Surname	StemUp Model Solution	Centre Number	Candidate Number
First name(s)			2

GCE A LEVEL

A410U20-1

S25-A410U20-1

MONDAY, 16 JUNE 2025 – MORNING

CHEMISTRY – A level component 2

Organic Chemistry and Analysis

2 hours 30 minutes

	For Examiner's use only		
	Question	**Maximum Mark**	**Mark Awarded**
Section A	**1. to 6.**	**15**	
Section B	**7.**	**17**	
	8.	**16**	
	9.	**17**	
	10.	**17**	
	11.	**19**	
	12.	**19**	
	Total	**120**	

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01

ADDITIONAL MATERIALS

- A calculator, pencil and ruler
- **Data Booklet** supplied by WJEC

INSTRUCTIONS TO CANDIDATES

Use black ink or black ball-point pen.
Do not use gel pen or correction fluid.

You may use a pencil for graphs and diagrams only.

Write your name, centre number and candidate number in the spaces at the top of this page.

Section A Answer **all** questions.
Section B Answer **all** questions.

Write your answers in the spaces provided in this booklet. If you run out of space, use the additional page(s) at the back of the booklet, taking care to number the question(s) correctly.

INFORMATION FOR CANDIDATES

The number of marks is given in brackets at the end of each question or part-question.

The maximum mark for this paper is 120.

Your answers must be relevant and must make full use of the information given to be awarded full marks for a question.

The assessment of the quality of extended response (QER) will take place in **Q10**(d) and **Q12**(b).

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SECTION A

Answer **all** questions.

1. An aqueous solution of some α-amino acids is analysed by thin layer chromatography.

The R_f value for leucine is 0.73 when a particular solvent is used.

If the solvent front has moved 12.2 cm from the start line, calculate the distance from the start line where the leucine spot should be seen. [1]

Distance = R_f × distance moved by solvent front

= 0.73 × 12.2 = 8.906 cm

Distance = *8.91* cm

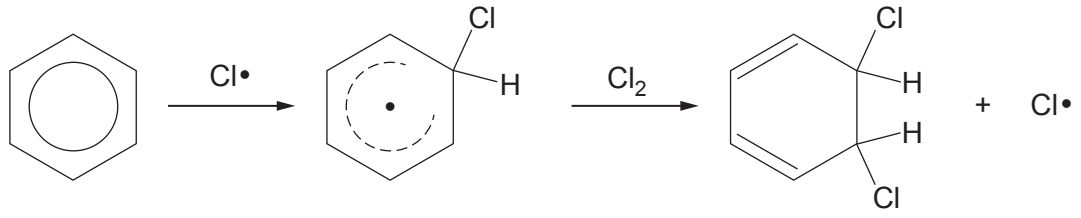
2. (a) State why benzene is normally resistant to addition reactions. [1]

The delocalised π electron ring is very stable; addition would disrupt the delocalised structure, which needs too much energy.

(b) Benzene and chlorine react together in the presence of ultraviolet light to produce chlorinated cyclohexadiene derivatives.

The first stage of this reaction is the production of chlorine radicals, Cl•.

These then react with benzene in a propagation stage.



Explain why these steps are called propagation stages. [1]

Each step uses up a radical but another radical is produced (the intermediate radical, then Cl·), which continues the chain reaction.

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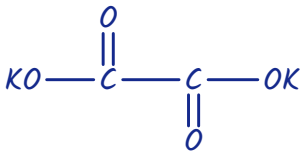
3. 0.0350 mol of the dipotassium salt of an aliphatic dicarboxylic acid has a mass of 5.81 g.

(a) Calculate the relative molecular mass of this compound. [1]

M_r = mass ÷ moles = 5.81 ÷ 0.0350

M_r = 166

(b) Use your answer to part (a) to suggest a structure for this compound. [1]



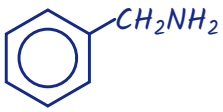
(dipotassium ethanedioate, KOOC–COOK)

4. The mass spectrum of a primary amine, R—NH_2, shows a strong signal at m/z 91 and a molecular ion at m/z 107.

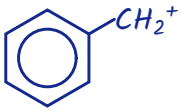
It reacts with cold nitric(III) acid to give nitrogen gas, rather than a diazonium compound.

Use this information to suggest a structure for this amine and for the fragment at m/z 91.

Explain your answer. [3]



amine (M_r 107)



fragment at m/z 91

Nitrogen gas (not a diazonium compound) forms, so it is an aliphatic amine: the NH_2 is not on the benzene ring.

107 − 91 = 16 = loss of NH_2, so m/z 91 is $C_6H_5CH_2^+$ ($C_7H_7^+$) and the amine is $C_6H_5CH_2NH_2$.

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5. The melting and boiling temperatures of three compounds are shown in the table.

Compound	Formula	Melting temperature / °C	Boiling temperature / °C
benzoic acid	C_6H_5COOH	122	249
methyl benzoate	$C_6H_5COOCH_3$	–12	198
ethyl benzoate	$C_6H_5COOCH_2CH_3$	–34	212

(a) In terms of intermolecular bonding, explain why benzoic acid has the highest melting and boiling temperatures of these compounds. [2]

Benzoic acid has hydrogen bonding between its molecules (the esters do not). Hydrogen bonds are stronger than other intermolecular forces, so more energy is needed to overcome them.

(b) In terms of intermolecular bonding, explain why ethyl benzoate has a higher boiling temperature than methyl benzoate. [1]

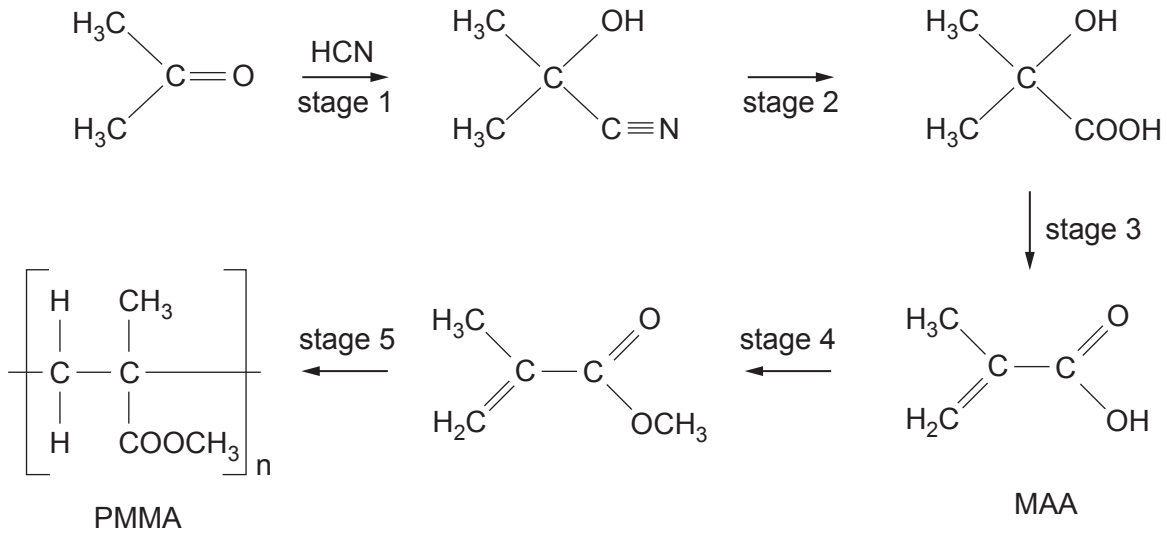
Both have permanent dipole forces, but ethyl benzoate is a larger molecule (more electrons), so it has greater van der Waals forces, needing more energy to overcome.

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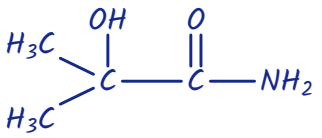
6. The flow chart shows an outline synthesis of poly(methylmethacrylate) (PMMA) starting from propanone.



(a) State the name of the reaction mechanism occurring in stage 1. [1]

nucleophilic addition

(b) Suggest the structure of an intermediate product in stage 2. [1]

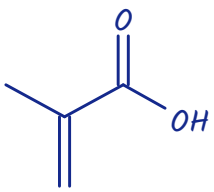


(amide intermediate)

(c) State why stage 5 is described as addition polymerisation and not condensation polymerisation. [1]

No small molecule (such as water) is lost: the monomers simply join together, so there is only one product.

(d) Give the **skeletal** formula of methacrylic acid (MAA). [1]



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SECTION B

Answer **all** questions.

7. (a) Alcohols react with sodium, giving hydrogen as one of the products.

$$2\,Na + 2\,R{-}OH \longrightarrow 2\,RO^{-}Na^{+} + H_2$$

1.23 g of a tertiary alcohol, compound **W**, reacted with sodium and produced 171 cm^3 of hydrogen measured at 25 °C and 1 atm pressure.

(i) Calculate the relative molecular mass of compound **W**. [2]

$n(H_2) = 171 \div 24\,500 = 6.98 \times 10^{-3}$ mol

$n(W) = 2 \times n(H_2) = 0.01396$ mol

$M_r = 1.23 \div 0.01396 = 88.1$

M_r = 88

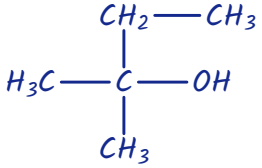
(ii) Deduce the molecular formula of compound **W**. [1]

OH = 17, so alkyl group = 88 − 17 = 71 = C_5H_{11}

Molecular formula $C_5H_{12}O$

(iii) Compound **W** is a tertiary alcohol.

Deduce its structure. [1]



(2-methylbutan-2-ol)

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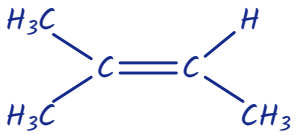
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(iv) I. State a dehydrating agent that will react with compound **W** to give an alkene. [1]

concentrated sulfuric acid, H_2SO_4 (heat)

II. Give the systematic name and the structure of an alkene produced by the dehydration of compound **W**. [2]



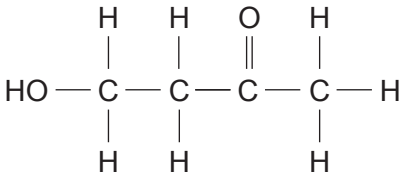
Name 2-methylbut-2-ene

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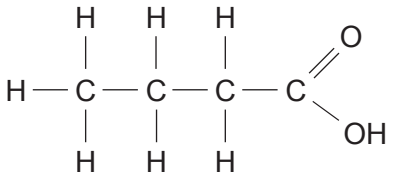
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(b) (i) The compounds shown below are two of many with the molecular formula $C_4H_8O_2$.



4-hydroxybutan-2-one



butanoic acid

Give the results observed when these two compounds are treated in turn with the four reagents in the table. [4]

Reagent	4-hydroxybutan-2-one	butanoic acid
sodium hydrogencarbonate	*no observable change*	*effervescence (CO_2 gas)*
acidified potassium dichromate	*orange to green solution*	*no change, remains orange*
universal indicator solution	*no change, remains green*	*turns orange / red*
aqueous alkaline iodine	*yellow precipitate*	*no observable change*

(ii) Suggest a structure for another compound of molecular formula $C_4H_8O_2$ that has no reaction with any of the reagents listed in part (i). [1]

$CH_3CH_2-C(=O)-O-CH_3$ (methyl propanoate)

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(c) (i) In industry, butanoic acid is obtained by oxidation of butan-1-ol. To separate the acid, a saturated solution of calcium chloride is added, giving calcium butanoate.

Complete the equation for this reaction. [1]

2 $CH_3CH_2CH_2COOH$ + $CaCl_2$ ⟶ $(CH_3CH_2CH_2COO)_2Ca$ + $2HCl$

(ii) Unusually, calcium butanoate is less soluble in hot water than in cold water.

You are given a sample of cold water and impure solid calcium butanoate.

Suggest a method to give a purified sample of calcium butanoate. [2]

Dissolve the impure solid in the minimum of cold water and filter off any insoluble impurities. Warm the filtrate to near boiling, so calcium butanoate crystallises out (less soluble hot). Filter while hot, wash with a little hot water and dry.

(iii) On strong heating, calcium butanoate undergoes decarboxylation to give calcium carbonate and a ketone.

Give the equation for this reaction and name the ketone produced. [2]

$(CH_3CH_2CH_2COO)_2Ca \rightarrow CaCO_3 + CH_3CH_2CH_2COCH_2CH_2CH_3$

Name of ketone heptan-4-one

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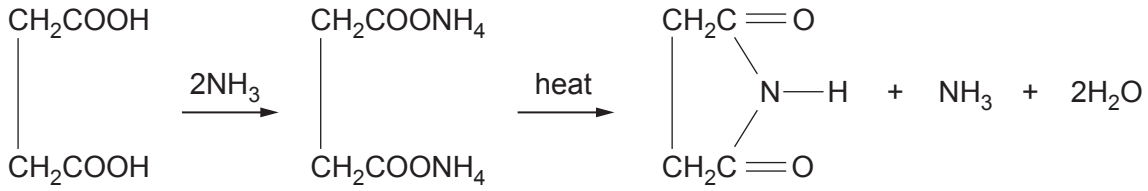
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8. (a) One method of producing an amide is to neutralise a carboxylic acid with ammonia and heat the resulting salt of the acid.

In an experiment, a sample of butanedioic acid (succinic acid) was neutralised by ammonia and the product heated to produce the corresponding cyclic amide (succinimide).



succinic acid succinimide

The melting temperature of the crude cyclic amide is 116-122 °C. After recrystallisation, the pure amide melted at 125 °C.

(i) Suggest **one** impurity that could be present in the crude amide. [1]

unreacted diammonium butanedioate

(ii) The low resolution ^{1}H NMR spectrum of the purified amide showed signals at 2.8 ppm and at 8.9 ppm.

Suggest the protons responsible for these two signals and their relative peak areas. [2]

2.8 ppm: the CH_2 protons next to C=O ($-CH_2-C=O$); 8.9 ppm: the N–H proton.

Relative peak areas CH_2 : NH = 4 : 1

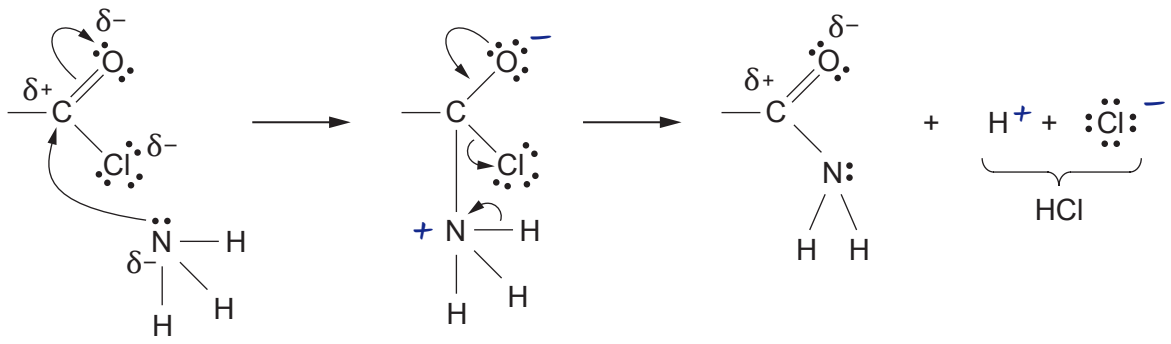
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(b) Another method to produce an amide is to react the corresponding acid chloride with ammonia.

An outline mechanism for the reaction is shown below.



(i) **Complete the mechanism** by adding full charges as appropriate. [2]

(ii) Complete the missing words in the sentence below. [1]

This reaction is a *nucleophilic substitution* reaction, where the attacking reagent is acting as a *nucleophile* .

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(c) Compound **T** is an acid chloride of formula R—COCl, where R is a group containing carbon, hydrogen and chlorine.

(i) Addition of water to 11.76 g of compound **T** hydrolysed only the acid chloride group.

The resulting mixture was treated with aqueous silver nitrate, giving 8.61 g of silver chloride, AgCl.

Use this information to calculate the relative molecular mass of compound **T** and hence the relative mass of the R group. [3]

$n(AgCl) = 8.61 \div 143.5 = 0.0600$ mol

$n(T) = n(AgCl) = 0.0600$ mol (1 : 1)

$M_r(T) = 11.76 \div 0.0600 = 196$

$R = 196 - (12.0 + 16.0 + 35.5) = 132.5$

Relative mass of R = 132.5

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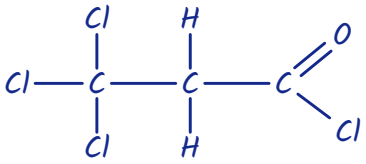
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(ii) The high resolution ^{1}H NMR spectrum of compound **T** shows only a singlet and the ^{13}C NMR spectrum shows three signals.

Use this information and your answer to part (i) to suggest a structure for compound **T**. Give your reasoning. [3]

^{13}C NMR: three signals; one C is in $-COCl$, so R has two carbon environments. ^{1}H NMR: only a singlet, so all protons are in one environment (no H on adjacent C). R = 132.5 = $C_2H_2Cl_3$, so T is CCl_3CH_2COCl.

Structure



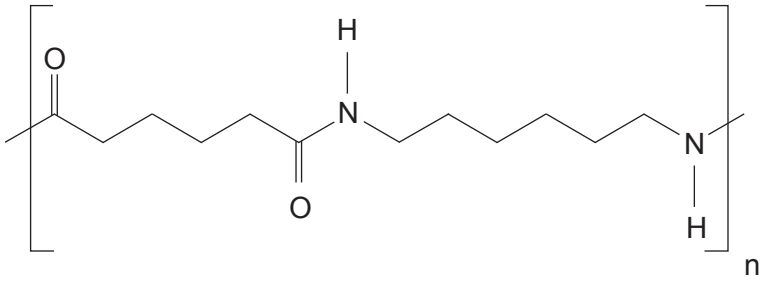
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(d) The formula below shows the repeating structure of the polyamide PA66 (nylon 66).

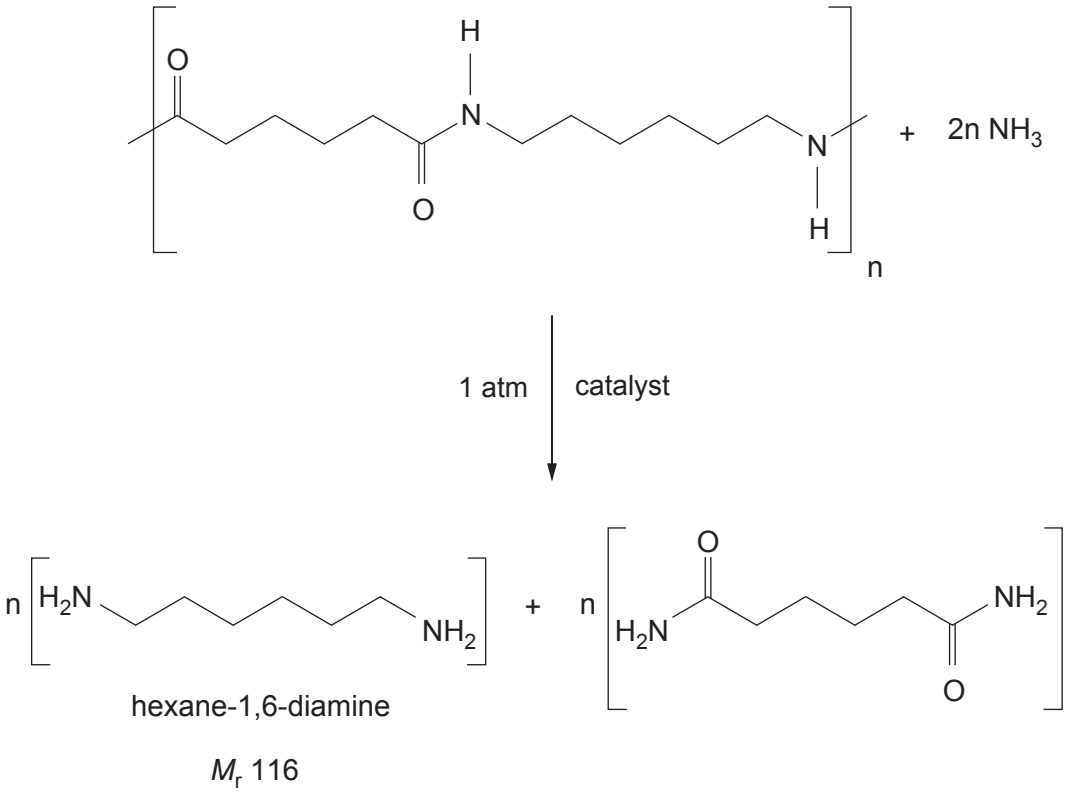


(i) State the **name** of the dicarboxylic acid that is reacted with the diamine to give this polyamide. [1]

hexane-1,6-dioic acid

(ii) PA66 is a very stable polyamide and is resistant to many of the usual methods used to recycle polymers.

A new method has recently been used to recycle PA66. It is carried out at atmospheric pressure in the presence of a suitable catalyst. The method uses propane-1,2,3-triol as the solvent (obtained as a waste product from another process) and a temperature of 200 °C, as compared to 300 °C in other methods.



hexane-1,6-diamine

M_r 116

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I. Suggest **two** reasons why this method can be described as a **green** method. [2]

Only 1 atm and a lower temperature (200 °C): less energy used.

A catalyst is used; the solvent is a recycled waste product.

II. The yield from this process is 68%.

Calculate the mass of the diamine (M_r 116) produced from 0.5 mol of PA66. [1]

n(diamine) = 0.5 × 68 ÷ 100 = 0.34 mol

mass = 0.34 × 116 = 39.44 g

Mass = *39.4* g

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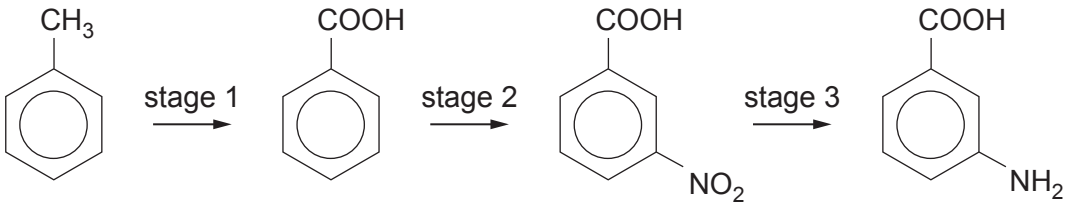
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9. (a) 3-Aminobenzoic acid can be produced in several stages from methylbenzene.



(i) In stage 1, methylbenzene is heated with aqueous alkaline potassium manganate(VII) and then acidified.

State why it is necessary to acidify the mixture to obtain benzoic acid. [1]

Before acidifying, the product is the benzoate ion (potassium benzoate, $C_6H_5COO^-$); the acid protonates it to give benzoic acid.

(ii) 3-Nitrobenzoic acid is produced during stage 2. The reaction is described as an electrophilic substitution.

I. Give the nitrating agent used in stage 2. [1]

concentrated nitric acid and concentrated sulfuric acid

II. Give the formula of the electrophile formed in stage 2. [1]

NO_2^+

(iii) 3-Nitrobenzoic acid obtained in stage 2 is contaminated with some 2-nitrobenzoic acid.

State how the presence of this impurity would affect the melting temperature of 3-nitrobenzoic acid. [1]

The melting temperature would be lower, and it would melt over a range of temperatures.

(iv) 3-Nitrobenzoic acid is reduced to 3-aminobenzoic acid in stage 3.

State the reducing agent for this reaction. [1]

tin and concentrated hydrochloric acid

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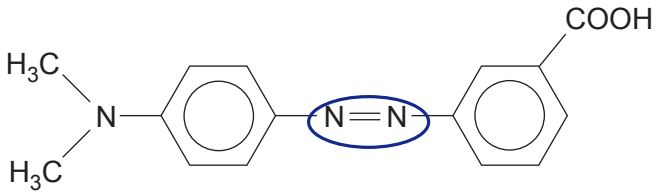
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(b) A diazonium compound can be produced from 3-aminobenzoic acid by reaction with nitric(III) acid.

(i) State the temperature used for this reaction. [1]

5 to 10 °C

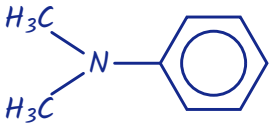
(ii) The diazonium compound reacts with an aromatic amine to produce the azo dye whose formula is shown below.



I. Azo dyes contain a chromophore, which is partly responsible for their colour.

Circle the chromophore present in the azo dye shown above. [1]

II. Draw the structure of the aromatic amine used to produce this azo dye. [1]



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(iii) This azo dye is red in colour and has a maximum absorption in the visible spectrum at 420 nm.

I. State why the dye is red in colour. [1]

It absorbs light at the blue end of the visible spectrum (420 nm), so the complementary colour, red, is transmitted and seen.

II. Calculate the energy, in kJ mol^{-1}, associated with this absorption at 420 nm. [2]

$E = hf$ and $f = c \div \lambda$, so $E = hc \div \lambda$

$E = (6.63 \times 10^{-34} \times 3.00 \times 10^{8}) \div (420 \times 10^{-9})$

$= 4.74 \times 10^{-19}$ J per molecule

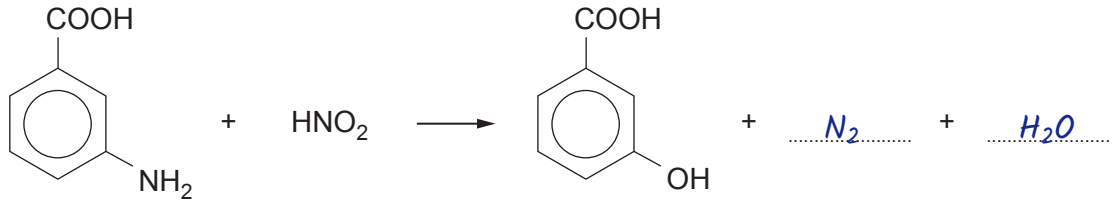
per mole: $4.74 \times 10^{-19} \times 6.02 \times 10^{23} = 2.85 \times 10^{5}$ J mol^{-1}

$= 285$ kJ mol^{-1}

Energy = ..285.. kJ mol^{-1}

(iv) The diazonium compound produced from 3-aminobenzoic acid by reaction with nitric(III) acid is not stable at higher temperatures. It breaks down to form 3-hydroxybenzoic acid.

Complete the equation for this reaction. [1]



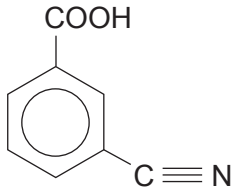
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(v) Diazonium compounds have many reactions other than producing azo dyes.

3-Cyanobenzoic acid can be produced from a diazonium intermediate.



This can then be hydrolysed to produce benzene-1,3-dioic acid.

I. State a reagent that can be used for this hydrolysis. [1]

dilute aqueous sulfuric acid (heat under reflux)

II. The progress of this reaction can be monitored using infrared spectroscopy.

Suggest how you would confirm that this hydrolysis is complete. Use information from the **Data Booklet**. [1]

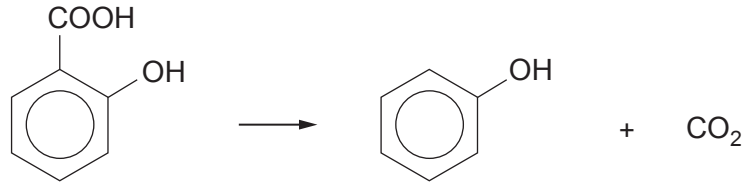
The C≡N absorption at 2100 to 2250 cm^{-1} will be absent when the hydrolysis is complete.

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(c) 2-Hydroxybenzoic acid decomposes when heated to 200 °C.



If phenol is removed from the reaction mixture as it is formed, then the yield can be above 50%.

(i) In a reaction, 6.90 g of 2-hydroxybenzoic acid was heated.

Calculate the mass of phenol produced if the yield is 60%. [2]

M_r: 2-hydroxybenzoic acid = 138, phenol = 94

n(acid) = 6.90 ÷ 138 = 0.0500 mol

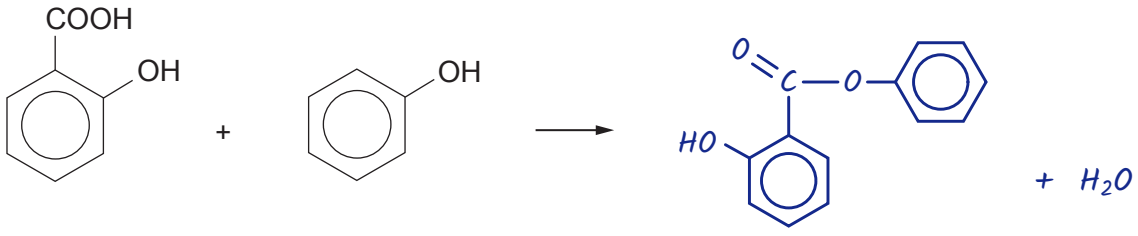
100% yield: 0.0500 × 94 = 4.70 g

60% yield: 4.70 × 60 ÷ 100 = 2.82 g

Mass = 2.82 g

(ii) The yield of phenol in this reaction is relatively low because some of the phenol produced reacts with unreacted 2-hydroxybenzoic acid to give phenyl 2-hydroxybenzoate.

Complete the equation for this esterification reaction. [1]



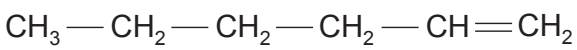
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10. (a) Hex-1-ene reacts with hydrogen bromide to form 2-bromohexane (boiling temperature 143 °C) and small amounts of 1-bromohexane (boiling temperature 155 °C).



hex-1-ene

(i) State the name of the mechanism occurring during this reaction. [1]

electrophilic addition

(ii) Explain why 2-bromohexane is the major product of this reaction. [1]

It forms via a secondary carbocation, which is more stable (formed more easily) than the primary carbocation.

(iii) Suggest a method that can be used to separate these two isomers. [1]

fractional distillation

(iv) A gas-liquid chromatogram of the products shows the presence of 1-bromohexane and 2-bromohexane (M_r 165) and some unreacted hex-1-ene.

Analysis of the mixture shows that 6.11 g of the mixture contains 2.85 g of bromine.

Calculate the percentage of unreacted hex-1-ene present. [2]

mass of bromohexanes = 2.85 × 165 ÷ 79.9 = 5.89 g

mass of hex-1-ene = 6.11 − 5.89 = 0.22 g

percentage = 0.22 ÷ 6.11 × 100 = 3.60%

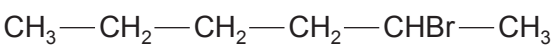
Percentage = *3.60* %

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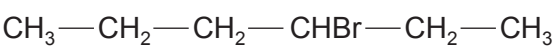
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(b) The reaction of hex-2-ene with hydrogen bromide gives a mixture of 2-bromohexane and 3-bromohexane in roughly equal proportions.



2-bromohexane

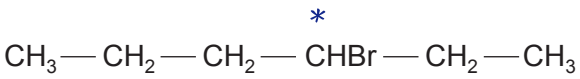


3-bromohexane

(i) Suggest why this reaction produces two products in roughly equal proportions unlike the reaction in part (a). [1]

Both intermediates are secondary carbocations of similar stability, so neither product is favoured.

(ii) I. Indicate the position of the chiral centre in 3-bromohexane by using an asterisk (*) on the structure below. [1]



II. Suggest why a sample of 3-bromohexane prepared in this way appears optically inactive when placed in a polarimeter. [1]

It is a racemic mixture: equal amounts of both enantiomers (planar carbocation attacked equally from both sides), so rotations cancel.

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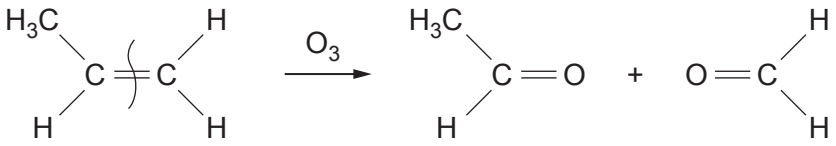
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(c) (i) Ozone can be used in analysis to find the position of a carbon-carbon double bond in a compound.

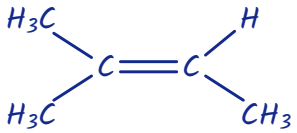
In the reaction, the double bond is broken, giving aldehydes and/or ketones.

For example, from propene



An alkene of formula C_5H_{10} reacts with ozone to produce ethanal and propanone.

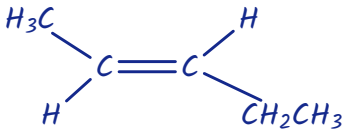
Deduce the structure of the alkene. Show your reasoning. [2]



(2-methylbut-2-ene)

The C=C is cleaved: the carbon with two CH_3 groups gives propanone (three carbon ketone) and the carbon with CH_3 and H gives ethanal (two carbon aldehyde), so the alkene is $(CH_3)_2C=CHCH_3$.

(ii) Give the structure of an alkene of formula C_5H_{10} that shows *E-Z* isomerism. [1]



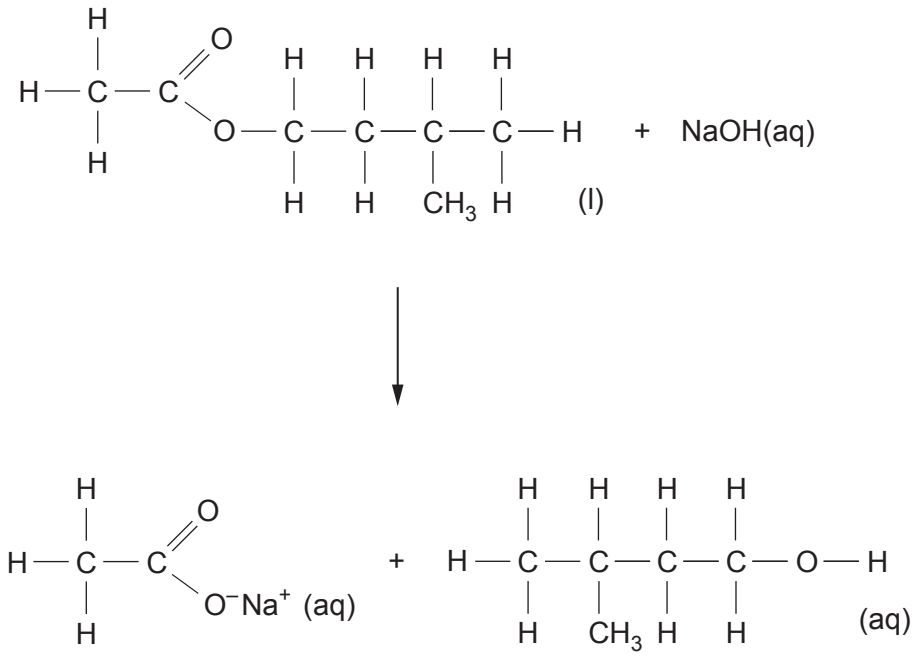
(E)-pent-2-ene

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(d) 3-Methylbutyl ethanoate is used as a banana flavouring in the food industry.

When it is refluxed with aqueous sodium hydroxide it produces sodium ethanoate and 3-methylbutan-1-ol.



Sodium ethanoate is soluble in the reaction mixture whereas 3-methylbutan-1-ol is only slightly soluble.

3-Methylbutan-1-ol can be extracted from the reaction mixture by solvent extraction with ethoxyethane, using a separating funnel. Evaporation of the ethoxyethane will leave 3-methylbutan-1-ol, which can then be further purified.

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Outline the method that you would use to obtain pure 3-methylbutan-1-ol.

Use the following information in planning your answer.

- 3-Methylbutan-1-ol is much more soluble in ethoxyethane than in water
- Ethoxyethane is less dense than the aqueous mixture
- Ethoxyethane is immiscible with the aqueous reaction products
- Solid anhydrous magnesium sulfate is used to dry the ethoxyethane layer
- Ethoxyethane is very flammable
- The boiling temperature of ethoxyethane is 35 °C [6 QER]

Pour the reaction mixture into a separating funnel (tap closed) and add about the same volume of ethoxyethane; 3-methylbutan-1-ol is much more soluble in ethoxyethane than in water, so it moves into the ethoxyethane.

Replace the stopper and shake, inverting and opening the tap often to release pressure. Clamp the funnel, remove the stopper and allow the two immiscible layers to separate.

Ethoxyethane is less dense, so it is the upper layer: run off the lower aqueous layer into a beaker, then collect the ethoxyethane layer in a dry flask.

Return the aqueous layer to the funnel and repeat the extraction with fresh ethoxyethane; combine the extracts.

Add anhydrous magnesium sulfate to the extract and shake until clear (dried); filter off the solid magnesium sulfate.

Distil off the ethoxyethane (35 °C) using an electric heater or water bath, with no naked flames as it is very flammable; then distil the remaining 3-methylbutan-1-ol to purify it.

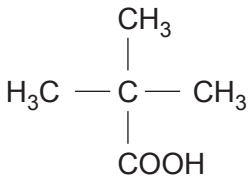
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11. (a) The formula of pivalic acid is shown below.



(i) Give the systematic name of this acid. [1]

2,2-dimethylpropanoic acid

(ii) Pivalic acid reacts with methanol to give the ester methyl pivalate, $(CH_3)_3CC(O)OCH_3$.

I. State a catalyst used for this reaction. [1]

concentrated sulfuric acid

II. Describe the high resolution ^1H NMR spectrum of methyl pivalate.

Include approximate chemical shifts and details of any peak splitting. Explain your reasoning. [3]

Two peaks (two proton environments), both singlets: no splitting, as no adjacent carbon atom has any protons.

$(CH_3)_3C-$ protons: about 0.9 to 1.2 ppm (0.1 to 2.0), 9H.

$-O-CH_3$ protons: about 3.7 ppm (3.3 to 4.3), deshielded by the O, 3H.

Peak areas 9 : 3 = 3 : 1.

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(iii) The acid reacts with phosphorus(V) chloride to give the corresponding acid chloride, pivaloyl chloride.

$$(CH_3)_3C{-}COOH(l) + PCl_5(s) \longrightarrow (CH_3)_3C{-}COCl(l) + POCl_3(l) + HCl(g)$$

boiling temp 106°C — boiling temp 106°C

Suggest **two** problems with this method to produce pivaloyl chloride. [2]

1. *Two products have the same boiling temperature (106 °C), so pivaloyl chloride is difficult to separate from $POCl_3$ by distillation.*

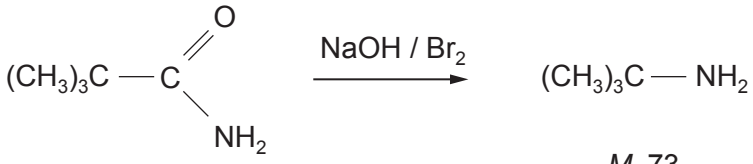
2. *Toxic HCl gas is produced, so it needs containment / must be carried out in a fume cupboard.*

(iv) One method to produce pivalamide, $(CH_3)_3C{-}CONH_2$, is to slowly add pivaloyl chloride to a dilute aqueous solution of ammonia.

Suggest why this method may give a poor yield of pivalamide. [1]

Some of the pivaloyl chloride is hydrolysed by the water present in the aqueous ammonia (to pivalic acid), so less amide forms.

(v) Amides, such as pivalamide, react with an alkaline solution of bromine producing an amine.



M_r 73

In a reaction, 0.10 mol of pivalamide gave an 82% yield of $(CH_3)_3C{-}NH_2$.

Calculate the mass of the amine obtained. Give your answer to an **appropriate** number of significant figures. [2]

mass = 0.10 × 82 ÷ 100 × 73

= 5.986 g

Mass = *6.0* g

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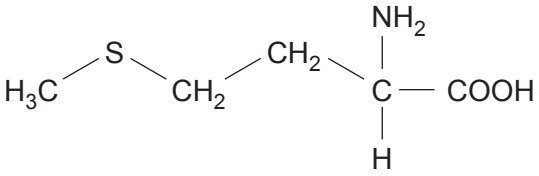
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(b) Explain why an aqueous solution of the amine produced in part (a)(v) has a pH greater than 7. Give an equation as part of your answer. [2]

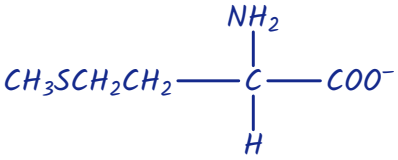
$(CH_3)_3C{-}NH_2 + H_2O \rightleftharpoons (CH_3)_3C{-}NH_3^+ + OH^-$

The lone pair on the nitrogen atom accepts a proton (acts as a base / electron pair donor), so OH^- ions are released.

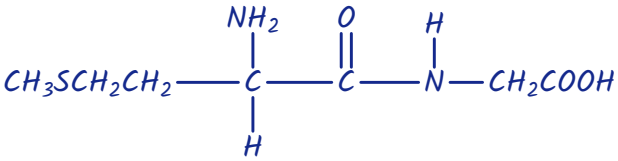
(c) The structure of the α-amino acid methionine is shown below.



(i) Give the structure of the species formed from methionine in a strongly alkaline solution. [1]



(ii) Give the structure of one of the dipeptides formed between methionine and glycine (aminoethanoic acid). [1]

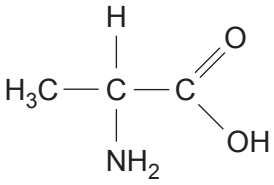


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(d) The structure of the α-amino acid alanine is shown below.



Explain why this compound has a very high melting temperature. [2]

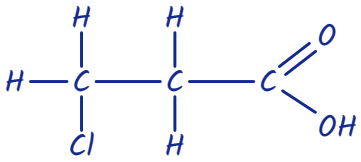
It exists as a zwitterion, $H_3C-CH(NH_3^+)-COO^-$, so there are strong ionic forces between the 'molecules'.

(e) Propanoic acid reacts with chlorine giving 2-chloropropanoic acid.

$$CH_3CH_2COOH + Cl_2 \longrightarrow CH_3CHClCOOH + HCl$$

The yield of 2-chloropropanoic acid is around 85% as other chlorinated propanoic acids are also produced.

(i) Suggest the structure of a monochlorinated propanoic acid that does **not** contain a chiral centre. [1]

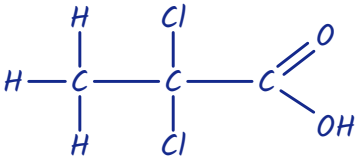


(3-chloropropanoic acid)

(ii) Another product of this reaction is a chlorine-containing propanoic acid that contains 49.7% chlorine by mass.

Show that this compound could be 2,2-dichloropropanoic acid.

Give its structure as part of your answer. [2]



M_r of CH_3CCl_2COOH = 143

% Cl = (2 × 35.5) ÷ 143 × 100

= 71 ÷ 143 × 100 = 49.7%

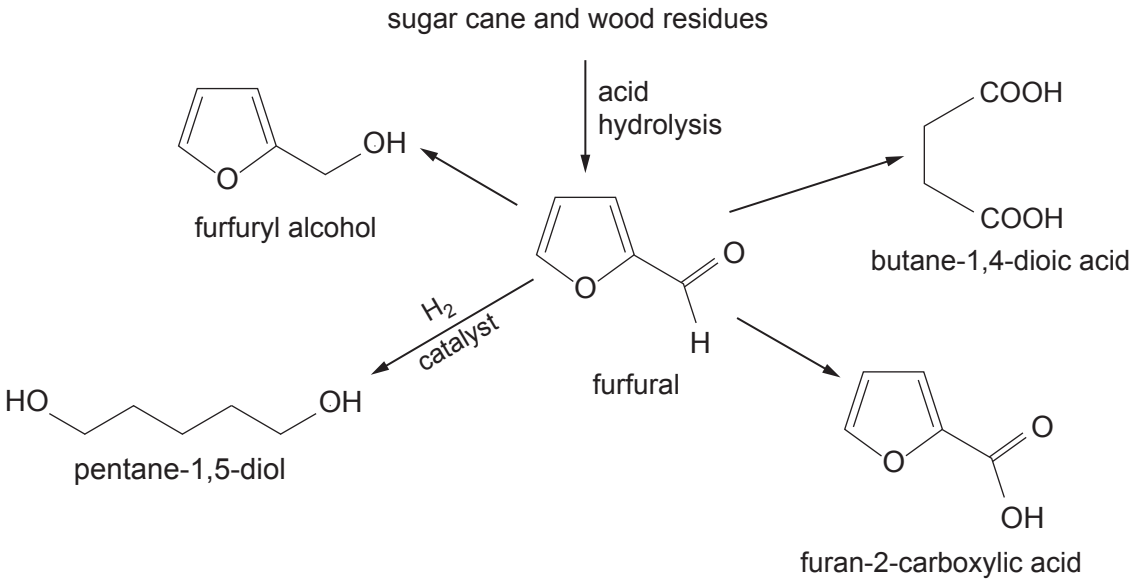
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12. (a) The preparation and some of the reactions of the aldehyde furfural are shown below.



(i) Wood residues contain pentose sugars, mainly xylose and arabinose. Both of these sugars are reducing agents and give a positive test with Fehling's reagent.

State what is seen during this test. Give the appearance of the reagent before and after the test. [1]

The deep blue solution gives a brown-red (brick-red) precipitate of copper(I) oxide.

(ii) Furfural behaves like benzaldehyde in many of its reactions.

I. Suggest a reagent that will produce furan-2-carboxylic acid when reacted with furfural. Give any observations. [1]

Acidified potassium dichromate (warm): the orange solution turns green.

II. State a reagent that can be used to produce furfuryl alcohol from furfural. [1]

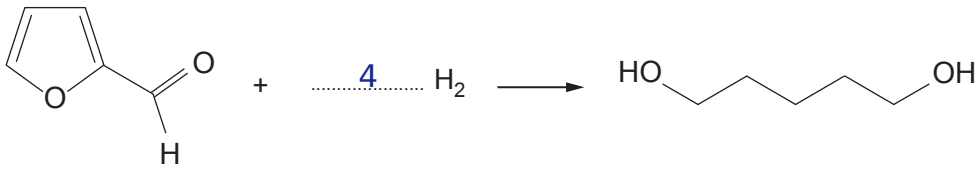
sodium tetrahydridoborate(III), $NaBH_4$

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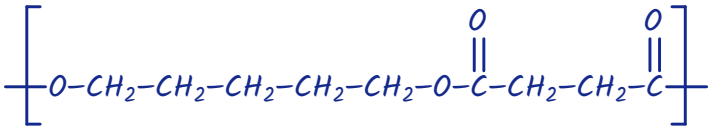
(iii) I. Furfural can be hydrogenated in a number of stages to give pentane-1,5-diol.



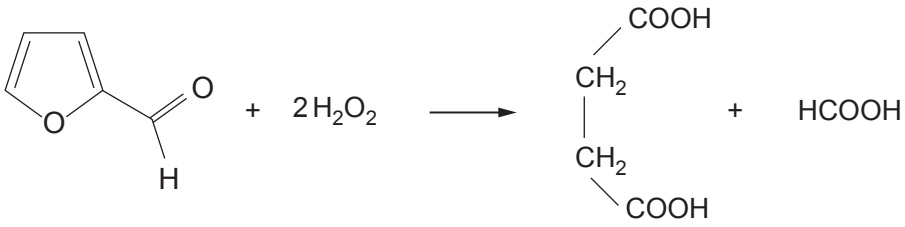
Balance the equation by inserting the number of moles of hydrogen required. [1]

II. Pentane-1,5-diol reacts with butane-1,4-dioic acid to produce a polyester.

Give the structure of the repeating unit of the polyester. [1]



(iv) Butane-1,4-dioic acid is produced by the reaction of aqueous furfural and hydrogen peroxide.



Calculate the atom economy of this reaction to produce butane-1,4-dioic acid. [1]

M_r: $C_5H_4O_2$ = 96, H_2O_2 = 34, $C_4H_6O_4$ = 118

atom economy = 118 ÷ (96 + 2 × 34) × 100

= 118 ÷ 164 × 100 = 71.95%

Atom economy = 72.0 %

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(b) You are given a sample of sodium benzoate that is contaminated with sodium hydroxide.

Devise a method to produce pure benzoic acid from this sample. Describe how you would find the percentage of sodium benzoate in the original sample.

Use the following information in planning your answer.

- Sodium benzoate is soluble in cold water
- Sodium benzoate reacts with hydrochloric acid to produce benzoic acid

$$C_6H_5COO^-Na^+(aq) + HCl(aq) \longrightarrow C_6H_5COOH(s) + NaCl(aq)$$

- Benzoic acid is insoluble in cold water
- The conversion of sodium benzoate to benzoic acid is 100%

[6 QER]

Weigh a sample of the impure sodium benzoate accurately (by difference) on a balance.

Dissolve it in cold distilled water in a beaker, stirring until it has all dissolved.

Add hydrochloric acid, stirring, until no more white benzoic acid precipitates (excess acid); the sodium hydroxide is neutralised to NaCl, which stays in solution.

Filter off the benzoic acid (suction filtration), wash it with a little cold water to remove NaCl and HCl, then dry it (oven or desiccator) to constant mass.

Weigh the dry benzoic acid crystals.

Calculation: moles of benzoic acid = mass ÷ 122. Conversion is 100% and 1 : 1, so moles of sodium benzoate = moles of benzoic acid, and mass of sodium benzoate = moles × 144.

Percentage of sodium benzoate = mass of sodium benzoate ÷ mass of original sample × 100.

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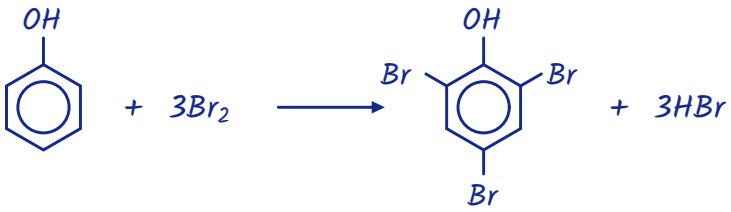
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(c) When aqueous bromine is added dropwise to an aqueous solution of phenol, the red-brown colour of the bromine disappears and a white precipitate appears.

Name the white precipitate formed and give an equation for the reaction. [2]

Name 2,4,6-tribromophenol



(d) The concentration of phenols in dilute aqueous solutions can be found using colorimetry.

Analysis of a sewage sample showed that the concentration of 4-nitrophenol present was 235 µg dm^{-3}.

Calculate the concentration of 4-nitrophenol in this sample in mol dm^{-3}. [2]

M_r(4-nitrophenol, $C_6H_5NO_3$) = 139

235 µg dm^{-3} = 235 × 10^{-6} g dm^{-3}

concentration = 235 × 10^{-6} ÷ 139

Concentration = 1.69 × 10^{-6} mol dm^{-3}

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(e) (i) Suggest why phenylethanoic acid ($C_6H_5CH_2COOH$) has a relatively low solubility in water. [1]

Only the polar COOH group can hydrogen bond with water molecules; it is a small part of the molecule, as the non-polar $C_6H_5CH_2$ part is large, so its effect is limited.

(ii) A saturated aqueous solution of phenylethanoic acid ($C_6H_5CH_2COOH$) was titrated against sodium hydroxide solution.

$25.0\,cm^3$ of the phenylethanoic acid solution was just neutralised by $24.50\,cm^3$ of $0.100\,mol\,dm^{-3}$ sodium hydroxide solution.

Show that the solubility of phenylethanoic acid in water at this temperature is $13.3\,g\,dm^{-3}$. [2]

$n(NaOH) = 24.50 \times 0.100 \div 1000 = 2.45 \times 10^{-3}$ mol

ratio 1 : 1, so 2.45×10^{-3} mol of acid in 25.0 cm^3

in 1 dm^3: $2.45 \times 10^{-3} \times 1000 \div 25.0 = 0.0980$ mol

$M_r(C_6H_5CH_2COOH) = 136$

solubility = $0.0980 \times 136 = 13.3$ g dm^{-3}

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