

Surname <i>StemUp Model Solution</i>	Centre Number	Candidate Number
First name(s)		2



GCE A LEVEL

1410U40-1



S23-1410U40-1

MONDAY, 19 JUNE 2023 – AFTERNOON

CHEMISTRY – A2 unit 4

Organic Chemistry and Analysis

1 hour 45 minutes

Section A

Section B

For Examiner's use only		
Question	Maximum Mark	Mark Awarded
1. to 7.	10	
8.	13	
9.	15	
10.	15	
11.	15	
12.	12	
Total	80	

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ADDITIONAL MATERIALS

In addition to this examination paper, you will need a:

- calculator;
- **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.

Candidates are advised to allocate their time appropriately between **Section A (10 marks)** and **Section B (70 marks)**.

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 80.

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(a)**.

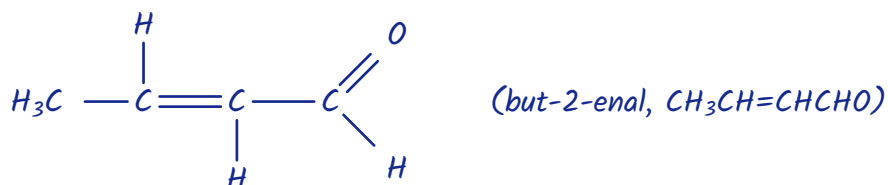


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SECTION A

Answer **all** questions.

1. Give the structure of an unsaturated aldehyde of molecular formula C_4H_6O . [1]



2. State a group that will give a positive triiodomethane (iodoform) test and give the observation for a positive result. [2]

Group: $\text{CH}_3\text{CO}-$ (methyl carbonyl / methyl ketone) or $\text{CH}_3\text{CH}(\text{OH})-$

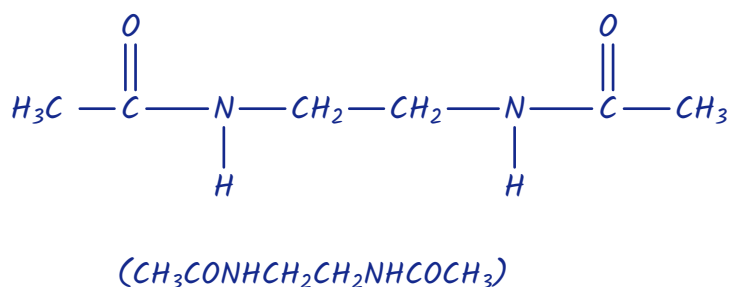
Observation: a (pale) yellow precipitate (solid) of CHI_3 forms.

3. (a) 1,2-Diaminoethane reacts as a base. [1]
- Explain how this compound acts as a base.

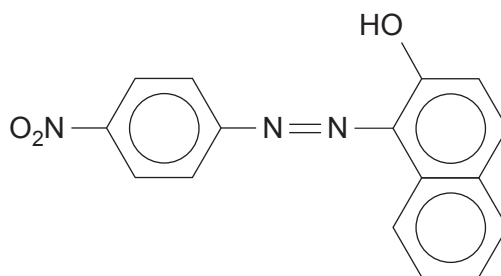
Each nitrogen atom has a lone pair of electrons which can accept a proton

(H^+) by forming a dative bond.

- (b) Give the structure of the organic compound formed when 1 mole of 1,2-diaminoethane reacts with 2 moles of ethanoyl chloride. [1]



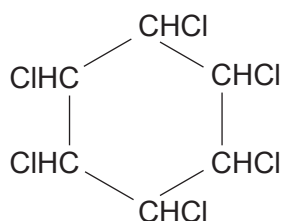
4. The formula of the azo dye, Para Red, is shown below.



Give the structure of the compound that couples with 4-nitrobenzenediazonium chloride to give this dye. [1]



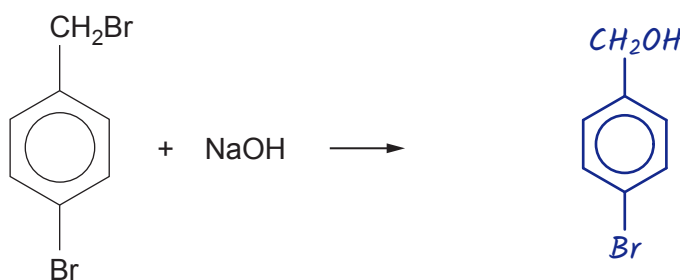
5. Hexachlorocyclohexane can be used as an insecticide.



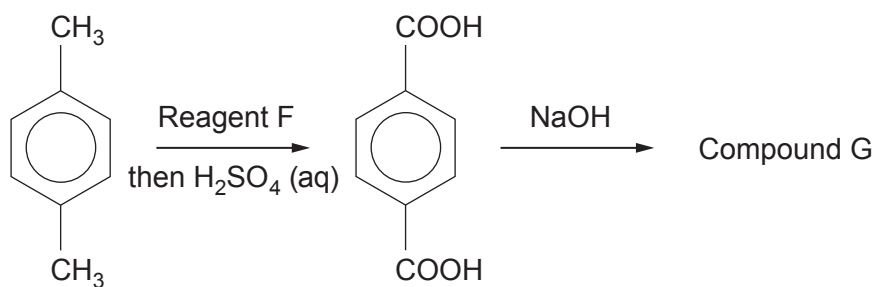
Deduce the empirical formula of this compound. [1]

CHCl

6. Give the structure of the organic product of the reaction below. [1]

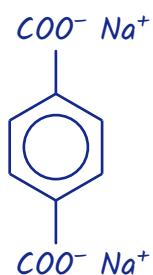


7. Study the reaction sequence below and answer the **two** questions that follow.



(a) Reagent F is alkaline potassium manganate(VII) [1]

(b) Give the structure of Compound G. [1]



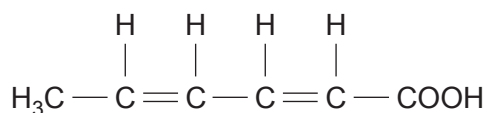
(disodium benzene-1,4-dicarboxylate)



Section B

Answer **all** questions.

8. (a) Sorbic acid was isolated in 1859 from mountain ash berry oil. It is a white solid that is slightly soluble in cold water.



- (i) The solubility of sorbic acid in water is 1.6 g dm^{-3} at 20°C and 40.0 g dm^{-3} at 100°C .

Calculate how much sorbic acid is precipitated from its aqueous solution if 200 cm^3 of a saturated solution at 100°C is cooled to 20°C .

Give your answer to an appropriate number of significant figures. [2]

at 100°C , 200 cm^3 contains $40.0 \times 0.200 = 8.0 \text{ g}$

at 20°C , 200 cm^3 contains $1.6 \times 0.200 = 0.32 \text{ g}$

mass precipitated = $8.0 - 0.32 = 7.68 \text{ g} = 7.7 \text{ g}$ (2 s.f.)

7.7

g

- (ii) Sorbic acid and its salts, for example sodium sorbate, have important uses as antimicrobial agents in food preservation. Some moulds are, however, able to detoxify the action of these sorbates. An example is the decarboxylation of sodium sorbate.

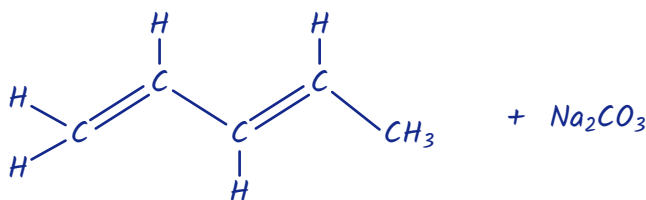
I. State what is meant by 'decarboxylation'. [1]

Loss of carbon dioxide, CO_2 (removal of a carboxyl, COO , group).

- II. In the laboratory sodium sorbate can be decarboxylated by heating it with soda lime.

The organic product of decarboxylation is *E*-penta-1,3-diene.

Write the equation for this decarboxylation of sodium sorbate with soda lime (which you should represent as NaOH in your equation), showing the structure of *E*-penta-1,3-diene. [2]

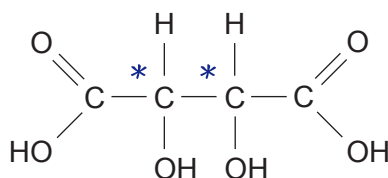


- III. *E*-penta-1,3-diene can then react with hydrogen using platinum as a catalyst giving pentane.

State the number of moles of hydrogen required to react with 0.2 mol of *E*-penta-1,3-diene in this way. [1]

0.4 mol of hydrogen (H₂)

- (b) Tartaric acid (2,3-dihydroxybutanedioic acid) is used in the food industry.



- (i) Indicate any chiral centre(s) present by means of an asterisk (*). [1]

- (ii) This acid occurs in a number of optically active forms. Complete the sentences below.

Forms of tartaric acid that rotate the plane of plane-polarised light are called

enantiomers

A solution containing an equimolar mixture of two forms of the acid that rotates the plane of plane-polarised light in equal and opposite directions is called a

racemic mixture (racemate)

- (c) Both sorbic acid and tartaric acid are described as showing stereoisomerism.

Explain what is meant by the term stereoisomerism. [1]

Molecules with the same structural formula but a different arrangement of their atoms in space (a different 3D arrangement).

- (d) Tartaric acid is formed when butenedioic acid reacts with a suitable oxidising agent.

Give the equation for this reaction, representing the oxidising agent as [O] and using water as a reactant. [1]



- (e) The solubility of unsaturated carboxylic acids in water decreases as the chain length increases.

Number of carbon atoms in the alkyl chain	Solubility in water at 25 °C / g dm ⁻³
3	94
5	1.6
7	0.7

Suggest why this solubility decreases as the chain length increases.

[2]

The polar COOH group forms hydrogen bonds with water molecules, which allows the acid to dissolve.

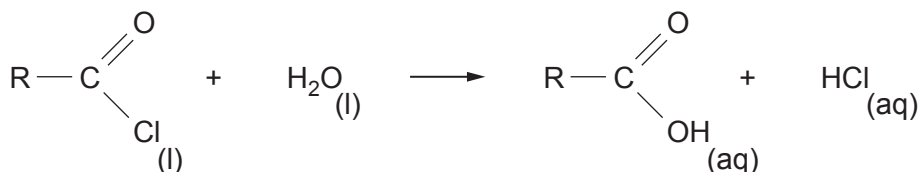
As the hydrocarbon chain gets longer, the polar group forms an increasingly smaller part of a largely non-polar molecule, so solubility decreases.

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9. (a) 1.598 g of an acid chloride, RCOCl , was added to water. The aqueous solution contained hydrochloric acid and a carboxylic acid, $\text{R}-\text{COOH}$, where R is an alkyl group



- (i) State the type of reaction occurring.

[1]

Hydrolysis

- (ii) This acidic solution was titrated with $0.400 \text{ mol dm}^{-3}$ aqueous sodium hydroxide, using a suitable indicator. Both acids were just neutralised by 75.00 cm^3 of the sodium hydroxide solution.

Use the results to calculate the relative molecular mass of the acid chloride.

[3]

$$\text{moles of NaOH} = 75.00/1000 \times 0.400 = 0.0300 \text{ mol}$$

$$\text{total moles of acid (HCl + RCOOH)} = 0.0300 \text{ mol}$$

$$\text{equal moles of each acid, so moles RCOOH} = 0.0150 \text{ mol}$$

$$= \text{moles of RCOCl} = 0.0150 \text{ mol}$$

$$M_r \text{ of RCOCl} = 1.598 / 0.0150 = 106.5$$

$$M_r \text{ } 106.5$$

- (iii) The low resolution ^1H NMR spectrum of the acid chloride showed two signals in the peak area ratio of 6:1.

Use this information and the relative molecular mass of the RCOCl , obtained in part (ii), to find the structure of the acid chloride.

[2]

$$M_r \text{ of COCl} = 12.0 + 16.0 + 35.5 = 63.5$$

$$\text{so } M_r \text{ of R} = 106.5 - 63.5 = 43, \text{ so R is } \text{C}_3\text{H}_7$$

peak ratio 6:1 means two equivalent CH_3 groups (6H)

and one CH (1H), so R is $(\text{CH}_3)_2\text{CH}-$

acid chloride is $(\text{CH}_3)_2\text{CHCOCl}$ (2-methylpropanoyl chloride)



- (b) (i) The acid chloride, benzene-1,4-dicarbonyl dichloride, $\text{ClOC} - \text{C}_6\text{H}_4 - \text{COCl}$ is made by reacting benzene-1,4-dicarboxylic acid with phosphorus(V) chloride. The other products of this reaction are hydrogen chloride and phosphoryl trichloride, POCl_3 .

Give the equation for this reaction.

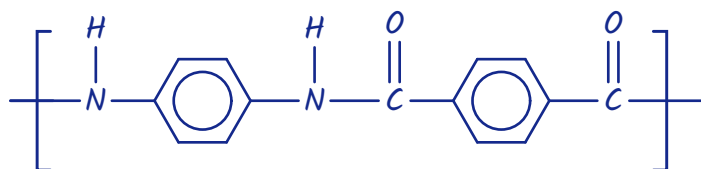
[1]



- (ii) Benzene-1,4-dicarbonyl dichloride reacts with benzene-1,4-diamine to give a polyamide.

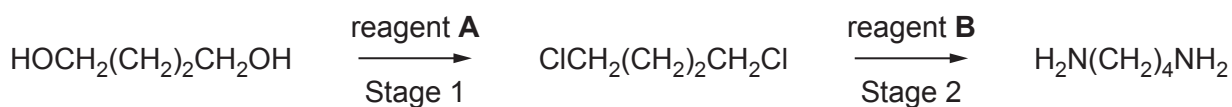
Show the repeating unit for this polyamide.

[1]



- (c) Nylon polyamides that are produced from starting materials with a different number of carbon atoms are given numbers. For example Nylon 4,5 has a 4-carbon diamine fragment and a 5-carbon dicarboxylic acid fragment.

Butane-1,4-diamine can be used as a starting material for this polyamide. This can be produced in a two-stage reaction from butane-1,4-diol.



- (i) State the name of reagent(s) **A**.

[1]

Phosphorus(V) chloride, PCl_5 (or thionyl chloride, SOCl_2)

- (ii) State the name of reagent(s) **B**.

[1]

Ammonia, NH_3 (excess, in ethanol)



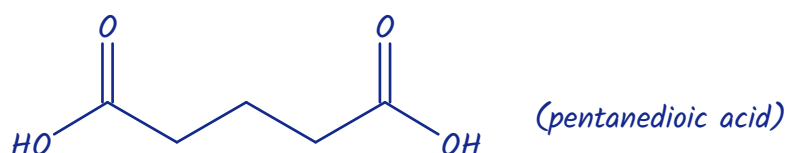
- (iii) State the type of mechanism occurring in Stage 2.

[1]

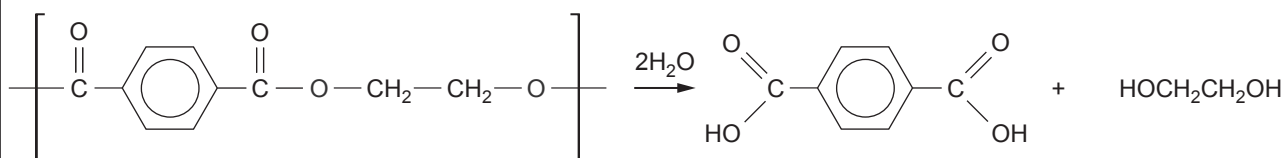
Nucleophilic substitution

- (iv) Draw the **skeletal** formula of the 5-carbon containing dicarboxylic acid used to produce Nylon 4,5.

[1]



- (d) The depolymerisation of polyamides and polyesters present a number of difficult problems as these polymers are very stable and only slowly decompose in the environment. Poly(ethyleneterephthalate) (PET) is very difficult to hydrolyse but a new process using specific enzymes is proving promising. In this process 90% of PET is depolymerised into benzene-1,4-dicarboxylic acid.



Calculate the mass of benzene-1,4-dicarboxylic acid produced from 75 kg of PET if the yield from this hydrolysis is 90%.

[3]

M_r of repeating unit, $C_{10}H_8O_4 = 192$

M_r of benzene-1,4-dicarboxylic acid, $C_8H_6O_4 = 166$

1 mol of repeating unit gives 1 mol of acid

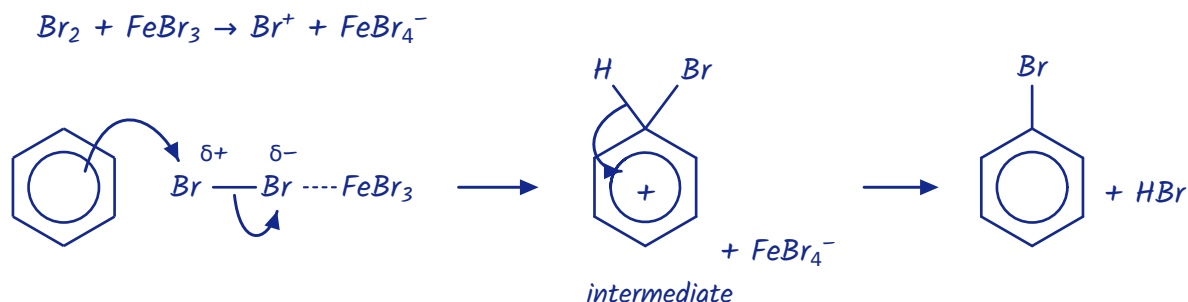
mass of acid = $75 \times 166/192 \times 90/100$

= 58.4 kg

mass of benzene-1,4-dicarboxylic acid produced = 58.4 kg



10. (a) Benzene reacts with bromine in the presence of a catalyst. Give the mechanism for this reaction and explain how the Br — Br bond becomes polarised during the reaction. Suggest why, in the absence of this catalyst, there is very little reaction between benzene and bromine under normal conditions. [6 QER]



Catalyst: iron(III) bromide, FeBr_3 (iron filings react with Br_2 to form it). The iron atom in FeBr_3 is electron deficient (only six outer electrons), so it accepts an electron pair from one Br atom. This draws electron density away from the Br—Br bond, which becomes polarised $\text{Br}^{\delta+}-\text{Br}^{\delta-}$, giving the electrophile Br^+ and FeBr_4^- .

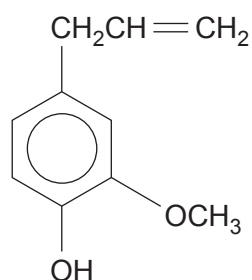
The delocalised π electron system of benzene attracts the $\delta+$ Br (electron movement from the π system): a pair of π electrons forms a new C—Br bond while the Br—Br bond breaks heterolytically. This gives a positive intermediate in which the delocalisation is partly lost.

The C—H bond then breaks and its electrons return to the ring, restoring the stable delocalised π system and giving bromobenzene (electrophilic substitution). The H^+ reacts with FeBr_4^- , producing the co-product hydrogen bromide, HBr , and regenerating the FeBr_3 catalyst.

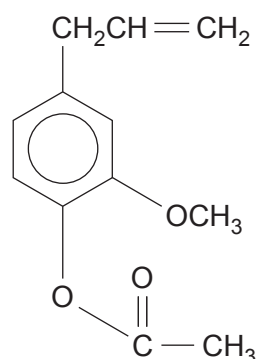
Without the catalyst there is only a little induced polarisation of the Br_2 molecule by the π electron system. The π electrons in benzene are delocalised, so their electron density is lower than in the localised π bond of an alkene; Br_2 is not polarised enough to give an electrophile strong enough to disrupt the stable delocalised ring, so there is very little reaction.



- (b) Eugenol is the main constituent of clove oil, together with smaller quantities of eugenyl ethanoate.



Eugenol



Eugenyl ethanoate

- (i) Describe what is seen if a few drops of iron(III) chloride solution are added to a solution of eugenol. [1]

A purple (blue-violet) colouration forms.

- (ii) State the colour change that occurs if a few drops of aqueous bromine are added to a solution of eugenol. [1]

From yellow-brown to colourless.

- (iii) If an excess of bromine is added to eugenol, a new compound is formed that contains the following percentages by mass of each element.

C 24.9% H 2.1% O 6.6%, the remainder being the % of bromine

Use this information to calculate the empirical and molecular formulae of this brominated compound and suggest a possible structure for it. [5]

$$\% \text{ Br} = 100 - 24.9 - 2.1 - 6.6 = 66.4\%$$

$$\text{C: } 24.9/12.0 = 2.08 \quad \text{H: } 2.1/1.01 = 2.08$$

$$\text{O: } 6.6/16.0 = 0.413 \quad \text{Br: } 66.4/79.9 = 0.831$$

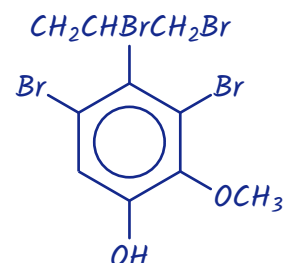
$$\div 0.413: \text{C } 5.0 : \text{H } 5.0 : \text{O } 1 : \text{Br } 2.0$$

$$\text{empirical formula} = \text{C}_5\text{H}_5\text{Br}_2\text{O}$$

eugenol has 2 O atoms (10 C atoms), so

$$\text{molecular formula} = \text{C}_{10}\text{H}_{10}\text{Br}_4\text{O}_2$$

(Br₂ adds across C=C; 2 ring H substituted)



- (iv) Explain how adding aqueous sodium hydroxide at room temperature to a solution of eugenol and eugenyl ethanoate dissolved in trichloromethane, enables the two compounds to be separated.

Trichloromethane and water are immiscible.

[2]

Eugenol is a phenol, so it is acidic and reacts with NaOH to give a salt

(sodium phenoxide) which dissolves in the aqueous layer.

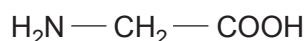
Eugenyl ethanoate is an ester, so it is not soluble in the aqueous layer

and stays in the trichloromethane.

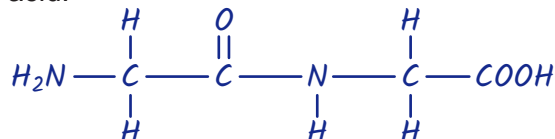
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11. (a) Aminoethanoic acid is the simplest α -amino acid.



- (i) Give the structure of the dipeptide formed from two molecules of aminoethanoic acid. [1]

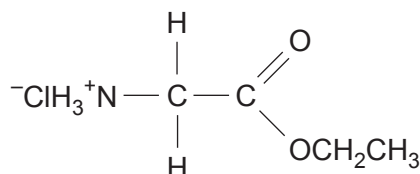


- (ii) Explain why aminoethanoic acid can only form one dipeptide. [1]

Both molecules are the same amino acid, so joining them either way round gives the same dipeptide.

- (b) Amino acids form esters in the usual way from the carboxylic acid group and an alcohol, in the presence of an acid catalyst. These esters can form a salt with the acid used in esterification.

The formula of one of these salts is shown below. Compound **M** is a white solid that is soluble in water, giving a colourless solution.



Compound **M**

- (i) I. Many amino acids exist as zwitterion forms in aqueous solution.

Give the zwitterion form of aminoethanoic acid. [1]

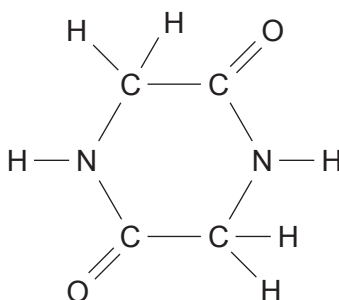


- II. Explain why compound **M** cannot form a zwitterion in this way. [1]

It has no acidic H atom: the COOH group is now an ester.



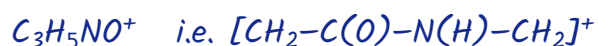
- (ii) Under suitable conditions, aminoethanoic acid condenses to give diketopiperazine.



- I. The mass spectrum of diketopiperazine shows a molecular ion at m/z 114 and two prominent fragments at m/z 43 and 71.

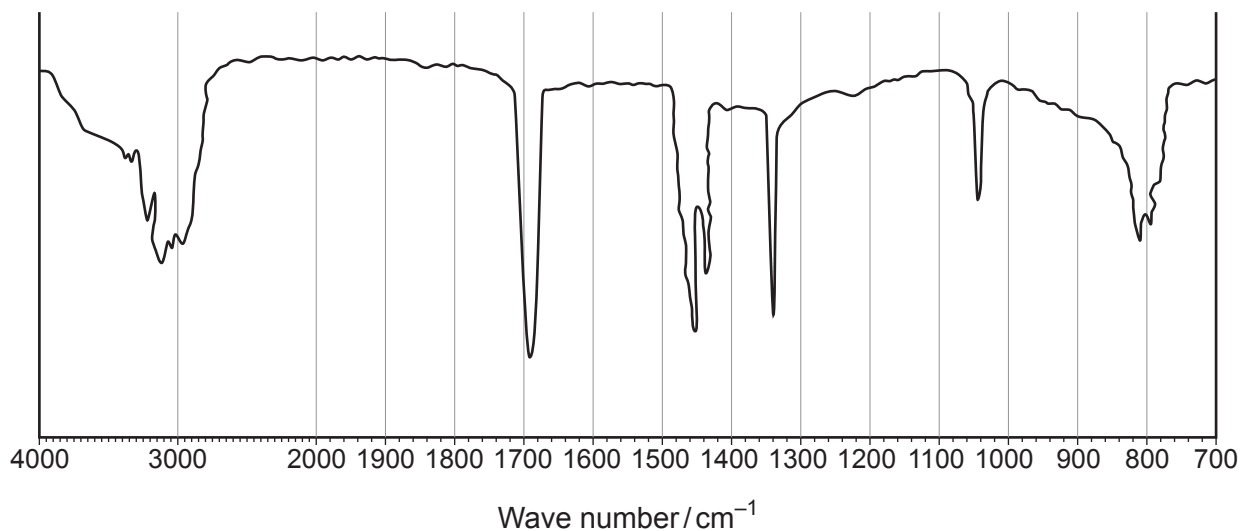
Suggest a formula for the fragment at m/z 71.

[1]



- II. An outline infrared absorption spectrum of diketopiperazine is shown below. Use the formula shown and the data sheet to suggest an absorption value for the N — H and C = O bonds.

[1]



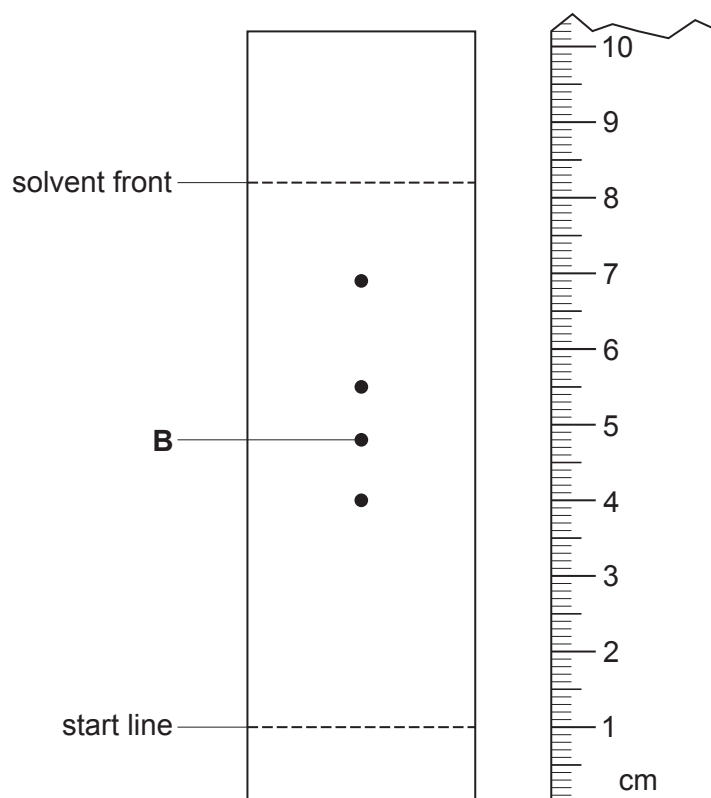
N — H 3300 cm^{-1} C = O 1700 cm^{-1}



(c) A mixture of α -amino acids can be separated and identified by thin layer chromatography.

- (i) These amino acids are colourless and the chromatogram is sprayed with a solution of ninhydrin, so that the amino acids appear as purple dots. The colour is due to the dye Ruhemann's Purple.

A thin layer chromatogram of a mixture of α -amino acids is shown below.



Calculate the R_f value for threonine (spot **B**).

[1]

$$R_f = \text{distance moved by B} / \text{distance moved by solvent}$$

$$= 3.8 \text{ cm} / 7.2 \text{ cm}$$

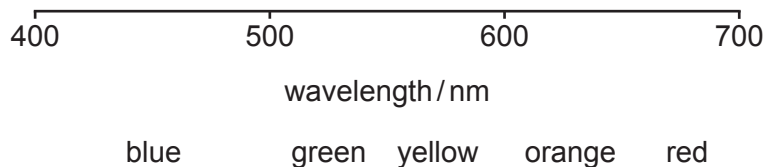
0.53



- (ii) Ruhemann's Purple has a maximum absorption at 564 nm.

The information below indicates the colours absorbed at various wavelengths in the visible spectrum.

Use this to help you explain why the colour of the dye is purple. [1]



The dye absorbs light at 564 nm, in the yellow/green region. The colour seen is the complementary colour, made from the remaining light (red and blue), so it appears purple.

- (iii) Calculate the energy (in kJ mol^{-1}) associated with this absorption at 564 nm. [3]
 $E = hc / \lambda$

$$E = (6.63 \times 10^{-34} \times 3.00 \times 10^8) / (564 \times 10^{-9})$$

$$= 3.53 \times 10^{-19} \text{ J (for one photon)}$$

$$\text{per mole: } 3.53 \times 10^{-19} \times 6.02 \times 10^{23} / 1000$$

$$= 212 \text{ kJ mol}^{-1}$$

energy = ...212..... kJ mol^{-1}



(d) Amino acids react with nitric(III) acid to produce nitrogen gas.



- (i) 0.500 g of 2-aminohexanoic acid, $\text{CH}_3(\text{CH}_2)_3\text{CH}(\text{NH}_2)\text{COOH}$, reacted with an excess of nitric(III) acid.

Calculate the volume of nitrogen produced, assume the temperature was measured at 298 K and at 1 atmosphere pressure. [2]

$$M_r \text{ of } \text{C}_6\text{H}_{13}\text{NO}_2 = 6(12.0) + 13(1.01) + 14.0 + 2(16.0) = 131$$

$$\text{moles of acid} = 0.500 / 131 = 3.82 \times 10^{-3} \text{ mol}$$

$$1 \text{ mol acid gives } 1 \text{ mol } \text{N}_2, \text{ so } 3.82 \times 10^{-3} \text{ mol } \text{N}_2$$

$$\text{volume} = 3.82 \times 10^{-3} \times 24.5 \times 1000 = 93.5 \text{ cm}^3$$

volume of nitrogen produced = 93.5 cm³

- (ii) The actual volume of nitrogen produced was 90.9 cm³, which was less than the calculated volume in part (i) above.

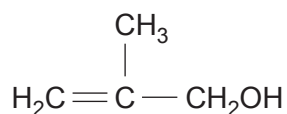
Suggest **two** reasons for this low result, apart from errors in weighing and in measuring the volume of nitrogen produced. [2]

1. The 2-aminohexanoic acid is impure, so less than 0.500 g of amino acid reacted.

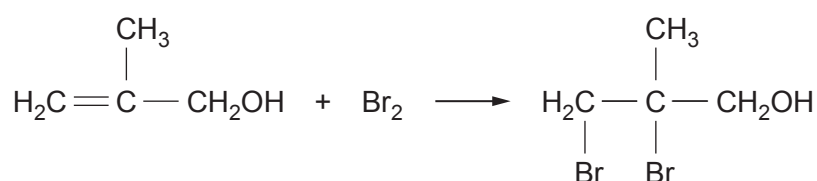
2. Some nitrogen is lost (escapes) before it is collected and measured.



12. (a) 2-Methylpropenoic acid can be obtained from 2-methylprop-2-en-1-ol.



The standard reagents used for the oxidation of a primary alcohol to a carboxylic acid may affect the C = C bond. To prevent this occurring the double bond is protected by bromination.

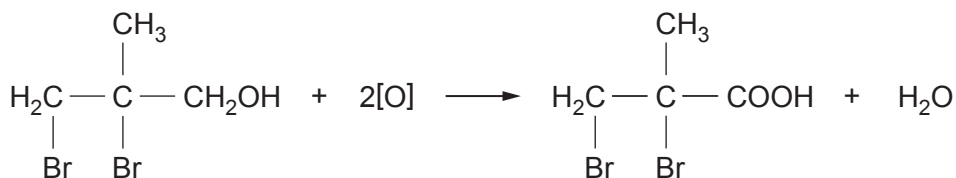


The bromine atoms are removed in a later reaction to give the required acid.

- (i) State the type of mechanism occurring during the bromination. [1]

Electrophilic addition

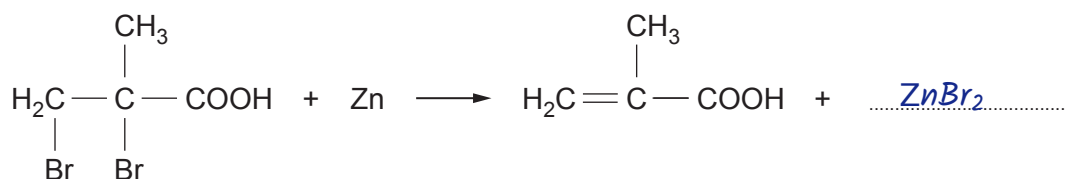
- (ii) Suggest an oxidising agent used for the oxidation of the brominated alcohol. [1]



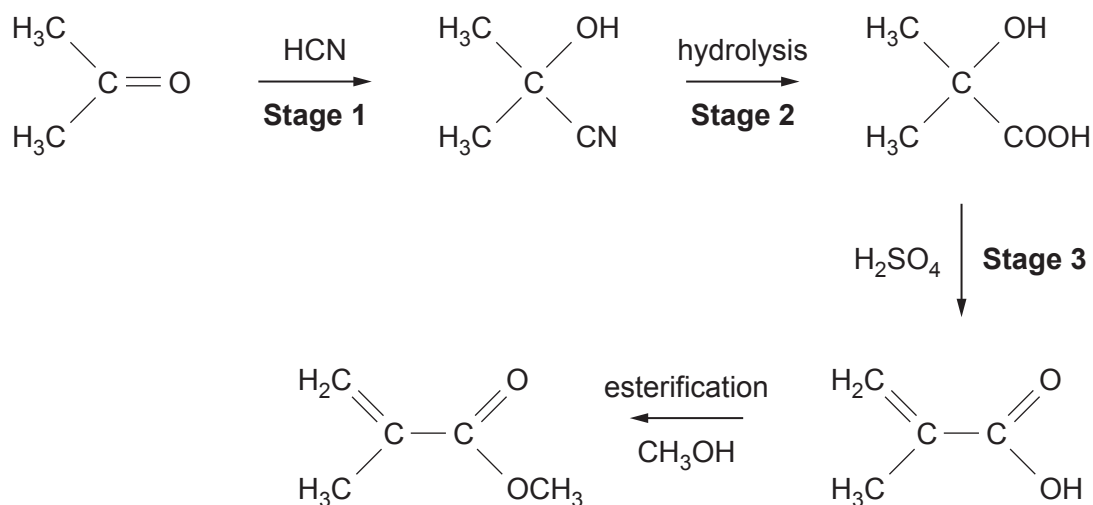
Acidified potassium dichromate(VI), K₂Cr₂O₇ / H₂SO₄

- (iii) The dibromoacid produced in part (ii) is then reacted with zinc under suitable conditions to give 2-methylpropenoic acid.

Complete the equation, showing zinc bromide as the co-product. [1]



(b) Methyl 2-methylpropenoate can be produced from propanone.



(i) **Stage 1** is a nucleophilic addition reaction.

Give the formula of the nucleophile taking part in this stage.

[1]

CN^- (the cyanide ion)

(ii) State why **Stage 1** is described as an **addition** reaction.

[1]

HCN is added across the $\text{C}=\text{O}$ bond, forming a single product.

(iii) State a reagent used for hydrolysis in **Stage 2**.

[1]

Dilute sulfuric acid, $\text{H}_2\text{SO}_4(\text{aq})$, heated under reflux

(iv) State the role of sulfuric acid in **Stage 3**.

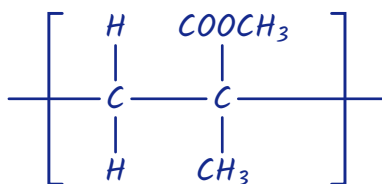
[1]

Dehydrating agent: it removes water from the hydroxy acid.

(v) Addition polymerisation of methyl 2-methylpropenoate gives 'Perspex'.

Give the repeating unit of this polymer.

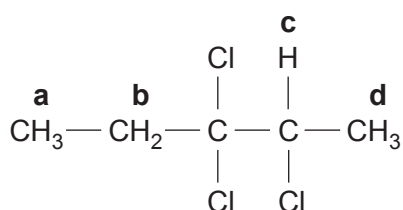
[1]



- (vi) Explain why the polymerisation in part (v) is described as addition polymerisation and not condensation polymerisation. [1]

In addition polymerisation the monomers join through their C=C bonds and the polymer is the only product; in condensation polymerisation a small molecule (such as water) is eliminated each time two monomers join, which does not happen here.

- (c) The formula of a halogenoalkane is shown below.



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

2,3,3-trichloropentane

- (ii) Complete the table below which describes the high resolution ^1H NMR spectrum of this compound. [2]

Hydrogen proton	Splitting pattern
a	<i>triplet</i>
b	<i>quartet</i>
c	<i>quartet</i>
d	<i>doublet</i>

END OF PAPER



[illegible]

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GCE A LEVEL

1410U40-1A



S23-1410U40-1A

MONDAY, 19 JUNE 2023 – AFTERNOON

CHEMISTRY – A2 unit 4

Data Booklet

Avogadro constant
molar gas constant
molar gas volume at 273 K and 1 atm
molar gas volume at 298 K and 1 atm
Planck constant
speed of light
density of water
specific heat capacity of water
ionic product of water at 298 K
fundamental electronic charge

$$\begin{aligned}N_A &= 6.02 \times 10^{23} \text{ mol}^{-1} \\R &= 8.31 \text{ J mol}^{-1} \text{ K}^{-1} \\V_m &= 22.4 \text{ dm}^3 \text{ mol}^{-1} \\V_m &= 24.5 \text{ dm}^3 \text{ mol}^{-1} \\h &= 6.63 \times 10^{-34} \text{ Js} \\c &= 3.00 \times 10^8 \text{ ms}^{-1} \\d &= 1.00 \text{ g cm}^{-3} \\c &= 4.18 \text{ J g}^{-1} \text{ K}^{-1} \\K_w &= 1.00 \times 10^{-14} \text{ mol}^2 \text{ dm}^{-6} \\e &= 1.60 \times 10^{-19} \text{ C}\end{aligned}$$

temperature (K) = temperature (°C) + 273

$1 \text{ dm}^3 = 1000 \text{ cm}^3$
 $1 \text{ m}^3 = 1000 \text{ dm}^3$
1 tonne = 1000 kg
 $1 \text{ atm} = 1.01 \times 10^5 \text{ Pa}$

Multiple	Prefix	Symbol
10^{-9}	nano	n
10^{-6}	micro	μ
10^{-3}	milli	m

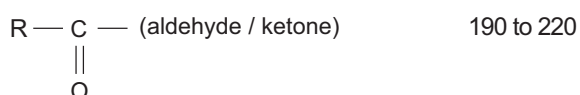
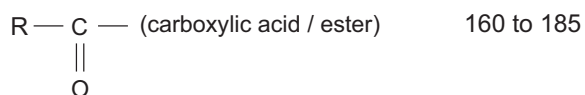
Multiple	Prefix	Symbol
10^3	kilo	k
10^6	mega	M
10^9	giga	G

Infrared absorption values

Bond	Wavenumber / cm^{-1}
C — Br	500 to 600
C — Cl	650 to 800
C — O	1000 to 1300
C = C	1620 to 1670
C = O	1650 to 1750
C $\equiv$ N	2100 to 2250
C — H	2800 to 3100
O — H (carboxylic acid)	2500 to 3200 (very broad)
O — H (alcohol / phenol)	3200 to 3550 (broad)
N — H	3300 to 3500

¹³C NMR chemical shifts relative to TMS = 0

Type of carbon	Chemical shift, δ (ppm)
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^1H NMR chemical shifts relative to TMS = 0

Type of proton	Chemical shift, δ (ppm)
$-\text{CH}_3$	0.1 to 2.0
$\text{R}-\text{CH}_3$	0.9
$\text{R}-\text{CH}_2-\text{R}$	1.3
$\text{CH}_3-\text{C}\equiv\text{N}$	2.0
$\text{CH}_3-\text{C}(=\text{O})-$	2.0 to 2.5
$-\text{CH}_2-\text{C}(=\text{O})-$	2.0 to 3.0
 - CH_3	2.2 to 2.3
$\text{HC}-\text{Cl}$ or $\text{HC}-\text{Br}$	3.1 to 4.3
$\text{HC}-\text{O}$	3.3 to 4.3
$\text{R}-\text{OH}$	4.5 *
$-\text{C}=\text{CH}$	4.5 to 6.3
$-\text{C}=\text{CH}-\text{CO}$	5.8 to 6.5
 - $\text{CH}=\text{C}$	6.5 to 7.5
 - H	6.5 to 8.0
 - OH	7.0 *
$\text{R}-\text{C}(=\text{O})\text{H}$	9.8 *
$\text{R}-\text{C}(=\text{O})\text{OH}$	11.0 *

*variable figure dependent on concentration and solvent

THE PERIODIC TABLE

Period **1** **2** **3** **4** **5** **6** **7** **0**

Group

s block		p block					
1	2	3	4	5	6	7	0
1.01 H Hydrogen 1	4.00 He Helium 2						
6.94 Li Lithium 3	9.01 Be Beryllium 4	10.8 B Boron 5	12.0 C Carbon 6	14.0 N Nitrogen 7	16.0 O Oxygen 8	19.0 F Fluorine 9	20.2 Ne Neon 10
23.0 Na Sodium 11	24.3 Mg Magnesium 12	27.0 Al Aluminium 13	28.1 Si Silicon 14	31.0 P Phosphorus 15	32.1 S Sulfur 16	35.5 Cl Chlorine 17	40.0 Ar Argon 18
39.1 K Potassium 19	40.1 Ca Calcium 20	69.7 Ga Gallium 31	72.6 Ge Germanium 32	74.9 As Arsenic 33	79.0 Se Selenium 34	79.9 Br Bromine 35	83.8 Kr Krypton 36
85.5 Rb Rubidium 37	87.6 Sr Strontium 38	112 Cd Cadmium 48	115 In Indium 49	122 Sb Antimony 51	128 Te Tellurium 52	127 I Iodine 53	131 Xe Xenon 54
133 Cs Caesium 55	137 Ba Barium 56	201 Hg Mercury 80	204 Tl Thallium 81	209 Pb Lead 82	210 Po Polonium 84	(210) At Astatine 85	(222) Rn Radon 86
(223) Fr Francium 87	(226) Ra Radium 88						

Key

Ar

Symbol

Name

Z

relative atomic mass

atomic number

f block							
1	2	3	4	5	6	7	0
140 Ce Cerium 58	141 Pr Praseodymium 59	144 Nd Neodymium 60	(147) Pm Promethium 61	150 Sm Samarium 62	(153) Eu Europium 63	157 Gd Gadolinium 64	159 Tb Terbium 65
163 Dy Dysprosium 66	165 Ho Holmium 67	167 Er Erbium 68	169 Tm Thulium 69	173 Yb Ytterbium 70	175 Lu Lutetium 71		
(231) Pa Protactinium 91	232 Th Thorium 90	238 U Uranium 92	(237) Np Neptunium 93	(242) Pu Plutonium 94	(243) Am Americium 95	(247) Cm Curium 96	(245) Bk Berkelium 97
(251) Cf Californium 98	(254) Es Einsteinium 99	(253) Fm Fermium 100	(256) Md Mendelevium 101	(254) No Nobelium 102	(257) Lr Lawrencium 103		

► Lanthanoid elements

►► Actinoid elements