

Tuesday 20 May 2025 – Morning

AS Level Chemistry B (Salters)

H033/02 Chemistry in depth

Time allowed: 1 hour 30 minutes

You must have:

- the Data Sheet for Chemistry B

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 page 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 **16** pages.

ADVICE

- Read each question carefully before you start your answer.

- 1 Catalytic converters on cars use metals such as platinum as heterogeneous catalysts.

Catalytic converters turn exhaust emissions such as carbon monoxide and nitrogen monoxide into less hazardous products.

(a)

- (i) Explain the meaning of the term **heterogeneous** here.

The catalyst is in a different physical state (phase) from the reactants; the catalyst is a solid and the exhaust gases are gases. [1]

- (ii) Why is carbon monoxide hazardous?

It is toxic (poisonous). [1]

- (iii) Write an equation for the reaction of carbon monoxide with nitrogen monoxide to give less hazardous products.



[1]

- (iv) A simple model to explain the function of a heterogeneous catalyst involves four steps.

Complete **Step 2** and **Step 3** in the sequence below.

Step 1 Reactants are adsorbed onto the surface of the catalyst.

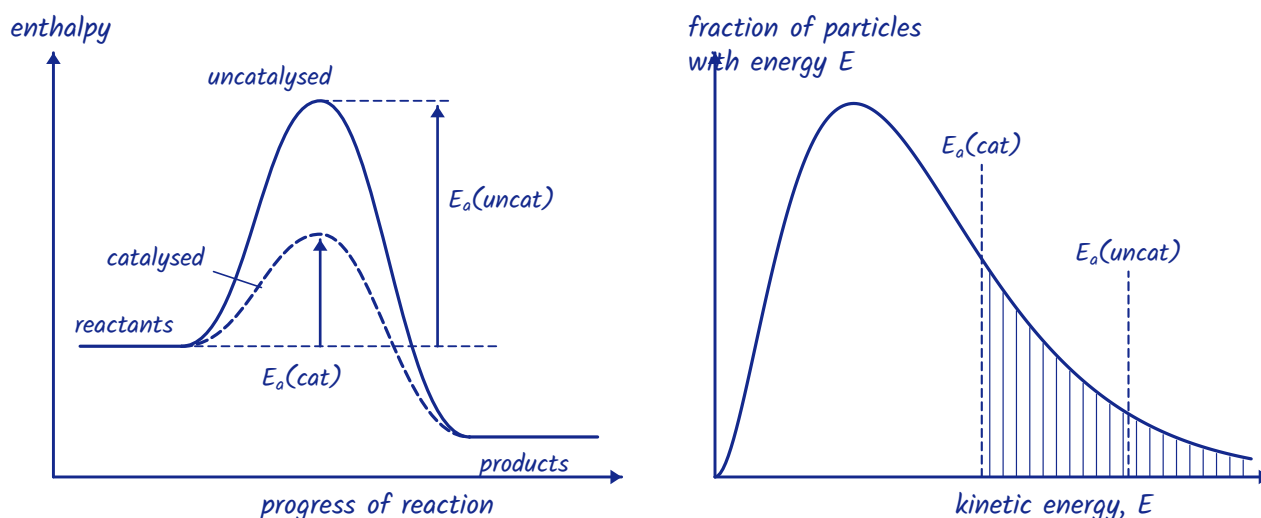
Step 2 *Bonds in the reactants are weakened and break.*

Step 3 *New bonds form to make the products.*

Step 4 Products are desorbed from the surface of the catalyst.

[1]

- (b)* Explain how a catalyst increases the rate of a reaction.
Draw an energy profile and a Boltzmann distribution.



Activation energy, E_a , is the minimum kinetic energy that colliding particles need in order to react.

A catalyst provides an alternative reaction pathway (route) with a lower activation energy, so $E_a(\text{cat})$ is less than $E_a(\text{uncat})$, as shown on the enthalpy profile. The enthalpy change of reaction is the same with or without the catalyst.

On the Boltzmann distribution, $E_a(\text{cat})$ is further to the left than $E_a(\text{uncat})$. The shaded area under the curve to the right of $E_a(\text{cat})$ is larger than the area to the right of $E_a(\text{uncat})$.

So with the catalyst a greater fraction (proportion) of particles have energy greater than or equal to the activation energy. A greater fraction of collisions are successful (lead to reaction) in a given time, so the rate of reaction increases.

[6]

Extra answer space if required.

The temperature, and so the shape of the distribution, is unchanged; the catalyst is not used up.

2 Ethanol is an important alcohol that is made industrially by the hydration of ethene.

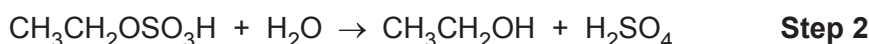
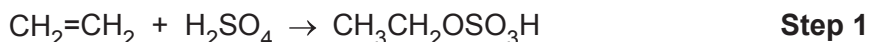
(a) Give the conditions required for this industrial process.

Heat (about 300 °C) and high pressure (about 60 atm), with steam.

Phosphoric acid (H₃PO₄) as the catalyst.

[2]

(b) Ethanol can also be made in the laboratory by a two-step process as shown:



Write the overall equation for this two-step process.



[1]

(c) A student does the two-step process in part (b) using an alkene that is a liquid at room temperature. The reaction is exothermic.

(i) The alkene has a boiling point of 30 °C and is highly flammable.

Suggest a practical arrangement that the student should use to avoid loss of the alkene as a vapour.

Carry out the reaction in a flask fitted with a reflux condenser (and stand the

flask in cold water while adding the acid).

[1]

(ii) When the student has carried out both steps, a mixture is left. This mixture contains an alcohol.

The student finds that drops of this mixture turn bromine water from brown to colourless.

Suggest what this colour change tells the student about the conversion of the alkene into alcohol.

The conversion has not gone to completion: some alkene is still present.

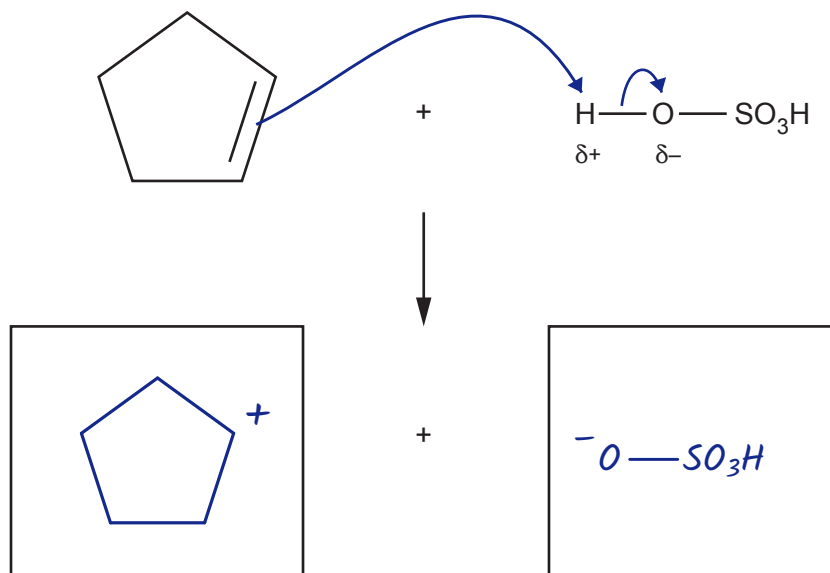
(unreacted).

[1]

- (d) Cyclopentene can be made into cyclopentanol using sulfuric acid.

Complete the first part of **step 1** of the mechanism for the addition of sulfuric acid to form a carbocation.

Show 'curly arrows' and charges.



[4]

- (e) Cyclopentene reacts with hydrogen in the presence of a catalyst.

Name a catalyst that allows this hydrogenation to occur at room temperature and pressure.

..Platinum (Pt)..... [1]

- (f) The student then looks at the isomers with the molecular formula C_5H_{10} .
- (i) There are two **unbranched** stereoisomers that are unsaturated with the molecular formula C_5H_{10} .

Draw **skeletal** formulae for these two stereoisomers and give the systematic name of each one, using the *E/Z* nomenclature.

Explain why this type of stereoisomerism arises.

Skeletal formula		
Name	<i>Z-pent-2-ene</i>	<i>E-pent-2-ene</i>

Explanation *Each carbon atom of the $C=C$ double bond has two different groups (atoms) bonded to it, and there is no free (restricted) rotation about the $C=C$ double bond.*

[3]

- (ii) There are other **branched** unsaturated isomers of molecular formula C_5H_{10} .

Give the **name** of **one** of these isomers.

State the **type** of isomerism by which this isomer is related to the stereoisomers in part (f)(i).

Name of isomer *2-methylbut-2-ene*

Type of isomerism *Structural (chain) isomerism*

[2]

3 A student investigates the reactions of some of the elements and compounds of Group 2.

(a) The student begins by comparing the reactivities of the metals with water.

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



[1]

(ii) The relative reactivities of the Group 2 elements are related to their ionisation enthalpies.

Write an equation for the **first** ionisation enthalpy of calcium.

Show state symbols.



[2]

(iii) Describe and explain, in terms of electrons, the difference between the reactivities of calcium and barium.

..Barium..is..more..reactive..than..calcium.....

..A..barium..atom..is..larger;..its..outer..electrons..are..in..a..shell..further..from..the.....

..nucleus..than..the..outer..electrons..in..calcium.....

..So..the..attraction..between..the..nucleus..and..the..outer..electrons..is..weaker..(less)..in.....

..barium..than..in..calcium.....

..So..the..outer..electrons..are..lost..more..easily..by..barium..(lower..ionisation..enthalpy),.....

..and..the..reactivity..increases..from..calcium..to..barium.....

.....

.....

..... [4]

- (b) A student makes a pure sample of hydrated magnesium sulfate using magnesium carbonate.

Describe and explain the method the student should use.

..Add magnesium carbonate to dilute sulfuric acid a little at a time, stirring, until
..it is in excess (no more fizzing and some solid remains), so that all the acid has
..reacted.
..Filter to remove the excess magnesium carbonate.
..Evaporate the filtrate to about half its volume (crystallisation point), then leave
..it to cool so that crystals form (do not heat to dryness).
..Filter off the crystals of hydrated magnesium sulfate and dry them on absorbent
..(filter) paper.

[4]

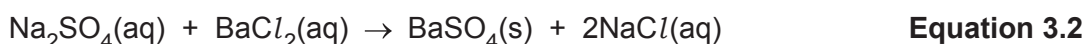
- (c)* A batch of Na_2SO_3 has partially oxidised to Na_2SO_4 .
Two students each have a 1.00 g sample of this partially oxidised batch.

Each student dissolves their sample in dilute hydrochloric acid.

Only the Na_2SO_3 reacts, as shown in **Equation 3.1**.



Student 1 then adds an excess of barium chloride solution to the resulting solution.
The reaction shown in **Equation 3.2** occurs.



Student 1 washes and dries the precipitate and obtains 0.33 g of dry BaSO_4 ($M_r = 233.4$).

Student 2 repeats the method but uses a volume of barium chloride solution that is **not** an excess.

Use the result from **Student 1** to calculate the percentage by mass of the Na_2SO_3 in the 1.00 g sample.

Explain the effect that the mistakes made by **Student 2** would have on the percentages they calculated.

[6]

..Amount of $\text{BaSO}_4 = 0.33 / 233.4 = 1.41 \times 10^{-3} \text{ mol}$
..Amount of $\text{Na}_2\text{SO}_4 = \text{amount of } \text{BaSO}_4 = 1.41 \times 10^{-3} \text{ mol}$ (1 : 1 ratio in
..Equation 3.2)
.. M_r of $\text{Na}_2\text{SO}_4 = 2(23.0) + 32.1 + 4(16.0) = 142.1$, so mass of $\text{Na}_2\text{SO}_4 =$

$$1.41 \times 10^{-3} \times 142.1 = 0.20 \text{ g}$$

$$\text{Mass of Na}_2\text{SO}_3 = 1.00 - 0.20 = 0.80 \text{ g}$$

$$\text{Percentage by mass of Na}_2\text{SO}_3 = (0.80 / 1.00) \times 100 = 80\%$$

Student 2: the barium chloride is not in excess, so not all of the sulfate ions are precipitated and less BaSO_4 is formed (a smaller mass of precipitate).

This suggests that less Na_2SO_4 is present, i.e. that less of the Na_2SO_3 has been oxidised.

So Student 2 would calculate a mass of Na_2SO_4 that is too low and a percentage by mass of Na_2SO_3 that is too high (higher than 80%).

Extra answer space if required.

- (d) Five students each do experiments to find the value of x in the formula of the hydrated salt $\text{MgSO}_4 \cdot x\text{H}_2\text{O}$.

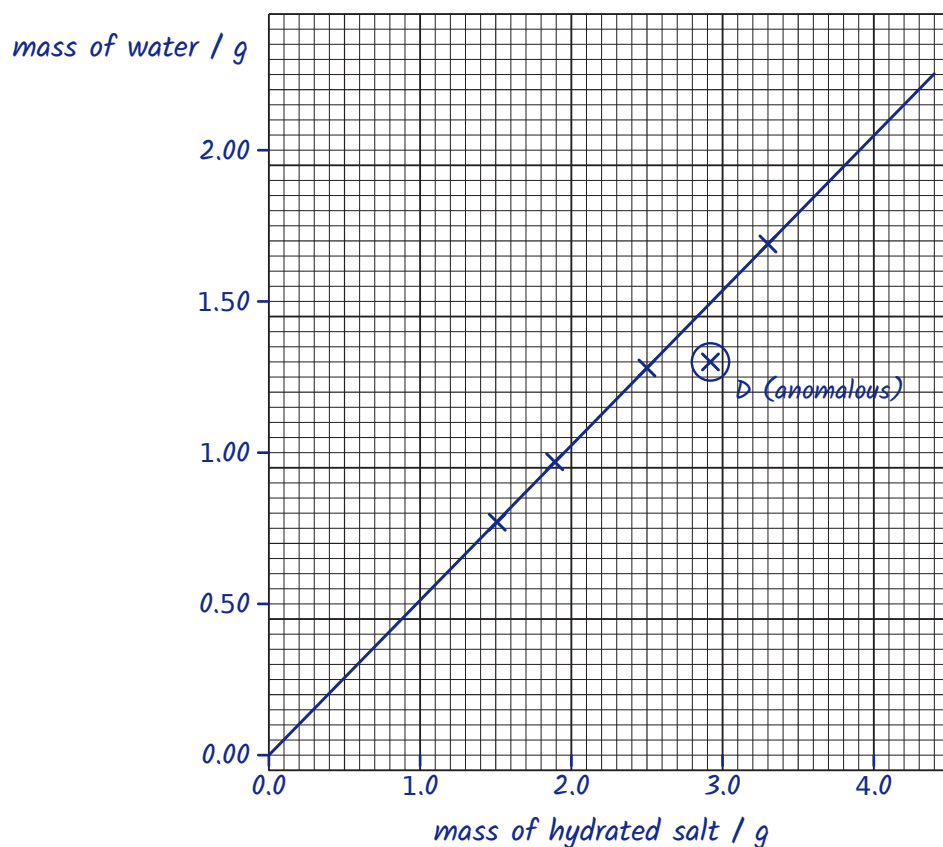
The students heat samples of the hydrated salt to constant mass.
Their results are shown in the table.

	Student				
	A	B	C	D	E
Mass of hydrated salt / g	1.51	1.89	2.50	2.92	3.30
Mass contents after heating / g	0.74	0.92	1.22	1.62	1.61
Mass of water / g	0.77	0.97	1.28	1.30	1.69

- (i) Plot a graph of mass of water against mass of hydrated salt on the graph paper below.

Include the origin.

Draw a line of best fit.



[3]

- (ii) Identify the anomalous point and suggest what caused this anomaly.

Anomalous point ...Student D (2.92, 1.30).....

Suggested cause of anomaly ...The hydrated salt was not heated to constant mass.....

...(not heated for long enough), so not all the water was lost.....

[1]

(iii) Calculate the value of x in the formula $\text{MgSO}_4 \cdot x\text{H}_2\text{O}$. Use the results from **Student C**.

$$\text{MgSO}_4 : \text{H}_2\text{O} \text{ mass ratio} = 1.22 \text{ g} : 1.28 \text{ g}$$

$$M_r \text{ MgSO}_4 = 24.3 + 32.1 + 4(16.0) = 120.4; \quad M_r \text{ H}_2\text{O} = 18.0$$

$$\text{moles: } 1.22 / 120.4 = 1.01 \times 10^{-2} \quad \text{and} \quad 1.28 / 18.0 = 7.11 \times 10^{-2}$$

$$\text{ratio} = (1.01 \times 10^{-2} / 1.01 \times 10^{-2}) : (7.11 \times 10^{-2} / 1.01 \times 10^{-2})$$

$$= 1 : 7.0, \text{ so } x = 7$$

$$x = \dots\dots\dots 7 \dots\dots\dots \text{ [3]}$$

(e) Magnesium exists as three isotopes: magnesium-24, 78.60%, magnesium-25, 10.11% and magnesium-26, 11.29%.

Calculate a value for the A_r of magnesium.

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

$$A_r = [(24 \times 78.60) + (25 \times 10.11) + (26 \times 11.29)] / 100$$

$$= (1886.4 + 252.75 + 293.54) / 100$$

$$= 2432.69 / 100 = 24.33$$

$$A_r = \dots\dots\dots 24.33 \dots\dots\dots \text{ [2]}$$

4 Esters are used as solvents.

(a) A student reacts propanoic acid, $\text{CH}_3\text{CH}_2\text{COOH}$, with propan-2-ol, $\text{CH}_3\text{CH}(\text{OH})\text{CH}_3$ to prepare an ester.

(i) Classify propan-2-ol as primary, secondary, or tertiary, explaining your reasoning.

Classification *Secondary*.....

Reasoning *The carbon atom bonded to the OH group is attached to two other carbon atoms (and has only one H atom)*.....

[2]

(ii) Give the reaction conditions that the student should use for this esterification reaction.

Heat under reflux with a few drops of concentrated sulfuric acid (as catalyst).....

[1]

(iii) Write a structural formula for the ester produced in this reaction.



[1]

(b) Another student wants to measure the equilibrium constant for the reaction between ethanoic acid, CH_3COOH , and ethanol, $\text{CH}_3\text{CH}_2\text{OH}$.



The student says that at equilibrium the forward and backward reactions have stopped and the composition of the mixture remains constant.

Comment on what the student says, giving the correct chemistry where necessary.

The student is wrong that the forward and backward reactions have stopped:.....

equilibrium is dynamic, so both reactions are still happening but at equal rates......

The student is correct that the composition (concentrations) of the mixture.....

remains constant...... [2]

- (c) The student mixes 20.0 cm^3 ethanoic acid with 20.0 cm^3 ethanol and leaves the mixture to stand for one week at 25°C after which it has reached equilibrium.
- (i) The density of ethanol is 0.790 g cm^{-3} . Calculate the amount (in mol) of ethanol in the 20.0 cm^3 used.

$$\text{mass} = \text{density} \times \text{volume} = 0.790 \times 20.0 = 15.8 \text{ g}$$

$$M_r \text{ CH}_3\text{CH}_2\text{OH} = 2(12.0) + 6(1.0) + 16.0 = 46.0$$

$$\text{amount} = 15.8 / 46.0 = 0.343 \text{ mol}$$

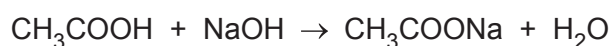
Amount of ethanol = ...0.343..... mol [2]

- (ii) The student then uses a 1.00 cm^3 volumetric pipette to transfer 1.00 cm^3 of the mixture to a conical flask containing 100 cm^3 of ice-cold water.

The student titrates the contents of the conical flask with $0.100 \text{ mol dm}^{-3}$ sodium hydroxide.

The mean titre is 29.50 cm^3 .

Ethanoic acid reacts with sodium hydroxide as shown:



Show that the amount of ethanoic acid in the 40.0 cm^3 of the equilibrium mixture is 0.118 mol .

$$\text{amount of NaOH in titre} = (29.50 / 1000) \times 0.100 = 2.95 \times 10^{-3} \text{ mol}$$

$$1 : 1 \text{ ratio, so amount of CH}_3\text{COOH in } 1.00 \text{ cm}^3 = 2.95 \times 10^{-3} \text{ mol}$$

$$\text{amount in } 40.0 \text{ cm}^3 = 2.95 \times 10^{-3} \times 40.0 = 0.118 \text{ mol}$$

[2]

- (d) The student uses further calculations to work out the amounts and concentrations of the four components of the 40.0 cm³ of equilibrium mixture.
- (i) Complete the table by calculating the equilibrium concentration of ethanoic acid.

Component	Equilibrium amount in 40 cm ³ equilibrium mixture /mol	Equilibrium concentration in 40 cm ³ equilibrium mixture /mol dm ⁻³
CH ₃ COOH	0.118	2.95.....
CH ₃ CH ₂ OH	0.111	2.78
CH ₃ COOCH ₂ CH ₃	0.232	5.80
H ₂ O	0.232	5.80

[1]

- (ii) Write the expression for the equilibrium constant for the reaction in **Equation 4.1**.



$$K_c = \frac{[\text{CH}_3\text{COOCH}_2\text{CH}_3][\text{H}_2\text{O}]}{[\text{CH}_3\text{COOH}][\text{CH}_3\text{CH}_2\text{OH}]}$$

[1]

- (iii) Calculate the numerical value for this equilibrium constant.

Give your answer to an **appropriate** number of significant figures.

$$K_c = (5.80 \times 5.80) / (2.95 \times 2.78)$$

$$= 33.64 / 8.201 = 4.10 \text{ (3 significant figures)}$$

Numerical value of equilibrium constant = ...4.10..... [2]

- (e) Suggest why the student uses a 1.00 cm³ volumetric pipette and not a small measuring cylinder for transferring 1.00 cm³ of the equilibrium mixture for the titration.

.....The volumetric pipette has a smaller uncertainty, so this reduces the uncertainty.....
(error) in the calculated value of the equilibrium constant..... [1]

- (f) Suggest why the student adds the sample of equilibrium mixture to 100 cm³ of ice-cold water before carrying out the titration.

Diluting and cooling the mixture slows the reactions, so it stops (prevents) the position of equilibrium shifting as the sodium hydroxide reacts with (removes) the ethanoic acid. [1]

- (g) The student is given some values of the equilibrium constant at various temperatures.

As temperature increases, the numerical value of the equilibrium constant decreases.

Explain what the student can deduce about the enthalpy change of the forward reaction in **Equation 4.1** from this information.

Since K_c decreases as temperature increases, increasing the temperature shifts the position of equilibrium to the left (towards the reactants), so less product forms. By Le Chatelier's principle the position of equilibrium shifts to oppose the change, i.e. in the endothermic direction to absorb the heat; this is the backward reaction. So the forward reaction is exothermic (ΔH is negative). [3]

END OF QUESTION PAPER

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