

RIVER VALLEY HIGH SCHOOL JC 2 PRELIMINARY EXAMINATION

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CENTRE NUMBER	S]	INDEX NUMBER		
CLASS	2	3	J]			
CANDIDATE NAME							

Paper 2 Structured Questions

09 September 2024 2 hours

Candidates answer on the Question Paper.

Additional Materials: Data Booklet

READ THESE INSTRUCTIONS FIRST

Write your Centre number, index number, class and name on all the work that you hand in. Write in dark blue or black pen.

You may use an HB pencil for any diagrams or graphs. Do not use staples, paper clips, glue or correction fluid.

Do not use staples, paper clips, glue or correction flui

DO NOT WRITE IN ANY BARCODES.

Answer **all** questions in the spaces provided on the Question Paper. If additional space is required, you should use the page at the end of this booklet. The question number must be clearly shown.

The use of an approved scientific calculator is expected, where appropriate. A Data Booklet is provided.

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

For Examiner's Use								
Question Number	1	2	3	4	5			
Marks	19	10	10	15	21			
significant figures			units				Total	75

This document consists of 25 printed pages and 3 blank pages.

1 (a) Use of the Data Booklet is relevant to this question.

Deuteron is the nucleus of deuterium, ${}^{2}_{1}D$.

(i) Compare and account for the behaviour of protons in an electric field with hydrogen atoms and deuterons.

(ii) Suggest a value for the enthalpy change to form 1 mole of deuteron from deuterium atoms. Explain your answer.

-[2]
- (b) Fig. 1.1 shows the first seven ionisation energies for nickel and two other main group elements, **A** and **B**.





(i)	Write the electronic configuration of nickel.	- 4 - 1
•••••		[1]
(ii)	Element A and nickel are found in the same period of the Periodic Table, but element B is not.	
	Explain the following features of Fig. 1.1.	
	 same general trend for all atoms 	
	 element A show large jump in values from the 2nd to the 3rd ionisation energy but not nickel. 	
		[3]
(iii)	State the identity of element B .	
		[1]

Nickel, rhodium (Rh) and platinum (Pt) are commonly used as heterogeneous catalysts in various chemical reactions. In a three-way catalytic converter fitted to the car exhaust, platinum is used to catalyse the oxidation of unburnt hydrocarbons, and rhodium is used to catalyse the reactions that remove the other pollutants.

Fig. 1.2 shows the simplified diagram of a three-way catalytic converter.



Fig. 1.2

Each catalyst matrix consists of a porous, honey-comb structure to allow exhaust gases to pass through easily. Finely divided catalysts are deposited on the wall of each pore.

(c) (i) Write an equation to show how an oxide of nitrogen is removed.

		[1]
(ii)	Describe how rhodium speeds up the reaction.	
		[3]

(d) Fig. 1.3 shows how the rate of a catalysed reaction varies with the concentration of C_xH_y passing through the three-way catalytic convertor.





(i) State and account for the change in order of reaction with respect to C_xH_y as its concentration increases.



(ii) Explain, with the aid of a labelled Boltzmann distribution diagram, the effect of catalyst on the rate constant.

		 		 	[2]
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- (iii) Sketch on Fig. 1.3, the graph obtained if the catalyst matrix is made more porous while the size of pores remained unchanged. [1]
- (e) Other than contributing to the formation of acid rain, state another environmental consequences of atmosphere NO₂.

[1] [Total: 19]

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2 The following reaction scheme shows the reactions involving organic compounds A to I.



pale yellow ppt

(a) (i) Draw the structures of A and B.

Α	В	
		[2

(ii) State the type of reaction undergone by **A** and **B** to form **C**.

.....[1]

(b) When A is heated with excess concentrated sulfuric acid, a mixture of constitutional isomers D, E and F are formed. F is the most thermodynamically stable product.

Draw the structures of **E** and **F**.

E	F

(c) Addition of hot, concentrated, acidified KMnO₄ to **F** gives **H** and **I**, of which **H** gives a positive iodoform reaction.

Draw the structures of H and I.

Н	Ι

(d) **D** reacts with HCl(g) to give **G**, which is the major product.

Explain in detail why **G** is formed in larger proportion than the other product.

.....[1]

[2]

[2]

(e) Describe a simple chemical test to distinguish between **C** and its constitutional isomer **J**. State the observations for each compound.



 •
[2]
 · [2]

[Total: 10]

10

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3 Alanine is a non-essential amino acid that can be synthesised metabolically in the human body.

Values for the acid dissociation constants, pK_a , for alanine and carbonic acid are shown below.

acid	structure	р <i>К</i> а
alanine	CH ₃ +H ₃ NCCO ₂ H H	р <i>К</i> _{а1} = 2.34 р <i>К</i> _{а2} = 9.87
carbonic acid	H ₂ CO ₃	3.49

(a) State what is meant by the term Arrhenius acid.



(b) When 10.0 cm³ of 0.100 mol dm⁻³ alanine solution is titrated with 0.100 mol dm⁻³ NaOH, the following titration curve was obtained.



(i) When the volume of NaOH added is between 0 to 10.0 cm³, a buffer solution is obtained. Use two equations to illustrate how the buffer solution works when a small volume of acid or base is added to the buffer solution.

(ii) Calculate the pH of the solution when 30.0 cm³ of NaOH has been added to the alanine solution.

[2]

(iii) Draw the structural formula of the organic product that would be formed at the **second** equivalence point.

[1]

(iv) Suggest the structure of the organic product that would be formed if CO₂ is bubbled through the solution at the **second** equivalence point.

Explain your answer.

.....

(c) A student attempted a similar experiment as (b). But instead of adding NaOH as a titrant, he placed 10.0 cm³ of 0.100 mol dm⁻³ NaOH in the conical flask and added 0.100 mol dm⁻³ alanine solution as a titrant. He remarked that the titration curve looked very different from that obtained in (b).

Sketch the shape of the titration curve that the student obtained. Indicate the volume(s) of alanine solution required at the equivalence point(s).

[2] [Total: 10]

[2]

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4 This question is about several polymers and their monomers.

Industrial chemists have increasingly focused on developing biodegradable polymer to replace conventional polymer (plastics).

Table 4.1 lists some monomers which can be used in polymerisation.

Monomers	Boiling point/ °C
но ОН	227
lactic acid	
lactide	286
H ₂ N NH ₂	158
1,4-butanediamine	

Table 4.1

- (a) Explain the difference in boiling points between:
 - lactic acid and lactide
 - lactic acid and 1,4-butanediamine

[3]

(b) (i) Draw a labelled diagram to show how the orbitals overlap to form the C=O bond in an ester functional group.

Assume that the oxygen atoms in the ester functional group are sp² hybridised.

(ii) The ring opening polymerisation of lactide can proceed via a mechanism catalysed by Sn(II), which is exothermic.



The sign of entropy change of this polymerisation is negative.

Use the information provided, predict the effect, if any, that increasing temperature will play in the spontaneity of the polymerisation of lactide.

 [2]

(c) Polyamides are commonly used for textiles and sportswear.

Polyamides can be synthesised from lactams. A lactam is structurally similar to a lactone (cyclic carboxylic ester, e.g. lactide), being an amide instead of an ester.

Table 4.2 compares the entropy changes, ΔS_{poly} , of ring opening polymerisation of different lactams to form polyamides.

lactams	polyamides	ΔS_{poly} / J mol ⁻¹ K ⁻¹
↓ Contract		-30.1
ο NH δ-valerolactam		-27.6
Caprolactam		+4.6

(i) Suggest a reason for the trend in the entropy change of polymerisation the lactams in Table 4.2.



More sustainable polyamides can be obtained from biobased resources.

1,4-butanediamine and ethylene brassylate, a plant oil-derived compound, react to form one repeat unit of a polyamide. Ethane-1,2-diol, (CH₂OH)₂, is released as the condensation by-product.



(ii) Use the *Data Booklet* to calculate the standard enthalpy change when one repeat unit is formed.

[2]

(d) Norbornene is a highly strained, bridged cyclohexene. When norbornene undergoes ring opening metathesis polymerisation (ROMP), followed by further modification, polymer **B** is formed.



By considering the change in hybridisation of carbon-1, suggest and explain how the bond length of C_{1} -H in norbornene might differ from that in polymer **B**.



(e) Compound X is a derivative of cyclohexene. With hydrogen bromide, compound X produces four isomeric products (J, K, L and M), which can be categorised as two constitutional isomers.



Compound X

J and K

L and M

(i) Suggest the mechanism to form the major constitutional isomer. Show all relevant charges, dipoles, lone pairs and curly arrows. (ii) In the reaction, J and K are formed as stereoisomers of each other. Explain, in terms of the mechanism in **e(i)**, how the two stereoisomeric compounds J and K are formed.

[1]
 (iii) L and M are also formed as a pair of stereoisomers, but L does not rotate plane-polarised light.

With the aid of suitable diagram, explain why L is optically inactive.

[2] [Total: 15]

Vanadium, a transition element, is known for its diverse oxidation states and 5 ability to form stable compounds and coloured complexes. Table 5.1 shows the common ions containing vanadium and their colours. Fig. 5.1 shows the wavelength of light in the visible light spectrum.

		Table 5.1		
	vanadium ion	aqueous complex	colour	
	V ²⁺	[V(H ₂ O) ₆] ²⁺	violet	
	V ³⁺	[V(H ₂ O) ₆] ³⁺	green	
	VO ²⁺	[VO(H ₂ O) ₅] ²⁺	blue	
	VO ₂ +	[VO ₂ (H ₂ O) ₄] ⁺	yellow]
7	00 nm		40	00nm
	Red Or	ange Yellow Green	Blue Violet	
		Fig. 5.1		
a)	(i) Explain what	is meant by a transition ele	ement.	
				[1]
	(ii) Using Fig. 5 V ³⁺ (aq) could	5.1, explain how differer arise.	nt colours of V ²⁺ (a	aq) and
				[3]

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VO₂⁺(aq) complexes exhibit cis-trans isomerism.

(iii) Draw and label the 3-dimensional structures of the pair of cis-trans isomers.

You may use a line, dash or wedge to represent the V \exists O bond.

— .	
Type of isomer	Type of isomer

[2]

Vanadium redox flow batteries (VRFBs) are a type of rechargeable flow battery that utilise vanadium ions in different oxidation states to store chemical potential energy. Unlike conventional batteries, VRFBs use aqueous electrolytes stored in external tanks and pumped through a cell stack during charge and discharge cycles. During a charge cycle, electrical current is passed through the cell, allowing electrical energy to be stored as chemical potential energy. During a discharge cycle, chemical potential energy is converted into electrical energy for use.

Fig. 5.2 shows a representation of the vanadium redox flow cell system.



(b) Use of the Data Booklet is relevant to this question.

(i) State the direction of electron flow during discharge for a VRFB that is set up as shown in Fig. 5.2.

.....[1]

(ii) Calculate the standard cell potential, E_{cell}^{\ominus} , for the reaction in the VRFB.

(iii) Explain the effect on E_{cell} as the pH of the electrolytes is increased.

(c) In an experiment, a VRFB was set-up using carbon electrodes with surface area of 50 cm². At the start of discharge, the half-cell with Tank A contained 5.00 dm³ of 2.00 mol dm⁻³ of V²⁺(aq). The half-cell with Tank B contained an equal volume and concentration of VO₂⁺(aq).

Some of the parameters used to evaluate the performance of this VRFB are as follows:

- Capacity the amount of charge a battery can store in a single cycle of charge and discharge
- Energy density the ratio of energy (or charge) store to the volume of a battery
- Current density current provided by per unit area of the electrode surface

Preliminary results shows that this VRFB has a current density of 600 mA per cm² of electrode surface area and has an initial cell potential of +2.31 V. When VRFB undergoes a full charge, initial concentrations of vanadium ions are restored. This VRFB consumes an average of 76.9% of the vanadium ions originally present before being considered fully discharged.

(i) Describe the expected colour change in tank **B** from the start of discharge till the cell becomes flat.

.....[1]

(ii) Calculate the capacity of the VRFB.

[2]

(iii) Using the information provided and your answer in (c)(ii), calculate the time taken, in hours, for the battery to be fully discharge.

You should assume no change to any parameters that may affect the performance of VRFB for the entire duration of discharge.

(iv) State the initial cell potential value if the VRFB in (c) is set up using another pair of carbon electrodes with doubled the surface area.

[1]]
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- (d) Another way to set up a VRFB is as follows:
 - 1. Fill both Tank **A** and Tank **B** with the same volume of 1.50 mol dm⁻³ VO²⁺ in dilute sulfuric acid.
 - 2. Pass a current through the cell to provide an initial charge.

During this initial charge, $VO^{2+}(aq)$ ions are converted to $V^{2+}(aq)$ ions in Tank **A**, and $VO^{2+}(aq)$ ions are converted to $VO_{2}^{+}(aq)$ ions in Tank **B**.

3. Stop the flow of current when VO²⁺(aq) ions are completely depleted in either one of the tanks.

At this point, the cell is charged to the maximum capacity for use. The cell is considered overcharged when the current continues to pass through the cell.

(i) Write balanced half-equations, with state symbols, to show the reaction at each electrode in Tank **A** and Tank **B** respectively.

Hence, state the ratio of charge required to convert all the VO²⁺ in both tanks.

Electrode in Tank A:

.....

Electrode in Tank **B**:

.....

Ratio of charge required for tank A to tank B: :

(ii) During overcharging, a colourless and odourless gas is discharged at one of the electrodes.

Identify this electrode and account for the formation of this gas.

[2] [Total: 21]

[3]

Additional answer space

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

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