H2

MINISTRY OF EDUCATION, SINGAPORE
in collaboration with
CAMBRIDGE INTERNATIONAL EDUCATION
General Certificate of Education Advanced Level

CANDIDATE NAME	

CENTRE NUMBER	S					INDEX NUMBER				

0123456789

CHEMISTRY **9476/03**

Paper 3 Structured Questions **For examination from 2026**

SPECIMEN PAPER **2 hours**

You must answer on the question paper.

You will need: Data booklet

INSTRUCTIONS

- Section A: answer **all** questions.
- Section B: answer **one** question.
- Use a black or dark blue pen. You may use an HB pencil for any diagrams or graphs.
- Write your name, centre number and index number in the boxes at the top of the page.
- Write your answer to each question in the space provided.
- Do **not** use an erasable pen. Do **not** use correction fluid or tape.
- Do **not** write on any bar codes.
- You may use an approved calculator.

INFORMATION

- The total mark for this paper is 75.
- The number of marks for each question or part question is shown in brackets [ ].

This document has **24** pages. Any blank pages are indicated.

Singapore Examinations and Assessment Board

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Section A

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

1 **(a)** State what is meant by dynamic equilibrium.

....

.... [2]

At high temperatures, steam and carbon undergo the reaction shown.

$$H_2O(g) + C(s) \rightleftharpoons H_2(g) + CO(g) \qquad \Delta H^{\ominus} = +131\ \text{kJ mol}^{-1}$$

(b) In an experiment, steam at a pressure of 2.00 atm and a temperature of 1000 K is introduced into a vessel containing an excess of powdered carbon.

At equilibrium, the partial pressure of hydrogen is 1.40 atm.

(i) Write an expression for K_p for this reaction. State its units.

....

.... [2]

(ii) Calculate the partial pressures of $H_2O(g)$ and CO(g) at equilibrium. Hence, calculate the total pressure at equilibrium.

[3]

(iii) Use your answer from **1(b)(ii)** to calculate the value of K_p.

[1]

(c) In a separate experiment, the same amount of carbon was used, but in the form of lumps rather than powder. All other conditions were kept the same.

(i) State how this change would affect the time taken to reach equilibrium. Explain your answer.

....

.... [1]

(ii) State how this change would affect both the position of equilibrium and the numerical value of K_p.

....

.... [1]

(d) Carbon monoxide is poisonous.

Explain how carbon monoxide affects the function of haemoglobin in the transport of oxygen in the human body.

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.... [2]

(e) Carbon monoxide can be 'inserted' into some organic molecules by different types of addition reactions.

1 the reaction of an alcohol with CO, for example the synthesis of ethanoic acid from methanol

$$CH_3OH + CO \rightarrow CH_3CO_2H$$

2 the reaction of an alkene with CO and H_2O, for example the synthesis of propanoic acid from ethene

$$C_2H_4 + CO + H_2O \rightarrow CH_3CH_2CO_2H$$

3 the reaction of an aldehyde with CO and H_2O, for example the synthesis of hydroxyethanoic acid from methanal

$$CH_2O + CO + H_2O \rightarrow CH_2(OH)CO_2H$$

(i) **A**, **B** and **C** can be synthesised by the addition reactions described.

$(CH_3)_2CHCH_2CO_2H$	$C_6H_5CH(OH)CO_2H$	$(CH_3)_3CCO_2H$
A	**B**	**C**

Suggest suitable starting materials for the synthesis of **A**, **B** and **C**.
Use a different reaction type, 1, 2 or 3, for the synthesis of each compound.

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....

.... [3]

(ii) Figure 1.1 shows the conversion of **B** into the diacid **F**, $C_6H_5C(OH)(CO_2H)_2$, in three steps.

D forms an orange precipitate with 2,4-DNPH.

$$\underset{\textbf{B}}{C_6H_5CH(OH)CO_2H} \xrightarrow{\text{step 1}} \textbf{D} \xrightarrow{\text{step 2}} \textbf{E} \xrightarrow{\text{step 3}} \underset{\textbf{F}}{C_6H_5C(OH)(CO_2H)_2}$$

Figure 1.1

State the reagents and conditions you would use for steps 1, 2 and 3.

Suggest the structures of compounds **D** and **E**.

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....

.... [5]

[Total: 20]

2 (a) An electrochemical cell is set up as shown in Figure 2.1.

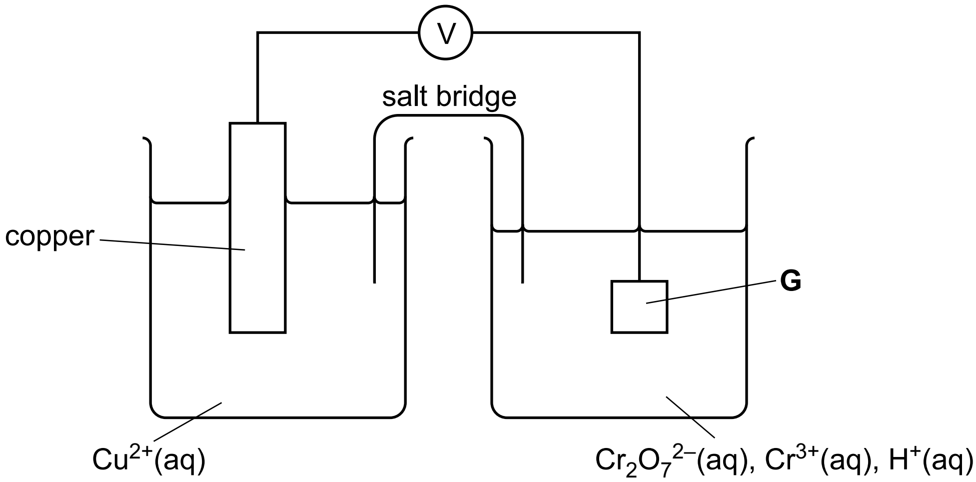

Figure 2.1

Table 2.1 lists relevant electrode potentials for some electrode reactions.

Table 2.1

electrode reaction	$E^{\ominus}$ **/ V**
$Cr_2O_7^{2-} + 14H^+ + 6e^- \rightleftharpoons 2Cr^{3+} + 7H_2O$	+1.33
$Cu^{2+} + 2e^- \rightleftharpoons Cu$	+0.34

(i) Suggest a suitable material for the electrode labelled **G** in Figure 2.1.

.... [1]

(ii) Describe **one** condition specified by the symbol $^{\ominus}$ when the electrode potentials shown in Table 2.1 are measured at 298 K.

....

.... [1]

(iii) For the cell drawn in Figure 2.1, use the data in Table 2.1 to calculate the $E^{\ominus}_{cell}$ for this electrochemical cell.

[1]

(iv) Construct the overall equation for the reaction that occurs in the cell when a current is allowed to flow.

.... [1]

(v) Calculate a value of $\Delta G^{\ominus}$ for the cell reaction, using the $E^{\ominus}_{cell}$ you calculated in **2(a)(iii)**, and your overall equation in **2(a)(iv)**.

[2]

(b) A sample of finely ground copper is contaminated with zinc powder.

An excess of $H^+(aq)$ is added to this sample and all the Zn is oxidised to Zn^{2+}.

The reaction forms 126 cm^3 of hydrogen gas, measured at a temperature of 300 K and a pressure of 1.00×10^5 Pa.

$$Zn(s) + 2H^+(aq) \rightarrow Zn^{2+}(aq) + H_2(g)$$

The mixture is filtered to remove the copper. Copper reacts with acidified manganate(VII) ions, $MnO_4^-(aq)$.

4.88×10^{-3} mol of acidified $MnO_4^-(aq)$ is required for all the Cu to be oxidised to Cu^{2+}.

$$5Cu(s) + 2MnO_4^-(aq) + 16H^+(aq) \rightarrow 5Cu^{2+}(aq) + 2Mn^{2+}(aq) + 8H_2O(l)$$

Calculate the masses of zinc and copper present in the sample.

[4]

(c) In aqueous solution, dichromate(VI) ions exist in equilibrium with chromate(VI) ions, as shown in equilibrium 2.1.

equilibrium 2.1 $$\underset{\text{orange}}{Cr_2O_7^{2-}(aq)} + H_2O(l) \rightleftharpoons \underset{\text{yellow}}{2CrO_4^{2-}(aq)} + 2H^+(aq)$$

(i) When aqueous sodium hydroxide is added, the solution changes colour from orange to yellow. Explain why.

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.... [1]

(ii) The resulting solution from **2(c)(i)** is cooled. The colour changes from yellow back to orange.

Use Le Chatelier's Principle to state and explain what you can conclude about the enthalpy change of the forward reaction for equilibrium 2.1.

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.... [2]

(iii) Barium chromate(VI), $BaCrO_4$, is sparingly soluble, while barium dichromate(VI), $BaCr_2O_7$, is soluble.

Aqueous barium nitrate, $Ba(NO_3)_2(aq)$, is added to an equilibrium mixture consisting of $Cr_2O_7^{2-}(aq)$ and $CrO_4^{2-}(aq)$.

State the effect on the equilibrium position of equilibrium 2.1 and the pH of the resulting solution. Explain your answer.

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.... [2]

[Total: 15]

3 **(a)** Halogens can behave as Lewis acids or Lewis bases.
Use the reactions of chlorine with aluminium chloride and iodine with iodide ions to form triiodide ions, I_3^-, to illustrate this behaviour. Write equations for the reactions that occur.

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.... [2]

(b) There are several ways of introducing chlorine atoms into organic molecules.
For each of the following reactions, state the reagents and conditions necessary.

(i) $C_2H_4 \rightarrow C_2H_5Cl$

.... [1]

(ii) $C_2H_4 \rightarrow C_2H_4Cl_2$

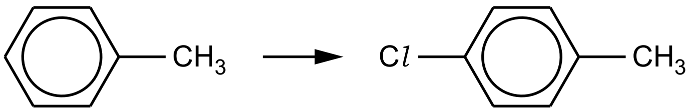
.... [1]

(iii) $C_2H_5OH \rightarrow C_2H_5Cl$

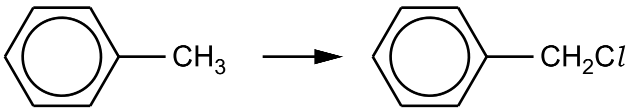
.... [1]

(iv) $CH_3CO_2H \rightarrow CH_3COCl$

.... [1]

(v) 

.... [1]

(vi) 

.... [1]

(c) Alkanes are generally considered to be unreactive compounds, showing an inertness to common reagents such as NaOH, H_2SO_4 and $K_2Cr_2O_7$.

(i) Suggest a reason why these reagents do **not** react with an alkane such as CH_4.

....

.... [1]

(ii) Ethane can be converted into chloroethane according to reaction 3.1.

reaction 3.1 $C_2H_6 + Cl_2 \rightarrow C_2H_5Cl + HCl$

Name the type of mechanism in reaction 3.1.

.... [1]

(iii) Use equations to describe the mechanism for reaction 3.1. Name each step involved.

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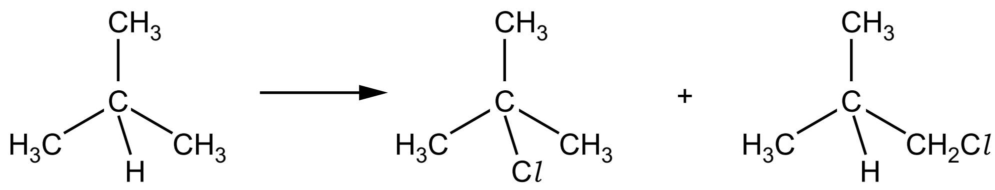
.... [3]

(d) It is found by experiment that during reactions of alkanes with chlorine, hydrogen atoms of the primary, secondary and tertiary carbons are replaced by chlorine atoms at different rates, as shown in Table 3.1.

Table 3.1

reaction	relative rate
$RCH_3 \rightarrow RCH_2Cl$	1
$R_2CH_2 \rightarrow R_2CHCl$	7
$R_3CH \rightarrow R_3CCl$	21

When 2-methylpropane is chlorinated, a mixture of two organic products, **H** and **I**, is formed.



2-methylpropane **H** **I**

Use the information in Table 3.1 and the number of hydrogen atoms of each type (primary, secondary or tertiary) within the molecule to predict the relative ratio of **H** and **I** formed.

.... [1]

(e) Draw the skeletal formulae of **four** different structural isomers of $C_5H_{11}Cl$ that could be obtained from the chlorination of 2-methylbutane.

Indicate any chiral centres in your structures by an asterisk (*).

[3]

(f) **(i)** Figure 3.1 shows the polymer poly(ethene), which can be used in food plastic wrapping.

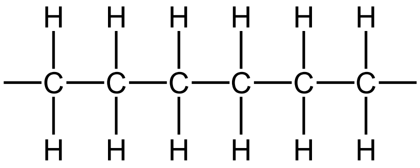


Figure 3.1

This polymer macromolecule has a relative molecular mass of between 15 000 and 20 000.

Calculate the minimum number of repeating units of ethene needed to be present on one macromolecule of poly(ethene).

[1]

(ii) Suggest why people are encouraged to recycle poly(alkenes).

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.... [2]

[Total: 20]

Section B

Answer **one** question from this section in the spaces provided.

4 **(a)** Explain what is meant by a transition element.

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.... [1]

(b) Suggest a reagent that could be used to convert $[Cu(H_2O)_6]^{2+}$ into $[CuCl_4]^{2-}$ in the laboratory.

.... [1]

(c) The complex $[Cu(H_2O)_6]^{2+}$ is octahedral.

In an octahedral complex, the d subshell of a transition metal ion is split into two sets of energy levels.

(i) On Figure 4.1, draw **one** of the d orbitals at the lower energy level in an octahedral complex. [1]

(ii) On Figure 4.2, draw **one** of the d orbitals at the upper energy level in an octahedral complex.

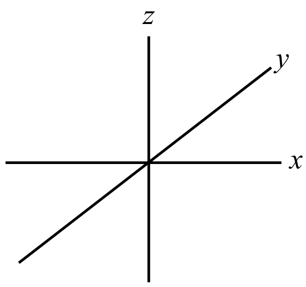

Figure 4.1

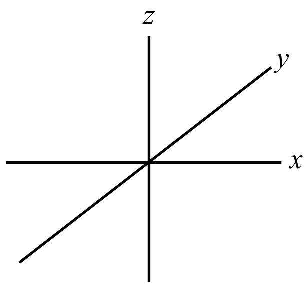

Figure 4.2

[1]

(iii) Use your d orbital diagrams in **4(c)(i)** and **4(c)(ii)** to explain why d orbital splitting occurs in an octahedral complex.

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.... [1]

(d) Copper can form stable compounds containing copper(II) ions or copper(I) ions.

Copper(II) salts are usually coloured, whereas copper(I) salts are usually white or colourless.

The complex ion $[Cu(H_2O)_6]^{2+}$ is blue, whereas the complex ion $[Mn(H_2O)_6]^{3+}$ is red. Both of these complexes are octahedral.

(i) State the electronic configuration of a copper(I) ion.

.... [1]

(ii) Explain why copper(II) salts are usually coloured, whereas copper(I) salts are usually white or colourless.

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.... [3]

(iii) Suggest why $[Cu(H_2O)_6]^{2+}$ and $[Mn(H_2O)_6]^{3+}$ have different colours.

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.... [1]

(iv) Draw the three-dimensional diagram for $[Cu(H_2O)_6]^{2+}$.

[1]

(e) Copper(I) oxide and copper(II) oxide can both be used in the ceramic industry for adding blue, green or red tints to glasses, glazes and enamels.

Table 4.1 lists the $\Delta H_f^\ominus$ values for some compounds.

Table 4.1

compound	$\Delta H_f^\ominus$ / kJ mol^{-1}
$Cu_2O(s)$	–168.6
$CuO(s)$	–157.3
$Cu(NO_3)_2(s)$	–302.9
$NO_2(g)$	+33.2

(i) Copper(II) oxide can be produced in a pure form by heating copper(II) nitrate, as shown in reaction 4.1.

reaction 4.1 $$Cu(NO_3)_2(s) \rightarrow CuO(s) + 2NO_2(g) + \frac{1}{2}O_2(g)$$

Calculate $\Delta H^\ominus$ for reaction 4.1, using suitable $\Delta H_f^\ominus$ values from Table 4.1.

[1]

(ii) Copper(I) oxide can be formed by heating copper(II) oxide, as shown in reaction 4.2.

reaction 4.2 $$2CuO(s) \rightleftharpoons Cu_2O(s) + \frac{1}{2}O_2(g) \qquad \Delta H^\ominus = +146\text{ kJ mol}^{-1}$$

Suggest which of the reactions, reaction 4.1 or reaction 4.2, would have the higher entropy change per mole of reactant. Explain your answer.

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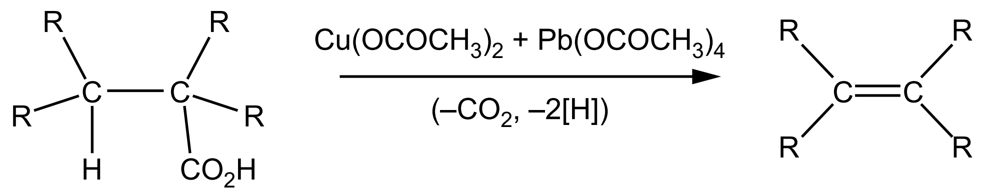
.... [1]

(f) Some copper compounds are used as reagents for organic reactions.

A mixture of copper(II) ethanoate and lead(IV) ethanoate is used for the conversion of carboxylic acids into alkenes containing one less carbon atom.



When carboxylic acid **J**, $C_8H_{14}O_2$, is treated in this way, alkene **K**, C_7H_{12}, is formed.
Treatment of **K** with a hot acidified solution of manganate(VII) ions produces compound **L**, $C_7H_{12}O_3$.
A series of tests are carried out on **L**. The tests and the results are recorded in Table 4.2.

Table 4.2

test on L	observations / results	type of reaction	functional groups identified in L
addition of $Na_2CO_3(aq)$	effervescence	acid-base	carboxylic acid
addition of 2,4-DNPH	orange precipitate formed		
addition of alkaline aqueous iodine, followed by acid	yellow precipitate and organic compound formed, $HO_2CCH_2CH(CH_3)CH_2CO_2H$		

(i) Complete Table 4.2 to give the type of reaction described and what the information tells you about the functional groups present in **L**. [4]

(ii) Suggest structures for compounds **J**, **K** and **L**.

[3]

[Total: 20]

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5 **(a)** **(i)** State the Arrhenius theory of acids and bases.

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.... [2]

(ii) Separate samples of Na_2O and MgO are shaken with water. The pH value of the solution formed with Na_2O is greater than the pH value of the solution formed with MgO.

The pH of the solution formed when SO_3 is shaken with water is **less** than both of these.

Explain these observations using the Arrhenius theory. Write equations for all the reactions described.

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.... [3]

(b) The ozone, O_3, molecule contains a dative covalent bond.

(i) Draw a 'dot-and-cross' diagram to show the bonding in a molecule of O_3. Include all outer shell electrons in your diagram.

[1]

(ii) Suggest a value for the bond angle in O_3. Explain your answer.

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.... [3]

(c) The compound FO_2 does not exist, but ClO_2 does. In the molecule of ClO_2 the central atom is chlorine.
Suggest reasons for this difference, by considering the possible types of bonding in each of the two compounds.

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.... [2]

(d) Ozone can be made by passing oxygen gas through a tube between two highly charged electrical plates. This forms an equilibrium mixture of the two gases O_2 and O_3.

$$3O_2(g) \rightleftharpoons 2O_3(g)$$

The concentration of O_3 in the mixture can be determined by its reaction with aqueous KI.

$$O_3 + 2KI + H_2O \rightarrow I_2 + O_2 + 2KOH$$

The iodine formed can be estimated by its reaction with sodium thiosulfate.

$$2Na_2S_2O_3 + I_2 \rightarrow Na_2S_4O_6 + 2NaI$$

In an experiment, 500 cm^3 of an oxygen / ozone gaseous mixture at a temperature of 300 K is passed into an excess of aqueous KI.

The iodine formed required 15.0 cm^3 of 0.100 mol dm^{-3} $Na_2S_2O_3$ for complete reaction.

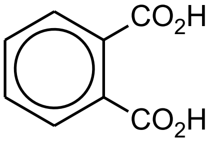
(i) Calculate the number of moles of iodine produced.

[1]

(ii) Calculate the concentration of ozone gas.

[1]

(e) **(i)** Compounds **M** and **N** each have the formula C_9H_{10}. Compound **P** has the formula $C_9H_{12}O$.
Compound **M** reacts with Br_2(aq), but compound **N** does **not**.
Compound **P** reacts with alkaline aqueous iodine.
In separate reactions, **M**, **N** and **P** are all oxidised by hot concentrated alkaline $KMnO_4$ and then acidified. The product of each of these oxidation and acidification reactions is benzene-1,2-dicarboxylic acid, **Q**.



Q

Suggest structures for compounds **M**, **N** and **P**.

[3]

(ii) Compound **S** can be synthesised from compound **Q** in two steps as shown in Figure 5.1.

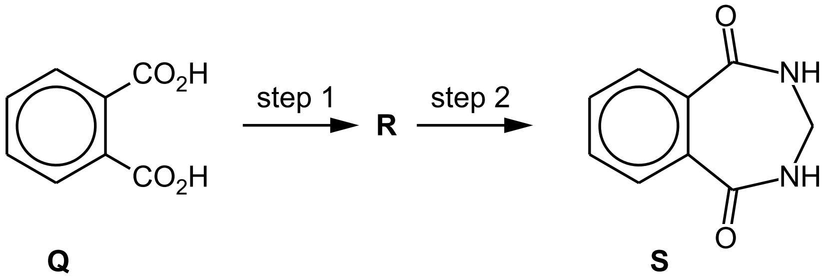


Figure 5.1

Suggest reagents for step 1 and for step 2.

Suggest the structure of the intermediate **R**.

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.... [3]

(f) Figure 5.2 shows the structure of 2-hydroxypropanoic acid.

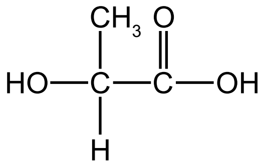

Figure 5.2

Draw the structure of a polyester that can be formed from 2-hydroxypropanoic acid. Show at least two repeat units.

[1]

[Total: 20]