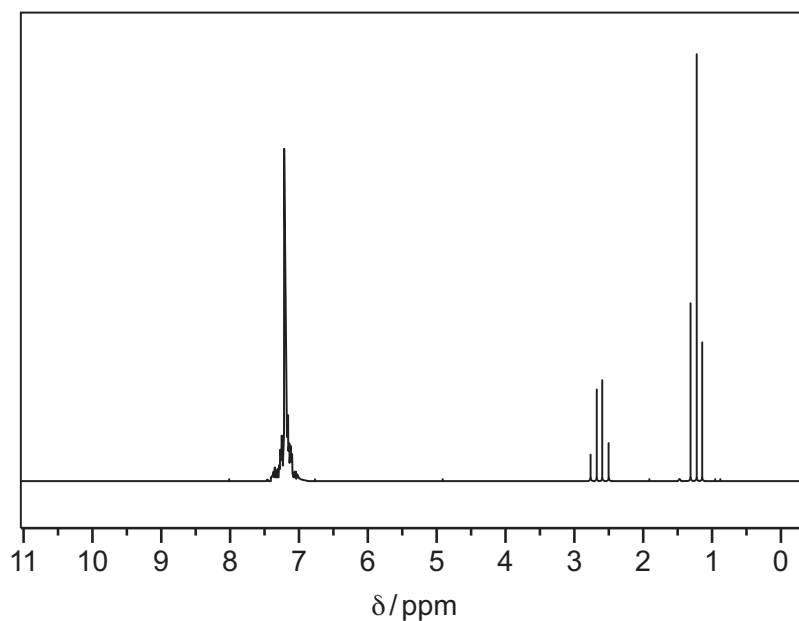


Fig. 6.1

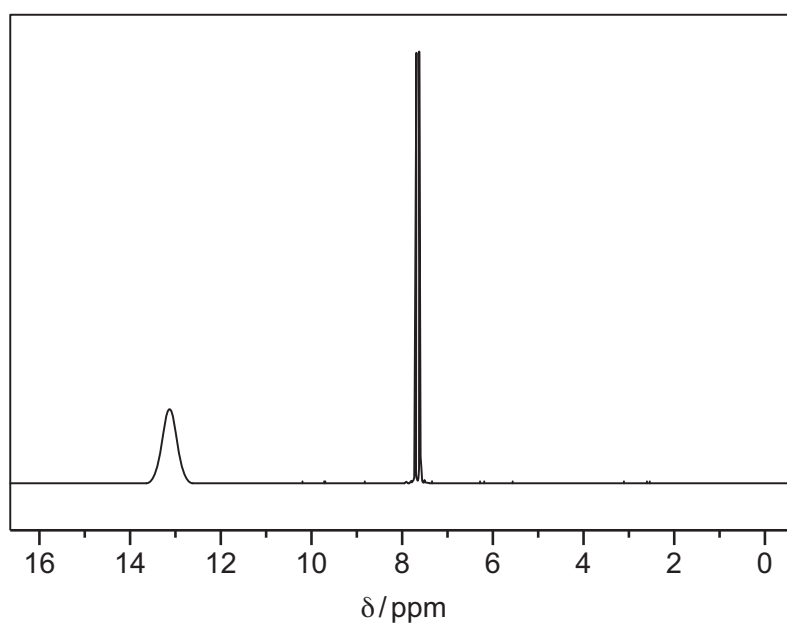


Fig. 6.2

- (i) Explain the use of CDCl_3 , instead of CHCl_3 , as the solvent when obtaining these spectra.

..... [1]

30. Question part 4/4 | 9701 Oct-Nov 2024 P4 V3 Q6



(ii) Identify the substance shown by the spectrum in Fig. 6.1, and complete Table 6.1.

substance

Table 6.1

	peak at $\delta = 1.2$	peak at $\delta = 2.6$
name of splitting pattern		
group responsible for peak		
explanation of splitting pattern		

[3]

(iii) Identify the substance shown by the spectrum in Fig. 6.2, and complete Table 6.2.

substance

Table 6.2

	peak at $\delta = 7.8$	peak at $\delta = 13.1$
group responsible for peak		

[1]

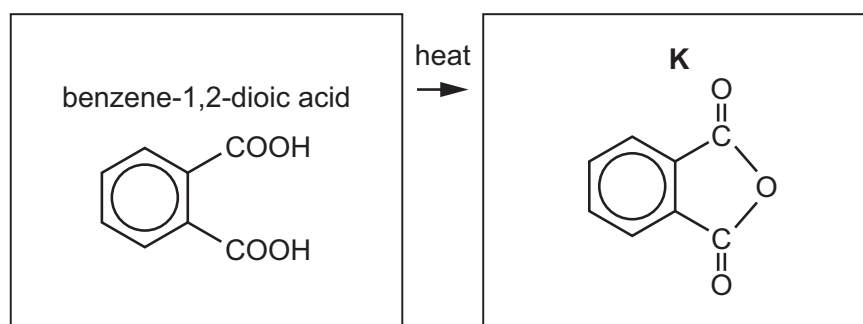
(iv) When D_2O is used as a solvent, the spectrum obtained is different from the spectrum in Fig. 6.2.

Describe this difference and explain your answer.

.....

.....

..... [1]

(e) Benzene-1,2-dioic acid can be used to produce **K**.

Suggest the name of this type of reaction.

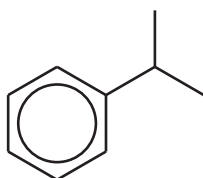
..... [1]

[Total: 14]

31. Question part 1/6 | 9701 Feb-March 2025 P4 V2 Q5

- 5 Cumene is an aromatic hydrocarbon used in the synthesis of other useful chemicals.

cumene

**Fig. 5.1**

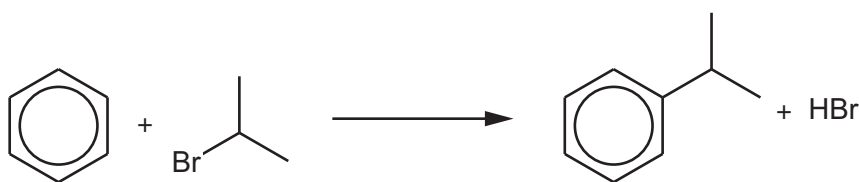
- (a) Complete Table 5.1 to show the number of sp^2 and sp^3 hybridised carbon atoms that are present in a molecule of cumene.

Table 5.1

type of hybridisation	sp^2	sp^3
number of carbon atoms		

[1]

- (b) Cumene can be synthesised via a Friedel–Crafts alkylation reaction, as shown in Fig. 5.2.

**Fig. 5.2**

- (i) Name the mechanism involved in the Friedel–Crafts alkylation shown in Fig. 5.2.

..... [1]

- (ii) The first step of the reaction forms the $(CH_3)_2CH^+$ cation.

Identify a suitable reagent for the formation of this cation from 2-bromopropane, $(CH_3)_2CHBr$.

..... [1]

31. Question part 2/6 | 9701 Feb-March 2025 P4 V2 Q5



- (iii) Complete Fig. 5.3 to show the mechanism for the reaction of benzene with the $(\text{CH}_3)_2\text{CH}^+$ cation.

Include all relevant curly arrows and charges.

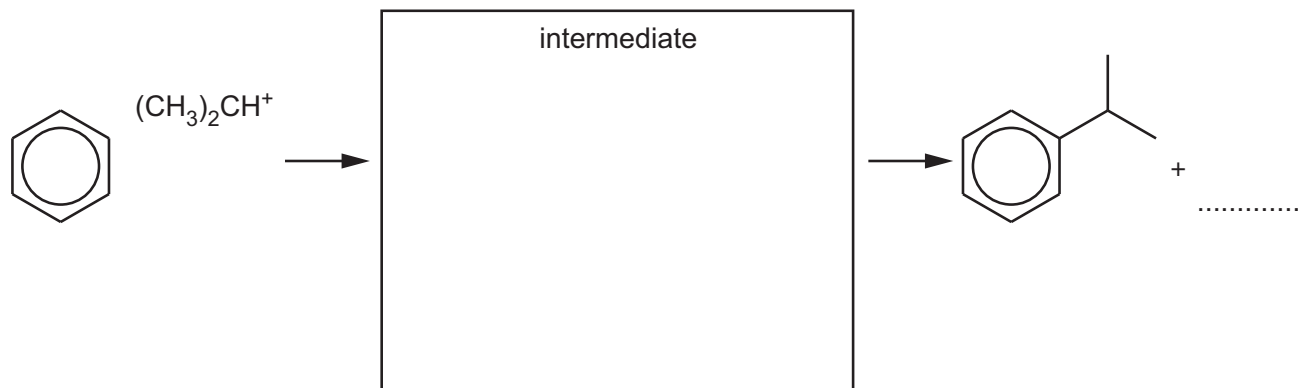


Fig. 5.3

[3]

- (iv) The Friedel–Crafts alkylation of benzene by 1-bromopropane, $\text{CH}_3\text{CH}_2\text{CH}_2\text{Br}$, also produces cumene as the major product.

The $\text{CH}_3\text{CH}_2\text{CH}_2^+$ cation formed in the first step quickly rearranges to form the $(\text{CH}_3)_2\text{CH}^+$ cation.

Suggest why this is the case. Explain your answer.

.....
.....
..... [1]

31. Question part 3/6 | 9701 Feb-March 2025 P4 V2 Q5



(c) Cumene oxidises in air to form phenol, $\text{C}_6\text{H}_5\text{OH}$, and propanone, CH_3COCH_3 .

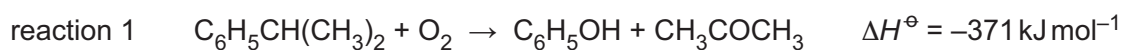


Table 5.2 gives some relevant standard entropies for reaction 1.

Table 5.2

compound	$\text{C}_6\text{H}_5\text{CH}(\text{CH}_3)_2$	O_2	$\text{C}_6\text{H}_5\text{OH}$	CH_3COCH_3
standard entropy, $S^\ominus/\text{JK}^{-1}\text{mol}^{-1}$	278	205	146	200

(i) Calculate the standard entropy change, $\Delta S^\ominus$, of reaction 1.

$$\Delta S^\ominus = \dots\dots\dots \text{JK}^{-1}\text{mol}^{-1} \quad [1]$$

(ii) Show that reaction 1 is feasible at 25°C .

[2]

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(d) Fig. 5.4 shows two reactions of phenol.

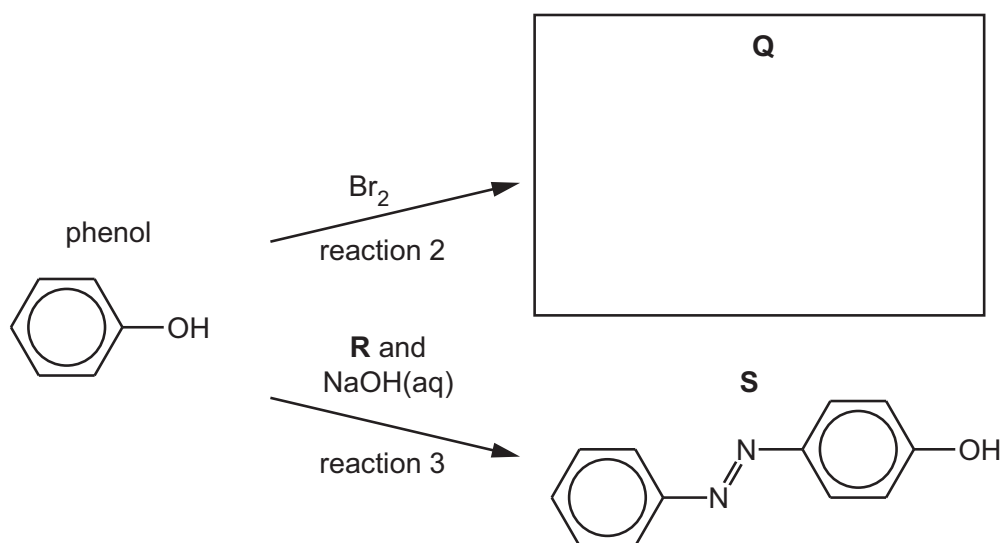


Fig. 5.4

(i) State the conditions for the bromination of phenol in reaction 2.

Explain why these conditions are different from those for the bromination of benzene.

conditions

explanation

.....

.....

.....

..... [4]

(ii) Draw the structure of organic compound **Q** in Fig. 5.4. [1]

(iii) Identify organic reagent **R**.

[1]

(iv) Name the functional group that is formed in reaction 3.

..... [1]

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31. Question part 5/6 | 9701 Feb-March 2025 P4 V2 Q5



- (v) The reaction of phenol with HNO_3 produces a mixture of isomers with molecular formula $\text{C}_6\text{H}_5\text{NO}_3$.

Identify the **two** isomers that are produced in the largest quantities.

Explain your answer.

isomer 1

isomer 2

explanation

.....

.....

[2]

[Total: 19]

9701 Chemistry Paper 4 - Hydrocarbons

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31. Question part 6/6 | 9701 Feb-March 2025 P4 V2 Q5



Question 6 starts on the next page.

32. Question part 1/3 | 9701 May-June 2025 P4 V2 Q6

- 6 (a) Methylbenzene reacts readily with nitronium ions, NO_2^+ .

NO_2^+ ions are generated by the reaction between concentrated nitric acid and concentrated sulfuric acid.

- (i) Write an equation for the formation of the NO_2^+ ion.

..... [1]

- (ii) Complete the mechanism in Fig. 6.1 for the nitration of methylbenzene to form 1-methyl-2-nitrobenzene.

Include all relevant curly arrows and charges.

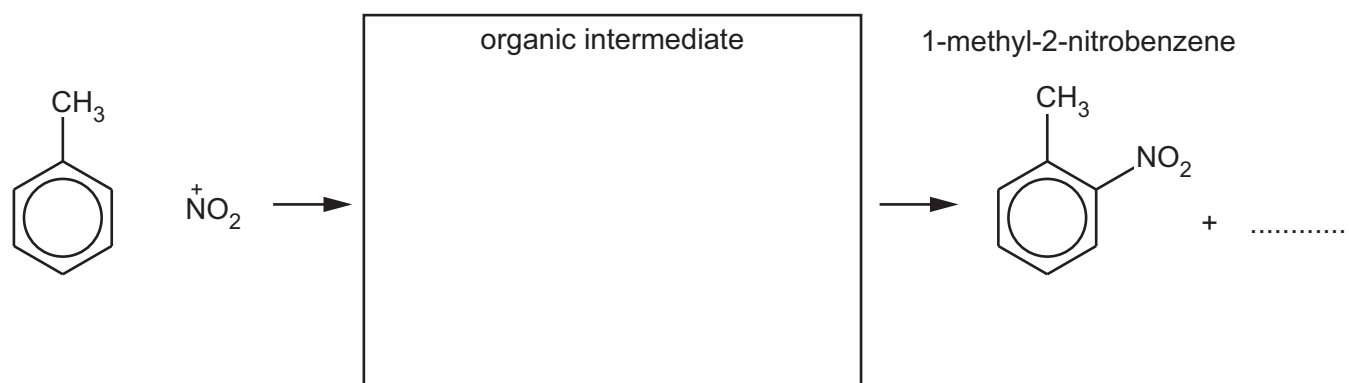


Fig. 6.1

[3]

- (b) Phenol can be nitrated with dilute nitric acid.

Explain why the nitration of phenol occurs under **milder** conditions than the nitration of benzene.

.....

.....

.....

.....

..... [2]

- (c) A sample of 2-nitrophenol is reacted with sodium.

Complete the equation in Fig. 6.2 for the reaction of 2-nitrophenol with sodium.

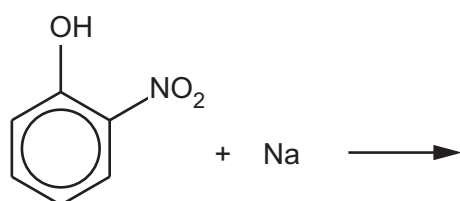


Fig. 6.2

[1]

32. Question part 2/3 | 9701 May-June 2025 P4 V2 Q6



(d) 2-nitrophenol can undergo different reactions as shown in Fig. 6.3.

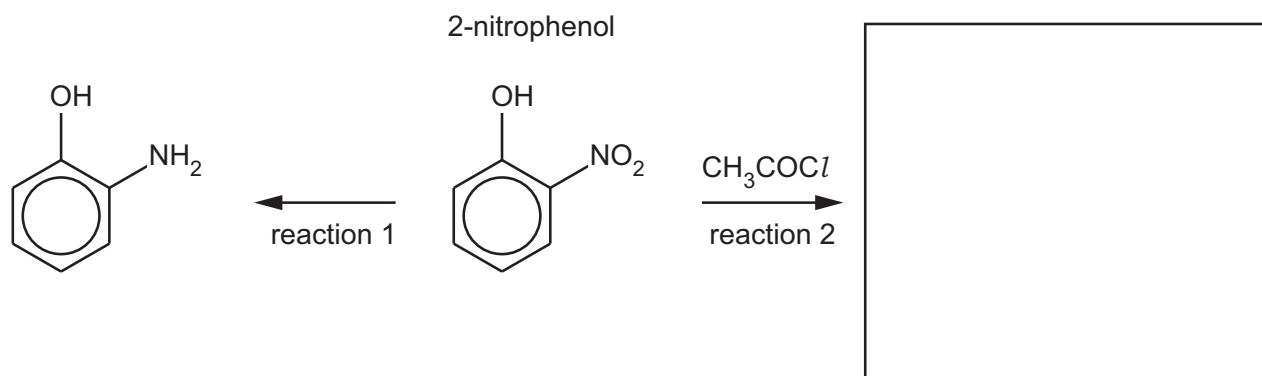


Fig. 6.3

(i) Suggest reagents and conditions for reaction 1.

..... [1]

(ii) Name the type of reaction for reaction 1.

..... [1]

(iii) Reaction 2 is carried out at room temperature.

Draw the structure of the organic product from reaction 2 in Fig. 6.3. [1]

(iv) Name the mechanism for reaction 2.

..... [1]

(e) The NO_2 group in 2-nitrophenol is electron withdrawing.

Suggest the relative acidities of ethanol, 2-nitrophenol, phenol and water.

Explain your answer.

.....

most acidic least acidic

.....

.....

.....

.....

.....

.....

[4]

32. Question part 3/3 | 9701 May-June 2025 P4 V2 Q6



- (f) Salbutamol is a pharmaceutical drug that contains a phenol functional group.

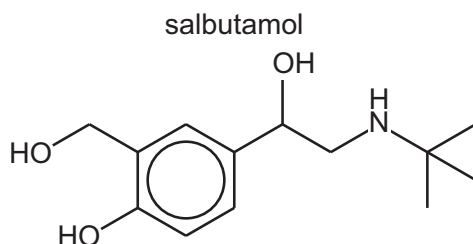


Fig. 6.4

- (i) Name and classify the **three** other functional groups in salbutamol in Table 6.1.

Table 6.1

name of functional group	classification of functional group

[2]

- (ii) Salbutamol reacts with $\text{Br}_2(\text{aq})$ to form organic product **X**.

Draw the structure of **X**.

[1]

- (iii) Salbutamol reacts with an excess of SOCl_2 to form organic product **Y**.

The molecular formula of **Y** is $\text{C}_{13}\text{H}_{19}\text{Cl}_2\text{NO}$.

Draw the structure of **Y**.

[1]

[Total: 19]

33. Question part 1/2 | 9701 Oct-Nov 2025 P4 V1 Q8

- 8 (a) In the electrophilic substitution of arenes, different substituents can direct to different ring positions.

(i) Describe the directing effect of the $-\text{NO}_2$ group. Explain your answer.

.....
..... [1]

- (ii) The nitration of arenes uses a mixture of concentrated HNO_3 and concentrated H_2SO_4 to generate the NO_2^+ electrophile.

Write an equation for the formation of the NO_2^+ electrophile.

..... [1]

- (b) Carbon-carbon bond formation is an important reaction in organic synthesis.

Fig. 8.1 shows the synthesis of compound **Q** from benzene in two reaction steps.

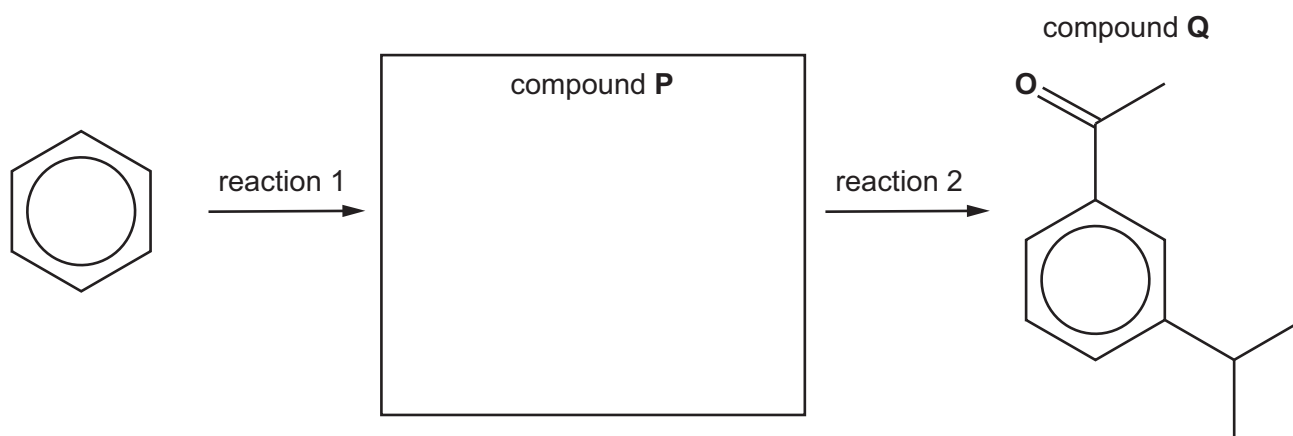


Fig. 8.1

- (i) Draw the structure of compound **P** in the box in Fig. 8.1. [1]

- (ii) Suggest reagents and conditions for reactions 1 and 2 in Fig. 8.1.

reaction 1

reaction 2

[2]

33. Question part 2/2 | 9701 Oct-Nov 2025 P4 V1 Q8



(c) Separate samples of $\text{C}_6\text{H}_5\text{Br}$ and $\text{C}_6\text{H}_5\text{CH}_2\text{Br}$ are added to warm $\text{AgNO}_3(\text{aq})$.

State the expected observations, if any. Explain your answer.

$\text{C}_6\text{H}_5\text{Br}$ with $\text{AgNO}_3(\text{aq})$

$\text{C}_6\text{H}_5\text{CH}_2\text{Br}$ with $\text{AgNO}_3(\text{aq})$

explanation

.....

.....

.....

[3]

(d) Acyl bromides, RCOBr , react readily with H_2O .

The mechanism of this reaction is similar to that of the reaction of H_2O with acyl chlorides, RCOCl .

(i) Name the mechanism of this reaction.

..... [1]

(ii) Complete the mechanism in Fig. 8.2 for the reaction of RCOBr with H_2O .

Include all relevant lone pairs of electrons, curly arrows, charges and dipoles.

Draw the structure of the intermediate.

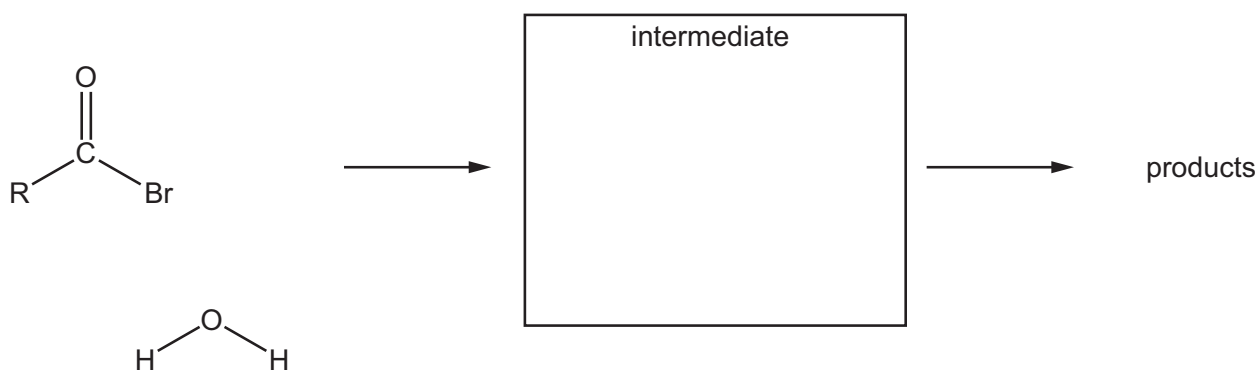


Fig. 8.2

[4]

[Total: 13]

34. Question part 1/2 | 9701 Oct-Nov 2025 P4 V4 Q5

5 (a) Describe and explain the shape of benzene.

In your answer, include:

- the shape and bond angle in the ring
- the hybridisation of the carbon atoms
- how orbital overlap forms σ and π bonds between the carbon atoms in the ring.

.....

.....

.....

.....

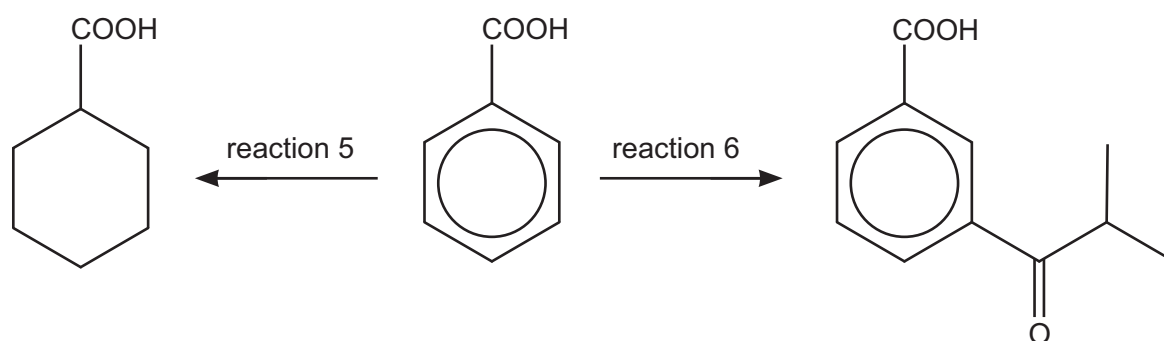
.....

.....

.....

.....

..... [4]

(b) Fig. 5.1 shows two reactions of benzoic acid.**Fig. 5.1****(i)** Suggest reagents and conditions for reaction 5 and for reaction 6 in Fig. 5.1.

reaction 5

reaction 6

[2]

(ii) State the type of reaction for reaction 5 in Fig. 5.1.

..... [1]

34. Question part 2/2 | 9701 Oct-Nov 2025 P4 V4 Q5



(c) In the electrophilic substitution of arenes, different substituents can direct to different ring positions.

(i) Describe the directing effect of the $-\text{CH}_2\text{CH}_3$ group.

Explain your answer.

.....
..... [1]

(ii) The alkylation of arenes uses a mixture of $\text{CH}_3\text{CH}_2\text{Br}$ and FeBr_3 to generate the CH_3CH_2^+ electrophile.

Write an equation for the formation of the CH_3CH_2^+ electrophile.

..... [1]

(iii) Complete the mechanism in Fig. 5.2.

Include all relevant curly arrows and charges. Draw the structure of the organic intermediate.

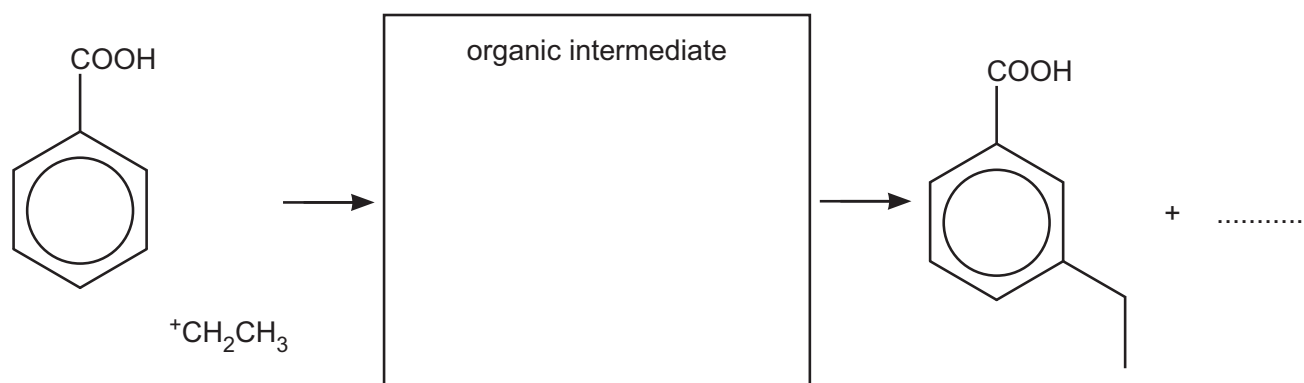


Fig. 5.2

[3]

(iv) Write an equation to show how FeBr_3 is regenerated after the reaction in Fig. 5.2.

..... [1]

[Total: 13]