

**NATIONAL JUNIOR COLLEGE**  
**SH2 PRELIMINARY EXAMINATION**  
Higher 2

CANDIDATE  
NAME

SUBJECT  
CLASS

REGISTRATION  
NUMBER

**CHEMISTRY**

Paper 3 Free Response

**9729/03**

**23 September 2025**

**2 hours**

Candidates answer on Question Paper.  
Additional Materials: Data Booklet

**READ THE INSTRUCTIONS FIRST**

Write your subject class, registration number and name on all the work you hand in.

Write in dark blue or black pen.

You may use a soft pencil for any diagrams or graphs.

Do not use staples, paper clips, glue or correction fluid.

**Section A**

Answer **all** questions.

**Section B**

Answer **one** question.

A Data Booklet is provided.

The use of an approved scientific calculator is expected, where appropriate.

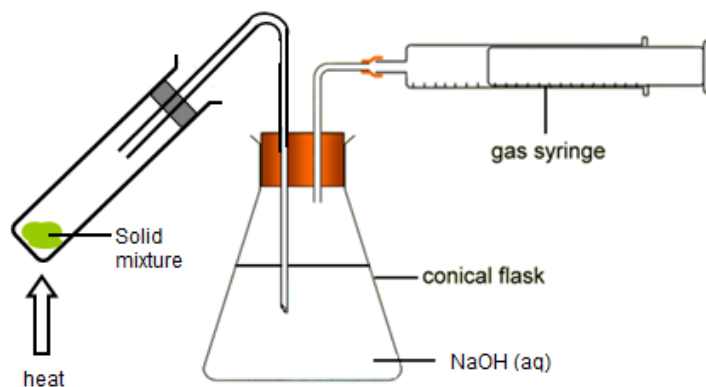
The number of marks is given in brackets [ ] at the end of each question or part question.

For Examiner's Use	
Section A	
1	/19
2	/20
3	/21
Section B (*circle the question you attempted)	
4	/20
5	/20
Paper 3 Total	/80

## Section A

Answer **all** the questions in this section.

- 1 (a) A student investigated the thermal decomposition of Group 2 compounds. He heated a mixture of 2.50 g of magnesium nitrate and magnesium carbonate using the setup shown in Fig. 1.1, till no further change was observed. A colourless gas of a volume of 80.8 cm<sup>3</sup> was collected at 30 °C and atmospheric pressure.



**Fig 1.1**

- (i) Write balanced equations for the thermal decomposition of  $\text{MgCO}_3$  and  $\text{Mg}(\text{NO}_3)_2$ . [1]
- (ii) Explain the purpose of sodium hydroxide in the above setup and hence identify the gas collected in the gas syringe. [2]
- (iii) Calculate the percentage by mass of magnesium nitrate present in the mixture. [3]

[illegible]

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- (b) The student carried out another experiment by heating equal amounts of carbonates of magnesium, calcium and barium for two minutes using a Bunsen burner. Table 1.1 shows the volume of gas collected.

**Table 1.1**

Group 2 carbonate	MgCO <sub>3</sub>	CaCO <sub>3</sub>	BaCO <sub>3</sub>
Volume of gas collected / cm <sup>3</sup>	80	25	5

Using relevant data from the *Data Booklet*, explain the results obtained by the student. [3]

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- (c) Table 1.2 shows the bond length of various nitrogen-oxygen bonds.

**Table 1.2**

Bond	N O	N=O	nitrogen-oxygen bond in NO <sub>3</sub>
Bond Length (nm)	0.136	0.115	0.128

Suggest an explanation for the observed NO bond length in nitrate ion.

[2]

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- (d) Sodium carbonate, a Group 1 carbonate, can be used to maintain the pH of swimming pool water to the ideal range of 7.0–7.6. If the concentration of sodium carbonate is too high, it will cause skin irritation to swimmers.

The management committee of a public swimming pool hired a chemist to advise them on the need to adjust the pH of pool water. The chemist titrated a 10.0 cm<sup>3</sup> sample of pool water (assume it contains only Na<sub>2</sub>CO<sub>3</sub>) against 0.05 mol dm<sup>-3</sup> HCl.

20.00 cm<sup>3</sup> of the HCl solution was required to turn the phenolphthalein indicator from pink to colourless. When the titration is repeated using methyl orange indicator, 40.00 cm<sup>3</sup> of HCl was required to reach the end point.

[The  $K_{b1}$  and  $K_{b2}$  values of Na<sub>2</sub>CO<sub>3</sub> at 25 °C are  $2.13 \times 10^{-4}$  and  $2.25 \times 10^{-8}$  respectively.]

- (i) The pH at the first equivalence point is found to be greater than 7. Write an equation to explain this observed pH. [1]
- (ii) Calculate the concentration of Na<sub>2</sub>CO<sub>3</sub> in the pool water sample. [1]
- (iii) Using your answer to (ii), calculate the initial pH of the pool water sample. [2]
- (iv) Sketch the pH volume added curve you would expect to obtain when 50.00 cm<sup>3</sup> of the HCl solution is added to 10.0 cm<sup>3</sup> of the pool water sample. Label the various key points on the curve. [2]

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- (e) Lithium carbonate is a sparingly soluble salt with a  $K_{sp}$  value of  $8.15 \times 10^{-4}$ .

Calculate the solubility of lithium carbonate.

[2]

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[Total : 19]

- 2** Cobalt is a *transition element* that can form coloured ions of various oxidation states in aqueous solutions.

- (a) (i) Explain what is meant by the term *transition element*. [1]

- (ii) Explain why an aqueous solution of  $\text{Co}^{3+}$  ions is coloured. [3]

- (iii) Explain why cobalt ions can exhibit variable oxidation states while calcium ion can only have an oxidation state of +2. [2]

[illegible]

### Table 2.1

ionic compound	amount of white ppt formed with excess $\text{AgNO}_3(\text{aq})$
<b>A</b>	1 mol
<b>B</b>	2 mol

- (i) Identify the type of reaction for the reaction between  $\text{CoCl}_3$  and  $\text{NH}_3$ . [1]
- (ii) Identify the white precipitate. Explain why different amounts of white precipitate are formed from **A** and **B**. [2]
- (iii) Deduce the formula for the **complex ions** in **A** and **B**. [2]
- (iv) The cobalt(III) complex ion in **A** exhibits *cis-trans* isomerism. Using your answer in (iii), draw the three-dimensional structure of the *cis* isomer of **A**.

If you are unable to deduce the formula for the complex ions found in **A** in (iii), you should use the formula  $[\text{Co}(\text{NH}_3)_2\text{Cl}_4]^-$ . This is **not** the correct answer. [1]

[illegible]



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- (c) The reaction between iodide ions,  $\text{I}^-$ , and peroxodisulfate ions,  $\text{S}_2\text{O}_8^{2-}$ , in the absence of catalyst is slow.  $\text{Co}^{3+}$  ion can act as a homogeneous catalyst to speed up the reaction.

By considering suitable  $E^\ominus$  value from the *Data Booklet*, explain how  $\text{Co}^{3+}$  functions as a catalyst for the reaction between  $\text{I}^-$  and  $\text{S}_2\text{O}_8^{2-}$ , writing equations where appropriate. [3]

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- (d) A series of experiments were carried out to investigate the kinetics of the uncatalysed reaction between  $\text{K}_2\text{S}_2\text{O}_8$  and  $\text{KI}$ .

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[Total : 20]

- 3 (a) Adrenaline is both a hormone and neurotransmitter in the body. A chemistry undergraduate student has proposed to synthesise adrenaline from compound **Y** using a 3-step synthetic route as shown in Fig. 3.1.

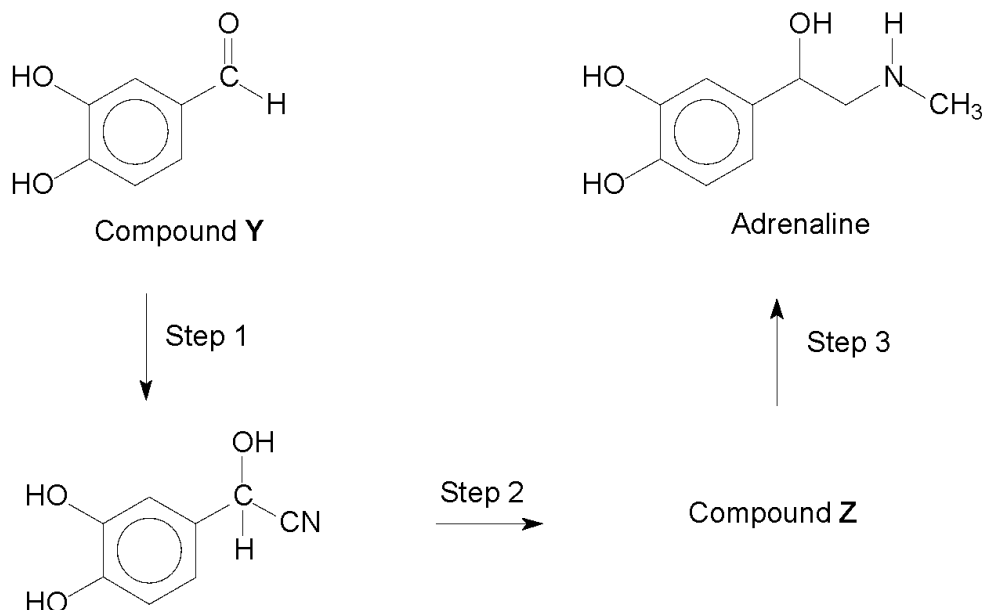


Fig. 3.1

- (i) State the reagent and condition for Step 1 and describe the reaction mechanism. Include all relevant lone pairs, dipoles, charges, and curly arrows. Include the structure of the organic intermediate. [4]
- (ii) Identify the structure of compound **Z** and state the reagents and conditions needed for Step 2 and Step 3. [3]
- (iii) Suggest how the adrenaline synthesised through the above reaction scheme is different from the naturally occurring adrenaline secreted by the adrenal glands in the body. [2]

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His teacher pointed out there were mistakes in both Step 1 and 2.

- (i) State the correct reagent and condition for Step 1. [1]
- (ii) Using  $\text{CH}_3\text{COOH}$  in Step 2 would produce compound **G** instead of paracetamol.  
Identify the structure of compound **G**. [1]
- (iii) Describe the observation when neutral  $\text{FeCl}_3(\text{aq})$  is reacted with paracetamol. [1]

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(c)

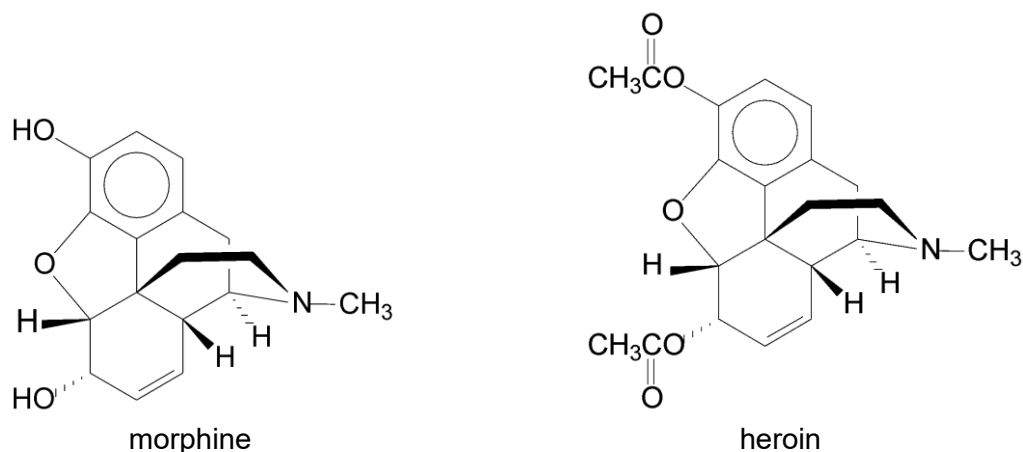


Fig. 3.3

In contrast to paracetamol, narcotic analgesics such as morphine and heroin are used to relieve intense pain. Studies on the structural activity of morphine molecule have identified the three essential functional groups of morphine that bind strongly with the pain receptors and block the transmission of pain signals between brain cells are as follows:

1. Phenolic –OH group
2. Aromatic ring of phenol
3. Positively charged amine group

When injected into human body, these drug molecules need to cross the hydrophobic blood-brain barrier to reach the pain receptors. It is observed that polar molecules cross the blood-brain barrier less readily. In the brain, esterase enzymes catalyse the hydrolysis of the ester groups.



- (i) In the physiological pH of 7.4, the tertiary nitrogen atoms of morphine and heroin are protonated. On Fig. 3.3, complete the structure to show the protonated form of morphine. [1]
- (ii) Suggest why heroin shows greater pain-relieving effect than morphine despite lacking the essential phenolic –OH group to bind with the pain receptors. [2]

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- (d) Compound **P**,  $\text{C}_{10}\text{H}_{12}\text{O}_2$ , reacts with hot  $\text{H}_2\text{SO}_4(\text{aq})$  to give compound **Q**,  $\text{C}_2\text{H}_4\text{O}_2$ , and compound **R**,  $\text{C}_8\text{H}_{10}\text{O}$ . Compound **R** reacts with  $\text{Br}_2(\text{aq})$  to give compound **S**,  $\text{C}_8\text{H}_9\text{OBr}$ , a symmetrical molecule.

Suggest possible structures for **P**, **Q**, **R**, **S**. For each reaction, state the type of reaction described and make deductions about the functional groups present. [6]

[illegible]

[Total : 21]

**(a) (i)** Construct the balanced equation for the reaction between Fe(s) and hot concentrated H<sub>2</sub>SO<sub>4</sub>. [1]

(ii) The  $E^{\circ}_{\text{cell}}$  for this reaction is +0.61 V. Give two reasons why an equilibrium mixture is not produced when iron reacts with an excess of hot concentrated sulfuric acid.

[3]

This image shows a full page of white paper with horizontal dashed lines, typical of primary-ruled notebook paper. The lines are evenly spaced and run across the width of the page. There are no margins, text, or other markings on the paper.





- (d) Describe and explain the trend in the thermal stability of the hydrogen halides  $\text{HCl}$ ,  $\text{HBr}$  and  $\text{HI}$ . Include an equation for the thermal decomposition reaction in your answer. [3]

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- (e) Three pure solid compounds, labelled **D**, **E** and **F**, are placed on the lab bench. It is known that the compounds are  $\text{AlCl}_3$ ,  $\text{Na}_2\text{CO}_3$  or  $\text{MgSO}_4$ .

A student performed several tests, and the results are summarised in Table 4.1.

**Table 4.1**

Compound	pH of the aqueous solution of the compound	results of adding $\text{NaOH(aq)}$ to a solution of the compound	results of adding $\text{HCl(aq)}$ to the solid compound
<b>D</b>	$> 7$	No observed reaction	Evolution of a gas
<b>E</b>	$< 7$	White ppt soluble in excess $\text{NaOH}$	No observed reaction
<b>F</b>	$< 7$	White ppt insoluble in excess $\text{NaOH}$	No observed reaction

- (i) Suggest the identities of the compounds **D**, **E** and **F** based on the observations in Table 4.1. [2]
- (ii) Suggest the formula of the white compound observed when an excess of  $\text{NaOH}$  is added to a solution of the compound **F**. [1]
- (iii) With the aid of an equation, explain why an aqueous solution of **E** has a  $\text{pH} < 7$ . [2]

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- (f) Beryllium oxide, BeO, has similar chemical properties as  $Al_2O_3$ .

Write the chemical equations when separate samples of BeO are reacted with  $HCl(aq)$  and  $NaOH(aq)$ . [2]

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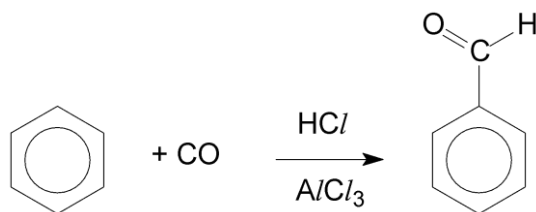
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[Total : 20]

- 5 (a) Benzaldehyde,  $\text{C}_6\text{H}_5\text{CHO}$ , served as a precursor in the production of various chemicals, including pharmaceuticals and dyes. Benzaldehyde can be synthesised from carbon monoxide and benzene by the Gatterman–Koch reaction in the presence of hydrogen chloride and aluminium chloride. This reaction is an electrophilic substitution reaction.



The following describes the mechanism for the reaction.

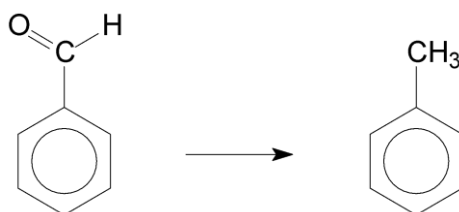
step 1: Carbon monoxide, hydrogen chloride and aluminium chloride react to form the

electrophile,  $\text{H}-\text{C}^+=\text{O}$ , and one other product.

step 2: The electrophile reacts with benzene to form an intermediate in the rate-determining step.

step 3: The intermediate loses a  $\text{H}^+$  to regenerate hydrogen chloride and aluminium chloride.

- (i) Explain why benzene undergoes substitution reactions rather than addition reaction. [1]
- (ii) Write the equation for the generation of the electrophile in step 1 of the Gatterman–Koch reaction. [1]
- (iii)  $\text{AlCl}_3$  acts as a *Lewis acid* in step 1 of the reaction. Describe how  $\text{AlCl}_3$  act as a *Lewis acid* in this step. [1]
- (iv) Draw a reaction mechanism for step 2 and step 3. Include all relevant charges and curly arrows. Include the structure of the organic intermediate. [2]
- (v) Benzaldehyde formed can undergo further reaction to form methylbenzene.



State the type of reaction that benzaldehyde undergoes and explain your answer. [2]

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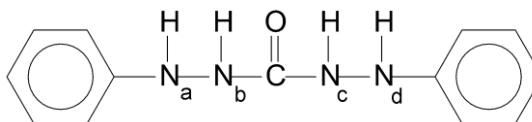


- 5 (b) The concentration of chromium(VI) in aqueous solution may be determined using a colorimeter. On adding 1,5-diphenylcarbazide, DPC, to a solution of chromium(VI) ions, an intensely coloured octahedral complex is formed. The formula of the complex is  $[\text{Cr}(\text{DPC})_3]^{6+}$ .

(i) The coordination number of the complex,  $[\text{Cr}(\text{DPC})_3]^{6+}$  is 6.

Explain what is meant by *coordination number* for the complex,  $[\text{Cr}(\text{DPC})_3]^{6+}$ . [1]

(ii) The structure of DPC is shown.



DPC is able to act as a bidentate ligand using lone pair electrons on  $\text{N}_a$  and  $\text{N}_d$ . Explain why the lone pair electrons on  $\text{N}_b$  and  $\text{N}_c$  are not available. [1]

(iii) Suggest why the intense colour of the complex,  $[\text{Cr}(\text{DPC})_3]^{6+}$ , is not due to the movement of electrons between split d-orbitals in the chromium ion. [1]

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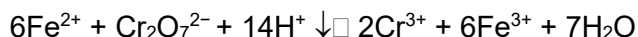
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- (c) Potassium dichromate(VI),  $\text{K}_2\text{Cr}_2\text{O}_7$ , is present in very small amounts in cement, to help increase the time for the cement to set.

A 50.0 g sample of cement was washed with portions of deionised water to dissolve the potassium dichromate(VI). Any insoluble residues were removed by filtration and the filtrate was transferred to a volumetric flask. The volume was made up to 100.0  $\text{cm}^3$  using 2.0  $\text{mol dm}^{-3}$  sulfuric acid.

50.0  $\text{cm}^3$  of this solution was transferred to a conical flask and titrated with a solution of ammonium iron(II) sulfate,  $(\text{NH}_4)_2\text{Fe}(\text{SO}_4)_2$ , of concentration  $3.24 \times 10^{-4} \text{ mol dm}^{-3}$ . The following reaction occurs.



The indicator *N*-phenylanthranilic acid was used, which gave an intense red-violet colour at the end-point. The mean titre of ammonium iron(II) sulfate was 10.90  $\text{cm}^3$ .

- (i) Suggest a reason why an indicator is necessary in this titration. [1]
- (ii) Calculate the percentage by mass of potassium dichromate(VI) in the cement sample. [3]
- (iii) Potassium dichromate(VI) can cause allergic contact dermatitis in some individuals. Regulations have been put in place in some countries to limit the content of potassium dichromate(VI) in cement to no more than 2mg per kg of cement.

Using your answer in (ii), determine if the 50.0 g sample of cement is safe for usage. [2]

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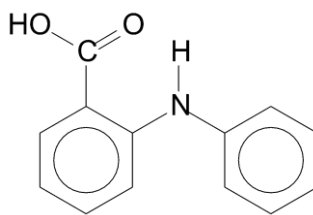
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(i) Explain why *N*-phenylanthranilic acid has low solubility in water. [1]

(ii) State the type of reaction between *N*-phenylanthranilic acid and NaOH(aq). [1]

(iii) Draw a labelled diagram to illustrate the interaction between the resultant organic species and a water molecule. [2]

[illegible]

[Total : 20]

[illegible]

