EUNOIA JUNIOR COLLEGE
JC2 Preliminary Examination 2025
General Certificate of Education Advanced Level
Higher 2

CHEMISTRY
Paper 1 Multiple Choice

9729/01

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, civics group and registration number on the Answer Sheet in the spaces provided unless this has been done for you.

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.
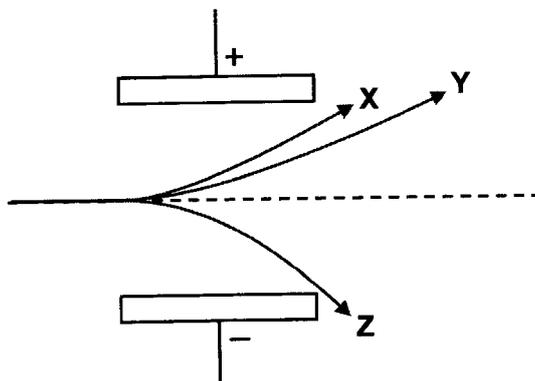Any rough working should be done in this question paper.
The use of an approved scientific calculator is expected, where appropriate.

This document consists of **13** printed pages and **3** blank pages.

1   Three particles approach an electric field at the same speed. They are deflected as they pass through the electric field.

What could be the identities of particles **X**, **Y** and **Z**?

	X	Y	Z
A	$^{35}_{17}Cl^-$	$^{37}_{17}Cl^-$	$^{23}_{11}Na^+$
B	$^{6}_{3}Li^+$	$^{7}_{3}Li^+$	$^{1}_{1}H^-$
C	$^{37}_{17}Cl^-$	$^{35}_{17}Cl^-$	$^{23}_{11}Na^+$
D	$^{7}_{3}Li^+$	$^{6}_{3}Li^+$	$^{1}_{1}H^-$

2   Which of the following about calcium and copper is correct?

A   The outermost orbital of the atoms of both elements has the same shape.

B   Atom of both elements have orbitals of only 2 different shapes of various sizes.

C   Atom of both elements have the same number of electrons in the outermost shell.

D   Both elements form ions of 2+ charge with the electronic configuration of [Ar].

3 The following diagrams show the structures of an element, one of its oxides and its halides. What could the element be?
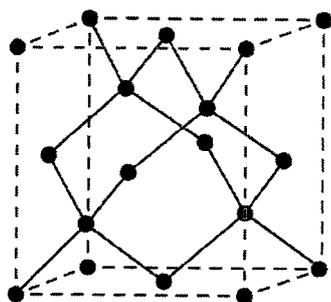
● element
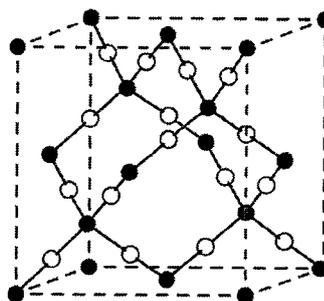
● element
○ oxygen
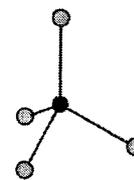
● element
◎ halogen

A aluminium **B** carbon **C** phosphorus **D** silicon

4 The boiling point of water (100 °C) is greater than that of HF (20 °C).
Which statement is a correct explanation of the above?

A Each hydrogen bond formed between water molecules is stronger than that formed between HF molecules.

B There are more atoms in a water molecule than there are in an HF molecule, resulting in stronger intermolecular forces in water.

C There are, on average, more hydrogen bonds between water molecules than there are between HF molecules.

D The water molecule has stronger permanent dipole–dipole interactions than the HF molecule.

5 For a fixed mass of an ideal gas, which of the following graphs does **not** have the same general shape as the rest?

(ρ = density of the gas; M = molar mass of gas)

A $\dfrac{p}{\rho}$ against T

B pV against $\dfrac{M}{T}$

C p against ρT

D $\dfrac{T}{p}$ against V

6 Which option correctly describes the species in terms of its behaviour as a Lewis base and as an Arrhenius acid?

	species	Lewis base	Arrhenius acid
A	HCl	no	yes
B	AlH_3	yes	no
C	NH_3	no	no
D	O^{2-}	yes	yes

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

Based on its position in the Periodic Table, which properties will indium, In, be expected to possess?

1　In the vapour state, the chloride dimerises to form In_2Cl_6.

2　Its oxide dissolves in both acids and alkalis.

3　Its ionic salts are typically coloured.

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

8 Metal peroxides decompose when heated to form metal oxides and oxygen gas. Which factor contributes to solid BaO_2 being more thermally stable than solid MgO_2?

A　The hydration enthalpy of Mg^{2+} ion is more exothermic than that of Ba^{2+} ion.

B　The lattice energy of BaO_2 is more negative than that of MgO_2.

C　The charge density of Ba^{2+} ion is lower than that of Mg^{2+} ion.

D　The O–O bond in O_2^{2-} is weaker than the O=O bond in O_2.

9 F_2 reacts with BrO_z^- ions in a 2 : 1 molar ratio to form F^- and BrO_4^- ions.

What is the value of z?

A　1　　　　**B**　2　　　　**C**　3　　　　**D**　5

10 Diamond is a pure form of carbon. The mass of a diamond can be measured in carats, where one carat is equivalent to 0.200 g of carbon.

How many carats is a diamond made up of 3.01×10^{23} carbon atoms?

A 0.4   B 2.5   C 30   D 60

11 The enthalpy change of formation of potassium bromide, KBr, can be calculated using a Born-Haber cycle.

The enthalpy changes related to potassium and bromine are shown in the table.

	enthalpy change /kJ mol^{-1}
$K(s) \rightarrow K(g)$	+90
$Br_2(g) \rightarrow 2Br(g)$	+193
$K(g) \rightarrow K^+(g) + e^-$	+418
$Br(g) + e^- \rightarrow Br^-(g)$	-325
$K^+(g) + Br^-(g) \rightarrow KBr(s)$	-678

What is the enthalpy change of formation of KBr?

A -302 kJ mol^{-1}

B -399 kJ mol^{-1}

C -958 kJ mol^{-1}

D -1054 kJ mol^{-1}

6

12 When heated, magnesium carbonate decomposes to form carbon dioxide and magnesium oxide.

A graphical plot of ΔG versus T, describing the change of the Gibbs free energy of the decomposition of magnesium carbonate with respect to temperature, is shown below.
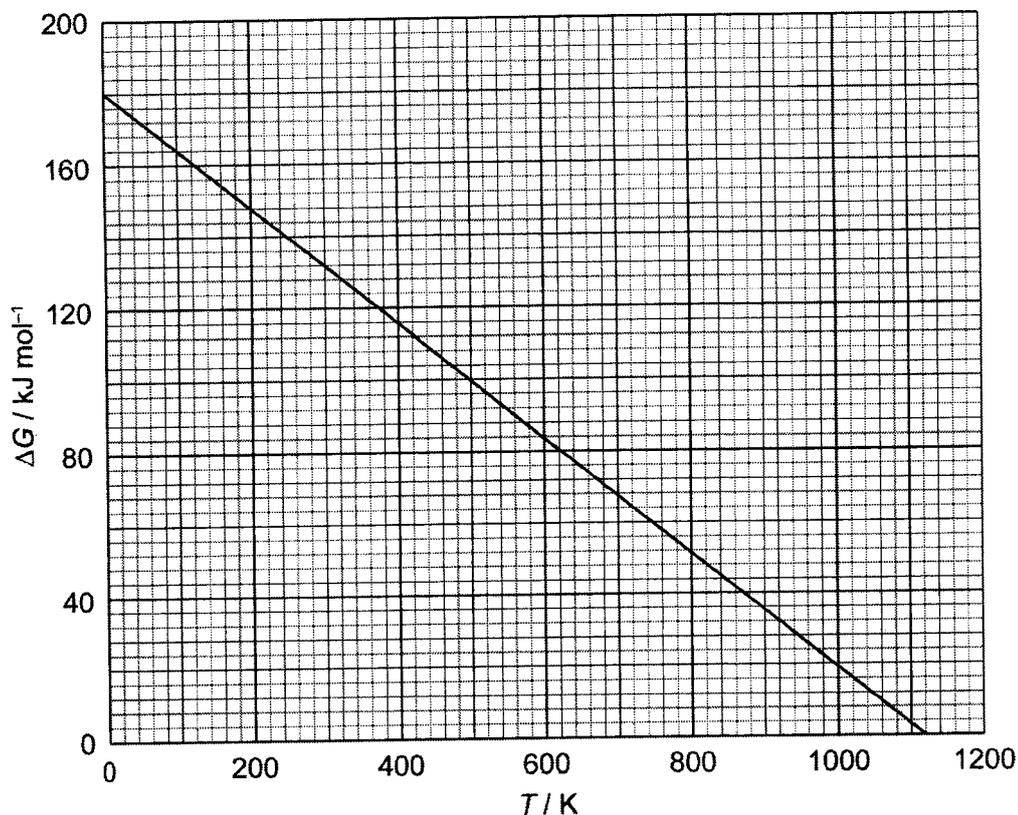
Using the information from the graph, what is the value of $\Delta S^{\ominus}$ for the decomposition reaction?

A $+6.04 \times 10^2$ J mol^{-1} K^{-1} 　　　B -6.04×10^2 J mol^{-1} K^{-1}

C $+1.61 \times 10^2$ J mol^{-1} K^{-1} 　　　D -1.61×10^2 J mol^{-1} K^{-1}

13 Caesium-137 undergoes radioactive decay to form barium-137. This decay is a first-order reaction with a half-life of 30.2 years.

How long would it take for the molar proportion of caesium to barium to reach a ratio 1:3 from pure caesium-137?

A 30.2 years 　　B 60.4 years 　　C 90.6 years 　　D 120.8 years

14 The reaction of hydrogen peroxide with iodide ions in an acidic solution can be monitored by an initial rates method.

$$H_2O_2(aq) + 2H^+(aq) + 2I^-(aq) \rightarrow 2H_2O(l) + I_2(aq)$$
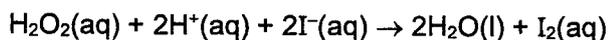
The rate equation was found to be as follows:

$$rate = k\,[H_2O_2][I^-]$$

What of the following mechanism correctly describes this reaction?

A $H_2O_2 + I^- \rightarrow H_2O + IO^-$ (slow)
    $IO^- + H^+ \rightarrow HIO$ (fast)
    $HIO + H^+ + I^- \rightarrow H_2O + I_2$ (fast)

B $H_2O_2 + I^- \rightarrow H_2O + IO^-$ (slow)
    $H_2O_2 + IO^- \rightarrow H_2O + IO_2^-$ (fast)
    $IO_2^- + I^- + 4H^+ \rightarrow 2H_2O + I_2$ (fast)

C $2H^+ + 2I^- \rightarrow 2HI$ (fast)
    $2HI + H_2O_2 \rightarrow 2H_2O + I_2$ (slow)

D $H_2O_2 + I^- + H^+ \rightarrow H_2O + HIO$ (fast)
    $HIO + I^- \rightarrow OH^- + I_2$ (slow)
    $OH^- + H^+ \rightarrow H_2O$ (fast)

15 When steam is passed over white hot coke, a mixture of combustible gases is obtained.

$$C(s) + H_2O(g) \underset{k_b}{\overset{k_f}{\rightleftharpoons}} H_2(g) + CO(g) \qquad \Delta H = +131 \text{ kJ mol}^{-1}$$
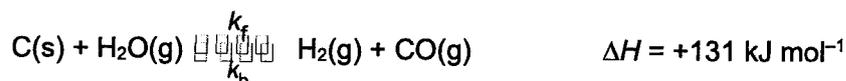
When equilibrium has been established, which of the following correctly describes what would happen if a proposed change is made to this system?

	proposed change	value of K_c	forward rate constant, k_f	backward rate constant, k_b
A	add catalyst	no change	increase	increase
B	add more C(s)	no change	increase	no change
C	increase volume	increase	decrease	decrease
D	increase temperature	increase	increase	decrease

16 Water dissociates into H^+ and OH^- as shown.

$$H_2O \rightleftharpoons H^+ + OH^-$$
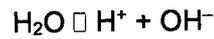
The pH of water decreases at higher temperatures.

Which statements are correct?

1 Water becomes acidic at higher temperatures.

2 The dissociation of water is endothermic.

3 The pOH decreases at higher temperatures.

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

17 The graph shows the changes in pH when excess 0.10 mol dm^{-3} base solution is added gradually to $y \text{ cm}^3$ of 0.10 mol dm^{-3} acid solution.

volume of 0.10 mol dm^{-3} base added / cm^3
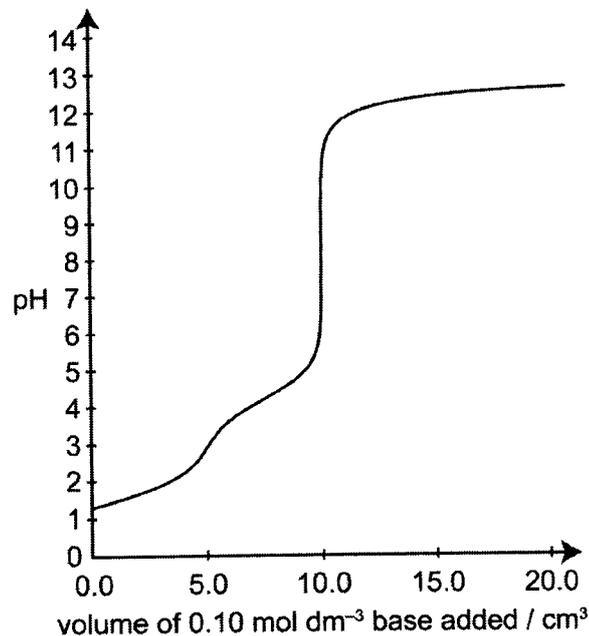
Which combination could have given these results?

	acid	base	y / cm^3
A	H_2SO_4	NH_3	10
B	H_2SO_4	NH_3	5
C	$(COOH)_2$	KOH	10
D	$(COOH)_2$	KOH	5

18 Given the following solubility product, K_{sp}, which of the following statements is correct?

salt	K_{sp}
Ag_2SO_4	1.4×10^{-5}
$PbSO_4$	1.6×10^{-8}
PbI_2	7.1×10^{-9}

A All three K_{sp} values have the same unit.

B $PbSO_4$ has a lower solubility in pure water than PbI_2.

C Solubility product of Ag_2SO_4 decreases when added to sulfuric acid.

D When solid Na_2SO_4 is added to a solution containing 0.01 mol dm^{-3} of Ag$^+$(aq) and Pb^{2+}(aq), Ag_2SO_4 precipitates before $PbSO_4$.

19 One molecule of a non-cyclic organic compound contains only carbon atoms, hydrogen atoms and one oxygen atom. The compound is a ketone and contains a chiral carbon atom. One molecule of this compound contains x carbon atoms.

What could be the value of x?

1   $x = 5$

2   $x = 6$

3   $x = 7$

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

20 Propane undergoes free-radical substitution when mixed with chlorine and exposed to ultra-violet light.

Which compounds are possible products from this reaction?

1   $CH_3CH_2CH_2Cl$

2   $CH_2ClCH_2CH_2Cl$

3   $CH_3CH_2CH_2CH_2CH_3$

4   $CH_3CH_2CH_2CH_2CH_2CH_3$

A 1, 2 and 3   **B** 1, 2 and 4 only   **C** 1 and 2 only   **D** 2 and 3 only

21 When cyclohexene reacts with bromine, only racemic *trans*-1,2-dibromocyclohexane is obtained. No *cis*-1,2-dibromocyclohexane is obtained.

cyclohexene   *trans*-1,2-dibromo-
cyclohexane
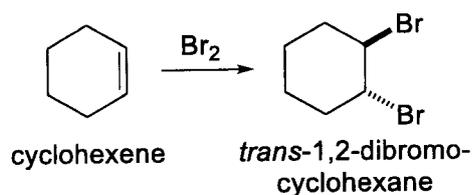
1-methylcyclohexene reacts with iodine monobromide, IBr, via the same mechanism giving the Markovnikov's product, M.

1-methylcyclohexene
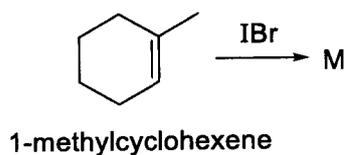
Which of the following is likely to be the structure of M?

22 Compound Y, C_9H_{10}, reacts upon prolonged heating with acidified concentrated $KMnO_4$ to produce $C_8H_6O_4$ as the only organic product.

What is the structural formula of Y?

23 1.00 g of each of the following compounds was heated with NaOH(aq), and then dilute HNO_3(aq) and $AgNO_3$(aq) was added.

Which compound will produce the largest mass of $AgCl$(s)?

A (M_r = 169.0)

B (M_r = 147.0)

C (M_r = 167.0)

D CH_3COCl (M_r = 78.5)
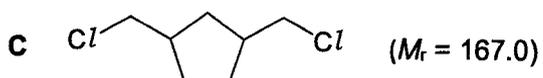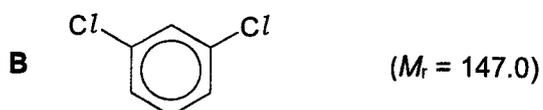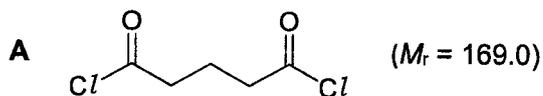
24 Which sets of reagents and conditions can be used to form the organic product $CH_3CH(OH)CH(CH_2NH_2)CO_2H$ from $CH_3COCH(CN)CO_2H$?

1   H_2, nickel catalyst, room temperature

2   $LiAlH_4$, dry ether as solvent, room temperature

3   $NaBH_4$, ethanol as solvent, room temperature

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

25 Propanone reacts with HCN at a slower rate compared to propanal.

Which statements are correct?

1   In both reactions, the carbonyl carbon reacts with a cyanide ion in the first step.

2   In propanone, the carbonyl carbon is more nucleophilic which repels the attacking cyanide ion.

3   A trace amount of $NaCl$ is needed to catalyse the reaction.

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

26 How many moles of $H_2(g)$ is produced when 1 mole of **Q** reacts with Na(s) and how many moles of $CO_2(g)$ is produced when 1 mole of **Q** reacts with $Na_2CO_3(aq)$?

CH(OH)CH₃ ... OH

Q
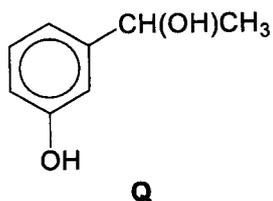
	$H_2(g)$ produced with Na(s)	$CO_2(g)$ produced with $Na_2CO_3(aq)$
A	0	1
B	1	2
C	1	0
D	2	1

27 Aldol addition products are formed when a small amount of NaOH(aq) is added to carbonyl compounds at room temperature.

O + O →(NaOH(aq)) O OH

aldol addition product
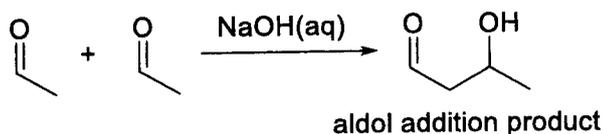
Which product is **not** formed when a small amount of NaOH(aq) is added to an equimolar mixture of propanone and propanal?

A

B

C

D

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

An electrochemical cell is set up using a $Zn^{2+}(aq)|Zn(s)$ half-cell and a $MnO_4^-(aq)|Mn^{2+}(aq)$ half-cell in acidic solution.

Which of the following gives a correct effect on the E_{cell} when each of the changes is made to the corresponding half-cell separately?

	change	half-cell	effect on E_{cell}
A	addition of water	$MnO_4^-(aq)|Mn^{2+}(aq)$	less positive
B	addition of $Mn(NO_3)_2(s)$	$MnO_4^-(aq)|Mn^{2+}(aq)$	no change
C	addition of $Zn(NO_3)_2(s)$	$Zn^{2+}(aq)|Zn(s)$	more positive
D	addition of $Na_2CO_3(s)$	$Zn^{2+}(aq)|Zn(s)$	no change

29 In an experiment, a cell was set up to obtain pure nickel from a nickel-silver alloy.
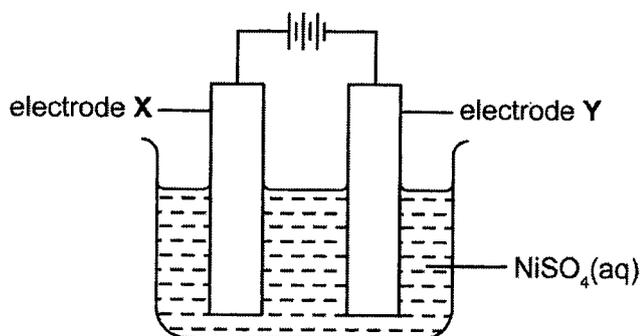
Which of the following statements is correct?

A Electrode **Y** is the nickel-silver alloy.

B The concentration of the electrolyte must be 1 mol dm⁻³.

C The electrolyte may be replaced with sodium sulfate solution.

D The mass of the cathode changes by the same mass as the anode.

30 Which of the following about period 4 transition elements is correct?

A The atomic radius decreases across the period.

B First ionisation energy remains relatively constant across the period.

C Period 4 transition elements have lower melting point than s block elements.

D The densities of period 4 transition elements are comparable to those of s block elements.

14

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EUNOIA JUNIOR COLLEGE
JC2 Preliminary Examination 2025
General Certificate of Education Advanced Level
Higher 2

CANDIDATE NAME

CIVICS GROUP | 2 | 4 | – | | |

INDEX NUMBER | | |

CHEMISTRY
Paper 2 Structured Questions

9729/02
02 September 2025
2 hours

Candidates answer on the Question Paper.

Additional Materials: Data Booklet

READ THESE INSTRUCTIONS FIRST

Write your name, civics group, index number in the spaces at the top of this page.
Write in dark blue or black pen.
You may use an HB pencil for any diagrams or graphs.
Do not use staples, paper clips, glue or correction fluid.

Answer **all** questions in the spaces provided on the Question Paper.
The use of an approved scientific calculator is expected, where appropriate.

A Data Booklet is provided.

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

For Examiner's Use
Paper 2
1	/ 13
2	/ 16
3	/ 14
4	/ 14
5	/ 18
Total	/ 75

This document consists of **22** printed pages and **2** blank pages.

1   Mount Ijen in East Java is famous for its rare blue flames, visible at night. The phenomenon occurs when sulfur vapour, from the volcano's cracks burns, producing bright blue flames and sulfur dioxide. In the cool high-altitude air, some of the vapour condenses into solid sulfur.

(a) A team of environmental chemists were authorised to collect solid sulfur deposits near Mount Ijen's crater to investigate volcanic activity.

The chemists burnt the sulfur sample and measured the temperature change for a fixed amount of water placed in a calorimeter. The data from their experiment is shown in Table 1.1.

Table 1.1

mass of solid sulfur powder burnt /g	0.76
mass of water in beaker /g	150
initial temperature of water /°C	29.8
final temperature of water / °C	39.7

(i)   Construct an equation to represent the standard enthalpy change of combustion of solid sulfur, S.

.... [1]

(ii)   Calculate the enthalpy change of combustion of solid sulfur, S, based on their experiment.

[2]

(iii) During volcanic activity, many sulfur-containing gases such as hydrogen sulfide, H_2S, and sulfur dioxide, SO_2, are released. In the atmosphere, H_2S can oxidise to form SO_2, and subsequently sulfur trioxide, SO_3, may be formed.

$$H_2S(g) + 3/2\ O_2(g) \rightarrow SO_2(g) + H_2O(l) \qquad \Delta H_r = -562\ \text{kJ mol}^{-1}$$
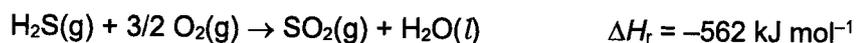
Use the data given in Table 1.2 to calculate the enthalpy change of combustion of solid sulfur, S.

Table 1.2

compound	ΔH_f / kJ mol^{-1}
$H_2S(g)$	−20.6
$H_2O(l)$	−285.8

[2]

(iv) Comment on the difference in values for the enthalpy change of combustion of solid sulfur determined in **(a)(ii)** and **(a)(iii)**.

....

....

.... [1]

(v) With reference to a relevant chemical equation, explain how the release of sulfur-containing gases during volcanic activity can have a negative impact on the environment.

....

....

....

.... [2]

(b) Sulfur in volcanic emissions primarily exists as a mixture of two stable isotopes: ^{32}S and ^{34}S.

The chemists analysed volcanic gas samples to determine the isotopes' relative abundance, which reveals the sulfur's origin.
- If the sample was enriched in ^{32}S, it originated from deep mantle degassing.
- If the sample was enriched in ^{34}S, it originated from hydrothermally recycled sources.

(i) 1.994 g of SO_2 evolved at Mount Ijen allowed the chemists to extract 1.00 g of elemental sulfur containing mixture of isotopes, ^{32}S and ^{34}S, for further analysis.

Calculate the percentage by mass of ^{32}S in the elemental sulfur extracted. You may use the chemical formula S to represent elemental sulfur in your calculations.

[3]

(ii) Hence, suggest the likely origin of the sulfur sample.

....

....

.... [1]

While volcanic emissions affect the isotopic fractions of sulfur, the natural isotopic abundance of sulfur in Earth's environment is generally found to be present as follows.

Table 1.3

isotope	relative isotopic mass	percentage abundance / %
^{32}S	31.972	95.02
^{33}S	32.971	0.75
^{34}S	33.968	4.21
^{36}S	35.967	0.02

(iii) Use the data in Table 1.3 to calculate the relative atomic mass of sulfur, giving your answer to two decimal places.

[1]

[Total: 13]

2 Group 17 elements form a range of oxoacids with different oxidation states, such as $HClO_4$.

(a) (i) $HClO_4$ has two central atoms; one chlorine atom and one oxygen atom. In addition, the H atom is bonded to a O atom. Draw the dot-and-cross diagram of $HClO_4$.

[1]

(ii) Use VSEPR to describe and explain the shape and bond angle about central Cl and O atom in $HClO_4$.

....

....

....

....

....

....

....

.... [3]

(b) With reference to your answer in **(a)(i)**, explain why HFO_4 does not exist?

....

.... [1]

(c) The Latimer diagram of some chlorine species in acidic solution is given in Fig. 2.1.

$$HOCl \xrightarrow{+1.64\ V} Cl_2 \xrightarrow{+1.36\ V} Cl^-$$
$$+1 \qquad\qquad\quad 0 \qquad\qquad\quad -1$$
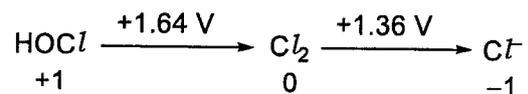
Fig 2.1

In Latimer diagram, oxidation numbers decrease from left to right and the numerical values of $E^\ominus$ of two adjacent species in volts. For example, the diagram shows that $E^\ominus(HOCl|Cl_2)$ is +1.64 V.

(i) Write a half-equation for the conversion of one mole of HOCl to one mole of Cl⁻ in acidic solution at 298 K.

.... [1]

(ii) Hess' Law is applicable to $\Delta G^\ominus$ in the same manner as $\Delta H^\ominus$.
With reference to the *Data Booklet* and Fig. 2.1, calculate $\Delta G^\ominus$ for the conversion of one mole HOCl to one mole of Cl⁻ in acidic solution.

[3]

(iii) Hence, calculate the standard electrode potential for the HOCl|Cl⁻ half-cell.

[1]

(d) A sample of group 2 metal ethanedioate, MC_2O_4, is analysed to determine the identity of the metal.

A 4.13 g sample of the metal ethanedioate is reacted with excess acidified potassium manganate(VII), $KMnO_4$.

$$2MnO_4^- + 5C_2O_4^{2-} + 16H^+ \rightarrow 2Mn^{2+} + 10CO_2 + 8H_2O$$
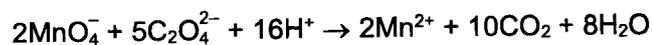
A 25 cm^3 portion from the remaining solution is reacted with periodate ions, IO_4^-, to produce IO_3^- and MnO_4^-. 22.2 cm^3 of 0.2 mol dm^{-3} of IO_4^- was required to react with the manganese(II) ions.

$$2Mn^{2+} + 5IO_4^- + 3H_2O \rightarrow 2MnO_4^- + 5IO_3^- + 6H^+$$
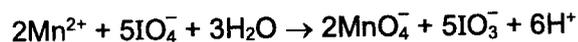
Deduce the identity of the metal in the metal ethanedioate.

[3]

(e) Periodic acid, HIO_4, is used as a selective oxidant in organic chemistry to split alcohols with two adjacent hydroxy groups into two carbonyl compounds.
An example is shown in Fig. 2.2.

$HIO_4(aq)$

R, R', R'' = H or alkyl
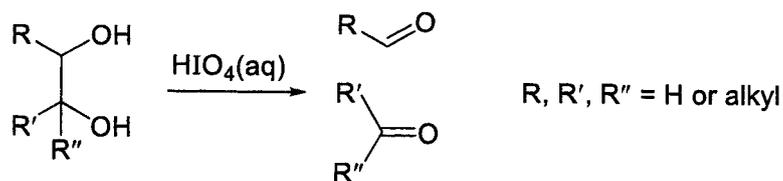
Fig. 2.2

Periodic acid also oxidises hydroxycarbonyl and dicarbonyl compounds by a hydration equilibrium, in which the carbonyl group is first converted into a diol.

$$R_2C=O + H_2O \rightleftharpoons R_2C(OH)_2 \qquad R = H \text{ or alkyl}$$

For example:

$HIO_4(aq)$

+
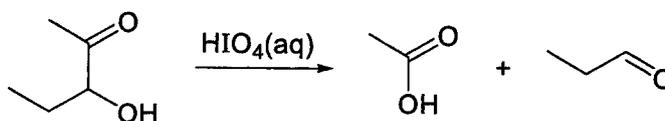
Fig. 2.3

Predict the organic products of the reactions shown in Fig. 2.4.

excess
$HIO_4(aq)$

excess
$HIO_4(aq)$
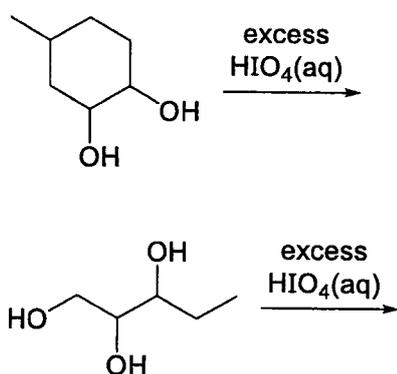
Fig. 2.4

[3]

[Total: 16]

3 (a) State whether trichloroethanoic acid or ethanoic acid, is the stronger acid. Explain your answer.

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.... [2]

(b) Phenyl ethanoate is often used as a solvent and as the building block for the synthesis of other chemicals.

(i) One method of its production involves phenol with an appropriate acid chloride via a **two**-step process. Identify the reactant required for each step.

step 1: ....

step 2: ....

[2]

(ii) Give two reasons why phenol does **not** react with carboxylic acids to form esters.

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.... [2]

Another method of production involves phenols reacting with a class of compounds known as acid anhydrides. Ethanoic anhydride, $(CH_3CO)_2O$, is an example of a common commercially available acid anhydride.
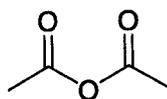
ethanoic anhydride

Acid anhydrides undergo similar reactions to acid chlorides, and are easier and safer to handle in organic synthesis.

(c) (i) Write a balanced chemical equation for the formation of phenyl ethanoate using phenol and ethanoic anhydride.

[1]

(ii) Suggest why acid anhydrides are generally less reactive than acid chlorides towards nucleophiles.

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.... [1]

(d) **R** is formed when an acid anhydride **S**, $C_{14}H_{10}O_3$, reacts with CH_3NH_2.

R is a neutral compound and has the molecular formula C_8H_9NO. **R** reacts with hot $H_2SO_4(aq)$ to produce **P** and CH_3NH_2.

P is not very soluble in water, but dissolves after reacting with an excess of $Na_2CO_3(aq)$.

(i) Name the type of reaction occurring when **R** reacts with hot aqueous sulfuric acid.

.... [1]

(ii) **P** has the molecular formula $C_7H_6O_2$. **P** can be formed when methylbenzene reacts with acidified potassium manganate(VII).

Draw the structure of **P**.

[1]

(iii) Write the equation for the reaction of **P** with an excess of $Na_2CO_3(aq)$.

.... [1]

BP~466

12

(iv) Suggest the structures of **R** and **S**.

R	S

[2]

(v) Use of the *Data Booklet* is relevant to this question.

Infra-red absorptions are useful in identifying functional groups present in molecules.

Suggest an absorption frequency range which can be used to distinguish between molecule **R** and **P**.

.... [1]

[Total:14]

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4   Industrial wastewater is wastewater produced by industrial facilities during manufacturing or other processes. It differs from domestic wastewater due to the presence of a wider range of pollutants and the potential for higher concentrations of contaminants.

(a) An industrial facility discharges wastewater containing Al^{3+}, Zn^{2+}, and Cu^{2+} ions. To meet environmental standards, the facility designs a treatment process by controlled precipitation to remove these ions from the wastewater.

(i) Table 4.1 shows the K_{sp} values for the hydroxides of the metal ions.
     Given that the wastewater initially contains 0.010 mol dm^{-3} of each metal ion, calculate the minimum pH at which copper(II) hydroxide begin to precipitate.

Table 4.1

metal hydroxide	K_{sp}	minimum pH for precipitation
$Al(OH)_3$	1.3×10^{-33}	3.70
$Cu(OH)_2$	2.2×10^{-20}	–
$Zn(OH)_2$	3.0×10^{-17}	6.74

[2]

(ii) Based on your calculations in (a)(i), explain how Al^{3+}, Cu^{2+} and Zn^{2+} ions in the wastewater can be separated in the treatment process.

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....[1]

(b) Industrial wastewater containing Cu^{2+} ions must be treated before it can be safe for discharge to a sanitary sewer for further treatment. The allowable limit of Cu^{2+} in the discharge is 1 mg per litre.

(i) Calculate the concentration of Cu^{2+} ions in the wastewater when zinc(II) hydroxide starts to precipitate.

[2]

(ii) The industrial wastewater is treated at pH 6.74. Using your answer in **(b)(i)**, deduce if the wastewater is safe for discharge to sanitary sewage for further treatment?

[1]

(c) There may be difficulty in removing Al^{3+} ion from the wastewater when excess sodium hydroxide solution is added.

Explain, with the aid of suitable equation(s), why this is so.

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....[2]

(d) A sample of the industrial wastewater was found to be pale blue in colour due to contamination by Cu^{2+} ions.

(i) Explain why the solution contaminated with Cu^{2+} is blue in colour.

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....[3]

(ii) A student took a sample of the solution and added excess concentrated hydrochloric acid. State the type of reaction and describe any observations. Construct a balanced equation for the reaction.

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....[3]

[total: 14]

5   Energy is crucial for life and bodily functions, stored in the form of adenosine triphosphate, ATP. Renown as "energy currency", ATP consists of a base, adenine, attached to ribose, to which is attached to a triphosphate group, as shown in Fig. 5.1.
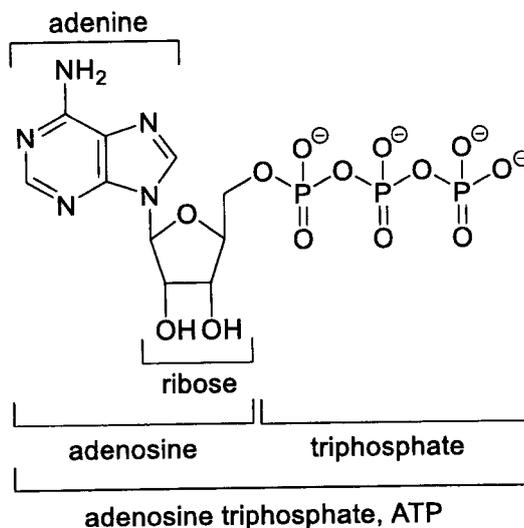
Fig. 5.1

(a) Adenine is made up of a six-membered pyrimidine ring fused with a five-membered imidazole ring, both of which are aromatic and planar.

The imidazole ring specifically contains six π electrons and can exist as an imidazole molecule. Two representations of imidazole molecule are shown in Fig. 5.2.
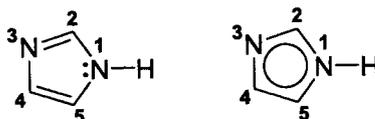
Fig. 5.2

Nitrogen atoms undergo the same type of hybridisation as carbon atoms.

(i) By reference to orbital overlap and the hybridisation of the nitrogen and carbon atoms, suggest how the σ and π bonds are formed in an imidazole molecule.

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.... [3]

(ii) An imidazole molecule is amphoteric as it can function both as an acid and a base.

By considering your answer in **(a)(i)** and its structure or otherwise, suggest and explain:

- The acidic proton is the H atom bonded to N1, not H atoms bonded to carbon atoms.
- N3 acts as the base.

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.... [2]

ATP hydrolysis breaks a high-energy P–O bond, releasing energy and forming ADP and HPO_4^{2-}, and is reversible under suitable conditions in reaction 1. The biochemical standard condition (as annotated by the superscript of $^{\ominus'}$) applies here where concentrations of all species are defined to be at 1 mol dm^{-3} at pH 7.0, at 37 °C.

reaction 1   (aq) + $2H_2O(l)$

ATP

⇌   (aq) + HPO_4^{2-}(aq) + H_3O^+(aq)

ADP

where R =

$\Delta G^{\ominus'} = -30.5$ kJ mol^{-1}

$\Delta H^{\ominus'} = -20.5$ kJ mol^{-1}
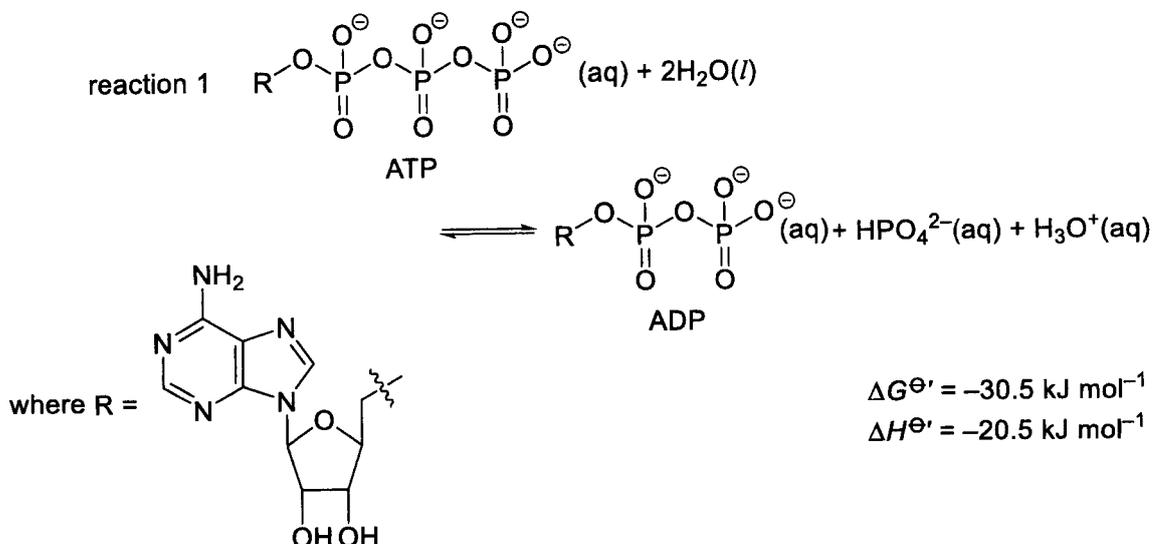
(b) The mechanism of the hydrolysis of ATP proceeds via the following stages:

1. Similar to nucleophilic addition, a nucleophilic attack of water on a phosphorus atom of the terminal phosphate unit while breaking the P=O π bond, forming intermediate 1.

2. The negative charge of the oxygen atom in intermediate 1 is then conferred to reforming of the π-bond in the P=O while another P–O bond involving the phosphorus atom of the terminal phosphate unit is cleaved to form intermediate 2 and ADP.

3. Another water molecule abstracts a proton from intermediate 2.

(i) Suggest why a water molecule is a nucleophile.

....

....

.... [1]

(ii) Complete Fig. 5.3 to suggest the mechanism for this reaction for stages 1 and 2 only. Show the displayed structure of intermediate 2, relevant dipoles, relevant lone pairs of electrons and the movement of electrons by using curly arrows. [3]
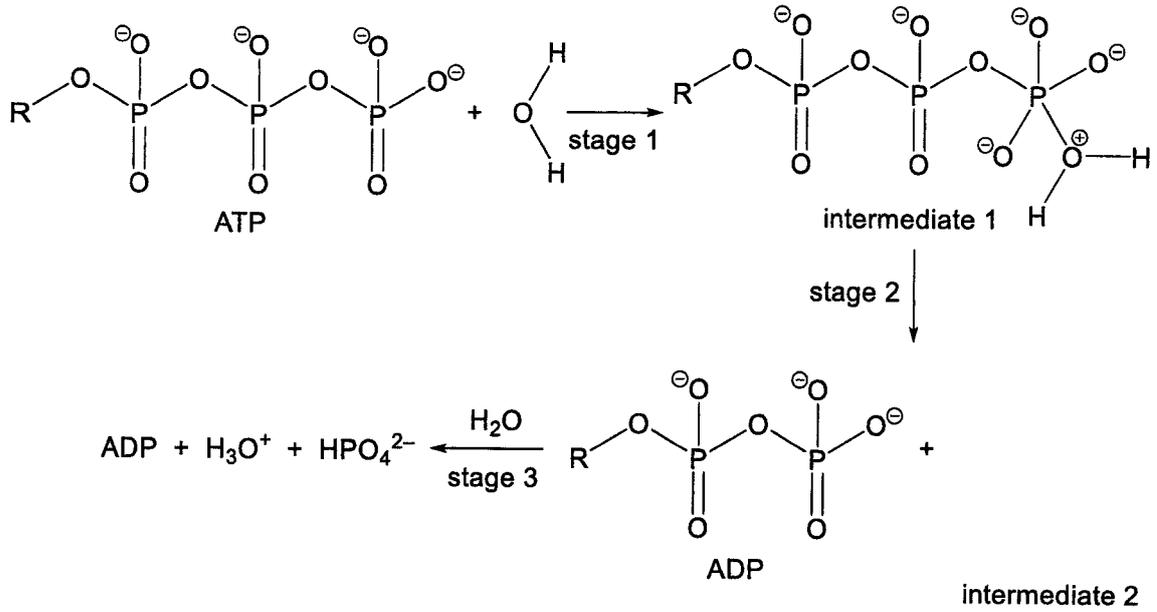
Fig. 5.3

(c) Calculate the entropy change of reaction, $\Delta S^{\ominus\prime}$, at 37 °C and comment on the sign of $\Delta S^{\ominus\prime}$ obtained.

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.... [2]

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(d) Physiological conditions vary depending on the organism, the specific tissue or cell compartment, and the current energy needs for metabolic and other reactions. Table 5.1 shows the concentrations of ATP, ADP and HPO_4^{2-} for various physiological conditions of organism.

Table 5.1

physiological condition of organism	ATP concentration / mol dm⁻³	ADP concentration / mol dm⁻³	HPO_4^{2-} concentration / mol dm⁻³
standard condition	1	1	1
human – resting muscle	8×10^{-3}	9×10^{-6}	4×10^{-3}
human – muscle recovery from severe exercise	8×10^{-3}	7×10^{-6}	1×10^{-3}

(i) Other than concentration to be 1 mol dm⁻³, state another condition specified by the symbol ⁻ when the enthalpy change, entropy change and Gibbs free energy for a reaction are described at 298 K.

.... [1]

(ii) By considering Table 5.1 or otherwise, suggest why the standard condition is not applicable to most physiological conditions.

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.... [1]

(iii) Equation 1 can be used to compute the actual Gibbs free energy change, ΔG due to ATP hydrolysis under physiological condition.

Equation 1 $\Delta G = \Delta G^{\ominus\prime} + RT \ln Q_c$

where Q_c refers to the reaction quotient which has the same expression as K_c.

Using equation 1, Table 5.1 and the *Data Booklet*, calculate the Gibbs free energy change, ΔG due to ATP hydrolysis in reaction 1 for human muscle of athletes recovering from severe physical exertion at 37 °C at pH = 7.4.

[2]

In the presence of magnesium ions, the Gibbs free energy change of reaction 1 changes. This is shown in Fig. 5.4.
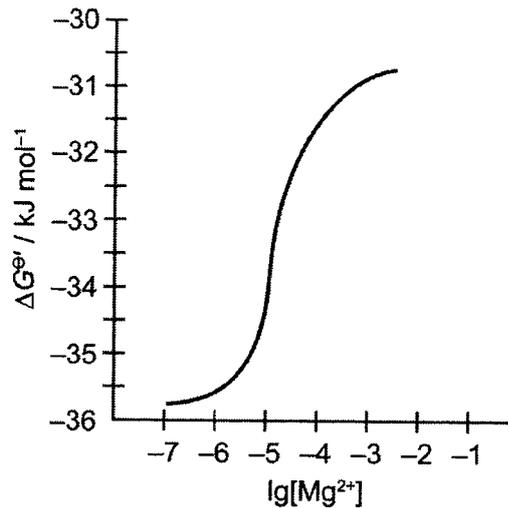
Fig. 5.4

(e) (i) Based on Fig. 5.4, describe how Gibbs free energy change varies with increasing concentration of magnesium ions.

....

.... [1]

(ii) ATP can form several complexes with magnesium ions such as the $[MgATP]^{2-}$ complex. The $[MgATP]^{2-}$ complex serves as the substrate for ATPase, the enzyme that catalyses reaction 1.

The rate of reaction 1 using a fixed amount of ATPase is investigated. Experiments are performed using different concentrations of $[MgATP]^{2-}$ complex (substrate) and the rate of each reaction is measured.

Sketch a graph to describe the relationship between the rate of the reaction and substrate concentration, using a fixed amount of ATPase enzyme, in this reaction. Explain your reasoning.

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.... [2]

[Total: 18]

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EUNOIA JUNIOR COLLEGE
JC2 Preliminary Examination 2025
General Certificate of Education Advanced Level
Higher 2

CANDIDATE NAME

| CIVICS GROUP | 2 | 4 | – | | | INDEX NUMBER | | |

CHEMISTRY
Paper 3 Free Response

9729/03

15 September 2025

2 hours

Candidates answer on the Question Paper.

Additional Materials: Data Booklet

READ THESE INSTRUCTIONS FIRST

Write your name, civics group and registration number on 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 staplers, 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.

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 Examiner's Use	
Paper 3	
A1	/ 20
A2	/ 20
A3	/ 20
B4 or 5	/ 20
Total	/ 80

This document consists of **32** printed pages.

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[Turn Over

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

1 Indirect calorimetry is used to estimate energy expenditure in humans by measuring the difference in oxygen concentration between inhaled and exhaled air. During aerobic respiration at 37 °C, glucose, $C_6H_{12}O_6$, is oxidised to carbon dioxide and water while producing energy as shown in reaction 1 below.

reaction 1 $\quad C_6H_{12}O_6(s) + 6O_2(g) \rightarrow 6CO_2(g) + 6H_2O(l) \quad \Delta H^\ominus = -2818$ kJ mol^{-1}

(a) (i) It is assumed that there are negligible intermolecular forces of attraction between gas particles in an ideal gas.

State **two** other basic assumptions of kinetic theory as applied to an ideal gas.
[2]

(ii) Air contains about 21% oxygen, by volume. Exhaled air contains 14% oxygen. At complete rest, a typical adult exchanges approximately 500 cm^3 of air per breath at a rate of 12 times per minute at a temperature of 37 °C at 1 atmospheric pressure.

By assuming oxygen to be an ideal gas, calculate the volume of oxygen gas consumed per minute. Hence, determine amount of oxygen gas used per minute.
[3]

(iii) Assuming that the oxygen inhaled is used for respiration directly, use relevant information in reaction 1 and your answer in **(a)(ii)**, calculate the approximate amount of energy released per minute. [1]

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(b) Glucose, $C_6H_{12}O_6$, is the ubiquitous source of energy for cells in the body.

(i) Define the standard enthalpy change of formation of glucose, $C_6H_{12}O_6(s)$. [1]

(ii) Use the following data, reaction 1 and appropriate data from the *Data Booklet*, to construct an energy cycle and calculate the standard enthalpy change of atomisation of C(s). Show your working.

enthalpy change of formation of $C_6H_{12}O_6(s)$ = –1270 kJ mol^{-1}
enthalpy change of combustion of $H_2(g)$ = –286 kJ mol^{-1}

[3]

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(c) Glucose exists in two forms, α-glucose and β-glucose as shown in Fig. 1.1. If a solution of α-glucose is left some time, it will come into dynamic equilibrium with β-glucose.
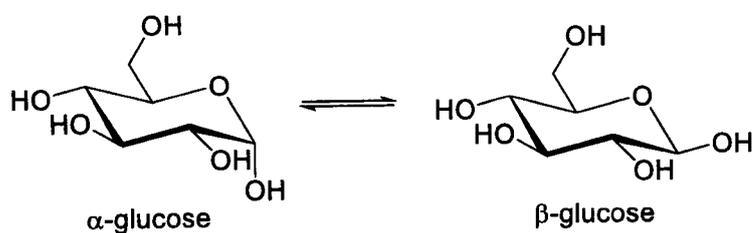
Fig. 1.1

When plane-polarised light is passed through an aqueous solution of glucose, the angle of rotation of the light is dependent upon the structure of the molecule. The angles of rotations of plane-polarised light caused by the two forms of glucose solutions under identical conditions are shown in Table 1.1.

Table 1.1

solution	angle of rotation of plane-polarised light
1.0 mol dm^{-3} of α-glucose	+111°
1.0 mol dm^{-3} of β-glucose	+19°

(i) When 1 dm^3 of a freshly prepared solution of 1.0 mol dm^{-3} α-glucose is left till equilibrium is achieved, the measured rotation is +53°. Assuming that the angle of rotation due to each glucose is directly proportional to its concentration, calculate a value for the equilibrium constant, K_c, for the conversion of α-glucose into β-glucose. [2]

(ii) The conversion of α-glucose into β-glucose is catalysed by acids. State and explain the effect on the final measured rotation if the conversion is now carried out in the presence of dilute sulfuric acid. [2]

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(d) Oxygen used in respiration binds to haemoglobin in red blood cells, which can undergo ligand exchange with water in tissues to regulate oxygen delivery. Both deoxyhaemoglobin and oxyhaemoglobin contain iron atoms in the +2 oxidation state. The oxygen-containing ligand is H_2O in deoxyhaemoglobin, Hb, and O_2 in oxyhaemoglobin, $Hb(O_2)_4$.

One molecule of deoxyhaemoglobin, Hb, can bind with four molecules of oxygen, as shown in equilibrium 1.

equilibrium 1 $\qquad$ $Hb(aq) + 4O_2(aq) \rightleftharpoons Hb(O_2)_4(aq)$ $\qquad$ $\Delta H^\ominus = -630.9$ kJ mol^{-1}
$\Delta G^\ominus = -160.7$ kJ mol^{-1}

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

(ii) During the initial stage of vigorous exercise, rapid muscle contractions generate heat that spreads through the body, raising core temperature.

Using Le Chatelier's Principle, explain how the initial increase in temperature affects equilibrium 1. [1]

(iii) Suggest how the magnitude of K_c for equilibrium 1 is likely to be and explain its significance. [2]

(iv) Carbon monoxide, CO, can bind to haemoglobin at the same binding site as oxygen. Explain why CO is poisonous. [2]

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[Total: 20]

2 **(a)** The Williamson ether synthesis involves nucleophilic substitution between a halogenoalkane (RX) and alkoxides (RO⁻), the conjugate base of an alcohol. The alkoxide serves as the nucleophile in the reaction. An example of the reaction can be seen below:

$$RO^- + R'X \longrightarrow ROR' + X^-$$

A solution containing CH_3ONa, is reacted separately with 1-bromopropane and 2-bromo-2-methylpropane.

(i) Predict the predominant mechanism for:
  I) the reaction of 1-bromopropane with CH_3ONa
  II) the reaction of 2-bromo-2-methylpropane with CH_3ONa

Explain your reasoning. [3]

(ii) For each mechanism, state and explain the stereochemical outcome of the nucleophilic substitution reaction. [2]

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Question 2 continues on the next page.

10

(b) Thiolates such as methyl thiolate, CH_3S^-, act similarly to alkoxides in the nucleophilic substitution of halogenoalkanes, forming a sulfide.

The synthesis of 2-hydroxyethyl methyl sulfide from 2-bromoethanol using CH_3S^- can be seen from the following reaction scheme:

(i) Describe a simple chemical test to distinguish between 2-bromoethanol and 2-hydroxyethyl methyl sulfide. [2]

The kinetics of the reaction was studied with the results given in Table 2.1.

Table 2.1

experiment	$[CH_3S^-]$ / mol dm^{-3}	$[CH_2BrCH_2OH]$ / mol dm^{-3}	relative rate
1	0.100	0.150	1.00
2	0.150	0.150	1.50
3	0.200	0.200	2.67

(ii) Define the term *order of reaction*. [1]

(iii) Use the data to determine the order of reaction with respect to both CH_3S^- and CH_2BrCH_2OH. [2]

(iv) Hence, write a rate equation for the reaction. [1]

(v) Using your answer in (b)(iv), describe the mechanism for the reaction. [3]

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(c) Sodium methoxide, CH_3ONa, can also be used to synthesis 2-hydroxyethyl methyl sulfide from 2-bromoethanol. The rate of reaction was found to be slower than when sodium methanethiol, CH_3SNa, is used.

By considering the strength of the nucleophile, suggest why the rate of reaction is slower when using sodium methoxide. [1]

(d) The rate of reaction for the synthesis increases when the temperature is increased. With the aid of a clearly labelled Maxwell-Boltzmann distribution curve, explain this observation. [3]

(e) Another series of experiments were done to study the difference in the rates of nucleophilic substitution for the following compounds using methyl thiolate.

| 2-chloroethanol | 2-bromoethanol | 2-iodoethanol |

Deduce the order of increasing rate of reaction of the following compounds. Explain your answer. [2]

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[Total: 20]

3   Hydroformylation shown in Fig. 3.1 is one of the largest homogeneous catalytic reactions used to manufacture aldehydes industrially. The aldehydes are subsequently hydrogenated to alcohols or oxidised to carboxylic acids.

Fig. 3.1

The phosphine-modified cobalt catalyst, $HCo(CO)_3(PR_3)$, was developed to increase the linear : branched aldehyde selectivity. This catalyst also functions as an effective aldehyde hydrogenation catalyst to produce the corresponding alcohol.

The proposed mechanisms for the hydroformylation cycle are shown in Fig. 3.2.

Fig. 3.2

An important step in catalytic cycle 1 is **step 1-2**, which involves addition of a Co–H bond adds across the C=C double bond within intermediate **A**, with binding of a carbon monoxide ligand, to give intermediate **B**.

Intermediate **B** reacts with more carbon monoxide, eventually giving intermediate **C**. Finally, intermediate **C** breaks down to give the aldehyde with regeneration of the catalyst.

The aldehyde formed from catalytic cycle 1 then enters catalytic cycle 2 and is reduced to give the corresponding alcohol.

15

(a) But-1-ene was reacted with CO and H_2 using $HCo(CO)_3(PR_3)$ as catalyst.

but-1-ene $\xrightarrow[\text{heat}]{\substack{\text{CO} \\ H_2 \\ HCo(CO)_3(PR_3)}}$ linear aldehyde + [branched aldehyde structure] $\longrightarrow$ alcohol

branched
aldehyde

(i) Draw the skeletal structure of the linear aldehyde. [1]

(ii) Starting from but-1-ene, suggest an alternative 5-step synthesis to form the branched aldehyde. The synthesis involves a nitrile intermediate. [5]

(iii) Suggest a simple chemical test to confirm that all the aldehydes have been hydrogenated to the corresponding alcohols. [2]

16

(b) (i) State the type of reaction in **step 1-1**. [1]

(ii) State the type of bond between the alkene and Co in intermediate **A** and suggest how it is formed. [2]

(iii) State the shapes of intermediate **B** and intermediate **C** about Co. [1]

(iv) Given that the Co in intermediate **C** is in the +3 oxidation state. State its full electronic configuration. [1]

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(c) The linear and branched product arises in **step 1-2** as the addition of Co–H across the C=C double bond can occur in two ways as shown in Fig. 3.3.

Fig. 3.3

(i) Based on your understanding of the mechanism of electrophilic addition, explain why intermediate **B** is formed preferentially over intermediate **B'**. [2]

(ii) Phosphine ligand, PR_3, with different R groups gives different linear : branched product ratio. State and explain one characteristic of the alkyl group, R, which will further favour formation of intermediate **B**. [2]

18

The Friedel-Crafts formylation of benzene using carbon monoxide can be achieved by the Gatterman-Koch reaction in which CO(g) and HCl(g) are used *in-situ* with a Lewis acid catalyst such as AlCl_3.

Assuming that CO(g) and HCl(g) reacts in the presence of AlCl_3 as shown.

$$CO + HCl + AlCl_3 \ \square \ {}^+CHO + AlCl_4^-$$

(d) Describe the mechanism for the Friedel-Crafts formylation of benzene to give benzaldehyde. Show the displayed structure of the electrophile, the structure of the intermediate and the movement of electron pairs by using curly arrows.   [3]

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[Total: 20]

Question 4 starts on the next page.

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Section B

Answer **one** question from this section.

4 **(a)** Glycolic acid, $CH_2(OH)COOH$, is an α-hydroxy acid used in some skincare products.

Sodium glycolate can be prepared by adding disodium hydrogen phosphate to a solution of glycolic acid in a cosmetic formulation. The reaction establishes the following equilibrium in water:

equilibrium 1 $CH_2(OH)COOH + HPO_4^{2-} \rightleftharpoons CH_2(OH)COO^- + H_2PO_4^-$
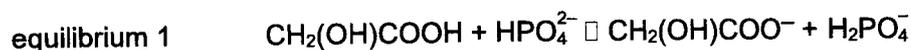
The K_a values for $CH_2(OH)COOH$ and $H_2PO_4^-$ are given in Table 4.1.

Table 4.1

acid	K_a
$CH_2(OH)COOH$	1.48×10^{-4}
$H_2PO_4^-$	6.20×10^{-8}

(i) Write down the IUPAC name for glycolic acid.   [1]

(ii) Identify the two different conjugate acid-base pairs in equilibrium 1.   [1]

(iii) Use the K_a values in Table 4.1 to calculate the equilibrium constant, K_c, for equilibrium 1.   [2]

(iv) In an experiment, a buffer solution of pH 4.00 is prepared using 50.0 cm^3 of 0.0500 mol dm^{-3} glycolic acid and x cm^3 of 0.100 mol dm^{-3} NaOH.

$CH_2(OH)COOH + NaOH \rightarrow CH_2(OH)COONa + H_2O$
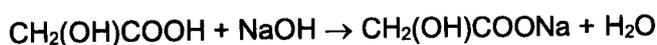
Assume that all NaOH reacts with glycolic acid, what is the volume, x cm^3, of 0.100 mol dm^{-3} NaOH required to make the buffer?   [4]

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(b) Table 4.2 shows the pK_a values of two isomeric benzoic acids: salicylic acid and 4-hydroxybenzoic acid.

Table 4.2

acid	pK_{a1}	pK_{a2}
OH COOH salicylic acid	3.0	13.4
OH COOH 4-hydroxybenzoic acid	4.1	9.7

Explain the following:

(i) pK_{a2} is larger than pK_{a1} of salicylic acid. [1]

(ii) pK_{a1} of salicylic acid is smaller than pK_{a1} of 4-hydroxybenzoic acid. [1]

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(c) Vanillin, a common flavor and fragrance ingredient, can be converted into vanillic acid by a two-step laboratory synthesis.

vanillin   vanillic acid

(i) State the reagent and conditions used in **step 1**. [1]

(ii) State the type of reaction that occurs in **step 1** and **2**. [2]

(iii) Draw the mechanism of the reaction in **step 1**. Show clearly all charges and the intermediate formed and use curly arrows to indicate the movement of electron pairs. [3]

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(d) Hexagonal boron nitride, h-BN, consist of planar sheets of alternate boron and nitrogen atoms, similar in arrangement to the carbon atoms in graphite. Its softness and sheen make powdered h-BN widely used in cosmetics.

(i) h-BN is often referred to as "white-graphite'. With reference to chemical bonding and structure, explain why both h-BN and graphite have a soft and slippery feel.

[2]

(ii) Explain, with reference to electronegativity, why h-BN does not conduct electricity readily, whereas graphite does. [2]

[Total: 20]

Question 5 starts on the next page.

5   In an effort to address pollution caused by industrial nitroaromatics and agricultural nitrates, researchers have developed a dual-function electrochemical system that converts these nitrogen-containing wastes into useful products. At the cathode, the electrolytic reduction of nitrobenzene to phenylamine is described in Fig. 5.1.
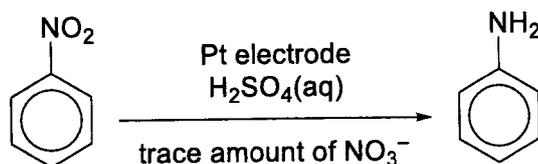
Fig 5.1

(a) State the reagents and conditions for the conversion of nitrobenzene to phenylamine in a laboratory.   [1]

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(b) (i) Given the nitrogen in nitrobenzene has an oxidation state of +3, describe the change in oxidation state of the nitrogen, in Fig. 5.1.   [1]

(ii) Hence or otherwise, write the half-equation for this reaction.   [1]

(iii) During a 4-hour electrolysis, a steady current of 2 A was passed. However, only 2.79 g of phenylamine was formed.

Using your answer to **(b)(ii)**, calculate the theoretical amount of electrons required to form 2.79 g of phenylamine.   [1]

(iv) Faradaic efficiency describes the efficiency with which charge is transferred in an electrolysis system and is given by the equation below.

$$\text{Faradaic efficiency} = \frac{\text{charge required}}{\text{charge passed}} \times 100\%$$

Hence, calculate the Faradaic efficiency of the electrolysis in **(b)(iii)**.   [3]

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(c) The use of the *Data Booklet* is relevant to this question.

(i) A student suggests that the trace amounts of NO_3^- ions at the cathode could also be reduced to NH_4^+ ions. Discuss how electrode potential and concentration might influence this competition.

(The $E^\ominus$(nitrobenzene | phenylamine) is +0.79 V.) [3]

(ii) Suggest other possible side products at the cathode. [1]

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(d) Rank the following compounds in order of increasing basicity and explain your reasoning.

<div align="center">phenylamine, methylamine, ethanamide   [4]</div>

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(e) The structures of two amino acids, glutamine and aspartic acid are given below.

$$H_2N-\underset{\underset{CH_2CH_2CONH_2}{|}}{\overset{\overset{H}{|}}{C}}-COOH \qquad H_2N-\underset{\underset{CH_2COOH}{|}}{\overset{\overset{H}{|}}{C}}-COOH$$

glutamine   aspartic acid

(i) Suggest a simple chemical test to distinguish between glutamine and aspartic acid. [2]

(ii) The three pK_a values associated with aspartic acid are 1.99, 3.90 and 9.90.

Draw the structures of the predominant species of aspartic acid at

- pH 3

- pH 8

- pH 11 [3]

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[Total: 20]

Additional answer space

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

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