



- 1 The most common oxidation state of americium, Am, in aqueous solution is +3.

Recently,  $\text{Cu}^{3+}$  has been shown to quantitatively oxidise  $\text{Am}^{3+}(\text{aq})$  in dilute  $\text{HNO}_3$ , while itself is reduced to  $\text{Cu}^{2+}$ .

In an experiment,  $20.0 \text{ cm}^3$  of  $0.0120 \text{ mol dm}^{-3} \text{ Am}^{3+}(\text{aq})$  was found to require  $24.00 \text{ cm}^3$  of  $0.0300 \text{ mol dm}^{-3} \text{ Cu}^{3+}$  for complete oxidation.

What is the formula of the americium-containing species formed?

- A  $\text{Am}_2\text{O}_2^{2+}$
- B  $\text{AmO}_2^{2+}$
- C  $\text{AmO}^{2+}$
- D  $\text{AmO}^+$

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

The table shows the fifth, sixth, seventh, eighth, ninth and tenth ionisation energies of an element ( $Z \leq 20$ ) in the Periodic Table.

	5th	6th	7th	8th	9th	10th
ionisation energy / $\text{kJ mol}^{-1}$	7975	9590	11343	14944	16964	48610

What can be inferred about the element from the above data?

- A It is in the third period of the Periodic Table.
  - B It is in Group 2 of the Periodic Table.
  - C It is likely to form an ionic compound when reacted with oxygen.
  - D Its 6<sup>th</sup> and 7<sup>th</sup> electrons are removed from different subshells.
- 3 Particle **R** has a proton number  $n$  and forms a stable monoatomic ion of charge  $-1$ .
- Particle **S** has a proton number of  $(n+2)$  and it forms a stable monoatomic ion which is isoelectronic with the ion of **R**.

Which statement is correct?

- A Ion of **S** has a smaller ionic radius than ion of **R**.
- B **R** has a larger atomic radius than **S**.
- C Ion of **S** requires less energy than ion of **R** when an electron is removed from each particle.
- D Ion of **R** releases more energy than ion of **S** when an electron is added to each particle.

4 Which statement about the trend in the property of the halogens down the group is correct?

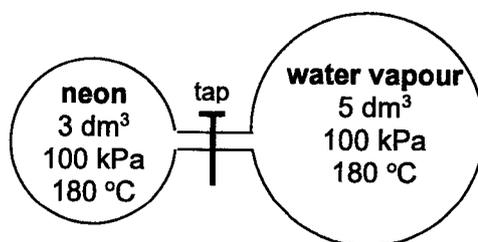
- A The electronegativity increases.
- B The volatility increases.
- C The enthalpy change of reaction with hydrogen becomes less exothermic.
- D The reactivity as reducing agents increases.

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

Which sequence is correct in terms of increasing radius?

- A  $\text{Rb}^+ < \text{Sr}^{2+} < \text{As}^{3-} < \text{Se}^{2-}$
- B  $\text{Sr}^{2+} < \text{Rb}^+ < \text{Se}^{2-} < \text{As}^{3-}$
- C  $\text{As}^{3-} < \text{Se}^{2-} < \text{Sr}^{2+} < \text{Rb}^+$
- D  $\text{Se}^{2-} < \text{Sr}^{2+} < \text{Rb}^+ < \text{As}^{3-}$

6 Two bulbs are connected as shown in the diagram below. The bulbs are connected by a narrow tube of negligible volume.



When the tap is opened, the two gases mix. The connected bulbs were then allowed to cool to room temperature.

What was the final pressure, in kPa, in the connected bulbs?

- A 13.9
- B 24.3
- C 37.5
- D 64.7

- 7  $(\text{CH}_3)_2\text{S} \cdot \text{BCl}_3$  is a solid that is commonly used in laboratories as a convenient source of  $\text{BCl}_3$ . When heated, it reversibly decomposes to  $(\text{CH}_3)_2\text{S}$  and  $\text{BCl}_3$ .

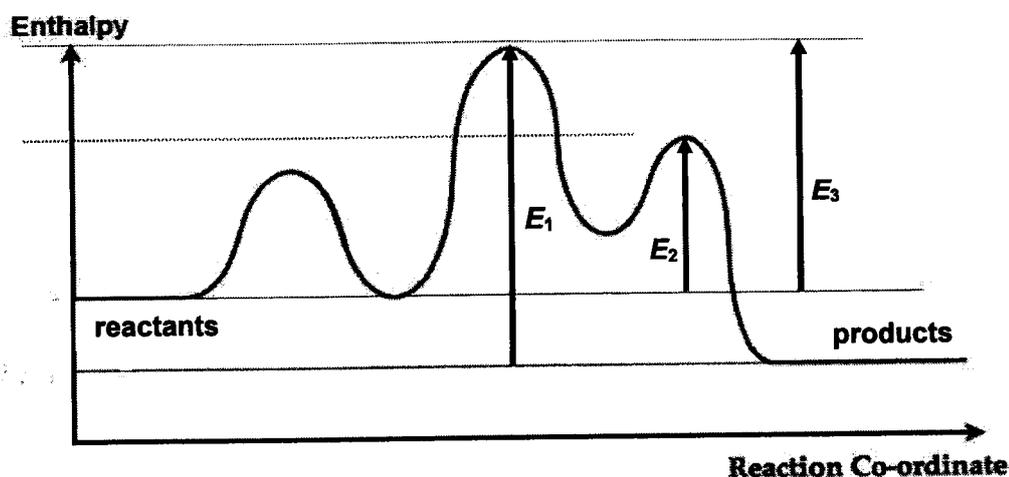
Which statement is true?

- A The dative bond is formed using the 2p orbitals of boron and sulfur.  
 B  $(\text{CH}_3)_2\text{S}$  and  $\text{BCl}_3$  act as the Lewis acid and Lewis base respectively in the formation of  $(\text{CH}_3)_2\text{S} \cdot \text{BCl}_3$ .  
 C The dative bond is from boron to sulfur.  
 D The C-S-C bond angle decreases when the solid decomposes.
- 8 The compound  $\text{Bi}_2\text{Sr}_2\text{Ca}_2\text{Cu}_3\text{O}_{10}$  is a superconductor.

In this compound, the oxidation number of bismuth is +3, strontium and calcium is +2 and oxygen is -2.

What are the possible oxidation numbers of the three copper atoms in  $\text{Bi}_2\text{Sr}_2\text{Ca}_2\text{Cu}_3\text{O}_{10}$ ?

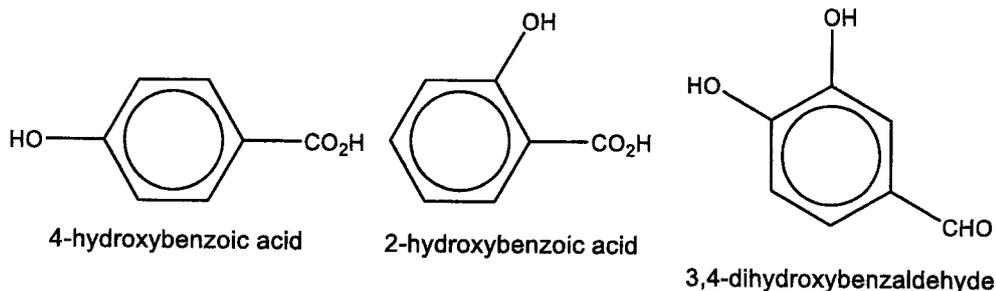
- A +1, +1, +2  
 B +1, +2, +3  
 C 0, +1, +3  
 D 0, +2, +3
- 9 The energy profile diagram below represents a certain three-step reaction.



Which statements are correct about the above reaction?

- 1  $E_3$  is the activation energy of the second step.  
 2  $\Delta H$  can be obtained by subtracting  $E_2$  from  $E_1$ .  
 3 There are equal number of intermediates and transition states.
- A 1 only      B 2 only      C 1 and 3      D 2 and 3

- 10 4-hydroxybenzoic acid (A), 2-hydroxybenzoic acid (B) and 3,4-dihydroxybenzaldehyde (C) share the same molecular formula.



All three compounds combust exothermically. Their standard enthalpy changes of formation are tabulated below.

	standard enthalpy change of formation / kJ mol <sup>-1</sup>
4-hydroxybenzoic acid	-481
2-hydroxybenzoic acid	-493
3,4-dihydroxybenzaldehyde	-392

Which statements are correct?

- 2-hydroxybenzoic acid and 3,4-dihydroxybenzaldehyde are chain isomers.
- The magnitude of the standard enthalpy change of combustion decreases in the order C > A > B.
- The thermodynamic stability decreases in the order B > A > C.

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

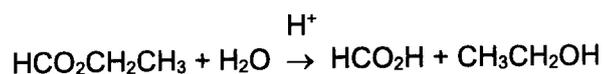
- 11 A 0.483 g sample of glycine ( $M_r = 75.0$ ) was placed in a bomb calorimeter and then ignited in the presence of excess oxygen. The temperature rose by 0.54 °C.

In a separate experiment using the same calorimeter, the combustion of 0.986 g of benzoic acid ( $M_r = 122.0$ ) gave a temperature rise of 2.14 °C. The enthalpy change of combustion of benzoic acid is -3054 kJ mol<sup>-1</sup>.

What is the enthalpy change of combustion, in kJ mol<sup>-1</sup>, of glycine?

- A** -615 kJ mol<sup>-1</sup>  
**B** -967 kJ mol<sup>-1</sup>  
**C** -2423 kJ mol<sup>-1</sup>  
**D** -3812 kJ mol<sup>-1</sup>

- 12 Ethyl formate undergoes a slow acid-catalysed hydrolysis in water.



The rate law is found to be

$$\text{rate} = k[\text{HCO}_2\text{CH}_2\text{CH}_3][\text{H}^+]$$

When  $0.1 \text{ mol dm}^{-3}$  of  $\text{HCl}$  is reacted with  $0.4 \text{ mol dm}^{-3}$  of ethyl formate, the half-life was found to be 62 min.

Another reaction was carried out with  $0.3 \text{ mol dm}^{-3}$  of  $\text{HCl}$  and  $0.4 \text{ mol dm}^{-3}$  of ethyl formate.

How long does it take for the concentration of ethyl formate to fall to  $0.050 \text{ mol dm}^{-3}$ ?

- A** 31 min      **B** 62 min      **C** 93 min      **D** 124 min

- 13 The decomposition of phosphorus pentachloride is reversible.

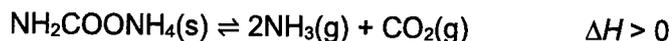


The rate constants of the forward and backward reactions are given as  $k_1$  and  $k_{-1}$  respectively.

What happens to the values of  $k_1$ ,  $k_{-1}$ ,  $K_c$  and the equilibrium position if an inert gas is introduced into the reaction vessel at constant temperature and pressure?

	$k_1$	$k_{-1}$	$K_c$	equilibrium position
<b>A</b>	unchanged	unchanged	unchanged	unchanged
<b>B</b>	increases	decreases	increases	shifts to right
<b>C</b>	decreases	increases	decreases	shifts to left
<b>D</b>	unchanged	unchanged	unchanged	shifts to right

- 14 Ammonium carbamate,  $\text{NH}_2\text{COONH}_4$ , undergoes thermal decomposition.



A vessel containing only  $\text{NH}_2\text{COONH}_4$  is heated to  $250\text{ }^\circ\text{C}$ . The reaction reached equilibrium at time  $t_1$ . Subsequently both the temperature and volume of the vessel are decreased, and the reaction established a new equilibrium at time  $t_2$ .

Which statements are correct?

- 1 At  $t_2$ ,  $P_{\text{NH}_3} : P_{\text{CO}_2}$  is 2 : 1.
- 2 The rate of the forward reaction at  $t_1$  is the same as that at  $t_2$ .
- 3 The degree of decomposition of  $\text{NH}_2\text{COONH}_4$  at  $t_1$  is smaller than that at  $t_2$ .
- 4 Decreasing the volume of the vessel at constant temperature has no effect on the equilibrium partial pressures of  $\text{NH}_3$  and  $\text{CO}_2$ .

- A 1 and 4      B 2 only      C 1 and 3      D 2 and 3

- 15 Nitrogen dioxide can decompose to form nitrogen monoxide and oxygen.

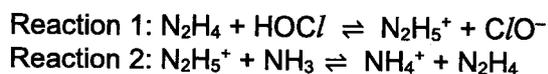


When 2.50 mol of nitrogen dioxide was allowed to undergo decomposition in a  $0.8\text{ dm}^3$  container, 0.528 mol of oxygen was present at equilibrium.

What is the numerical value of the equilibrium constant,  $K_c$ , for this reaction?

- A 3.54      B 2.83      C 0.353      D 0.282

- 16 The position of equilibrium lies to the right in each of these reactions.



Which statement can be deduced from the information given above?

- A The order of acid strength is  $\text{HOCl} < \text{N}_2\text{H}_5^+ < \text{NH}_4^+$ .
- B  $\text{N}_2\text{H}_4$  is the Bronsted–Lowry acid in Reaction 1.
- C  $\text{N}_2\text{H}_5^+$  and  $\text{NH}_3$  are a conjugate acid–base pair in Reaction 2.
- D  $\text{N}_2\text{H}_4$  is a weaker base than  $\text{NH}_3$ .

- 17 The value of  $\text{p}K_w$  at  $80\text{ }^\circ\text{C}$  is 13.94.

What is the pH of an aqueous solution of  $0.05\text{ mol dm}^{-3}$   $\text{Ba}(\text{OH})_2$  at  $80\text{ }^\circ\text{C}$ ?

- A 12.64      B 12.94      C 13.44      D 13.94

- 18 The table below shows the numerical values of the solubility products (measured at 25 °C) for some salts.

Salt	CdCO <sub>3</sub>	FeS	CoCO <sub>3</sub>	CuS
$K_{sp}$	$1.0 \times 10^{-12}$	$6.0 \times 10^{-19}$	$1.0 \times 10^{-10}$	$8.0 \times 10^{-37}$

Which statement can be deduced from the information given above?

- A CuS is more soluble than FeS.  
 B CdCO<sub>3</sub> is more soluble than CoCO<sub>3</sub>.  
 C The solubility of these four salts will be increased at lower pH.  
 D The  $K_{sp}$  value of CuS will decrease as less of it can dissolve when copper(II) nitrate is added to a saturated solution.
- 19 The solubilities of AgCl and AgI are  $x$  and  $y$  mol dm<sup>-3</sup> respectively at 298 K.

Which statements are correct about a solution saturated with both AgCl and AgI?

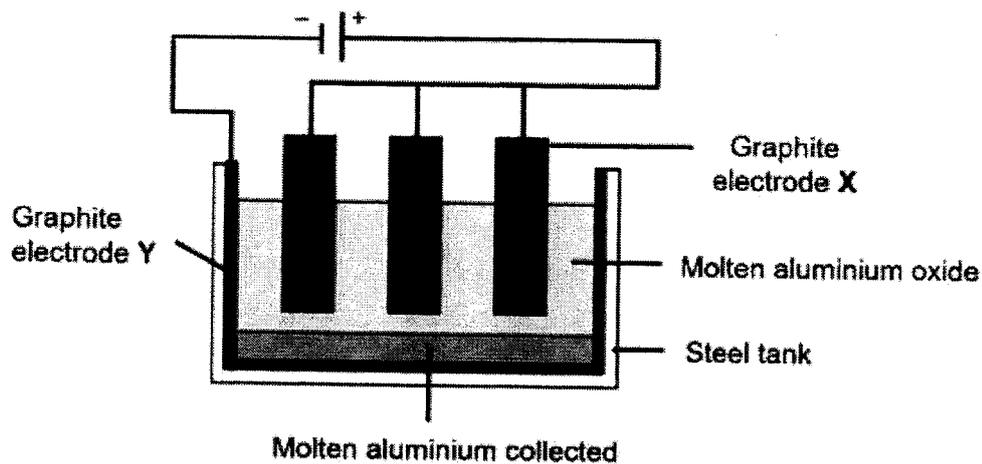
1  $[Ag^+] = x + y$

2  $[Ag^+] = [I^-] + [Cl^-]$

3  $[I^-] < y$

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

- 20 Aluminium is extracted from its ore by electrolysis.

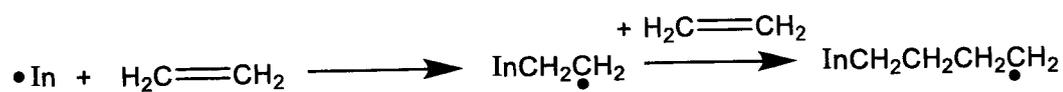


Which statements are correct?

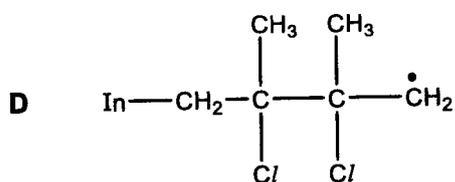
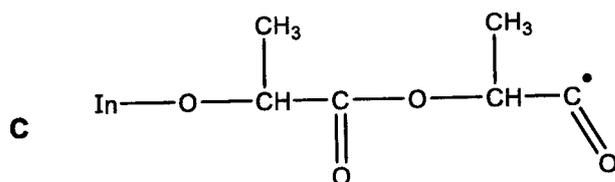
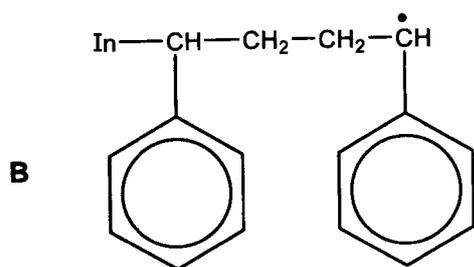
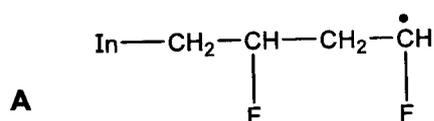
- 1 Aluminium ions migrate to electrode X.
- 2 Oxygen gas is produced.
- 3 Electrons move from electrode X to electrode Y via the external circuit.

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

- 21 Free radical addition is a mechanism used in the synthesis of some addition polymers. Alkene monomers will polymerise in the presence of a radical initiator ( $\text{In}^\bullet$ ). For instance, the synthesis of polyethene begins as such.



Which chain could **not** have arisen from free radical addition?





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

A sample of an ester is hydrolysed by heating under reflux with aqueous sodium hydroxide. The two organic products of the hydrolysis are separated, purified and weighed.

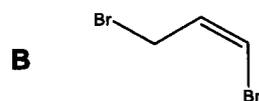
Which ester would produce a 3:1 mass ratio of the two products obtained?

- A propyl methanoate
- B ethyl ethanoate
- C butyl methanoate
- D methyl propanoate

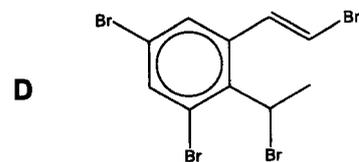
25 0.04 mol of each of the following compounds was heated with KOH(aq), followed by addition of dilute HNO<sub>3</sub> and AgNO<sub>3</sub>(aq).

Which compound will produce the highest mass of AgBr(s)?

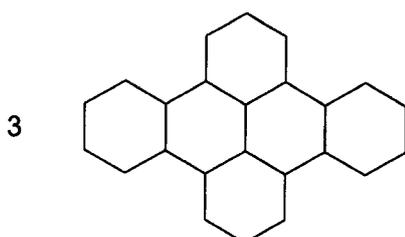
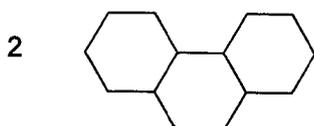
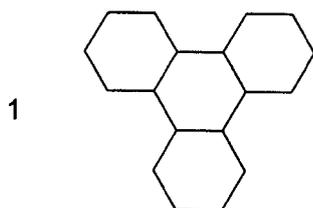
A BrCOCH2COBr



C CH3CH2CH2Br



- 26 Which pair of compounds will **not** form when cyclohexane is reacted with excess bromine gas in the presence of ultraviolet light?

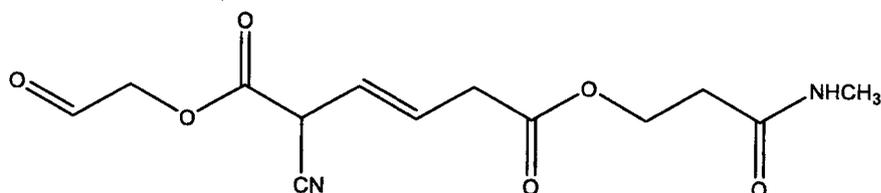


- A 1 and 2      B 2 and 4      C 1 and 3      D 1 and 4

- 27 Esters can be reduced by  $\text{LiAlH}_4$  in dry ether to give two alcohols as shown below.



Which product may be formed when the following compound is reacted with excess  $\text{LiAlH}_4$  in dry ether?



- A  $\text{H}_2\text{NCH}_2\text{CH}(\text{CH}_2\text{OH})\text{CH}_2\text{CH}_2\text{CH}_2\text{OH}$   
 B  $\text{NCCH}(\text{CO}_2\text{H})\text{CH}=\text{CHCH}_2\text{CO}_2\text{H}$   
 C  $\text{HOCH}_2\text{CH}_2\text{NHCH}_3$   
 D  $\text{HOCH}_2\text{CH}_2\text{OH}$

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

The structure of tetrapeptide **X** and  $M_r$  of selected amino acids are given below.

tetrapeptide **X**: Val–Lys–Phe–Arg

amino acid	$M_r$
Val	117
Lys	146
Phe	165
Arg	174

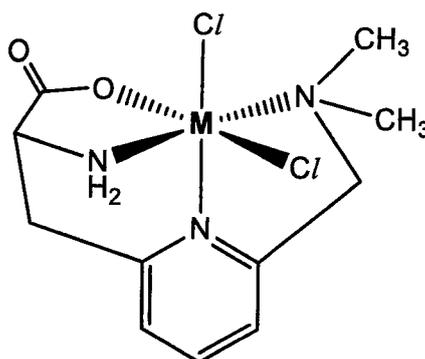
What are the  $M_r$  of the two fragments obtained when tetrapeptide **X** is hydrolysed by chymotrypsin?

- A 174 and 392  
 B 174 and 428  
 C 245 and 321  
 D 263 and 339
- 29 *Use of the Data Booklet is relevant to this question.*

Which statement is true?

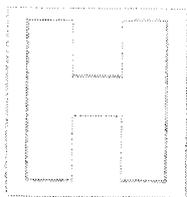
- A  $\text{CoF}_3$  is stable in water because  $2\text{Co}^{3+} + 2\text{F}^- \rightarrow \text{F}_2 + 2\text{Co}^{2+}$  is a non-spontaneous reaction.  
 B It is possible to prepare aqueous iron(III) iodide.  
 C  $\text{Cr}_2\text{O}_7^{2-}$  is the oxidised form of  $\text{CrO}_4^{2-}$  because it contains more oxygen atoms.  
 D The oxidation of iron(II) to iron(III) can be prevented at lower pH.

30 Which statement regarding the neutral metal complex below is **false**?



- A The oxidation number of **M** in the complex is +2 because the complex is neutral and there are two chloride ligands.
- B The coordination number of the complex is 6.
- C The complex contains a tetradentate ligand.
- D The complex contains a ligand which is an  $\alpha$ -amino acid.





**Anglo-Chinese Junior College**  
 JC2 Preliminary Examinations  
 Higher 2



A Methodist Institution  
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**CHEMISTRY**

Paper 2 Structured Questions

**9729/02**

27 August 2025

2 hours

Candidates answer on the Question Paper.  
 Additional Materials: Data Booklet

**READ THESE INSTRUCTIONS FIRST**

Write your index number and name in the spaces at the top of this page.  
 Write in dark blue or black pen.  
 You may use an HB pencil for any diagrams, graphs or rough working.  
 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.

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

For Examiners' use only	
1	/ 7
2	/ 12
3	/ 10
4	/ 11
5	/ 11
6	/ 16
7	/ 8
<b>Total</b>	<b>/ 75</b>

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

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

- 1 When ammonium dichromate(VI) is added gradually to molten ammonium thiocyanate, Reinecke's salt is formed. It has the formula  $\text{NH}_4[\text{Cr}(\text{SCN})_x(\text{NH}_3)_y]$  and the following composition by mass: Cr 15.5 %; S 38.15 %; N 29.2 %.

(a) Calculate the values of  $x$  and  $y$  in the above formula.

[2]

(b) Suggest a shape for the complex anion.

.....[1]

(c) Draw two possible structures for the anion and state the type of isomerism it exhibits.

.....[2]

- (d) Linkage isomerism is a form of constitutional isomerism in which certain coordination compounds have the same composition but differ in which atom of the ligand is bonded to the metal.

Examples of linkage isomers are violet-colored  $[(\text{NH}_3)_5\text{Co-SCN}]^{2+}$  (S being the donor atom) and the orange  $[(\text{NH}_3)_5\text{Co-NCS}]^{2+}$  (N being the donor atom).

Draw the dot-and-cross diagrams of  $\text{NCS}^-$  and  $\text{SCN}^-$ . In each diagram, underline the donor atom.

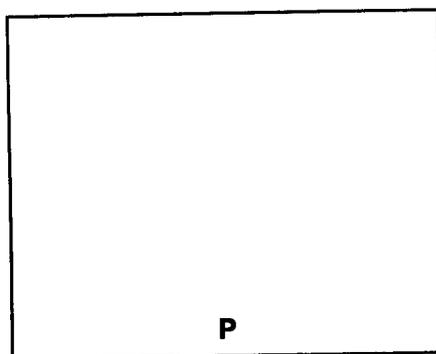
[2]

[Total: 7]

- 2 (a) X can be converted to Y via three steps as shown in the reaction scheme below.



- (i) There are two isomers possible for P. Draw the structure of P that will eventually lead on to Y.



[1]

- (ii) Explain if your answer in (a)(i) is the major product.

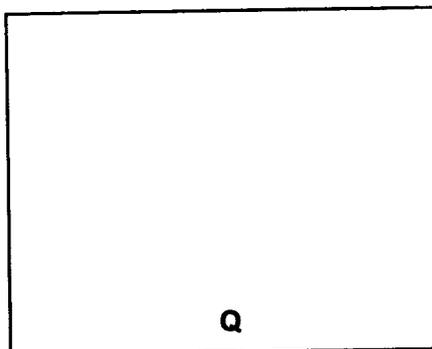
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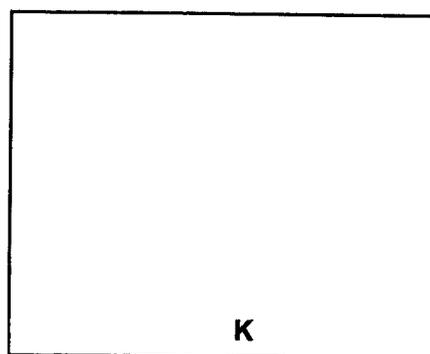
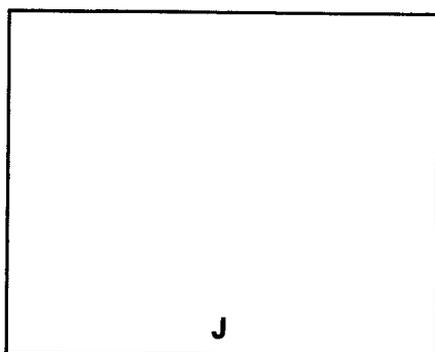
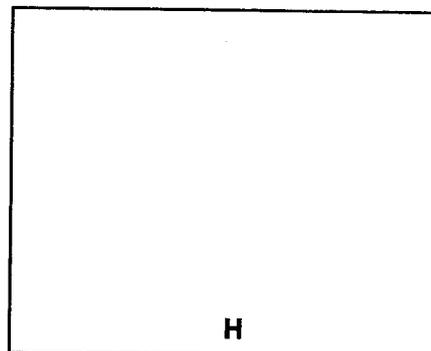
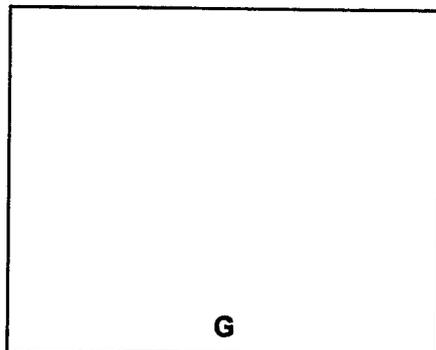
- (iii) Draw the structure of Q. State the reagents and conditions to synthesise Q from P.



reagents & conditions ..... [2]

- (b) (i) **G** has the molecular formula,  $C_8H_{14}$ . Treating **G** with hydrogen in the presence of Ni, yields **H**, with the molecular formula,  $C_8H_{16}$ . Upon mild oxidation, **G** gives a tertiary diol, **J**. Upon vigorous oxidation **G** gives a diketone, **K**, which reacts with aqueous alkaline iodine to produce hexanedioic acid upon acidification.

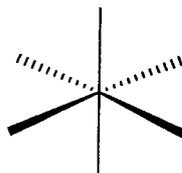
Draw the structures of **G**, **H**, **J** and **K**.



[4]



- 3 (a) At the time of its discovery by Scottish chemist Sir William Ramsay, the noble gas xenon was considered to be inert. It has since been discovered that xenon will react with strong oxidants. For example, xenon reacts with fluorine gas, forming a series of fluorides,  $\text{XeF}_2$ ,  $\text{XeF}_4$  and  $\text{XeF}_6$ .
- (i) The structure of xenon tetrafluoride has six electron pairs on xenon and therefore the structure is based on an octahedral configuration as shown below.



On Fig. 3.1, draw the two possible three-dimensional arrangements of the electron pairs on xenon in xenon tetrafluoride and tick the one observed, that gives the molecule its shape, explaining your choice with appropriate reasoning based on the principles of the VSEPR theory.

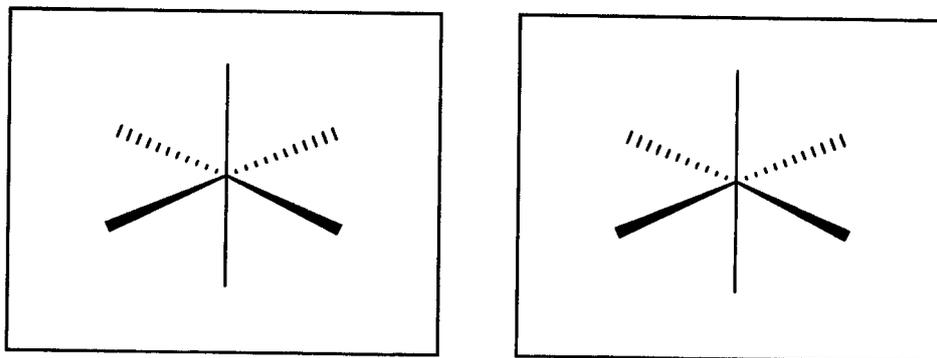


Fig. 3.1

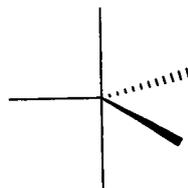
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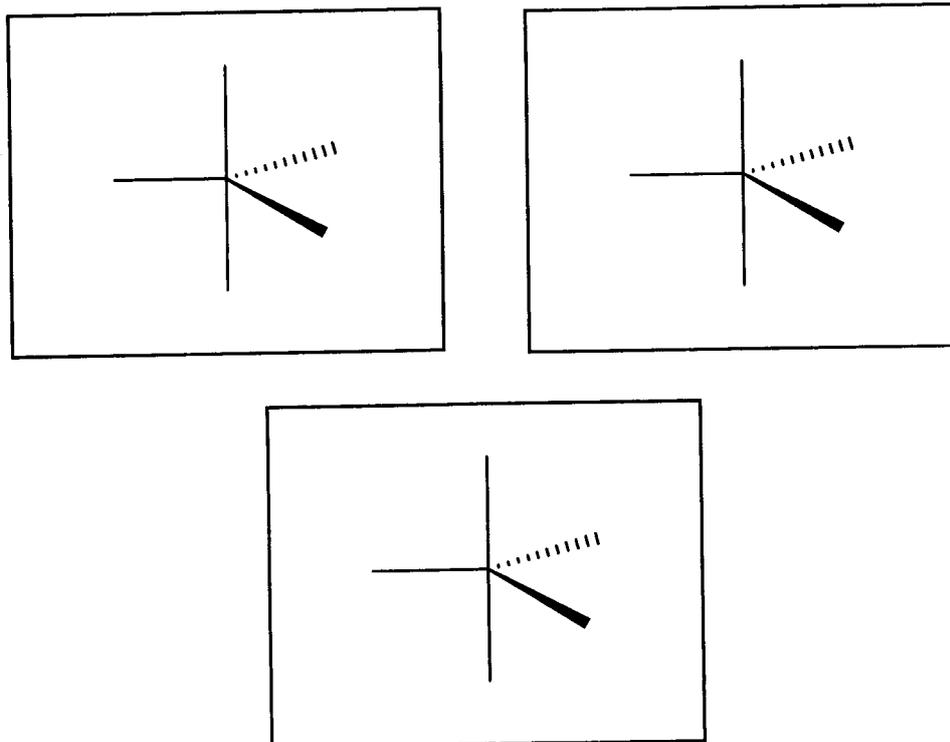
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.....[2]

- (ii) The structure of xenon difluoride has five electron pairs on xenon and therefore the structure is based on a trigonal bipyramidal configuration as shown below.



On Fig. 3.2, draw the three possible three-dimensional arrangements of the five electron pairs on xenon in xenon difluoride and tick the one observed, that gives the molecule its shape, explaining your choice with appropriate reasoning based on the principles of the VSEPR theory.



**Fig. 3.2**

.....

.....

.....

..... [3]

(b) The kinetics of the formation of xenon difluoride from xenon and fluorine has been studied under various conditions. At 120 °C, the rate equation for the formation of XeF<sub>2</sub> is found to be first order with respect to Xe and zero order with respect to F<sub>2</sub>.

(i) Write the rate equation for the formation of XeF<sub>2</sub> and suggest the units for the rate constant.

[2]

(ii) The Arrhenius equation describes the relationship between the rate constant and temperature.

$$k = Ae^{-\frac{E_a}{RT}}$$

The uncatalysed reaction between xenon and fluorine to form XeF<sub>2</sub> at a temperature  $T$  has a rate constant  $k$ , with collision frequency factor  $A$  and activation energy,  $E_a$ .

When a nickel difluoride catalyst is added to the reaction mixture, the rate constant changes to  $k_{\text{cat}}$ , with a different collision frequency  $A_{\text{cat}}$  and a different activation energy,  $E_{\text{cat}}$ . It is found that the catalysed reaction is 13 times faster at 120 °C and 23 times faster at 100 °C. The change in activation energy,  $\Delta E = E_a - E_{\text{cat}}$ .

Assuming that the collision frequency factors do not depend on temperature, write an expression for the ratio  $k_{\text{cat}}/k$  in terms of  $T$ ,  $\Delta E$  and any constants.

[1]

10

- (iii) Hence, using the ratio in (b)(ii) and the information given below, calculate the change in activation energy,  $\Delta E$ , in  $\text{kJ mol}^{-1}$ , when the temperature increased from 373 K to 393 K. Given that  $\frac{k_{\text{cat}}(393 \text{ K})}{k(393 \text{ K})} = 13$  and  $\frac{k_{\text{cat}}(373 \text{ K})}{k(373 \text{ K})} = 23$ .

[2]

[Total: 10]

- 4 (a) Ethanol is dissolved in blood and distributed to organs in the body. As a volatile compound, ethanol can be vaporised quite easily. In the lungs, ethanol can change its phase from liquid to gaseous and it can be exhaled with air. Since the concentration of alcohol vapor in lungs is directly related to its concentration in blood, blood alcohol concentration can be measured using a device called a breathalyser.

In one of the older versions of breathalyser, a suspect breathes into the device and exhaled air is allowed to pass through a solution of potassium dichromate which oxidises ethanol to acetic acid. This oxidation is accompanied by a colour change from orange to green and a detector records the change in colour intensity, which is used to calculate the percentage of alcohol in breath. When the oxidation of alcohol by potassium dichromate is carried out in an electrochemical cell, either the electrical current generated by this reaction or the change in the electromotive force can be measured and used for the estimation of alcohol content of blood.

- (i) Write a balanced ionic equation for the oxidation of ethanol by the dichromate ion in acidic solution.

[2]

- (ii) If the standard potential for the reduction of  $\text{Cr}_2\text{O}_7^{2-}$  to  $\text{Cr}^{3+}$  is 1.330 V and that for the reduction of ethanoic acid to ethanol is 0.058 V, calculate the standard electromotive force,  $E^\ominus$ , for the overall reaction.

[1]

- (iii) When a suspect breathes into a breathalyser which is designed as an electrochemical cell, the oxidation of the ethanol generates a current of 0.10 A for 60 s.

Calculate the mass of alcohol in the exhaled breath.

[3]

- (iv) In calculating the alcohol content in blood from the mass of alcohol in a breath, the "2100:1 partition ratio" needs to be considered. The ratio states that each milliliter of blood has 2100 times the mass of ethanol as each milliliter of expired air.

If the volume of expired air described in (a)(iii) is 60.0 cm<sup>3</sup>, calculate the mass of alcohol per cm<sup>3</sup> of blood.

[1]

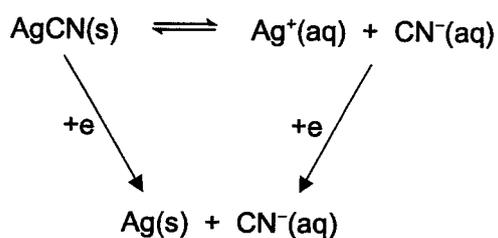
- (b) The value of the solubility product is related to the Gibbs free energy change,  $\Delta G^\circ$ , in  $\text{J mol}^{-1}$ , by the mathematical expression given below.

$$K_{\text{sp}} = 10^{-\left(\frac{\Delta G^\circ}{2.3RT}\right)}$$

Using the expression above and the cycle in Fig. 4.1 that involves the standard reduction potentials in Table 4.1, calculate the numerical value of the solubility product,  $K_{\text{sp}}$ , of AgCN at 25 °C.

**Table 4.1**

	$E^\circ / \text{V}$
$\text{AgCN(s)} + e \rightleftharpoons \text{Ag(s)} + \text{CN}^{\text{-}}(\text{aq})$	-0.01
$\text{Ag}^+(\text{aq}) + e \rightleftharpoons \text{Ag(s)}$	+0.80



**Fig. 4.1**

[4]

[Total: 11]

- 5 The Haber process is used to make ammonia, the main use of which is in fertilisers that are often sprayed on crops. Around 1% of the entire global energy supply is used in the Haber process and so research groups are looking to find more sustainable methods of producing ammonia.

One recently published approach to making ammonia uses the following three-step method.

Step 1 Electrolysis of molten lithium hydroxide at 750 K to form lithium metal.



Step 2 Reaction of lithium metal with nitrogen to form lithium nitride.

Step 3 Reaction of lithium nitride with water to re-form lithium hydroxide and ammonia.

Thus, the lithium hydroxide formed in Step 3 can be re-used in Step 1 and the process can be repeated.

The relevant thermochemical data are provided in Table 5.1.

**Table 5.1**

At 750 K	LiOH	Li	H <sub>2</sub> O	O <sub>2</sub>
$\Delta H_f / \text{kJ mol}^{-1}$	-446.0	+15.0	-268.0	+15.8
$\Delta S_r$ for step 1 at 750 K is $+427 \text{ J K}^{-1} \text{ mol}^{-1}$				

- (a) Explain why the enthalpy changes of formation of the elements Li and O<sub>2</sub> are not zero at 750 K.

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

- (b) Calculate  $\Delta H_r$  and hence  $\Delta G_r$  for Step 1 at 750 K.

[2]

- (c) Given that the electrolysis will only proceed at an appreciable rate when the applied potential exceeds the electrochemical cell potential by 0.60 V, calculate the minimum potential that should be applied in Step 1.

[1]

- (d) Write the chemical equations for Step 2 and Step 3. Hence calculate the stoichiometric ratio between the lithium produced in Step 1 and the ammonia produced in Step 3.

[2]

- (e) In a small-scale experiment, the researchers applied a current of 0.200 A for 1000 seconds. The yield of lithium production in this process was 88.5% in Step 1. The yield of Steps 2 and 3 can be assumed to be 100%.

Calculate the mass of lithium generated in Step 1.

[2]

- (f) Calculate the volume of ammonia produced, in  $\text{cm}^3$ , at room temperature and pressure.

[1]

- (g) A potential application of this approach is to use renewable energy sources as the source of electricity for the electrolysis and to produce ammonia at a farm where it can be used straight away. The average size of a UK farm is 130 acres, and a farm requires 0.0770 tonnes of ammonia per acre annually.

If the lithium hydroxide was not recycled at the end of the process, calculate the total mass of lithium, in tonnes, that would have to be produced to generate the required mass of ammonia for a year. [1 tonne = 1000 kg]

[2]

[Total: 11]

- 6 (a) Propanone can exist in *keto* and *enol* forms.



The enol form is derived from the keto form by transferring a hydrogen atom to the oxygen atom.

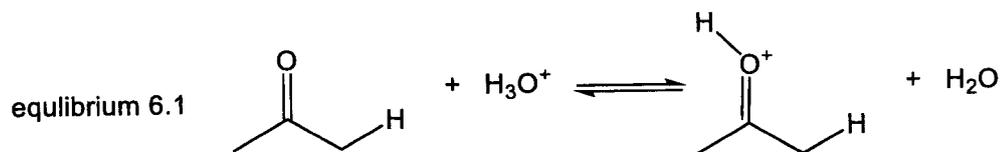
At room temperature and pressure, the keto form is the predominant form at equilibrium suggesting that the keto form is the more stable form.

Using bond energy data from the *Data Booklet*, calculate the enthalpy change for the above interconversion, and hence explain why the equilibrium lies heavily towards the keto form.

[2]

- (b) The conversion of keto form to the enol form of propanone can be catalysed by an acid.

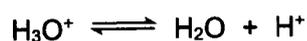
The first equilibrium step of the mechanism involves protonation of oxygen atom of the C=O bond as given below.



The  $K_c$  expression for equilibrium 6.1 is given as follows.

$$K_c = \frac{\left[ \text{CH}_3\text{C}(\text{OH}^+)\text{CH}_2\text{H} \right] \left[ \text{H}_2\text{O} \right]}{\left[ \text{CH}_3\text{C}(=\text{O})\text{CH}_2\text{H} \right] \left[ \text{H}_3\text{O}^+ \right]}$$

- (i) Write the  $K_a$  expressions for the acid dissociation of  $\text{H}_3\text{O}^+$  and  $(\text{CH}_3)_2\text{C}=\text{OH}^+$  using their respective equilibrium equations given below.



[2]

- (ii) Hence, express  $K_c$  for equilibrium 6.1 in terms of the two  $K_a$  expressions in (b)(i).

[1]

- (iii) Given that the  $pK_a$  of  $H_3O^+$  is  $-1.7$  and the  $pK_a$  of  $(CH_3)_2C=OH^+$  is  $-7.2$ , calculate a value of  $K_c$  for equilibrium 6.1.

[1]

- (iv) Given that  $\Delta G^\circ = -RT \ln K$ , calculate the Gibbs Free energy change, in  $\text{kJ mol}^{-1}$ , for equilibrium 6.1.

[2]

- (v) Based on your answers to the values of  $K_c$  and  $\Delta G^\circ$ , comment on the relative stability of the keto form versus the enol form.

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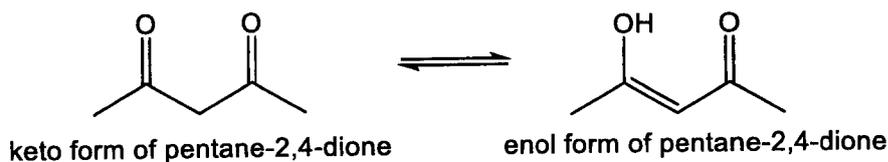
.....[2]

- (vi) Tautomerisation is a type of isomerisation where two molecules with the same molecular formula but different connectivity (constitutional isomers) rapidly interconvert in a solution or equilibrium. The most well-known example is the interconversion between a keto (containing a carbonyl group) and an enol (containing an alcohol and a double bond) form of a molecule.

Outline the mechanism for the tautomerisation of propanone to its enol form catalysed by acid, showing all curly arrows, lone pairs and charges.

[3]

- (c) The enol form of pentane-2,4-dione is unusually stable and hence the equilibrium lies more towards the enol form.



It is also observed that the percentage of the enol form increases as the solvent used is changed from a polar solvent to a non-polar solvent.

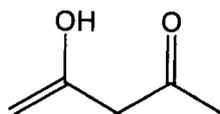
- (i) By comparing the structures of the enol form with the keto form, suggest a reason for the increased stability of the enol form in pentane-2,4-dione.

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

- (ii) Explain why the keto form is favoured with polar solvents.

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

- (iii) Another enol form of pentane-2,4-dione, as shown below can also be drawn.



another enol form of pentane-2,4-dione

Explain if this enol form is likely to be formed as well.

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

[Total: 16]

7 (a) Solid magnesium hydroxide decomposes when heated to form two products. One of the products formed is steam.

(i) Construct a balanced equation, with state symbols, for the above reaction.

.....[1]

(ii) The variation in thermal stability of Group 2 hydroxides is similar to that of Group 2 carbonates.

Explain whether magnesium hydroxide is more or less thermally stable than barium hydroxide.

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.....[3]

(b) (i) Using relevant data from the *Data Booklet*, comment on the thermal stability of hydrogen bromide and hydrogen iodide.

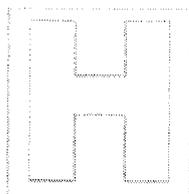
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.....[1]

- (ii) Identify a transition metal cation that can be used to differentiate the oxidising strengths of  $\text{Br}_2$  and  $\text{I}_2$ . Explain your answer with appropriate workings.

[3]

[Total: 8]





**Anglo-Chinese Junior College**  
 JC2 Preliminary Examination  
 Higher 2



A Methodist Institution  
 (Founded 1862)

CANDIDATE  
 NAME

FORM  
 CLASS

TUTORIAL  
 CLASS

INDEX  
 NUMBER

**CHEMISTRY**

Paper 3 Free Response

**9729/03**

1 September 2025

2 hours

Candidates answer on the Question Paper.  
 Additional Materials: Data Booklet

**READ THESE INSTRUCTIONS FIRST**

Write your index number and name on all the work you hand in.  
 Write in dark blue or black pen.  
 You may use an HB pencil for any diagrams or graphs.  
 Do not use staples, paper clips, glue or correction fluid.

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

**Section A**

Answer **all** questions.

**Section B**

Answer **one** question.

Circle the number of the question you have attempted.

A Data Booklet is provided.

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

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 Examiners' use only	
Section A	
1	/ 15
2	/ 24
3	/ 21
Section B	
4 / 5	/ 20
Presentation	
<b>Total</b>	<b>/ 80</b>

This document consists of **28** printed pages.

**Section A**

Answer all the questions in this section.

- 1 The Mars Curiosity rover's landing in August 2012 was achieved using hydrazine fuelled rocket thrusters. The rapid decomposition of hydrazine,  $\text{N}_2\text{H}_4$ , over a suitable catalyst to produce hot gaseous elements as products provides the thrust. Ammonia can be formed as an intermediate during the decomposition.

- (a) Write a balanced equation for hydrazine decomposing to ammonia and nitrogen gas. [1]

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- (b) Hydrazine may be obtained from the reaction between ammonia and hydrogen peroxide as shown in equation 1.

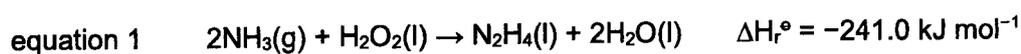


Table 1.1 shows the standard enthalpy change of formation,  $\Delta H_f^\ominus$ , for some compounds in equation 1.

**Table 1.1**

compound	$\Delta H_f^\ominus / \text{kJ mol}^{-1}$
$\text{NH}_3$	-46.1
$\text{H}_2\text{O}_2$	-187.8
$\text{H}_2\text{O}$	-285.8

Calculate the standard enthalpy change for the decomposition of hydrazine to its elements. [2]

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(d) Hydrazine is also commonly combined with dinitrogen tetroxide,  $N_2O_4$ , in rocket fuels.

(i) Reactions used in rocketry produce chemically stable gaseous products.

Suggest the products that are formed in the reaction between  $N_2H_4$  and  $N_2O_4$ . [1]

(ii) Pure  $N_2O_4$ , when warmed, does not immediately decompose into its elements, but instead forms a brown gas.

Suggest the identity of this brown gas. [1]

(iii)  $N_2H_4$  does not exhibit ideal gas behaviour.

State and explain two reasons for its deviation from ideal gas behaviour. [2]

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e) A derivative of hydrazine with formula  $C_2H_8N_2$  was used as rocket fuel in the Apollo missions. Draw two isomers of  $C_2H_8N_2$  containing an N–N bond. [1]

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2 Cocoa trees have been used as a source of food for more than 5,000 years. In modern times, they are used to make chocolates.

- (a) Palmitic acid and stearic acid are saturated fatty acids, while oleic acid and linoleic acid are unsaturated fatty acids commonly found in chocolates.

An example of an unsaturated fatty acid is shown below in Fig. 2.1.

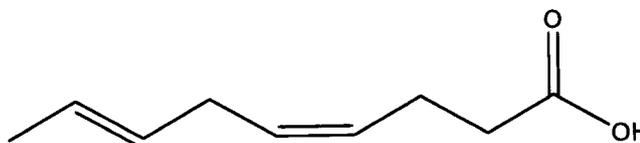


Fig. 2.1

The systematic name of the unsaturated fatty acid in Fig. 2.1 is *cis,trans*-4,7-nonadienoic acid. The numbers indicate the positions of the alkene functional groups, and "dien" indicates that there are two alkenes in the chain.

Table 2.2 shows the percentage composition of fatty acids found in three different cocoa butter samples.

Table 2.2

fatty acid	% of fatty acids in cocoa butter samples		
	A	B	C
palmitic acid	28	25	35
stearic acid	35	40	40
oleic acid	31	28	21
linoleic acid	6	7	4



- (b) A chocolatier investigated the quality of two varieties of cocoa beans from the same producer. Table 2.3 shows the results of the chemical analysis.

Table 2.3

chemicals	variety of cocoa beans	
	D	E
theobromine (mg / g)	12.5	15.2
epicatechin (mg / g)	4.8	6.1
ash content (% mass)	3.0	3.5
reducing sugars (% mass)	2.5	3.0

- (i) The ash content of cocoa beans is determined by burning the sample until all organic matters are combusted, leaving behind the inorganic residue, which is reported as the percentage mass of the original sample.

Suggest one use for determining the ash content. [1]

- (ii) Chocolate is poisonous to dogs as they metabolise theobromine much more slowly compared to humans. The median lethal dose of theobromine for dogs is 120 mg per kg of body weight.

A 60 g of a dark chocolate bar contains 85% cocoa content of variety E.

Calculate the percentage of a chocolate bar, to 1 decimal place, that would be the median lethal dose for a small dog weighing 5.4 kg. [2]

- (iii) Theobromine is metabolised more slowly than caffeine in the human body. Following a first-order kinetics, the half-life of theobromine is 8 hours.

The integrated rate law for a first-order reaction is given.

$$\ln [A]_t = -kt + \ln[A]_0$$

where  $k$  = rate constant

$t$  = time

$[A]_t$  = concentration of A at time  $t$

$[A]_0$  = initial concentration of A

A social media influencer consumed a large quantity of giant chocolate bars during a broadcast. An immediate blood test revealed a theobromine level of  $15.5 \text{ mg dm}^{-3}$ .

Calculate the time taken for his theobromine level to fall below  $1.5 \text{ mg dm}^{-3}$ . [2]







- (d) Compared to other types of chocolate, dark chocolate is richer in epicatechin, which is an antioxidant.

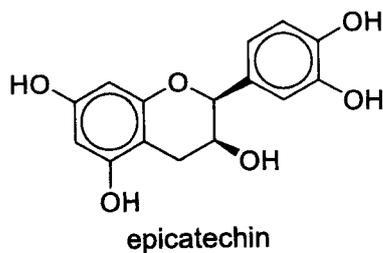


Fig 2.4 shows a possible synthetic pathway of epicatechin in the laboratory.

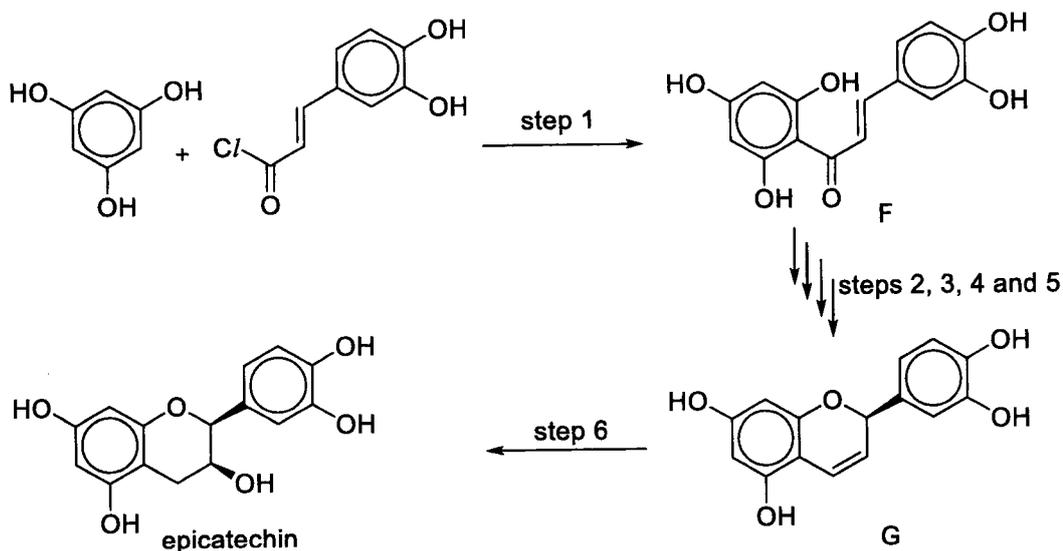


Fig. 2.4

- (i) In step 1, electrophilic substitution occurs to form F in the presence of  $AlCl_3$ .

Draw the mechanism for step 1. Show the relevant curly arrows and charges, and all the products formed.



- (ii) Intermediate G can be formed from F in four steps. The reactions involved are:
- electrophilic addition,
  - acid-base reaction and intramolecular nucleophilic substitution,
  - reduction, and
  - elimination.

Suggest reagents and conditions for each step. Draw the structure of the intermediate compound formed after each step.



















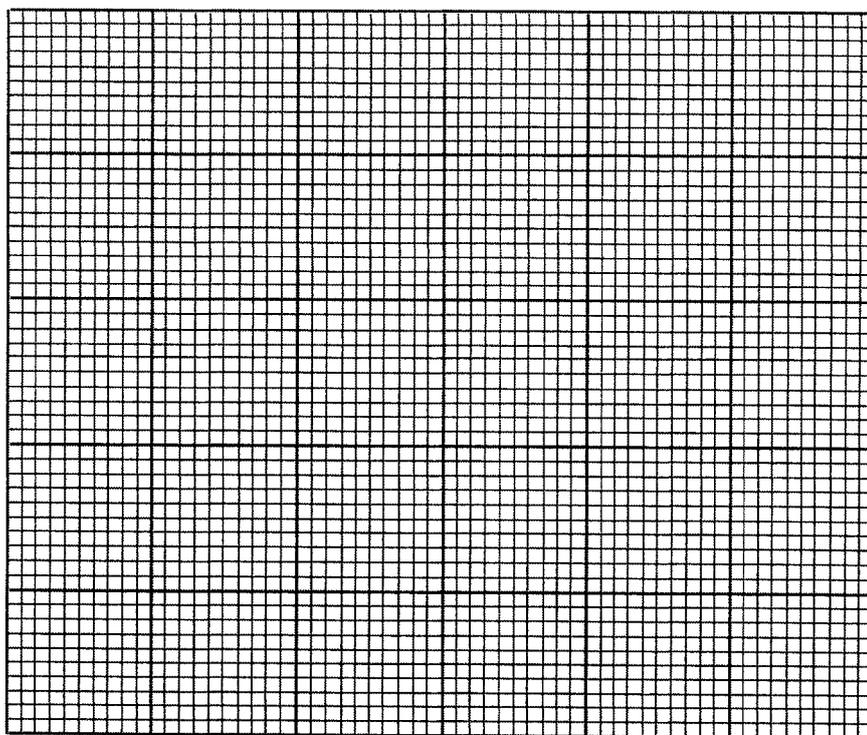


Fig. 4.2

- (iv) Calculate the initial concentration of the trichloroethanoic acid used in the experiment. [2]
- (v) Use your graph in Fig. 4.2 to deduce the order of reaction with respect to trichloroethanoic acid, calculate the value of the rate constant, and write an expression for the rate equation. Show how you obtained your answer. [3]
- (vi) Use the graph to estimate the time taken for the initial concentration of trichloroethanoic acid to fall by 10 %. [1]

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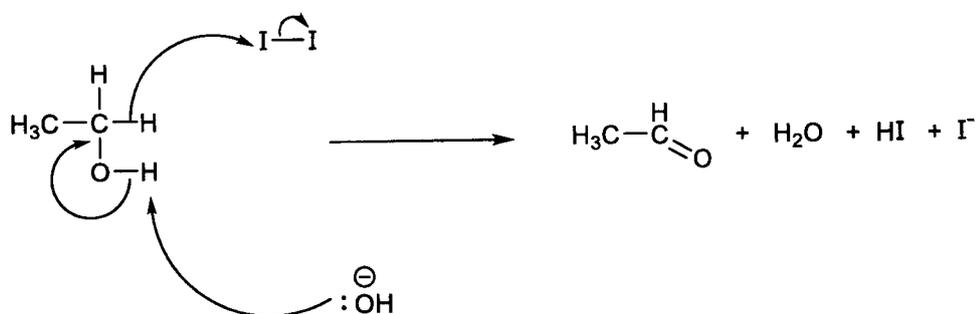




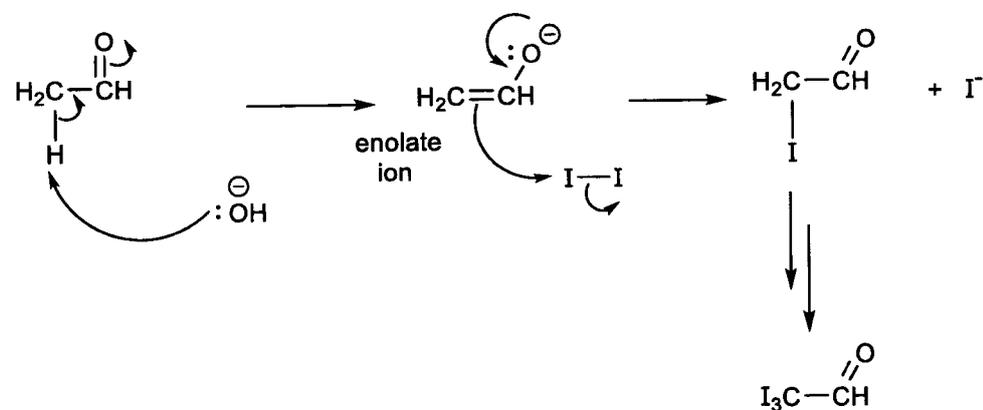
- 5 Iodoform reaction is a chemical reaction in which a methyl ketone or a secondary alcohol with a methyl group in the alpha position is oxidised to a carboxylate by reaction with aqueous  $\text{OH}^-$  and  $\text{I}_2$ . Ethanoic acid, esters of ethanoic acid and ethanoyl chloride do not undergo the iodoform reaction even though they possess the methyl keto,  $\text{CH}_3\text{CO}-$ , moiety in their structures.

(a) Fig. 5.1 shows the mechanism of the different stages in the iodoform reaction.

Step 1



Step 2



Step 2 proceeds repeatedly to replace all the remaining hydrogen atoms of the methyl group that is directly attached to the carbonyl to form  $\text{CI}_3\text{CHO}$

Step 3

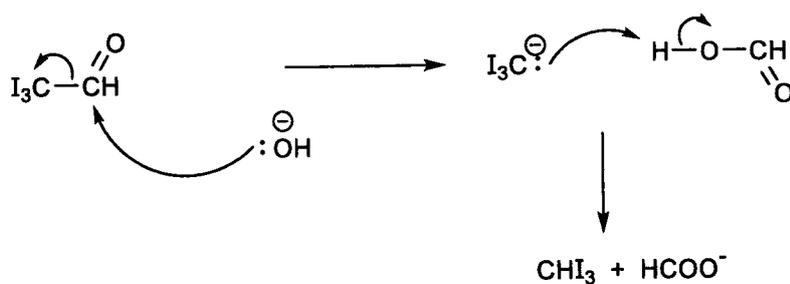


Fig. 5.1







