TEMASEK JUNIOR COLLEGE

2025 JC2 PRELIMINARY EXAMINATION

Higher 2

CHEMISTRY	9729/01
Paper 1 Multiple Choice	17 September 2025
	1 hour

Additional Materials: Multiple Choice Answer Sheet (OMS)
Data Booklet

READ THESE INSTRUCTIONS FIRST

Write in soft pencil.
Do not use staples, paper clips, glue or correction fluid.

There are **thirty** questions In this paper. Answer **all** questions. For each question there are four possible answers **A, B, C, D**.
Choose the **one** you consider correct and record your choice in **soft pencil** on the separate Answer sheet.

Read the instructions on the Answer sheet very carefully.

Write your name & Civics Group on the Answer sheet. Shade your index number in the appropriate boxes.

Name	_____	Use only 2B pencil for all entries on this sheet.
Class	_____	Shade the bubble completely.
Test Name	_____	Rub out errors thoroughly
Subject	_____	Do not make any stray mark on this sheet
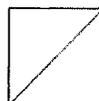
First 2 characters are your class. Next 2 characters are your class index number.

Example:

JC students: write and shade 0501 for CG05 & index number 01.

IP students: write and shade 1A01 for IP1A & index number 01.

Write		Shade appropriate bubbles														
Index Number		0	1	2	3	4	5	6	7	8	9	A	B	C	D	E	F

Each correct answer will score one mark. A mark will not be deducted for a wrong answer.

Any rough working should be done in this booklet.

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

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

1   Which ion would undergo the greatest deflection in an electric field?

A $^4He^{2+}$ B $^{19}F^-$

C $^{14}N_2^+$ D $^{16}O_2^{2+}$

2   An isolated gaseous species has paired electrons in at least one of its 3d orbitals and a fully filled 4s subshell.
    What could be the identity of the species?

A   Cu   B   Mn   C   Fe   D Fe^{2+}

3   Which of the following **cannot** be explained by hydrogen bonding?

A   The existence of the hydrogen-difluoride anion, HF_2^-.

B   The difference in volatility between pentan-1-ol and hexan-1-ol.

C   The difference in melting point between 2-nitrophenol and 4-nitrophenol.

D   The higher than expected relative molecular mass of ethanoic acid in benzene.

4   Four substances have the physical properties shown.
    Which substance exists as a simple molecular solid at room temperature?

	melting point / °C	electrical conductivity	solubility in water
A	-7	does not conduct	slightly soluble
B	46	does not conduct	insoluble
C	420	conducts	insoluble
D	782	does not conduct	soluble

5   Which species contain dative (co-ordinate) bonding?

   1   CO

   2   N_2H_4

   3   N_2O_4

   A   1, 2 and 3   **B**   1 and 2 only   **C**   1 and 3 only   **D**   3 only

6   10 cm^3 of a hydrocarbon was mixed with 50 cm^3 of oxygen and combusted completely. After the resulting gas mixture was cooled and passed through aqueous sodium hydroxide, the volume of the residual gas mixture was found to be ¼ the volume of the original gas mixture before combustion. All volumes were measured at room temperature and pressure.

What is the formula of the hydrocarbon?

A C_2H_4

B C_2H_6

C C_3H_6

D C_3H_8

7   Which species contains a different number of electrons from the other three?

A ClO_4^-

B H_2SO_4

C SO_4^{2-}

D Sn^{2+}

8 Group 2 carbonates such as calcium carbonate decompose thermally to give the metal oxide and carbon dioxide gas.

$$CaCO_3 \rightarrow CaO + CO_2$$

The numerical values of the enthalpy change of the reaction and activation energy are 178 kJ mol^{-1} and 356 kJ mol^{-1}, respectively.

Which reaction pathway diagram best represents this reaction?

A
energy
progress of reaction

B
energy
progress of reaction

C
energy
progress of reaction

D
energy
progress of reaction

9 Equations involving four enthalpy changes are shown.

$Na(g) \rightarrow Na^+(g) + e^-$ $\quad \Delta H = w$

$Na(g) \rightarrow Na^{2+}(g) + 2e^-$ $\quad \Delta H = x$

$Na(s) \rightarrow Na(g)$ $\quad \Delta H = y$

$Na(s) \rightarrow Na^{2+}(g) + 2e^-$ $\quad \Delta H = z$

Which expression represents the second ionisation energy of sodium?

A 2w

B x − w

C y + x − w

D z − y

10 Consider the following mechanism.

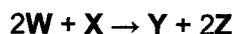|	
L + M → N	fast
L + N → P + Q	slow
N + Q → M + P	fast
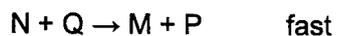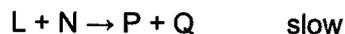
What can be deduced from the mechanism?

    1   The unit for the rate constant, k, in the rate equation is $mol^{-1}\ dm^3\ s^{-1}$.

    2   The overall equation is 2L + N → 2P.

    3   M is a catalyst and Q is an intermediate.

A 1, 2 and 3   **B** 1 and 2 only   **C** 2 and 3 only   **D** 1 only

11 The kinetics of a reaction was investigated, and the following results were obtained.

2W + X → Y + 2Z

run	[W] / mol dm^{-3}	[X] / mol dm^{-3}	initial rate / mol dm^{-3} s^{-1}
1	0.020	0.015	6.40×10^{-3}
2	0.020	0.030	2.56×10^{-2}
3	0.030	0.030	3.84×10^{-2}

What is the numerical value of the rate constant for this reaction?

A 0.213   **B** 0.320   **C** 21.3   **D** 1420

12 When an evacuated tube of volume 400 cm^3 is filled with gas at 300 K and 101 kPa, the mass of the tube increases by 0.65 g.

What is the identity of the gas?

A argon   **B** helium   **C** krypton   **D** neon

6

13 Equal amounts of $H_2(g)$ and $I_2(g)$ are mixed and the composition of the mixture is monitored. A graph of the results is shown below.

$$H_2(g) + I_2(g) \rightleftharpoons 2HI(g) \qquad \Delta H < 0$$
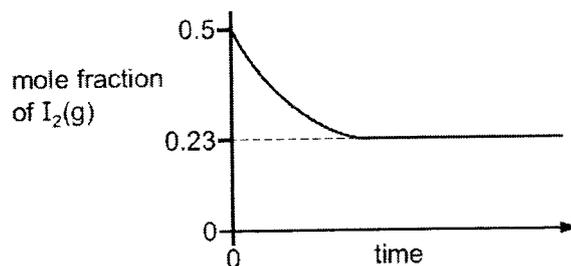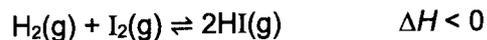
The experiment is repeated with a change in condition and the following graph of results is obtained.
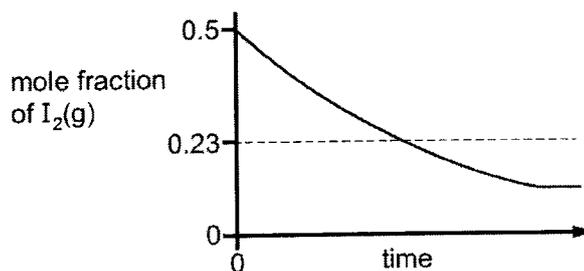
Which of the following is a possible change made in the second experiment?

A A catalyst is used in the second experiment.

B $H_2(g)$ and $I_2(g)$ are mixed in a ratio of 2 : 1 in the second experiment.

C The second experiment is conducted at a higher pressure compared to the first experiment.

D The second experiment is conducted at a lower temperature compared to the first experiment.

14 X, Y and Z represent elements in the Periodic Table.

The first ionisation energy of X is greater than the first ionisation energy of Y.

The melting point of Z is higher than that of Y.

Which row shows the possible identities of X, Y and Z?

	X	Y	Z
A	N	P	Al
B	B	Al	P
C	Ga	Al	P
D	As	P	Al

15 Which statement about the halogens or halide ions is correct?

A Chloride ions are stronger reducing agents than iodide ions.

B Bromine does not oxidise chloride ions when added to sodium chloride solution.

C A yellow precipitate that is partially soluble in aqueous ammonia is formed when iodine is added to silver nitrate solution.

D A pink solution is obtained when one drop of potassium manganate(VII) is added to aqueous sodium bromide solution.

16 An aqueous solution containing 0.10 mol dm^{-3} zinc sulfate and 0.10 mol dm^{-3} of copper(II) sulfate is saturated with hydrogen sulfide, H_2S, at 15 °C. The concentration of S^{2-}(aq) in the solution is 10^{-35} mol dm^{-3}.

The solubility product, K_{sp}, of zinc sulfide and copper(II) sulfide at 15 °C is given below.

	K_{sp} /mol^2 dm^{-6}
zinc sulfide	10^{-24}
copper(II) sulfide	10^{-40}

Which statement describes what happens in the solution?

A Only zinc sulfide is precipitated.

B Only copper(II) sulfide is precipitated.

C Copper(II) sulfide is precipitated, followed by zinc sulfide.

D More precipitate is observed by lowering the pH of the mixture.

17 The graph below shows the change in pH when an acid is gradually added to 10 cm^3 of a base.
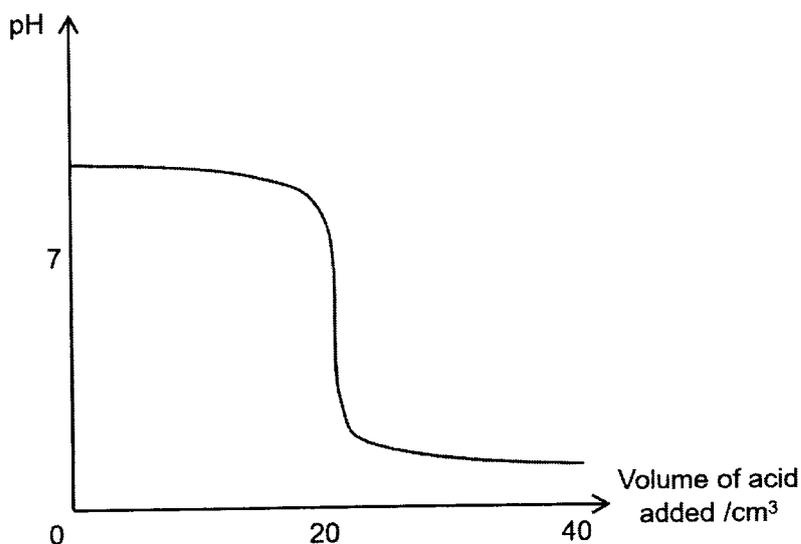
Which pair of acid and base will give the graph above?

A 0.1 mol dm^{-3} HCl(aq) and 0.1 mol dm^{-3} NH$_3$(aq)

B 0.2 mol dm^{-3} HCl(aq) and 0.2 mol dm^{-3} Ba(OH)$_2$(aq)

C 0.1 mol dm^{-3} HCl(aq) and 0.2 mol dm^{-3} NH$_3$(aq)

D 0.1 mol dm^{-3} CH$_3$CO$_2$H(aq) and 0.2 mol dm^{-3} NaOH(aq)

18 Water dissociates as shown.

$$H_2O \rightleftharpoons H^+ + OH^- \qquad \Delta H > 0$$
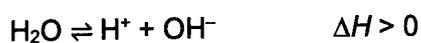
At 25 °C, the concentration of water is given as 55.6 mol dm^{-3}.

Which of the following statements are correct?

1 At 25 °C, the pK_a of water is 14.

2 At 25 °C, the value of pH < pK_w < pK_a of water.

3 At 50 °C, the value of pK_w is lower than 14.

A 1 and 2 only

B 1 and 3 only

C 2 and 3 only

D 3 only

19 Which molecule contains one sp hybridised and two sp^3 hybridised carbon atoms?

A $CH_2=C=CHCH_3$

B $CH_2=CHCN$

C $HOCH_2C\equiv CH$

D $CH_3CH_2CH=CHCN$
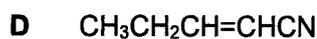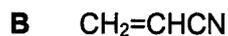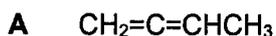
20 The presence of a halogen in an organic compound may be detected by heating the organic compound with ethanolic silver nitrate.

The following three compounds are heated with ethanolic silver nitrate.
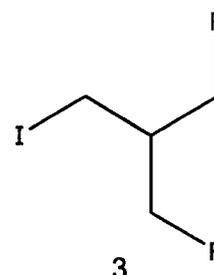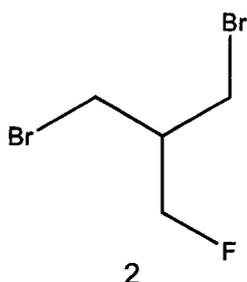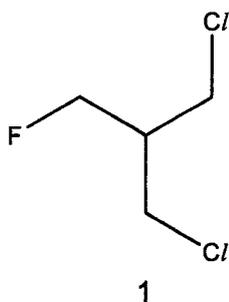
Which of the following shows the correct time taken, from the shortest to the longest, for the compounds to produce a precipitate?

A $1 < 2 < 3$

B $2 < 1 < 3$

C $3 < 2 < 1$

D $3 < 1 < 2$
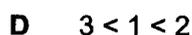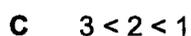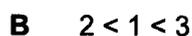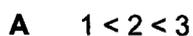
21 In 1869, Ladenburg suggested a structure for benzene, C_6H_6, in which one hydrogen atom is attached to each carbon atom.
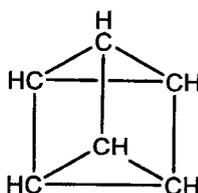
Ladenburg structure

A compound, $C_6H_3Cl_3$, could be formed with the same carbon skeleton as the Ladenburg structure.

How many constitutional isomers would this compound have?

A 3   **B** 4   **C** 5   **D** 6

22 Compound **Z** is responsible for the pleasant aroma of apples. It can be prepared from phenol by the following 3-step synthesis.
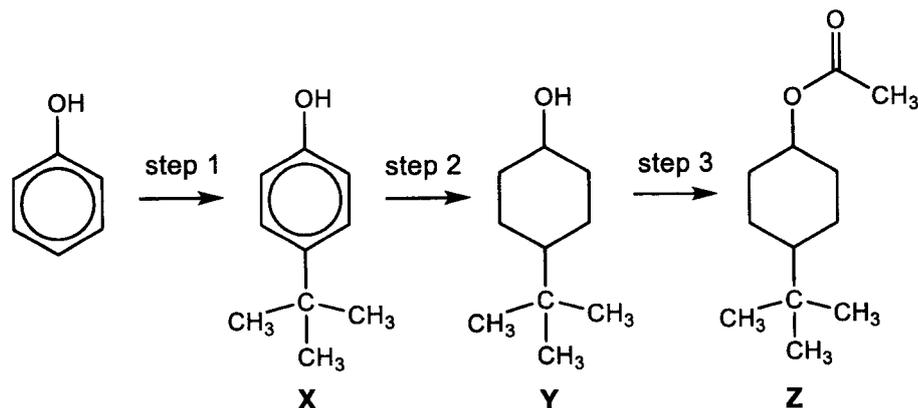
Which row shows the correct information?

	reagent used in step 1	type of reaction occurring in step 2	reagent used in step 3
A	$(CH_3)_3CCl$	oxidation	CH_3COCl
B	$(CH_3)_3CCl$	reduction	CH_3COOH
C	$(CH_3)_3COH$	oxidation	CH_3COCl
D	$(CH_3)_3COH$	reduction	CH_3COOH

23 The naturally-occurring molecule civetone, $C_{17}H_{30}O$, is found in a gland of the African civet cat and has been used in perfumery.
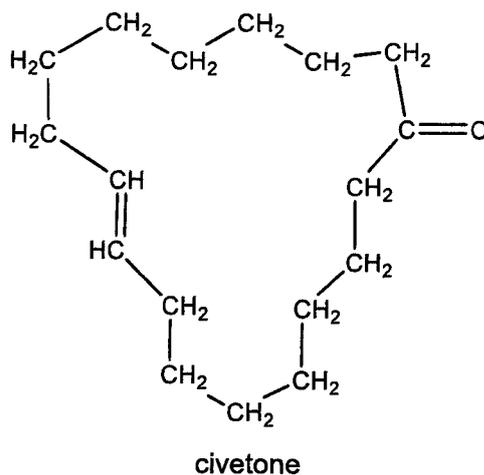
civetone

Which statements about civetone are correct?

1 Civetone can exhibit stereoisomerism.

2 It reacts with Br_2 in CCl_4 to form a product with molecular formula, $C_{17}H_{32}OBr_2$.

3 Hydrogen bonding does not exist between molecules of civetone.

A 1, 2 and 3   B 1 and 3 only   C 2 and 3 only   D 1 only

24 The following three compounds below are heated with excess concentrated H_2SO_4.

How many of these compounds can form more than one final product with the molecular formula, C_7H_{10}?
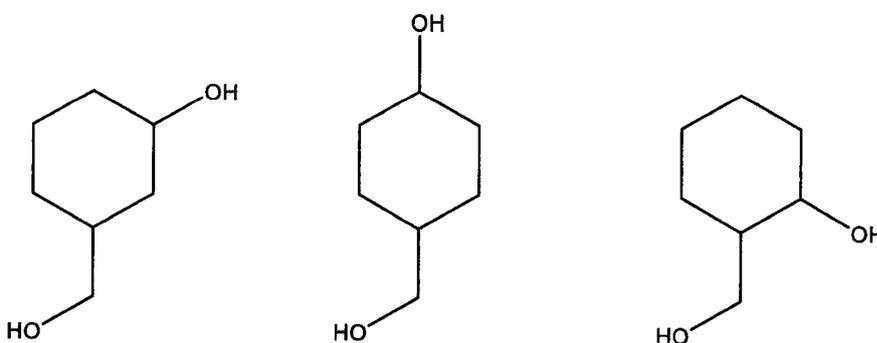
A All three compounds   B Two compounds

C One compound   D None of the compounds

25 Which reaction scheme produces the highest yield of 3-bromophenylamine?

3-bromophenylamine

A

 $\xrightarrow{\text{Br}_2(\text{aq})}$

B

 $\xrightarrow[\text{heat}]{\text{conc HNO}_3, \text{ conc H}_2\text{SO}_4}$ $\xrightarrow[\text{2. NaOH(aq)}]{\text{1. Sn, conc HC}l, \text{ heat}}$

C

 $\xrightarrow[\text{heat}]{\text{Br}_2, \text{ anhydrous FeBr}_3}$ $\xrightarrow{\text{LiA}l\text{H}_4 \text{ in dry ether}}$

D

 $\xrightarrow[\text{heat}]{\text{Br}_2, \text{ Fe}}$ $\xrightarrow[\text{2. NaOH(aq)}]{\text{1. Sn, conc HC}l, \text{ heat}}$
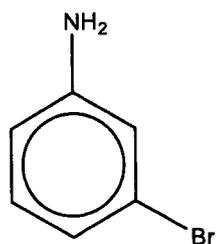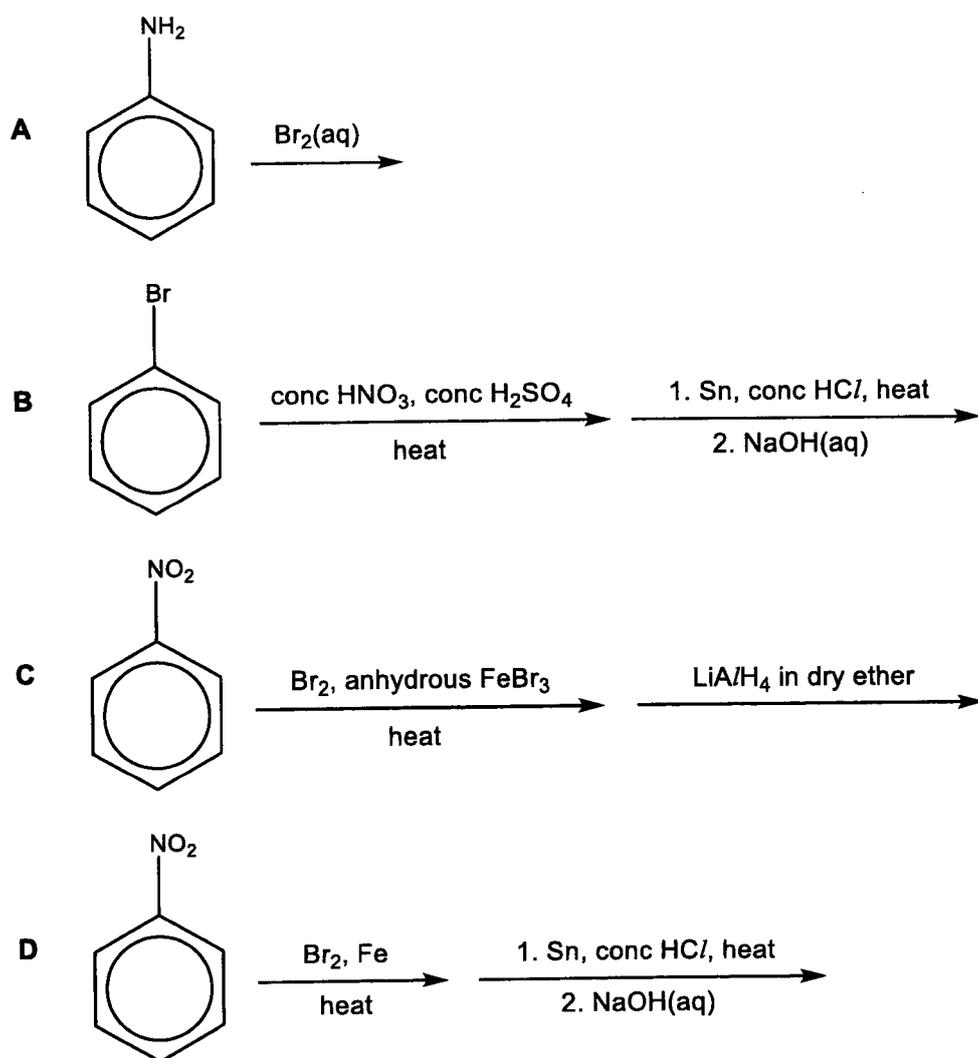
26   Caffeine is a natural stimulant found in coffee, tea, and cacao plants.
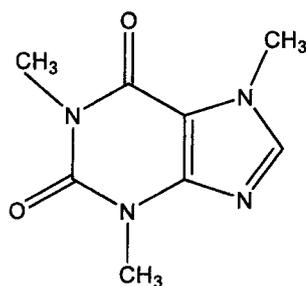
caffeine

Which statement about the caffeine molecule is correct?

A   It reacts with $NaBH_4$.

B   It reacts with ethanoyl chloride to give white fumes.

C   It reacts with hot NaOH(aq) to give an alkaline gas.

D   1 mole of caffeine reacts with 4 moles of HCl(aq) at room temperature.

27   Which statement about the anodising of an aluminium object is correct?

A   The aluminium object is placed at the cathode.

B   Water is reduced at the cathode to produce H_2 gas.

C   Anodising increases the thickness of the aluminium layer of the object.

D   A current of 3.2 A is required to form 0.01 mol of coating on the object for 30 minutes.

28 *Use of the Data Booklet is relevant to this question.*

A cell is set up under standard conditions as shown below.
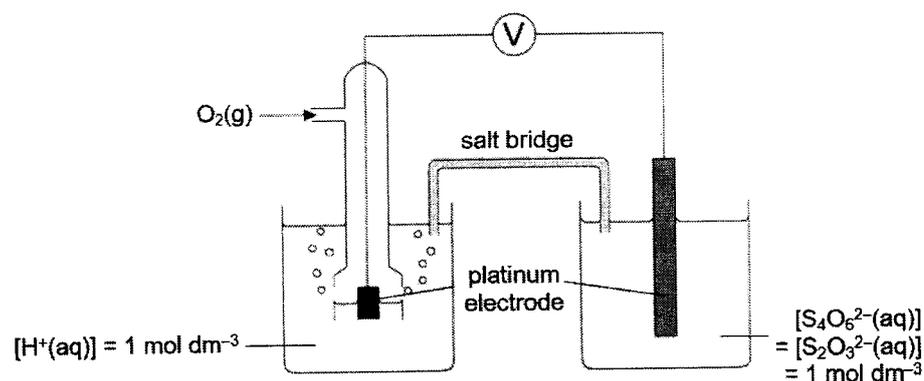
Which changes would decrease the cell potential?

1 Adding water to the $S_4O_6^{2-}$(aq) / $S_2O_3^{2-}$(aq) half-cell.

2 Adding iodine crystals to the $S_4O_6^{2-}$(aq) / $S_2O_3^{2-}$(aq) half-cell.

3 Using O_2(g) at 0.5 bar.

A 1, 2 and 3   **B** 1 and 2 only   **C** 2 and 3 only   **D** 3 only

29 A stability constant is an equilibrium constant for the formation of a complex relative to its aqua complex in solution.

Consider the formation of $[FeL_6]^{3-}$(aq) in solution:

$$[Fe(H_2O)_6]^{3+}(aq) + 6L^-(aq) \rightleftharpoons [FeL_6]^{3-}(aq) + 6H_2O(l)$$
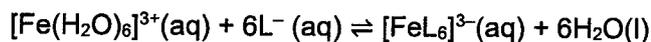
where L^- can be either F^- or CN^-.

The equilibrium constant, K_{stab}, of the above reaction is

$$K_{stab} = \frac{[FeL_6^{3-}]}{[Fe(H_2O)_6^{3+}][L^-]^6}$$

The table below shows the values of the stability constants and colours of some iron complexes.

complex	K_{stab}	colour
$[FeF_6]^{3-}$	2×10^{15}	colourless
$[Fe(CN)_6]^{3-}$	1×10^{31}	orange red

What would be observed when NaCN(aq) is added to a solution of $Fe(NO_3)_3$, followed by adding NaF(aq)?

A The yellow solution turns orange red and remains orange red.

B The yellow solution turns orange red and then to colourless.

C The green solution turns orange red and remains orange red.

D The green solution turns orange red and then to colourless.

30 A reaction scheme involving Cr^{3+}(aq) ions is shown.
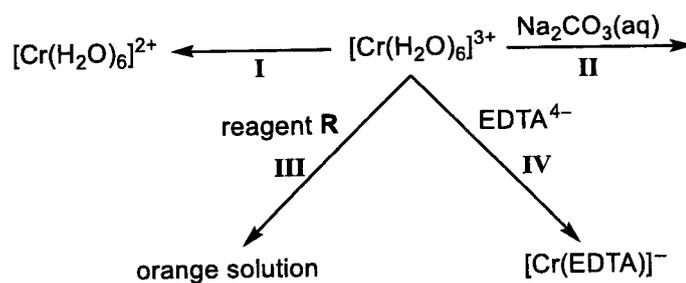
Which statement about the reaction scheme is correct?

A   Reactions **I** and **II** are redox reactions.

B   The observations of reaction **II** are a grey-green precipitate and effervescence.

C   Reagent **R** could be zinc metal.

D   The ΔS for reaction **IV** is negative.

H

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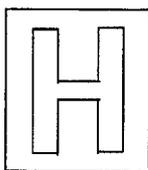
2025 JC2 PRELIMINARY EXAMINATION

Higher 2

TEMASEK
JUNIOR COLLEGE

CANDIDATE NAME		CLASS	/ 24

CENTRE NUMBER	S					INDEX NUMBER				

Chemistry   **9729/02**

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.

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

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	
Q1	
Q2	
Q3	
Q4	
Q5	
Q6	
Total	

This document consists of **22** printed pages and **2** blank pages.

1   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 1.1.

Table 1.1

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

(a)   (i)   Explain the difference in the Pauling electronegativity values of Na and Cl.

....

....

....

....[2]

The ionic character of a bond is directly related to the electronegativity difference (ΔEN) between the bonded atoms. Fig. 1.1 shows the plot of percent ionic character against ΔEN for $NaCl$.
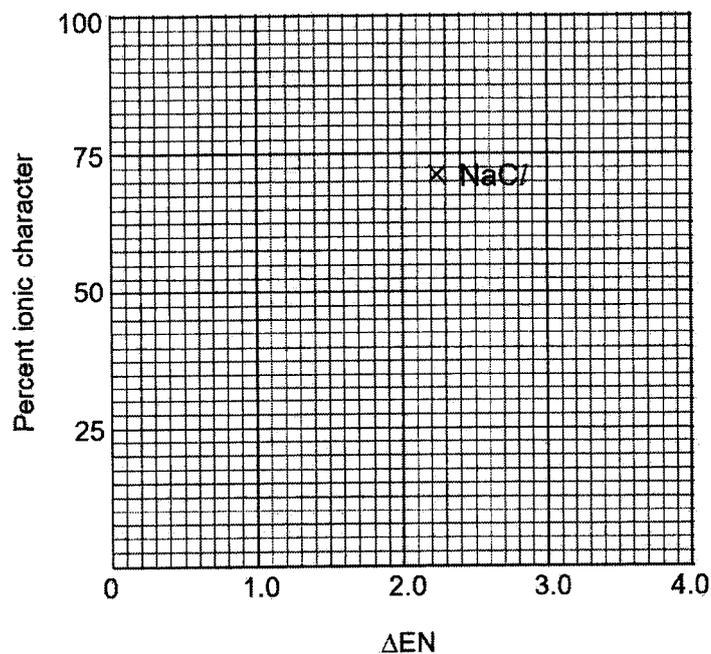
Fig. 1.1

(ii)   Using the values in Table 1.1, calculate ΔEN for $AlCl_3$ and PCl_5 respectively. Hence plot the percent ionic character of $AlCl_3$ and PCl_5 on Fig. 1.1. Label your points clearly.

[2]

(iii) Explain the difference in bonding for NaC*l* and PC*l*$_5$ in terms of electronegativity.

....

....

....

....[2]

(b) **(i)** 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]

(ii) Using VSEPR theory, predict and explain the shape and bond angles of SeF$_4$. Illustrate the shape of SeF$_4$ with an appropriate diagram.

....

....

....

....[3]

[Total: 10]

2   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) $PCl_3(g) + Cl_2(g) \rightleftharpoons PCl_5(g)$

(a)   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.

....

....

....

....[2]

x mol of Cl_2 gas is added to a 2 dm³ 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.

(b)   (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]

(c) 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.

....

....

....

....

....

....

....

....[3]

[Total: 9]

3 **(a)** 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.

Identity of the nitrogen-containing product is ....

[2]

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

....

....[1]

(b) Figure 3.1 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.
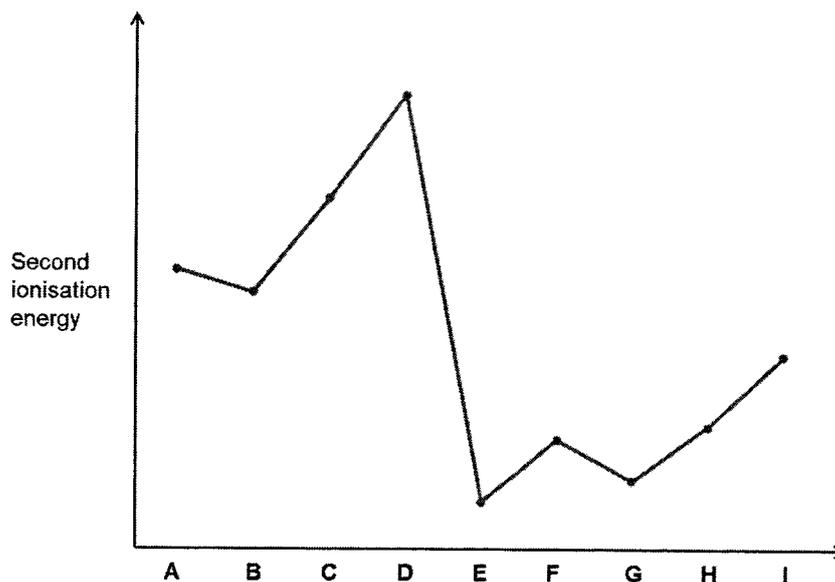
Fig. 3.1

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

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....

....[1]

(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: 9]

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

(a)　(i)　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, $C_{14}H_8O_2$ process. This process involves the two steps shown below.
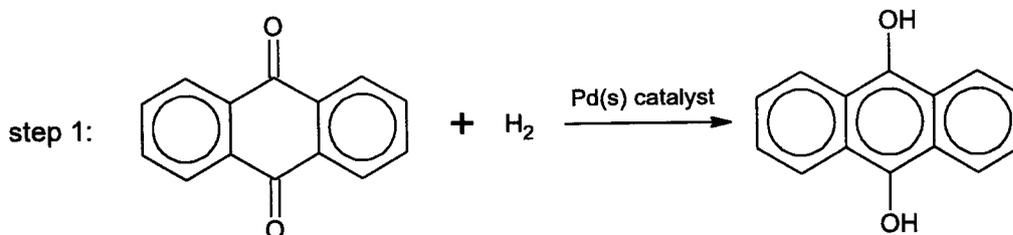
step 1:

Anthraquinone

Anthrahydroquinone

step 2:
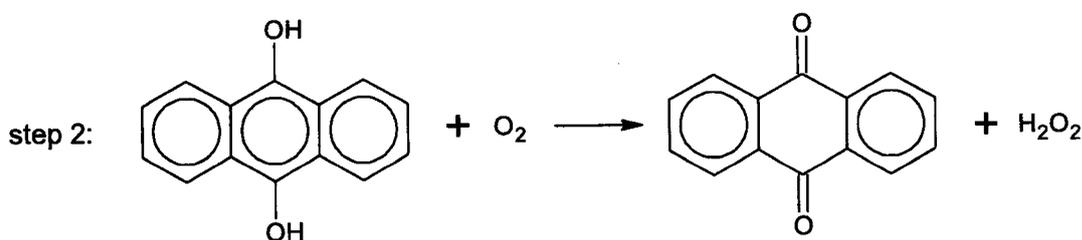
Anthrahydroquinone

Anthraquinone

(ii)　State the type of reaction in step 1.

....[1]

(iii)　In step 1, if Sn is used instead of Pd, compound **P**, $C_{14}H_{10}O$ is obtained. Suggest the structure of **P**.

[1]

(iv) Describe a chemical test that can be used to distinguish anthraquinone from anthrahydroquinone. State the observations and write a balanced equation for the reaction that occurred.

....

....

Equation

[2]

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]

(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) Nanoparticles are particles with all its dimensions from 1 to 100 nm on the nanoscale. 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) Explain why catalytic activity is vastly increased when nanoparticles of palladium are used.

....

....[1]

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

....

....

....[1]

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

....

....[1]

[Total: 15]

5   Copper is a first-row transition metal which has two stable isotopes, ^{63}Cu and ^{65}Cu, that exist naturally in mineral ores.

(a)   Explain the trend of first ionisation energy of first-row transition metals.

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....[2]

(b)   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.
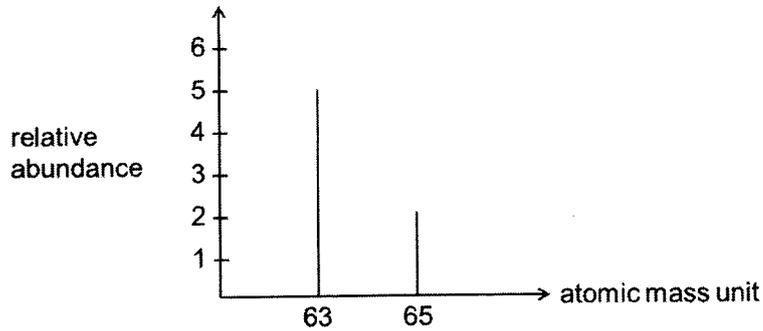
Fig. 5.1

(i)   Define the term *isotope*.

....

....[1]

(ii)   Using Fig. 5.1, determine the relative atomic mass, A_r, of copper. Give your answer to 4 decimal places.

[1]

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

Table 5.1

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.
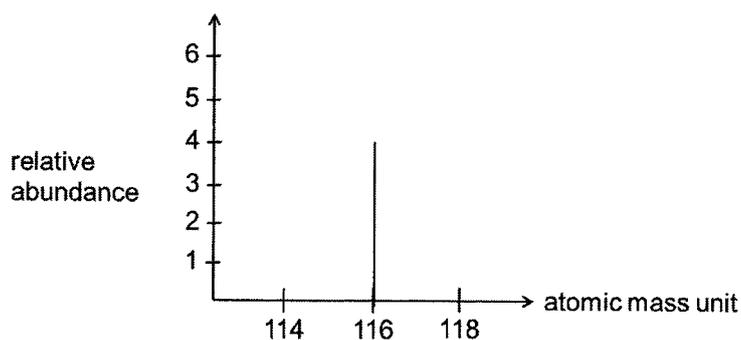
Fig. 5.2

(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 5.2.

[2]

(c) 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.

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

$Cu_xFeS_y + (6 + 4x)HNO_3 \rightarrow Fe(NO_3)_3 + xCu(NO_3)_2 + yS + (3 + 2x)NO_2 + (3 + 2x)H_2O$
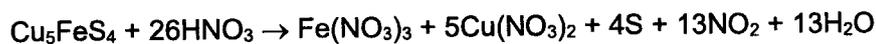
(i) Explain the role of HNO_3 in the above reactions.

....

....

....[1]

(ii) When 1 mole each of bornite and chalcopyrite were fully reacted with HNO_3, bornite produced 64.2 g *more* sulfur precipitate and 182 dm^3 *more* nitrogen dioxide than chalcopyrite, at standard temperature and pressure.

Determine the values of x and y.

[2]

[Total: 11]

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6 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 6.1.

Table 6.1

	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.
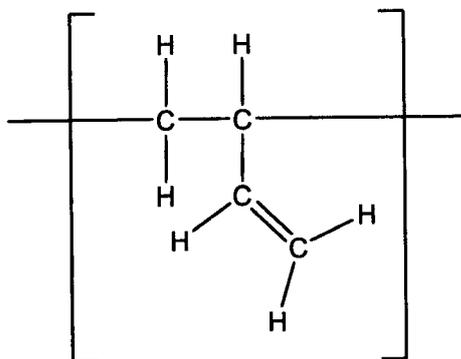
(i) The molecular formula of the monomer of **X** is C_4H_6.

Give the systematic name of the monomer used to make **X**.

....[1]

(ii) Draw the carbon-containing products formed when the monomer undergoes the reactions below.

$$\boxed{} \xleftarrow[\text{heat}]{\text{acidified KMnO}_4,} \; \begin{array}{c} \text{monomer} \\ \text{of polymer } \textbf{X} \end{array} \; \xrightarrow[\text{cold}]{\text{alkaline KMnO}_4,} \boxed{}$$
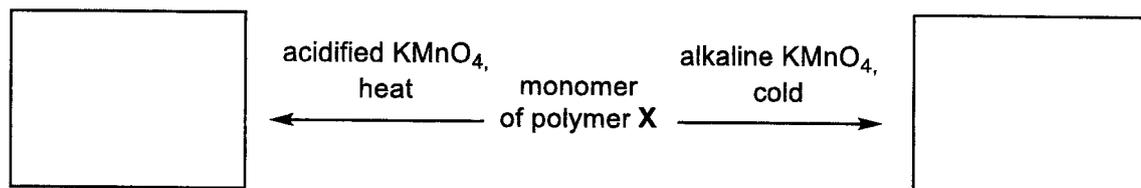
[2]

(c) **(i)** Polymers **Y** and **Z** are stereoisomers. One of the polymers has a repeating unit with the structure shown.
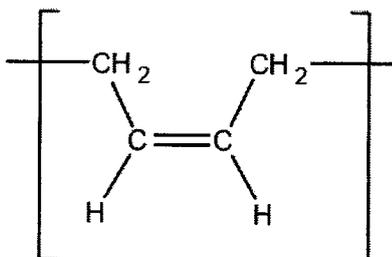
State the type of stereoisomerism and explain why it arises.

....

....

....[2]

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

repeating unit of the other polymer
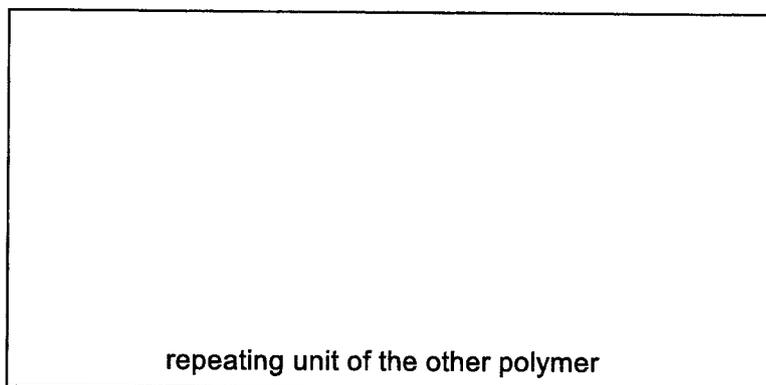
[1]

Table 6.2 shows some properties of polymers Y and Z.

Table 6.2

	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 6.2, 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. The structure of PET is shown below where n is the number of repeating units in the polymer chain. One of the two monomers used to synthesise PET is benzene-1,4-dicarboxylic acid.

$$\left[\begin{array}{c}\overset{O}{\underset{\parallel}{C}}-\bigcirc-\overset{O}{\underset{\parallel}{C}}-O-CH_2CH_2-O\end{array}\right]_n$$
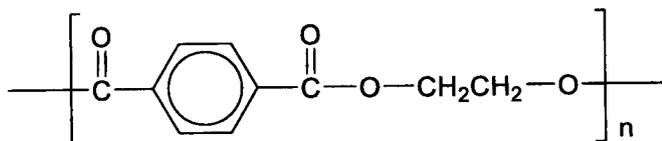
PET

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

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

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

....

....

....[1]

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

....

....

....[1]

(f) Figure 6.1 shows a two-step synthesis of benzene-1,4-dicarboxylic acid from methylbenzene. State the reagents and conditions for each step and draw the structure of the intermediate.
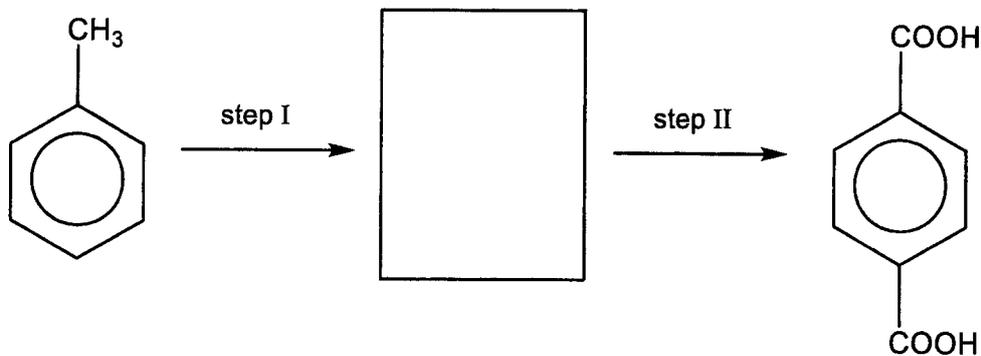
Fig. 6.1

step I ....

step II ....[2]

(g) Benzene-1,2-dicarboxylic acid molecules can also be found in the product mixture in **(f)**.

Table 6.3

	$\Delta H^{\ominus}$ / kJ mol^{-1}
standard enthalpy change of formation of $H_2O(l)$	−286
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

(i) Use relevant data from Table 6.3 to deduce whether benzene-1,2-dicarboxylic acid or benzene-1,4-dicarboxylic acid is more energetically stable under standard conditions. Explain your answer.

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....[1]

(ii) The standard enthalpy change of atomisation of carbon is +715 kJ mol^{-1}.

Use this information and the *Data Booklet* to calculate a value for the standard enthalpy change of combustion of carbon.

[2]

(iii) The standard enthalpy change of formation of benzene-1,2-dicarboxylic acid, **x**, cannot be determined via direct experiment. Using relevant data from Table 6.3 and your answer to **(g)(ii)**, draw an energy cycle to determine a value for **x**. Show your working clearly.

If you were unable to calculate a value for the standard enthalpy change of combustion of carbon in **(g)(ii)**, you should use -450 kJ mol^{-1}. This is **not** the correct answer.

[2]

(h) **(i)** Define the term *standard enthalpy change of neutralisation*.

....

....

....[1]

24

The molarity of a buffer is defined as the *total* number of moles of buffering solutes in 1 dm^3 of solution. For example, a 1 dm^3 buffer solution containing 0.3 mol of CH_3COOH and 0.2 mol of CH_3COO^- will have a molarity of 0.5 mol dm^{-3}.

Potassium hydrogen phthalate is a salt that contains the monoanion of benzene-1,2-dicarboxylic acid, HA^-.

(ii)   250 cm^3 of buffer solution at pH 5.0 is prepared by adding 0.1 mol dm^{-3} NaOH(aq) to solid potassium hydrogen phthalate and the resulting solution is made up to 250 cm^3. The molarity of this buffer is 0.1 mol dm^{-3}.

Given that the pK_a of the monoanion of benzene-1,2-dicarboxylic acid, HA^-, is 5.40, calculate the volume of NaOH(aq) required.

[2]

[Total: 21]

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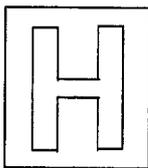
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CANDIDATE NAME

CENTRE NUMBER **S**

INDEX NUMBER

Chemistry

9729/03

Paper 3 Free Response Questions

15 September 2025

2 hours

Candidates answer on the Question Paper.

Additional Materials: Data Booklet

READ THESE INSTRUCTIONS FIRST

Write your name, civics class, centre number and index number 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. If additional space is required, you should use the pages at the end of this booklet. The question number must be clearly shown.

Section A
Answer **all** questions.

Section B
Answer **one** question.

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

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		
Paper 3	**Q1**	
	Q2	
	Q3	
	Q4	
	Q5	
	Total	**/80**

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

[Turn over

Section A

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

1 Schweizer's reagent is used in purifying cellulose. This dark blue compound has the formula, $[Cu(NH_3)_4(H_2O)_2](OH)_2$ and contains the tetraamminediaquacopper(II) cation, $[Cu(NH_3)_4(H_2O)_2]^{2+}$.

(a) Explain the origin of the dark blue colour of the tetraamminediaquacopper(II) cation. [3]

(b) When a solution of $[Cu(NH_3)_4(H_2O)_2]^{2+}$ was gently heated, NH_3 gas was released. A precipitate of $Cu(OH)_2$ and NH_4^+ ions were also obtained as products.

The $Cu(OH)_2$ formed was purified and separated into two samples. One of the samples was added to concentrated hydrochloric acid, forming complex ion **X**.

The other sample of $Cu(OH)_2$ was added to dilute sulfuric acid, forming blue complex ion **Y**.

$[Cu(NH_3)_4(H_2O)_2]^{2+}$, **X** and **Y** are of different colours.

When $[Cu(NH_3)_4(H_2O)_2]^{2+}$ was strongly heated, a black solid **Z** is formed.

(i) Write an equation for the reaction when a solution of $[Cu(NH_3)_4(H_2O)_2]^{2+}$ was gently heated. [1]

(ii) Write an equation for the reaction of $Cu(OH)_2$ with concentrated hydrochloric acid, forming **X**. [1]

(iii) Suggest the identities of **Y** and **Z**. [2]

(iv) Explain why $[Cu(NH_3)_4(H_2O)_2]^{2+}$ and **X** are of different colours. [1]

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(c) Tetraamminediaquacopper(II) cation, $[Cu(NH_3)_4(H_2O)_2]^{2+}$, has two possible stereoisomers. Draw the two stereoisomers. [2]

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(d) Copper based nanopesticides like $Cu(OH)_2$ and CuO, have been used to protect crops from bacteria induced diseases.

The minimum effective concentration for Cu^{2+} ion as a pesticide is 6.35×10^{-5} g dm^{-3}.

(i) Write the expression for the solubility product of $Cu(OH)_2$, giving its units. [1]

(ii) A sample of solid $Cu(OH)_2$ is added to water. Given that the value of the solubility product of $Cu(OH)_2$ is 2.20×10^{-20}, calculate the solubility of $Cu(OH)_2$ in mol dm^{-3}. [1]

(iii) Hence, deduce if the sample in part **(d)(ii)** is suitable for use as a pesticide. [2]

(e) Gilman reagent is an organometallic reagent containing two R groups (alkyl or aryl), copper, and lithium. The general formula of Gilman reagents can be expressed as R_2CuLi.

The Gilman reagent, lithium dimethylcopper, can react with an acyl chloride via nucleophilic reaction to form a ketone. The steps of the reaction are shown in Fig. 1.1.
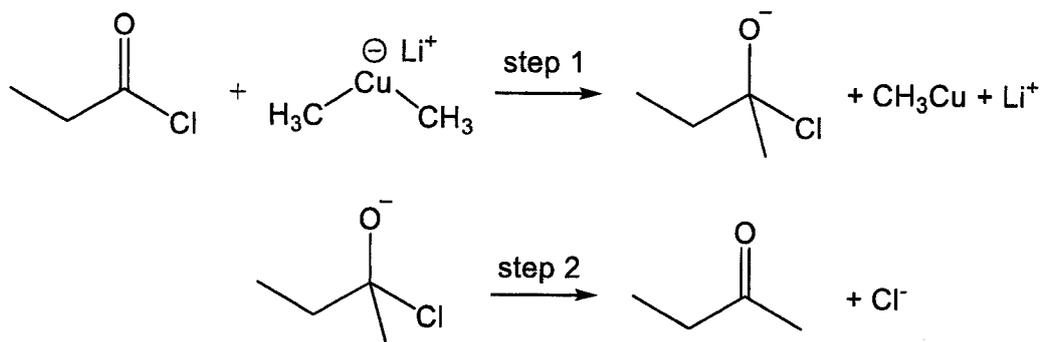
Fig. 1.1

(i) Draw four curly arrows on Fig. 1.1 to complete the mechanism. Include relevant lone pairs and partial charges. [2]

(ii) Lithium dimethylcopper can also react with alkyl halides. A product of this reaction is shown.
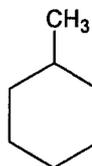
Suggest the structure of the alkyl halide that reacted with lithium dimethylcopper to give the product above. [1]

(f) Transition elements like copper and iron are commonly used as catalysts.

The reaction between $S_2O_8^{2-}$ ions and I^- ions is very slow. If a small amount of aqueous iron(II) ions is added to the mixture, the rate of reaction increases.

Write two equations to illustrate the catalytic role of Fe^{2+} in the $S_2O_8^{2-}/I^-$ reaction. [2]

[Total: 19]

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2 Chlorine-containing organic compounds are widely used in both industrial and laboratory settings due to their diverse chemical properties and applications.

One such compound is 1-chloro-1-phenylethane, an aromatic halogenoalkane, which exhibits reactivity typical of benzylic halides. A typical reaction is the reaction between 1-chloro-1-phenylethane and hydroxide ions to produce 1-phenylethanol.

$$C_6H_5CHClCH_3 + OH^- \rightarrow C_6H_5CH(OH)CH_3 + Cl^-$$

The rate of this reaction can be studied by measuring the amount of hydroxide ions that remained in the solution at a given time. The reaction can effectively be stopped if the solution is diluted with an ice-cold solvent.

(a) Briefly describe a suitable method for studying the rate of this reaction at a temperature of 40 °C.

[3]

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[Turn over

(b) The reaction was studied by carrying out four experiments at different initial concentrations of the two reagents. Table 2.1 shows the results obtained.

Table 2.1

experiment	$[C_6H_5CHClCH_3]$ / mol dm^{-3}	$[OH^-]$ / mol dm^{-3}	relative rate
1	0.05	0.10	0.5
2	0.10	0.20	1.0
3	0.15	0.10	1.5
4	x	0.15	2.0

(i) Show that the overall order of the reaction is 1. Explain your reasoning. [2]

(ii) Write the rate equation for this reaction. [1]

(iii) Deduce the value of x in Table 2.1. [1]

(iv) Using your answer to **(b)(i)**, name and draw the mechanism for the reaction of 1-chloro-1-phenylethane with hydroxide ions. Include all relevant lone pairs, dipoles and curly arrows to show the movement of electron pairs. [3]

(v) With reference to the structure of relevant species in the mechanism, explain why the reaction would proceed via such a mechanism. [1]

(vi) This reaction was carried out using a single enantiomer of 1-chloro-1-phenylethane. Use your mechanism in **(b)(iv)** to predict whether the product will be optically active. Explain your answer. [2]

(vii) The reaction was contaminated with a small amount of benzene to give a side product, $C_{14}H_{14}$. Suggest the structure of the side product. [1]

(c) Chlorofluorocarbons, CFCs, such as $CFCl_3$, are extremely stable. This extreme stability allows CFCs to slowly make their way into the stratosphere. However, when the CFCs come into contact with ultraviolet light, they can cause extensive damage to the ozone layer. One such process of ozone destruction is believed to be the reaction shown below.

step 1

step 2 $Cl\bullet$ + $\overset{-}{O}-\overset{+}{O}=O$ ⟶ $ClO\bullet$ + O_2

step 3 $ClO\bullet$ + $O\bullet$ ⟶ $Cl\bullet$ + O_2

step 4 O_3 + $O\bullet$ ⟶ $2O_2$

(i) State the role of $Cl\bullet$. Explain your answer.   [1]

To address the problem of ozone destruction, material chemists have developed new hydrofluorocarbons (HFCs) such as CF_3CH_2F. The HFCs contain carbon–hydrogen bonds which are susceptible to homolytic cleavage caused by small amounts of hydroxyl radicals present in the lower atmosphere. This degradation occurs before the HFCs molecules have a chance to drift higher up to the stratosphere and damage the ozone layer. The organic degradation products are unstable and can easily degrade to harmless by-products.

(ii) Write an equation for the reaction of CF_3CH_2F with hydroxyl radical. Draw three curly arrows to illustrate the mechanism for the reaction.   [2]

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[Total: 17]

BP-655

3 **(a)** Aqueous halogens react with methanoic acid to form hydrogen halides and an acidic gas.

    (i) Suggest the chemical equation for the reaction between bromine and methanoic acid. [1]

    (ii) With the use of relevant data from the *Data Booklet*, describe and explain the trend in the thermal stability of the hydrogen halides, HC*l*, HBr and HI. [2]

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(b) When iron is heated separately with chlorine and iodine, the respective iron halide is formed but each containing iron of a different oxidation state.

Using $E^⦵$ values from the *Data Booklet*, suggest the formula of the final iron halide formed for each reaction. [3]

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(c)   Halogenated esters are used as intermediates in pharmaceutical drugs.

The reaction scheme below shows how a chlorinated ester, **S**, can be made from ethanoic acid.
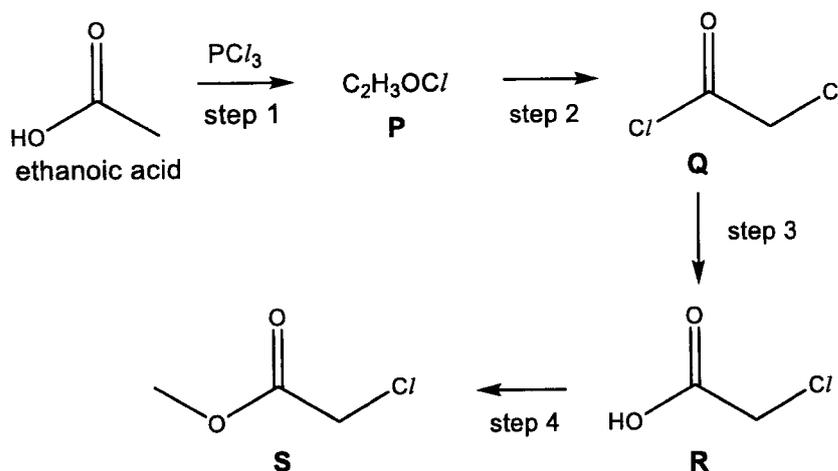
(i)   Suggest the structure of intermediate **P** formed in step 1.   [1]

(ii)   State the reagents and conditions for step 4.   [1]

(iii) Compare and explain the relative acidity of aqueous solutions of ethanoic acid, **Q** and **R**.   [3]

(iv)   Steps 1 and 2 need to be carried out carefully to prevent the formation of compound **T**.
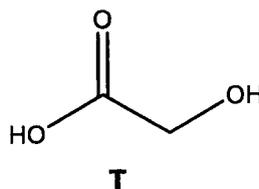
If **T** is present in the reaction mixture of step 3, a different compound **U** will also be formed in the final reaction mixture. Compound **U** has two identical functional groups.

The infrared spectrum of **U** shows strong absorptions at these wavenumbers, 1100 cm^{-1} and 1745 cm^{-1}, but no absorption due to O–H bonds.

Use the *Data Booklet* to identify the chemical bonds responsible for the absorption at these wavenumbers and deduce the functional group present in **U**. Hence, state the type of reaction that has taken place to form **U**.   [2]

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(d) Some further reactions of compound **T** are shown below.

(i) Draw the structure of compound **V**. [1]

(ii) Explain why $NaBH_4$ cannot be used in place of $LiAlH_4$ to form **W** from **T**. [1]

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(e) Compound **K**, C_4H_9ClO, is optically active. Upon heating with excess sodium metal, **K** produces effervescence and compound **L**, C_4H_8O. Compound **L** is optically inactive and does not decolourise bromine water and does not produce an orange precipitate with 2,4-DNPH.

K gives a yellow precipitate with hot alkaline aqueous iodine and organic compound **M**, which produces $C_2H_2O_4$ after acidifying the mixture.

Deduce the structures of **K** to **M**, explaining clearly the reactions involved. [9]

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[Total: 24]

Section B

Answer **one** question from this section.

4   The Gibbs free energy change, ΔG, is related to temperature, T, by the equation:

$$\Delta G = \Delta H - T\Delta S$$

Fig. 4.1 shows the Ellingham diagram which is a plot of ΔG against T and is used to evaluate the ease of reduction of oxides. The diagram shows how ΔG changes with T from 300 K to 2000 K for the following reactions.

reaction (1): $C(s) + O_2(g) \rightleftharpoons CO_2(g)$

reaction (2): $2C(s) + O_2(g) \rightleftharpoons 2CO(g)$

reaction (3): $Ti(s) + O_2(g) \rightleftharpoons TiO_2(s)$

Fig. 4.1

Use Fig. 4.1 to answer parts **(a)** and **(b)**.

(a)   **(i)**   With reference to the ΔG equation, explain why the ΔG for reaction (1) is almost independent of temperature.   [1]

   (ii)   Calculate the entropy change for reaction (3), in J mol^{-1} K^{-1}.   [1]

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(b) Titanium can be obtained by the reduction of TiO_2 with carbon, via the reaction below.

reaction (4): $TiO_2(s) + 2C(s) \rightleftharpoons Ti(s) + 2CO(g)$

(i) Similar to enthalpy change of reaction, the Gibbs free energy change of a reaction can be calculated using an energy cycle.

Using ΔG values at 2000 K from Fig. 4.1 and with the aid of a suitable energy cycle, calculate ΔG for reaction (4) at 2000 K. [2]

(ii) State the temperature range for reaction (4) to be spontaneous. Explain your answer. [2]

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(c) **(i)** State two main assumptions of the kinetic theory as applied to an ideal gas. [2]

(ii) The Gibbs free energy change of any reversible reaction can be expressed as a function of K_p given by:

$$\Delta G = - RT \ln K_p$$

where K_p is the equilibrium constant expressed in terms of partial pressures of gases in bar. [1 bar = 10^5 Pa]

Using your answer to **(b)(i)**, determine the value of K_p for reaction (4) at 2000 K. [1]

If you were unable to calculate a value for the ΔG in **(b)(i)**, you should use -15 kJ mol^{-1}. This is **not** the correct answer for **(b)(i)**.

(iii) Write an expression for the equilibrium constant, K_p, for reaction (4). [1]

A typical reaction vessel for the reduction of TiO_2 with carbon has a volume of 100 dm^3.

(iv) Determine the equilibrium partial pressure of CO at 2000 K, in Pa. [1]

You may assume that carbon monoxide behaves as an ideal gas under such conditions.

(v) Hence, calculate the equilibrium mass of titanium produced at 2000 K. [2]

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(d) The chemistry of carboxylic acids involves a range of reactions from their formation via oxidation to their conversion into other useful derivatives.

Two electrode reactions are shown in Table 4.1.

Table 4.1

electrode reaction	$E^\ominus$ / V
$Cr_2O_7^{2-} + 14H^+ + 6e^- \rightleftharpoons 2Cr^{3+} + 7H_2O$	+1.33
$CH_3COOH + 2H^+ + 2e^- \rightleftharpoons CH_3CHO + H_2O$	U

(i) Draw a fully labelled diagram of the experimental set-up used to measure the standard electrode potential, $E^\ominus$, of the $Cr_2O_7^{2-}$(aq) / Cr^{3+}(aq) electrode. Include all necessary chemicals and show the direction of electron flow in the circuit. [3]

(ii) Construct the ionic equation for the reaction between ethanal and acidified potassium dichromate. [1]

(iii) The $E^\ominus_{cell}$ of an electrochemical cell consisting of a standard CH_3COOH / CH_3CHO electrode and a standard $Cr_2O_7^{2-}$(aq) / Cr^{3+}(aq) electrode is +2.27 V.

Calculate the value of the standard electrode potential, **U**, in Table 4.1. [1]

(iv) Explain how the voltage of this cell would change when aqueous sodium hydroxide is added to the CH_3COOH / CH_3CHO half-cell. [2]

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[Total: 20]

5   Amino acids play central roles both as building blocks of proteins and as intermediates in metabolism.

Some amino acids found in proteins are shown in Table 5.1.

Table 5.1

amino acid	abbreviation	formula of side chain
aspartic acid	asp	$-CH_2CO_2H$
glutamine	gln	$-CH_2CH_2CONH_2$
phenylalanine	phe	$-CH_2-$

(a)   Blood plasma contains 90 % water. Suggest and explain which amino acids in Table 5.1 are likely to be found on the outer surface of proteins molecules in blood plasma at pH 7.4.

[2]

(b) **(i)**

The structure of another amino acid, proline (pro), is

Draw the structural formula of the tripeptide, asp–pro–phe. [1]

(ii) The enzyme, chymotrypsin, selectively hydrolyses at the carboxyl end of phenylalanine (phe) and tyrosine (tyr) residues.

The enzyme, trypsin, selectively hydrolyses at the carboxyl end of arginine (arg) residues.

An octapeptide **J** was analysed and the results were as follows.

- **J** contains the partial sequence tyr–ala–pro.

- Complete hydroylsis of **J** gave the following eight amino acids:

  ala, arg, asp, gln, pro, tyr, 2 × phe

- On reaction with chymotrypsin, **J** gave tyr, gln and two different tripeptides.

- On reaction with trypsin, **J** gave arg and a heptapeptide only.

Determine the amino acid sequence of **J**. [2]

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[Turn over

(c) Electrophoresis is a technique used to separate mixtures of amino acids based on the mobility of ions in an electric field.

A mixture of arginine, aspartic acid and phenylalanine was placed at the center of the electrophoresis plate in a buffer solution of pH 6.0. A potential difference was then applied across the plate.

The pK_a values of the acidic groups of each amino acid are shown in Table 5.2.

Table 5.2

amino acid	formula of side chain	pK_a of α–carboxyl group	pK_a of α–amino group	pK_a of side chain
arginine	$(CH_2)_3$ NH HN=⟍NH_2	2.03	9.00	12.10
aspartic acid	$-CH_2CO_2H$	1.95	9.66	3.71
phenylalanine	$-CH_2-$⟨◯⟩	2.18	9.09	–
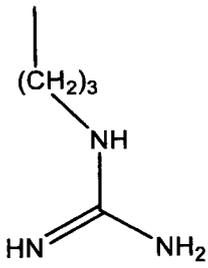
(i) Draw the structure of the major species in a phenylalanine solution at pH 6.0. [1]

(ii) On Fig. 5.1, use a 'x' to indicate the relative positions of each of the amino acid after the electrophoresis at pH 6.0. Label the amino acids clearly. [2]

sample loaded here

positive
electrode

negative
electrode
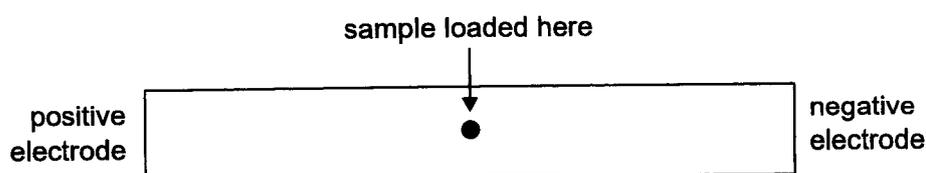
Fig. 5.1

(iii) The side chain of arginine is shown.

$(CH_2)_3$

c NH

HN= NH_2
a   b
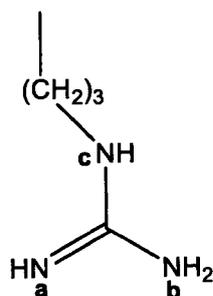
Nitrogen atoms, **a, b** and **c**, are all sp^2 hybridised. Only one of the nitrogen atoms will be protonated in an acidic medium. Identify which nitrogen atom would be protonated. Explain your answer. [1]

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(d) The Strecker method is a series of chemical reactions which synthesises an amino acid from an aldehyde as a starting material.
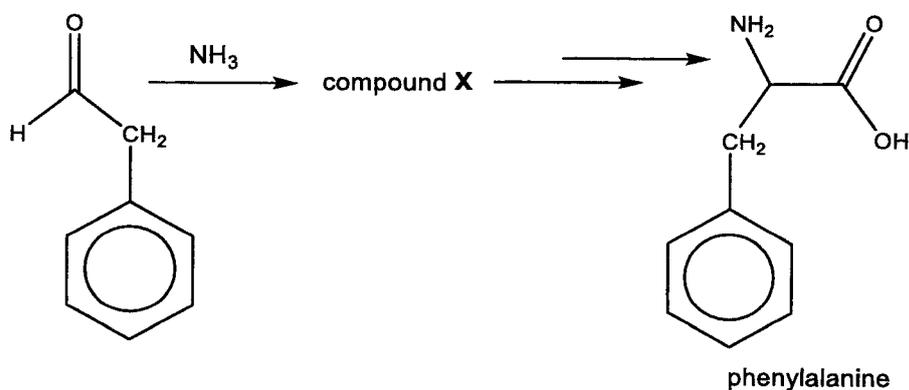
Fig. 5.2

(i) In Fig. 5.2, the first stage involves ammonia acting as a nucleophile, followed by the elimination of a water molecule to form compound **X**. Suggest a structure for **X**.   [1]

(ii) A starting material, compound **Y**, can be used to prepare aspartic acid via the Strecker method.

Suggest the structure of **Y**.   [1]

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(e) Group 2 carbonates decompose when heated.

Describe and explain the trend in the thermal stability of the Group 2 carbonates. [2]

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(f) An impure copper bar containing impurities of cobalt and metal **M** was purified using electrolysis.

battery

impure Cu ——| |—— **pure Cu**

—— **CuSO$_4$(aq)**

A current of 0.850 A was passed through the cell above. After 40.0 minutes, the mass of one electrode increased by 0.680 g and the mass of the other electrode decreased by 0.714 g. The electrolyte was further analysed and it was found that the amount of Cu^{2+} ions decreased by 4.62×10^{-4} mol.

M was found underneath one of the electrodes.

(i) Explain, in terms of electrode reactions, how each of the two impurity metals was removed from copper, using relevant data from the *Data Booklet*.   [3]

(ii) Use the information in part **(f)** to calculate a value for the Faraday's constant obtained from this experiment.   [1]

(iii) Use your answer to **(f)(ii)** and the *Data Booklet* to calculate a value for the Avogadro's constant obtained from this experiment.   [1]

(iv) Calculate the masses of copper, cobalt and **M** removed from the copper bar.   [2]

[Total: 20]

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Additional answer space

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