ST ANDREW'S JUNIOR COLLEGE

JC2 PRELIMINARY EXAMINATIONS

HIGHER 1 **(STUDENT REVIEW)**

CANDIDATE NAME					
CLASS	2	4	S		

CHEMISTRY 8873/02

Paper 2 Structured Questions **02 September 2025**

Candidates answer on the Question Paper. **2 hours**

Additional Materials: Data Booklet

READ THESE INSTRUCTIONS FIRST

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

Write in dark blue or black pen.

You may use a HB pencil for any diagrams or graphs.

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

Section A

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

Section B

Answer **one** question.

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

A Data Booklet is provided.

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

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

For Examiner's Use		
Section A		
Q1		**25**
Q2		**12**
Q3		**12**
Q4		**11**
Section B		
Q5		**20**
Q6		**20**
Total		**80**

This document consists of **25** printed pages (including this cover page).

1 (a) Aluminium oxide, Al_2O_3, is a white, crystalline solid with high thermal stability and hardness.

(i) Complete the electronic configuration of an aluminium atom.

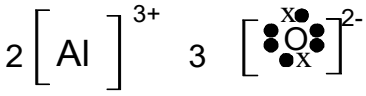
$1s^2$ ..... **[1]**

$1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^1$

(ii) Explain why the first ionisation energy of Al is lower than the first ionisation energy of Mg. **[2]**

In Mg, the first electron is removed from the 3s orbital, whereas for Al, the first electron is removed from the 3p orbital (√). In Al, the valence electron in the 3p orbital experiences additional shielding effect (√) by the 2s electrons. This is so as valence electron of Al in the 3p orbital is further away (√) from the nucleus than the electrons in the 3s orbital. This factor outweighs the effect of increase in nuclear charge from Mg to Al. The valence electron in 3p orbital of Al experiences weaker attraction(√) to the nucleus and requires less energy to be removed.

(iii) Draw the 'dot-and-cross' diagram of Al_2O_3. **[1]**



(iv) The ionic radius of Al^{3+} is 0.050 nm and Ga^{3+} is 0.062 nm.

Explain the difference in ionic radii between Al^{3+} and Ga^{3+}. **[2]**

Ga^{3+} has a higher nuclear charge than Al^{3+}. Ga^{3+} also has one more filled electronic/electron shells / inner shells and the valence electrons are further away from the nucleus and shielding effect increases. The valence electrons are less strongly attracted to the nucleus. Ga^{3+} has a larger ionic size than Al^{3+}.

(v) The melting point of Al_2O_3 is 2072 °C while the melting point of Ga_2O_3 is 1720 °C. Explain the difference in melting points of these two oxides. **[2]**

Al_2O_3 & Ga_2O_3 have giant ionic lattice structure, with strong electrostatic forces of attraction between oppositely charged ions.

The charges of the cations and anions of both oxides are similar. The ionic radius of O^{2-} is the same.

$|LE| \propto \left|\frac{q^+ \times q^-}{r_+ + r_-}\right|$; (ionic radius) r_+ of Al^{3+} < r_+ of Ga^{3+}, more energy is required to overcome the stronger electrostatic forces of attraction between Al^{3+} & O^{2-} (or ionic bonding) (√) in Al_2O_3 than in Ga_2O_3, & hence Al_2O_3 has a higher mpt.

(b) **(i)** Aluminium oxide, Al_2O_3 and silicon dioxide, SiO_2, are both solid ceramic materials with high melting points and are electrical insulators.

Explain how differences in their structure and bonding account for their high melting points and poor electrical conductivity. **[3]**

Al_2O_3 has a giant ionic lattice/structure which is made up of strong electrostatic attraction (or ionic bonding) between the cations and anions/ oppositely charged ions .

Hence, it is used as an insulator because there is no mobile ions/ charge carriers to conduct electricity. The strong ionic bonds require a lot of energy to overcome, hence having a high melting point.

SiO_2 has a giant covalent structure/lattice, made up of a 3D tetrahedral network of strong covalent bonds between Si and O atoms. Hence, it is used as an insulator because there are no mobile electrons/ charge carriers to conduct electricity. The strong covalent bonds require a lot of energy to break, hence, leading to high melting point.

(b) **(ii)** Al_2O_3 and SiO_2 have different acid-base behaviour.

With the aid of equations, explain the difference in the acid and base behaviour of these two oxides. **[4]**

Al_2O_3 is amphoteric /reacts with both acids and bases while SiO_2 is acidic/ reacts with bases only:

Al_2O_3 (s) + 6HCl (aq) → 2$AlCl_3$ (aq) + $3H_2O$ (*l*)

Al_2O_3 (s) + 2NaOH (aq) + $3H_2O$ (*l*) → 2Na[$Al(OH)_4$] (aq)

SiO_2 (s) + 2NaOH (conc) →Na_2SiO_3 (aq) +H_2O (*l*)

(c) The pH values of two Period 3 chloride solutions are given below.

Compound	pH of 1.0 mol dm^{-3} solution
$AlCl_3$	3.0
$SiCl_4$	2.0

[4]

Suggest explanations for the pH values of the two chloride solutions. Include appropriate equation(s) in your answer.

$AlCl_3$ undergoes partial hydrolysis to form an acidic solution of pH≈ 3.

Al^{3+} has a smaller radius and higher charge (or high charge density) than Na^+, which polarises the electron cloud of water molecules, thus weakening O–H bond to release H^+ in water.

$AlCl_3$ (s) + $6H_2O(l)$ → $[Al(H_2O)_6]^{3+}$ (aq) + 3Cl^- (aq)

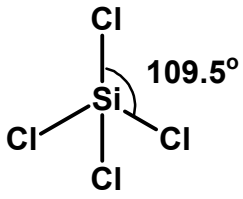
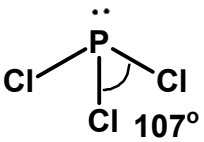
$[Al(H_2O)_6]^{3+}$ (aq) + $H_2O(l)$ ⇌ $[Al(H_2O)_5(OH)]^{2+}$(aq) + H_3O^+(aq)

Si in $SiCl_4$ has empty 3d orbitals to accommodate lone pair of electrons from O of H_2O molecules, forming dative bonds. Complete hydrolysis takes place and HCl (aq) is formed.

$SiCl_4$ (*l*) + $4H_2O$ (*l*) → $SiO_2.2H_2O$ (s) + 4HCl (aq)

Or $SiCl_4$ (*l*) + $2H_2O$ (*l*) → SiO_2 (s) + 4HCl (aq)

(d) Name the shapes and state the bond angles of $SiCl_4$ and PCl_3.
Explain your answers using the Valence Shell Electronic Pair Repulsion (VSEPR) Theory. Draw diagrams to illustrate your answers.

	$SiCl_4$	PCl_3
diagram		
shape	tetrahedral	Trigonal pyramidal
bond angle	109.5°/ 110°	107°

[6]

According to VSEPR Theory, the electron pairs are arranged as far apart to minimise repulsion. (√) $SiCl_4$ has 4 bond pairs and no lone pair(√) while PCl_3 has 3 bond pairs and 1 lone pair. (√) Hence, the lone-pair-bond pair repulsion is greater than the bond-bond pair repulsion, (√) the bond angle of PCl_3 is smaller.

[Total: 25 marks]

2 Manganese can form ions that are bonded to oxygen atoms in different oxidation states. Two examples are MnO_4^{2-} and MnO_4^-.

(a) Both ions of manganese differ in their oxidation number.

State the oxidation of each ion. **[2]**

Oxidation state of Mn in MnO_4^{2-} : +6

Oxidation state of Mn in MnO_4^- : +7

(b) To standardise $Na_2S_2O_3$ solution, 25.0 cm^3 of 0.025 mol dm^{-3} $KMnO_4$ was added to an excess of acidified KI solution. The iodine liberated required 22.40 cm^3 of $Na_2S_2O_3$ for reduction.

(i) Use the *Data Booklet* to write an equation for

1. the reaction between and MnO_4^- ions and I^-
2. the reaction between and I^- and $S_2O_3^{2-}$

[2]

$16H^+ + 2MnO_4^- + 10I^- \longrightarrow 2Mn^{2+} + 5I_2 + 8H_2O$

$2S_2O_3^{2-} + I_2 \longrightarrow S_4O_6^{2-} + 2I^-$

(ii) Calculate the concentration of $Na_2S_2O_3$, in mol dm^{-3}. **[2]**

Amount of $KMnO_4$ used = 25.0 / 1000 × 0.025 = 6.25×10^{-4} mol

Amount of I_2 liberated = 5/2 × 6.25× 10^{-4} = 1.563×10^{-3} mol [1]

Amount of $S_2O_3^{2-}$ reacted = 2 × 1.563 × 10^{-3} = 3.125×10^{-3} mol

Concentration of $Na_2S_2O_3$ = 3.125 x 10^{-3} ÷ 22.40 / 1000 = 0.1395 = 0.140 mol dm^{-3} (3.s.f.) [1]

(c) When K_2MnO_4 is dissolved in water, the solution appears green. Upon acidification, the green solution, MnO_4^{2-}, slowly turns into purple MnO_4^-. This equilibrium is represented by the following equation:

$3MnO_4^{2-}(aq) + 4H^+(aq) \rightleftharpoons 2MnO_4^-(aq) + MnO_2(s) + 2H_2O(l)$

The equilibrium concentrations are shown in Table 2.1.

Table 2.1

Temperature/ °C	$[MnO_4^{2-}]$/ mol dm^{-3}	$[H^+]$/ mol dm^{-3}	$[MnO_4^-]$/ mol dm^{-3}
25	0.010	0.020	0.005

(i) Write the expression for K_c and give its units. **[2]**

$3MnO_4^{2-}(aq) + 4H^+(aq) \rightleftharpoons 2MnO_4^-(aq) + MnO_2(s) + 2H_2O(l)$

$K_c = \frac{[MnO_4^-]^2}{[H^+]^4[MnO_4^{2-}]^3}$

Units: $mol^{-5}\ dm^{15}$

(ii) Calculate the value of K_c at 25°C. **[1]**

$K_c = \frac{[0.005]^2}{[0.02]^4[0.010]^3} = 1.56 \times 10^8$

(iii) Explain the colour change upon acidification of aqueous K_2MnO_4. **[1]**

When $[H^+]$ increase, the position of equilibrium shifts to the right to reduce the $[H^+]$, hence, more MnO_4^- is formed and the solution turned purple.

(iv) When the equilibrium is established at a lower temperature, the value of K_c increases. Deduce whether the reaction is exothermic or endothermic. Explain your answer. **[2]**

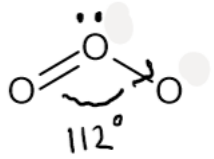
The reaction is exothermic.

Since $K_c = \frac{k_f}{k_b}$ and it increases, this shows that the rate (constant) of forward reaction decreases less than the rate (constant) of the backward reaction when temperature decreases OR The position of equilibrium shifts to the right, hence the reaction is exothermic to increase the temperature in the system.

[Total: 12 marks]

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

(a) By considering the number of bonding and non–bonding electron pairs, draw a diagram to show the shape of ozone. In your diagram, clearly state a value of the bond angle. **[2]**



(b) The overall reaction for the decomposition of ozone can be represented as follows:

$$2O_3 \rightarrow 3O_2$$

The rate of decomposition of ozone in ground water, at pH 8, was investigated and the following results were obtained as shown in Fig. 3.1. The reaction is first order with respect to ozone.

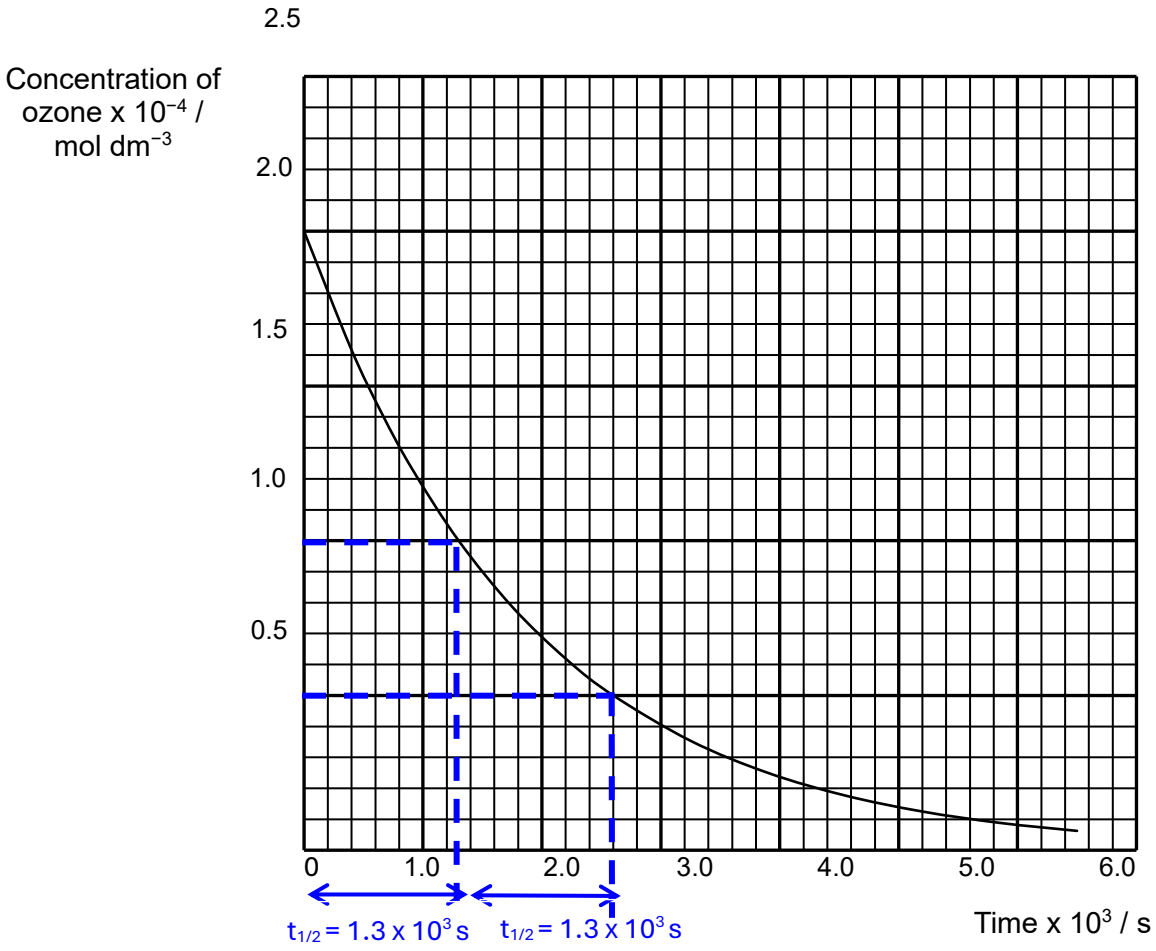


Fig. 3.1

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

It is the the power to which the concentration of the reactant is raised in the experimentally determined rate equation.

(ii) Use the graph in Fig. 3.1 to show that the overall order of reaction is first order. **[1]**

Since the half-life of the reaction for decomposition of ozone is relatively constant at 1.30×10^3 s, the order of the reaction is first order with respect to [ozone].

(iii) Write the rate equation for this reaction and give the units for rate constant, *k*. **[1]**

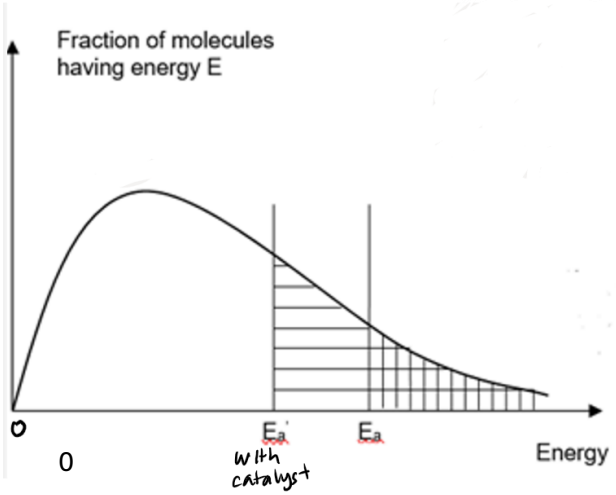
Rate = $k[O_3]$

Units for k : s^{-1}

(iv) The decomposition of ozone was found to be faster in the presence of OH^-.

Explain, with the aid of a Boltzmann distribution curve, how the rate of decomposition of ozone changes when OH^- is added.

(Temperature and pressure are kept constant.) **[3]**



- OH^- increases the rate by providing an alternative reaction pathway with lower activation energy, E_a.
- The number of reactant particles/ozone molecules having energy greater than or equal to the activation energy, E_a, increases.
- Frequency of effective collisions increases.

(c) The ozone layer plays a crucial role in protecting life on Earth by absorbing a significant portion of the sun's harmful UV radiation. Human activities, such as the use of certain chemicals like chlorofluorocarbons (CFCs), have historically led to ozone depletion, particularly in the Antarctic, where an "ozone hole" has been observed.

(i) CF_3CH_2F has been used as a replacement for CFCs such as $CFCl_3$, CCl_2F_2 and $C_2Cl_2F_4$ as they cause ozone depletion. With the aid of relevant data from *Data Booklet*, explain why CF_3CH_2F is a suitable replacement. **[2]**

C-F 485 kJ mol^{-1} ; C-Cl 340 kJ mol^{-1}

C-F bonds are stronger than C-Cl bonds. Hence they would not easily be decomposed by UV light to produce radical.

(ii) Suggest a simple chemical test to distinguish between $C_2Cl_2F_4$ and CF_3CH_2F. State the observations for both compounds. **[2]**

1. Add NaOH(aq) to both compounds and heat.
2. Cool and add HNO_3(aq)
3. Add $AgNO_3$(aq)

Alternative: ethanolic $AgNO_3$, warm/heat

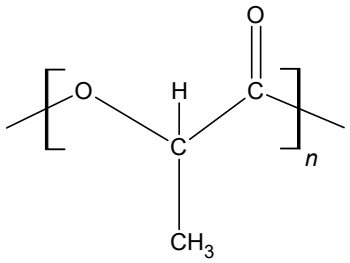
$C_2Cl_2F_4$ gives white ppt but CF_3CH_2F does not give white ppt.

[Total: 12]

4 (a) Define *polymer*. **[1]**

Polymers are macromolecules built up from monomers, with average molar mass of at least 1000 or at least 100 repeat units.

(b) Polylactic Acid (PLA) is a biodegradable thermoplastic made from renewable resources such as corn starch or sugarcane. It has a wide range of applications due to its biocompatibility, transparency and environmentally friendly profile.



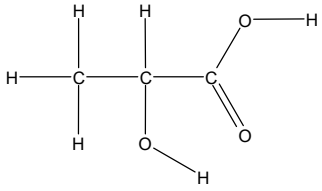
PLA

(i) Name the functional group present in the thermoplastic polymer PLA and classify the type of polymerisation used to make it. **[2]**

Functional group: Ester

Classification of polymerisation: Condensation

(ii) Draw the **displayed formula** of the monomer and give its systematic name. **[2]**



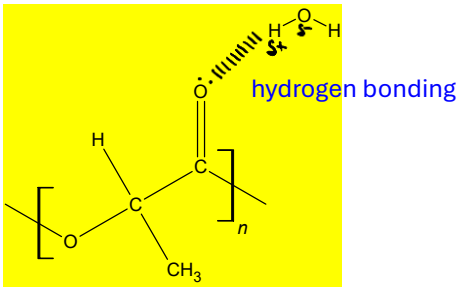
Systematic name: 2-hydroxypropanoic acid

(c) PLA is a biodegradable thermoplastic commonly used in medical implants such as dissolvable stitches. Over time, it interacts with water in the body and gradually breaks down.

(i) Explain the meaning of the term *thermoplastic*. **[1]**

Thermoplastic are long linear chains in which the monomer units are linked to one another.

(ii) With the aid of a diagram, explain how PLA interacts with water. **[1]**



PLA interacts with water by forming hydrogen bonding.

(iii) Describe how PLA degrades naturally in medical applications such as dissolvable stitches. **[1]**

The ester linkages hydrolyse to form the monomer in the water present in the bodies.

(iv) Medical implants must accommodate tissue movement without causing discomfort. Suggest a reason why PLA is suitable for this function. **[1]**

PLA is a thermoplastic which is soft and flexible/ flexible to bend and conform to the tissue movement.

(d) PLA can be processed into polymeric nanoparticles for use in drug delivery and tissue engineering.

(i) Define the term *nanoparticles*. **[1]**

Nanoparticles are defined as particles with all dimensions between 1-100 nm on the nanoscale.

(ii) Suggest why nanoparticles are advantageous in drug delivery and tissue engineering. **[1]**

Nanoparticles have high surface-area to volume ratio to allow higher rate of reaction or interaction with the targeted tissue or cells/ better efficiency (words to the same effect) to achieve the medical function.

[11 marks]

Section B

Answer **one** question from this question in the spaces provided.

5 **(a)** Calcium carbide, CaC_2, is an ionic compound primarily used in industry to generate acetylene gas, C_2H_2, which has numerous applications in welding, cutting and chemical synthesis.

$CaC_2(s) + 2H_2O(l) \rightarrow Ca(OH)_2(s) + C_2H_2(g)$ reaction 1

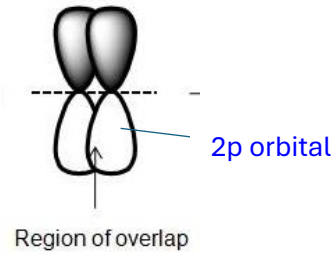
The structure of the carbide ion is as shown:

$$[C\equiv C]^{2-}$$

(i) State the number of σ and π bonds in one carbide ion. **[1]**

1 σ and 2 π

(ii) Draw a labelled diagram to show the formation of one π bond in carbide ion. **[1]**



(iii) Explain, in terms of structure and bonding, why C_2H_2 is a gas at room temperature. **[1]**

C_2H_2 has a **simple molecular structure** with **weak intermolecular instantaneous dipole - induced dipole attractions are easily broken.**

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

Using the data in Table 5.1, calculate the standard enthalpy change of reaction for reaction 1.

$$CaC_2(s) + 2H_2O(l) \rightarrow Ca(OH)_2(s) + C_2H_2(g) \qquad \text{reaction 1}$$

Table 5.1

compound	$\Delta H_f^{\ominus}$ / kJ mol^{-1}
$CaC_2(s)$	– 59.0
$H_2O(l)$	–285.8
$Ca(OH)_2(s)$	– 985.2
$C_2H_2(g)$	+ 226.6

[2]

$CaC_2(s) + 2H_2O(l) \rightarrow Ca(OH)_2(s) + C_2H_2(g)$

$\Delta H_r^{\theta} = \Sigma\Delta H_f^{\theta}$ (products) – $\Sigma\Delta H_f^{\theta}$ (reactants)

$= +226.6 - 985.2 - (-59.0 - 2 \times 285.8)$

$=$ **-128 kJ mol^{-1}**

(c) When fighting fires near calcium carbide storage, extreme caution is required due to its violent reaction with water, which produces flammable acetylene, C_2H_2, gas and poses explosion risks.

(i) Define the term *standard enthalpy change of combustion*, $\Delta H_c^{\ominus}$, of C_2H_2. **[1]**

The standard enthalpy change of combustion, $\Delta H_c^{\ominus}$, is the enthalpy change/energy change/released when one mole of gaseous C_2H_2 is completely burnt in excess oxygen at standard conditions/ 298 K and 1 bar.

(ii) The structure of acetylene, C_2H_2, is H–C≡C–H.

The following equation represents the standard enthalpy change of combustion of combustion, $\Delta H_c^\ominus$ of C_2H_2.

$C_2H_2\,(g) + \frac{5}{2}O_2\,(g) \rightarrow 2CO_2\,(g) + H_2O\,(l)$

Use bond energy values from the *Data Booklet* to calculate the standard enthalpy change of combustion, $\Delta H_c^\ominus$ of C_2H_2. **[2]**

H–C≡C–H + $\frac{5}{2}$O=O → 2 O=C=O + H–O–H

Bonds broken	**Bonds formed**
2 BE(C–H)	4 BE(C=O)
BE (C≡C)	2 BE(O–H)
$\frac{5}{2}$ BE(O=O)	

$\Delta H_c^\ominus$ = [2 BE(C–H) + BE (C≡C) + $\frac{5}{2}$ BE(O=O)] – [4 BE(C=O) + 2 BE(O–H

$\Delta H_c^\ominus$ = [2 × (410) + (840) + $\frac{5}{2}$× (496)] – [4 × (805) + 2 × (460)]

= –1240 kJ mol^{-1}

(iii) The experimental standard enthalpy change of combustion of acetylene, C_2H_2 is –1280.7 kJ mol^{-1}.

Suggest **one reason** for the difference between the experimental value and the value calculated in **(c)(ii)**. **[1]**

Bond energies are average bond energies between two atoms and not representative of the actual bonds.

Bond energy values are for gaseous compounds, whereas water is a liquid, hence the difference between the standard enthalpy changes of combustion.

The value calculated in (c)(ii) did not take into account the standard enthalpy change of vapourisation/condensation of water.

(iv) Suggest an appropriate storage method for calcium carbide to minimise risks. **[1]**

Use airtight, waterproof containers or

(Prevents contact with atmospheric humidity or accidental water exposure)

Store in a cool, dry, well-ventilated area away from water sources (e.g., sprinklers, pipes). or

No open flames/ignition sources in storage areas (acetylene is highly explosive). or

Store away from oxidisers (nitrates, chlorates, peroxides etc) and water.

or

For bulk storage, use nitrogen (N_2) or argon purging to displace oxygen and prevent acetylene accumulation.

(d) Acetylene, C_2H_2, is a weak acid.

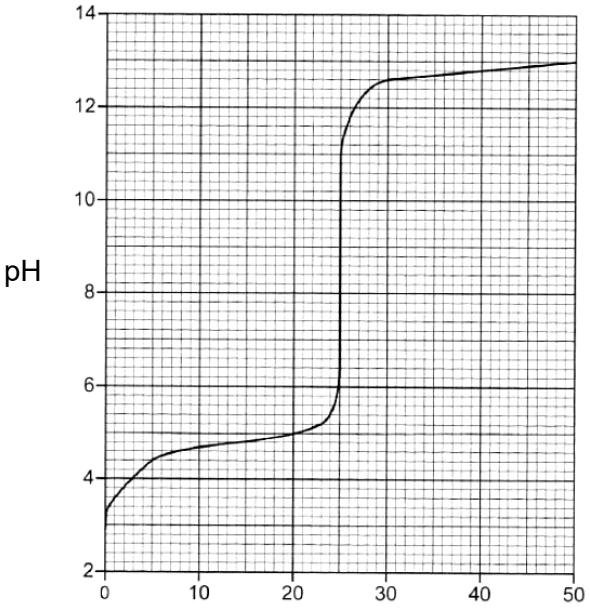
$C_2H_2\,(aq) \rightleftharpoons C_2H^-\,(aq) + H^+(aq)$

(i) Write an expression for the acid dissociation constant, K_a, of C_2H_2, including its units. **[2]**

$K_a = [C_2H^-]\,[H^+] / [C_2H_2]$

Units: mol dm^{-3}

The graph shows the pH changes during the titration of 25.0 cm^3 of 0.05 mol dm^{-3} C_2H_2 with 0.05 mol dm^{-3} sodium hydroxide. During this titration, sodium hydroxide is added gradually, from a burette, until a total volume of 50.00 cm^3 has been added to the acid.



(ii) Using the pH from the graph, calculate the concentration of hydrogen ions, in mol dm^{-3}, in the mixture when 20.00 cm^3 of sodium hydroxide has been added. **[2]**

At 20.00 cm^3, pH = 5

$pH = -\log_{10} [H^+]$

$[H^+] = 10^{-5} = 1 \times 10^{-5}$ mol dm^{-3}

(iii) The *equivalence point* of a titration is the point at which the acid and the alkali have been mixed in stoichiometric proportions. An indicator for this titration would be chosen so that it changes colour as close as possible to the equivalence point. At this point one drop of sodium hydroxide, when added to the acid, will change the colour of the indicator permanently. This is called the *end-point*.

Suggest which indicator should be used for this titration, using information from the graph and the table below.

State the colour change of your chosen indicator at the end-point of this titration. **[2]**

Indicator	Colour		pH range for colour change (working range)
	Acid	Base	
2,4-dinitrophenol	Colourless	Yellow	2.4 – 4.0
Screened methyl orange	Violet	Green	3.2 – 4.4
Phenolphthalein	Colourless	Pink	8.2 – 10.0

Indicator: phenolphthalein

Colour change at the end-point: colourless to (pale) pink

(e) During the addition of the first 25.00 cm^3 of sodium hydroxide, the mixture is behaving as a buffer.

(i) What is meant by the term *buffer solution*? **[1]**

A buffer solution is one whose pH remains almost unchanged when small amounts of acid or base is added.

(ii) How does the shape of the graph show this? **[1]**

The shape of the curve (close to zero gradient) shows that the pH remains almost constant.

(iii) Explain how the mixture is behaving as a buffer at this stage of the titration when small amount of OH^- is added.

Include an equation in your answer. **[2]**

On adding small amount of OH^-

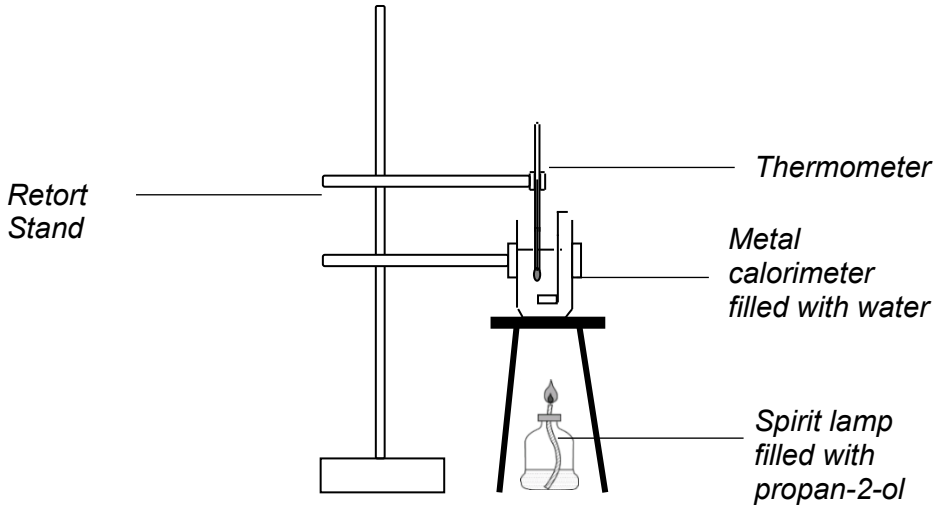
$$OH^- + C_2H_2 \longrightarrow C_2H^- + H_2O$$

The additional OH^- ions are removed by the large amount of undissociated C_2H_2 in the buffer. Thus, $[OH^-]$ changes very slightly and the pH remains almost unchanged/ relatively the same.

[Total: 20]

6 Propan-2-ol, $CH_3CH(OH)CH_3$, is commonly used in industrial and household applications as a solvent.

(a) A student used the apparatus below to determine the enthalpy change of combustion of propan-2-ol.



The student burns the propan-2-ol for 10 minutes.

Table 6.1 shows the data recorded by the student.

Table 6.1

Mass of water/ g	50
Mass of spirit lamp and propan-2-ol before combustion/ g	172.55
Mass of spirit lamp and propan-2-ol after combustion/ g	171.70
Temperature of water in calorimeter before combustion/ ^oC	30.5
Temperature of water in calorimeter after combustion/ ^oC	44.0

The specific heat capacity of water is 4.18 $Jg^{-1}K^{-1}$ and density of water is 1.0 g cm^{-3}.

(i) Calculate the temperature change and hence, the heat absorbed by the water, $\mathbf{Q_{water}}$ in kJ. **[2]**

Temperature change = 44 – 30.5 = 13.5 ^oC

Q_{water}= mcΔT = 50 x 4.18 x 13.5 = 2821.5 J = 2.82 kJ

(ii) The heat capacity of the metal calorimeter, C, is 1410 J K^{-1}.

The heat absorbed by the calorimeter can be calculated by

$$\mathbf{Q_{calorimeter} = C\Delta T}$$

Using the temperature change in **(a)(i)**, calculate this value in kJ. **[1]**

$Q_{calorimeter} = C\Delta T = 1410 \times 13.5 = 19035\ J = 19.0\ kJ$

(iii) The energy evolved from the combustion of propan-2-ol was transferred to both the calorimeter and water.

$$\mathbf{Q_{total} = Q_{calorimeter} + Q_{water}}$$

Calculate the total energy evolved from the combustion of propan-2-ol, $\mathbf{Q_{total}}$. Hence, calculate enthalpy change of combustion of propan-2-ol in kJ mol^{-1}. **[2]**

$Q_{total} = 2.821 + 19.035 = 21.856\ kJ$

Mass of propan-2-ol = 172.55 – 171.70 = 0.85 g

No. of moles of propan-2-ol used = $\frac{0.85}{12x3+8+16}$ = 0.0142 mol

$\Delta H = -\frac{Total\ heat\ evolved}{no.\ of\ moles\ of\ propan-2-ol} = -\frac{21.856}{0.0142}$ = – 1543 kJ mol^{-1}

= – 1540 kJ mol^{-1}

(iv) Although the heat absorbed by the calorimeter is taken into account in the experiment, the enthalpy change of combustion of propan-2-ol is still different from the theoretical value of – 2006 kJ mol^{-1}.

Suggest a reason for the difference. **[1]**

Heat loss to the surrounding

(b) A student constructed an energy cycle to calculate the standard enthalpy change of formation of propan-2-ol, $\Delta H_1^{\ominus}$.

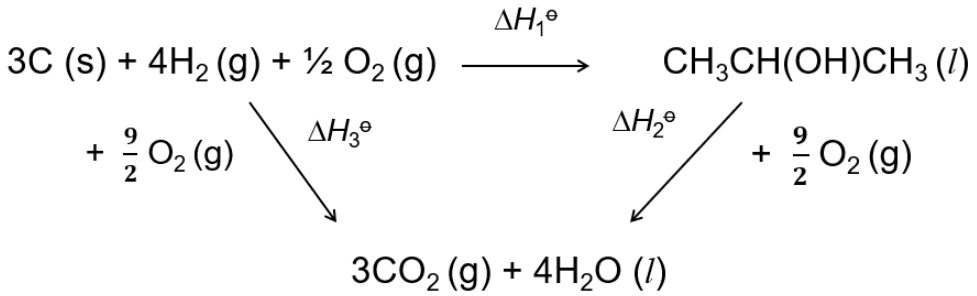


Fig. 6.1

(i) Define the *standard enthalpy change of formation.* **[1]**

The standard enthalpy change of formation, $\Delta H_f^{\ominus}$, is the enthalpy change when one mole of compound is formed from its constituent elements in their standard states/ 298 K and 1 bar.

(ii) State the standard enthalpy change represented by $\Delta H_2^{\ominus}$. **[1]**

$\Delta H_2^{\ominus}$: standard enthalpy change of combustion of propan-2-ol(*l*)

(iii) Calculate the standard enthalpy change of formation of propan-2-ol, $\Delta H_1^{\ominus}$, using the energy cycle in Fig. 6.1 and data in Table 6.2.

Table 6.2

$\Delta H_c^{\ominus}$ (propan-2-ol(l)) / kJ mol^{-1}	–2006
$\Delta H_c^{\ominus}$ (C(s)) / kJ mol^{-1}	–394
$\Delta H_c^{\ominus}$ (H_2(g)) / kJ mol^{-1}	–286

[2]

$\Delta H_1^{\ominus} = \Delta H_3^{\ominus} - \Delta H_2^{\ominus}$

$\Delta H_1^{\ominus} = 3(-394) + 4(-286) - (-2006) = -320$ kJ mol^{-1}

(c) Propan-2-ol reacts with ethanoic acid in the presence of an acid catalyst, concentrated H_2SO_4, to form an ester.

Propan-2-ol + ethanoic acid → ester + water

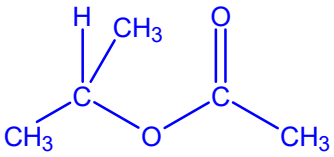
The order of reaction with respect to the [H_2SO_4] is zero.

A chemist performs three different experiments at 25 °C to find out how the initial rate is affected by the initial concentrations of propan-2-ol and ethanoic acid.

For all the experiments, the total volume is kept constant by adding water in order for the concentrations of the reactants to be proportional to the volumes of reactants.

Expt	Volume of propan-2-ol /cm^3	Volume of ethanoic acid /cm^3	Volume of water /cm^3	Initial rate / mol dm^{-3} min^{-1}
1	50	50	0	6.0×10^{-3}
2	50	25	25	3.0×10^{-3}
3	25	40	35	2.4×10^{-3}

(i) Draw the structure of the ester formed. **[1]**



(ii) Sketch on Fig. 6.2 the graph of $[H_2SO_4]$ against time that represents the order of reaction with respect to $[H_2SO_4]$ is zero. **[1]**

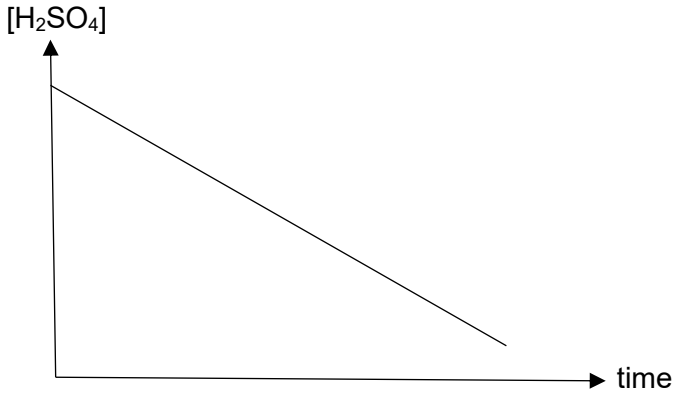


Fig. 6.2

(iii) Deduce the order of reaction with respect to [ethanoic acid] and [propan-2-ol]. **[2]**

Comparing experiment 1 and 2, when the volume/[ethanoic acid] x2, rate x2. Hence, order of reaction with respect to [ethanoic acid] is 1.

Comparing experiment 2 and 3, when the volume/ [propan-2-ol] x2 and vol/[ethanoic acid] x 0.625, rate x 1.25 (2 x 0.625). Since reaction is first order with respect to [ethanoic acid], order of reaction with respect to / [propan-2-ol] is 1.

OR

Let the order of reaction with respect to [propan-2-ol] be y.

Comparing experiments 2 and 3,

$\frac{(50)^y(25)}{(25)^y(40)} = \frac{0.003}{0.0024}$

$(2)^y = 2$

y = 1

Order of reaction with respect to [propan-2-ol] is 1.

(iv) Hence, write the rate equation for the reaction and state the overall order of reaction. **[2]**

Rate = k[$CH_3CH(OH)CH_3$][CH_3COOH]

Overall order = 2

(v) State and provide reason for any change in the rate constant value in experiment 1 and experiment 2. **[1]**

The rate constant remains the same as rate constant is temperature dependent.

(vi) When propan-2-ol is reacted with hydrobromic acid, HBr, is formed. Write an equation to show the thermal decomposition of HBr and explain how the thermal stability of the Group 17 hydrides varies down the group. **[3]**

$2HBr \rightarrow Br_2 + H_2$

Thermal stability decreases from HCl to HBr and to HI. Atomic radius / size of halogen atom increases from Cl to Br and to I. Hence, the extent of effective orbital overlap between halogen and H atom is lesser down the group. The bond energy of H-X thus decreases from HCl to HBr and to HI .

[Total: 20]