

RAFFLES INSTITUTION
2025 YEAR 6 PRELIMINARY EXAMINATION

Higher 2



CHEMISTRY

Paper 1 Multiple Choice

9729/01

26 September 2025

1 hour

Additional Materials: Multiple Choice Answer Sheet
 Data Booklet

READ THESE INSTRUCTIONS FIRST

Do not open this question booklet until you are told to do so.

Write in soft pencil.

Do not use staples, paper clips, glue or correction fluid.

Write your name, class and index number in the spaces provided on the Answer Sheet.

There are **thirty** questions in this paper. Answer **all** questions. For each question there are four possible answers **A, B, C** and **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.

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

Any rough working should be done in the question booklet.

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

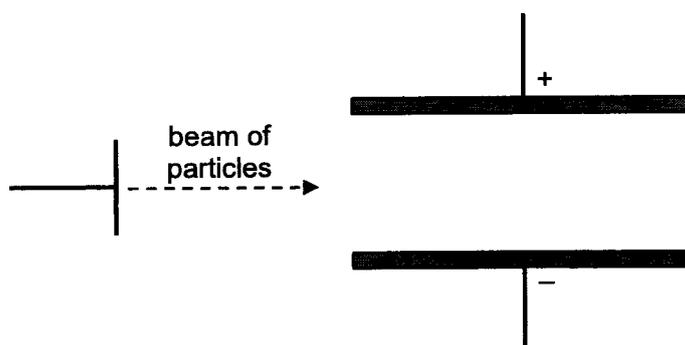
This document consists of **13** printed pages and **1** blank page.

- 1 Use of the Data Booklet is relevant to this question.

What are the numbers of electrons and neutrons in the $^{37}\text{Cl}^+$ ion?

	electrons	neutrons
A	16	20
B	16	37
C	17	20
D	17	37

- 2 In two separate experiments, a beam of $^{17}\text{O}^+$ ions and a beam of $[^{16}\text{O}^{18}\text{O}]^{2-}$ ions, travelling at the same velocity, pass through an electric field as shown.

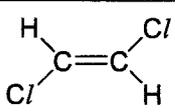
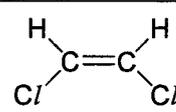


Which statements are correct?

- 1 The $[^{16}\text{O}^{18}\text{O}]^{2-}$ ions are deflected to a larger extent than the $^{17}\text{O}^+$ ions.
- 2 The $[^{16}\text{O}^{18}\text{O}]^{2-}$ ions are deflected in the opposite direction to the $^{17}\text{O}^+$ ions.
- 3 The beam of $^{17}\text{O}^+$ ions travels in a straight path towards the negatively charged plate.

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

- 3 The table shows the structural formulae of three compounds.

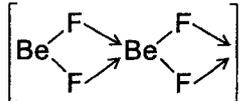
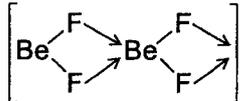
compound	P	Q	R
structural formulae			CH ₃ CH ₂ CH ₂ CH ₃

What is the correct order of **increasing** boiling point of these compounds?

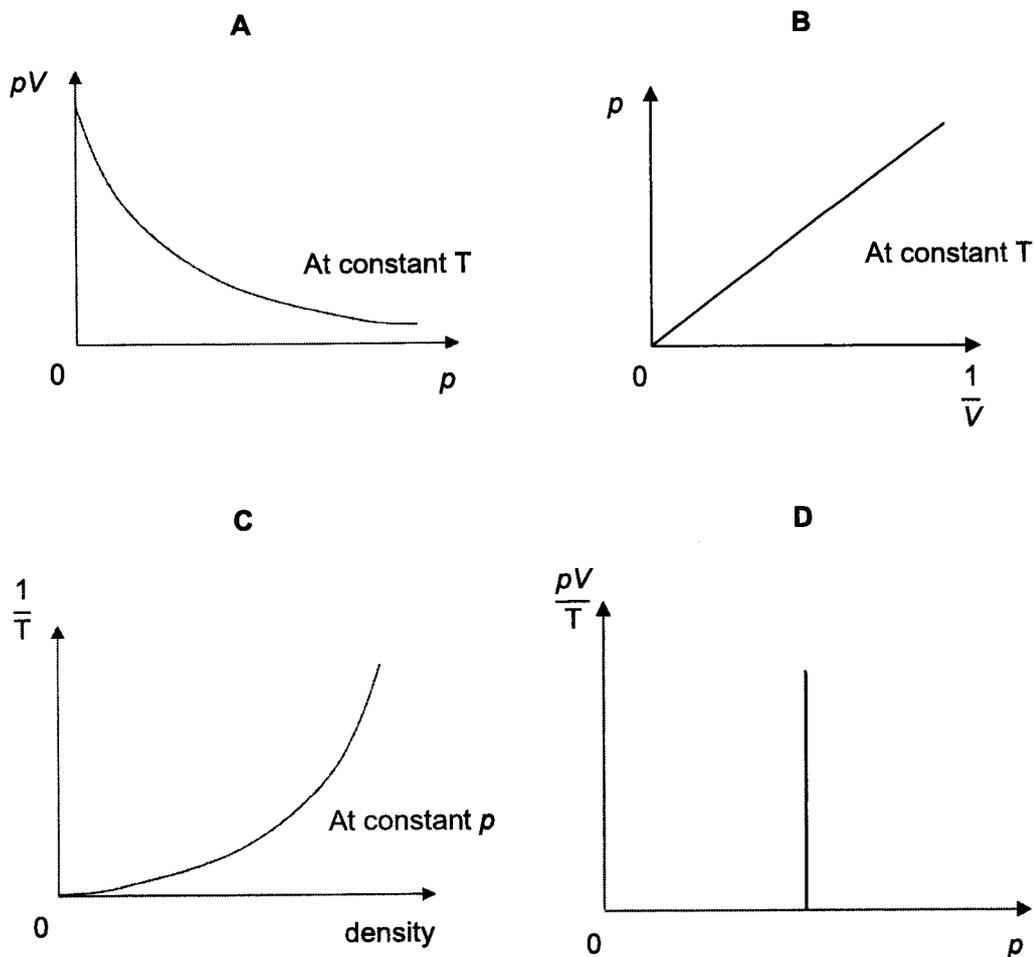
- A P → Q → R
 B P → R → Q
 C R → P → Q
 D R → Q → P
- 4 Beryllium is the first member of Group 2 and forms covalent compounds which are said to be electron deficient. In many ways, beryllium resembles aluminium.

Which statement regarding compounds of beryllium is correct?

- A BeF₂ acts as a Lewis base when it reacts with NH₃ to form the BeF₂•NH₃ adduct.
 B BeF₂•NH₃ is a planar molecule.
 C BeF₄²⁻ contains two co-ordinate bonds.

D  The  polymer cannot form hydrogen bonds with H₂O.

- 5 Which graph correctly describes the behaviour of a fixed mass of an ideal gas?
[T is measured in K.]



- 6 Elements X, Y and Z are in Period 3 of the Periodic Table.

- X has the highest melting point among all the Period 3 elements.
- The chloride of Y has the highest pH among all the Period 3 chlorides when dissolved in water.
- Z has the largest ionic radius among all the Period 3 elements.

Which statement is correct?

- A** Y has a smaller atomic radius than Z.
- B** Y has a lower electrical conductivity than X.
- C** X has a higher first ionisation energy than Z.
- D** X has a higher electronegativity value than Y.

- 7 Which statement about the behaviour of the Group 2 elements from magnesium to barium is correct?
- A The reducing power decreases.
B The reactivity with cold water decreases.
C The thermal stability of the metal carbonate increases.
D The magnitude of the enthalpy of hydration of the metal ion increases.

- 8 0.015 mol of NO_2 reacts completely with H_2O to form 0.010 mol of HNO_3 and a nitrogen-containing compound.

What could be the identity of the nitrogen-containing compound?

- A NH_3 B NO C HNO_2 D N_2O_3
- 9 The relative abundances of the isotopes of chromium are given below.

^{50}Cr	^{52}Cr	^{53}Cr	^{54}Cr
4.3%	83.8%	9.5%	2.4%

What is the relative atomic mass of chromium calculated from these data?

- A 51.9 B 52.1 C 52.2 D 52.4
- 10 Which process is always endothermic?
- 1 the sublimation of a solid
2 the combustion of a fuel
3 the hydration of a gaseous ion
- A 1 only B 1 and 2 only C 2 and 3 only D 1, 2 and 3

- 11 The following table shows the lattice energies for two silver halides.

compound	theoretical lattice energy / kJ mol ⁻¹	experimental lattice energy / kJ mol ⁻¹
AgBr	-759	-877
AgI	-736	-867

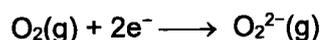
Which statement best explains the difference in the deviation of the experimental lattice energy from the theoretical lattice energy?

- A The difference in electronegativity between Ag and the halogen is greater in AgBr than in AgI.
- B The interionic distance in AgBr is smaller than that in AgI.
- C The relative formula mass of AgBr is smaller than that of AgI.
- D The I⁻ ion is more polarisable than the Br⁻ ion.
- 12 When heated with oxygen, barium forms barium peroxide, BaO₂.

The relevant enthalpy changes are shown in the table.

	enthalpy change / kJ mol ⁻¹
Ba(g) → Ba ²⁺ (g) + 2e ⁻	p
Ba ²⁺ (g) + O ₂ ²⁻ (g) → BaO ₂ (s)	q
Ba(s) → Ba(g)	r
Ba(s) + O ₂ (g) → BaO ₂ (s)	s

What is the enthalpy change of the following reaction?



- A s - q + p - r
- B s - q - p - r
- C r - s + p + q
- D r - s + p - q

- 13 The rates of chemical reactions can often be increased by catalytic action.

Which statement about catalysts is correct?

- A A catalysed reaction has a higher rate constant than the uncatalysed reaction.
 - B In an autocatalytic reaction, the rate of the reaction increases continuously as the reaction progresses.
 - C In a reaction catalysed by a heterogeneous catalyst, the reactant molecules are in the same phase as the catalyst.
 - D In a reaction catalysed by an enzyme, increasing the concentration of the substrate will always result in an increase in the rate of the reaction.
- 14 The decomposition of a gas, A, undergoes a 3-step mechanism. The rate constants of the three steps are given by k_1 , k_2 , and k_3 respectively.

The overall rate equation for the reaction is given by

$$\text{rate} = \frac{k_1 k_3 [A]^2}{k_3 + k_2 [A]}$$

Consider the two statements about the order of reaction for the decomposition of A at constant temperature.

- 1 At very low pressures of A, the reaction is second order with respect to A.
- 2 At very high pressures of A, the reaction is first order with respect to A.

Which statements are correct?

- A Both statements are correct.
- B Neither statement is correct.
- C Statement 1 only is correct.
- D Statement 2 only is correct.

- 15 In a titration experiment, 25.0 cm^3 of a solution of a weak acid, HA, required $V \text{ cm}^3$ of NaOH solution to neutralise completely.

In a separate titration, $\frac{1}{2}V \text{ cm}^3$ of the same NaOH solution was added to 25.0 cm^3 of the same solution of HA. The pH was measured at this point.

How are the value of V and the pH at $\frac{1}{2}V$ affected when the experiment was repeated at a higher temperature?

	value of V	pH at $\frac{1}{2}V$
A	decreases	decreases
B	decreases	remains the same
C	remains the same	decreases
D	remains the same	remains the same

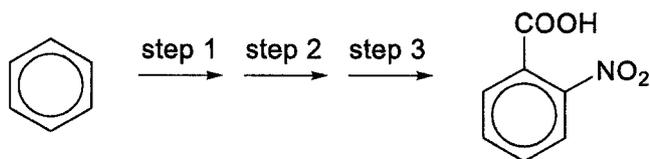
- 16 A small amount of solid CuSO_4 was added to a saturated solution of PbSO_4 .

Which observation is correct?

The K_{sp} of $\text{PbSO}_4 = 1.8 \times 10^{-8} \text{ mol}^2 \text{ dm}^{-6}$.

- A** No precipitate will form.
- B** A blue precipitate of CuSO_4 will form.
- C** A white precipitate of PbSO_4 will form.
- D** Both CuSO_4 and PbSO_4 will precipitate.

- 17 Which set of reagents and conditions gives the highest yield of the product?



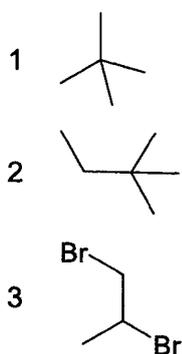
	step 1	step 2	step 3
A	CH ₃ Cl, AlCl ₃ catalyst	hot acidified KMnO ₄	conc. H ₂ SO ₄ , conc. HNO ₃ , heat
B	CH ₃ Cl, AlCl ₃ catalyst	conc. H ₂ SO ₄ , conc. HNO ₃ , heat	hot acidified KMnO ₄
C	conc. H ₂ SO ₄ , conc. HNO ₃ , heat	CH ₃ Cl, AlCl ₃ catalyst	hot acidified KMnO ₄
D	conc. H ₂ SO ₄ , conc. HNO ₃ , heat	hot acidified KMnO ₄	CH ₃ Cl, AlCl ₃ catalyst

- 18 How many isomers, including stereoisomers, are there with the formula C₄H₈?

A 4 **B** 5 **C** 6 **D** 7

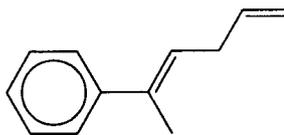
- 19 Propane undergoes free-radical substitution when mixed with bromine and exposed to ultra-violet light.

Which compounds are possible products from this reaction?

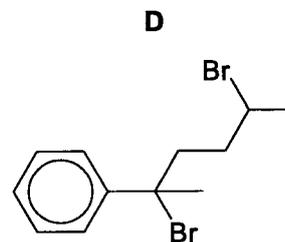
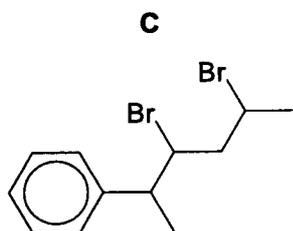
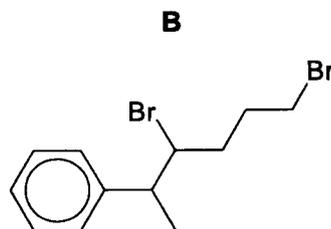
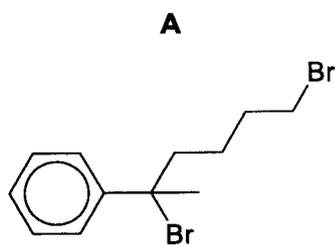


A 1 only **B** 3 only **C** 1 and 2 **D** 2 and 3

- 20 The following alkene reacts with two moles of HBr to give J as the major product.



What is the structure of J?

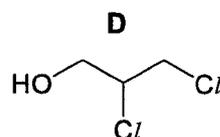
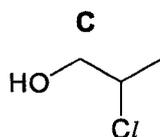
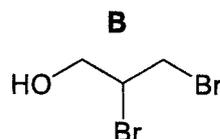
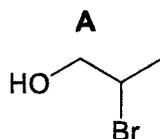


- 21 Consider the two statements.

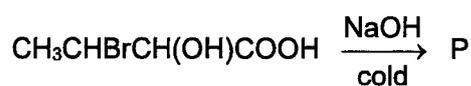
- 1 An optically active sample rotates plane-polarised light and contains chiral molecules.
- 2 A racemic mixture contains chiral molecules.

- A** Neither statement is correct.
B Both statements are correct.
C Statement 1 only is correct.
D Statement 2 only is correct.

22 Which alcohol is the most acidic?

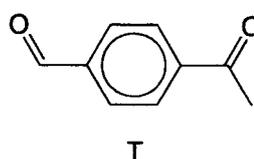
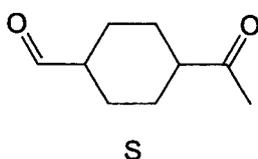


23 3-Bromo-2-hydroxybutanoic acid is reacted with an excess of cold aqueous NaOH to give compound P.



What could P be?

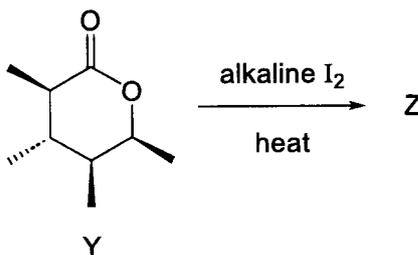
- A $\text{CH}_3\text{CH}(\text{OH})\text{CH}(\text{OH})\text{COOH}$
 - B $\text{CH}_3\text{CHBrCH}(\text{OH})\text{COO}^-\text{Na}^+$
 - C $\text{CH}_3\text{CHBrCH}(\text{O}^-\text{Na}^+)\text{COO}^-\text{Na}^+$
 - D $\text{CH}_3\text{CH}(\text{O}^-\text{Na}^+)\text{CH}(\text{O}^-\text{Na}^+)\text{COO}^-\text{Na}^+$
- 24 The structures of compounds S and T are shown.



Which reagents and conditions can be used to distinguish between S and T?

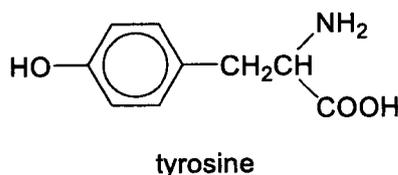
- A $\text{K}_2\text{Cr}_2\text{O}_7(\text{aq}), \text{H}_2\text{SO}_4(\text{aq}), \text{heat}$
- B 2,4-dinitrophenylhydrazine
- C Fehling's solution, heat
- D Tollens' reagent, heat

- 25 A sample that contains one enantiomer of compound Y reacts completely with warm alkaline aqueous iodine to give Z, which contains more than one carbon atom.



Which statement about Z is correct?

- A Z is a meso compound.
 B Z contains three oxygen atoms.
 C Effervescence is observed when sodium metal is added to Z.
 D Z can form hydrogen bonds with another particle of Z.
- 26 Tyrosine is dissolved in heavy water, D_2O . It contains a number of hydrogen atoms which can be replaced by deuterium, D.
 [D = 2_1H]



What is the maximum number of hydrogen atoms which could be replaced by deuterium atoms in each molecule of tyrosine?

- A 2 B 3 C 4 D 7
- 27 Which statement is correct about the standard hydrogen electrode?
- A The standard hydrogen electrode contains 1 atm of H_2 gas.
 B The standard hydrogen electrode contains 1 mol dm^{-3} of $H_2SO_4(aq)$.
 C The standard hydrogen electrode is measured at s.t.p.
 D The standard hydrogen electrode is measured at 298 K.

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

An electrolysis cell was set up to purify copper and it consists of an impure copper electrode, a pure copper electrode and copper(II) sulfate solution as the electrolyte. The impure copper electrode has silver and nickel as minor impurities.

Which statement is correct?

- A The concentration of Cu^{2+} in the electrolyte decreases during the purification process.
- B Both silver and nickel are oxidised during the purification process.
- C The same number of moles of copper was oxidised and reduced.
- D The impure copper is the cathode while the pure copper is at the anode.

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

Titanium is a transition metal.

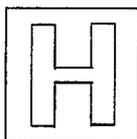
Which titanium compound is **unlikely** to exist?

- A TiO B TiCl_3 C K_3TiF_6 D K_2TiO_4

30 Which statement best explains the difference in physical properties between magnesium and iron?

- A Iron has a higher melting point than magnesium because it forms stronger metallic bonds.
- B Magnesium is denser than iron because it has a smaller atomic radius and a larger atomic mass.
- C Iron has a higher first ionisation energy than magnesium because the increase in shielding effect outweighs the increase in nuclear charge.
- D Magnesium conducts electricity better than iron because it loses electrons more easily.

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RAFFLES INSTITUTION
2025 YEAR 6 PRELIMINARY EXAMINATION

Higher 2



CANDIDATE
NAME

CLASS

INDEX NUMBER

CHEMISTRY

9729/02

Paper 2 Structured Questions

16 September 2025

2 hours

Candidates answer on the Question Paper.

Additional Materials: Data Booklet

READ THESE INSTRUCTIONS FIRST

Do not open this question booklet until you are told to do so.

Write your name, class and index number in the spaces 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.

A Data Booklet is provided. Do not write anything in it.

You are reminded of the need for good English and clear presentation in your answers.

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	
1	/ 13
2	/ 15
3	/ 15
4	/ 16
5	/ 16
Total	/ 75

This document consists of **24** printed pages.

Answer all questions in the space provided.

- 1 Table 1.1 lists the 7th, 8th, 9th and 10th ionisation energies, in kJ mol^{-1} , of four consecutive elements **A**, **B**, **C** and **D** in the Periodic Table. These elements have an atomic number of less than 20.

Table 1.1

element	7th ionisation energy	8th ionisation energy	9th ionisation energy	10th ionisation energy
A	27 110	31 720	36 620	43 180
B	11 020	33 600	38 600	43 960
C	12 000	13 840	40 760	46 190
D	11 340	14 940	16 960	48 610

- (a) Give the equation, with state symbols, for the 7th ionisation energy of **B**.

..... [1]

- (b) Deduce which element is a noble gas.

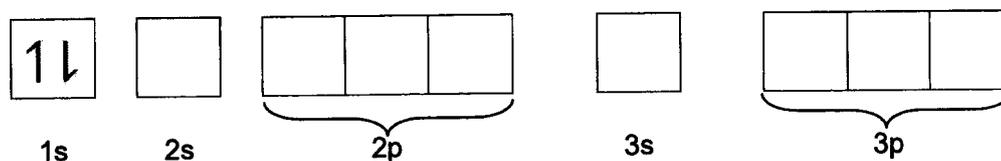
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 [2]

- (c) (i) State the identity of **A**.

..... [1]

- (ii) Complete the diagram to show the arrangement of electrons in the orbitals of an atom of **A**.



[1]

- (d) State and explain how the 2nd ionisation energy of D compares to the 1st ionisation energy of C.

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..... [2]

Table 1.2 shows the electronegativity values of some elements.

Table 1.2

element	electronegativity / Pauling units
phosphorus	2.2
chlorine	3.0
fluorine	4.0

- (e) (i) Explain what is meant by the term *electronegativity*.

.....

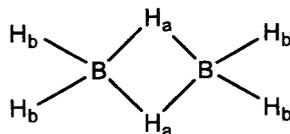
..... [1]

- (ii) Suggest a value for the electronegativity of sulfur.

..... [1]

A bridging hydrogen refers to a hydrogen atom which is simultaneously bonded to two other atoms in a chemical structure.

In diborane, the two boron atoms form a three-centre two-electron bond with a bridging hydrogen, where two electrons are shared between three atoms.



diborane

- The two bridging hydrogens present in diborane are labelled as H_a .
- The four other hydrogen atoms, labelled as H_b , lie on the same plane as the two boron atoms.
- One of the bridging hydrogens lies above this plane while the other lies below this plane.

(f) (i) State and explain how the $B-H_a$ bond length compares to that of $B-H_b$.

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..... [2]

(ii) Suggest, with reasoning, a value for the H_b-B-H_b bond angle, given that experiments have confirmed that it is **not** 109.5° .

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..... [2]

[Total: 13]

2 (a) Graphene comprises a single layer of carbon atoms arranged in interconnecting hexagonal planar rings while graphite is composed of multiple layers of graphene stacked on top of one another.

(i) Draw a diagram to represent part of a graphene layer which contains at least 12 carbon atoms and two complete carbon rings.

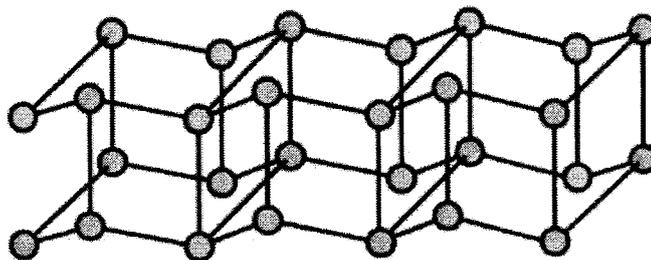
[1]

(ii) With reference to orbital overlap and apart from the σ bonds present, explain why all carbon-carbon bonds in a graphene layer are of equal length.

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.....
..... [2]

Under certain conditions, graphene can be converted into two other forms, or allotropes, of carbon. These allotropes have giant molecular structure.

Fig. 2.1 shows part of the structure present in one such allotrope.



allotrope F

Fig. 2.1

(iii) Deduce the hybridisation of carbon in allotrope F.

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..... [2]

(iv) State and explain the difference in electrical conductivity of allotrope F and graphite.

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..... [2]

A representation of part of the structure of a carbon allotrope is given in Fig. 2.2.

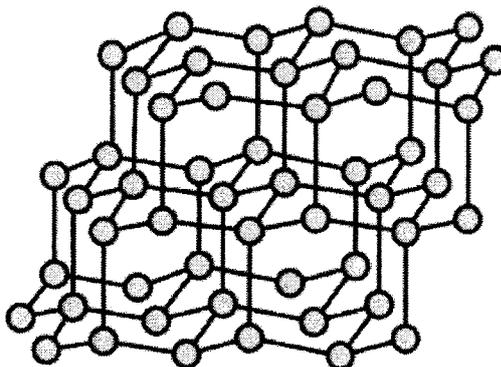


Fig. 2.2

- (v) A researcher has concluded that the two structures given in Fig. 2.1 and Fig. 2.2 show the same allotrope.

Explain if the researcher's conclusion is correct.

You may annotate on the given diagrams in your answer, or include any drawings, where relevant.

.....
 [1]

- (b) One method of converting graphene to the two allotropes uses xenon difluoride.

Xenon difluoride reacts with nitrogen monoxide to form nitrosyl fluoride, NOF.



- (i) Draw a dot-and-cross diagram to show the bonding present within NOF, where nitrogen is the central atom.

[1]

Compound **H** decomposes to form xenon difluoride at room temperature.

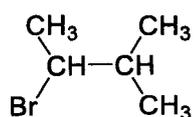
In a molecule of **H**

- there are only three elements: Xe, F and O
- the ratio of F:O is 1:1
- Xe has an oxidation state of +6.

(ii) By considering the Valence Shell Electron Pair Repulsion theory, suggest the shape of the molecule.

..... [1]

(c) Bromoalkane **J** reacts with sodium hydroxide, under different conditions, to form three different organic products **K**, **L** and **M**.



bromoalkane **J**

K is the product formed when **J** is warmed with aqueous sodium hydroxide. Compounds **L** and **M** are hydrocarbons.

(i) Describe the reagents and conditions needed to favour the formation of a mixture of products **L** and **M**, rather than product **K**.

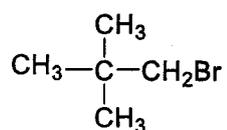
..... [1]

(ii) Draw the **skeletal formulae** of **L** and **M**.

L	M

[2]

Bromoalkane **N** is an isomer of **J**.

bromoalkane **N**

When **N** was heated with aqueous sodium hydroxide over a 24-hour period, no substitution reaction took place.

(iii) Suggest why neither S_N1 nor S_N2 occurred for **N**.

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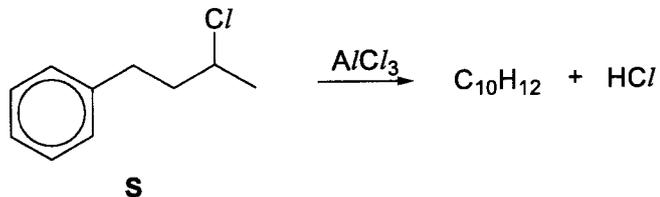
..... [2]

[Total: 15]

10

3 Using the appropriate catalysts and reagents, unsaturated compounds such as alkenes and arenes can undergo various reactions.

(a) Compound **S** undergoes electrophilic substitution reaction, as shown below.



(i) Draw the mechanism of the reaction, showing any intermediates.

[3]

(ii) Explain why benzene undergoes substitution reactions rather than addition reactions.

.....
.....
..... [1]

(iii) State the role of $AlCl_3$ in this reaction.

..... [1]

(iv) A single enantiomer of **S** reacts completely in the presence of $AlCl_3$.

Explain why the product mixture has no effect on the plane of polarised light.

.....
.....
.....
..... [2]

(b) Fig. 3.1 shows the reaction between two alkenes using the Grubbs catalyst.

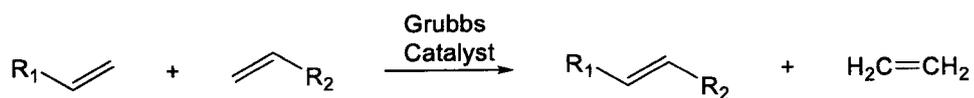


Fig. 3.1

(i) In Fig. 3.2, compound **T** reacts with the Grubbs catalyst to form compound **U**, which contains a total of 9 carbon atoms. Draw the structure of **U**.

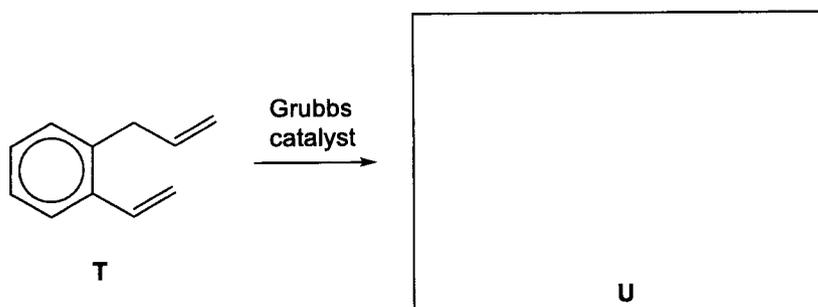


Fig. 3.2

[1]

(ii) Fig. 3.3 shows a reaction scheme involving Grubbs catalyst.

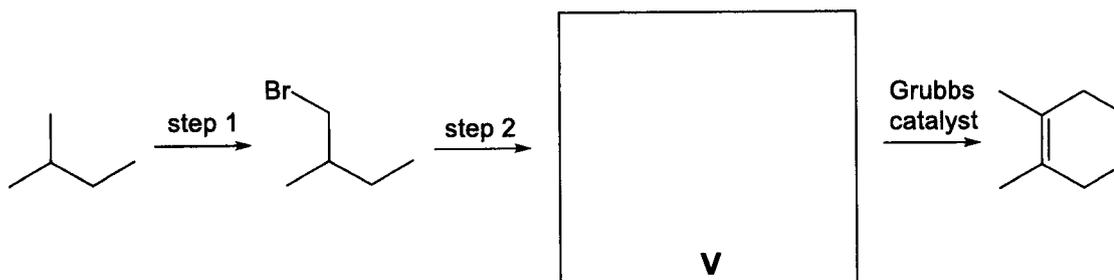


Fig. 3.3

Suggest the structure of compound **V** in Fig. 3.3.

[1]

(iii) Suggest one disadvantage of using free radical substitution in step 1.

.....
 [1]

- (c) Fig. 3.4 shows part of the mechanism of a reaction involving the Grubbs catalyst. Compound **W** is the intermediate, where **M** represents the catalyst.

Draw two curly arrows on **W** in Fig. 3.4 to complete the mechanism.

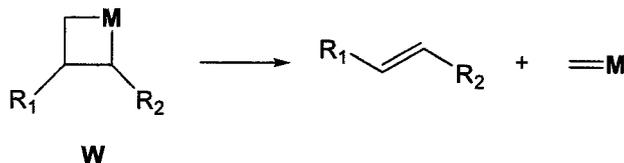
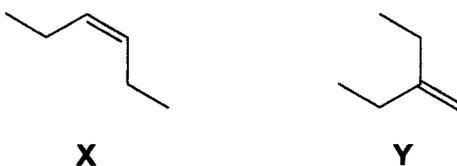


Fig. 3.4

[1]

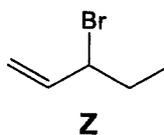
- (d) Describe a simple chemical test that could distinguish between compounds **X** and **Y**.



.....

 [2]

- (e) (i) Suggest the name of compound **Z**.



..... [1]

- (ii) Draw three-dimensional structures for the two stereoisomers of **Z**.

[1]

[Total: 15]

- 4 In Singapore, air quality is assessed using the Pollutant Standards Index (PSI), which is based on measurements of five pollutants: particulate matter (PM10), sulfur dioxide, carbon monoxide, ozone and nitrogen dioxide.

Table 4.1 provides the relevant data for determining the PSI values for ozone, O₃, and nitrogen dioxide, NO₂.

Table 4.1

<i>i</i>	PSI value, P_i	concentration, C_i	
		O ₃ / $\mu\text{g m}^{-3}$	NO ₂ / $\mu\text{g m}^{-3}$
1	50	118	–
2	100	157	–
3	200	235	1130
4	300	785	2260

The PSI value of a pollutant can be calculated using equation 4.1.

equation 4.1 PSI of pollutant = $\left[\left(\frac{P_{i+1} - P_i}{C_{i+1} - C_i} \right) (C_p - C_i) \right] + P_i$
 where C_p is the concentration of pollutant in $\mu\text{g m}^{-3}$,
 and $C_i < C_p < C_{i+1}$.

For example:

If $i = 1$, $P_i = P_1 = 50$; $P_{i+1} = P_2 = 100$

- (a) (i) A collected sample of air contains 2×10^{-5} % by mass of O₃.

Given that the density of air is 1 kg m^{-3} , calculate the concentration of O₃, in $\mu\text{g m}^{-3}$, in the sample collected.

[1 $\mu\text{g} = 10^{-6} \text{ g}$]

[1]

- (ii) Hence calculate the PSI value for O_3 using equation 4.1 and relevant data from Table 4.1.

[1]

- (b) During the Circuit Breaker period in Singapore in 2020, when strict lockdown measures were implemented, people worked from home and had home-based learning. This led to changes in various air quality parameters.

Table 4.2 shows some of these changes.

Table 4.2

	average reading during 2016 – 2019	average reading during Circuit Breaker
$NO_2 / \mu g m^{-3}$	33.1	15.1
$O_3 / \mu g m^{-3}$	21.1	24.9

- (i) Suggest one reason for the change in concentration of NO_2 during the Circuit Breaker.

.....

 [1]

- (ii) O_3 can be destroyed by radicals.

Suggest one reason for the change in concentration of O_3 during the Circuit Breaker.

.....

 [1]

(c) The equation for the formation of NO_2 from NO is shown.



Experiments were carried out to find the initial rate of reaction at different initial concentrations of NO and O_2 . The results of these experiments are shown in Table 4.3.

Table 4.3

experiment	initial $[\text{NO}]$ / mol dm^{-3}	initial $[\text{O}_2]$ / mol dm^{-3}	initial rate of reaction / $\text{mol dm}^{-3} \text{s}^{-1}$
1	0.05	0.005	z
2	0.05	0.015	1.47×10^{-4}
3	0.10	0.005	1.96×10^{-4}

Fig. 4.1 shows the concentration of O_2 recorded against time for experiment 1.

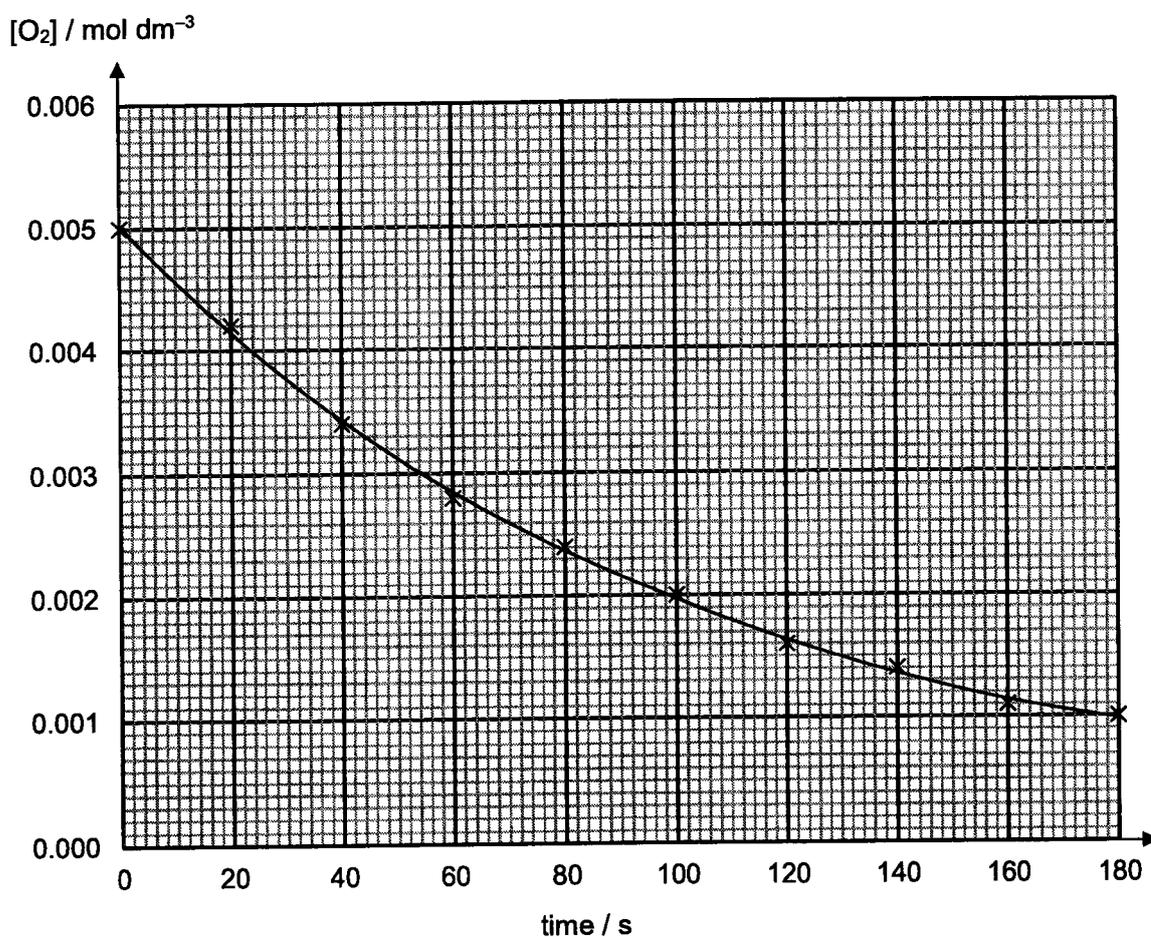


Fig. 4.1

- (i) Using Fig 4.1, determine a value for the initial rate of reaction for experiment 1, z .

[1]

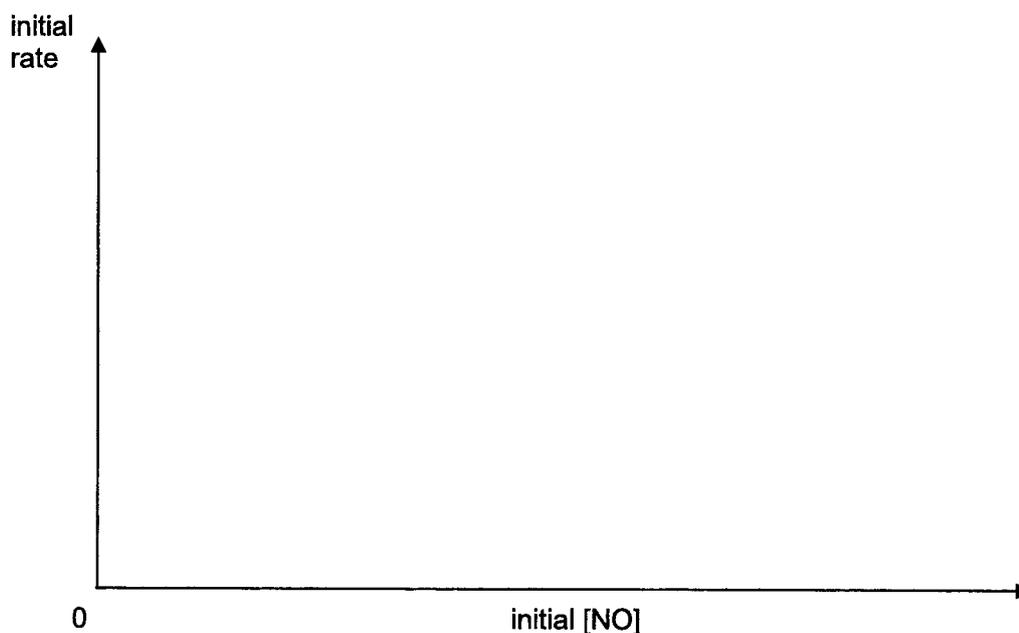
- (ii) Use the value of z to deduce the order of reaction with respect to O_2 .

.....
.....
.....
..... [1]

- (iii) The reaction is second order with respect to NO.

Experiments were carried out to find the initial rate of reaction at different initial concentrations of NO. The initial concentration of O_2 was in large excess and was kept the same across experiments.

Sketch a graph of initial rate against initial [NO].



[1]

(iv) Write the rate equation for this reaction.

..... [1]

(v) Define the term *half-life of reaction*.

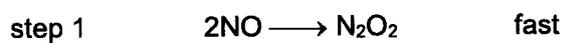
.....
 [1]

(vi) The half-life of O₂ for experiment 1 was found to be 74 s.

Determine the half-life of experiment 3.

[1]

(vii) The first step of the mechanism for the reaction in equation 4.2 is shown below.



The second step is rate-determining and is bimolecular.

Suggest an equation for the second step such that the mechanism is consistent with the rate equation in (c)(iv).

..... [1]

- (d) Atmospheric nitrogen dioxide and sulfur dioxide are major air pollutants.

NO_2 catalyses the oxidation of atmospheric sulfur dioxide.

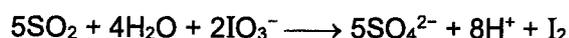
- (i) State the **type** of catalysis occurring.

..... [1]

- (ii) Write equations to illustrate the role of NO_2 in the oxidation reaction.

.....
 [2]

- (e) The amount of sulfur dioxide in a sample of air can be determined by first reacting it with aqueous sodium iodate(V), NaIO_3 .



When a 1 m^3 sample of air was bubbled through a solution of sodium iodate(V), the iodine formed requires 15.60 cm^3 of $4.00 \times 10^{-4} \text{ mol dm}^{-3}$ aqueous sodium thiosulfate solution for complete reaction, as shown.



Calculate the mass concentration of sulfur dioxide, in g m^{-3} , in the sample of air.
 [M_r : SO_2 , 64.1]

[2]

[Total: 16]

- 5 The zinc-air (Zn-air) battery was first developed as a non-rechargeable, single-use battery. However, it was further adapted into a rechargeable battery for sustainable energy applications.

The discharge of the Zn-air battery involves the oxidation of zinc at the anode and the reduction of oxygen at the cathode, which is made of carbon coated with a solid catalyst.

Fig. 5.1 illustrates the electrochemical cell in a Zn-air battery.

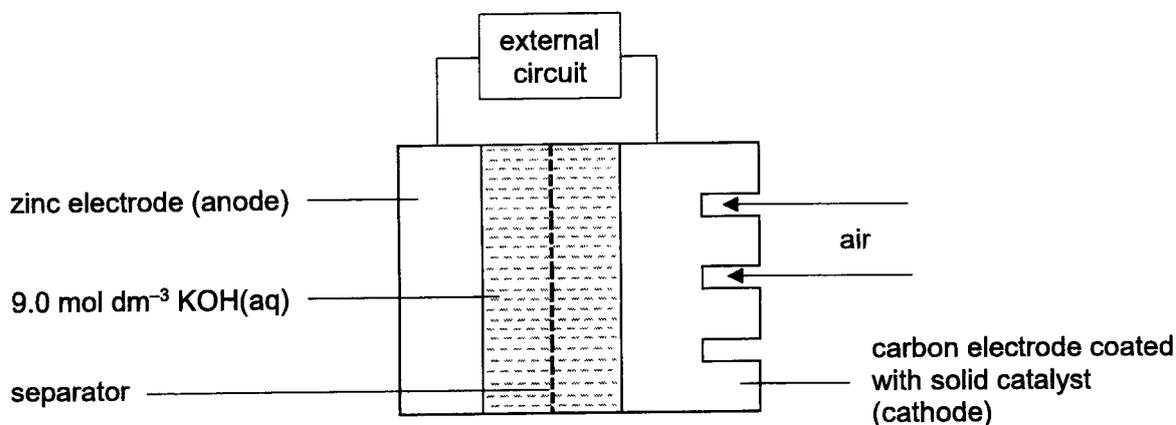


Fig. 5.1

During discharge, zinc is oxidised to zinc ions, which immediately form insoluble zinc hydroxide. However, in the presence of the highly concentrated potassium hydroxide solution, zinc hydroxide then dissolves to form zincate, $[\text{Zn}(\text{OH})_4]^{2-}$.

During charging, zinc ions are reduced and deposited as metallic zinc on the zinc electrode surface.

- (a) Construct a balanced equation for the conversion of zinc ions to zincate, under basic conditions.

..... [1]

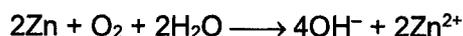
- (b) In the battery, the $E(\text{Zn}^{2+}/\text{Zn})$ value is -1.25 V and the $E(\text{O}_2/\text{OH}^-)$ value is $+0.34\text{ V}$.

- (i) With reference to your answer in (a), explain why the value of $E(\text{Zn}^{2+}/\text{Zn})$ is more negative than $E^\ominus(\text{Zn}^{2+}/\text{Zn})$.

.....

 [1]

- (ii) The overall reaction during discharge is given below.



Using the reduction potential values provided, calculate the Gibbs free energy change of the reaction.

[2]

- (iii) When the 9.0 mol dm^{-3} $\text{KOH}(\text{aq})$ electrolyte was replaced with 0.90 mol dm^{-3} $\text{KOH}(\text{aq})$, the discharge process stopped prematurely.

Without referencing changes to the E values, suggest why the process stopped prematurely.

.....

 [2]

(c) The cathode is a carbon electrode coated with solid catalyst.

Describe the mode of action of the heterogeneous catalyst at the cathode.

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.....
.....
..... [2]

(d) Suggest an advantage of using rechargeable Zn-air batteries over single-use batteries.

.....
.....
..... [1]

- (e) The capacity of a battery is directly proportional to the amount of active zinc present at the anode. Active zinc refers to the amount of pure zinc metal within the anode that can participate in the electrochemical reactions. The depletion of active zinc is usually caused by side reactions occurring at the anode even when the battery is not discharging. This reduces the capacity of the battery.

A new Zn-air battery with a current of 2.0 A was tested for its capacity. The battery was fully charged and left to idle for 7 days. Then, it was discharged and the capacity measured. This charging-discharging process was repeated over four weeks and the results are shown in Table 5.1.

Table 5.1

week	capacity of battery on day 7 / %
1	97
2	80
3	67
4	54

- (i) Based on the data given in Table 5.1, state how the amount of active zinc present changes across the four weeks.

.....
 [1]

- (ii) As the battery was left to stand, a side reaction occurs which causes the battery to lose active zinc, even without having to discharge.

A gas was formed in this side reaction. Suggest the identity of this gas.

..... [1]

The Zn-air battery was used to electroplate silver onto an object as shown in Fig. 5.2.

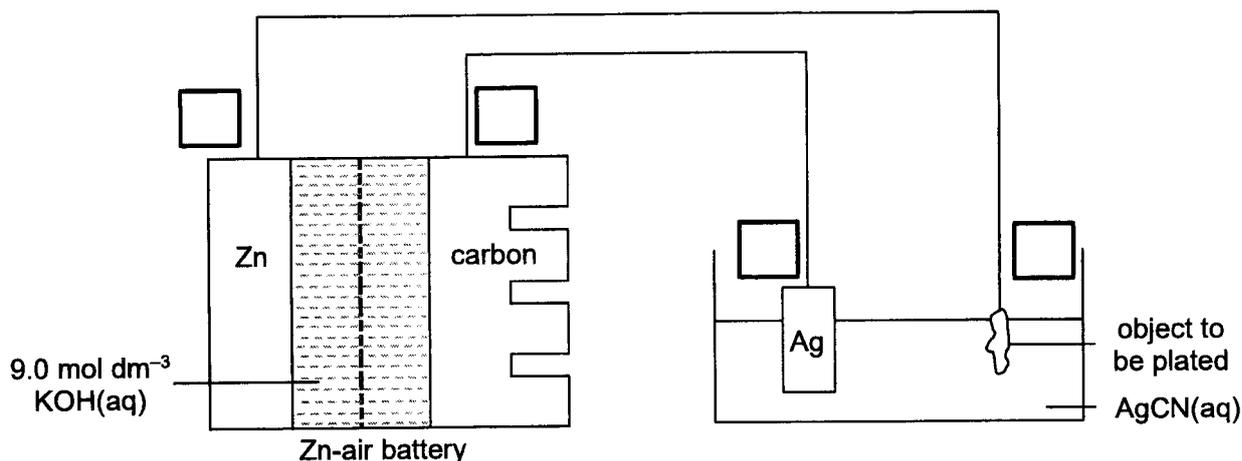


Fig. 5.2

- (f) (i) Draw on Fig. 5.2 the direction of electron flow and indicate the polarity of the electrodes on both cells in the boxes provided. [2]

The two cells were connected and a current of 1.5 A was passed through the electrolytic cell. After some time, the mass of the object increased by 1.75 g.

- (ii) Calculate the amount of electrons transferred for the reduction of Ag⁺.

[1]

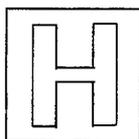
- (iii) Using your answer in (f)(ii), calculate the decrease in mass of the zinc anode.

[1]

- (iv) Calculate the time taken for 1.75 g of silver to be plated onto the object.

[1]

[Total: 16]



RAFFLES INSTITUTION
2025 YEAR 6 PRELIMINARY EXAMINATION

Higher 2



CANDIDATE
NAME

CLASS

INDEX NUMBER

CHEMISTRY

9729/03

Paper 3 Free Response

23 September 2025

2 hours

Candidates answer on the Question Paper.

Additional Materials: Data Booklet

READ THESE INSTRUCTIONS FIRST

Do not open this question booklet until you are told to do so.

Write your name, class 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 page at the end of this booklet. The question number must be clearly shown.

Section A

Answer **all** questions.

Section B

Answer **one** question.

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

A Data Booklet is provided. Do not write anything in it.

You are reminded of the need for good English and clear presentation in your answers.

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				
Section A		Section B		Total
1	/ 20	(Circle the question you have answered)		/ 80
2	/ 20	4	/ 20	
3	/ 20	5	/ 20	

This document consists of **30** printed pages and **2** blank pages

- 2 (a) Equation 1 shows the Haber process for manufacturing ammonia.



A mixture of H_2 and N_2 in the molar ratio of 3:1 is added to a sealed vessel and heated to $450\text{ }^\circ\text{C}$ with an iron catalyst. At equilibrium, the total pressure in the vessel is 200 atm and the partial pressure of NH_3 is 35 atm.

- (i) Write the expression for the equilibrium constant, K_p , for the reaction in equation 1. Use your expression to calculate the value of K_p for this reaction. Include its units. [3]
- (ii) The value of the equilibrium constant, K_p , for the Haber process measured at different temperatures is shown in Table 2.1.

Table 2.1

temperature / $^\circ\text{C}$	K_p
300	4.34×10^{-3}
400	1.64×10^{-4}
500	1.45×10^{-5}
600	2.25×10^{-6}

Deduce the sign for the enthalpy change of the forward reaction of equation 1. Explain your reasoning. [2]

- (iii) Predict the effect of adding a small amount of inert gas into the reaction vessel, under constant temperature and pressure, on the position of equilibrium for equation 1. Explain your answer. [2]
- (iv) Explain why iron can act as a heterogenous catalyst. [1]
- (v) Explain the conditions used in the Haber process for manufacturing ammonia. [2]

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- (c) Complex ions with a coordination number of 4, such as $[\text{Co}(\text{CN})_4]^{2-}$, can adopt either the tetrahedral or the square planar structure. Fig. 2.2 shows how the d-orbitals of the metal ion are split in such complexes.

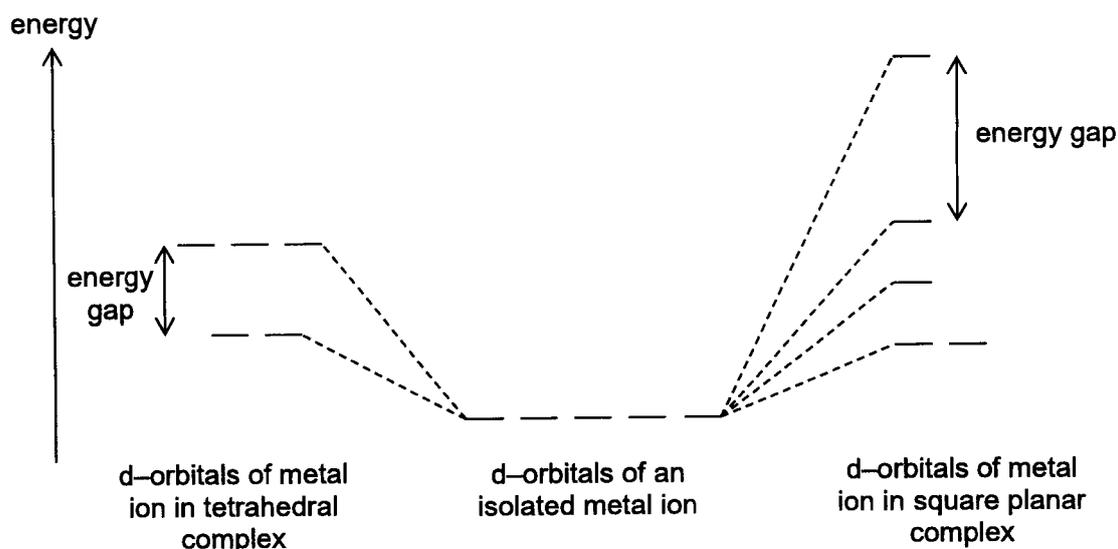


Fig. 2.2

The arrangement of electrons in the d-orbitals depends on the spin states of the complexes.

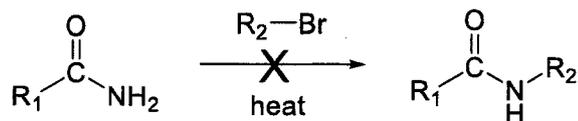
In a '*high spin*' state, the electrons occupy all the d-orbitals singly, before starting to pair up in the lower energy d-orbitals.

In a '*low spin*' state, the lower energy d-orbitals are filled first, by pairing up if necessary, before the higher energy d-orbitals are used.

- (i) State the electronic configuration of a cobalt(II) ion. [1]
- (ii) Explain why an aqueous solution of $[\text{Co}(\text{CN})_4]^{2-}$ is coloured. [3]
- (iii) Electrons usually occupy d-orbitals singly before pairing up.
Suggest why a complex might still adopt a *low spin* state. [1]

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- (d) A substituted amide cannot be synthesised from the corresponding primary amide using a nucleophilic substitution reaction.



- (i) Explain why an amide is not nucleophilic. [2]
- (ii) The Ritter reaction is a reaction between a nitrile and an alcohol, in the presence of concentrated H_2SO_4 , to form a substituted amide as shown in Fig. 3.5.

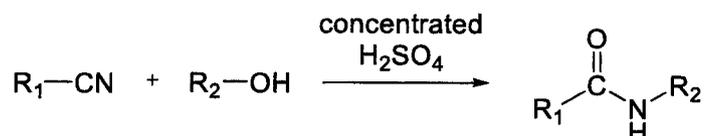


Fig. 3.5

Using the reaction in (c) and the Ritter reaction, a substituted amide **R** can be synthesised from a primary amide **P** and alcohol **Q** in two steps as shown in Fig. 3.6.



Fig. 3.6

Suggest the structures of primary amide **P** and alcohol **Q**. [2]

.....

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(c) Information about three amino acids found in proteins are provided in Table 5.1.

Table 5.1

name	structure	abbreviation	pK _a of α-COOH	pK _a of α-NH ₃ ⁺	pK _a of side chain
serine	$\begin{array}{c} \text{O} \\ \parallel \\ \text{H}_2\text{N}-\text{CH}-\text{C}-\text{OH} \\ \\ \text{CH}_2 \\ \\ \text{OH} \end{array}$	ser	2.2	9.2	-
histidine	$\begin{array}{c} \text{O} \\ \parallel \\ \text{H}_2\text{N}-\text{CH}-\text{C}-\text{OH} \\ \\ \text{CH}_2 \\ \\ \text{N} \quad \text{C} \\ \diagdown \quad \diagup \\ \text{H} \quad \text{N} \\ \text{(2)} \end{array}$	his	1.8	9.2	6.1
aspartic acid	$\begin{array}{c} \text{O} \\ \parallel \\ \text{H}_2\text{N}-\text{CH}-\text{C}-\text{OH} \\ \\ \text{CH}_2 \\ \\ \text{C}=\text{O} \\ \\ \text{OH} \end{array}$	asp	1.9	9.6	3.7

Histidine plays a key role in buffering the pH in biological systems. Histidine is an amino acid with a five-membered imidazole side chain that contains two nitrogen atoms, one of which is protonated under acidic conditions.

- (i) Define an Arrhenius acid. [1]
- (ii) Histidine contains two nitrogen atoms in its side chain. Explain why N(1) is more basic than N(2). [1]
- (iii) Ser–his–asp is a sequence of amino acid residues that is commonly found in the active sites of many enzymes. Draw the structure of the tripeptide ser–his–asp. [1]
- (iv) Explain whether the tripeptides ser–his–asp and asp–his–ser are the same compound. [1]
- (v) Draw the structure of the predominant species of aspartic acid at pH 7.4. [2]

.....

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