



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

CANDIDATE
NAME

CLASS

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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.

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..... [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+} .

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..... [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.

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..... [1]

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

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..... [2]

[TURN OVER

- (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° values, suggest why KMnO_4 is a stronger oxidising agent than $\text{K}_2\text{Cr}_2\text{O}_7$.

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[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.

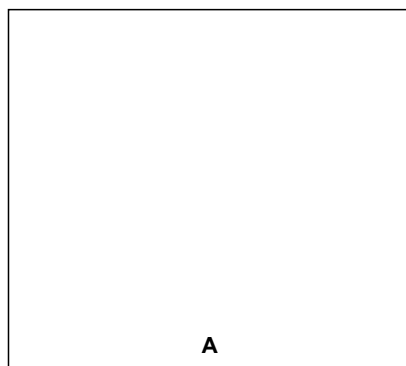
- Alkene
- Alcohol
- Carbonyl

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**.

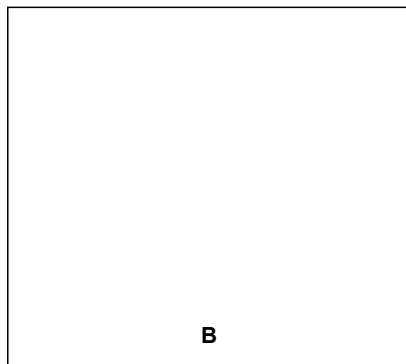


[1]

[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]

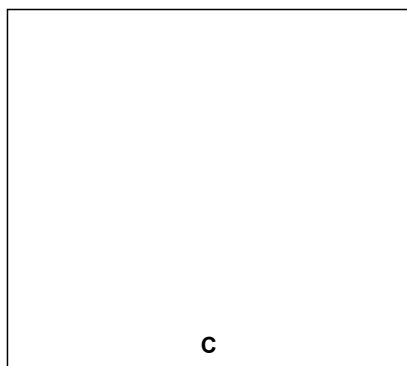
- (iv) State all possible functional groups in **C**.

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[1]

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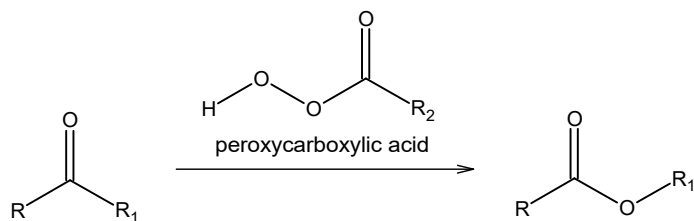
- (v) **C** is unable to exhibit stereoisomerism. Draw the structure of **C**.



[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 $\text{O}_3(\text{g})$.

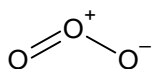
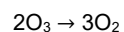


Fig. 2.1

[TURN OVER

- (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.

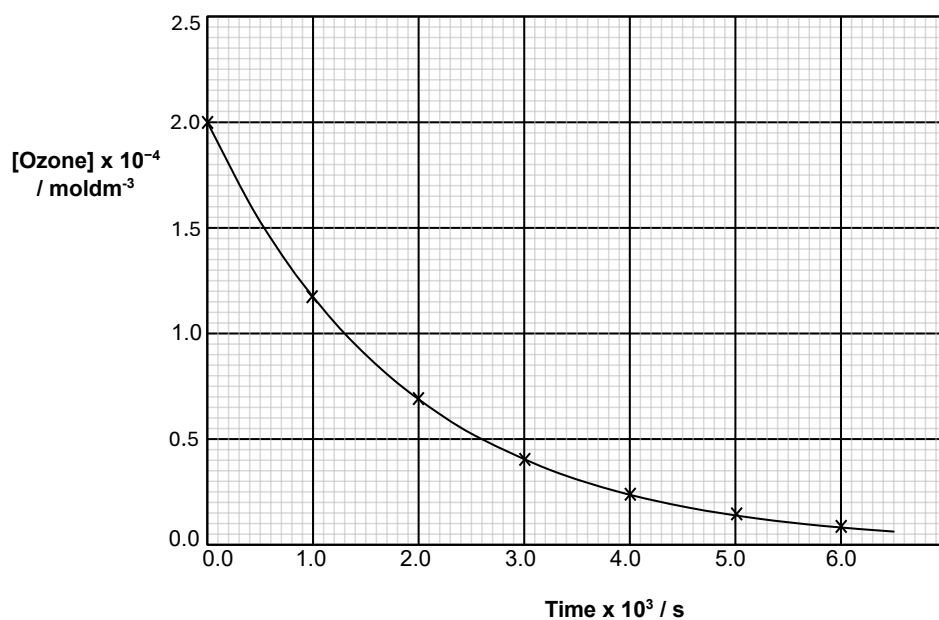


Fig. 2.2

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

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[1]

Commented [KCH1]: Define what is meant by the term "order of reaction".

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

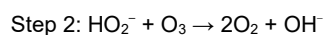
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[1]

- (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.

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[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.

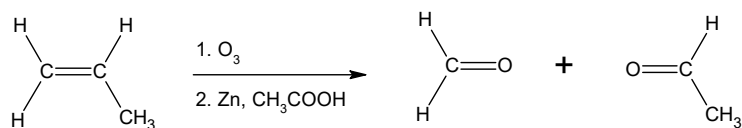


Fig. 2.3

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.

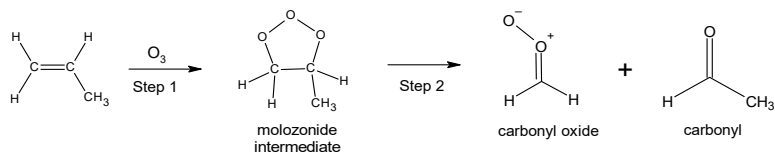


Fig. 2.4

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.

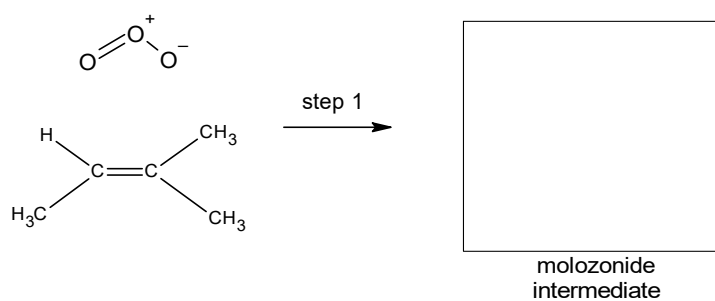


Fig. 2.5

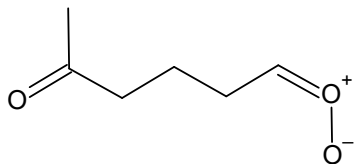
[2]

Commented [SXF2]: On Fig 2.5

[TURN OVER

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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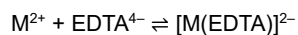
..... [2]

- (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.

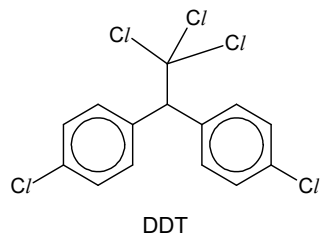
Table 3.1 shows the K_{sp} values for the corresponding metal sulfides.

Table 3.1

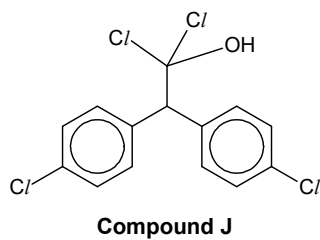
Metal Sulfide	$K_{\text{sp}} / \text{mol}^2\text{dm}^{-6}$
PbS	9×10^{-29}
HgS	2×10^{-53}

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.



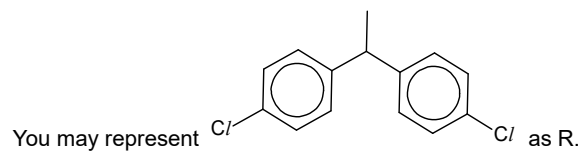
- (i) A student proposed that compound **J** will be formed when DDT is reacted with hot aqueous sodium hydroxide, assuming that the rate of reaction is independent of the concentration of NaOH.



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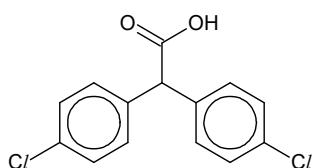
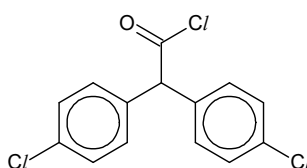
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Name and describe the mechanism for the reaction between DDT and hot aqueous sodium hydroxide to form compound **J**. Include all relevant lone pairs, dipoles, curly arrows and charges. Include the structure of the organic intermediate.



[2]

- (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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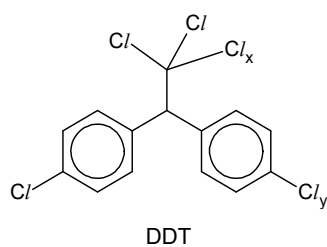
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[2]

[TURN OVER]

- (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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[Total: 16]

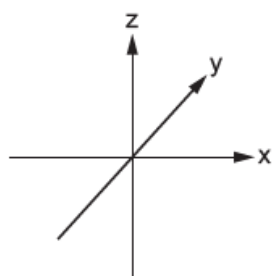
- 4 Haemoglobin is a critical protein found in red blood cells that carries oxygen from the lungs to the rest of the body.

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.

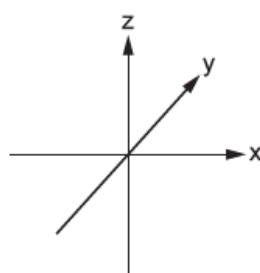
In an octahedral complex such as haemoglobin, the 3d subshell of Fe^{2+} is split into two energy levels.

- (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.



lower energy level



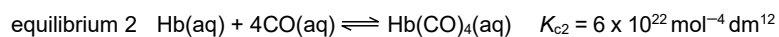
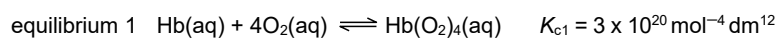
higher energy level

Fig. 4.1

[2]

[TURN OVER

- (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]

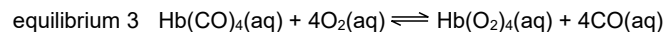
- (ii) Carbon monoxide binds to haemoglobin, Hb, to form carboxyhaemoglobin, Hb(CO)_4 .

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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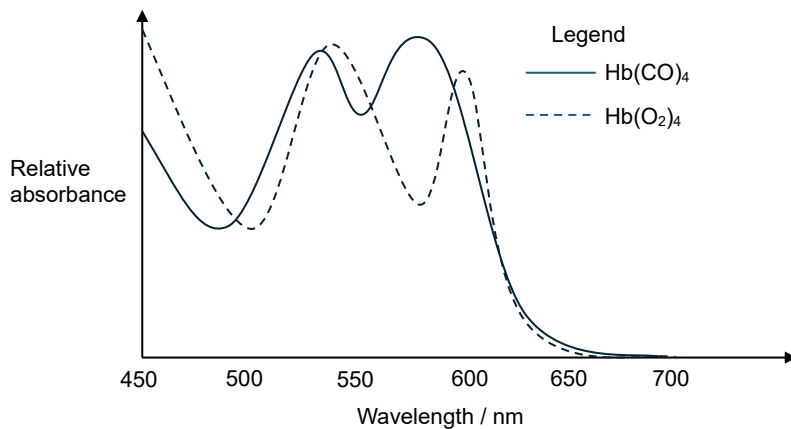
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[2]

[TURN OVER]

- (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]

[TURN OVER]

- (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]

[TURN OVER

- (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/cm ³)	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.

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..... [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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Commented [KCH5R3]: To be discussed.

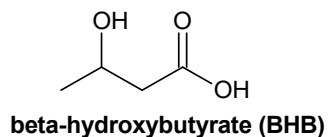
Commented [LW(6)]: Include definition of tensile strength

- (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.



- (i) State the systematic name for BHB.

..... [1]

[TURN OVER

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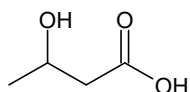
- (v) Suggest a disadvantage of using BHB as an energy supplement.

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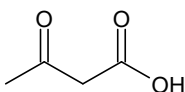
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[TURN OVER

- (d) BHB, acetoacetate (AcAc) and acetone are fat-derived compounds made mainly in the liver. They form about 80% of the ketones in the blood and provide energy especially to the brain during fasting, intense exercise or low-carbohydrate diets.



beta-hydroxybutyrate (BHB)



acetoacetate (AcAc)



acetone

Describe a simple chemical test, with appropriate observations, that can be carried out to distinguish between each of the following pairs of compounds.

- AcAc and acetone
- AcAc and BHB

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[4]

[Total: 19]

END OF PAPER

Additional Answer Space

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