Catholic Junior College
JC2 Preliminary Examination
Higher 2

CANDIDATE NAME			
CLASS	**2T**	**INDEX**	

CHEMISTRY
Paper 2 Structured Questions

9729/02
26 August 2024
2 hours

Candidates answer on the Question Paper.
Additional Materials: Data Booklet

READ THESE INSTRUCTIONS FIRST

Write your name and class on all the work 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.

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.

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

For Examiner's Use		
Paper 1		**30**
Paper 2	**Q1**	**/7**
	Q2	**/11**
	Q3	**/13**
	Q4	**/15**
	Q5	**/15**
	Q6	**/14**
		75
Paper 3		**80**
Paper 4		**55**
OVERALL (100%)		
GRADE		

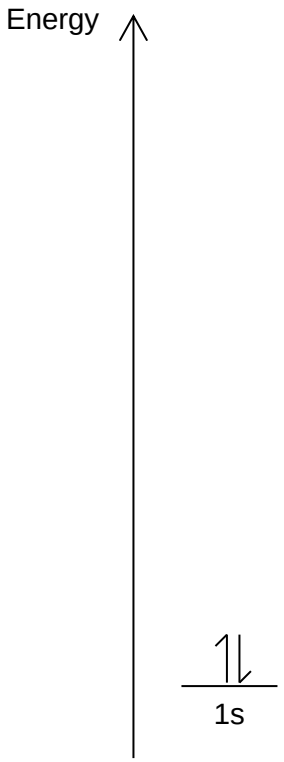
This document consists of **16** printed pages.

[Turn over

Answer **all** the questions in the space provided.

1 Tetrahalosilanes have the general formula Si$\mathbf{X}_4$, where **X** represents one of the halogens. A sample of Si$\mathbf{X}_4$ is atomised and ionised. The ions produced are then analysed.

(a) Complete the following energy level diagram to show the arrangement of electrons in the orbitals of Si^+ ion.



[2]

(b) In the first analysis, the second ionisation energy of silicon is recorded.
Write an equation for the second ionisation energy of silicon.

…….…….. [1]

(c) Explain why the second ionisation energy of silicon is higher than that of the first.

……..……..…

……..……..……

…..……..

..... [1]

(d) In the second analysis, ions of $\mathbf{X}^+$ are analysed.
A sample each of $^{28}_{14}Si^+$ and $\mathbf{X}^+$ is passed through an electric field. The angles of deflection of $^{28}_{14}Si^+$ and $\mathbf{X}^+$ are 5.6^o and 2.0^o respectively.

(i) Deduce, by calculation, the identity of **X**. [2]

(ii) Suggest why there is another beam detected with an angle of deflection of 1.9^o.

……..……. [1]

[Total: 7]

2 This question is about phosphorus and its compounds.

(a) With reference to relevant electronic configurations where necessary, explain why the first ionisation energy of phosphorus is higher than the elements that come immediately before and after it in Period 3.

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…… [3]

(b) With reference to structure and bonding, explain why the melting point of phosphorus is lower than the elements that come immediately before and after it in Period 3.

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…… [2]

The most important oxide of phosphorus is phosphorus(V) oxide, P_4O_{10}. It is a powerful dessicant and dehydrating agent.

(c) Write a balanced equation for the reaction of P_4O_{10} with water and state the pH of the resulting solution.

……

…… [1]

The structure of phosphorus(V) sulfide, P_4S_{10}, is closely related to that of P_4O_{10}.

(d) Reaction of P_4S_{10} with water gives two products. One of the products is the same as the product of the reaction in **(c)**, the other product is a gaseous compound.
Suggest a balanced equation for this reaction.

…… [1]

(e) In vapour form, phosphorus(V) sulfide exists as P_2S_5 molecules. When P_2S_5 is heated under a vacuum together with caesium sulfide, Cs_2S, and sulfur, it produces an ionic compound **R** which has the following composition by mass:
Cs, 58.1%; P, 6.78%; S, 35.1%.

(i) Calculate the empirical formula of compound **R** and hence deduce its chemical formula, given that the relative formula mass, M_r, is 914.6.

[2]

(ii) Compound **R** contains Cs^+ cation and an anion. Given that the cation and anion of compound **R** are present in a 4:1 ratio, write the formula of the anion.

Anion: …… [1]

(iii) Suggest the structure of the anion, given that there are three S–S single bonds, a plane of symmetry exists within the anion structure and the constituent atoms show their usual valencies.

[1]

[Total: 11]

3 Compound **G** is a colourless liquid with the formula $C_xH_y(OH)_z$.

When 3.00×10^{-4} mol of **G** was dissolved in an inert solvent and an excess of sodium metal added, 10.8 cm^3 of hydrogen gas, H_2, was produced.

In a vessel with 50.0 cm^3 of oxygen gas, the complete combustion of 3.00×10^{-4} mol of **G** is carried out. When the resultant mixture is cooled, a total volume of 46.4 cm^3 of gas remains.

When this gaseous mixture is passed repeatedly over NaOH(s), the final volume of gas which remains is 24.8 cm^3.

All volumes are measured at room temperature and pressure.

(a) **(i)** Write the equation for the reaction of ethanol with an excess of sodium metal.

..... [1]

(ii) Show that the value of **z** for **G** is 3.

[1]

(iii) Complete the following equation for the complete combustion of **G**, using **x** and **y**.

$C_xH_y(OH)_3(l)$ + ☐ $O_2(g) \rightarrow$ ☐ $CO_2(g)$ + ☐ $H_2O(l)$ [1]

(iv) Hence determine the value of **x** and **y** for **G**.

[3]

(b) Compound **H**, is an optically inactive five-membered unsaturated cyclic compound with molecular formula $C_6H_{10}O$. It decolourises aqueous bromine and gives off misty acid fumes when reacted with PCl_5.

Upon heating **H** with hot concentrated $KMnO_4$, a single product, **J**, $C_6H_{10}O_5$, is formed.
1 mol of **J** reacts with only 3 mol of PCl_5 giving misty acid fumes.
1 mol of **J** reacts with only 1 mol of Na_2CO_3 giving effervescence.

(i) Name the type of reaction occurring when **H** reacts with aqueous bromine.

…….…… [1]

(ii) Compound **J** does not contain a chiral centre. Hence, deduce the structure of **J**, explaining the chemistry of the reactions of **J**.

[3]

(iii) Draw the skeletal formula for **H**.

[1]

(c) $NaBH_4$ is a mild reducing agent that contains the anion $[BH_4]^-$ which can react with C=O bonds. But it cannot react with C=C bonds in alkenes. Explain why.

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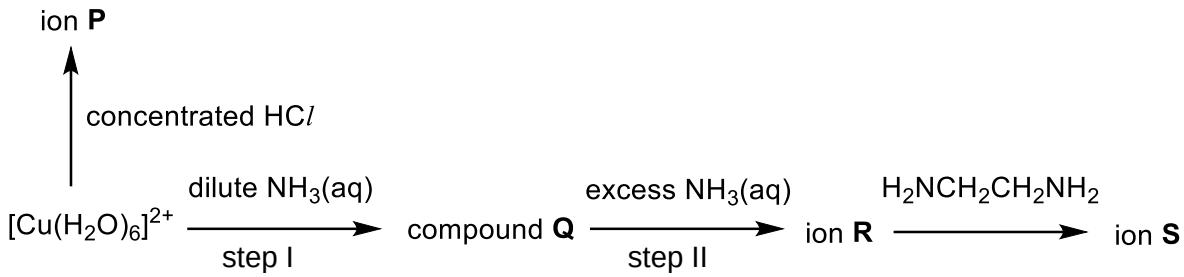
..... [2]

[Total: 13]

4 This question is about some reactions of copper compounds.



(a) Write the electronic configuration of Cu atom in *spdf* notation.

…… [1]

(b) **(i)** Identify ion **P.**

……..…… [1]

(ii) Copper forms an octahedral complex with fluorine with the formula $[CuF_6]^{4-}$. Suggest why ion **P** is formed instead of $[CuCl_6]^{4-}$.

……..…….

……..……

.....…….…… [1]

(c) Describe the observations in steps I and II and write balanced equations for the two reactions.

Observations in step I: ……

Equation: ……..…….....

Observations in step II: ……..

Equation: ……..…..... [3]

(d) Ethylenediamine, $H_2NCH_2CH_2NH_2$, (abbreviated as **en**) is a bidentate ligand. When a dilute aqueous solution containing ethylenediamine is added to ion **R**, a purple solution of ion **S** is formed.

The stability constant, K_{stab}, is the equilibrium constant for the formation of the complex ion in a solvent from its constituent ions or molecules. The following shows the stability constant, K_{stab}, for the formation of three possible copper complexes with the **en** ligand from $[Cu(H_2O)_6]^{2+}$.

$[Cu(H_2O)_6]^{2+}$ + **en** $\rightleftharpoons$ $[Cu(H_2O)_4(\mathbf{en})]^{2+}$ + $2H_2O$ $\quad K_{stab1} = 3.55 \times 10^{10}$

$[Cu(H_2O)_6]^{2+}$ + $2\mathbf{en}$ $\rightleftharpoons$ $[Cu(H_2O)_2(\mathbf{en})_2]^{2+}$ + $4H_2O$ $\quad K_{stab2} = 3.98 \times 10^{19}$

$[Cu(H_2O)_6]^{2+}$ + $3\mathbf{en}$ $\rightleftharpoons$ $[Cu(\mathbf{en})_3]^{2+}$ + $6H_2O$ $\quad K_{stab3} = 3.98 \times 10^{18}$

(i) From the K_{stab} values shown above, suggest the likely formula of ion **S**.

…… [1]

(ii) Explain why hydrazine, H_2NNH_2, cannot act as a bidentate ligand.

……

……

…… [1]

(e) Ethanedioate, $C_2O_4^{2-}$, is another bidentate ligand. When excess potassium ethanedioate, $K_2C_2O_4$, is added to a solution containing $Cu^{2+}(aq)$ ions, a pale blue precipitate containing CuC_2O_4 is formed.
The K_{sp} of CuC_2O_4 is 4.30×10^{-10} mol^2 dm^{-6}.

(i) Write an expression for the solubility product, K_{sp}, of CuC_2O_4.

…… [1]

(ii) Calculate the solubility (in mol dm^{-3}) of CuC_2O_4 in water.

[1]

(iii) The K_{sp} of FeC_2O_4 is 2.00×10^{-7} mol^2 dm^{-6}.
Deduce which precipitate, FeC_2O_4 or CuC_2O_4 will be formed first if $K_2C_2O_4$ is added slowly into a solution containing 0.015 mol dm^{-3} of Fe^{2+} and 0.025 mol dm^{-3} of Cu^{2+}.

[2]

(iv) When dilute H_2SO_4 is slowly added to CuC_2O_4 the pale blue precipitate dissolves to form $H_2C_2O_4$ and a blue solution of Cu^{2+}. Explain why the precipitate dissolves.

……

……

……

…… [1]

(v) It has been suggested that the blue solution formed in **(iv)** turns colourless after some time with the liberation of CO_2 gas.

$$2CO_2 + 2H^+ + 2e^- \rightleftharpoons H_2C_2O_4 \qquad E^\ominus = -0.49 \text{ V}$$

With reference to relevant data from the *Data Booklet* and the equation given above, write an equation and calculate the standard cell potential, $E^\ominus_{cell}$ to account for the above observation.

……

……

……

……

……

…… [2]

[Total: 15]

5 Pyruvic acid is an important compound in biochemistry as it is involved in metabolic pathways in our body, including formation of lactic acid in anaerobic metabolism.

Some reactions in the laboratory involving these acids are shown in Fig. 5.1.

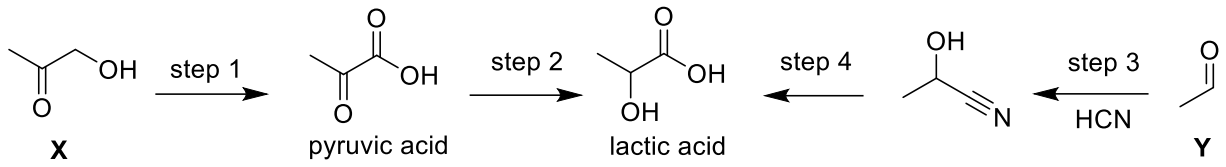


Fig. 5.1

(a) Give the systematic name for lactic acid.

…… [1]

(b) Name the two functional groups present in **X.**

…… [1]

(c) State the number of σ bonds and π bonds in pyruvic acid.

Number of σ bonds: …… Number of π bonds: …… [1]

(d) State the types of reaction and reagents and conditions for step 1 and for step 2.

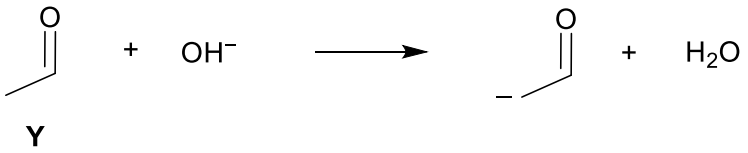
Step 1: ……....

Step 2: …… [2]

(e) Draw the nucleophilic addition mechanism for step 3. Show relevant lone pairs of electrons, dipoles, and curly arrows in your answer.

[2]

(f) Compound **Y** reacts with NaOH to form an anionic intermediate as shown below in Fig. 5.2.



Y

Fig. 5.2

This anion is represented by two different structures as shown below in Fig. 5.3. The actual structure of the anion is between these two structures, with the negative charge delocalised over both the oxygen and the carbon atoms.

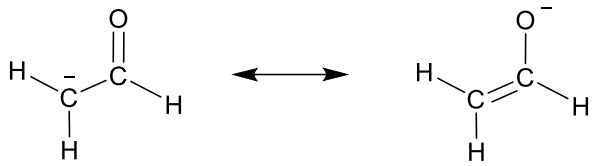


Fig. 5.3

(i) With the aid of a suitable diagram, suggest how the delocalisation of electrons occurs in this anion.

.....

..... [2]

(ii) Deduce the number of delocalised electrons in this anion.

..... [1]

(iii) Compound **Y** behaves as an acid in reactions shown in Fig. 5.1 and 5.2. Identify the type of acid behaviour shown by **Y** in each of these reactions. Explain your answers.

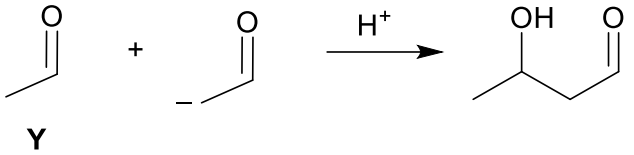
Fig. 5.1: ……

……

Fig. 5.2: ……

…… [2]

(iv) Another molecule of **Y** can react with the anion formed in Fig. 5.2 to give a final product of $CHOCH_2CH(OH)CH_3$ as shown in Fig. 5.4.



Y

Fig. 5.4

Suggest the final product formed when two molecules of CH_3COCH_3 undergo the same reaction with NaOH followed by H^+.

[1]

(g) Write a balanced equation for the reaction of compound **Y** (liquid) with alkaline aqueous iodine, including state symbols.

..... [2]

[Total: 15]

6 **(a)** The nickel–cadmium battery (Ni–Cd battery) is a type of rechargeable battery using nickel oxide hydroxide and metallic cadmium as electrodes. The cathode consists of nickel oxy-hydroxide, NiO(OH), as the active material and is separated from the anode made of finely divided cadmium metal. The electrolyte used is a mixture of potassium hydroxide, KOH, in water. During discharge, $Ni(OH)_2(s)$ and $Cd(OH)_2(s)$ are formed at the cathode and anode respectively.

(i) Construct the half-equations at the electrodes of this Ni–Cd electrochemical cell. Hence, give the overall balanced equation for the reaction that occurs during discharge.

Anode: ..... [1]

Cathode: ..... [1]

Overall: ..... [1]

(ii) Ni–Cd batteries can be recharged by applying a current across the two electrodes.
Calculate the time taken to recharge a Ni–Cd battery at a current of 2.0 A, if 5.62 g of cadmium was converted to $Cd(OH)_2$.
[A_r of Cd = 112.4]

[2]

(iii) Overcharging the Ni–Cd battery may result in the formation of other products at the electrodes. With reference to the *Data Booklet* and species present in a Ni–Cd battery, predict the possible products at the electrodes of the Ni–Cd battery by writing the relevant half equations.

Anode: ..... [1]

Cathode: ..... [1]

(b) The propane-oxygen fuel cell is another efficient source of electrical energy. The overall reaction for this fuel cell is identical to the combustion of propane in oxygen.

$$C_3H_8(g) + 5O_2(g) \rightarrow 3CO_2(g) + 4H_2O(l)$$

(i) Given that the standard enthalpy change of combustion of propane is –2220 kJ mol^{-1}, calculate the energy that is being produced by the propane-oxygen fuel cell if 100 g of propane is used, assuming that it is 70% efficient.

[2]

(ii) In this propane-oxygen fuel cell, O_2 is reduced. Explain, with reference to relevant standard electrode potential values from the *Data Booklet*, why the electrolyte used is more often acidic than alkaline.

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…….. [2]

(iii) Air may be used instead of pure oxygen as the oxidising agent. Suggest one advantage of using air as an oxidising agent.

……

…….. [1]

(c) Give the name of the mechanism for the synthesis of 2-bromopropane from propane in the laboratory. State the reagent(s) and conditions used.

Name of mechanism: …… [1]

Reagent(s) and conditions: …… [1]

[Total: 14]