



Oxford Cambridge and RSA

Friday 20 June 2025 – Morning

A Level Chemistry A

H432/03 Unified chemistry

Time allowed: 1 hour 30 minutes

You must have:

- the Data Sheet for Chemistry A

You can use:

- a scientific or graphical calculator
- an HB pencil



Please write clearly in black ink. **Do not write in the barcodes.**

Centre number

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Candidate number

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First name(s)

Last name

StemUp Model Solution

INSTRUCTIONS

- Use black ink. You can use an HB pencil, but only for graphs and diagrams.
- Write your answer to each question in the space provided. If you need extra space use the lined pages at the end of this booklet. The question numbers must be clearly shown.
- Answer **all** the questions.
- Where appropriate, your answer should be supported with working. Marks might be given for using a correct method, even if your answer is wrong.

INFORMATION

- The total mark for this paper is **70**.
- The marks for each question are shown in brackets [].
- Quality of extended response will be assessed in questions marked with an asterisk (*).
- This document has **20** pages.

ADVICE

- Read each question carefully before you start your answer.

2
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1 This question is about spectra.

- (a) The mass spectrum for Br_2 has peaks at m/z values of 79, 81, 158, 160 and 162. The peaks at m/z 79 and 81 have virtually the same relative abundance.
- (i) Complete the table to show the number of protons, neutrons and electrons in the particles that cause the peaks at m/z 79 and 81.

m/z	Number of protons	Number of neutrons	Number of electrons
79	35	44	34
81	35	46	34

[2]

- (ii) Explain why there are peaks with m/z values of 158, 160 and 162 and predict their relative abundances.

Explanation *Br_2 molecules are made from the two isotopes ^{79}Br and ^{81}Br , which have (virtually) equal abundance. The peaks are Br_2^+ ions: m/z 158 is $^{79}\text{Br}^{79}\text{Br}$, m/z 160 is $^{79}\text{Br}^{81}\text{Br}$ (or $^{81}\text{Br}^{79}\text{Br}$) and m/z 162 is $^{81}\text{Br}^{81}\text{Br}$.*

Relative abundances *$158 : 160 : 162 = 1 : 2 : 1$. There are two ways to make $^{79}\text{Br}^{81}\text{Br}$, so the peak at 160 is twice the height of the peaks at 158 and 162.*

[3]

- (b) This question looks at proton NMR spectra of dibromoalkanes.

Predict the following.

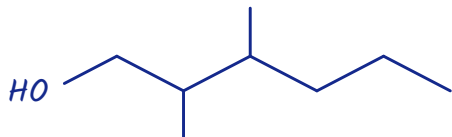
Compound	Number of peaks	CH_2 splitting pattern(s)
$\text{BrCH}_2\text{CH}_2\text{Br}$	1	singlet
$\text{BrCH}_2\text{CH}_2\text{CH}_2\text{Br}$	2	triplet and quintet

[3]

2 This question is about different compounds that each contain O and H atoms covalently bonded together.

(a) The alcohol 2,3-dimethylhexan-1-ol has the molecular formula $C_8H_{18}O$.

(i) Draw the skeletal formula of 2,3-dimethylhexan-1-ol.



[1]

(ii) What is the number of H atoms in 8.45 g of 2,3-dimethylhexan-1-ol?

Give your answer to **3** significant figures and in standard form.

$$M_r(C_8H_{18}O) = 8 \times 12.0 + 18 \times 1.0 + 16.0 = 130.0$$

$$n(C_8H_{18}O) = 8.45 \div 130.0 = 0.0650 \text{ mol}$$

$$n(H \text{ atoms}) = 18 \times 0.0650 = 1.17 \text{ mol}$$

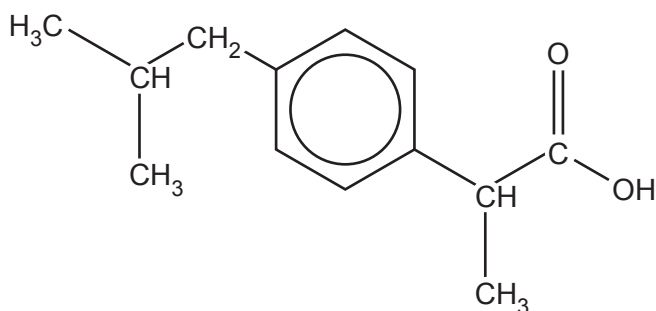
$$\text{number of H atoms} = 1.17 \times 6.02 \times 10^{23} = 7.04 \times 10^{23}$$

$$\text{Number of H atoms} = \dots\dots\dots 7.04 \times 10^{23} \dots\dots\dots [3]$$

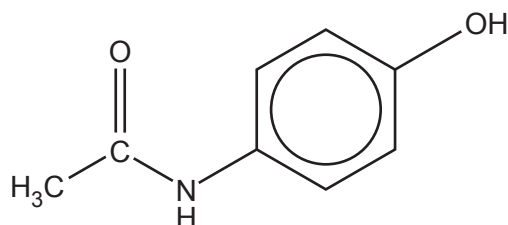
(b) Nuromol tablets are used to relieve pain.

Nuromol tablets contain a mixture of ibuprofen and paracetamol.

The structures of ibuprofen and paracetamol are shown.



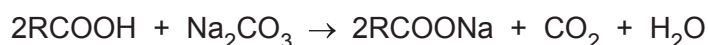
Ibuprofen



Paracetamol

A student carries out an investigation to determine the mass of ibuprofen and the mass of paracetamol in one nuromol tablet.

- Ibuprofen reacts with aqueous sodium carbonate, $Na_2CO_3(aq)$, to produce a gas.



- Paracetamol does **not** react with $Na_2CO_3(aq)$.

- (i) Why does paracetamol **not** react with $\text{Na}_2\text{CO}_3(\text{aq})$?

Paracetamol does not contain a carboxylic acid (COOH) group; its OH group is a phenol group, and phenols are too weakly acidic to react with carbonates.

[1]

- (ii) The student uses the reaction of nuromol tablets with $\text{Na}_2\text{CO}_3(\text{aq})$ to determine the mass of ibuprofen and the mass of paracetamol in one nuromol tablet.

The student's method is outlined below.

- Weigh **four** nuromol tablets.
- Add the tablets to an excess of aqueous sodium carbonate.
- Collect the gas produced and measure its volume.

Results

Mass of four nuromol tablets = 2.80 g

Volume of gas collected at RTP = 48.0 cm^3

Assume that ibuprofen is the only compound in nuromol tablets that reacts with $\text{Na}_2\text{CO}_3(\text{aq})$.

Determine the mass of ibuprofen and the mass of paracetamol, in mg, in **one** nuromol tablet.

$$n(\text{CO}_2) = 48.0 \div 24000 = 2.00 \times 10^{-3} \text{ mol}$$

$$n(\text{ibuprofen}) = 2 \times 2.00 \times 10^{-3} = 4.00 \times 10^{-3} \text{ mol (in 4 tablets)}$$

$$M_r(\text{ibuprofen}, \text{C}_{13}\text{H}_{18}\text{O}_2) = 206.0$$

$$\text{mass of ibuprofen in 4 tablets} = 4.00 \times 10^{-3} \times 206.0 = 0.824 \text{ g}$$

$$\text{mass of ibuprofen in 1 tablet} = 0.824 \div 4 = 0.206 \text{ g} = 206 \text{ mg}$$

$$\text{mass of 1 tablet} = 2.80 \div 4 = 0.700 \text{ g} = 700 \text{ mg}$$

$$\text{mass of paracetamol in 1 tablet} = 700 - 206 = 494 \text{ mg}$$

Mass of ibuprofen = ... **206** mg

Mass of paracetamol = ... **494** mg

[4]

Turn over

(c) Barium hydroxide, $\text{Ba}(\text{OH})_2$, is an alkali.

A student is supplied with a solution of $\text{Ba}(\text{OH})_2$ with a concentration of 46.80 g dm^{-3} at 25°C .

The student dilutes 20.0 cm^3 of this solution of $\text{Ba}(\text{OH})_2$ with water and the solution is made up to 100.0 cm^3 at 25°C .

Calculate the pH of the diluted solution of $\text{Ba}(\text{OH})_2$ at 25°C .

Give your answer to **2** decimal places.

$$M_r(\text{Ba}(\text{OH})_2) = 137.3 + 2 \times 17.0 = 171.3$$

$$[\text{Ba}(\text{OH})_2] = 46.80 \div 171.3 = 0.2732 \text{ mol dm}^{-3}$$

diluted from 20.0 cm^3 to 100.0 cm^3 ($\div 5$):

$$[\text{Ba}(\text{OH})_2] = 0.2732 \div 5 = 0.05464 \text{ mol dm}^{-3}$$

$$[\text{OH}^-] = 2 \times 0.05464 = 0.1093 \text{ mol dm}^{-3}$$

$$[\text{H}^+] = K_w \div [\text{OH}^-] = 1.00 \times 10^{-14} \div 0.1093 = 9.15 \times 10^{-14} \text{ mol dm}^{-3}$$

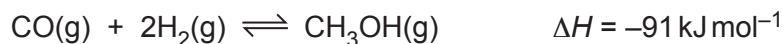
$$\text{pH} = -\log(9.15 \times 10^{-14}) = 13.04$$

pH = ...13.04..... [5]

3 This question is about equilibrium and rates.

- (a) Methanol, CH_3OH , can be made industrially by the reaction of carbon monoxide, CO , with hydrogen, H_2 , in the presence of a catalyst. This is a reversible reaction.

The equilibrium below is set up.



The concentrations of CO(g) and $\text{CH}_3\text{OH(g)}$ in the equilibrium mixture are shown in the table below.

	CO(g)	$\text{CH}_3\text{OH(g)}$
equilibrium concentration/ mol dm^{-3}	0.27	0.11

The value of the equilibrium constant, K_c , for this reaction is $1.8 \text{ dm}^6 \text{ mol}^{-2}$.

- Explain the conditions of pressure and temperature that would give the maximum equilibrium yield of $\text{CH}_3\text{OH(g)}$.
- Calculate the concentration of $\text{H}_2\text{(g)}$ in the equilibrium mixture to an **appropriate** number of significant figures.

Pressure: use a high pressure. The right-hand side has fewer gaseous moles (3 mol of gas form 1 mol of gas), so increasing the pressure shifts the equilibrium position to the right, increasing the yield of CH_3OH .

Temperature: use a low temperature. The forward reaction is exothermic (ΔH is negative), so decreasing the temperature shifts the equilibrium position to the right, in the exothermic direction.

$$K_c = [\text{CH}_3\text{OH}] \div ([\text{CO}] [\text{H}_2]^2), \text{ so } 1.8 = 0.11 \div (0.27 \times [\text{H}_2]^2)$$

$$[\text{H}_2]^2 = 0.11 \div (0.27 \times 1.8) = 0.2263$$

$$[\text{H}_2] = \sqrt{0.2263} = 0.476 = 0.48 \text{ mol dm}^{-3} \text{ (2 significant figures, as the data are given to 2 significant figures)}$$

[5]

(b)* A reaction takes place when aqueous solutions of propanone, $\text{CH}_3\text{COCH}_3(\text{aq})$, and bromine, $\text{Br}_2(\text{aq})$, are mixed in the presence of dilute acid, $\text{H}^+(\text{aq})$.

The overall equation for this reaction is shown below.



- A student carries out three experiments to investigate the rate of this reaction.
- In each experiment, the student investigates the effect of changing the concentration of one of the three chemicals whilst keeping the concentrations of the other chemicals constant.

The student's results are shown below.

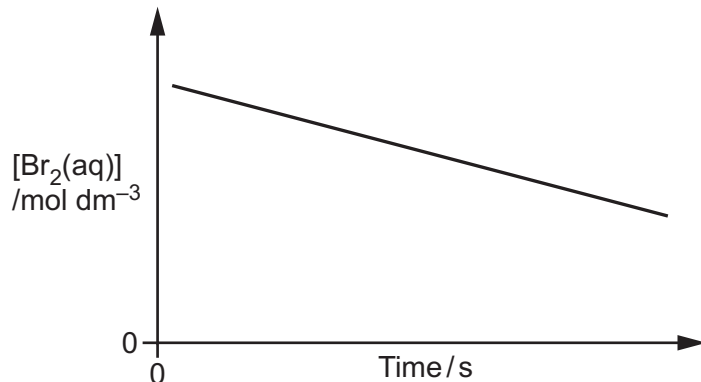
Experiment 1

Only $[\text{CH}_3\text{COCH}_3(\text{aq})]$ is varied.

Initial concentrations			Initial rate / $\text{mol dm}^{-3} \text{s}^{-1}$
$\text{CH}_3\text{COCH}_3(\text{aq})$ / mol dm^{-3}	$\text{Br}_2(\text{aq})$ / mol dm^{-3}	$\text{H}^+(\text{aq})$ / mol dm^{-3}	
1.50×10^{-3}	2.00×10^{-1}	2.50×10^{-1}	1.70×10^{-7}
4.50×10^{-3}	2.00×10^{-1}	2.50×10^{-1}	5.10×10^{-7}

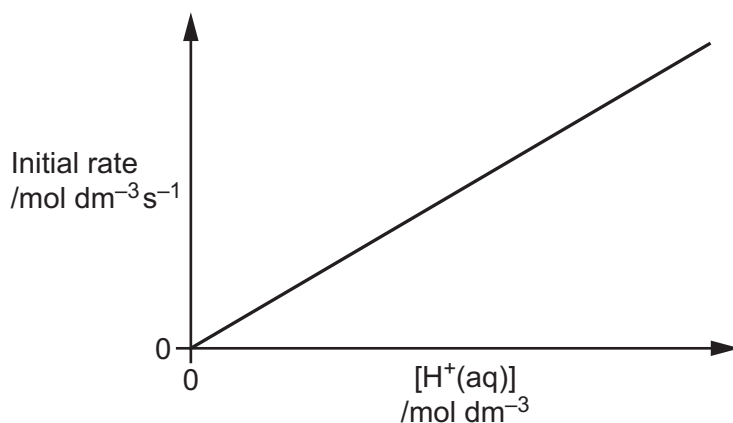
Experiment 2

Only $[\text{Br}_2(\text{aq})]$ is varied.



Experiment 3

Only $[\text{H}^+(\text{aq})]$ varied.



Use the student's results to determine the order with respect to each of the three chemicals, the rate equation and rate constant for **Reaction 3.1**. Explain your reasoning.

Explain how the student's results can be used to show that the mechanism of **Reaction 3.1** has more than one step.

Experiment 1: when $[\text{CH}_3\text{COCH}_3]$ increases by a factor of 3 (1.50 to 4.50×10^{-3}), the initial rate also increases by a factor of 3 (1.70 to 5.10×10^{-7}), so the reaction is 1st order with respect to CH_3COCH_3 .

Experiment 2: the $[\text{Br}_2]$ against time graph is a straight line with a constant (negative) gradient, so the rate stays constant as $[\text{Br}_2]$ falls. The rate is independent of $[\text{Br}_2]$, so the reaction is zero order with respect to Br_2 .

Experiment 3: the initial rate against $[\text{H}^+]$ graph is a straight line through the origin (0,0), so rate is directly proportional to $[\text{H}^+]$ (doubling $[\text{H}^+]$ doubles the rate). The reaction is 1st order with respect to H^+ .

Rate equation: $\text{rate} = k[\text{CH}_3\text{COCH}_3][\text{H}^+]$

$$k = \text{rate} \div ([\text{CH}_3\text{COCH}_3][\text{H}^+]) = 1.70 \times 10^{-7} \div (1.50 \times 10^{-3} \times 2.50 \times 10^{-1}) \\ = 4.53 \times 10^{-4} \text{ dm}^3 \text{ mol}^{-1} \text{ s}^{-1}$$

More than one step: Br_2 is in the overall equation but not in the rate equation, so Br_2 must react in a fast step after the rate-determining step. H^+ is in the rate equation but not in the overall equation (it is a catalyst). So the slow, rate-determining step involves CH_3COCH_3 and H^+ only, and the stoichiometry of the overall equation is different from the rate equation, so the mechanism must have more than one step.

[6]

Extra answer space if required.

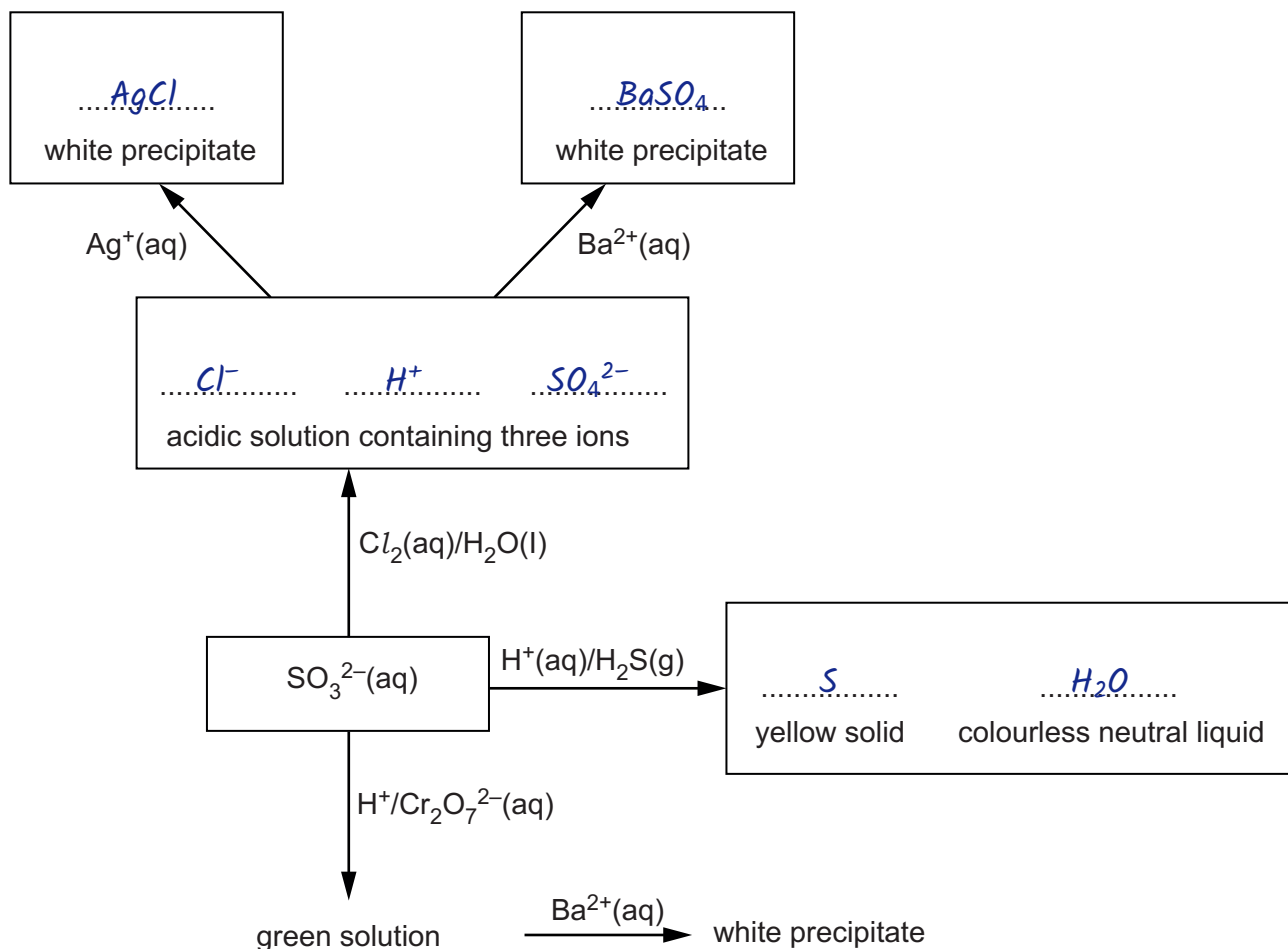
4 This question is about inorganic chemistry.

(a) The flowchart shows reactions involving $\text{SO}_3^{2-}(\text{aq})$ ions.

(i) What is the systematic name of a SO_3^{2-} ion?

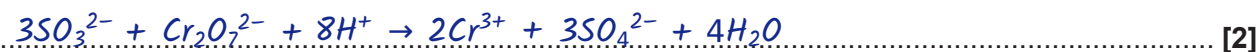
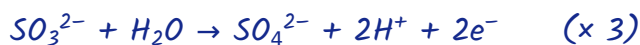
sulfate(IV) (sulfite ion)..... [1]

(ii) Complete the flowchart by adding formulae in the boxes.

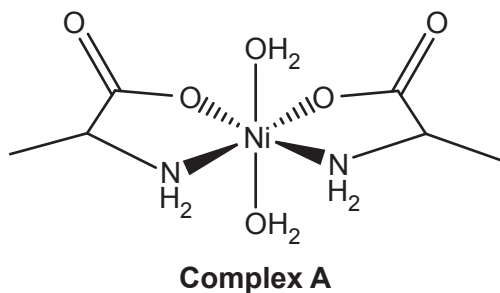


[7]

(iii) Construct an ionic equation for the reaction of SO_3^{2-} with $\text{H}^+/\text{Cr}_2\text{O}_7^{2-}$.



(b) The structure of a neutral nickel(II) complex, **A**, is shown below.



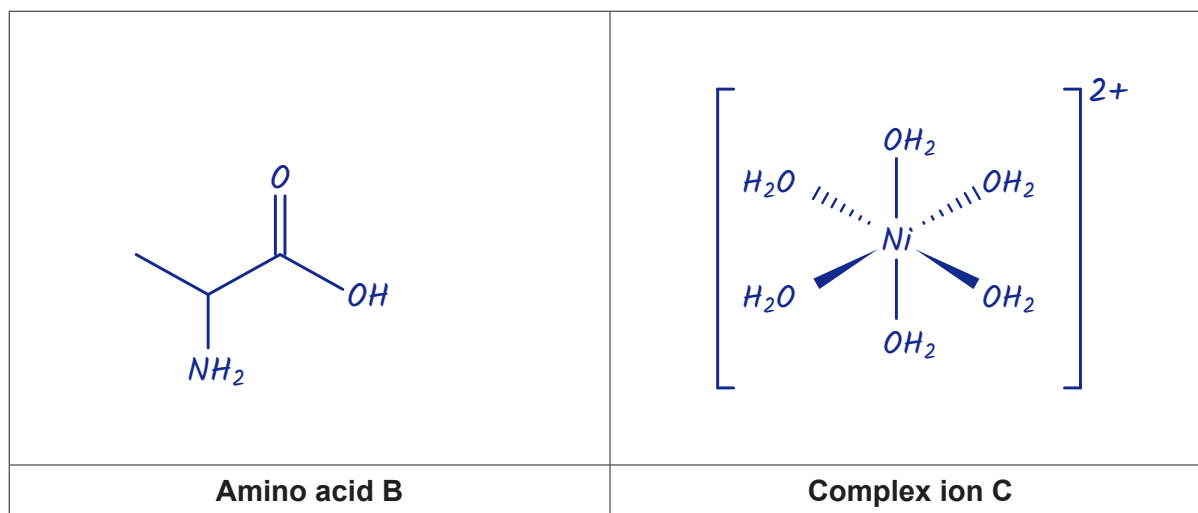
(i) What is the empirical formula of complex **A**?

$C_8H_{16}N_2NiO_6$ [1]

(ii) Complex **A** can be prepared by reacting an aqueous solution of nickel(II) sulfate with amino acid **B** and potassium hydroxide.

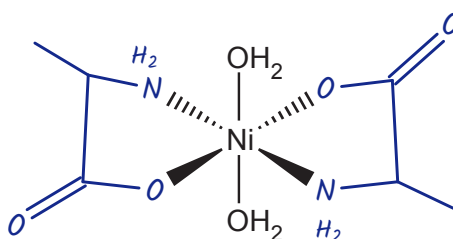
Aqueous nickel(II) sulfate contains the octahedral hexaaquo complex ion **C**.

Draw the structure of amino acid **B** and the 3D structure, including the overall charge, of complex ion **C**.



[3]

(iii) Complete the 3D diagram below to show a stereoisomer of complex **A**.



[1]

- 5 This question is about two metal hydrides, lithium aluminium hydride, LiAlH_4 , and sodium borohydride, NaBH_4 . Both hydrides are used as reducing agents in organic chemistry.

- (a) LiAlH_4 is a stronger reducing agent than NaBH_4 , and can reduce esters to alcohols.

A student plans to use LiAlH_4 to reduce the liquid ester, ethyl phenylmethanoate, $\text{C}_6\text{H}_5\text{COOC}_2\text{H}_5$ (density = 1.05 g cm^{-3}) to the alcohol, $\text{C}_6\text{H}_5\text{CH}_2\text{OH}$ ($M_r = 108$).

The student uses $\text{C}_6\text{H}_5\text{COOC}_2\text{H}_5$ and LiAlH_4 (an excess) in a 1.0 : 2.5 molar ratio.

The student's method is outlined below.

Step 1 7.50 cm^3 of $\text{C}_6\text{H}_5\text{COOC}_2\text{H}_5$ is dissolved in an organic solvent.

Step 2 LiAlH_4 is added to the solution from **Step 1**. The reduction takes place.

Step 3 The mixture from **Step 2** is heated with dilute aqueous acid.

Step 4 The impure $\text{C}_6\text{H}_5\text{CH}_2\text{OH}$ is purified.

The student carries out this preparation and obtains 4.40 g of pure $\text{C}_6\text{H}_5\text{CH}_2\text{OH}$.

- (i) What is the systematic name of the alcohol $\text{C}_6\text{H}_5\text{CH}_2\text{OH}$?

phenylmethanol [1]

- (ii) Calculate the mass of LiAlH_4 that the student should use in **Step 2** and the percentage yield of pure $\text{C}_6\text{H}_5\text{CH}_2\text{OH}$ obtained in **Step 4**.

Give the mass of LiAlH_4 and the percentage yield of pure $\text{C}_6\text{H}_5\text{CH}_2\text{OH}$ to **3** significant figures.

$$\text{mass of ester} = 7.50 \times 1.05 = 7.875 \text{ g}; \quad M_r(\text{C}_6\text{H}_5\text{COOC}_2\text{H}_5) = 150.0$$

$$n(\text{ester}) = 7.875 \div 150.0 = 0.0525 \text{ mol}$$

$$n(\text{LiAlH}_4) = 2.5 \times 0.0525 = 0.13125 \text{ mol}; \quad M_r(\text{LiAlH}_4) = 37.9$$

$$\text{mass of LiAlH}_4 = 0.13125 \times 37.9 = 4.97 \text{ g}$$

$$\text{theoretical } n(\text{C}_6\text{H}_5\text{CH}_2\text{OH}) = n(\text{ester}) = 0.0525 \text{ mol}$$

$$\text{actual } n(\text{C}_6\text{H}_5\text{CH}_2\text{OH}) = 4.40 \div 108.0 = 0.04074 \text{ mol}$$

$$\text{percentage yield} = 0.04074 \div 0.0525 \times 100 = 77.6\%$$

Mass of LiAlH_4 = ... **4.97** g

Percentage yield of pure $\text{C}_6\text{H}_5\text{CH}_2\text{OH}$ = ... **77.6** %
[4]

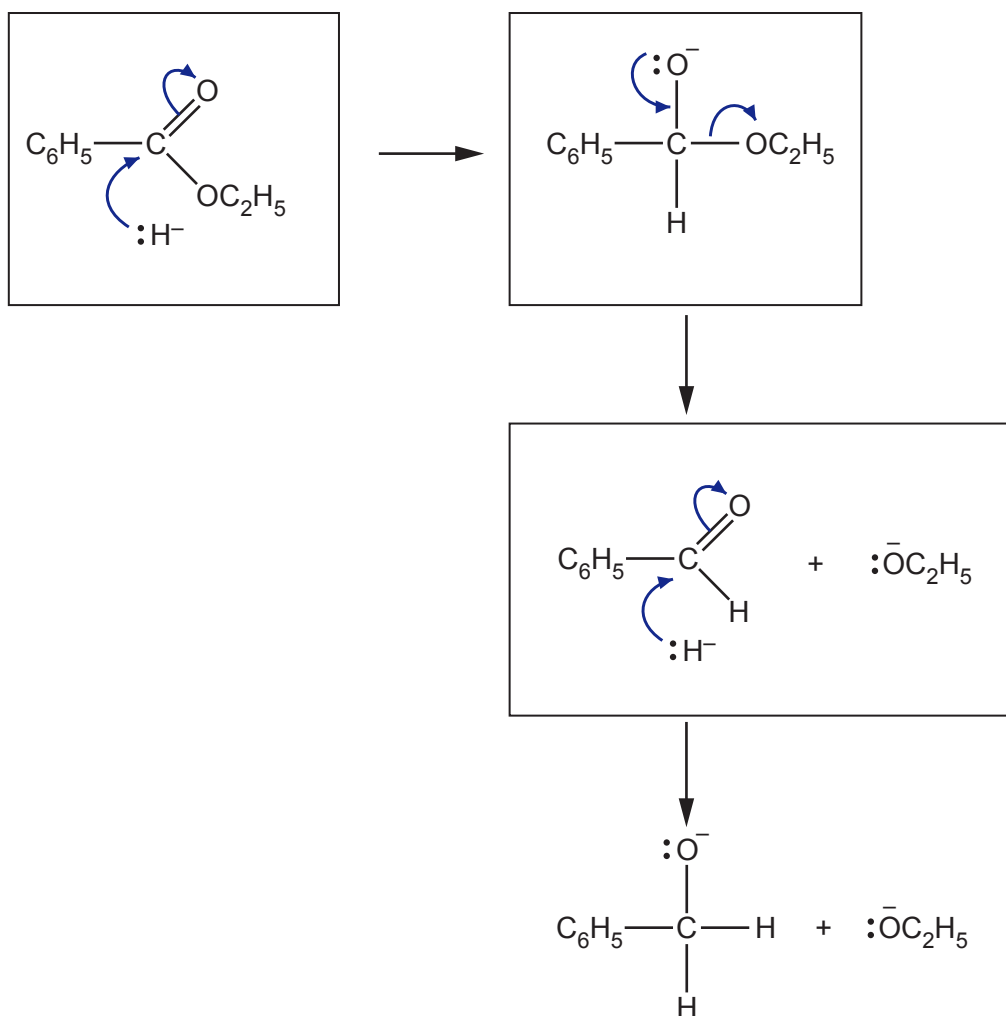
(iii) In the preparation, LiAlH_4 behaves as a nucleophile.

What is meant by the term **nucleophile**?

*An electron pair donor; a species that donates a lone pair of electrons to form
a new covalent (dative) bond.* [1]

(iv) The mechanism for **Step 2** in the reduction of $\text{C}_6\text{H}_5\text{COOC}_2\text{H}_5$ is shown below.
In the mechanism, LiAlH_4 can be represented as H^- .

Complete the mechanism by adding curly arrows to the three boxes.



[4]

(v) Suggest why the student heated the mixture from **Step 2** with dilute aqueous acid in **Step 3**.

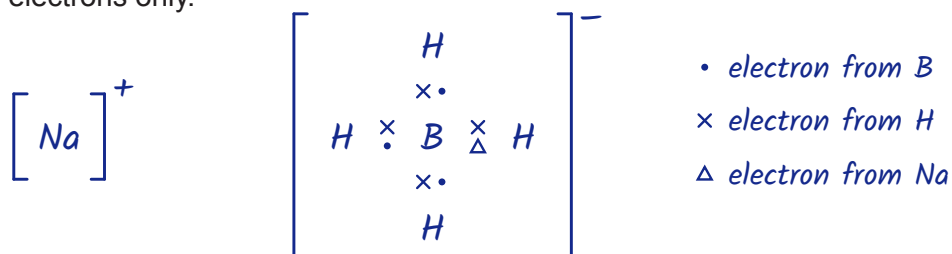
*To protonate the negative ion; H^+ from the acid adds to the O^- of the alkoxide
ion formed in Step 2 ($\text{O}^- + \text{H}^+ \rightarrow \text{OH}$), forming the alcohol $\text{C}_6\text{H}_5\text{CH}_2\text{OH}$.* [1]

(b) NaBH_4 contains Na^+ and BH_4^- ions.

Draw a 'dot-and-cross' diagram for NaBH_4 .

Use a different symbol for the electrons from each element.

Show outer electrons only.

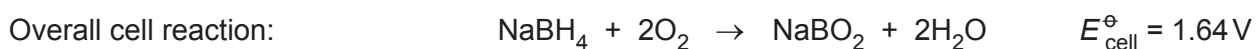
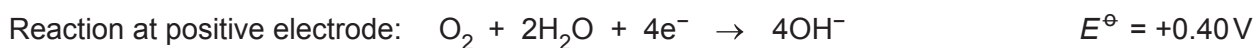


[2]

(c) NaBH_4/O_2 cells are being investigated as potential fuel cells.

- The positive electrode contains O_2 .
- The negative electrode contains NaBH_4 .

The reaction at the positive electrode and the overall cell reaction for a NaBH_4/O_2 fuel cell are shown below.



(i) What is the standard electrode potential of the negative electrode in this cell?

$$E_{\text{cell}} = E(\text{positive}) - E(\text{negative})$$

$$1.64 = +0.40 - E(\text{negative}), \text{ so } E(\text{negative}) = 0.40 - 1.64 = -1.24 \text{ V}$$

Standard electrode potential = ... -1.24 V [1]

(ii) Construct the equation for the reaction at the negative electrode of this cell.



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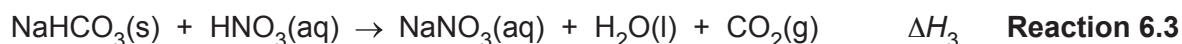
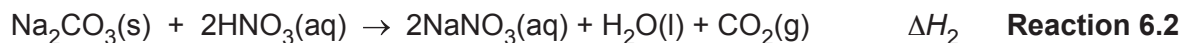
Turn over for the next question

- 6* The enthalpy change of **Reaction 6.1**, ΔH_1 , shown below, is difficult to measure directly by experiment.



The enthalpy changes of reaction for the reactions of Na_2CO_3 and NaHCO_3 with excess $\text{HNO}_3(\text{aq})$ can be measured by experiment.

The reactions are shown below as **Reaction 6.2** and **Reaction 6.3**.



A student reacts $\text{Na}_2\text{CO}_3(\text{s})$ with $\text{HNO}_3(\text{aq})$ to find ΔH_2 for **Reaction 6.2**.

Student's method

Weigh a bottle containing $\text{Na}_2\text{CO}_3(\text{s})$ and weigh a polystyrene cup.

Add about 30 cm^3 of 1.00 mol dm^{-3} $\text{HNO}_3(\text{aq})$ to the polystyrene cup and measure its temperature.

Add the $\text{Na}_2\text{CO}_3(\text{s})$, stir the mixture, and measure the maximum temperature reached. Weigh the empty bottle and weigh the polystyrene cup with the final solution.

Mass readings

Mass of bottle + $\text{Na}_2\text{CO}_3(\text{s})/\text{g}$	3.26
Mass of empty bottle/g	1.29
Mass of polystyrene cup/g	21.08
Mass of polystyrene cup + final solution/g	54.58

Temperature readings

Initial temperature of $\text{HNO}_3(\text{aq})/^{\circ}\text{C}$	20.0
Maximum temperature of final solution/ $^{\circ}\text{C}$	24.0

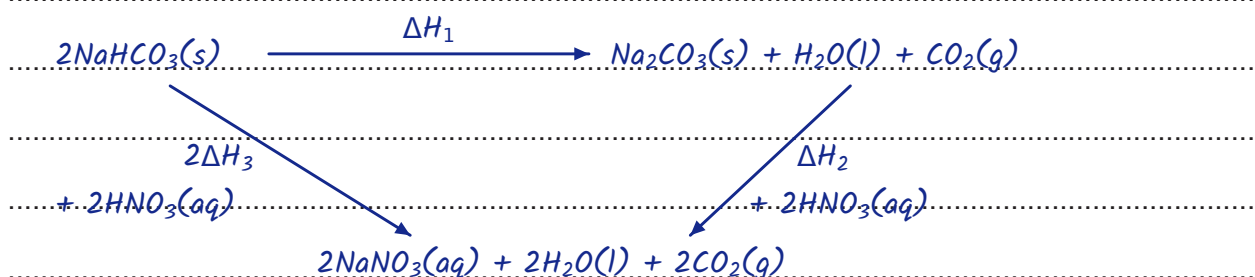
The student follows a similar method and reacts $\text{NaHCO}_3(\text{s})$ with $\text{HNO}_3(\text{aq})$ to find ΔH_3 for **Reaction 6.3**.

The student calculates ΔH_3 for **Reaction 6.3** as $+19.8\text{ kJ mol}^{-1}$.

Calculate ΔH_2 for **Reaction 6.2** and determine the enthalpy change of **Reaction 6.1**, ΔH_1 .

Assume that the density and specific heat capacity, c , of the final solution are the same as for water.

Show your working, including an energy cycle linking the enthalpy changes.



From the cycle: $\Delta H_1 + \Delta H_2 = 2\Delta H_3$, so $\Delta H_1 = 2\Delta H_3 - \Delta H_2$

Mass of final solution, $m = 54.58 - 21.08 = 33.50 \text{ g}$; $\Delta T = 24.0 - 20.0 = 4.0 \text{ K}$

Energy change, $q = mc\Delta T = 33.50 \times 4.18 \times 4.0 = 560.12 \text{ J} = 0.56012 \text{ kJ}$

Mass of $\text{Na}_2\text{CO}_3 = 3.26 - 1.29 = 1.97 \text{ g}$; $M_r(\text{Na}_2\text{CO}_3) = 106.0$

$n(\text{Na}_2\text{CO}_3) = 1.97 \div 106.0 = 0.01858 \text{ mol}$

The temperature rises, so Reaction 6.2 is exothermic and ΔH_2 is negative:

$\Delta H_2 = -0.56012 \div 0.01858 = -30.1 \text{ kJ mol}^{-1}$

$\Delta H_1 = 2\Delta H_3 - \Delta H_2 = 2 \times (+19.8) - (-30.1) = +69.7 \text{ kJ mol}^{-1}$

So Reaction 6.1 is endothermic, $\Delta H_1 = +69.7 \text{ kJ mol}^{-1}$.

[6]

Extra answer space if required.

END OF QUESTION PAPER

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