

Please write clearly in block capitals.

Centre number

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Candidate number

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Surname *StemUp Model Solution*

Forename(s)

Candidate signature

I declare this is my own work.

INTERNATIONAL A-LEVEL CHEMISTRY (9620)

Unit 4: Organic 2 and Physical 2

Friday 7 June 2024

07:00 GMT

Time allowed: 1 hour 30 minutes

Materials

For this paper you must have:

- the Periodic Table/Data Sheet, provided as an insert
- a ruler with millimetre measurements
- a scientific calculator, which you are expected to use where appropriate.

Instructions

- Use black ink or black ball-point pen.
- Fill in the boxes at the top of this page.
- Answer **all** questions.
- You must answer the questions in the spaces provided. Do **not** write outside the box around each page or on blank pages.
- If you need extra space for your answer(s), use the lined pages at the end of this book. Write the question number against your answer(s).
- All working must be shown.
- Do all rough work in this book. Cross through any work you do not want to be marked.

Information

- The marks for questions are shown in brackets.
- The maximum mark for this paper is 80.

For Examiner's Use	
Question	Mark
1	
2	
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TOTAL	

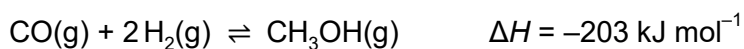


J U N 2 4 C H O 4 0 1

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

0 1

This question is about the equilibrium



In one experiment, a mixture of 0.850 mol of carbon monoxide and 1.44 mol of hydrogen is allowed to reach equilibrium at a fixed temperature.

At equilibrium, 0.280 mol of methanol is formed.
The total pressure of the equilibrium mixture is 190 kPa

0 1 . 1

Calculate the amount, in mol, of carbon monoxide and of hydrogen in the equilibrium mixture.

[2 marks]

$$\text{CO: } 0.850 - 0.280 = 0.570 \text{ mol}$$

$$\text{H}_2: 1.44 - (2 \times 0.280) = 1.44 - 0.560 = 0.880 \text{ mol}$$

Amount of carbon monoxide 0.570 mol

Amount of hydrogen 0.880 mol

0 1 . 2

In a different experiment, the equilibrium amount of methanol is 0.260 mol, of carbon monoxide is 0.350 mol and of hydrogen is 0.550 mol.

The total pressure of the equilibrium mixture is 190 kPa

Calculate the partial pressure of hydrogen, in kPa, in the equilibrium mixture.

[2 marks]

$$\text{total moles} = 0.260 + 0.350 + 0.550 = 1.16 \text{ mol}$$

$$\text{mole fraction of H}_2 = 0.550 \div 1.16 = 0.474$$

$$p(\text{H}_2) = 0.474 \times 190 = 90.1 \text{ kPa}$$

Partial pressure of hydrogen 90.1 kPa



0 1 3

Write an expression for the equilibrium constant (K_p) for this reaction.

[1 mark]

$$K_p = \frac{p(\text{CH}_3\text{OH})}{p(\text{CO}) \times p(\text{H}_2)^2}$$

0 1 4

The experiment is done at two different temperatures, T_1 and T_2 .
The equilibrium constant (K_p) is determined at each temperature.

The results are shown in **Table 1**.**Table 1**

Temperature	K_p / kPa^{-2}
T_1	4.50×10^{-5}
T_2	8.95×10^{-6}

Explain how you can deduce that T_2 is the higher temperature.

[2 marks]

The forward reaction is exothermic (ΔH is negative). K_p is smaller at T_2 than at T_1 , so at T_2 the equilibrium has shifted to the left, in the endothermic direction, to oppose an increase in temperature.

7

Turn over for the next question**Turn over ►**

0 2

This question is about rates of reaction.

0 2 . 1

Explain what is meant by the order of a reaction with respect to an individual substance.

[1 mark]

The power to which the concentration of that substance is raised in the rate equation.

Compounds **A** and **B** react together as shown

The initial rates of the reaction are found for different initial concentrations of **A** and **B**. **Table 2** shows data from this reaction.

Table 2

Experiment	[A] / mol dm ⁻³	[B] / mol dm ⁻³	Initial rate / mol dm ⁻³ s ⁻¹
1	0.100	0.150	3.68×10^{-5}
2	0.300	0.150	3.31×10^{-4}
3	0.200	0.300	2.94×10^{-4}

0 2 . 2

Deduce the order of the reaction with respect to **A** and the order of the reaction with respect to **B**.

[2 marks]

Exp 1 to 2: [A] $\times 3$, [B] same, rate $\times 9$ (3^2), so 2nd order in A

Exp 1 to 3: [A] $\times 2$ gives $\times 4$, [B] $\times 2$, rate $\times 8$, so 1st order in B

Order with respect to **A** 2Order with respect to **B** 1

0 2 . 3 The rate of reaction between compound **D** and compound **E** is investigated.

The reaction is first order with respect to **D** and first order with respect to **E**.

In one experiment, the initial rate is $7.10 \times 10^{-5} \text{ mol dm}^{-3} \text{ s}^{-1}$ when the initial concentration of **D** is $0.160 \text{ mol dm}^{-3}$ and the initial concentration of **E** is $0.220 \text{ mol dm}^{-3}$.

Calculate the value of the rate constant, k , at this temperature.

Give the units of k

[3 marks]

$$k = \frac{\text{rate}}{[D][E]} = \frac{7.10 \times 10^{-5}}{0.160 \times 0.220}$$

$$k = 2.02 \times 10^{-3}$$

$$k \quad 2.02 \times 10^{-3}$$

$$\text{Units} \quad \text{dm}^3 \text{ mol}^{-1} \text{ s}^{-1}$$

6

Turn over for the next question

Turn over ►



0 3

This question is about the effect of temperature on the rate of a reaction.

The Arrhenius equation can be written

$$\ln k = \frac{-E_a}{RT} + \ln A$$

A compound decomposes when heated.

Table 3 shows the value of the rate constant at different temperatures for this decomposition.

Table 3

Rate constant k / s^{-1}	$\ln k$	Temperature / K	$\frac{1}{T}$ / K^{-1}
8.68×10^5	13.67	278	3.60×10^{-3}
2.20×10^6	14.60	298	3.36×10^{-3}
4.98×10^6	15.42	318	3.14×10^{-3}
1.01×10^7	16.13	338	2.96×10^{-3}
1.92×10^7	16.77	358	2.79×10^{-3}

0 3**. 1**

Complete **Table 3**.
Give values to 3 significant figures.

[2 marks]

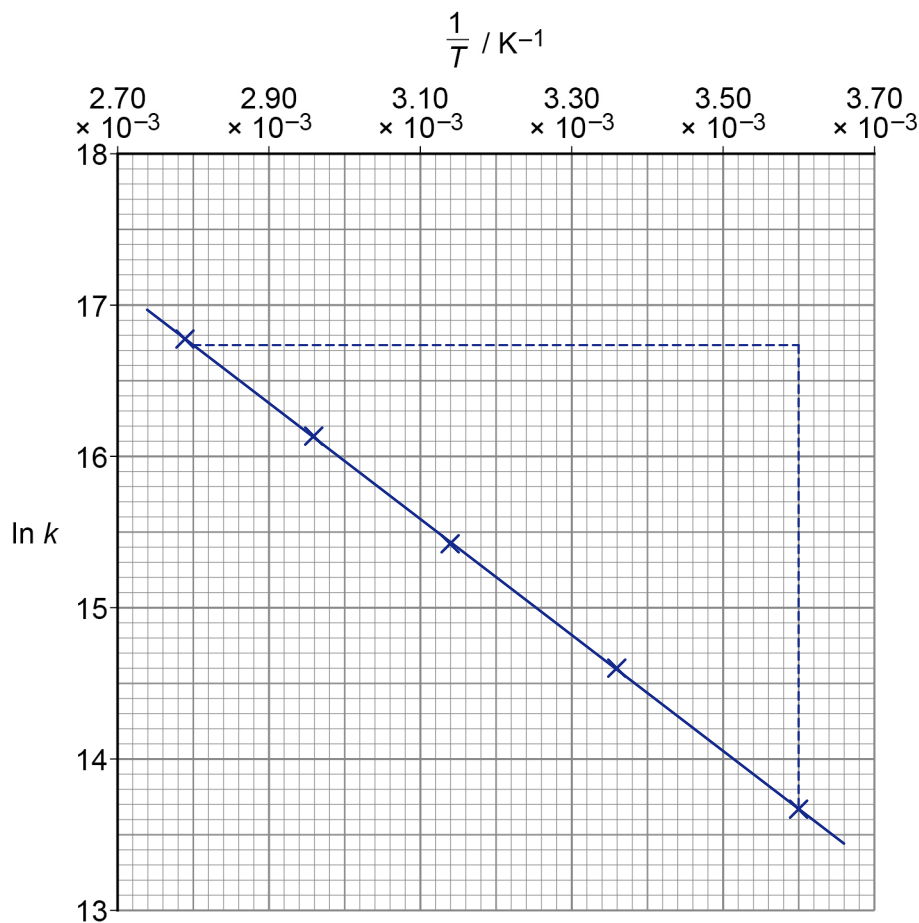
$$k = e^{15.42} = 4.98 \times 10^6 \text{ s}^{-1}$$

$$1/T = 1 \div 318 = 3.14 \times 10^{-3} \text{ K}^{-1}$$



0 3 . 2 Plot a graph of $\ln k$ against $\frac{1}{T}$

[2 marks]



0 3 . 3 Use your graph to calculate a value for the activation energy (E_a), in kJ mol^{-1} , for this reaction.

The gas constant, $R = 8.31 \text{ J K}^{-1} \text{ mol}^{-1}$

[3 marks]

$$\text{gradient} = (13.67 - 16.73) \div (3.60 - 2.80) \times 10^{-3} = -3825 \text{ K}$$

$$\text{gradient} = -E_a \div R, \text{ so } E_a = 3825 \times 8.31 = 31\,786 \text{ J mol}^{-1}$$

$$E_a = 31\,786 \div 1000 = 31.8 \text{ kJ mol}^{-1} \approx 32 \text{ kJ mol}^{-1}$$

E_a 32 kJ mol^{-1}

7

Turn over ►



0 4

This question is about carbonyl compounds.

Compound **F** ($\text{C}_3\text{H}_6\text{O}$) reacts with Fehling's solution to form a red precipitate.

0 4 . 1

Draw the skeletal formula of **F**.

[1 mark]



0 4 . 2

Identify the organic product formed when **F** reacts with Fehling's solution.

[1 mark]

propanoic acid, $\text{CH}_3\text{CH}_2\text{COOH}$ Butanone reacts with NaBH_4 in aqueous solution to form butan-2-ol.

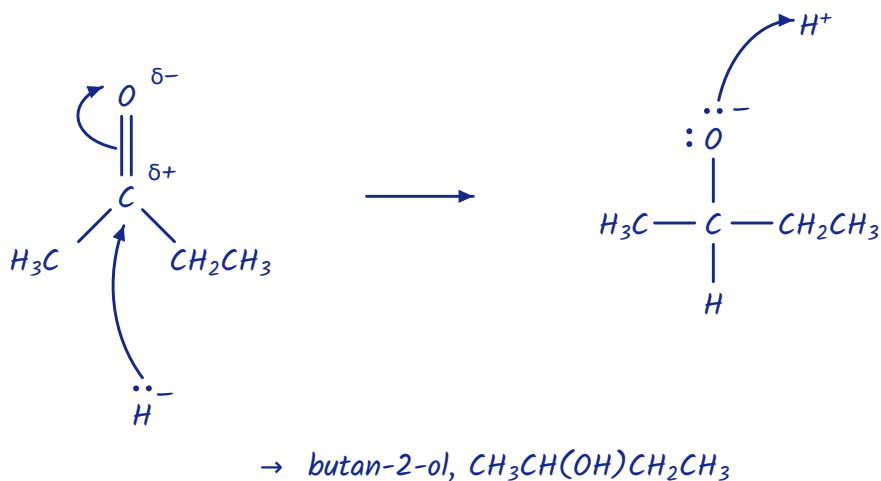
0 4 . 3

Name and outline the mechanism for this reaction.

[4 marks]

Name of mechanism nucleophilic addition

Mechanism



0 4 . 4

The product from the reaction between butanone and NaBH_4 is dried.

State how infrared spectroscopy can show that the reaction between butanone and NaBH_4 is complete.

Use **Table A** on the Chemistry Data Sheet.

[1 mark]

Take the IR spectrum of the product: when the reaction is complete

there is no absorption at 1680 to 1750 cm^{-1} , because no $\text{C}=\text{O}$

(butanone) remains (fingerprint region matches pure butan-2-ol).

7

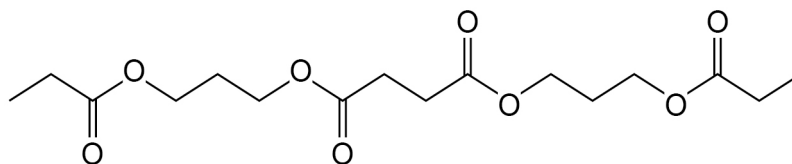
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0 5

This question is about polymers.

A section of a condensation polymer, **G**, is shown.Polymer **G**

0 5 . 1

Name this type of condensation polymer.

[1 mark]

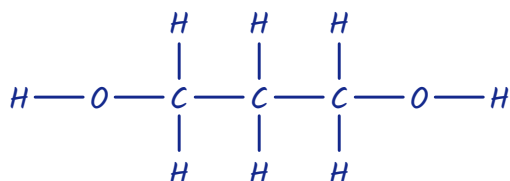
polyester

0 5 . 2

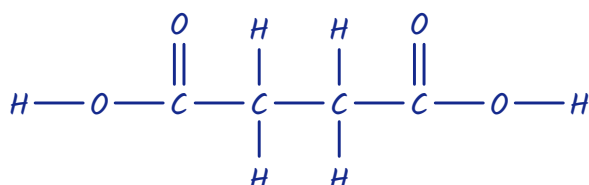
Draw displayed formulas for each of the **two** monomers used to make polymer **G**.

[2 marks]

Monomer 1



Monomer 2

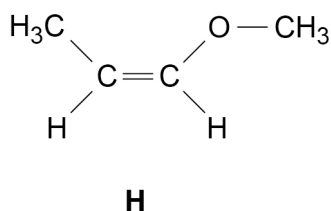


0 5 . 3 Explain why polymer **G** is biodegradable.

[2 marks]

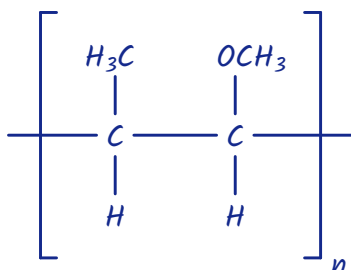
The polymer chain contains polar C-O and C=O bonds (ester links); the δ^+ carbon atoms can be attacked by nucleophiles, so the ester links can be hydrolysed (by acids, alkalis or enzymes) and the polymer breaks down.

A different type of polymer can be formed from the monomer **H**.



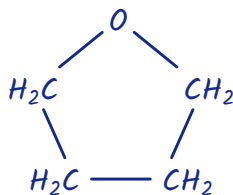
0 5 . 4 Draw the repeating unit of this polymer.

[1 mark]



0 5 . 5 Draw an isomer of **H** that only has two peaks in its ^{13}C NMR spectrum.

[1 mark]



Turn over ►

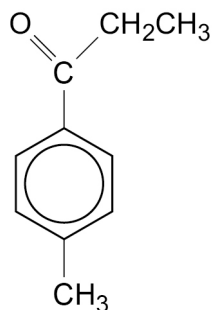


0 6

This question is about the reactions of methylbenzene.

0 6 . 1

Compound **J** can be made from methylbenzene, propanoyl chloride and another reagent.

**J**

This reagent reacts with propanoyl chloride to make the reactive intermediate that reacts with methylbenzene.

Identify this reagent.

Write an equation for the formation of this reactive intermediate.

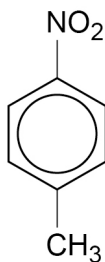
[2 marks]

Reagent AlCl_3 (aluminium chloride)

Equation $\text{CH}_3\text{CH}_2\text{COCl} + \text{AlCl}_3 \rightarrow \text{CH}_3\text{CH}_2\text{C}^+\text{O} + \text{AlCl}_4^-$



Compound **K** is formed when methylbenzene reacts with the reactive intermediate $^+\text{NO}_2$

**K**

0 6 . 2

Write an equation to show how $^+\text{NO}_2$ is formed from concentrated nitric acid and concentrated sulfuric acid.

[1 mark]

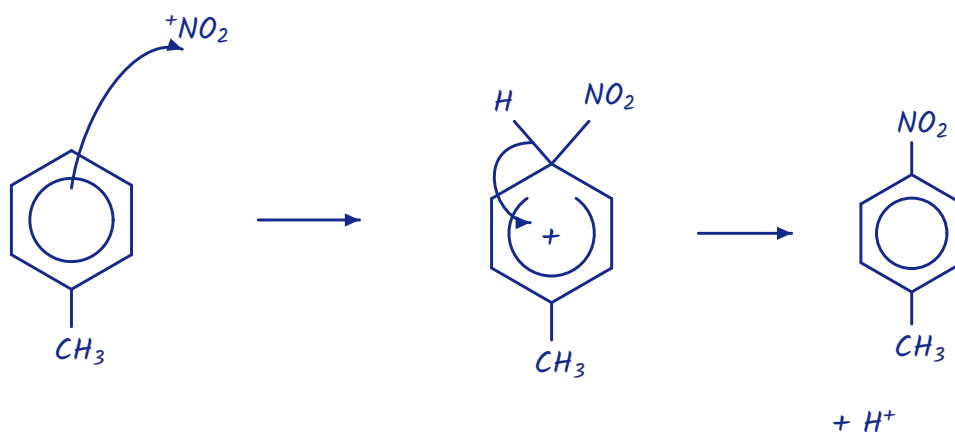
0 6 . 3

Name and outline the mechanism for the reaction of $^+\text{NO}_2$ with methylbenzene to form **K**.

[4 marks]

Name of mechanism electrophilic substitution

Mechanism



7

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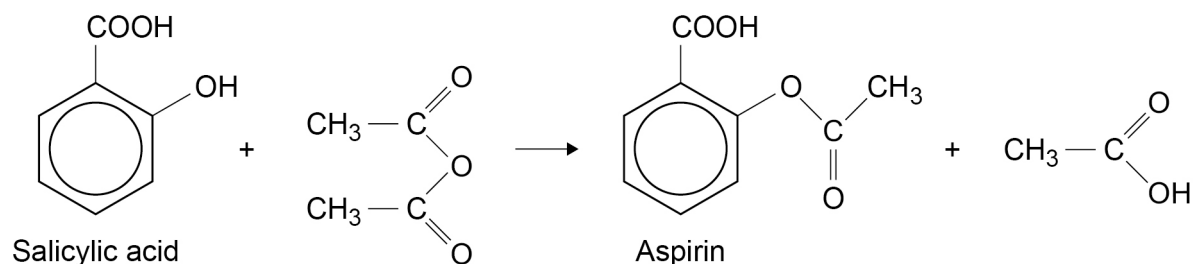


0 7

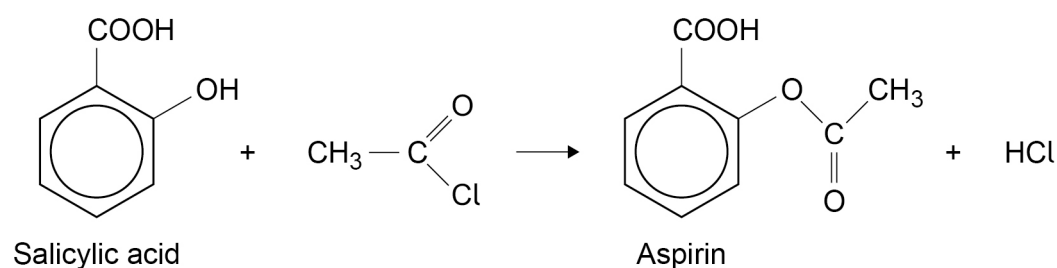
This question is about the synthesis of aspirin.

Aspirin can be prepared from salicylic acid by Reaction 1 or Reaction 2.

Reaction 1



Reaction 2



0 7 . 1

Explain why Reaction 2 has the higher atom economy.

[1 mark]

The only by-product of Reaction 2 is HCl, which has a lower M_r than CH_3COOH , so the M_r of aspirin is a greater fraction of the total M_r of the products.

0 7 . 2

Companies that manufacture aspirin need to consider factors other than atom economy before deciding which reaction to use.

Give **one** other factor that needs to be considered.

[1 mark]

The hazards of the reagents and products (e.g. ethanoyl chloride reacts violently and gives toxic HCl).



Aspirin made by either reaction is impure.

0 7 . 3

Give **two** ways that the melting point of impure aspirin would differ from the melting point of pure aspirin.

[2 marks]

Difference 1 The impure aspirin melts at a lower temperature than pure aspirin.

Difference 2 It melts over a range of temperatures, not sharply.

Question 7 continues on the next page

Turn over ►



Impure aspirin can be purified using the following steps.

- Step 1** A small volume of ethanol is heated using a water bath.
- Step 2** An impure sample of aspirin is dissolved in a minimum volume of the hot ethanol.
- Step 3** The mixture is filtered while hot.
- Step 4** The filtrate is cooled in ice.
- Step 5** The crystals formed are collected by filtration and washed with a small amount of ice-cold ethanol.

0 7 . 4

State why a water bath is used to heat the ethanol in **Step 1**.

[1 mark]

Ethanol is flammable, so a naked flame (Bunsen burner) would be a fire risk.

0 7 . 5

State why the mixture is filtered in **Step 3**.

[1 mark]

To remove insoluble impurities.

0 7 . 6

State why the crystals are washed in **Step 5**.

[1 mark]

To remove soluble impurities left on the surface of the crystals.

0 7 . 7

State why the ethanol used in **Step 5** is ice-cold.

[1 mark]

To prevent the aspirin crystals from dissolving in the ethanol.



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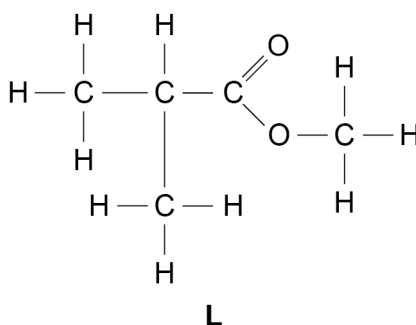
0 8

This question is about esters.

0 8 . 1

Give a use of esters.

[1 mark]

*Solvents, perfumes or food flavourings.*The structure of ester **L** can be confirmed using ^{13}C NMR and ^1H NMR spectroscopy.

0 8 . 2

State the number of peaks in the ^{13}C NMR spectrum of **L**.

[1 mark]

*4***Table 4** shows data for the ^1H NMR spectrum of **L**.**Table 4**

Chemical shift / ppm	1.2	2.6	3.7
Integration value	<i>6</i>	<i>1</i>	<i>3</i>

0 8 . 3

Complete **Table 4** to show the integration values for each peak.Use **Table B** on the Chemistry Data Sheet.

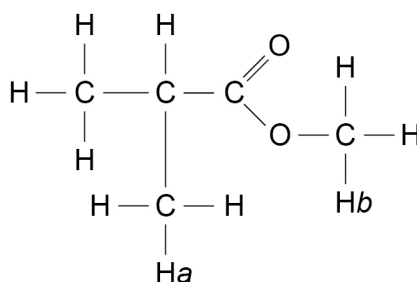
[1 mark]



0 8 . 4

In **Figure 1**, two of the H atoms are marked *a* and *b*. These H atoms are in different environments and produce different peaks in the ^1H NMR spectrum.

Figure 1



Give the spin-spin splitting pattern that is observed for the peaks that are produced by *Ha* and *Hb*

[2 marks]

Ha spin-spin splitting pattern doublet

Hb spin-spin splitting pattern singlet

0 8 . 5

Acid hydrolysis of ester **L** produces methanol and compound **M**.

Identify **M**.

Give a reagent that can be used to confirm the functional group in **M**.

State an observation that is made when **M** reacts with this reagent.

[3 marks]

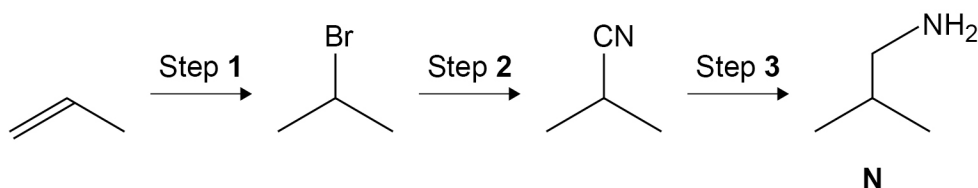
Identity of **M** 2-methylpropanoic acid, $(\text{CH}_3)_2\text{CHCOOH}$

Reagent sodium hydrogencarbonate, NaHCO_3

Observation effervescence (bubbles of CO_2 gas)



0 9

A synthetic route to form the amine **N** is shown.

0 9 . 1

Identify the reagent for **Step 1**.Name the mechanism for **Step 1**.

[2 marks]

Reagent HBr (hydrogen bromide)Name of mechanism electrophilic addition

0 9 . 2

Identify a reagent for **Step 2**.

[1 mark]

Reagent KCN (potassium cyanide) in ethanol and water

0 9 . 3

Identify a reagent for **Step 3**.State a condition for **Step 3**.

[2 marks]

Reagent H₂ (hydrogen)Condition nickel (Ni) catalyst

0 9 . 4

Amine **N** can be formed in a one-step synthesis from a halogenoalkane.

Identify the halogenoalkane needed for this one-step synthesis.

[1 mark]

1-bromo-2-methylpropane, (CH₃)₂CHCH₂Br

0 9 . 5

Amine **N** can be used to form other organic products.

N can act as a nucleophile and a base.

Explain why **N** can act as a nucleophile and as a base.

[2 marks]

The N atom has a lone pair of electrons, which it can donate to a δ^+ carbon atom (so it is a nucleophile) and which it can use to accept a proton, H^+ ion (so it is a base).

0 9 . 6

Ethylamine can react with chloromethane to form a secondary amine.

Name the secondary amine.

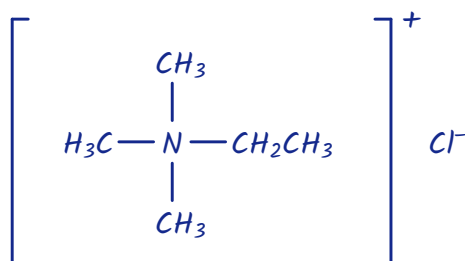
[1 mark]

N-methylethylamine

0 9 . 7

Give the structure of the final product in the reaction between ethylamine and an excess of chloromethane.

[1 mark]



Turn over for the next question

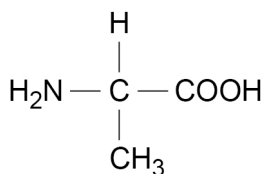
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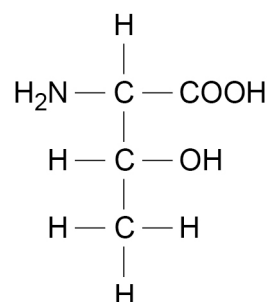
1 0

This question is about amino acids and proteins.

Two amino acids are shown.



alanine



threonine

1 0 . 1

Use IUPAC rules to name threonine.

[1 mark]

2-amino-3-hydroxybutanoic acid

Most amino acids can exist as optical isomers (enantiomers).

1 0 . 2

State what is meant by the term optical isomers.

Describe how to distinguish between the **two** optical isomers of alanine.

[3 marks]

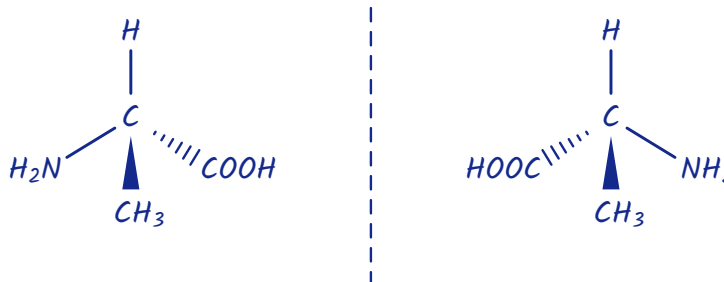
Meaning of term non-superimposable mirror images

Description Shine a beam of plane-polarised light through a solution of
each isomer (in a polarimeter). The two enantiomers rotate the plane
of polarised light by the same angle but in opposite directions.

1 0 . 3

Draw 3D representations of the **two** optical isomers of alanine.

[1 mark]



1 0 . 4

Consider the structure of threonine.

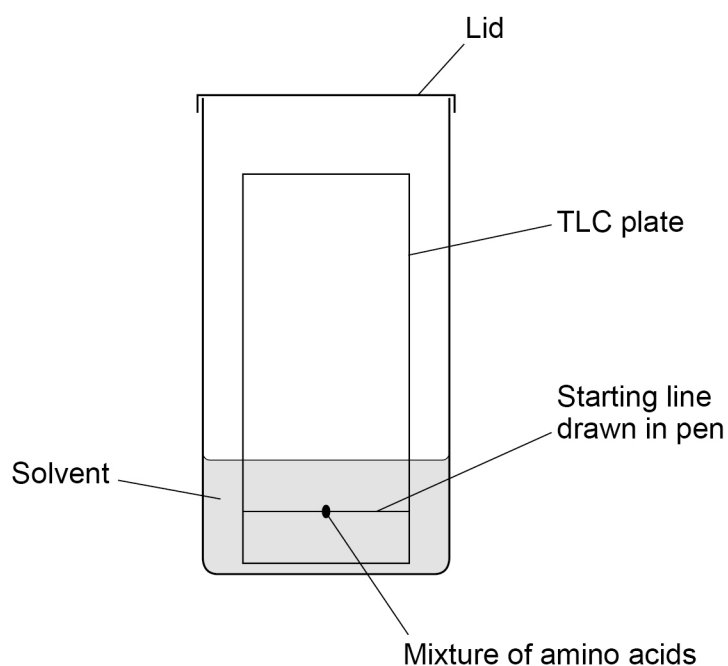
How many optical isomers of threonine are there?

Tick (✓) **one** box.

[1 mark]

2	☐	4	☒	6	☐	8	☐
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Chromatography can be used to identify the compounds in a mixture of amino acids. A student sets up a thin-layer chromatography (TLC) plate as shown in **Figure 2**.

Figure 2

1 0 . 5

Give **two** errors the student made in the experiment shown in **Figure 2**.

[1 mark]

Error 1 The starting line was drawn in pen, so the ink would run (it should be drawn in pencil).

Error 2 The solvent level is above the starting line, so the amino acids dissolve into the solvent.

Turn over ►



Another student sets up the experiment correctly but uses a longer TLC plate. The amino acids cannot be seen as they move up the plate.

1 0 . 6

State how the position of amino acids can be seen on a TLC plate at the end of the experiment.

[1 mark]

Spray the plate with ninhydrin (or place it under UV light).

1 0 . 7

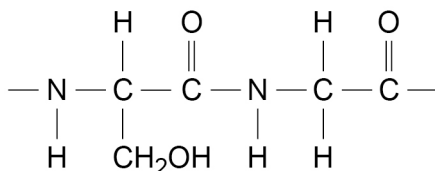
State the effect, if any, on the R_f values of using a longer TLC plate.

[1 mark]

No effect, the R_f values stay the same.

Amino acids can react together to form proteins.

A section of a protein chain is shown.

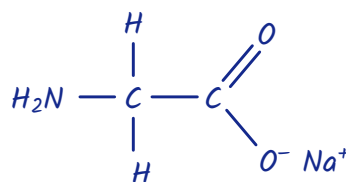
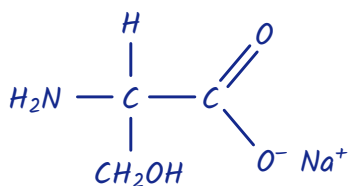


A student hydrolyses this protein with hot sodium hydroxide solution.

1 0 . 8

Draw the products of this hydrolysis.

[2 marks]



Proteins can have primary, secondary and tertiary structures.

1 0 . 9

Give the names of the **two** types of secondary structures of proteins.

[2 marks]

1 *alpha (α) helix*

2 *beta (β) pleated sheet*

13

END OF QUESTIONS



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