TEMASEK JUNIOR COLLEGE

2025 JC2 PRELIMINARY EXAMINATION

Higher 1

CANDIDATE NAME		CLASS	/ 24
CENTRE NUMBER	S	INDEX NUMBER	

Chemistry **8873/02**

Paper 2 Structured Questions **3 September 2025**

2 hours

Candidates answer on the Question Paper.

Additional Materials: Data Booklet

READ THESE INSTRUCTIONS FIRST

Write your name, CG, centre and index number in the space provided at the top of this page.
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.

Section A

Answer **all** questions.

Section B

Answer **one** question.

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

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

For Examiner's Use	
Section A	
Q1	
Q2	
Q3	
Q4	
Q5	
Section B	
Q6	**/20**
Q7	**/20**
Total	**/80**

This document consists of **27** printed pages and **1** blank page.

Section A

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

1 Steel is an *interstitial* alloy, as carbon atoms fit in between iron atoms in the lattice.

Brass is a *substitution* alloy, as zinc atoms replace the copper atoms in the lattice.

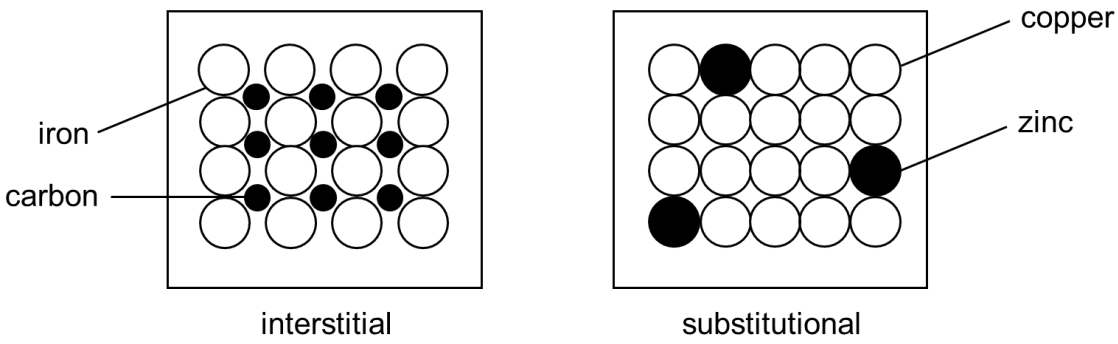

Fig. 1.1

Stainless steel is a combination of interstitial and substitution alloys, because carbon atoms fit in between the lattice, but some of the iron atoms are replaced with nickel atoms.

The structure of the alloy will determine properties such as *hardness*, which measures the material's resistance to permanent shape change when a force is applied. These properties rely on how much electrostatic attraction is present between ions and electrons in any given volume of the lattice. The magnitude of the lattice strength can be measured using the formula below.

$$\text{Lattice Strength } \alpha \frac{q^+}{r^+}$$

(a) The ionic radius and ionic charge of the following ions with their respective chemical symbols are given in the following table.

Table 1.1

Element	C	V	Cr	Fe	Ni	Cu	Zn	W
Ionic radius (10^{-12} m)	15	64	62	55	56	73	74	66
Ionic charge	+4	+3	+3	+3	+3	+2	+2	+4

(i) State which **metallic** element when added in small amount increases the lattice strength of iron to the largest extent. Give a reason for your answer.

……..

……..[1]

(ii) From the Table 1.1 above, suggest another element, other than nickel, that can be added to iron to form a substitutional alloy.

……..[1]

(iii) With the aid of a labelled diagram, describe the structure and bonding in iron.

……..

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……..[2]

Metals are malleable because they can be hammered or pressed into shapes without breaking the metallic bond. The hardness of iron is enhanced when carbon atoms are added to iron atoms in the lattice.

(iv) With reference to your answer in **(a)(iii)**, explain how adding carbon atoms enhance the hardness of iron in steel.

……..

……..[1]

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(b) The melting points, in °C, of chlorides and iodides of two elements, iron and silicon, are shown below.

Table 1.2

	iron	silicon
chloride	677	-70
iodide	587	121

Explain, in terms of structure and bonding, the differences in melting points between $FeCl_2$, $SiCl_4$ and SiI_4.

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……..[3]

[Total: 8]

2 Hydrogen peroxide, H_2O_2, finds its applications in a diversity of fields as it is considered an environmentally-friendly oxidising agent.

(a) Suggest why it is environmentally-friendly to use H_2O_2 as an oxidising agent.

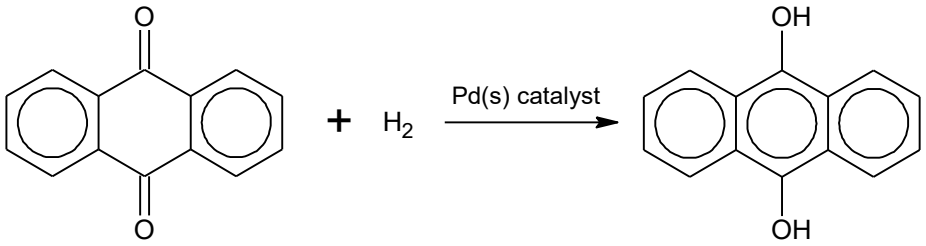
……...

……..[1]

Today, most of the world's hydrogen peroxide is manufactured by the anthraquinone process.

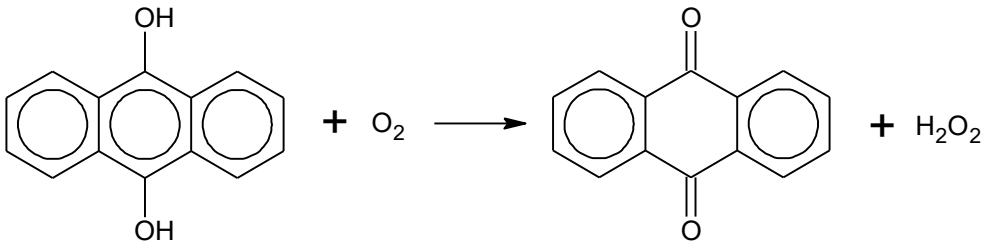
This process involves the two steps shown below.

step 1:



Anthraquinone Anthrahydroquinone

step 2:



Anthrahydroquinone Anthraquinone

At the end of step 2, only anthraquinone and H_2O_2 remain in the reaction mixture. H_2O_2 can be separated out from the reaction mixture by adding water to the reaction mixture.

(b) With reference to the interactions between relevant molecules, explain how the addition of water separates H_2O_2 from the reaction mixture.

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……..[2]

DO NOT WRITE IN THIS MARGIN

(c) **(i)** Palladium metal is often used as a heterogeneous catalyst.

Explain what is meant by a *heterogeneous* catalyst.

……..

……..[1]

(ii) Explain how a *heterogeneous* catalyst increases the rate of reaction. Include a sketch of the Maxwell-Boltzmann distribution and use it to illustrate your answer.

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……..[4]

(d) It is observed that the catalytic activity of palladium is vastly increased when the catalyst is finely divided into nanoparticles. These nanoparticles are usually deposited onto the surface of inert metal particles such as gold. This prevents the nanoparticles from being a health hazard.

(i) State the meaning of the term *nanoparticles*.

……..

……..[1]

(ii) Explain why catalytic activity is vastly increased when nanoparticles of palladium are used.

……..

……..[1]

(iii) Predict how nanoparticles could present a risk to human health.

……..

……..[1]

(iv) Explain how the deposition of palladium nanoparticles on gold particles prevents them from being a health hazard.

……..

……..[1]

[Total: 12]

3 **(a)** Pentan-1-ol, $C_5H_{11}OH$, is an important precursor in the synthesis of organic compounds.

(i) Give the structural formula and the name of another primary alcohol which is an isomer of pentan-1-ol.

……...

……...[2]

(ii) Pentan-1-ol can be converted to valeric acid, $CH_3(CH_2)_3CO_2H$, that can then be used to form methyl valerate, $CH_3(CH_2)_3CO_2CH_3$, an ester that is used in the manufacture of plastics.

State the necessary reagents and conditions required to prepare methyl valerate from valeric acid.

……...[1]

(b) Valeric acid dissociates in water as shown in the equation.

$$CH_3(CH_2)_3CO_2H(aq) \rightleftharpoons CH_3(CH_2)_3CO_2^-(aq) + H^+(aq)$$

(i) Write the expression for the acid dissociation constant, K_a.

……...[1]

(ii) The concentration of H^+ is commonly expressed in terms of pH. Likewise, the acid dissociation constant, K_a, of an acid can be expressed in terms of pK_a, where

$$pK_a = -\log_{10} K_a$$

The pK_a value for valeric acid is 4.82 at 25 ºC. Calculate the value of K_a for valeric acid at 25 ºC. State its units.

[1]

DO NOT WRITE IN THIS MARGIN

When valeric acid reacts with sodium hydroxide, sodium valerate is formed. A buffer solution can be made from sodium valerate and valeric acid.

(iii) Explain what is meant by the term *buffer solution*.

……

……[1]

(iv) Write an equation to show how this buffer solution behaves as a buffer when a small amount of $H_3O^+(aq)$ is added to it.

……

……[1]

A 250 cm^3 buffer solution was prepared by adding 100 cm^3 of 0.100 mol dm^{-3} aqueous sodium hydroxide to a 150 cm^3 valeric acid solution.

The amount of valeric acid remaining in 250 cm^3 of this buffer solution was then determined through titration. 25.0 cm^3 portion of this buffer solution requires 22.0 cm^3 of 0.0500 mol dm^{-3} aqueous potassium hydroxide for complete reaction.

(v) Calculate the amount of valeric acid present in this 250 cm^3 buffer solution.

[2]

(vi) Hence, calculate the **initial** molar concentration of valeric acid present in the 150 cm^3 solution before any aqueous sodium hydroxide was added.

[2]

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(c) In another experiment, when 100.0 cm^3 of 0.9 mol dm^{-3} valeric acid was added to 100.0 cm^3 of 1.0 mol dm^{-3} sodium hydroxide solution, the temperature rose by 5.5 °C.

Assume that the specific heat capacity of the reaction mixture is 4.18 J g^{-1} K^{-1} and the density of each solution is 1.00 g cm^{-3}.

Calculate a value for the enthalpy change of neutralisation for the reaction between valeric acid and sodium hydroxide.

[2]

[Total: 13]

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4 **(a)** Polyvinyl acetate, PVAc, is a synthetic polymer commonly used in adhesives for gluing together materials made from wood or paper. The synthesis of PVAc from the monomer, ethenyl acetate, is shown in Fig. 4.1.

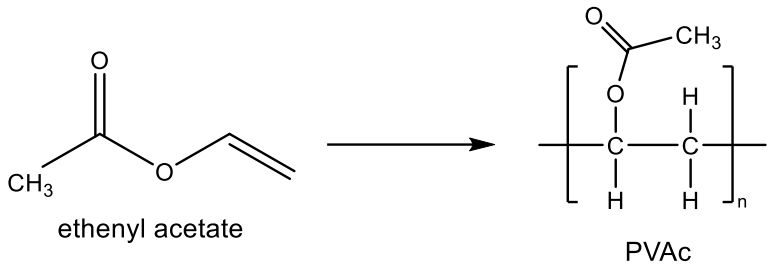


Fig. 4.1

(i) Using your knowledge of the bonding in polymers, explain why PVAc is a thermoplastic.

……

……[2]

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

Infra-red absorptions are useful in identifying functional groups present in molecules.

Suggest how the infra-red spectra of ethenyl acetate and PVAc would differ. Explain your answer.

……

……[1]

Ethenyl acetate can be prepared by a sequence of reactions, with all of its carbon atoms coming from bromoethane molecules as shown in Fig. 4.2.

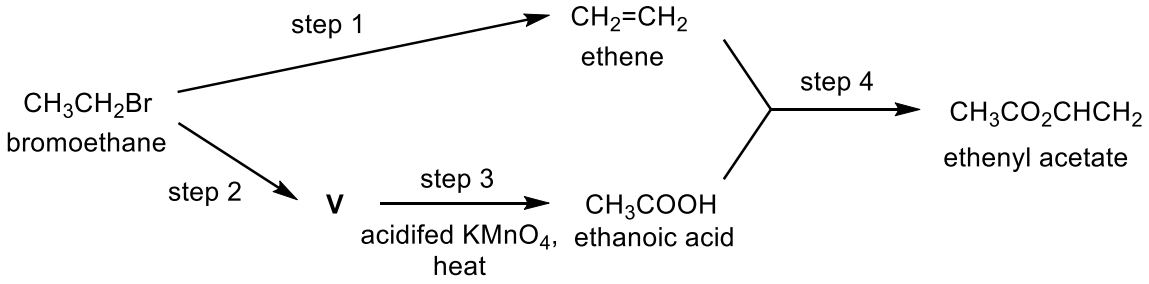


Fig. 4.2

(iii) State the reagents and conditions required for step 1 and suggest the structure of intermediate **V** formed in step 2.

……

……

……[2]

(iv) Step 4 involves the reaction of ethene and ethanoic acid with oxygen gas in the presence of a suitable catalyst.

Construct an equation for step 4.

……

……[1]

Ethenyl acetate can be broken down into two compounds as shown in Fig. 4.3.

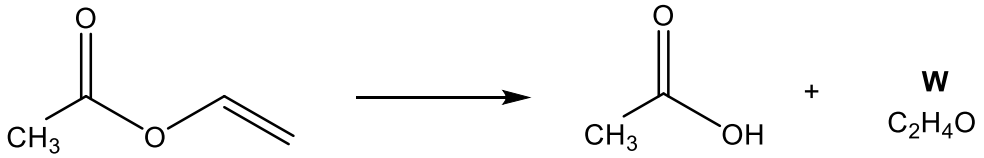


Fig. 4.3

When **W** is extracted from the product mixture, it is found that it does not decolourise aqueous bromine but it decolourises potassium dichromate(VI) under suitable conditions.

(v) Suggest a structure for **W**.

[1]

(b) Research has shown that incorporating amino acids such as alanine into hydrogels prepared from PVAc, can improve their compatibility with living cells.

Alanine is formed when $CH_3CHC\!l\!COOH$ reacts with excess NH_3. However, when $CH_3CHC\!l\!COOH$ and NH_3 are added in a 1:1 stoichiometric ratio, the conjugate acid and base of the reactants are quickly formed as shown.

$$CH_3CHC\!l\!COOH + NH_3 \rightarrow CH_3CHC\!l\!COO^- + NH_4^+$$

Identify the two conjugate acid–base pairs in the above reaction.

conjugate acid–base pair I: ……

conjugate acid–base pair II: ……

[2]

[Total: 9]

5 Polymers are macromolecules which consist of chains built up from small molecules known as monomers, with at least 100 repeating units. In general, polymers can be made via addition or condensation reactions.

The characteristic properties exhibited by polymers are the result of their unique structure and bonding. Not all polymers are biodegradable, which poses difficulty in recycling them. The monomers and biodegradability of addition and condensation polymers are shown in Table 5.1.

Table 5.1

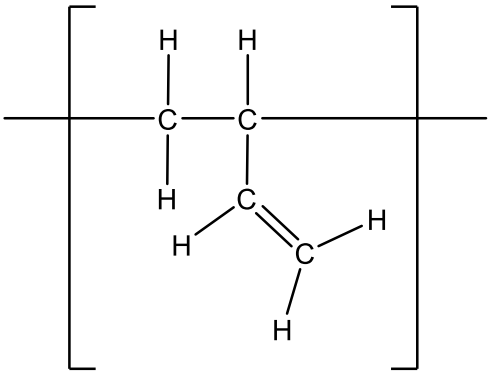
	addition polymer	condensation polymer
monomers	molecules containing C=C bonds	molecules containing two functional groups
biodegradability of polymer	generally difficult to biodegrade	generally biodegradable

(a) The outer layers of some golf balls are made from a polymer called polyisoprene. The isoprene monomer is a non-cyclic branched hydrocarbon with five carbon atoms. One mole of isoprene reacts with two moles of Br_2 in CCl_4.

Suggest a possible structure of isoprene.

[1]

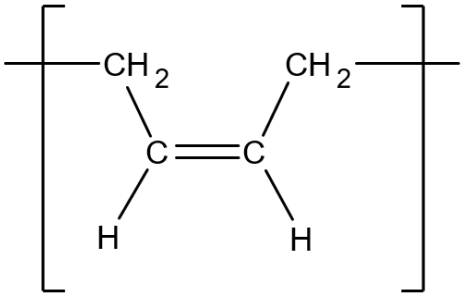
(b) The insides of some golf balls are made from a mixture of three other polymers, **X**, **Y** and **Z**. The repeating unit for polymer **X** is shown.



Draw the structure of the monomer used to make this polymer.

[1]

(c) **(i)** Polymers **Y** and **Z** are stereoisomers. One of the polymers has a repeating unit with the structure shown.



State the type of stereoisomerism and explain why it arises.

.....

.....

.....[2]

(ii) Draw the structure of the repeating unit of the other polymer.

repeating unit of the other polymer

[1]

Table 5.2 shows some properties of polymers **Y** and **Z**.

Table 5.2

	polymer **Y**	polymer **Z**
arrangement of polymer chains	crystalline with regular repeating pattern	amorphous with random arrangement
rigidity	high	low
melting point	75 to 135 °C	–25 to 12 °C

(iii) By referring to the information in Table 5.2, identify whether polymer **Y** or **Z** has the repeating unit in **(c)(i)**.

.....[1]

(d) Golf balls recovered from lakes and ponds can be used again even after being in water for several years. Suggest why these golf balls do not biodegrade.

.....

.....

.....[1]

(e) Another polymer, poly(ethylene terephthalate), PET, is commonly used to make shirts worn by golfers. PET is made from the two monomers, benzene-1,4-dicarboxylic acid and ethane-1,2-diol.

(i) Draw the structure of PET. The functional group formed should be shown displayed.

[1]

Atom economy is a measure of the amount of starting materials which are in the final desired product.

$$\text{percentage atom economy} = \frac{M_r \text{ of the final desired product}}{\text{total } M_r \text{ of all reactants}} \times 100\%$$

(ii) Suggest why chemists usually aim to design production methods with a high percentage atom economy.

.....

.....[1]

(iii) Explain how the percentage atom economy of the reaction to form PET compares with that of polymer **X**.

.....

.....[1]

(f) Table 5.3 shows data relevant to this question.

Table 5.3

	$\Delta H^{\ominus}$ / kJ mol^{-1}
standard enthalpy change of combustion of benzene-1,2-dicarboxylic acid, $C_6H_4(COOH)_2(s)$	–3220
standard enthalpy change of combustion of benzene-1,4-dicarboxylic acid, $C_6H_4(COOH)_2(s)$	–3190
standard enthalpy change of formation of $H_2O(l)$	–286
standard enthalpy change of atomisation of carbon, C(s)	+715

(i) Benzene-1,2-dicarboxylic acid is an isomer of benzene-1,4-dicarboxylic acid. Use relevant data from Table 5.3 to deduce whether benzene-1,2-dicarboxylic acid or benzene-1,4-dicarboxylic acid is more energetically stable with a lower energy under standard conditions. Explain your answer.

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.....

.....[1]

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Figure 5.1 shows an energy cycle.

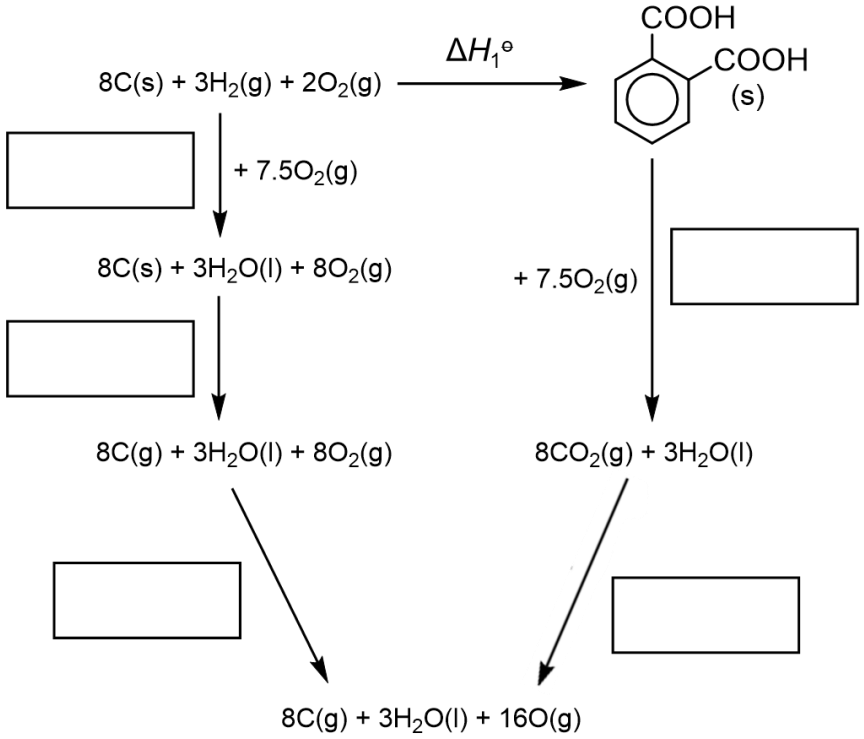


Fig. 5.1

(ii) State what the enthalpy change, $\Delta H_1^{\ominus}$, in Fig. 5.1 represents.

.....[1]

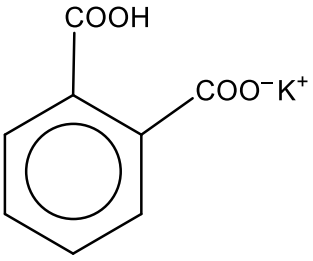
(iii) The standard enthalpy change of atomisation of an element is the energy absorbed when one mole of free gaseous atoms is formed from the element in its standard state at 298 K and 1 bar.

Using relevant data from Table 5.3 and the *Data Booklet*, complete Fig. 5.1 by filling in the values in the boxes. [3]

(iv) Hence, determine a value for $\Delta H_1^{\ominus}$. Show your working clearly.

[1]

(g) Potassium hydrogen phthalate, KHP, has the structure below.



KHP

Suggest and explain how the magnitude of lattice energy of KHP and potassium oxide, K_2O, would compare.

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.....[2]

[Total: 18]

Section B

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

6 Copper has two stable isotopes, ^{63}Cu and ^{65}Cu, that exist naturally in mineral ores.

(a) A sample of mineral ore containing the two isotopes of copper is run in a mass spectrometer to determine their relative amounts. The following mass spectrum is obtained.

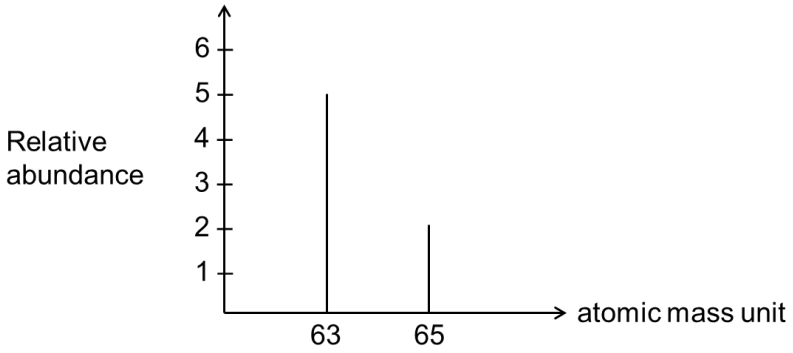

Fig. 6.1

(i) Define the term *isotope*.

.....[1]

(ii) Using Fig. 6.1, determine the relative atomic mass, A_r, of copper. Give your answer to 4 decimal places. [1]

[1]

DO NOT WRITE IN THIS MARGIN

Chlorine and bromine each has two naturally occuring isotopes. Their relative abundance are shown below.

Table 6.1

Element	Isotope	Relative abundance
chlorine	^{35}Cl	75%
	^{37}Cl	25%
bromine	^{79}Br	50%
	^{81}Br	50%

The following *incomplete* mass spectrum is obtained from a sample of $BrCl$ where only the abundance for atomic mass unit of 116 is shown.

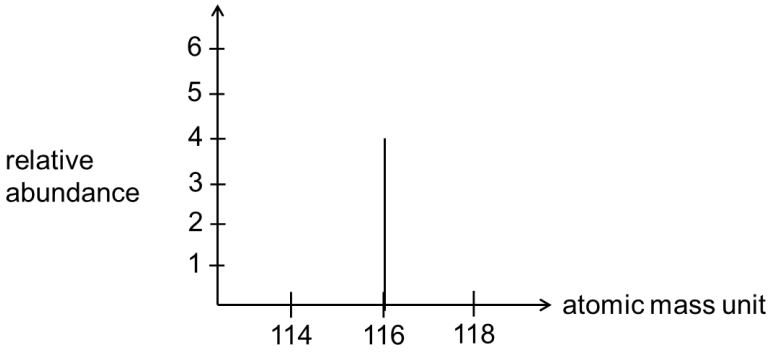

Fig. 6.2

(iii) Identify the species responsible for the atomic mass unit of 114, 116 and 118, taking into consideration the various isotopes.

atomic mass unit of 114 .....

atomic mass unit of 116 .....

atomic mass unit of 118 .....

[2]

(iv) Hence, calculate the relative abundance of $BrCl$ with atomic mass unit of 114 and 118 and complete Fig 6.2.

[2]

(b) Most of the world's copper comes from the mining of copper-containing minerals. Two such minerals are bornite, Cu_5FeS_4, and chalcopyrite, Cu_xFeS_y, where x and y are integer values to be determined.

Bornite and chalcopyrite react with concentrated HNO_3 as follows.

$Cu_5FeS_4 + 26HNO_3 \rightarrow Fe(NO_3)_3 + 5Cu(NO_3)_2 + 4S + 13NO_2 + 13H_2O$

$Cu_xFeS_y + (6 + 4x)HNO_3 \rightarrow Fe(NO_3)_3 + xCu(NO_3)_2 + yS + (3 + 2x)NO_2 + (3 + 2x)H_2O$

(i) Explain the role of HNO_3 in the above reactions.

.....

.....

.....[2]

(ii) When 1 mole of chalcopyrite was fully reacted with HNO_3, 64.2 g of sulfur precipitate and 114 dm^3 of nitrogen dioxide at standard temperature and pressure were produced.

Determine the values of x and y.

[2]

(c) Nitrogen exhibits a range of oxidation numbers in its compounds. A few of such species are NO, N_2O, NO_2, N_2 and NH_2OH.

(i) Draw the dot-and-cross diagram for NO_2.

[1]

0.074 g of hydroxylamine, NH_2OH, is dissolved in water. Excess solution of acidified iron(III) salt is added to the dissolved hydroxylamine to form a nitrogen-containing product and iron(II) ions. The iron(II) ions produced requires 44.8 cm^3 of 0.02 mol dm^{-3} acidified potassium manganate(VII) for complete reaction.

The reacting ratio of iron(II) ions and manganate(VII) ions is 5:1.

(ii) Calculate the amount of iron(III) reacted with hydroxylamine.

[1]

(iii) Determine the oxidation state of the nitrogen atom in the nitrogen-containing product. Hence, deduce the identity of the nitrogen-containing product.

Identify of the nitrogen-containing product .....

[2]

(iv) Construct a balanced ionic equation for the reaction of NH_2OH with Fe^{3+}.

.....

.....[1]

(d) Figure 6.3 shows the second ionisation energies of nine consecutive elements **A** to **I** with atomic numbers below 20 in the Periodic Table. Labels **A** to **I** are not the atomic symbols of the elements.

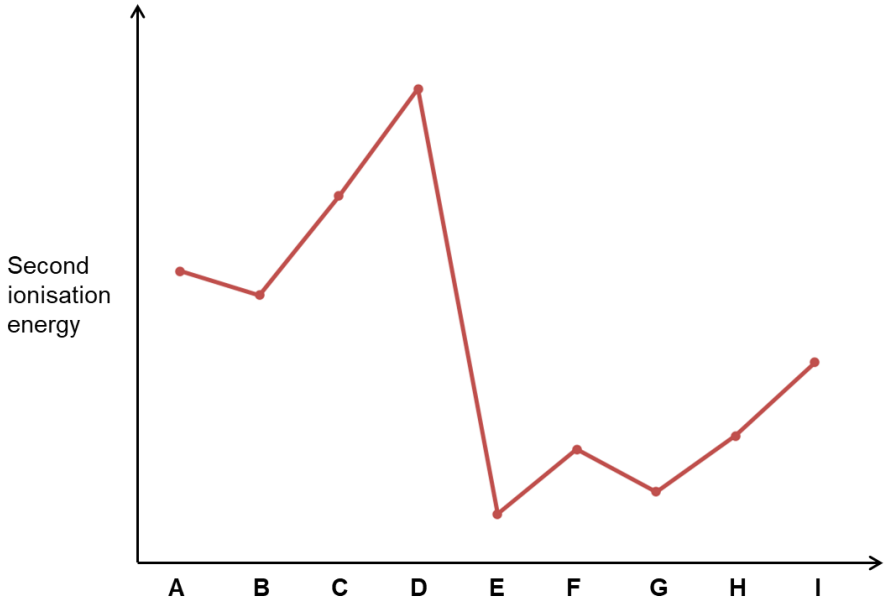

Fig. 6.3

(i) Define the *second ionisation energy* of element **F**.

.....

.....

.....[2]

(ii) Suggest the identity of **B**. Explain how you arrived at your answer.

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.....[2]

(iii) Explain the difference in second ionisation energy between element **A** and element **B**.

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.....

.....[1]

[Total: 20]

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7 In 1932, the American chemist Linus Pauling developed the most common scale of relative electronegativity (EN) values for the elements. The Pauling EN values of elements can be used to predict the chemical properties of compounds. The EN values of four Period 3 elements are given in Table 7.1.

Table 7.1

Element	Sodium	Aluminium	Phosphorus	Chlorine
Pauling EN value	0.93	1.61	2.19	3.16

(a) (i) Define electronegativity.

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.....[1]

(ii) Explain the difference in the Pauling electronegativity values of Na and C*l*.

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.....[2]

The ionic character of a bond is directly related to the electronegativity difference, ΔEN, between the bonded atoms. Fig. 7.1 shows the plot of percent ionic character against ΔEN for NaC*l*.

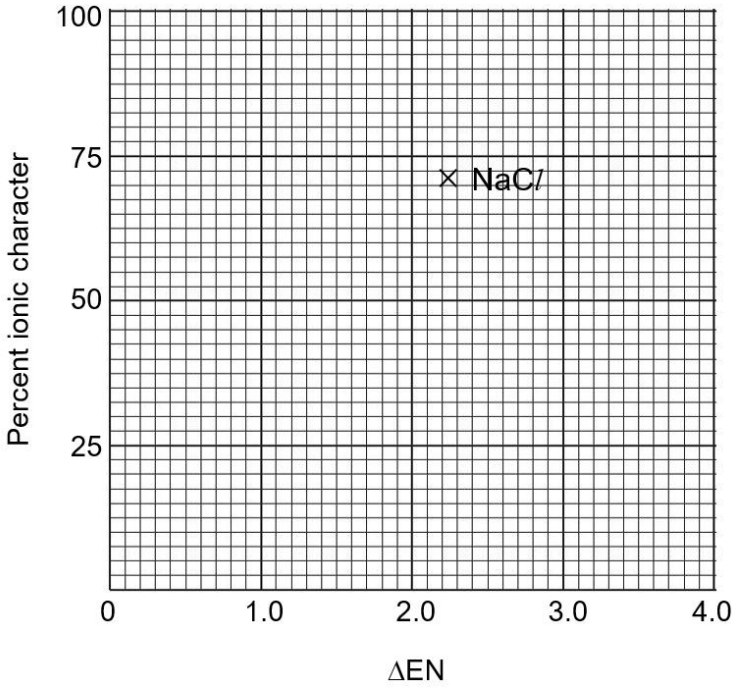

Fig. 7.1

(iii) Using the values in Table 7.1, calculate ΔEN for A*l*Cl_3 and PCl_5 respectively. Hence plot the percent ionic character of A*l*Cl_3 and PCl_5 on Fig. 7.1. Label your points clearly.

[2]

(iv) Explain the difference in bonding for NaC*l* and PCl_5 in terms of electronegativity.

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.....

.....[2]

DO NOT WRITE IN THIS MARGIN

(b) The polarity of bonds in covalent molecules is also affected by ΔEN. SeF_4 and BrF_3 are two fluorine-containing molecules. State whether SeF_4 or BrF_3 contains covalent bonds with a higher ionic character.

Higher ionic character .....[1]

PCl_5 is a Period 3 chloride commonly used as a chlorinating agent and catalyst in making organic compounds. Industrial production of PCl_5 involves the reaction of Cl_2 with PCl_3.

Reaction (1) $PCl_3(g) + Cl_2(g) \rightleftharpoons PCl_5(g)$

(c) Using VSEPR theory, predict and explain the shape and bond angle of PCl_3. Illustrate the shape of PCl_3 with an appropriate diagram

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.....[3]

(d) Suggest, with an explanation, how the position of equilibrium and the composition of the equilibrium mixture might change when chlorine is added to the equilibrium system.

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.....[2]

x mol of Cl_2 gas is added to a 2 dm^3 vessel containing an equilibrium system of 0.4 mol of PCl_3, 0.25 mol of Cl_2 gas and 1.2 mol of PCl_5. The new equilibrium amount of PCl_5 is 1.28 mol.

(e) **(i)** Write the K_c expression for reaction (1), giving its units.

[1]

(ii) Using the information given above, calculate K_c.

[1]

(iii) Hence calculate x, the amount of Cl_2 added.

[2]

(f) Period 3 oxides follow a similar trend in bonding as the Period 3 chlorides.

Describe the action of water on the oxides of sodium, aluminium and phosphorus, write equations for any reactions that occur, and suggest the pH of each solution formed.

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.....[3]

[Total: 20]