

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.

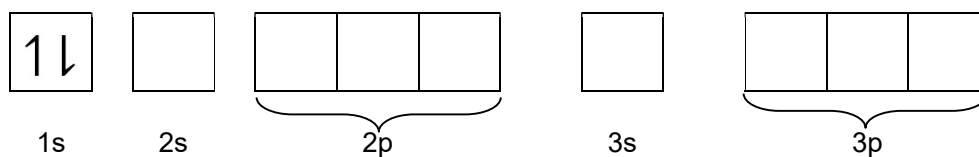
.....

 [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*.

.....

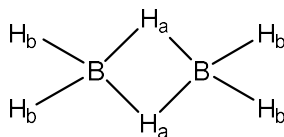
..... [1]

- (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° .

.....

.....

.....

..... [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.

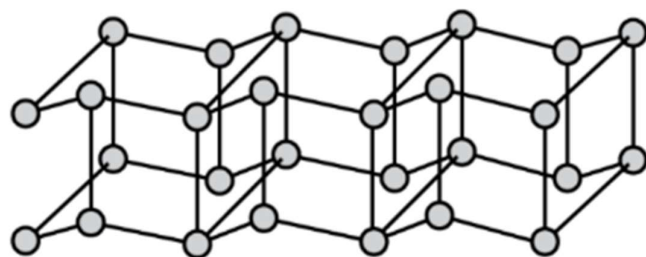
[1]

(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.

.....
.....
.....
.....
.....
..... [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.

.....

 [2]

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

.....

 [2]

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

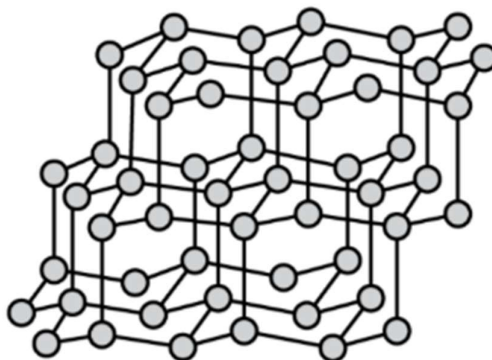


Fig. 2.2

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

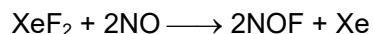
Explain if the researcher's conclusion is correct.

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.

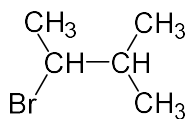
In a molecule of **H**

- 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**.

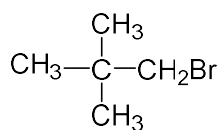
..... [1]

(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 $\text{S}_{\text{N}}1$ nor $\text{S}_{\text{N}}2$ occurred for **N**.

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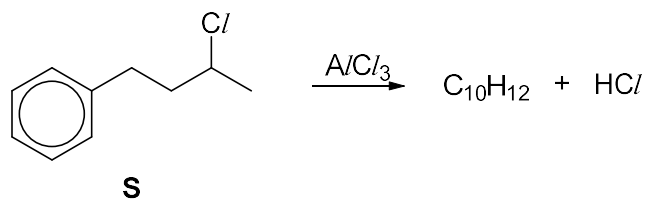
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..... [2]

[Total: 15]

- 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.

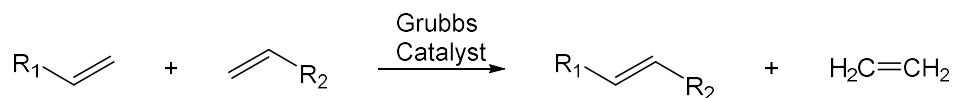


Fig. 3.1

(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**.

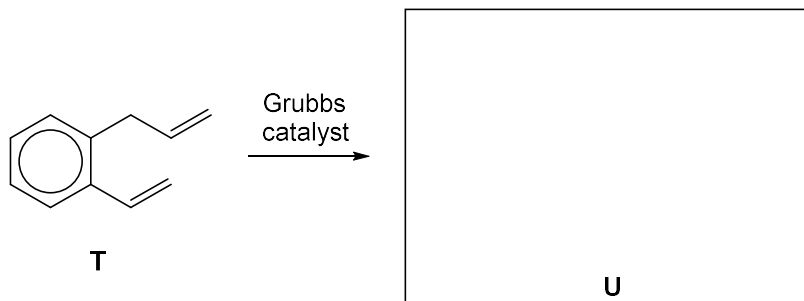


Fig. 3.2

[1]

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

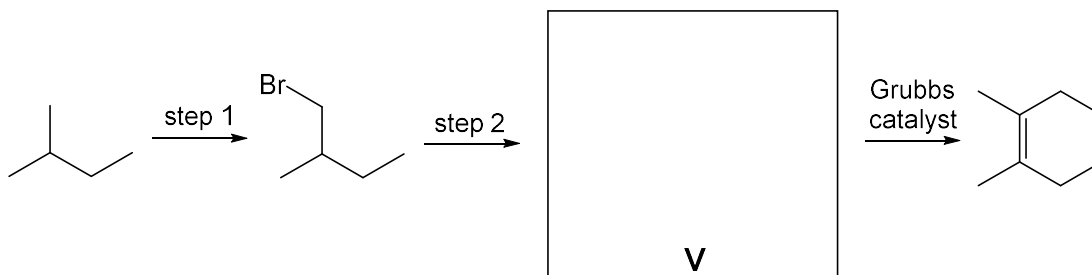


Fig. 3.3

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.

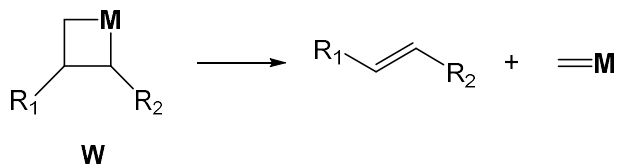
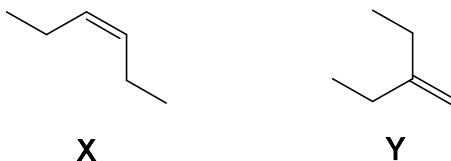


Fig. 3.4

[1]

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



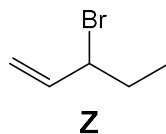
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..... [2]

- (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, O_3 , and nitrogen dioxide, NO_2 .

Table 4.1

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
$$\text{PSI of pollutant} = \left[\left(\frac{P_{i+1} - P_i}{C_{i+1} - C_i} \right) (C_p - C_i) \right] + P_i$$

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 O_3 .

Given that the density of air is 1 kg m^{-3} , calculate the concentration of O_3 , 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.

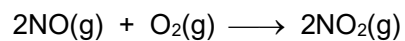
Suggest one reason for the change in concentration of O_3 during the Circuit Breaker.

.....

 [1]

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

equation 4.2



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.

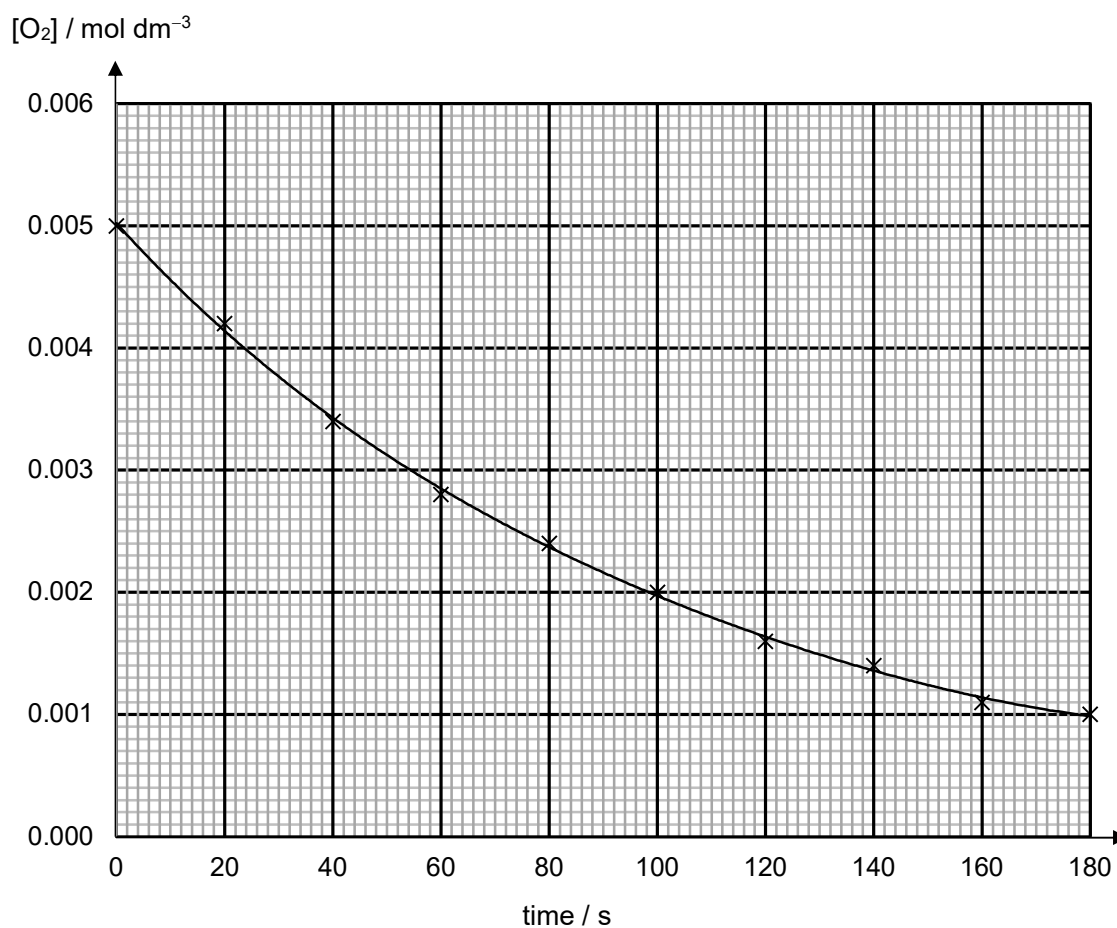


Fig. 4.1

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

[1]

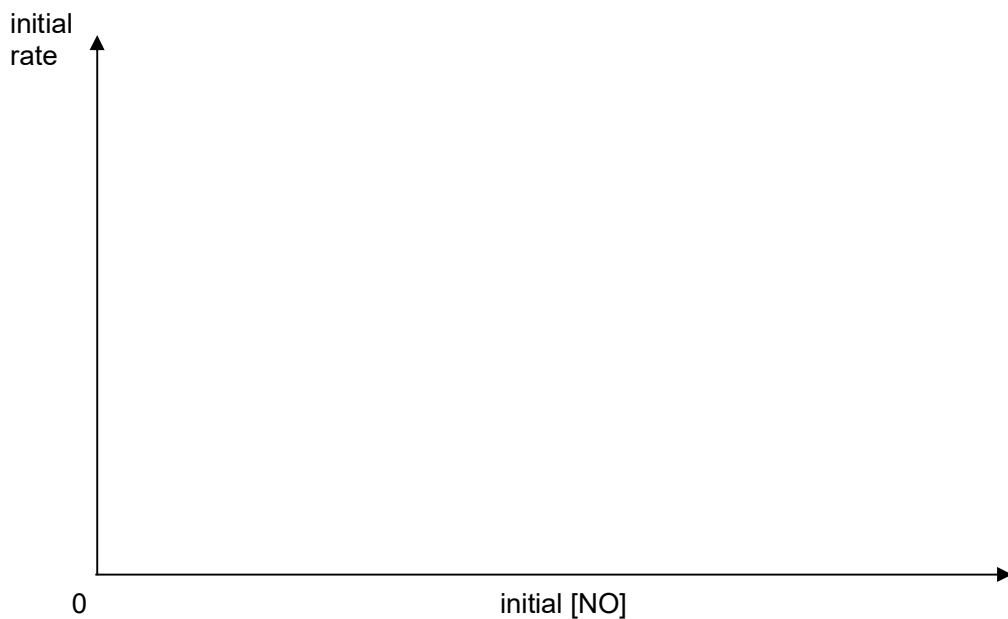
- (ii) Use the value of **z** to deduce the order of reaction with respect to O_2 .

.....
.....
.....
..... [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*.

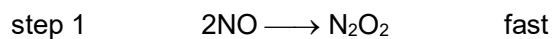
.....
 [1]

- (vi) The half-life of O_2 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.

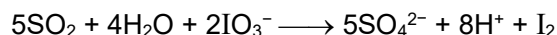
- (i) State the **type** of catalysis occurring.

..... [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.

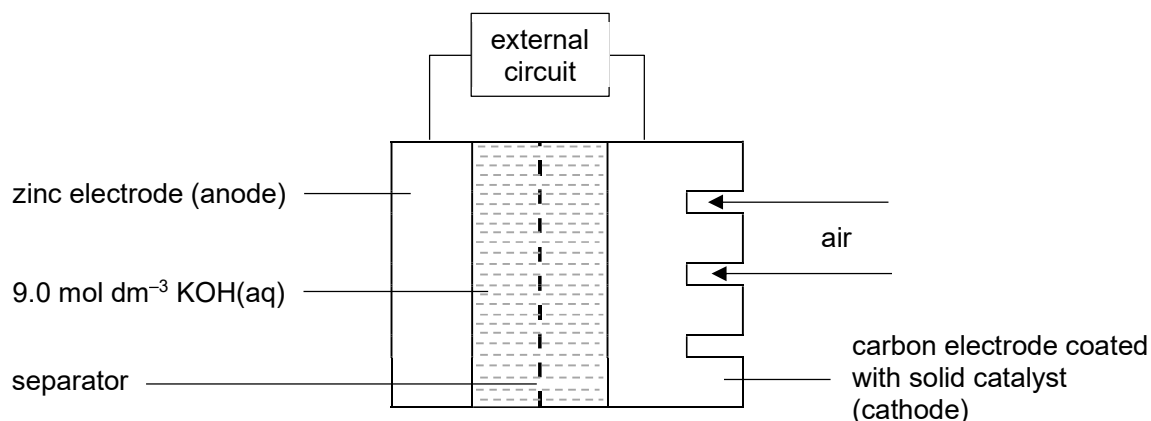


Fig. 5.1

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]

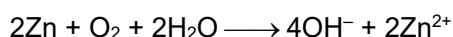
- (b) In the battery, the $E(\text{Zn}^{2+}/\text{Zn})$ value is -1.25 V and the $E(\text{O}_2/\text{OH}^-)$ value is $+0.34 \text{ V}$.

- (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.

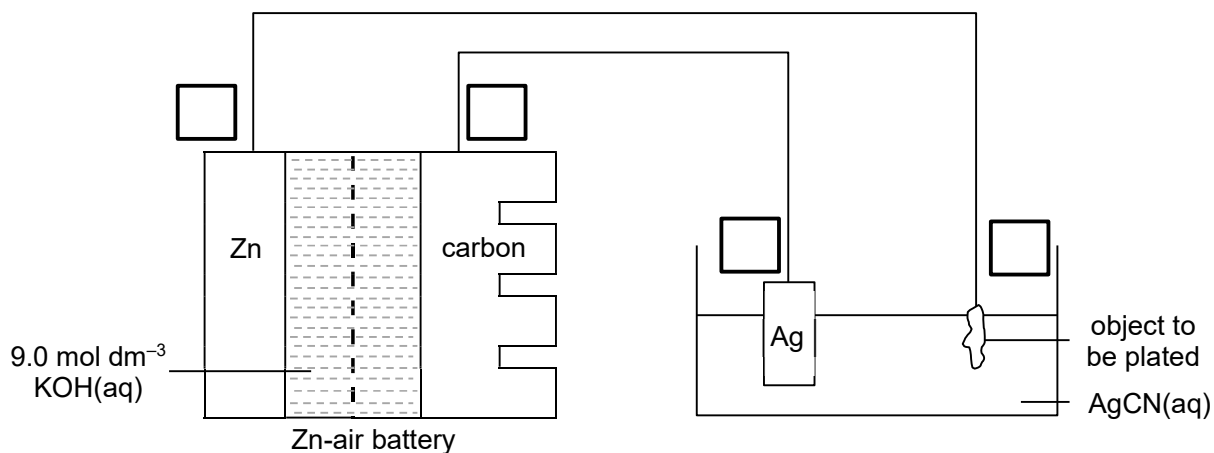


Fig. 5.2

- (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]