



ST. ANDREW'S JUNIOR COLLEGE
 JC2 PRELIMINARY EXAMINATIONS
 HIGHER 2

CANDIDATE
 NAME

CLASS

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CHEMISTRY

9729/01

Paper 1 Multiple Choice

18 September 2025

Candidate answer on the Optical Answer Sheet.

1 hour

Additional Materials: Data Booklet

READ THESE INSTRUCTIONS FIRST

Write in soft pencil.

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

There are **thirty** questions on 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 Optical Answer Sheet.

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 **15** printed pages (including this cover page).

1 Which statement is correct?

A One mole of a compound is the amount that contains the same number of atoms as there are in 12.0 g of carbon-12.

B The relative isotopic mass of beryllium-9 is given by the following expression.

$$\frac{\text{average mass of all isotopes of beryllium}}{\frac{1}{12} \text{ the mass of one atom of } ^{12}\text{C}}$$

C The relative atomic mass of nitrogen is given by the following expression.

$$\frac{\text{average mass of one atom of nitrogen}}{\frac{1}{12} \text{ the mass of one atom of } ^{12}\text{C}}$$

D The relative molecular mass of Q is given by the following expression.

$$\frac{\text{average mass of one atom of Q}}{\frac{1}{12} \text{ the mass of one atom of } ^{12}\text{C}}$$

2 10 cm³ of a gaseous hydrocarbon, C_xH_y, was exploded with an excess of oxygen. There was a contraction of 40 cm³. When the products were treated with aqueous sodium hydroxide, there was a further contraction of 50 cm³. All gas volumes were measured at room temperature and pressure.

What is the molecular formula of the hydrocarbon?

A C₄H₈

B C₄H₁₀

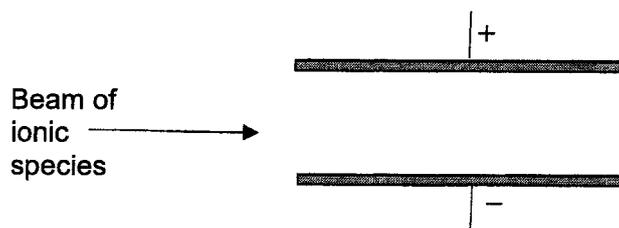
C C₅H₁₀

D C₅H₁₂

3 In which row are X and Y atoms or ions of different isotopes of the same element?

	X			Y		
	Number of electrons	Charge	Nucleon number	Number of electrons	Charge	Nucleon number
A	3	+3	12	9	-3	12
B	8	0	16	11	-1	19
C	10	+1	23	10	+1	24
D	18	-3	31	12	+3	31

- 4 Which particle will deflect the most when moving with the same speed through an electric field?



- A ${}^7\text{Li}^+$ B ${}^{11}\text{B}^{3+}$ C ${}^{19}\text{F}^-$ D ${}^{31}\text{P}^{3-}$
- 5 Which molecules are **not** polar?
- 1 H_2S 2 CS_2 3 SO_2 4 SF_6
- A 1 and 2
 B 2 and 4
 C 3 and 4
 D 4 only
- 6 A mixture consisting of gaseous compounds, S, T, U and V, is slowly cooled.

Gaseous Compound	M_r	Compound
S	72	$\text{CH}_3\text{CH}_2\text{COCH}_3$
T	74	$\text{CH}_3\text{CH}_2\text{CH}(\text{OH})\text{CH}_3$
U	72	$(\text{CH}_3)_4\text{C}$
V	72	$\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_3$

In which order, from first to last, will the compounds condense to form their liquids?

- A $\text{T} \rightarrow \text{S} \rightarrow \text{V} \rightarrow \text{U}$
 B $\text{U} \rightarrow \text{V} \rightarrow \text{S} \rightarrow \text{T}$
 C $\text{S} \rightarrow \text{T} \rightarrow \text{V} \rightarrow \text{U}$
 D $\text{V} \rightarrow \text{U} \rightarrow \text{S} \rightarrow \text{T}$

7 Which equation corresponds to the enthalpy change stated?

- | | | |
|---|--|---|
| A | $S_8(s) + 12O_2(g) \rightarrow 8SO_3(l)$ | $\Delta H^\ominus_{\text{formation}}(SO_3(l))$ |
| B | $CaCl_2(s) + aq \rightarrow Ca^{2+}(g) + 2Cl^-(g)$ | $\Delta H^\ominus_{\text{solution}}(CaCl_2(s))$ |
| C | $2Fe^{3+}(g) + 3O^{2-}(g) \rightarrow Fe_2O_3(s)$ | $H^\ominus_{\text{lattice energy}}(Fe_2O_3(s))$ |
| D | $H_2SO_4(aq) + Ca(OH)_2(aq) \rightarrow CaSO_4(aq) + 2H_2O(l)$ | $\Delta H^\ominus_{\text{neutralisation}}$ |

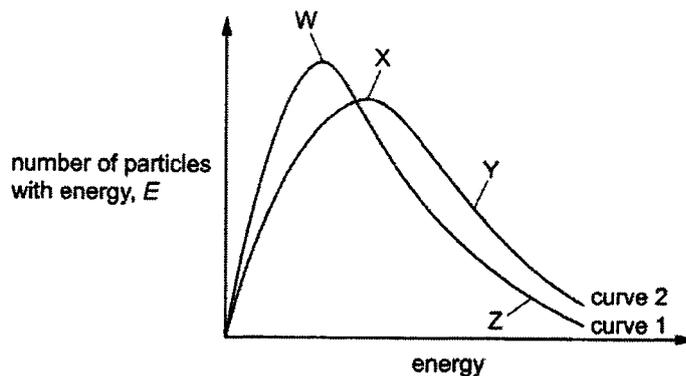
8 Use of the Data Booklet is relevant to this question.

A student mixes 20.0 cm³ of 5.00 mol dm⁻³ sulfuric acid with an equal volume of 6.00 mol dm⁻³ sodium hydroxide. The initial temperature of both solutions is 25.0 °C. The maximum temperature reached after the reaction is 55.0 °C. Assume the density of both solutions is 1 g cm⁻³.

What is the value of the enthalpy change of neutralisation, in kJ mol⁻¹, calculated using these values?

- A -41.8
 B -50.2
 C -83.6
 D -100.3
- 9 The half-life of the first-order gaseous reaction in which M₂ molecules become converted into M atoms is 40 minutes. 1 mol of M₂ is put into a sealed vessel at pressure *p*.
- What will be true when 87.5% of M₂ has been converted into M atoms?
- 1 80 minutes have elapsed.
 - 2 1.5 mol of M have been formed.
 - 3 The total pressure is $\frac{15}{8} p$ (at constant pressure).
- A 1, 2 and 3
 B 1 and 2 only
 C 2 and 3 only
 D 3 only

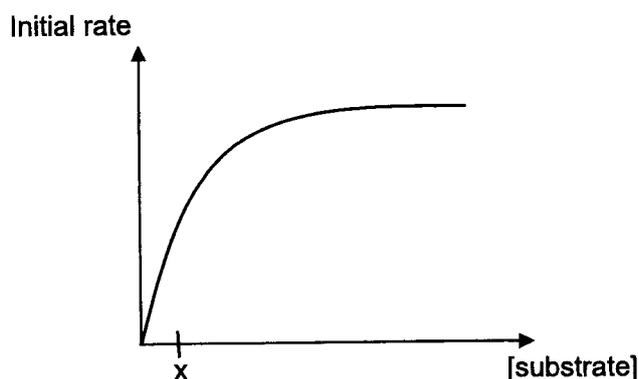
- 10 Curves 1 and 2 show the Boltzmann distributions for identical compositions of a reaction mixture which occur at different temperatures.



Which statement is correct?

- A Curve 1 applies to the faster reaction and point W indicates particles with lower energy than point Z.
- B Curve 1 applies to the faster reaction and point W indicates particles with higher energy than point Z.
- C Curve 2 applies to the faster reaction and point X indicates particles with lower energy than point Y.
- D Curve 2 applies to the faster reaction and point X indicates particles with higher energy than point Y.

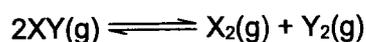
- 11 The graph shows how the initial rate of reaction varies for an enzyme catalysed reaction as the substrate concentration changes.



Which of the statements correctly describe the situation when [substrate] = x ?

- 1 The initial rate of reaction is affected by increasing [substrate].
- 2 The order of reaction with respect to [substrate] is 1.
- 3 There are no more enzyme active sites available.

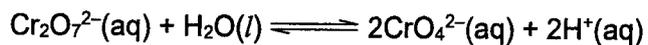
- A 1, 2 and 3
 B 1 and 2 only
 C 2 and 3 only
 D 3 only
- 12 A sample of 1 mol of XY was placed in an empty 1 dm³ container and allowed to reach equilibrium with a total pressure, p , according to the following equation.



At equilibrium, x mol of XY had dissociated. What is the value of the equilibrium constant, K_p , at the temperature of the experiment?

- A $\frac{x^2}{(1-x)^2}$
 B $\frac{(1-x)^2}{x^2}$
 C $\frac{4(1-x)^2}{x^2}$
 D $\frac{x^2}{4(1-x)^2}$

- 13 Orange dichromate(VI), $\text{Cr}_2\text{O}_7^{2-}$, and yellow chromate(VI) ions, CrO_4^{2-} , exist in equilibrium in aqueous solution.



Which statement about this equilibrium is correct?

- A Lowering the pH will increase concentration of CrO_4^{2-} ions.
 B Addition of a catalyst will shift the position of equilibrium to the left.
 C Addition of water will shift the position of equilibrium to the left.
 D In strong alkali, the solution appears yellow.
- 14 The table shows the fifth ionisation energies of four consecutive elements in the Periodic Table.

Element	E	F	G	H
Fifth IE / kJmol^{-1}	37832	9445	10989	13327

What is the formula of the chloride of E?

- A ECl_2 B ECl_3 C ECl_4 D ECl_5
- 15 Which pair contains an Arrhenius acid and Arrhenius base?

	Acid	Base
A	KCl	NaOH
B	HCl	KOH
C	CH_3COOH	NH_3
D	H_2SO_4	NH_3

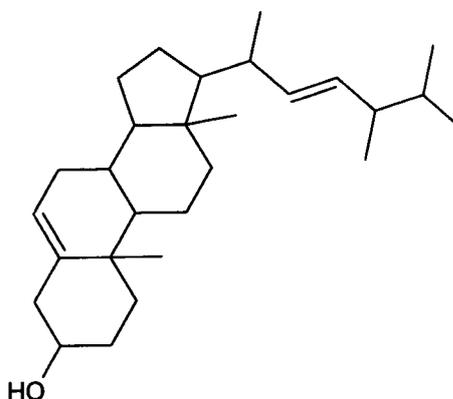
- 16 An excess of silver bromide is added to water and the mixture is shaken until equilibrium is reached.

How is the solubility of silver bromide, in this equilibrium mixture, affected by the addition of either

- aqueous ammonia or
- aqueous potassium bromide?

	addition of aqueous ammonia	addition of aqueous potassium bromide
A	decreases	decreases
B	decreases	increases
C	increases	increases
D	increases	decreases

- 17 Brassicasterol is a plant sterol found in sources like rapeseed oil and marine algae.



brassicasterol

How many stereoisomers does brassicasterol have?

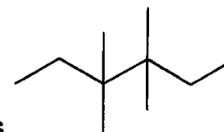
- A** 2^9
- B** 2^{10}
- C** 2^{11}
- D** 2^{12}

- 18 In the free radical substitution of 2-methylbutane with chlorine, a mixture of mono-chlorinated compounds was obtained.

Assuming the rate of reaction at all the carbon atoms are the same, which statements are correct?

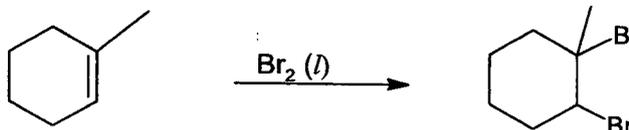
- 1 The ratio for the two compounds with the highest yields is 2:1.
- 2 Homolytic fission only occurs in the initiation step.

3



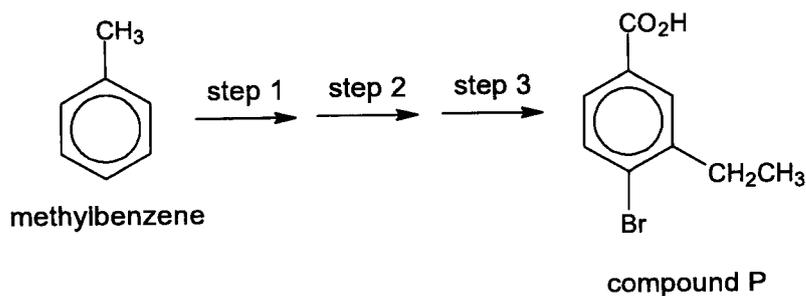
One of the products formed in this reaction is

- A 1 and 2 only
 - B 1 and 3 only
 - C 2 and 3 only
 - D 1 only
- 19 Which statement about this reaction is correct?



- A The product as shown above is the major product when $\text{Br}_2(\text{aq})$ is used instead.
- B Electrons in the carbon-carbon σ bond are donated to an electrophile.
- C The carbocation has the same hybridisation state as the C in the $\text{C}=\text{C}$.
- D A primary carbocation is formed in this reaction.

- 20 Compound P can be synthesised from methylbenzene as shown below.



Which of the following could be a possible sequence for converting methylbenzene to compound P?

- | | Step 1 | Step 2 | Step 3 |
|----------|---|--|--|
| A | $\text{CH}_3\text{CH}_2\text{Cl}$, AlCl_3 | Br_2 , AlBr_3 , dark | Hot acidified KMnO_4 |
| B | Br_2 , AlBr_3 , dark | Hot acidified KMnO_4 | $\text{CH}_3\text{CH}_2\text{Cl}$, AlCl_3 , heat |
| C | Br_2 , AlBr_3 , dark | $\text{CH}_3\text{CH}_2\text{Cl}$, AlCl_3 | Hot acidified KMnO_4 |
| D | Hot acidified KMnO_4 | $\text{CH}_3\text{CH}_2\text{Cl}$, AlCl_3 , heat | Br_2 , AlBr_3 , dark |
- 21 Equal amounts of compounds X, Y and Z were heated with ethanolic silver nitrate in three separate test-tubes. After some time, the precipitate formed in each test-tube, if any, was filtered, dried and weighed.

Compound X produced the largest mass of precipitate in the shortest time, while compound Z did not produce any precipitate.

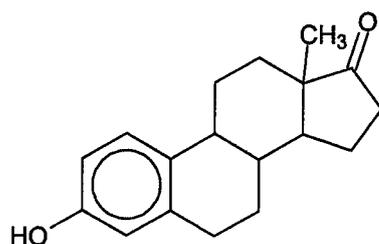
Which of the following could be the identities of X, Y and Z?

- | | X | Y | Z |
|----------|------------------------------|--------------------------|-------------------------|
| A | <chem>BrC(=O)c1ccccc1</chem> | <chem>BrCc1ccccc1</chem> | <chem>Brc1ccccc1</chem> |
| B | <chem>Ic1ccccc1</chem> | <chem>Brc1ccccc1</chem> | <chem>Clc1ccccc1</chem> |
| C | <chem>CCCl</chem> | <chem>CCBr</chem> | <chem>CCI</chem> |
| D | <chem>CC=CBr</chem> | <chem>CC=CCl</chem> | <chem>CC=CFl</chem> |

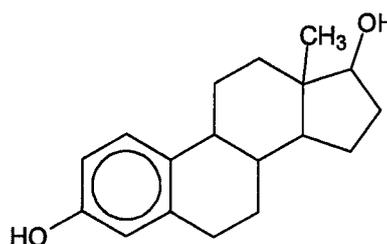
- 22 Compound W has the empirical formula CH_2O and has the following properties.
- It gives a yellow precipitate when warmed with alkaline aqueous iodine.
 - White fumes are produced when it is heated with PCl_3 .

What could W be?

- A $\text{CH}_3\text{CO}_2\text{H}$
 B $\text{CH}_3\text{CH}(\text{OH})\text{CO}_2\text{H}$
 C $\text{CH}_3\text{COCH}_2\text{CH}_2\text{CO}_2\text{H}$
 D $\text{HO}_2\text{CCH}_2\text{CH}(\text{OH})\text{CH}_2\text{OH}$
- 23 Two female sex hormones are oestrone and oestradiol.



oestrone



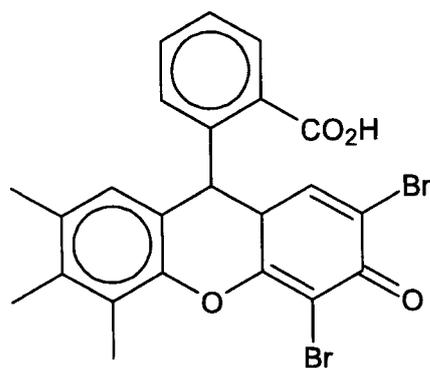
oestradiol

Which of the following reagents could be used to distinguish between the two hormones?

- 1 Acidified aqueous $\text{K}_2\text{Cr}_2\text{O}_7$
- 2 Acidified aqueous KMnO_4
- 3 Aqueous alkaline iodine

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

- 24 The classic red colour from many lipsticks are obtained from pigments and dyes, such as the compound, eosin. Eosin reacts with proteins of the skin to produce a deep red colour.



Eosin

Eosin was reduced separately by NaBH_4 and by H_2 with Pt.

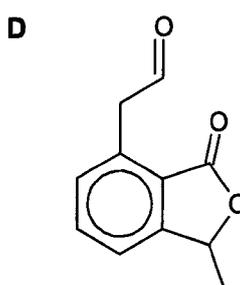
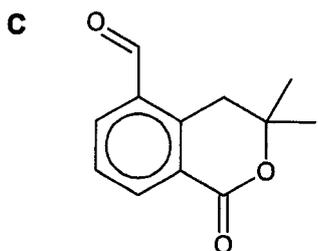
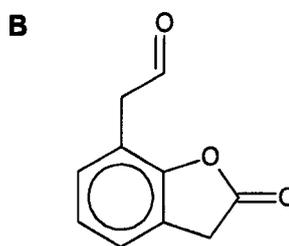
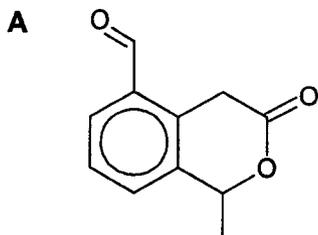
What is the number of hydrogen atoms added to each molecule of eosin?

	NaBH_4	H_2 with Pt
A	2	4
B	2	6
C	4	4
D	4	6

- 25 Compound X reacts with $[\text{Ag}(\text{NH}_3)_2]^+$, but not with alkaline Cu^{2+} .

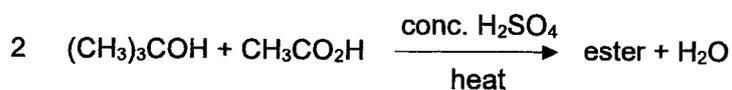
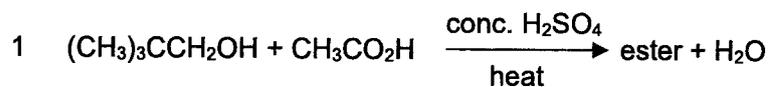
Upon warming X with alkaline aqueous iodine, a yellow precipitate is observed.

What could X be?



- 26 The ester 2,2-dimethylpropyl ethanoate is found in rare flowers and has a very strong scent.

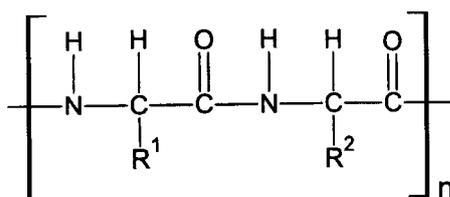
How may this ester be made in the laboratory?



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

[Turn Over

- 27 The diagram below shows the general structure of a protein.



Chymotrypsin is an enzyme that hydrolyses protein into smaller peptides and amino acids. It specifically hydrolyses the peptide bond on the carboxylic end of phenylalanine (Phe).

The structure of hexapeptide Y and the M_r of selected amino acids are given below.

Hexapeptide Y: Val-Ala-Lys-Phe-Ser-Arg

Amino acid	M_r
Valine (Val)	117
Alanine (Ala)	89
Lysine (Lys)	146
Phenylalanine (Phe)	165
Ser (Serine)	105
Arginine (Arg)	174

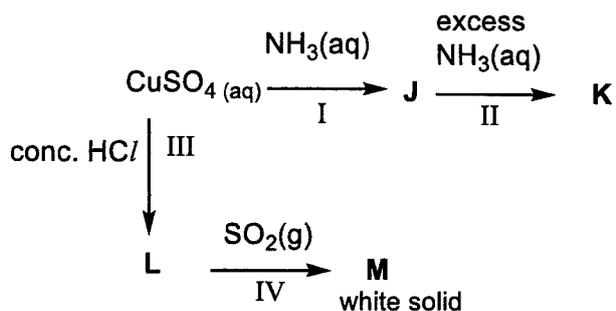
What are the M_r of the two fragments obtained when hexapeptide Y is hydrolysed by chymotrypsin?

	M_r of fragment 1	M_r of fragment 2
A	517	279
B	463	261
C	316	408
D	352	444

- 28 Which factors determine the number of atoms of nickel deposited on the cathode of an electrolytic cell?

	$[\text{Ni}^{2+}(\text{aq})]$	current	time
A	✓	✓	✓
B	✓	✓	x
C	x	✓	x
D	x	✓	✓

- 29 Copper(II) sulfate solution reacted as shown in the scheme below.



Which of the following statements is correct?

- A NH_3 functions as a ligand in reaction I.
 B The coordination number of complex L is 6.
 C The oxidation number of Cu in L and M is the same.
 D Ligand exchange has taken place in reaction II.
- 30 Which of the following statements about manganese are correct?
- 1 Manganese have a greater number of oxidation states than titanium.
 - 2 Aqueous solution of Mn^{3+} is acidic.
 - 3 Mn^{3+} can catalyse the reaction between $\text{S}_2\text{O}_8^{2-}(\text{aq})$ and $\text{I}^-(\text{aq})$.
- A 1, 2 and 3
 B 1 and 2
 C 2 and 3
 D 1 only

END OF PAPER



ST. ANDREW'S JUNIOR COLLEGE
 JC2 PRELIMINARY EXAMINATIONS
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CHEMISTRY

9729/02

Paper 2 Structured Questions

2 September 2025

Candidates answer on the Question Paper.

2 hours

Additional Materials: Data Booklet

READ THESE INSTRUCTIONS FIRST

Write your name and class on all the work that you hand in.

Write in dark blue or black pen.

You may use a 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.

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		
Q1		21
Q2		7
Q3		16
Q4		12
Q5		19
Total		75

This document consists of **37** printed pages (including this cover page).

1 (a) Titanium dioxide, TiO_2 , is a white solid, which is an amphoteric oxide. In the structure of titanium dioxide, the titanium ion is bonded to six oxide anions.

(i) Complete the electronic configuration of a titanium atom.

$1s^2$

[1]

(ii) Suggest the shape around the titanium ion in titanium dioxide.

.....

[1]

(b) (i) Aluminium oxide is another example of an amphoteric oxide.

Write two equations to illustrate the reaction of Al_2O_3 with an acid and a base of your choice respectively.

.....

.....

[2]

(ii) The ionic radius of Al^{3+} is 0.050 nm and Ti^{2+} is 0.086 nm.

Explain the difference in ionic radii between Al^{3+} and Ti^{2+} .

.....

.....

.....

.....

[2]

- (c) Titanium(II) chloride is prepared by the thermal decomposition of TiCl_3 at 500°C . The reaction is driven by the loss of volatile TiCl_4 .



- (i) State and explain the sign for ΔS° .

.....

..... [1]

- (ii) Deduce the sign of the enthalpy change, ΔH , of the thermal decomposition of TiCl_3 , given that the decomposition is spontaneous only at high temperature. Explain your answer.

.....

.....

..... [1]

- (iii) Explain why TiCl_3 forms a violet solution, but TiCl_4 forms a colourless solution.

.....

.....

.....

..... [2]

- (d) Another transition element that is bonded to oxygen atoms is manganese. Two examples are manganate(VI) ion, MnO_4^{2-} , and manganate(VII) ion, MnO_4^- .
- (i) Given that the structure of MnO_4^{2-} is similar to that of SO_4^{2-} , draw the 'dot-and-cross' diagram of MnO_4^{2-} and state its bond angle.

Bond angle:

[2]

- (ii) Acidified potassium manganate(VII), KMnO_4 , and acidified potassium dichromate, $\text{K}_2\text{Cr}_2\text{O}_7$, can be used as oxidising agents in organic reactions.

With reference to relevant E^\ominus values, suggest why KMnO_4 is a stronger oxidising agent than $\text{K}_2\text{Cr}_2\text{O}_7$.

.....

.....

.....

.....

[2]

(e) **A**, **B** and **C** are isomers with the molecular formula, $C_5H_{10}O$, that contains one or two of the following functional groups.

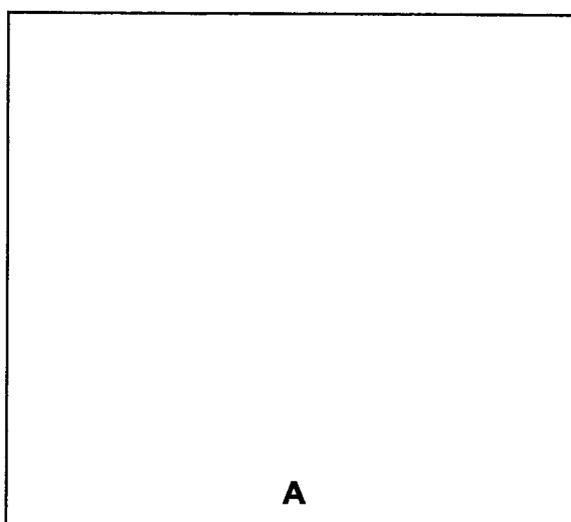
- Alkene
- Alcohol
- Carbonyl

Reactions are carried out on **A**, **B** and **C** and the observations are shown in Table 1.1.

Table 1.1

	with acidified $K_2Cr_2O_7$ (aq)	with acidified $KMnO_4$ (aq)	with 2,4-DNPH	with Br_2 (aq)
A	orange to green	purple to colourless	no reaction	no reaction
B	no reaction	no reaction	orange precipitate	no reaction
C	no reaction	purple to colourless	no reaction	orange to colourless

(i) **A** is a cyclic compound and does not rotate plane of polarised light. Draw the structure of **A**.

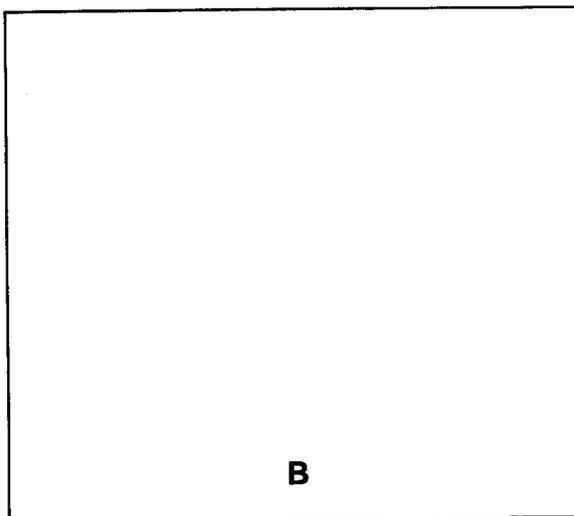


[1]

[TURN OVER

6

- (ii) **B** is a symmetrical molecule. Draw the structure of **B**.



[1]

- (iii) Write the equation for the reaction which occurs when **A** reacts completely with an excess of acidified potassium dichromate(VI). Use [O] to represent the oxidising agent in the reaction.

[1]

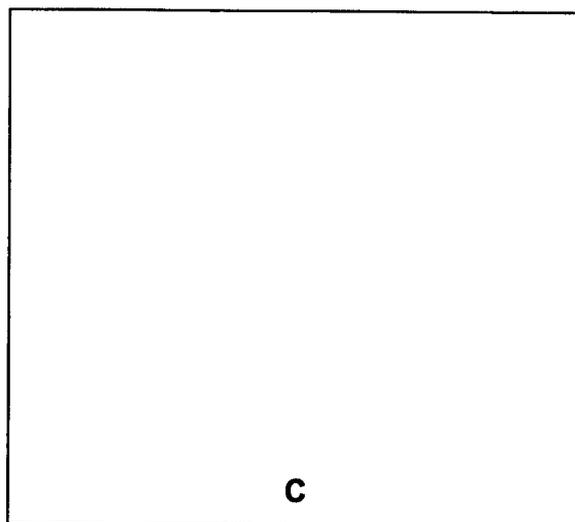
- (iv) State all possible functional groups in **C**.

.....

[1]

7

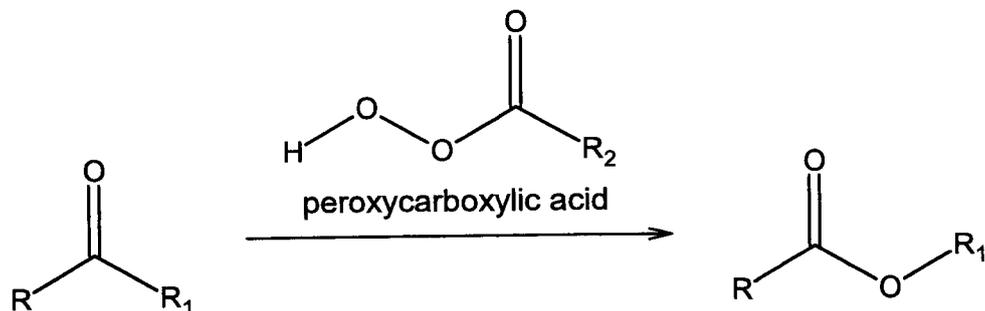
(v) **C** is unable to exhibit stereoisomerism. Draw the structure of **C**.



[1]

[TURN OVER

- (f) Ketones can undergo oxidation forming esters through the Baeyer–Villiger oxidation reaction by using peroxycarboxylic acids as shown in the equation below.



The first step of the mechanism of the Baeyer–Villiger oxidation reaction involves the nucleophilic attack of the lone pair of electrons on the oxygen atom bonded to the hydrogen atom in the peroxycarboxylic acid to the carbonyl carbon in the ketone.

Draw the first step of the mechanism of the Baeyer–Villiger oxidation reaction. Show all relevant dipoles, curly arrows and the structure of the intermediate.

[2]

[Total: 21]

- 2 Ozone, O_3 , plays a crucial role in the Earth's atmosphere by absorbing harmful ultraviolet radiation. It is also widely used for its oxidising and disinfecting properties. For example, ozone can be dissolved in ground water or drinking water for disinfection and water quality enhancement.

Fig. 2.1 shows one possible structure of O_3 (g).

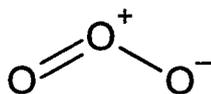
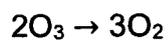


Fig. 2.1

- (a) The overall reaction for the decomposition of ozone can be represented as follows.



The rate of decomposition of ozone in ground water, at pH 8, was investigated and the following results were obtained. The reaction is first order with respect to ozone.

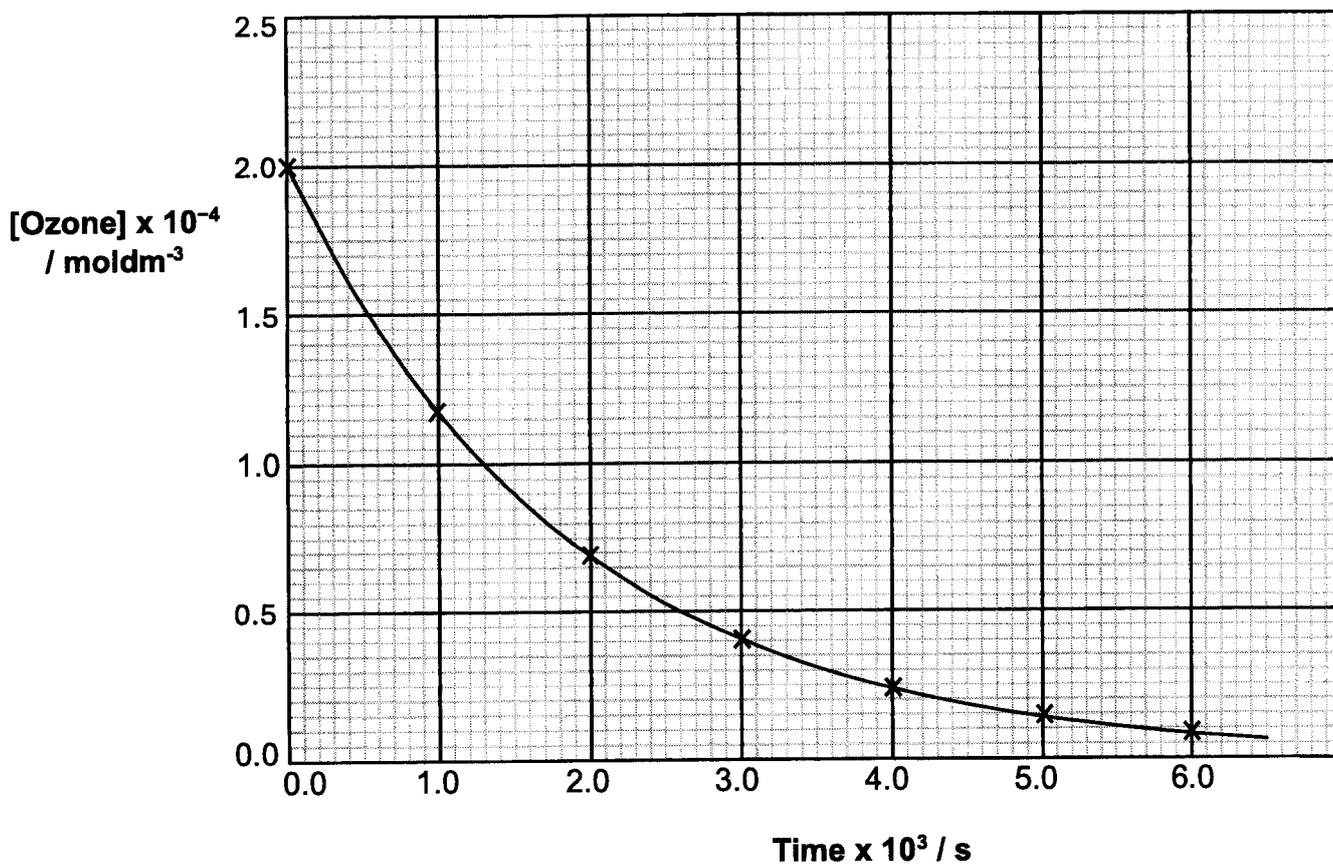


Fig. 2.2

- (i) Define the term *order of reaction*.

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[1]

- (ii) Use the graph in Fig. 2.2 to show that the overall order of reaction is first order.

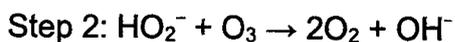
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[1]

- (iii) Hence, calculate the value of the rate constant, k . Include its units.

[1]

- (iv) The presence of OH^- was found to initiate the decomposition of ozone and the following reaction mechanism was suggested.



State the role of OH^- in this mechanism and explain how the presence of OH^- would affect the rate of the reaction.

.....

[1]

[TURN OVER

- (b) Ozone is a strong oxidising agent, useful for oxidative cleavage of alkenes to form carbonyl compounds.

The reaction of ozone with alkenes can be shown in Fig. 2.3.

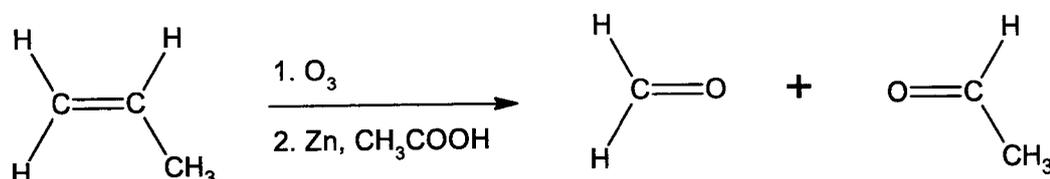


Fig. 2.3

The first step in the mechanism is the initial electrophilic attack by ozone to the carbon-carbon double bond, which then forms the molozonide intermediate. In the second step, the unstable molozonide intermediate undergoes further reaction and breaks apart to form a carbonyl oxide and a carbonyl compound.

The first and second step of the mechanism is shown in Fig. 2.4.

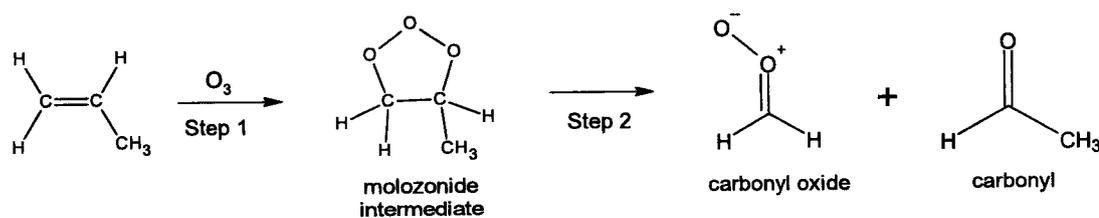


Fig. 2.4

The carbonyl oxide and carbonyl then further react to form the respective carbonyl compounds.

- (i) 2-methylbut-2-ene reacts with ozone in a similar reaction to that in Fig. 2.3.

On Fig. 2.5, draw the structure of the molozonide intermediate and suggest the mechanism for the reaction of 2-methylbut-2-ene with ozone in step 1 to form the molozonide intermediate. Include all relevant lone pairs and three curly arrows.

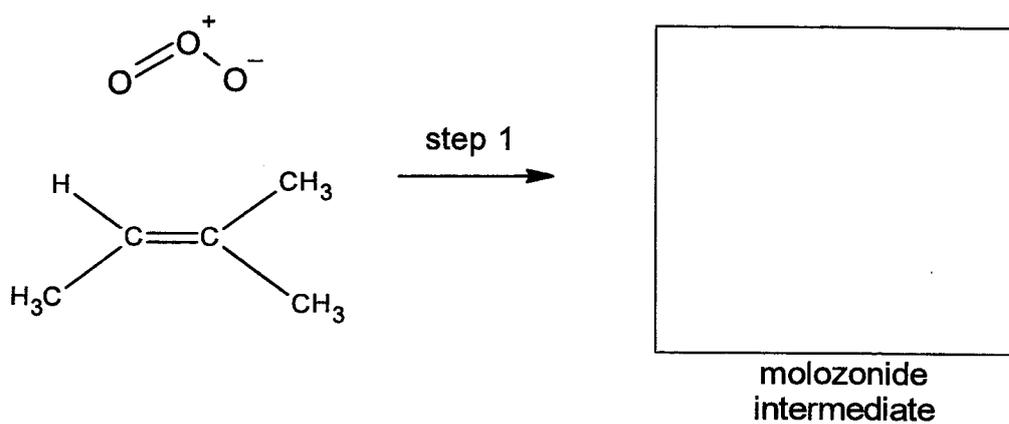
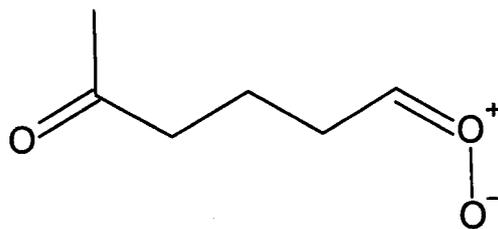
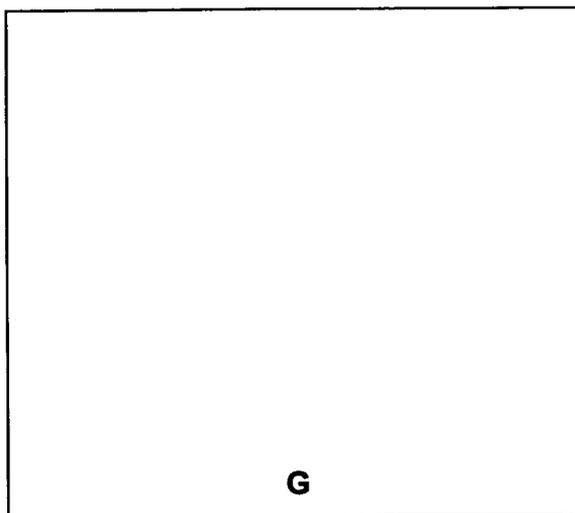


Fig. 2.5

[2]

14

- (ii) Compound **F** was formed in step 2 of the mechanism in Fig 2.4 when ozone reacts with another alkene, **G**. Suggest the identity of **G**.

Compound **F**

[1]

[Total: 7]

3 Heavy metal contamination in water poses significant risks to environmental and human well-being. Common heavy metals found in water include cadmium (Cd), lead (Pb) and mercury (Hg).

(a) The standard electrode potential of the $\text{Cd}^{2+}(\text{aq})/\text{Cd}(\text{s})$ electrode is -0.403V .

(i) Define the term *standard electrode potential*, E^\ominus .

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[1]

(ii) Draw a fully labelled diagram of the experimental set-up used to measure the standard electrode potential, E^\ominus , of the $\text{Cd}^{2+}(\text{aq})/\text{Cd}(\text{s})$ half-cell.

[2]

[TURN OVER

- (iii) Predict how the electrode potential, E^{\ominus} , of $\text{Cd}^{2+}(\text{aq})/\text{Cd}(\text{s})$ will be affected when aqueous sodium hydroxide is added to the $\text{Cd}^{2+}(\text{aq})/\text{Cd}(\text{s})$ half-cell. Explain your answer.

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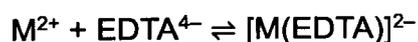
..... [2]

- (b) A water source was found to be contaminated by heavy metal contaminant, Pb^{2+} .

To determine whether the water is safe to drink, complexometric back titration was employed to determine the concentration of Pb^{2+} in a water sample.

The water sample containing Pb^{2+} will be reacted with an excess amount of EDTA^{4-} , where a lead-EDTA complex will be formed in the process.

The general reaction of metal ion, M^{2+} and EDTA^{4-} is as shown:



The remaining amount of EDTA^{4-} is then determined by titrating with zinc sulfate, with Eriochrome Black T as an indicator.

- (i) 10.0 cm^3 of $5.0 \times 10^{-7} \text{ mol dm}^{-3}$ of EDTA^{4-} was added to 10.0 cm^3 of water sample containing Pb^{2+} . The resulting solution was found to require 10.0 cm^3 of $2.0 \times 10^{-7} \text{ mol dm}^{-3}$ of zinc sulfate solution for complete reaction.

Calculate the amount, in moles, of Pb^{2+} present in 10.0 cm^3 of the water sample.

[1]

- (ii) Calculate the mass of Pb^{2+} , in mg, present in 1 dm^3 of water sample.

Given that the safe limit of maximum mass of Pb^{2+} is $0.0100 \text{ mg dm}^{-3}$, comment on whether the water is safe to drink.

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.....

[2]

[TURN OVER]

- (iii) Hydrogen sulfide, H_2S , is added to another 1 dm^3 of water sample containing $1.0 \times 10^{-9} \text{ mol dm}^{-3}$ of Hg^{2+} and Pb^{2+} each.

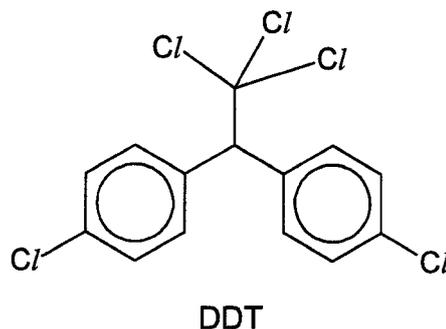
Table 3.1 shows the K_{sp} values for the corresponding metal sulfides.

Table 3.1

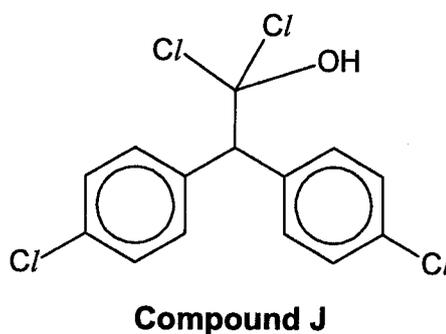
Metal Sulfide	$K_{\text{sp}} / \text{mol}^2\text{dm}^{-6}$
PbS	9×10^{-29}
HgS	2×10^{-53}

Calculate the minimum concentration of hydrogen sulfide added to remove the maximum concentration of Hg^{2+} without precipitating Pb^{2+} . Hence, determine the maximum mass of HgS precipitated in 1 dm^3 .

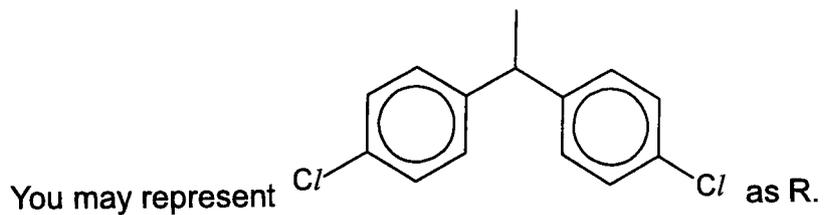
- (c) DDT is a common ingredient in insecticides and it can enter groundwater as an organic pollutant through processes like runoff and leaching.



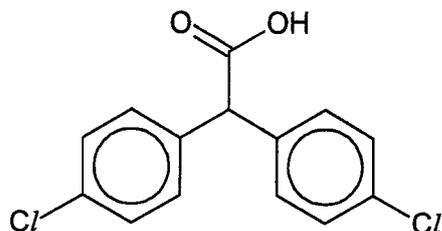
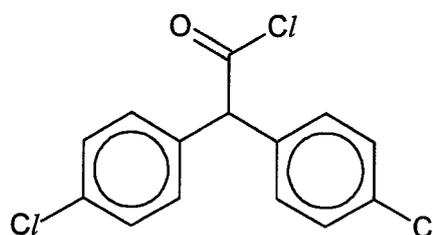
- (i) A student proposed that compound J will be formed when DDT is reacted with hot aqueous sodium hydroxide, assuming that the rate of reaction is independent of the concentration of NaOH.



Name and describe the mechanism for the reaction between DDT and hot aqueous sodium hydroxide to form compound J. Include all relevant lone pairs, dipoles, curly arrows and charges. Include the structure of the organic intermediate.



- (ii) It was found that compound **K** is formed when DDT reacts with hot aqueous sodium hydroxide. **K** then reacts with phosphorus pentachloride to form compound **L**.

compound **K**compound **L**

When the same amount of compounds **K** and **L** (not necessarily in that order) are added to separate and equal volumes of water, solutions are formed with pH values of 0.5 and 3.0.

Suggest which pH value is associated with compounds **K** and **L**. Explain your answer.

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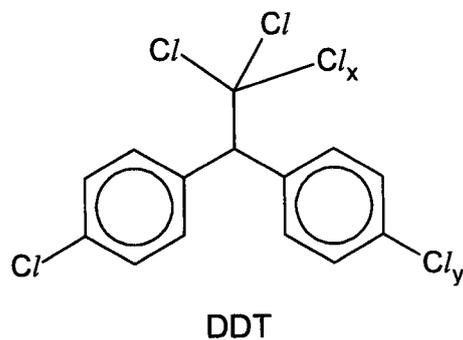
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[2]

- (iii) Explain the difference in reactivity of the two chlorine atoms labelled Cl_x and Cl_y in DDT towards hot aqueous sodium hydroxide.



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[2]

[Total: 16]

- 4 Haemoglobin is a critical protein found in red blood cells that carries oxygen from the lungs to the rest of the body.

Deoxyhaemoglobin and oxyhaemoglobin both contain iron in the +2 oxidation state. Each Fe^{2+} is coordinated to five nitrogen-containing ligands and one oxygen-containing ligand, forming an octahedral arrangement.

In an octahedral complex such as haemoglobin, the 3d subshell of Fe^{2+} is split into two energy levels.

(a) Using the axes in Fig. 4.1, draw **fully-labelled** diagrams of the following.

- One of the d orbitals at the lower energy level in an octahedral complex.
- One of the d orbitals at the higher energy level in an octahedral complex.

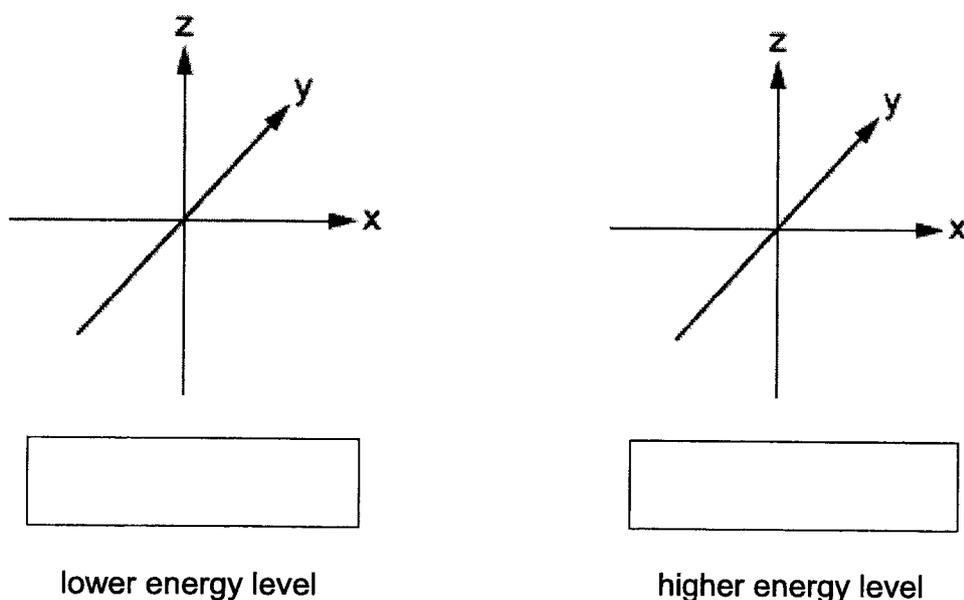
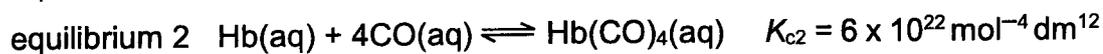


Fig. 4.1

[2]

- (b) Haemoglobin can react with oxygen and carbon monoxide respectively as shown in the following two equilibria.



- (i) Explain why carbon monoxide is toxic.

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[1]

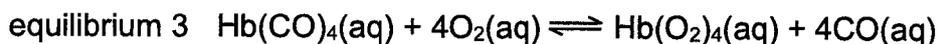
- (ii) Carbon monoxide binds to haemoglobin, Hb, to form carboxyhaemoglobin, Hb(CO)_4 .

If the percentage of haemoglobin bound to carbon monoxide reaches 45%, the result is fatal to humans.

Use the value of K_{c2} to calculate the concentration of carbon monoxide necessary for 45% of the Hb to be converted to Hb(CO)_4 .

[2]

- (iii) Equilibrium 1 and 2 can be expressed as a single equilibrium 3.



Using K_{c1} and K_{c2} , calculate the value of K_c for equilibrium 3.

[1]

- (iv) Use the K_c value calculated in **b(iii)** to suggest the position of equilibrium and the sign for ΔG for equilibrium 3.

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[1]

- (v) A patient suffering from carbon monoxide poisoning can be treated by giving pure oxygen to breathe. Suggest a reason why this treatment is effective.

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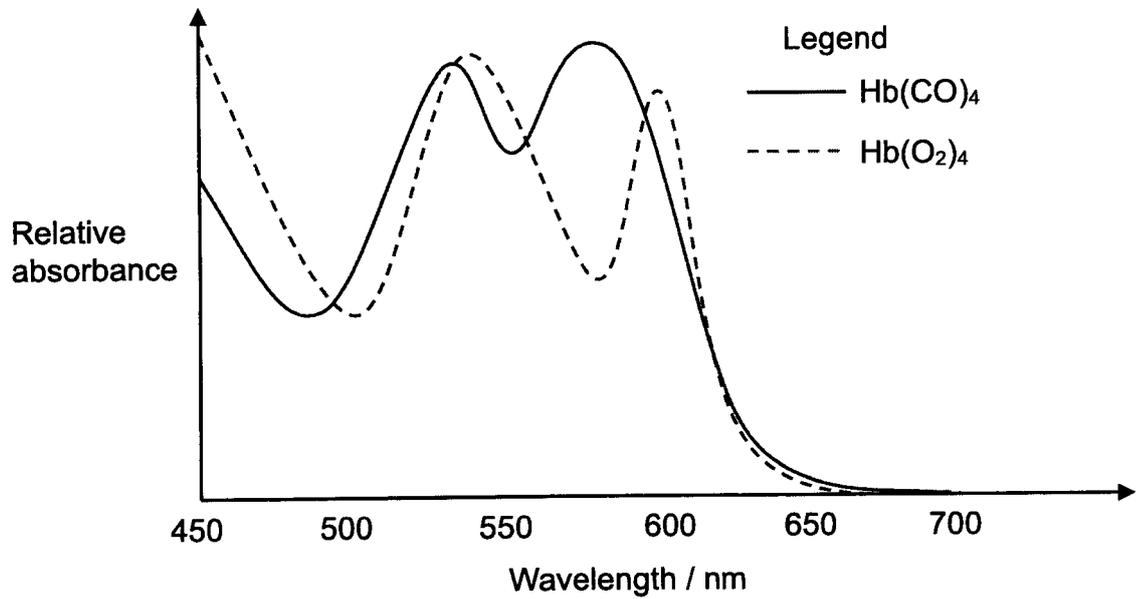
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[2]

- (c) Carboxyhaemoglobin, $\text{Hb}(\text{CO})_4$, and oxyhaemoglobin, $\text{Hb}(\text{O}_2)_4$, were analysed and the absorption spectrum was observed.



Species	Colour Observed
$\text{Hb}(\text{CO})_4$	Cherry-red
$\text{Hb}(\text{O}_2)_4$	Orange-red

Colour	Wavelength (nm)	Colour	Wavelength (nm)
Violet	380 – 400	Yellow	560 – 580
Blue	400 – 490	Orange	580 – 620
Green	490 – 560	Red	620 – 800

- (i) With reference to the absorption spectrum, explain why both $\text{Hb}(\text{CO})_4$ and $\text{Hb}(\text{O}_2)_4$ are generally red in colour.

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[1]

- (ii) Suggest why $\text{Hb}(\text{CO})_4$ and $\text{Hb}(\text{O}_2)_4$ have different shades of red.

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[2]

[Total: 12]

- 5 Cycling is a demanding endurance sport that pushes athletes to optimise every aspect of their performance. Chemists play a critical role in this field by enhancing bicycle materials, improving energy metabolism in cyclists and in ensuring safety.

- (a) Cyclists often look for ways to reduce the weight of their bicycles, which typically weigh around 7.4 kg. One proposed idea is to inflate bicycle tyres with helium instead of air to reduce weight.

- (i) State two basic assumptions of kinetic theory as applied to an ideal gas.

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[2]

- (ii) Using the data in Table 5.1, calculate the respective mass of helium and mass of air required under the same given conditions.

Suggest, with a reason, whether the use of helium provides a significant advantage in terms of mass.

Table 5.1

	Value
Molar mass of helium (He)	4.0 g mol ⁻¹
Molar mass of air (approximate)	29.0 g mol ⁻¹
Volume of gas in a standard bicycle tyre	2.0 dm ³
Pressure in tyre	8 bar
Temperature	298 K

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[3]

- (iii) Rubber tyres are made of vulcanised rubber, a cross-linked polymer. Although they appear solid, they contain tiny free volumes between polymer chains at the nanometer scale, typically around 0.3 – 0.5 nm.

With reference to the *Data Booklet*, suggest why helium should not be used to inflate the tyres.

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[1]

- (b) A bicycle frame must balance tensile strength, weight, durability and cost. Choosing the right material is key to optimising cycling performance.

Tensile strength is the maximum stress that a material can withstand before it shows significant deformation of its body shape.

Table 5.2

Material	Density (g/cm³)	Tensile Strength (MPa)	Relative Cost	Corrosion Resistance
Aluminium	2.70	310	Moderate	Moderate
Titanium	4.50	900	High	High
Steel	7.85	500	Low	Low
Graphite Fibre	1.60	600	Very High	High

- (i) Explain, in terms of structure and bonding, why graphite fibre has relatively high tensile strength.

.....
 [1]

- (ii) Considering the data provided in Table 5.2, recommend the most suitable material for a high-performance racing bicycle frame. Justify your choice in terms of the factors in Table 5.2.

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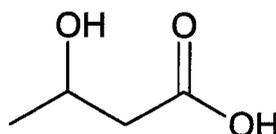
 [2]

- (c) Endurance athletes, such as cyclists, are constantly seeking ways to boost stamina and fight fatigue. One option is to consume BHB energy supplement.

Beta-hydroxybutyrate (BHB), is a lab-made compound that serves as an efficient fuel source for both the brain and body when glucose levels are low.

In cells, BHB enters the mitochondria to produce ATP, which is the body's main source of energy.

Compared to glucose, it generates less waste, helps conserve NAD^+ (a molecule essential for energy metabolism) and avoids blood sugar spikes. However, BHB is also expensive, has a bitter taste, may cause nausea and is absorbed more slowly than glucose. This makes it less ideal for short, intense bursts of energy.



beta-hydroxybutyrate (BHB)

- (i) State the systematic name for BHB.

..... [1]

- (ii) BHB has stereoisomers. State the type of stereoisomerism present in BHB and draw the stereoisomers.

Type of stereoisomerism:

[2]

- (iii) Use the data in Table 5.3, calculate the energy released in kJ g^{-1} for both BHB and glucose when they undergo combustion.

Table 5.3

	Molar mass / g mol^{-1}	Standard enthalpy change of combustion / kJ mol^{-1}
BHB	118.13	-2430
Glucose	180.16	-2805

[1]

(iv) Based on your calculations in **(c)(iii)**, suggest whether using BHB as an energy supplement would benefit endurance cyclists. Give a reason for your answer.

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

(v) Suggest a disadvantage of using BHB as an energy supplement.

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



ST. ANDREW'S JUNIOR COLLEGE
 JC2 PRELIMINARY EXAMINATIONS
 HIGHER 2

CANDIDATE

NAME

CLASS

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CHEMISTRY

9729/03

Paper 3 Free Response

15 September 2025

Candidates answer on the Question Paper.

2 hours

Additional Materials: Data Booklet

READ THESE INSTRUCTIONS FIRST

Write your name and class on all the work that you hand in.

Write in dark blue or black pen.

You may use a 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.

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.

For Examiner's Use		
Q1		22
Q2		18
Q3		20
Q4 / Q5		20
Total		80

A Data Booklet is provided.

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.

This document consists of **35** printed pages (including this cover page).

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(b) Calcium carbide reacts vigorously and explosively with water.

Using the data in Table 1.1, calculate the standard enthalpy change of reaction for reaction 1.

Table 1.1

compound	$\Delta H_f^\ominus / \text{kJ mol}^{-1}$
$\text{CaC}_2(\text{s})$	- 59.0
$\text{H}_2\text{O}(\text{l})$	-285.8
$\text{Ca}(\text{OH})_2(\text{s})$	- 985.2
$\text{C}_2\text{H}_2(\text{g})$	+226.6

[2]

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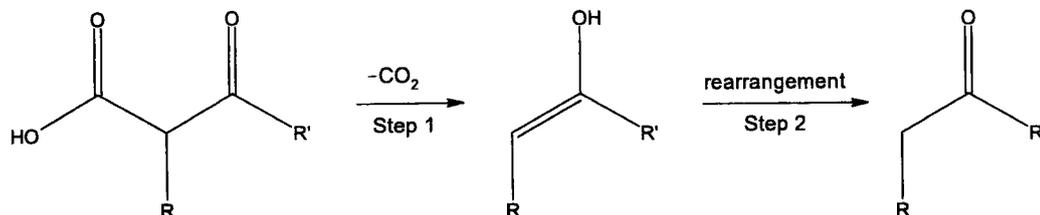
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[TURN OVER

- (b) Decarboxylation is the loss of carbon dioxide from a carboxylic acid group. It plays an important role in organic synthesis and occurs under specific thermal or catalytic conditions.

Two examples of decarboxylation are shown in Fig. 2.1.

Example 1:



Example 2:

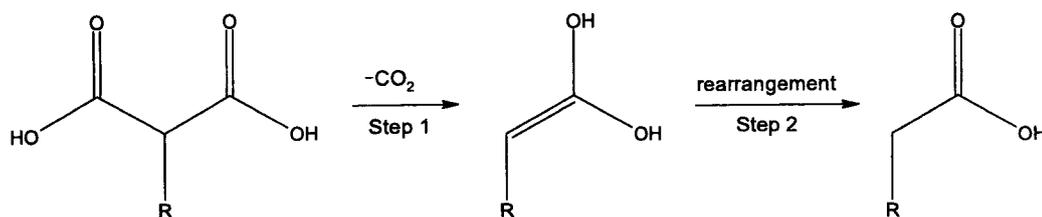
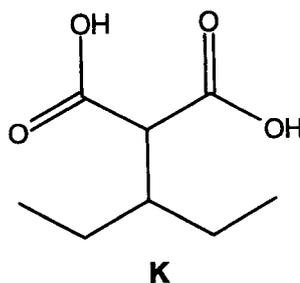


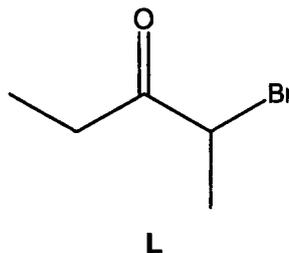
Fig. 2.1

- (i) Draw the structure of the organic product formed when compound **K** undergoes decarboxylation.



[1]

- (ii) Two different acids, **M** and **N**, each can undergo decarboxylation to give **L**.



[2]

Suggest possible structures of **M** and **N**.

- 3 (a) Describe and explain the trend in the thermal stability of the hydrogen halides HCl, HBr and HI. Include an equation for the thermal decomposition reaction in your answer. [3]

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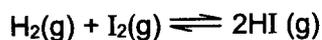
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- (b) To form concentrated solutions of hydroiodic acid, hydrogen iodide gas is first formed by reaction of hydrogen and iodine gas before being bubbled into water.



- (i) State the conditions necessary for a gas to approach ideal behaviour. [1]
- (ii) The graphs of pV/RT against p for HI gas and gas J are shown in Fig. 3.1.

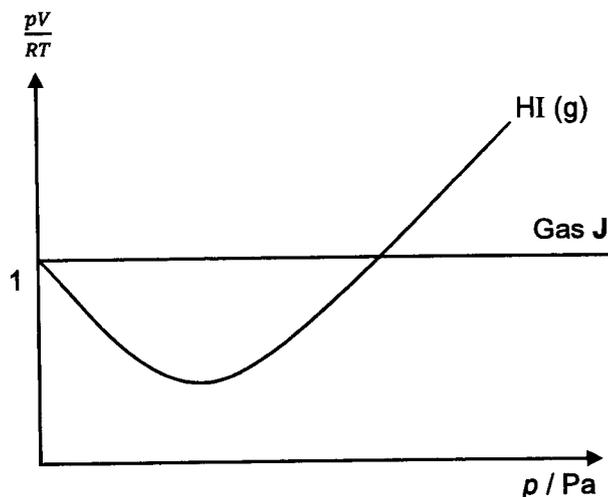
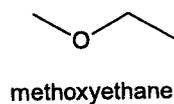


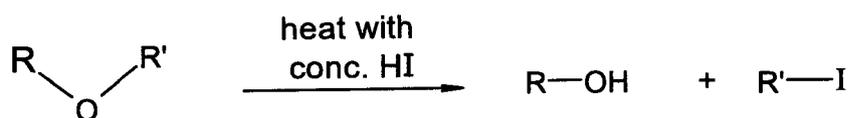
Fig. 3.1

- Explain the shape of the graph for HI gas and gas J. Your answer should include references to intermolecular forces. [2]

- (c) Ethers have the general structure of R_1-O-R_2 , where R_1 and R_2 are alkyl or aryl groups, for example, like methoxyethane.



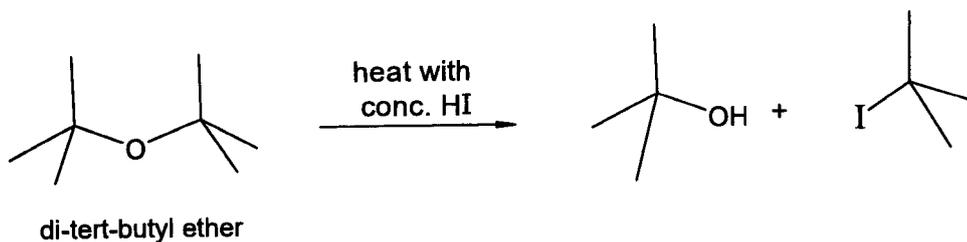
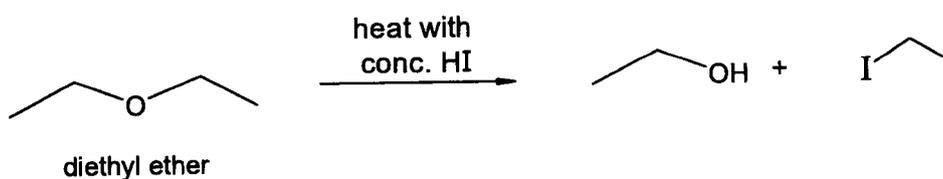
When reacted with hot concentrated solutions of hydroiodic acid, HI, ether can form an alkyl halide and an alcohol as shown in Fig. 3.2.



where R and R' are different alkyl groups

Fig. 3.2

Two examples are shown below.



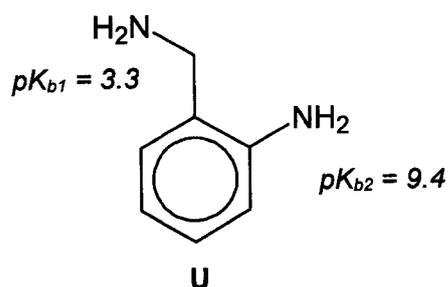
- (i) It was found that primary or secondary ethers, like diethyl ether, reacts via S_N2 mechanism while tertiary ethers, like di-tert-butyl ether, reacts via S_N1 mechanism.

Explain why this reaction proceeds mainly via:

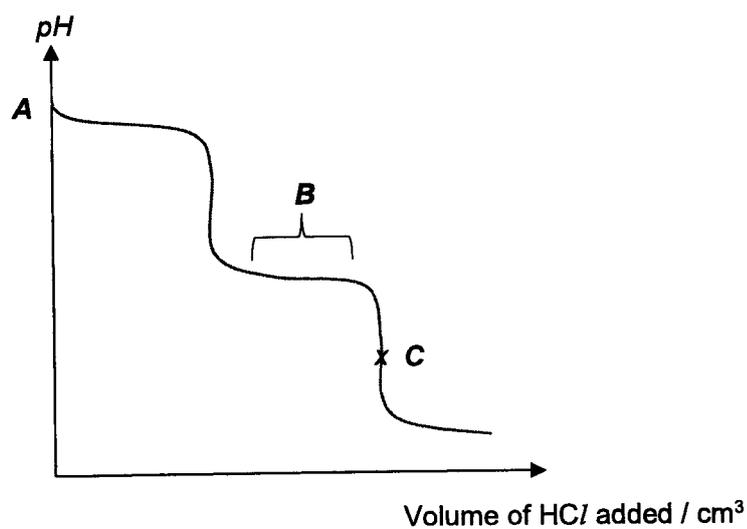
1. S_N2 mechanism for primary or secondary ethers
2. S_N1 mechanism for tertiary ethers

[2]

(d) The two pK_b values for each amine groups in **U** is shown below.



The pH curve below shows the addition of $0.010 \text{ mol dm}^{-3} \text{ HCl}$ to 10.0 cm^3 of $0.020 \text{ mol dm}^{-3}$ compound **U**.



- (i) Calculate the pH at point A. [2]
- (ii) Draw the two organic structures at region B and explain how these species help to maintain the pH of the solution when a small amount of H^+ or OH^- is added. [3]
- (iii) Calculate the concentration of the salt at point C. [2]

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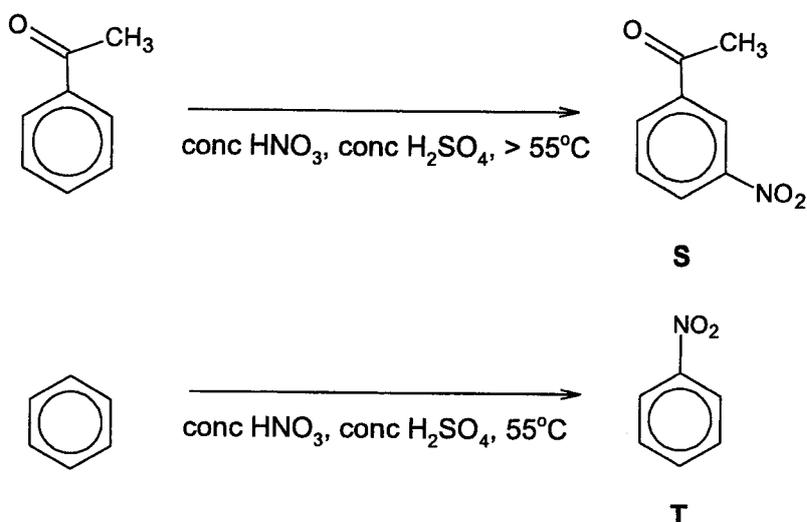
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- (b) (i) Both acetophenone and benzene react with nitric acid, but under different conditions to form compounds **S** and **T** respectively.



Explain why different conditions are needed for these two reactions. [2]

- (ii) The solubility of **S** and **T** in water are shown in Table 5.1.

Table 5.1

Compound	Solubility in water / mg dm ⁻³
S	108
T	80

Explain, in terms of structure and bonding, the difference in solubility between **S** and **T**. [2]

[TURN OVER

