VICTORIA JUNIOR COLLEGE
JC 2 PRELIMINARY EXAMINATION
Higher 2

CHEMISTRY **9729/01**

Paper 1 Multiple Choice **19 September 2025**

1 hour

Additional Materials: Multiple Choice Answer Sheet
Data Booklet

READ THESE INSTRUCTIONS FIRST

Write in soft pencil.
Do not use staples, paper clips, glue or correction fluid.
Write your name, CT group and VJC index number on the Answer Sheet.

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 Answer Sheet.

Read the instructions on the Answer Sheet very carefully.

Each correct answer will score one mark. A mark will not be deducted for a wrong answer.
Any rough working should be done in this booklet.
The use of an approved scientific calculator is expected, where appropriate.

This document consists of **12** printed pages

For each question there are four possible answers, **A**, **B**, **C**, and **D**. Choose the **one** you consider to be correct.

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

Berkelium, Bk, and Fermium, Fm, are both actinoids. An isotope of Bk^{2+} and an isotope of Fm^{3+} have 249 and 252 nucleons respectively.

Which row of the table is correct?

	ion containing larger number of neutrons	ion containing larger number of electrons
A	Bk^{2+}	Fm^{3+}
B	both the same	Fm^{3+}
C	Fm^{3+}	Bk^{2+}
D	both the same	Bk^{2+}

2 Consider the atoms of the Period 3 elements from Na to Ar.

What is the total number of paired electrons in the valence shells of these eight elements?

A 26 **B** 28 **C** 30 **D** 32

3 The boiling points of HF, HC*l* and HBr are different. HC*l* has the lowest boiling point.

Which statements are correct?

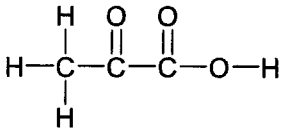
1 HC*l* has a lower boiling point than HBr because HC*l* molecules have weaker permanent dipole-permanent dipole forces of attraction.

2 HF molecules experience weaker temporary dipole-induced dipole forces of attraction than HBr molecules.

3 HF molecules experience stronger permanent dipole-permanent dipole forces of attraction than HC*l* molecules.

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

4 The diagram shows the structure of a pyruvic acid.



pyruvic acid

What set of bond angles are present in pyruvic acid?

A 180°, 120°, 90°

B 180°, 120°, 109°

C 120°, 105°, 90°

D 120°, 109°, 105°

5 Which statement applies to both ideal and real gases?

A Collisions between molecules are elastic.

B Molecules are in constant random motion.

C Molecules attract each other.

D Molecules have zero size.

6 Acetylene (C_2H_2) is unable to react with water but is able to react with a strong base like sodium amide ($NaNH_2$).

$$HC{\equiv}CH + NaNH_2 \longrightarrow HC{\equiv}CNa + NH_3$$

Which of the following statements is correct?

A Acetylene acts as an Arrhenius acid as it contains a hydrogen atom.

B Acetylene does not act as an Arrhenius acid as it unable to dissociate in water to form H_3O^+.

C The conjugate base of acetylene is $HC{\equiv}CNa$.

D Acetylene acts as a Lewis acid in the reaction with sodium amide.

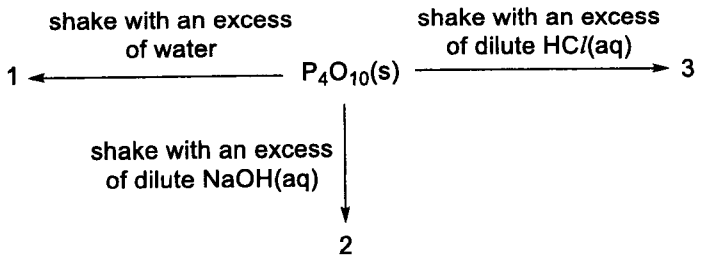
7 The three minerals below are known as double carbonates, which are carbonates containing 2 metallic elements. Double carbonates decompose in two steps, with each step involving the decomposition of one of the metallic carbonates that it contains. The decomposition of the carbonates releases carbon dioxide, which helps to smother fire, thus acting as fire retardants.

mineral	chemical formula
dolomite	$CaMg(CO_3)_2$
huntite	$Mg_3Ca(CO_3)_4$
norsethite	$BaMg(CO_3)_2$

Which row correctly shows the relative effectiveness of the minerals as a fire retardant?

	most effective ⟶		least effective
A	dolomite	huntite	norsethite
B	norsethite	dolomite	huntite
C	norsethite	huntite	dolomite
D	huntite	dolomite	norsethite

8 A student carries out an investigation using phosphorus (V) oxide. All experiments are carried out room temperature.



Which observations would the student make of the results of these experiments?

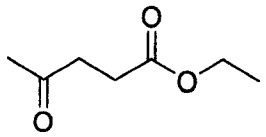
A No solid remains in any experiment.

B A solid remains in one experiment only.

C A solid remains in two experiments only.

D Solid remains in all three experiments.

9 Compound **G**, $C_7H_{12}O_3$, is a diesel fuel additive which reduces the amount of soot formed when the fuel burns.



compound **G**

How many moles of oxygen gas are needed to completely burn 1 mole of compound **G**?

A 8.5 **B** 9.0 **C** 9.5 **D** 10.0

10 Magnesium(I) chloride, MgC*l*, does not exist as a stable compound but its lattice energy can be estimated.

What is the predicted order of increasing magnitude of lattice energy of MgC*l*, $MgCl_2$ and $SrCl_2$?

A MgC*l*, $MgCl_2$, $SrCl_2$

B MgC*l*, $SrCl_2$, $MgCl_2$

C $MgCl_2$, $SrCl_2$, MgC*l*

D $SrCl_2$, MgC*l*, $MgCl_2$

11 Some $\Delta H_f^\ominus$ values are given below.

compound	$\Delta H_f^\ominus$ / kJ mol^{-1}
$H_2O(l)$	–286
$CO_2(g)$	–394
$C_6H_{12}O_6(s)$	–1273

The overall reaction in photosynthesis can be represented by the following equation.

$$6CO_2(g) + 6H_2O(l) \rightarrow C_6H_{12}O_6(s) + 6O_2(g)$$

Which of the following statements are correct?

1 The enthalpy change of the reaction is +2807 kJ mol^{-1}

2 In the formation of products, the system becomes less disordered.

3 The reaction is not spontaneous at all temperatures.

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

12 The hydrolysis of ethyl ethanoate in aqueous solution can be catalysed by hydrogen ions from sulfuric acid.

To determine the order of this reaction with respect to hydrogen ions, which method should be used?

A Measure the change in pH during the reaction.

B Measure the rate of the reaction several times, but with a different concentration of ethyl ethanoate each time.

C Measure the rate of the reaction several times, but with a different concentration of sulfuric acid each time.

D Remove samples at various time intervals and titrate against a standard solution of aqueous sodium hydroxide.

13 The mechanism below has been proposed for the reaction of $CHCl_3$ with Cl_2.

Step 1: $Cl_2(g) \rightleftharpoons 2Cl(g)$ fast

Step 2: $Cl(g) + CHCl_3(g) \rightarrow CCl_3(g) + HCl(g)$ slow

Step 3: $CCl_3(g) + Cl(g) \rightarrow CCl_4(g)$ fast

Which of the following rate equations is consistent with this mechanism?

A rate = $k[CHCl_3][Cl]$

B rate = $k[CHCl_3][Cl_2]$

C rate = $k[CHCl_3][Cl_2]^{1/2}$

D rate = $\frac{k[CHCl_3]}{[Cl_2]}$

14 The rates of chemical reaction can be increased by increasing the concentration of reactants, raising the temperature or adding a catalyst.

Which statement is **not** correct?

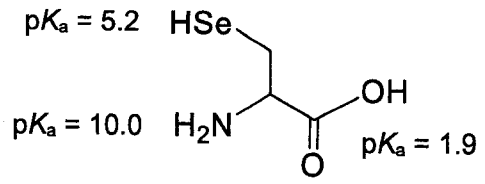
A Increasing the temperature increases the proportion of particles having energy greater than the activation energy.

B Adding a catalyst increases the proportion of particles having energy greater than the activation energy.

C Increasing the temperature increases the rate constant.

D Increasing the concentration of the reactants increases the rate constant.

15 The structure of an amino acid, Selenocysteine, with its three functional groups is shown below. The pK_a of –SeH, –NH_2 and –COOH are 5.2, 10.0 and 1.9 respectively.



Which statements are correct about Selenocysteine at fixed temperature?

1 The carboxylic acid group (–COOH) is the most acidic group.

2 At pH 8, Selenocysteine will migrate towards the positive terminal in an electric field.

3 When the concentration of H^+ is high, K_a of the three functional groups decreases due to lower extent of dissociation.

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

16 Which scenario best demonstrates a common ion effect that reduces the solubility of the underlined salt?

A Adding $Pb(NO_3)_2$ to a solution of $\underline{PbCl_2}$

B Adding KNO_3 to a solution of $\underline{AgCl}$

C Adding Na_2SO_4 to a solution of $\underline{BaCl_2}$

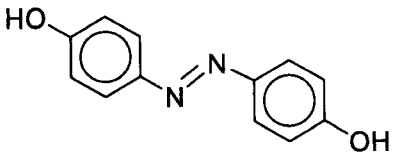
D Adding $AgCl$ to a solution of $\underline{NaCl}$

17 In the following sequence of reactions, what is the mechanism of each step?

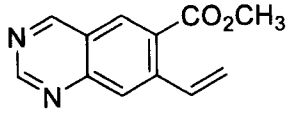
$$CH_3OH \xrightarrow[\text{step 1}]{\text{HBr, heat}} CH_3Br \xrightarrow[\text{step 2}]{(CH_3)_3P} (CH_3)_4P^+Br^-$$

	step 1	step 2
A	electrophilic substitution	electrophilic addition
B	electrophilic substitution	nucleophilic addition
C	nucleophilic substitution	electrophilic substitution
D	nucleophilic substitution	nucleophilic substitution

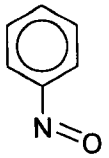
18 The three compounds **E**, **F** and **G** have the following structures.



E



F



G

Which statements about **E**, **F** and **G** are correct?

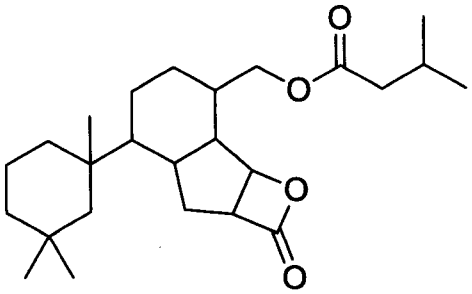
1 **E** and **G** have the same empirical formula.

2 **E** and **F** are isomers.

3 The M_r of **F** is exactly twice that of **G**.

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

19 The structure of compound **T** is shown below.



compound **T**

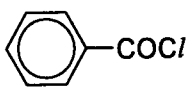
How many chiral centers does 1 molecule of **T** have?

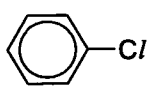
A 5 **B** 6 **C** 7 **D** 8

20 When a substance, **Z**, is shaken with aqueous silver nitrate at room temperature, there is no immediate precipitate.

In a second experiment, **Z** is boiled under reflux for some time with aqueous sodium hydroxide. The resulting solution is cooled and acidified with dilute nitric acid. When aqueous silver nitrate is now added, a white precipitate readily forms.

What could **Z** be?

A 

B 

C $CH_3CH_2CHCHCl$

D $CH_3CH_2CH_2CH_2Cl$

21 Alcohols can be dehydrated by passing their vapour over heated aluminium oxide.

Which compound is **not** produced when hexan-3-ol is treated in this way?

A $CH_3CH_2CH_2CH=CHCH_3$

B $CH_3CH_2CH=CHCH_2CH_3$

C $CH_2=CHCH_2CH_2CH_2CH_3$

D H_2O

22 Which reaction will form $(CH_3)_2CHCH_2CO_2H$?

A 2-methylpropanenitrile with dilute sodium hydroxide

B ethyl 2-methylbutanoate with dilute sulfuric acid

C 3-methylbutan-1-ol with acidified $Cr_2O_7^{2-}$

D 3-methylbutan-2-ol with acidified MnO_4^-

23 Which statements are correct about the reaction between ethylamine and ethanoyl chloride?

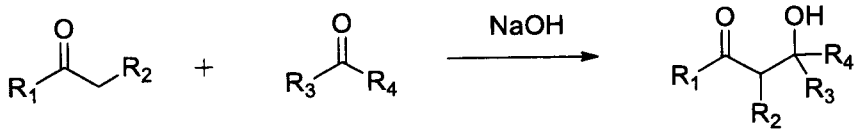
1 During the reaction, a carbon-chlorine bond is broken and a carbon-nitrogen bond is formed.

2 The same reaction will take place if ethanoyl chloride is replaced by ethanoic acid.

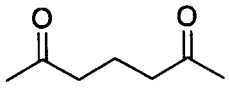
3 The organic product formed, when dissolved in water will give a solution that has a pH greater than 7.

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

24 The aldol reaction between two carbonyl compounds involves the removal of a H^+ from a carbon atom adjacent to the carbonyl group by NaOH, and subsequent formation of the product. An example is shown below.

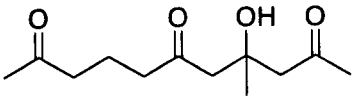


The following compound is a diketone.

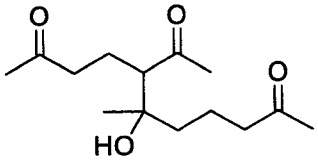


Which one of the following products **cannot** possibly be formed from the above diketone via the aldol reaction?

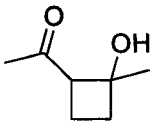
A



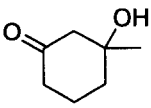
B



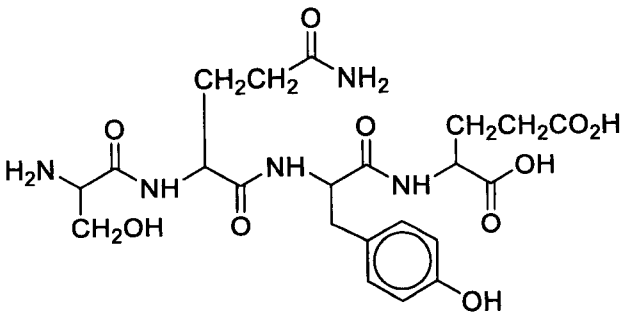
C



D



25 The diagram shows the structure of the tetrapeptide T.



T

When 0.1 mol of T is heated under reflux with NaOH(aq) until no further reaction occurs, how many mol of NaOH will react?

A 0.4 **B** 0.5 **C** 0.6 **D** 0.7

26 **J** is a synthetic nonapeptide that is found in honeybee venom.

To investigate the sequence of amino acids in **J**, the nonapeptide was first hydrolysed by two enzymes. The protein fragments were then separated and their sequence determined.

The first enzyme, which hydrolysed the polypeptide chain at the carboxylic end of the amino acid lysine, Lys, yielded the following fragments.

Trp-Ile-Lys
Leu-Arg
Arg-Ile-Ser-Lys

The following protein fragments were obtained from the second enzyme which hydrolysed the polypeptide chain at the carboxylic end of the amino acid isoleucine, Ile.

Ser-Lys-Trp-Ile
Arg-Ile
Lys-Leu-Arg

Which is the correct primary structure of the nonapeptide **J**?

A Lys-Leu-Arg-Ile-Ser-Lys-Trp-Ile-Lys

B Arg-Ile-Ser-Lys-Trp-Ile-Lys-Leu-Arg

C Ser-Lys-Trp-Ile-Lys-Leu-Arg-Ile-Ser

D Trp-Ile-Lys-Leu-Arg-Ile-Ser-Lys-Trp

27 A current was passed through two cells connected in series. The first cell contained molten magnesium chloride, $MgCl_2$, while the other contained molten chromium(III) chloride, $CrCl_3$.

4.8 g of magnesium was liberated from the first cell. What is the mass of chromium liberated from the other cell?

A 2.4 g **B** 3.2 g **C** 6.8 g **D** 15.6 g

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

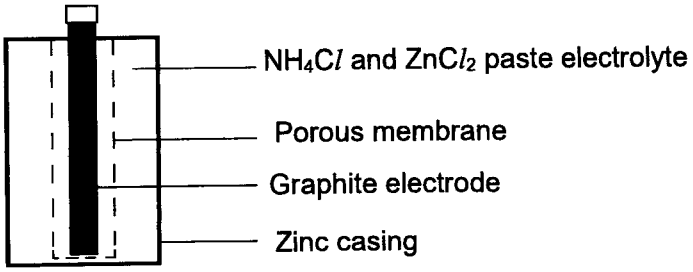
An excess of sulfur dioxide, SO_2, is bubbled into a warm solution containing VO_2^+ ions in acid conditions.

What will be the final oxidation state of vanadium?

A +2 **B** +3 **C** +4 **D** +5

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

A dry cell is a type of electrochemical cell that serves as a portable source of electrical energy. The diagram below shows the setup for a dry cell.



The NH_4Cl and $ZnCl_2$ paste electrolyte are sufficiently mobile to travel to the electrodes.

The half-cell equation for NH_4^+ is shown below.

$$2NH_4^+ + 2e^- \rightleftharpoons 2NH_3 + H_2 \qquad E^\ominus = +0.74V$$

Which row correctly shows the direction of flow of electrons and the $E^\ominus_{cell}$ of the dry cell?

	direction of electron flow in external circuit	$E^\ominus_{cell}$ / V
A	zinc casing to graphite electrode	+1.50
B	zinc casing to graphite electrode	+2.12
C	graphite electrode to zinc casing	+1.50
D	graphite electrode to zinc casing	+2.12

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

A student noted the relevant standard electrode potentials and correctly deduced that bubbling $O_2(g)$ through an acidic solution of HBr(aq) should oxidise it to $Br_2(aq)$.

On bubbling air through an acidic solution of HBr(aq) in a test tube, the student observed no effect.

What could be reasons for this?

1 The oxygen pressure was smaller than 1.0 atmosphere.

2 The activation energy for the reaction is high.

3 The $Br^-(aq)$ concentration is much smaller than 1.0 mol dm^{-3}.

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

VICTORIA JUNIOR COLLEGE
JC 2 PRELIMINARY EXAMINATION
Higher 2

CANDIDATE NAME .....

CT GROUP .....

CHEMISTRY

9729/02

Paper 2 Structured Questions

29 August 2025

2 hours

Additional Materials: Data Booklet

READ THESE INSTRUCTIONS FIRST

Write your name and CT group on this cover page.
Write in dark blue or black pen on both sides of the paper.
You may use a soft pencil for any diagrams, graphs or rough working.
Do not use staples, paper clips, highlighters, glue or correction fluid.

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

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

The number of marks is given in brackets [ ] at the end of each question or part question.

For Examiner's Use	
1	/ 18
2	/ 16
3	/ 17
4	/ 9
5	/ 15
Total	/ 75

This document consists of **19** printed pages and **1** blank page

Answer **all** the questions in the spaces provided.

1 Alkynes are a class of organic compounds with the general formula C_nH_{2n-2}.

(a) (i) With the aid of a labelled diagram, explain how the orbitals overlap to form the C≡C bond in ethyne, H–C≡C–H.

.....

.....

.....

..... [3]

(ii) Table 1.1 shows the carbon-hydrogen bond length in ethane, ethene and ethyne.

Table 1.1

Molecule	Carbon-hydrogen bond length / nm
ethane	0.114
ethene	0.109
ethyne	0.106

Use the concept of hybridisation to explain the difference in bond length of the carbon-hydrogen bond between the molecules as shown in Table 1.1.

.....

.....

.....

..... [2]

(b) Table 1.2 contains data that is relevant for this question.

Table 1.2

Equation	$\Delta H^{\ominus}$ / kJ mol^{-1}
$3C(s) + H_2O(l) \rightarrow CO(g) + C_2H_2(g)$	+401
$2C(s) + O_2(g) \rightarrow 2CO(g)$	–221
$2H_2O(l) \rightarrow 2H_2(g) + O_2(g)$	+572

(i) Write an equation to represent the standard enthalpy change of formation of $C_2H_2(g)$.

..... [1]

(ii) Use data from Table 1.2 to calculate the standard enthalpy change of formation of $C_2H_2(g)$.

[2]

(c) **(i)** Using the bond energies in the *Data Booklet*, calculate the enthalpy change of combustion of ethyne shown in equation 1.1.

equation 1.1 $H–C{\equiv}C–H(g) + \frac{5}{2}O{=}O(g) \rightarrow 2O{=}C{=}O(g) + H–O–H(g)$

[2]

(ii) The entropy change of combustion of ethyne is –2150 J K^{-1} mol^{-1} at 305 °C.

Explain what is meant by the term *entropy*.

.....

..... [1]

(iii) With reference to equation 1.1, explain why the entropy change of combustion of ethyne has a negative sign.

.....

..... [1]

(d) Alkynes undergo similar reactions as alkenes. Ethyne can be reduced to ethane in a two-stage process using a transition metal as the *heterogeneous catalyst* as shown in Fig. 1.1.

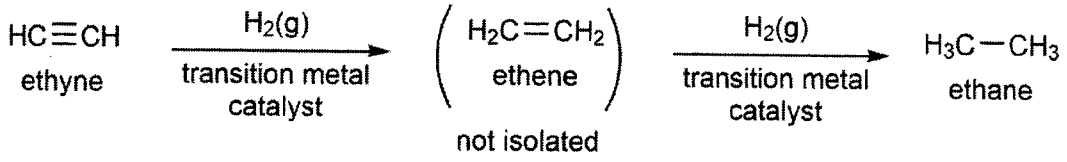


Fig. 1.1

The higher the activity of a catalyst, the more effective it is at catalysing the reaction.

Fig.1.2 shows the relative activity of each catalyst against ΔH_{ads}, the enthalpy change of adsorption of hydrogen gas onto the catalyst surface in the reduction of alkyne.

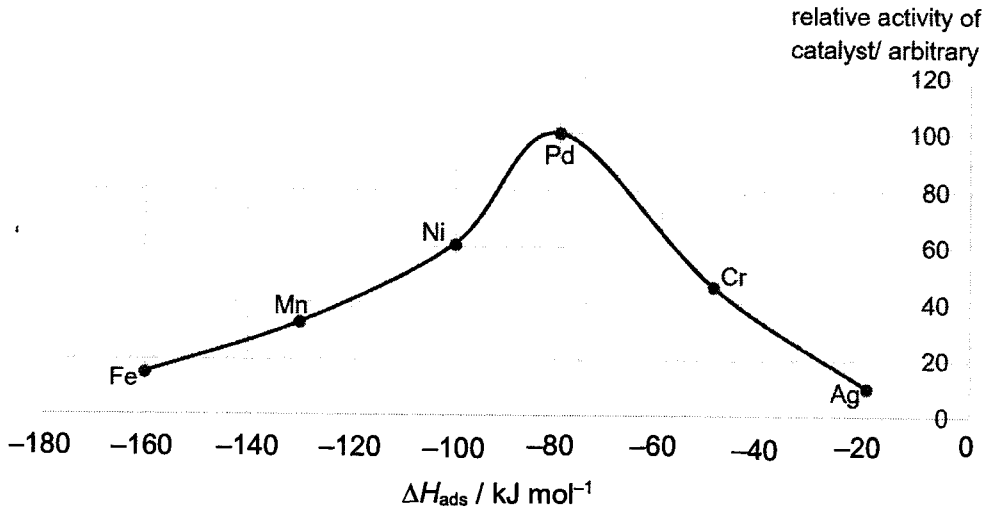


Fig. 1.2

(i) State the meaning of the term *heterogenous catalyst*.

.....

.....

..... [1]

(ii) State which catalyst is the most effective in the reduction of alkyne.

..... [1]

(iii) Use your knowledge of the mode of action of heterogenous catalysts, suggest an explanation for the trend observed in Fig.1.2.

.....

.....

.....

.....

..... [2]

(iv) In 1952, Herbert Lindlar found that adding a thin layer of impurity, such as lead(II) oxide, to palladium catalyst reduced its activity, allowing the reaction to stop at the alkene stage rather than reducing to the alkane as shown in Fig. 1.3.

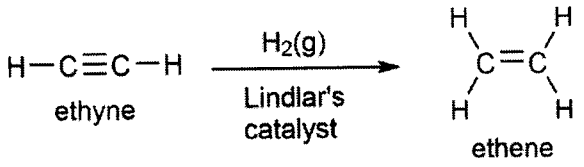


Fig. 1.3

This is also known as "poisoning" the catalyst.

By considering the shape of the molecules in Fig.1.3, suggest how the addition of lead(II) oxide "poisons" the palladium catalyst.

.....

.....

.....

..... [2]

[Total: 18]

2 An aquatic system thrives on a delicate balance based on key chemical processes.

(a) Ammonia is the primary component of fish waste. When the concentration of ammonia in an aquatic system is too high, aquatic life is adversely affected.

Ammonia can be removed with oxygen, in the presence of nitrifying bacteria, to form nitrite, NO_2^-, and water.

(i) Write a balanced equation for the reaction of ammonia and oxygen.

..... [1]

(ii) Draw the dot-and-cross diagram of nitrite ion, NO_2^-.

[1]

(iii) Some NO_3^- ions may also be formed from ammonia by the action of nitrifying bacteria. Given that the shape of NO_3^- ion is trigonal planar, use VSEPR theory to explain the difference in the bond angles between NO_2^- and NO_3^- ion.

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.....

..... [2]

(iv) The ammonia levels in a 50 dm^3 freshwater aquarium tank was investigated. It is found that the concentration of dissolved ammonia and oxygen in the tank were 0.020 mol dm^{-3} and 0.030 mol dm^{-3} respectively. Upon adding nitrifying bacteria, 50% of ammonia was converted to NO_2^- ions after one hour.

Use your answer to **(a)(i)** and the information given, determine the mass of NO_2^- ions formed.

[2]

(b) Calcium and magnesium ions can be used to estimate the total dissolved solids (TDS) in an aquatic system. Different aquatic species require different TDS levels for optimal health and survival.

(i) Explain why calcium has a lower first ionisation energy than magnesium.

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..... [2]

(ii) State two reasons why magnesium and calcium tend to form cations with +2 charge.

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..... [2]

(c) An aquarist wishes to determine the TDS in a freshwater aquarium. For this investigation, the TDS is taken to be the combined amount of Ca^{2+} and Mg^{2+} ions, in mol, present in the water.

The ethylenediaminetetraacetate ion ($EDTA^{4-}$) was used as a reagent to analyse a sample of tank water.

$EDTA^{4-}$ reacts with M^{2+} ions (M = metal) to form complexes according to equation 2.1.

equation 2.1 $\quad M^{2+}(aq) + EDTA^{4-}(aq) \rightarrow [M(EDTA)]^{2-}(aq)$

A 25.0 cm^3 sample of tank water was treated with an excess of 50.0 cm^3 of 0.0500 mol dm^{-3} $EDTA^{4-}$ solution. 10.0 cm^3 of the resulting reaction mixture then required 19.40 cm^3 of 0.0100 mol dm^{-3} zinc nitrate solution to react completely with the unreacted $EDTA^{4-}$ solution.

(i) Determine the TDS that were originally present in the 25.0 cm^3 sample of tank water.

[3]

(ii) A list of aquatic species is shown below in Table 2.1 with their recommended TDS ranges in ppm. (1 ppm = 1 g per 1000 dm^3 of water)

Table 2.1

Species	Recommended TDS Range (ppm)
Cherry Shrimp	150 – 350
African Cichlid	300 – 600
Guppy	700 – 1500
Mollies	1000 – 2800
Archerfish	1500 – 5000
Green Spotted Puffer	5000 – 15000
Marine Reef Tank (Clownfish + Corals)	30000 – 40000

Using your answer in **(d)(i)**, determine the TDS in ppm in the tank water and hence state the species that is best suited for the tank.

If you were unable to obtain the answer in **(d)(i)**, use 1.50×10^{-3} mol in your calculation. This is **not** the correct value.

Assume that the concentrations of Mg^{2+} and Ca^{2+} contributing to the TDS are in a 1:1 ratio.

Best suited species: .....

[3]

[Total: 16]

3 Pyruvic acid, CH_3COCO_2H, is an important intermediate in several metabolic pathways.

(a) A synthetic pathway involving pyruvic acid and other organic compounds is shown in Fig. 3.1.

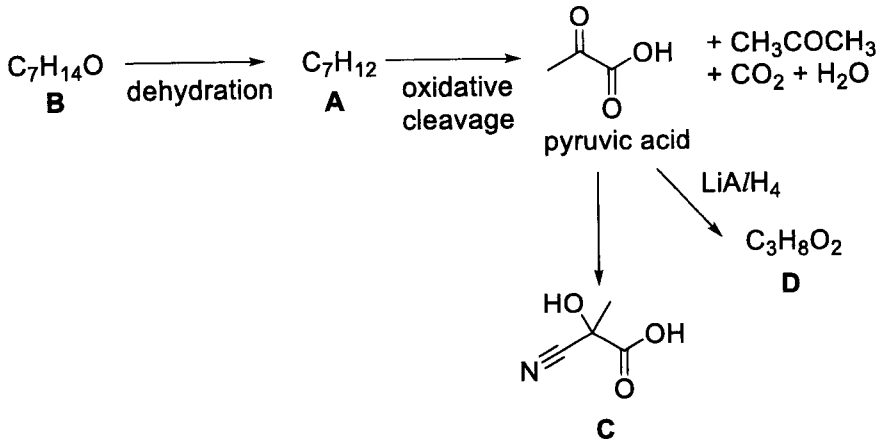

Fig. 3.1

(i) Suggest two possible structures of **A**.

[2]

(ii) **B** is non-chiral and does not react with acidified $K_2Cr_2O_7$.

Use your answer in **(a)(i)**, suggest a structure for **B**.

[1]

(iii) Name the type of reaction, and state the reagents and conditions, for the conversion of pyruvic acid to **C**.

Type of reaction: .....

Reagents and conditions: .....

[2]

(iv) State and explain whether **C** synthesised from pyruvic acid is optically active.

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.....

..... [2]

(v) When pyruvic acid reacts with $LiAlH_4$, **D** is produced.

Name **D**.

..... [1]

(b) Pyruvic acid behaves as a weak *Brønsted–Lowry acid* in water.

Fig 3.2 shows the pH curve when aqueous pyruvic acid was titrated with aqueous sodium hydroxide. The equivalence point was reached when 24.00 cm^3 of aqueous sodium hydroxide had been added.

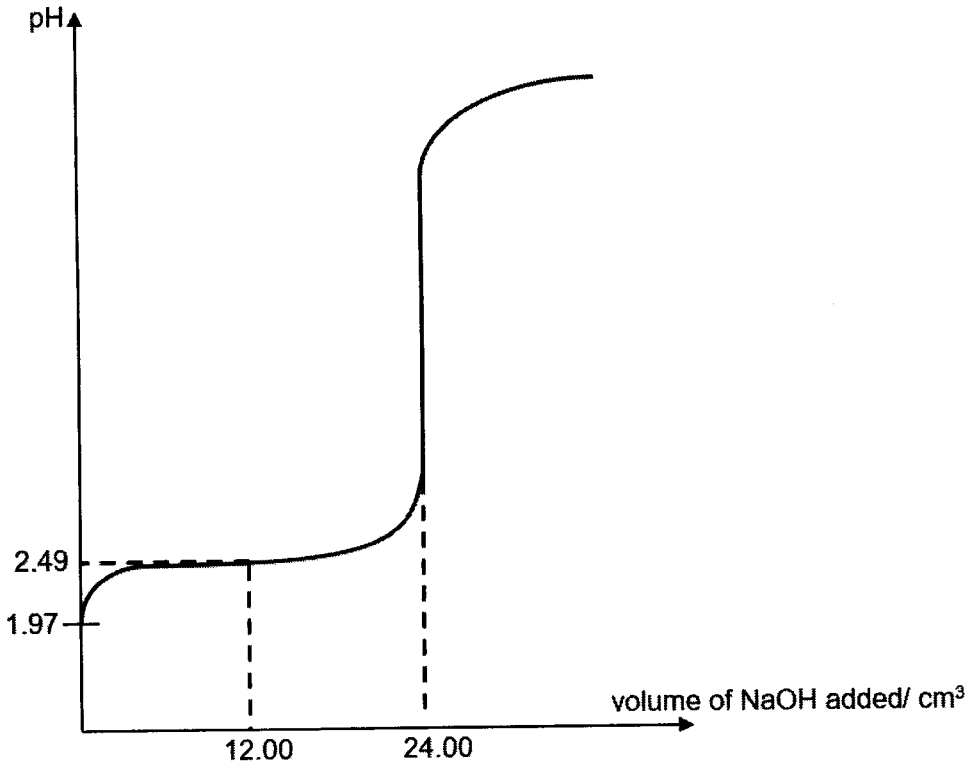


Fig. 3.2

(i) Define the term *Brønsted–Lowry acid.*

..... [1]

(ii) Calculate the acid dissociation constant, K_a, of pyruvic acid.

[1]

(iii) Calculate the concentration of aqueous pyruvic acid.

[2]

(iv) Explain, with the aid of an equation, why pH at the equivalent point is more than 7.

.....

.....

.....

..... [2]

(v) Use your value of K_a calculated in **(b)(ii)** to determine the pH of the solution when 0.300 g of solid sodium hydroxide is dissolved in 500 cm^3 of 0.080 mol dm^{-3} aqueous pyruvic acid.

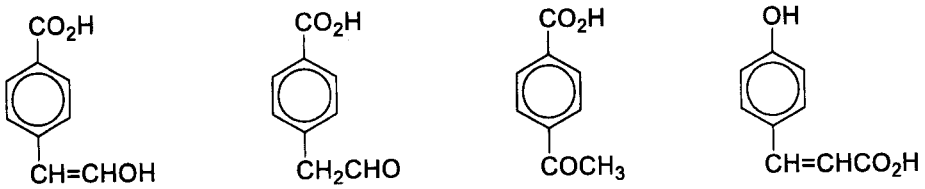
If you were unable to obtain a value of K_a in **(b)(ii)**, use $K_a = 3.0 \times 10^{-3}$ mol dm^{-3} in your calculation. This is **not** the correct value.

[3]

[Total: 17]

4 *p*-Coumaric acid, $C_9H_8O_3$, occurs in some fruits and is thought to help prevent the development of stomach cancer.

p-Coumaric acid is an aromatic organic compound with two substituents occupying positions 1 and 4 of the benzene ring. Four possible structures of *p*-coumaric acid are given in Fig. 4.1.



A **B** **C** **D**

Fig. 4.1

(a) A series of tests are carried out on *p*-coumaric acid. Table 4.1 shows the compound formed, when *p*-coumaric is added to different reagents under specific conditions.

(i) Complete the last column of Table 4.1 by using **only** the letters **A**, **B**, **C** or **D** to represent structures in Fig. 4.1 that give the results as described in each test.

Table 4.1

test	reagents and conditions	compound formed	possible compound(s)
1	Tollens' reagent	no reaction	
2	2,4-dinitrophenylhydrazine	no reaction	
3	HBr	$C_9H_9O_3Br$	
4	Na	$C_9H_6O_3Na_2$	
5	NaOH(aq)	$C_9H_6O_3Na_2$	

[5]

(ii) One of the tests in Table 4.1 confirms the structure of *p*-coumaric acid.

Suggest the structural formula of the product formed in this test.

[1]

(b) When compounds **A**, **B** and **C** are heated separately under reflux with alkaline $KMnO_4$, the same compound is formed in each case.

Suggest the structure of this compound.

[1]

(c) Draw the structures of the compound formed when **A** and **D** are separately reacted with Na_2CO_3.

A produces	**D** produces

[2]

[Total: 9]

5 This question is about Fe and its compounds.

(a) In human blood plasma under physiological condition of pH 7.4, Fe^{3+} has low solubility due to its tendency to form insoluble $Fe(OH)_3$. The dissolution of $Fe(OH)_3$ is represented by the equation 5.1.

equation 5.1 $\quad Fe(OH)_3\,(s) \rightleftharpoons Fe^{3+}\,(aq) + 3OH^-(aq)$

The solubility product of $Fe(OH)_3$ at 25 °C is $2.6 \times 10^{-39}\,mol^4\,dm^{-12}$.

(i) Write the expression for the solubility product of $Fe(OH)_3$.

..... [1]

(ii) Calculate the concentration of Fe^{3+} in blood plasma at 25 °C, assuming the pH remains constant at 7.4.

[2]

(b) Fe^{2+} is able to form complexes with various ligands. Fig. 5.1 shows how the d orbitals of Fe^{2+} are split when the shape of the complex formed is octahedral.

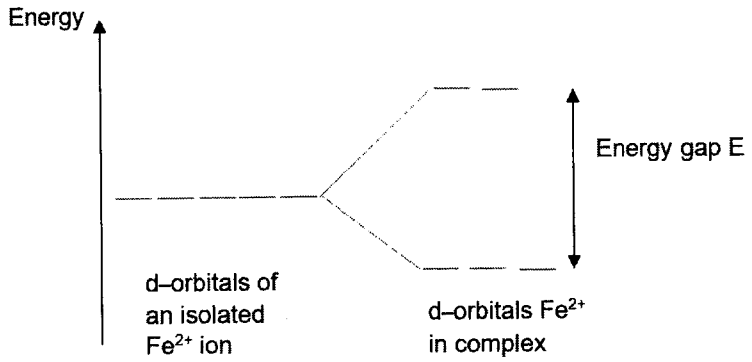
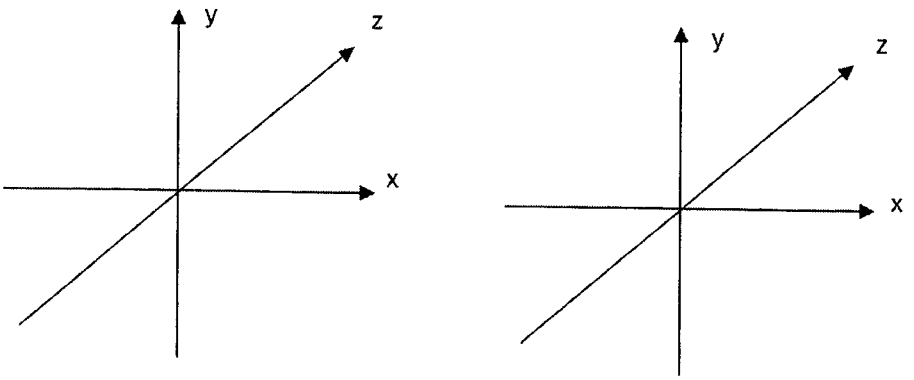


Fig. 5.1

(i) State the full electronic configuration of Fe^{2+}.

..... [1]

(ii) Using the axes below in Fig. 5.2, draw the shape of a 3d orbital of a higher energy level and of a lower energy level, in the octahedral Fe^{2+}complex.



higher energy d orbital lower energy d orbital

Fig. 5.2

[2]

(c) Ligands can be classified as strong field or weak field. In an octahedral complex, strong field ligands are known to give rise to a larger energy gap E between the two sets of d orbitals as compared to weak field ligands.

Octahedral complexes can be classified as either high spin or low spin state.

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

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

(i) Using ↑ or ↓ to represent electrons, complete the two diagrams in Fig. 5.3 to show the electronic distribution of Fe^{2+} in a high spin and in a low spin state.

The energy axis is not drawn to scale, i.e. $E_1 \neq E_2$.

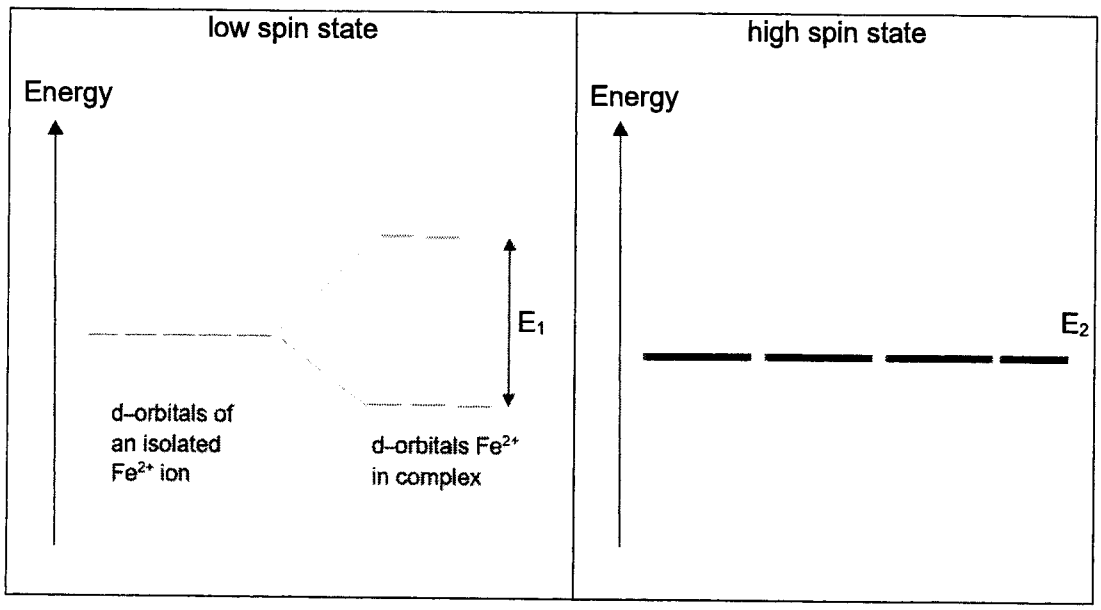


Fig. 5.3

[2]

(ii) Suggest why electrons usually prefer to occupy orbitals singly, rather than in pairs.

.....

..... [1]

(ii) Fe^{2+} in $[Fe(H_2O)_6]^{2+}$ has a high spin state while in $[Fe(CN)_6]^{4-}$ has a low spin state.

State and explain which of the above two complexes will contain the larger energy gap, E, between the d orbitals of Fe^{2+} and hence predict which is a strong field ligand.

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..... [2]

(d) The equilibrium constant, K_{stab}, measures the stability of a complex. For equation 5.2 below,

equation 5.2 $[Fe(H_2O)_6]^{2+}(aq) + 6CN^-(aq) \rightleftharpoons [Fe(CN)_6]^{4-}(aq) + 6H_2O(l)$

$$K_{stab} = \frac{[Fe(CN)_6]^{4-}}{[Fe(H_2O)_6]^{2+}[CN^-]^6}$$

It is given that the $\log_{10} K_{stab}$ values of $[Fe(CN)_6]^{4-}$ and $[FeF_6]^{4-}$ are 35 and 15 respectively.

Using only the information above, explain which ligand is better able to stabilise Fe^{2+}.

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..... [1]

(e) Haemoglobin (Hb) is a large protein complex that contains an Fe^{2+} centre that can bind to ligands such as O_2 and CO. In the lungs, O_2 binds to Hb to form oxyhaemoglobin, $Hb(O_2)_4$ as shown in equation 5.3. $Hb(O_2)_4$ is essential in transporting oxygen to the rest of the human body.

CO competes with O_2 in the lungs, binding with Hb to form carboxyhaemoglobin, $Hb(CO)_4$ as shown in equation 5.4.

equation 5.3 $\quad Hb(aq) + 4O_2(g) \rightleftharpoons Hb(O_2)_4(aq) \quad K_c = 1.0 \times 10^6$

equation 5.4 $\quad Hb(aq) + 4CO(g) \rightleftharpoons Hb(CO)_4(aq) \quad K_c = 2.0 \times 10^{10}$

Use the above information to explain why exposure to carbon monoxide can be potentially life threatening.

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.....[2]

(f) Iron deficiency in bacterial cells trigger secretion of enterobactin, a hexadentate ligand, which combines with one Fe^{3+}. Enterobactin is a very strong field ligand and forms very stable Fe^{3+} complex with a K_{stab} value of approximately 1×10^{49}.

Fig. 5.4 shows the structure of the deprotonated form of enterobactin.

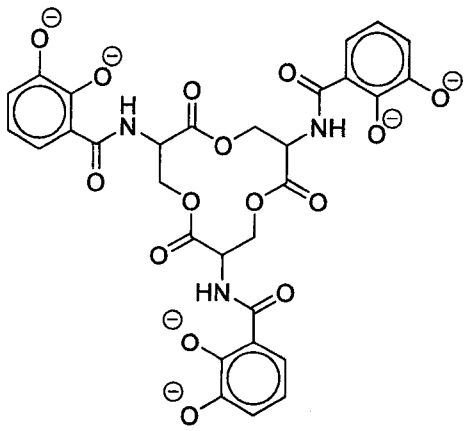

Fig. 5.4

Circle on the structure of the deprotonated form of enterobactin in Fig. 5.4 the six atoms that form bonds with Fe^{3+}. [1]

[Total: 15]

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VICTORIA JUNIOR COLLEGE
JC 2 PRELIMINARY EXAMINATION
Higher 2

CANDIDATE NAME .....

CT GROUP .....

CHEMISTRY

9729/03

Paper 3 Free Response

17 September 2025

2 hours

Additional Materials: Data Booklet

READ THESE INSTRUCTIONS FIRST

Write your name and CT group on this cover page.
Write in dark blue or black pen on both sides of the paper.
You may use a soft pencil for any diagrams, graphs or rough working.
Do not use staples, paper clips, highlighters, glue or correction fluid.

Answer all questions in the spaces provided on the Question Paper.
If additional space is required, you should use the pages at the end of this booklet. The question number must be clearly shown.

Section A
Answer **all** questions.

Section B
Answer **one** question.

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

The number of marks is given in brackets [ ] at the end of each question or part question.

For Examiner's Use	
1	**/ 20**
2	**/ 20**
3	**/ 20**
4	**/ 20**
5	**/ 20**
Total	**/ 80**

This document consists of **23** printed pages and **1** blank page.

[Turn over

Section A

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

1 **(a)** Potassium is a highly reactive alkali metal that must be stored under oil, while copper is a much less reactive metal that resists corrosion. Table 1.1 shows the melting points of both metals.

Table 1.1

Metal	Melting point / °C
K	63.5
Cu	1085

(i) Copper does not react with most dilute acids, unlike potassium.
With reference to the standard electrode potentials in the *Data Booklet*, explain why this is so. [2]

(ii) Describe with the aid of a labelled diagram the structure of copper at room temperature. [2]

(iii) Suggest why the melting point of copper is significantly higher than that of potassium as shown in Table 1.1. [2]

(iv) Fig. 1.1 shows the first ionisation energies for the elements K to Cu.

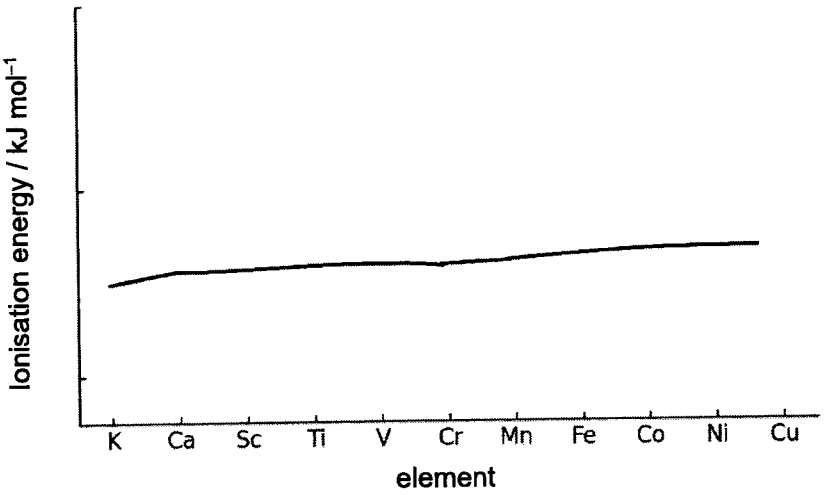

Fig 1.1

Explain why the first ionisation energy remains relatively constant from scandium to copper. [2]

(v) Using your knowledge in the variation of first ionisation energy of the elements from potassium to copper, sketch the trend of the second ionisation energies on Fig 1.1. [1]

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(b) Copper is a transition element which form many different complexes.

(i) Explain what is meant by the term *transition element*. [1]

(ii) Copper(II) ions form a coloured *complex* with mercaptoethylamine, MEA, a bidentate *ligand* as shown in equation 1.1.

equation 1.1 $Cu^{2+} + HSCH_2CH_2NH_2 \rightarrow [Cu(HSCH_2CH_2NH_2)_2]^{2+}$
MEA

With reference to the complex in equation 1.1, explain what is meant by the term *ligand*. [1]

(iii) Explain why complexes of copper(II) are usually coloured. [3]

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(c) Polymerisation is a process where small molecules called monomers are combined to form larger polymer chains. Polymers are large molecules made of many repeat units.

Thiirane,  , can undergo free radical ring-opening polymerisation in the presence of a radical initiator, benzoyl peroxide and an excess of dodecanol, $CH_3(CH_2)_{10}CH_2OH$.

Fig. 1.2 shows a proposed mechanism via three reactions.

Reaction 1: Homolytic fission of a C–S bond in thiirane, generating a 'double-ended' free radical, $\bullet CH_2CH_2S\bullet$, that initiates a chain reaction.

Reaction 2: A chain reaction occurs where the ring opens and units of $\bullet CH_2CH_2S\bullet$ adds to a growing chain. Repeated steps involve production of other free radicals.

Reaction 3: Termination with dodecanol to form $CH_3(CH_2)_{10}CH_2–O–(CH_2CH_2S)_n–H$.

Fig 1.2

(i) Use curly arrows to show the movement of electrons which occur in reactions 1 and reaction 2 on Fig. 1.2. [2]

(ii) Suggest why thiirane undergoes the reaction more easily as compared to $(CH_3)_2S$. [1]

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(d) The three compounds in Table 1.2 behave as monoprotic acids in aqueous solution.

Table 1.2

name	formula
MEA	$NH_2CH_2CH_2SH$
glycine	NH_2CH_2COOH
ethanolamine	$NH_2CH_2CH_2OH$

Arrange the compounds in order of increasing acidity. Explain your answer. [3]

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[20 marks]

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2 Oxidation is one of the important processes for the disinfection of water and wastewater treatment.

Ferrate ions, FeO_4^{2-}, are effective disinfectants, superior to many common oxidants, such as chlorine dioxide, hydrogen peroxide and manganate(VII) ions.

(a) The electrochemical synthesis of ferrate ions usually consists of a sacrificial iron anode and an inert cathode in an electrolytic cell containing a highly concentrated alkaline solution of potassium hydroxide.

(i) Draw a labelled diagram of the electrolytic cell used to synthesise ferrate ions. Include details of the electron flow, cathode, anode and electrolyte. [3]

(ii) Write the half-equation for the formation of FeO_4^{2-} at the anode. [1]

(iii) Effervescence was observed at the cathode.

Suggest the product formed at the cathode, including the relevant half equation. Explain your answer. [2]

(iv) Hence construct the equation for the overall reaction for the electrochemical synthesis of ferrate ions. [1]

(v) In an electrolytic cell above, mass of anode decreased by 0.605 g after 30 minutes.

Assume 100% purity of iron at the anode, determine the current of this cell. [2]

(vi) Numerous research reported a maximum current efficiency of ferrate ion production in 14 mol dm^{-3} KOH solution. When the concentration of KOH approaches its saturated value of around 20 mol dm^{-3}, the electrolyte solution will become very viscous, resulting in a lower rate of ferrate ion produced.

Suggest a reason for the lower rate of production of ferrate ions. [1]

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(b) Chlorine dioxide, ClO_2, is also used in the treatment of wastewater to oxidise organic pollutants. A simplified overall reaction is:

$$2\,ClO_2(aq) + C_xH_yO_z \rightarrow 2\,ClO_2^-(aq) + CO_2(g) + \text{other products}$$

To investigate the kinetics of this reaction, x mol of ClO_2 was reacted with a large excess of $C_xH_yO_z$ in 400 cm^3 of solution. Fig 2.1 shows the volume of CO_2, measured at r.t.p, produced over time by this reaction.

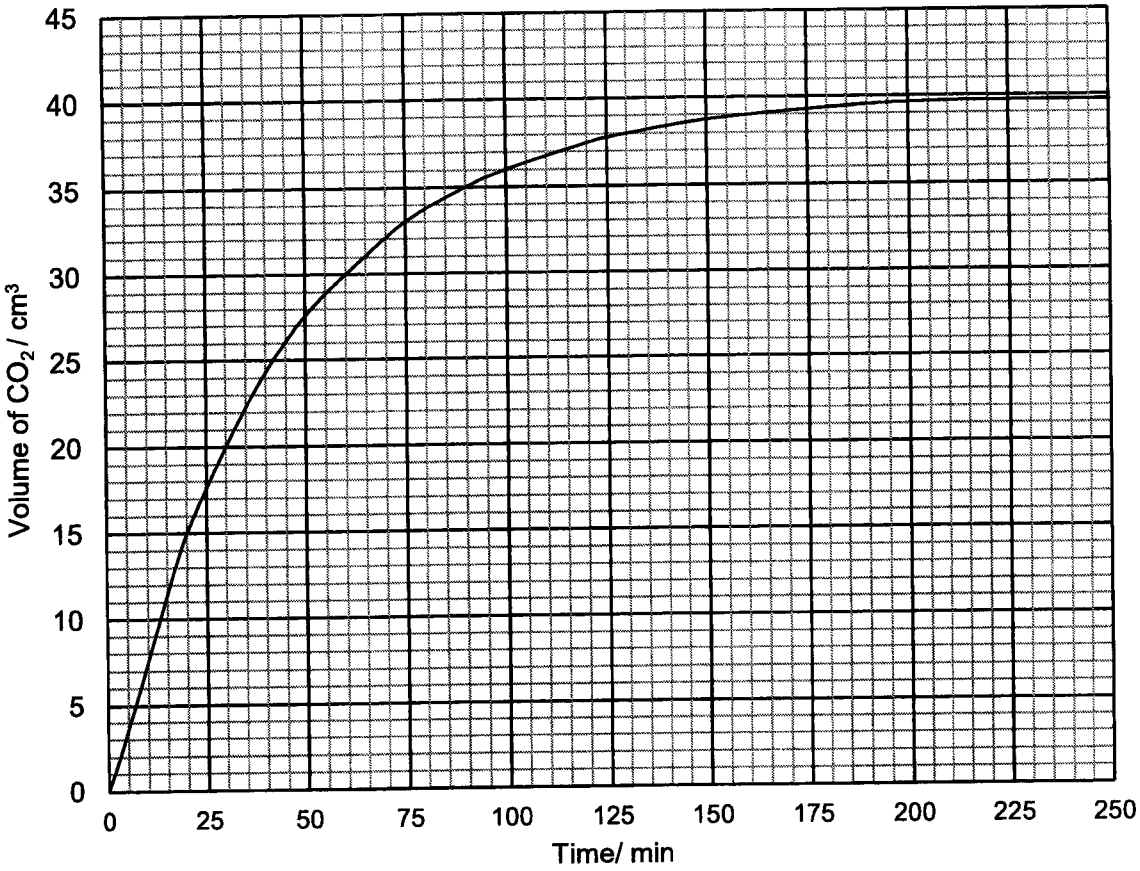

Fig. 2.1

(i) The maximum volume of CO_2 evolved is 40 cm^3.

Use Fig. 2.1 to show that the reaction is overall first order. [1]

(ii) Calculate the initial rate of CO_2 formation and hence determine the initial change in concentration of ClO_2 per min. [3]

(iii) Assume that the reaction is also first order with respect to $C_xH_yO_z$, state and explain the two changes you would expect to observe in the graph in Fig. 2.1, when the above experiment is repeated with twice the concentration of $C_xH_yO_z$. [2]

(c) Chlorine gas is commonly used to disinfect drinking water. However, it can react with naturally occurring organic matter to form trihalomethanes, THMs. THMs are harmful at high levels because they may cause cancer.

The common THMs found in treated water and their boiling points are listed in Table 2.1. The average concentrations detected in a particular sample of treated water are also listed.

Table 2.1

THMs	M_r	Boiling point / °C	Average concentration / $\times 10^{-6}$ g dm^{-3}
$CHCl_3$	119.5	61	54.9
$CHBrCl_2$	163.9	90	10.7
$CHBr_2Cl$	208.3	120	7.7
$CHBr_3$	252.7	149	3.0

(i) State the most volatile THMs in Table 2.1.

Using data in Table 2.1, explain your answer with reference to the type and relative strength of intermolecular interactions. [2]

(ii) Suggest one reason for the trend of the average concentrations of THMs. [1]

(iii) Rising global temperatures, a consequence of the enhanced greenhouse effect, directly influence THMs formation.

Describe what is meant by the term *enhanced greenhouse effect*. [1]

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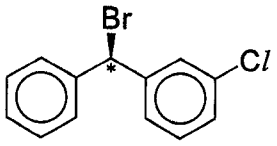
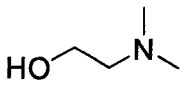
[Total:20]

3 **(a)** Drug **C** can be synthesised by a reaction between **A** and **B** as the first step. The halogenoalkane in **A** undergoes nucleophilic substitution via S_N2 with the alcohol functional group in **B** to form an ether.



A



B

(*) denotes a chiral centre

(i) Explain why S_N2 reactions do not occur at the C-C*l* bond in **A**. [2]

(ii) With reference to the structure, suggest why it is more likely for the alcohol rather than the amine functional group in **B** to undergo S_N2 with the halogenoalkane. [2]

(iii) For drug **C** to be effective, it must be able to bind to the relevant receptors in the body. Using the other enantiomer of **A** as starting reactant would make the drug ineffective.

Consider the nature of the receptors and the S_N2 mechanism, explain why the drug becomes ineffective. [2]

(iv) Draw the structural formula of the product from the reaction between **A** and **B**. Show the stereochemistry of the compound in your drawing. [1]

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(b) Arrange benzene, nitrobenzene and phenylamine in order of their ease of bromination.

Explain your reasoning by reference to their structures. [3]

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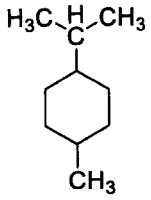
(c) α-Terpineol, $C_{10}H_{18}O$, contains an alcoholic group which is not readily oxidised. On hydrogenation in the presence of palladium catalyst, it gives **D**, $C_{10}H_{20}O$. **D** reacts readily in the presence of a few drops of concentrated sulfuric acid to give **E**, $C_{10}H_{18}$, which can be hydrogenated to give the compound below.



Heating **E** and α-terpineol separately with acidified $KMnO_4$ gives **F** and **G** respectively.

Table 3.1 shows the observations when **F** and **G** are tested under specific conditions.

Table 3.1

test	reagents and conditions	**F**, $C_9H_{16}O$	**G**, $C_{10}H_{18}O_4$
1	Na_2CO_3	no effervescence	effervescence
2	Warm alkaline iodine(aq)	yellow ppt	yellow ppt

For reactions described above, including the tests in Table 3.1, state the type of reaction occurring. For each compound, state what information above tells you about the functional groups it contains. Include your reasoning.

Suggest structures for α-terpineol, **D**, **E**, **F** and **G**. [10]

[Total: 20]

Section B

Answer **one** question from this section.

4 **(a)** Describe the variation in the acid-base behaviour of the Period 3 oxides by reference to the reactions of Na_2O, Al_2O_3 and SiO_2 separately with phosphoric acid, H_3PO_4, and with sodium hydroxide.

Write equations for any reactions described. [6]

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(b) Hydration of carbonyl compounds yields gem-diols which are compounds where two hydroxyl groups are bonded to the same carbon atom. Gem-diols are often unstable and exist in equilibrium, as shown in the hydration of propanone.

equation 4.1 $CH_3COCH_3(aq) + H_2O(l) \rightleftharpoons CH_3C(OH)_2CH_3(aq)$

Table 4.1 shows the equilibrium constant, K_c, values for the hydration of propanone at two different temperatures.

Table 4.1

Temperature /K	K_c
298	1.58
318	1.06

(i) State Le Chatelier's Principle. [1]

(ii) Use data in Table 4.1, explain if the formation of gem-diols from propanone is endothermic or exothermic. [2]

(iii) A sample of 29.5 g of trichloroethanal, CCl_3CHO, is dissolved in 250 cm^3 of water and left to reach equilibrium at 298K similar to the reaction shown in equation 4.1.

At equilibrium, it is found that only 0.01% of CCl_3CHO remains.

Determine the equilibrium amount of CCl_3CHO and $CCl_3C(OH)_2H$ and hence calculate the value of K_c for this hydration. [2]

(iv) Suggest why CCl_3CHO has a higher K_c value than that of propanone. [1]

(c) Under certain conditions, carbonyl compounds can also react with each other as shown in equations 4.2 and 4.3.

The hydrogen bonded to a carbon that is adjacent to a carbonyl group can be removed by addition of a catalytic quantity of a strong base.

equation 4.2 $$RCH_2CHO + \underset{\text{base}}{B} \longrightarrow \underset{\text{anion}}{R\bar{C}HCHO} + BH^+$$

The anion formed then reacts with another molecule of the original carbonyl compound.

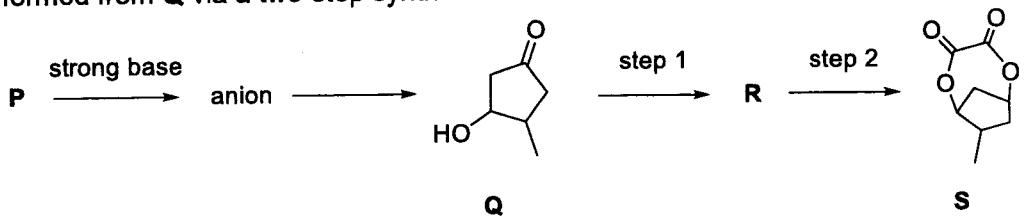
equation 4.3 $$RCH_2CHO + \underset{\text{anion}}{R\bar{C}HCHO} + BH^+ \longrightarrow RCH_2CH(OH)CHRCHO + B$$

(i) Equation 4.3 shows the overall equation for a two-step mechanism where the first step involves the anion attacking the carbonyl molecule.

Suggest a two-step mechanism. Show all charges, relevant lone pairs and the movement of electron pairs by using curly arrows. [2]

(ii) Suggest the structure of the final product formed in the reaction of propanone with a strong base. [1]

As shown in Fig. 4.1, carbonyl compound **P** forms **Q** by the same mechanism. **S** can be formed from **Q** via a two-step synthesis.



Q **S**

Fig. 4.1

(iii) State one reagent that can be used to distinguish **Q** from **S**. [1]

(iv) Suggest the structures of **P** and **R**. [2]

(v) Suggest reagents and conditions for each of the steps 1 and 2 in Fig. 4.1. [2]

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[Total: 20]

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

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(b) The chlorides sodium and phosphorus behave differently when added to water.

State what you would observe when NaC*l* and P$C\mathit{l}_5$ are each added separately to water and suggest the pH of the solution formed in each case. [2]

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(c) In the gas phase, the chloride of beryllium exists as a mixture of $BeCl_2$ and Be_2Cl_4 molecules.

equation 5.1 $2BeCl_2(g) \rightleftharpoons Be_2Cl_4(g)$

You may assume both $BeCl_2$ and Be_2Cl_4 behave like ideal gases here.

(i) State three basic assumptions of the kinetic theory as applied to an ideal gas. [2]

(ii) Sketch and label a graph showing how the pressure for a given mass of an ideal gas varies with temperature in two different vessels of volumes, V_1 and V_2, where $V_1 > V_2$.

Explain your answer. [2]

(iii) Draw the structure of Be_2Cl_4. Label the co-ordinate bonds on your structure. [1]

(iv) A sample of 0.800 mol of $BeCl_2$ is allowed to reach equilibrium in a sealed vessel. At equilibrium, it is found that 20% of the original sample of $BeCl_2$ has reacted. The total pressure in the vessel is 1.50×10^4 Pa.

Determine the equilibrium amount of $BeCl_2$ and Be_2Cl_4 and hence calculate the value of K_p for the reaction in equation 5.1. State the units. [3]

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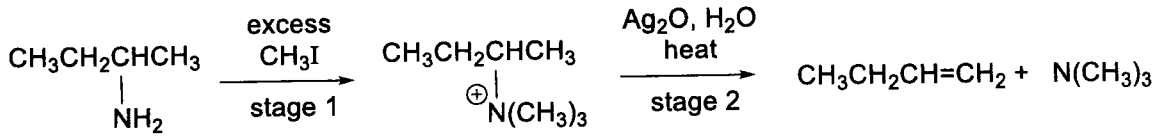
(d) Iodomethane, CH_3I, is used as a reagent in the first step of the Hofmann elimination reaction, which converts amines to alkenes. It reacts with an amine to form a quaternary ammonium salt. Upon heating this salt with moist silver(I) oxide, Ag_2O, an elimination reaction occurs, breaking a C – N bond and producing an alkene.

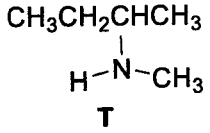
In Hofmann elimination, the less substituted alkene is typically the major product. This is illustrated as the two-stage process of converting 2-aminobutane to but-1-ene in Fig. 5.1.



2-aminobutane

Fig 5.1

(i) Compound **T** is an intermediate in stage 1 of Fig. 5.1. It is formed via an S_N2 attack of 2-aminobutane on iodomethane, followed by the removal of a proton on the nitrogen atom by iodide ion.

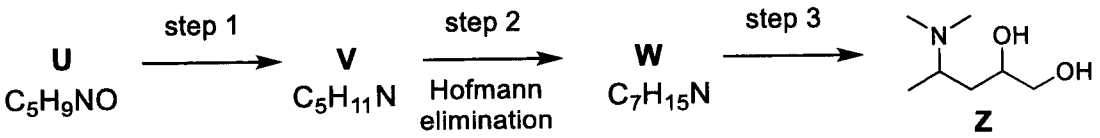


T

Suggest the two-step mechanism for the formation of **T**. Show all charges, relevant lone pairs and the movement of electron pairs by using curly arrows.

You may represent 2-aminobutane as RNH_2. [2]

Compound **Z** can be synthesized in 3 steps as shown in Fig. 5.2. Step 2 involves a Hofmann elimination.



Z

Fig. 5.2

(ii) Suggest structures of organic compounds **U**, **V** and **W**. [3]

(iii) Suggest the reagents and conditions required for step 1 and 3. [2]

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[Total: 20]

Additional answer space

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

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