ST ANDREW'S JUNIOR COLLEGE

JC2 PRELIMINARY EXAMINATIONS

HIGHER 2

CANDIDATE NAME	

CLASS					
	2	**3**	**S**		

CHEMISTRY 9729/02

Paper 2 Structured Questions **27 August 2024**

Candidates answer on the Question Paper. **2 hours**

Additional Materials: Data Booklet

READ THESE INSTRUCTIONS FIRST

Write your name and class on all the work that you hand in.

Write in dark blue or black pen.

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

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

Answer **all** questions in the **spaces provided** on the Question Paper.

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

A Data Booklet is provided.

At the end of the examination, fasten all your work securely together.

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

For Examiner's Use		
Q1		**8**
Q2		**17**
Q3		**11**
Q4		**14**
Q5		**25**
Total		**75**

This document consists of **22** printed pages (including this cover page).

[TURN OVER

1 Hydrogen sulfide, H_2S is a toxic gas which is commonly formed as a by-product in oil and gas refining industries. The Claus process has been widely used to remove H_2S. It involves two main reactions as shown.

Reaction 1: $2H_2S(g) + 3O_2(g) \rightarrow 2SO_2(g) + 2H_2O(l)$ ΔH^{θ}_1

Reaction 2: $2H_2S(g) + SO_2(g) \rightarrow \frac{3}{8}S_8(s) + 2H_2O(l)$ $\Delta H^{\theta}_2 = -108$ kJ mol^{-1}

(a) (i) Use the data in Table 1.1 to calculate the standard enthalpy change of reaction for Reaction 1, ΔH^{θ}_1.

Table 1.1

Compound	ΔH^{θ}_f / kJ mol^{-1}
$H_2S(g)$	−20.2
$SO_2(g)$	−296.8
$H_2O(l)$	−285.8

[2]

(ii) The standard Gibbs free energy, $\Delta G^{\ominus}_2$, for Reaction 2 is −89.6 kJ mol^{-1}.

Calculate the entropy change, $\Delta S^{\ominus}_2$, for Reaction 2 and explain the significance of its sign with respect to the process that is occurring. **[2]**

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(b) Besides the Claus process, organic solvents like methanol can also be used to remove H_2S.

With reference to the intermolecular forces, explain why methanol is a good solvent to remove H_2S. **[2]**

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(c) One of the key advantages of the Claus process is the recovery of S_8, which is a valuable product that can be used for other purposes.

S_8 consists of 8 sulfur atoms bonded to each other in a crown conformation as shown in Fig. 1.1.

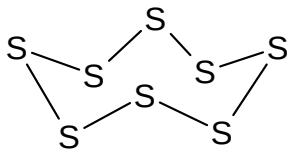

Fig. 1.1

Use the VSEPR theory to state and explain the shape and bond angle around each S atom in S_8.

[2]

Shape: ……

Bond angle: ……...

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[Total: 8]

2 Sulfur dioxide, SO_2, and sulfite, SO_3^{2-}, are found in food and beverages as preservatives. Despite this, they may cause allergic reactions. Hence, the concentration of sulfur dioxide or sulfite in any food and beverages cannot exceed 10 parts per million (ppm).

For this question, 1 ppm refers to 1 g of SO_3^{2-} for every 1 000 000 g of food sample.

(a) Magnesium oxide, aluminium oxide and sulfur dioxide are Period 3 oxides.

Describe reactions that illustrate the variation in acid-base behaviour of these three oxides. Write equations for all the reactions described. **[6]**

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(b) To determine the concentration of SO_3^{2-}, a food sample is treated to obtain the extracted solution, before being titrated against potassium iodate-iodine solution, with starch as the indicator.

In the presence of strong acid, a solution of potassium iodate(V), KIO_3, and potassium iodide, KI, will liberate iodine, I_2. The equation to represent this is as shown.

$$IO_3^- + 5I^- + 6H^+ \rightarrow 3I_2 + 3H_2O$$

SO_3^{2-} which is present in the food sample will react with I_2 to form iodide and sulfate ions. When SO_3^{2-} has completely reacted, I_2 will then combine with starch to form a blue-black complex, which is the colour seen at the end-point.

The procedures for an experiment on SO_3^{2-} analysis are as follows.

Step 1	1.0 kg of food sample was treated to obtain the extracted solution. The solution was diluted to 1 dm^3 in a volumetric flask.
Step 2	0.010 g of KIO_3 was dissolved in water. Excess KI and excess aqueous acid were added to this solution, before making up to 250 cm^3 in a volumetric flask.
Step 3	25.0 cm^3 of the food sample solution from Step 1 required 18.00 cm^3 of acidified potassium iodate-iodide solution to reach end-point.

(i) Write an ionic equation for the reaction between SO_3^{2-} and I_2. **[1]**

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(ii) Calculate the concentration, in mol dm^{-3}, of SO_3^{2-} in 25.0 cm^3 of the food sample solution. **[3]**

(b) **(iii)** Calculate the concentration of SO_3^{2-} in the food sample in ppm. Hence, state whether the food sample is safe for consumption. **[2]**

(c) 100 cm^3 of 0.106 mol dm^{-3} sodium sulfite, $Na_2SO_3(aq)$, is added to 100 cm^3 of 0.500 mol dm^{-3} sodium hydrogensulfite, $NaHSO_3(aq)$, to produce a buffer solution **X**. The pH of the resultant solution is 6.5.
(K_a of $HSO_3^-(aq)$ = 6.73 x 10^{-8} mol dm^{-3} at 298K)

(i) Explain what is meant by the term *buffer solution*. **[1]**

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(ii) Write an equation to show what happens when small amounts of $OH^-(aq)$ are added to solution **X**. **[1]**

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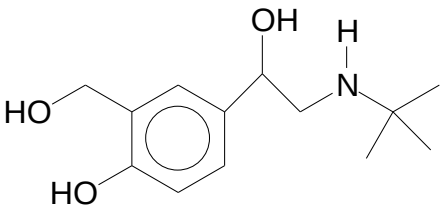
(iii) 5 cm^3 of 0.100 mol dm^{-3} of $Ba(OH)_2$ was added to 75.0 cm^3 of solution **X**.
Calculate the pH of the resulting solution at 298K. **[3]**

[Total: 17]

3 Salbutamol is a drug that is commonly used to treat asthmatic symptoms. In recent times, it has been used to treat patients with mild COVID-19 symptoms. The structure of salbutamol is as shown.



(a) A four-step synthesis of salbutamol is shown in Fig. 3.1.

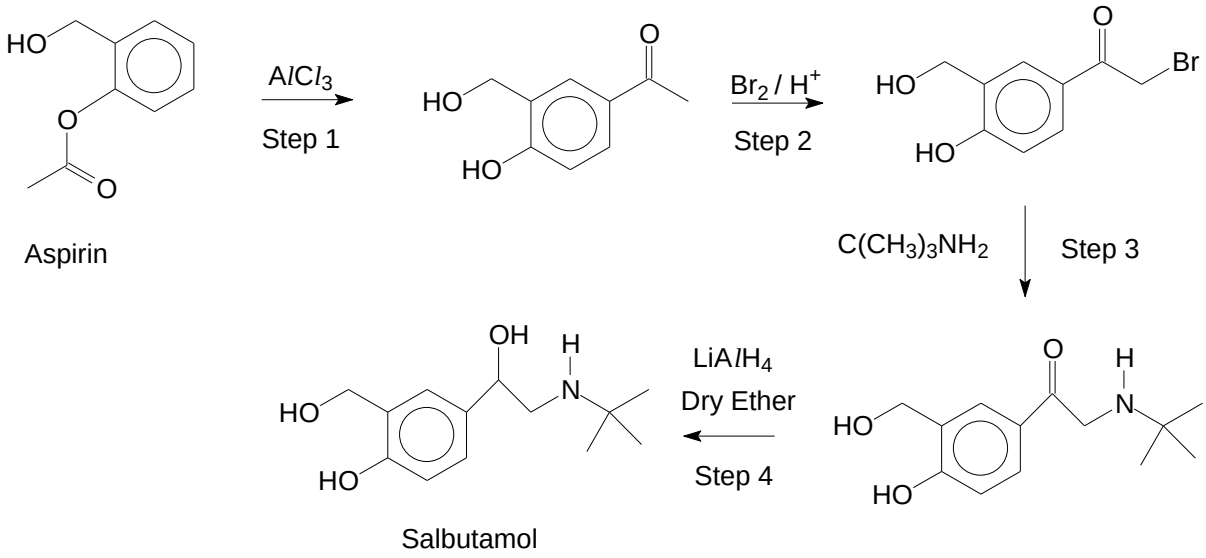


Fig. 3.1

(i) State the type of reaction in step 3. **[1]**

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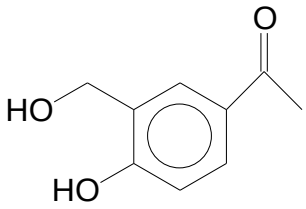
(a) (ii) A series of experiment was carried out to investigate the kinetics of step 3.
The following data was obtained.

Experiment	$[RCH_2Br]$ / mol dm^{-3}	$[C(CH_3)_3NH_2]$ / mol dm^{-3}	Rate / mol dm^{-3} s^{-1}
1	0.100	0.100	2.0×10^{-3}
2	0.100	0.200	4.0×10^{-3}
3	0.150	0.200	6.0×10^{-3}

R = 

Using the data above, determine the order of reaction with respect to $[RCH_2Br]$ and $[C(CH_3)_3NH_2]$. **[2]**

(iii) Hence, write the rate equation for step 3, stating the units for the rate constant. **[1]**

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(a) (iv) Based on your answer in **(a)(iii)**, outline the mechanism for step 3. Show relevant lone pairs of electrons, dipoles and curly arrows. **[2]**

(v) Use data from the *Data Booklet* to explain fully how the rate of synthesis of salbutamol will be affected when RCH_2Cl is used in step 3 instead. **[3]**

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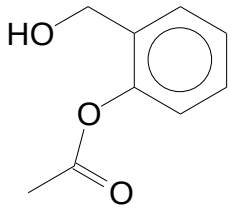
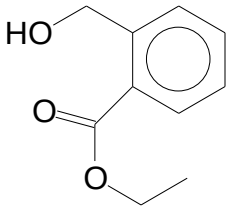
(b) The labels for the bottles containing aspirin and compound **A** are misplaced.



Aspirin



Compound A

Suggest a chemical test to differentiate between the two compounds. **[2]**

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[Total: 11]

4 The empirical formula of Compound **V** is $C_8H_{15}O_2$.
A sample of **V** was analysed and the observations were noted in the following questions.

(a) **V** was insoluble in both NaOH(aq) and H_2SO_4(aq).
State the nature of **V**. **[1]**

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(b) Upon heating with H_2SO_4(aq), **V** forms two compounds **W** and **X**. The molecular formula of **W** and **X** are $C_6H_{14}O$ and $C_4H_6O_4$ respectively.
State the type of reaction that has taken place. Hence, state the functional group which could be found in **V**. **[1]**

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(c) Deduce the molecular formula of **V**. **[2]**

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(d) **W**, $C_6H_{14}O$, is optically active and reacts with hot acidified $K_2Cr_2O_7$ to form **Y**, $C_6H_{12}O$.
State the deductions that can be made about **W** and **Y**. **[2]**

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(e) **Y**, $C_6H_{12}O$, is optically active and forms a yellow precipitate when it is warmed with alkaline aqueous iodine. **[2]**

Suggest the structures of **Y** and the yellow precipitate.

Y	**Yellow precipitate**

(f) Heating **W**, $C_6H_{14}O$, with concentrated H_2SO_4 produces **Z**, C_6H_{12} as one of the organic products. Vigorous oxidation of **Z** produces butanone as one of the products.

State the type of reaction for the conversion of **W** to **Z.** Draw the **skeletal** structures of **W** and **Z**. **[3]**

Type of reaction: ……

W	**Z**

(g) **X** can be produced from 1,2-dibromoethane in two steps.

Step 1: Reaction of 1,2-dibromoethane with hot ethanolic NaCN.

Step 2: Heat the product from step 1 with dilute hydrochloric acid.

Suggest the structure of **X** and write a balanced equation for step 2. **[2]**

X

Equation: ……

(h) Draw the structural formula of **V**. **[1]**

V

[Total: 14]

5 Most public buses in Singapore run on diesel. To promote sustainability, Singapore targets to replace 400 diesel buses with electric buses by 2025. Almost all the electricity in Singapore is generated by natural gas (methane), which is a cleaner fuel than diesel.

Table 5.1

Fuel	Formula	Density at 298K and 1 bar / g dm^{-3}	Energy per gram released on combustion / kJ g^{-1}
Diesel	$C_{16}H_{34}$	850	45
Natural gas	CH_4	0.65	56

Table 5.2

Bus	Energy consumption per 100 km
diesel bus	19 litres of diesel
electric bus	130 kWh

(a) (i) When natural gas and kerosene are burnt in an excess of air, carbon dioxide and water are formed. The following equation represents the complete combustion of natural gas.

$$CH_4(g) + 2O_2(g) \rightarrow CO_2(g) + 2H_2O(l)$$

Balance the following equation for the complete combustion of diesel.

……$C_{16}H_{34}$ + ……O_2 → ……CO_2 + ……H_2O **[1]**

(ii) Use information from Tables 5.1 and 5.2 to show that a diesel bus requires 162 g of diesel per km, while an electric bus requires 83.6 g of methane per km.
[1 kWh = 3600 kJ] **[2]**

(a) **(iii)** The Land Transport Authority claims that for the same distance travelled, an electric bus emits less than half the amount of CO_2 as compared to a diesel bus. State and explain whether their claim is true. Show your working clearly. **[3]**

(iv) Besides reduced CO_2 emissions, suggest another benefit of using electric buses over diesel buses. **[1]**

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(b) The most popular rechargeable battery used in electric vehicles today is that of lithium iron phosphate (LFP), $LiFePO_4$. LFP batteries are of lower cost and have a longer life cycle as compared to other options, such as the lithium cobalt oxide (LCO) and lithium nickel metal hydride (Li-NiMH) batteries.

Table 5.3

element	abundance in earth's crust / ppm
Li	20
O	461000
P	1050
Fe	56300
Co	25
Ni	84

[ppm = parts per million]

(b) **(i)** With reference to Table 5.3, suggest why LFP batteries are of lower cost than LCO and Li-NiMH batteries. **[1]**

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(ii) Complete the electronic configuration of Fe^{2+} in an LFP battery.

$1s^2$ ……. **[1]**

(iii) Draw a 'dot-and-cross' diagram to show the type(s) of bonding present within a formula unit of $LiFePO_4$. This compound is made up of two cations and one polyatomic anion. **[2]**

(c) The LFP battery consist of a lithium iron phosphate electrode and a graphite electrode separated by an electrolyte. When the battery discharges, iron(II) ions are oxidised and the electrons flow through an external circuit. Concurrently, the lithium ions travel through an ion-selective membrane (which only allows lithium ions to pass through) to the graphite electrode where they are reduced to form solid LiC_6.

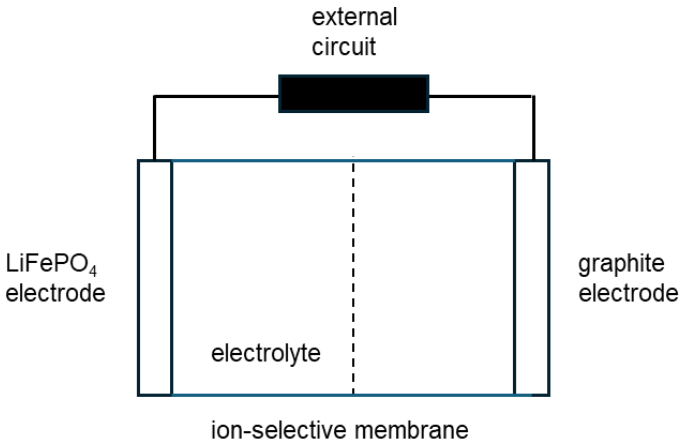

Fig. 5.1

The structure of solid LiC_6 is given in Fig. 5.2. where lithium ions are found in between layers of carbon atoms. The hexagonal rings of carbon atoms resemble the structure of graphite.

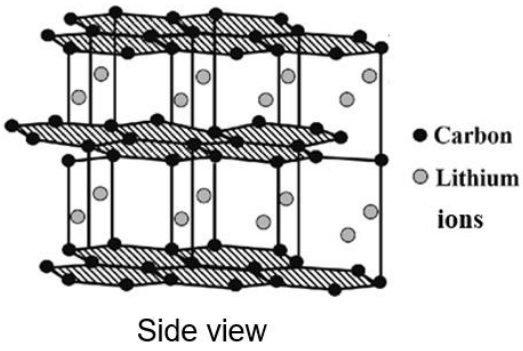

Fig. 5.2

(i) Label the polarity of each electrode in Fig. 5.1 and write the relevant half-equations during the discharge of the LFP battery.

Anode: ……

Cathode: …… **[3]**

(c) (ii) *Use of the Data Booklet is relevant to this question.*
The standard cell potential for the LFP battery is +3.20 V. Calculate the standard electrode potential for the Li^+/LiC_6 half cell. **[1]**

(iii) A LFP battery, which contains 364 g of iron, is completely discharged.
Calculate the time, in hours, required to charge the battery to 80% using 125 A current. **[2]**

(iv) Suggest the type of bonding between the lithium ions and the layers of carbon atoms in LiC_6. Explain your answer in terms of the particles present. **[1]**

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(v) Scientists have been trying to replace lithium with sodium to develop a greener substitute for LFP batteries. However, they have not succeeded as NaC_6 is not stable. With reference to the *Data Booklet*, suggest why NaC_6 is not stable. **[2]**

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(d) Besides electricity generation, natural gas can also be used in steam methane reforming. This is a process where methane from natural gas is heated with steam and a catalyst to produce a mixture of carbon monoxide and hydrogen, which are useful products for fuels and organic synthesis.

$$CH_4(g) + H_2O(g) \rightleftharpoons CO(g) + 3H_2(g) \qquad \Delta H > 0$$

(i) The pressures of the gases are measured in bar.
Write an expression for K_p, including units. **[1]**

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(ii) 1.00 mol of CH_4 and 1.00 mol of H_2O were added to a sealed vessel and heated to 500 K with a catalyst. Fig. 5.3 shows the amount of H_2 in the vessel as the reaction progressed. The total pressure in the vessel was 5.20 bar at equilibrium. Calculate the value of K_p for this reaction. **[3]**

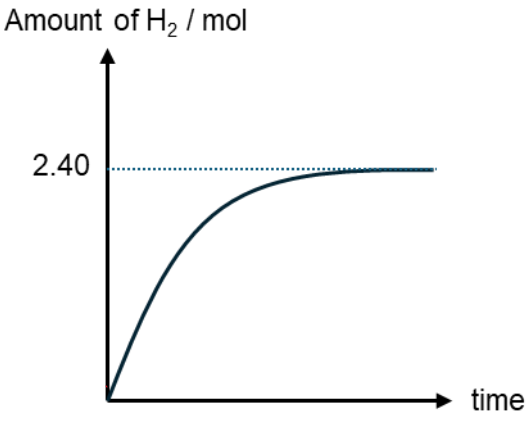

Fig. 5.3

(d) (iii) On Fig. 5.3, sketch a graph to represent the reaction at 1000 K. **[1]**

[Total: 25]

END OF PAPER

Additional Answer Space

If you use the following pages to complete the answer to any question, the question number must be clearly shown.

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