RAFFLES INSTITUTION
2025 YEAR 6 PRELIMINARY EXAMINATION

Higher 1

CANDIDATE NAME			
CLASS		INDEX NUMBER	

CHEMISTRY 8873/02

Paper 2 Structured Questions **16 September 2025**

2 hours

Candidates answer on the Question Paper.

Additional Materials: Data Booklet

READ THESE INSTRUCTIONS FIRST

Do not open this question booklet until you are told to do so.

Write your name, class and index number in the spaces provided 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.

Section A
Answer **all** the questions.

Section B
Answer **one** question.

For Examiner's Use		
Section A	1	/ 11
	2	/ 8
	3	/ 9
	4	/ 7
	5	/ 9
	6	/ 12
	7	/ 4
Section B (Please circle the question you have attempted)	8	/ 20
	9	/ 20
Total		/ 80

The use of an approved scientific calculator is expected, where appropriate.
A Data Booklet is provided. Do not write anything in it.

You are reminded of the need for good English and clear presentation in your answers.

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

Section A

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

1 (a) Oxygen exists in various forms, including atoms, ions, and isotopes, each with distinct properties and applications.

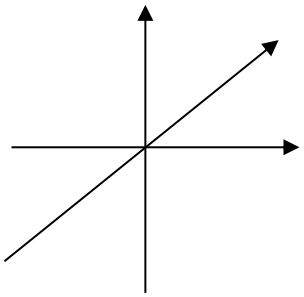
(i) Complete Table 1.1 for two species of oxygen.

Table 1.1

species	number of protons	number of neutrons	number of electrons	electronic configuration
$^{16}_{8}O^{+}$	8			$1s^2$
$^{16}_{8}O_2^{2-}$				

[2]

(ii) Sketch an orbital in which the highest energy electron can be found in $^{16}_{8}O^{+}$. Label the orbital.



[1]

(b) The magnitude of angle of deflection for the path of a beam of O^+ ions in an electric field is **x**°.

Add labelled lines to Fig. 1.1 to represent the paths of the beams of O^+ and O_2^{2-} ions in this electric field.

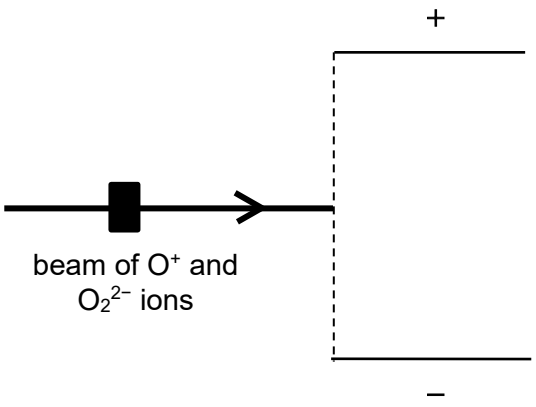


Fig. 1.1 [1]

Hence, state if the angle of deflection of O_2^{2-} ions is greater, smaller or equal to **x**°.

……..……[1]

(c) The relative atomic mass of an element depends on the percentage abundance of each isotope present.

A sample of oxygen atoms contains three isotopes, as shown in Table 1.2.

Table 1.2

isotope	relative isotopic mass	percentage abundance / %
^{16}O	15.994	99.76
^{17}O	16.999	0.038
^{18}O	17.999	0.202

Calculate the relative atomic mass of oxygen in this sample, giving your answers to **two** decimal places.

[2]

(d) Table 1.3 shows some properties of two ionic compounds.

Table 1.3

ionic compound	melting point / °C	lattice energy / kJ mol^{-1}
MgO	2852	−3795
$Ca(NO_3)_2$	561	−1276

(i) Draw a 'dot-and-cross' diagram for $Ca(NO_3)_2$.

[2]

(ii) Explain why the magnitude of lattice energy of MgO is much higher than that of $Ca(NO_3)_2$.

……

……

……

……

……[2]

[Total: 11]

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2 Many industries produce wastewater containing heavy metal ions such as dichromate ions that must be removed before the water is released into the environment. This can be done by carrying out a three-step process.

step 1: An acidified iron(II)-containing solution was added in excess to a wastewater sample containing dichromate ions, $Cr_2O_7^{2-}$, to form chromium(III) ions, Cr^{3+}.

step 2: To the same sample, hydroxide ions, OH^-, was added to fully precipitate Cr^{3+} as chromium(III) hydroxide, $Cr(OH)_3(s)$.

step 3: The mixture was filtered to remove $Cr(OH)_3(s)$.

(a) Define the term *mole*.

……..……..

……..……..[1]

(b) Write half−equations to show the oxidation and reduction for the reaction between Fe^{2+} and $Cr_2O_7^{2-}$, in acidic medium. Hence, write the overall ionic equation for the reaction.

oxidation ……..…….

reduction ……..…….

overall ……..……..

[2]

(c) 30.00 cm^3 of wastewater from a factory and 20.0 cm^3 of excess acidified iron(II)-containing solution were added to a 250 cm^3 volumetric flask. Deionised water was added so that the total volume of the solution was 250 cm^3. This solution was labelled **Y**.

25.0 cm^3 of solution **Y** was reacted with a hydroxide solution to give 0.0588 g of $Cr(OH)_3$.

(i) Calculate the amount of $Cr(OH)_3$ in the dry sample.

[1]

(ii) Calculate the amount of $Cr_2O_7^{2-}$ present in 30.00 cm^3 of wastewater.

[2]

(iii) Hence, calculate the minimum concentration of Fe^{2+} in the iron(II)-containing solution needed for the complete reduction of $Cr_2O_7^{2-}$ to Cr^{3+}.

[2]

[Total: 8]

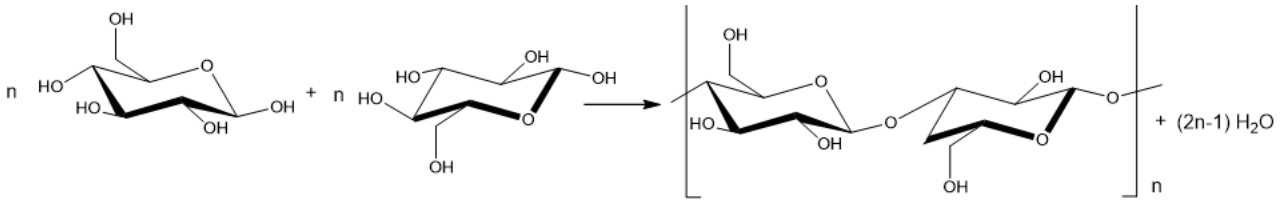
3 **(a)** Cellulose is one of the most abundant linear polymers found in nature. Besides wood and paper, cellulose can also be found in fabrics such as cotton.

(i) Define the term *polymer*.

……..……

……..……[1]

(ii) Cellulose polymer is formed by the following reaction.



State the class of polymers for cellulose.

……..[1]

(iii) Fig. 3.1 shows two linear cellulose polymer chains.

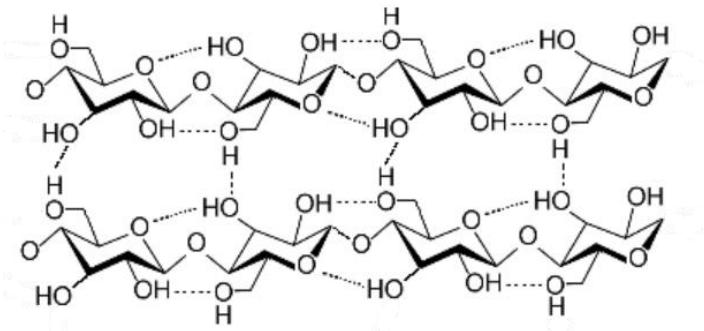


Fig. 3.1

With reference to Fig. 3.1, suggest the type of bonding represented by the dotted lines.

……..[1]

(iv) Hence, explain why a new cotton shirt tends to crease when it is washed and dried.

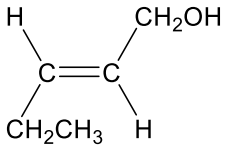
……..…….....

……..…….....

……..…….....

……..…….[2]

(b) The structure of compound **A**, $C_5H_{10}O$, is shown.



A

(i) Explain why **A** is able to exist as *cis* and *trans* isomers.

……

……

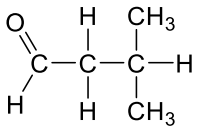
……[2]

(ii) **B** is an isomer of **A**.
B contains a C=C but cannot exist as *cis-trans* isomers.
B reacts with acidified $K_2Cr_2O_7$ to form a ketone.

Draw the structure of **B**.

[1]

(iii) **C** is another isomer of **A**, and the structure of **C** is shown.



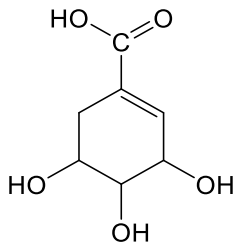
C

State the type of isomerism shown by **A** and **C**.

……[1]

[Total: 9]

4 Shikimic acid is a naturally occurring compound found in plants, and it is used in production of vitamins, amino acids and drugs.



shikimic acid

(a) State the molecular formula of shikimic acid.

……[1]

(b) Shikimic acid contains alkene and other functional groups.

(i) Suggest a chemical test to confirm the presence of the alkene functional group present in shikimic acid.

……[1]

(ii) For the chemical test suggested in **(b)(i)**, state the observation that confirms the presence of the alkene functional group.

……[1]

(c) Shikimic acid is heated with CH_3NH_2 in the presence of DCC to form molecule **D**, $C_8H_{13}NO_4$.

Suggest the structure of **D**.

[1]

(d) Compound **E** contains carbon, hydrogen and oxygen only.

E contains 35.8% by mass, of carbon and 4.48% by mass, of hydrogen.

The relative molecular mass, M_r, of **E** is 134.

Calculate the empirical formula of **E** and hence deduce the molecular formula of **E**.

[3]

[Total: 7]

5 Unsaturated fats in canola oil are hydrogenated to convert some of the C=C double bonds into C−C single bonds to increase its shelf-life. This reaction is typically slow at room temperature but can be sped up using a nickel catalyst in a heterogeneous catalytic process.

(a) **(i)** Define the term *heterogeneous catalyst*.

……

……[2]

(ii) Outline the mode of action of the nickel catalyst in the reaction of unsaturated fats with hydrogen.

……

……

……

……

……

……

……

……

……[2]

(b) The hydrogenation of alkenes with nickel catalyst requires heat, while that with platinum can occur at room temperature.

Suggest why this is so.

……

……

……[1]

(c) The relationship between the pressure of hydrogen gas and its solubility in canola oil is illustrated in Fig. 5.1.

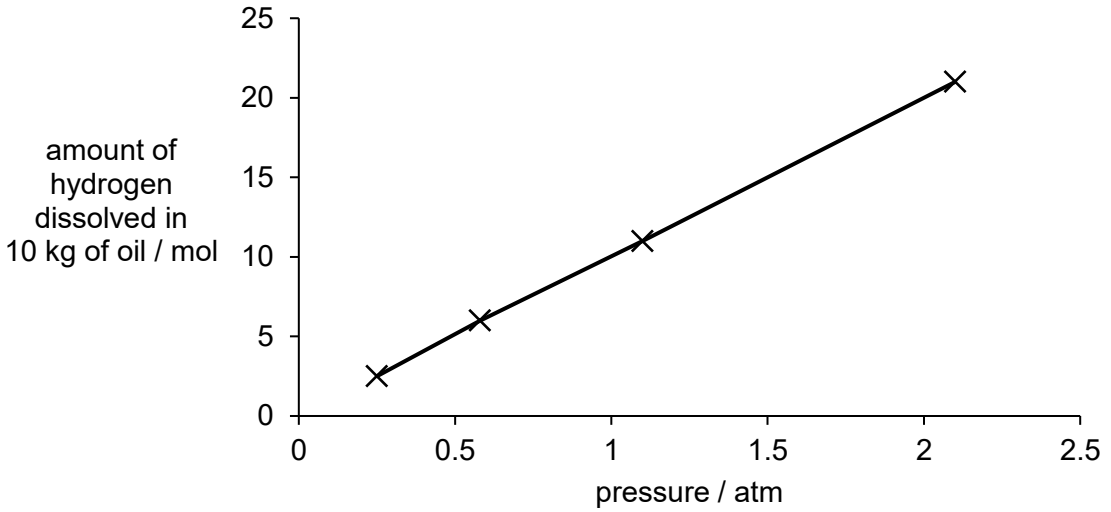


Fig. 5.1

Use the information in Fig. 5.1 to explain why rate of hydrogenation increases with increasing pressure.

……

……

……[2]

(d) Group 1 metals, M, react readily with hydrogen gas to form metal hydrides, MH.

(i) Write an equation for the reaction of lithium with hydrogen.

……[1]

(ii) Explain why the reducing power of metals in Group 1 increases down the group.

……

……

……[1]

[Total: 9]

6 Poly(HEMA) is a polymer commonly used in soft contact lenses. The monomer of poly(HEMA) is shown in Fig. 6.1.

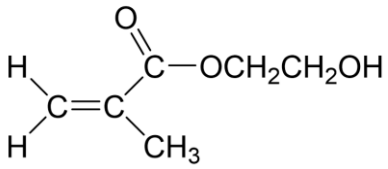


Fig. 6.1

Oxygen permeability refers to the ability of oxygen to diffuse through a material. Poly(HEMA) can be synthesised with more cross-links to enhance the structural stability of contact lenses. Cross-linking agents can be used to form strong bonds between different poly(HEMA) chains to create a more rigid and stable structure. However, more cross-links will cause a decrease in oxygen permeability as shown in Fig. 6.2.

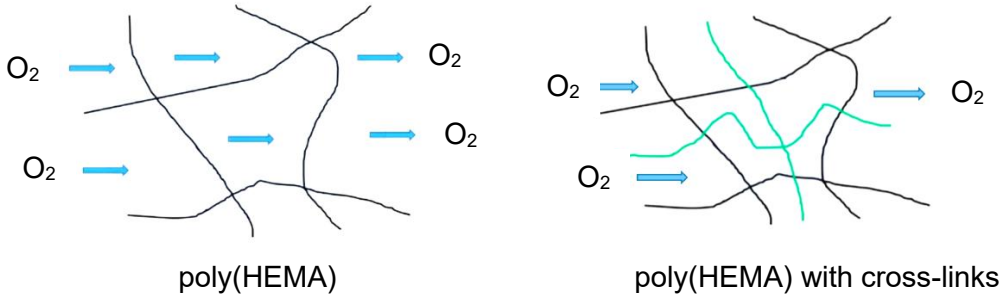


Fig. 6.2

Contact lenses should be maintained in an environment within the pH range of 6.5 to 7.5. Poly(HEMA) contact lenses are typically packaged in a buffered saline solution which helps to maintain the shape and water content of the lenses so that the oxygen permeability of the lenses is not greatly affected. Two commonly used buffers are the borate and phosphate buffers.

A series of experiments was conducted to investigate the effect of varying pH on the oxygen permeability of poly(HEMA) contact lenses using the borate and phosphate buffers respectively. The results are shown in Fig. 6.3.

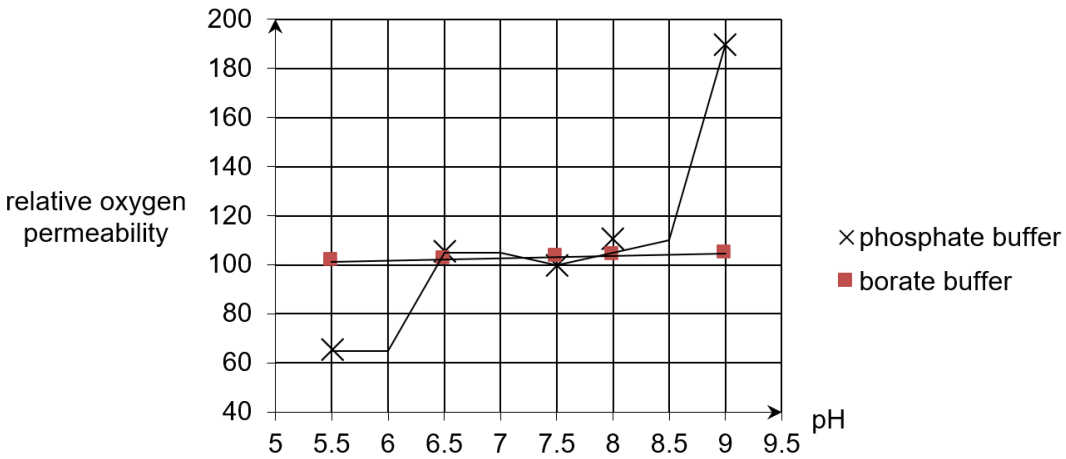


Fig. 6.3

[Turn Over

(a) **(i)** Identify all the functional groups present in the monomer of poly(HEMA).

……[1]

(ii) Draw the structure of poly(HEMA) and state the type of polymerisation.

type of polymerisation ……

[2]

(iii) Poly(HEMA) is classified as a thermoplastic.

State a property of thermoplastic.

……

……[1]

(iv) State the type of bonds form when different poly(HEMA) chains are cross-linked.

……[1]

(v) Suggest a reason why formation of cross-links between different chains of poly(HEMA) decreases its oxygen permeability.

……

……

……[1]

(b) **(i)** Boric acid is a weak acid.

Define the term *weak acid*.

…….[1]

(ii) The dissociation of boric acid is shown in equation 1.

equation 1 $H_3BO_3 \rightleftharpoons H_2BO_3^- + H^+$

Write the K_a expression for boric acid.

[1]

(iii) The pK_a of a solution is calculated by equation 2.

equation 2 $pK_a = -\lg(K_a)$

The pH of a buffer can be calculated using equation 3.

equation 3 $pH = pK_a + \lg\left(\frac{[H_2BO_3^-]}{[H_3BO_3]}\right)$

Use equations 2 and 3 to calculate the value of $\frac{[H_2BO_3^-]}{[H_3BO_3]}$ for a borate buffer of pH 7.27.

The K_a is 6.31×10^{-10} mol dm^{-3}.

[2]

(iv) $H_2PO_4^-$ is the weak acid used in the phosphate buffer.

State the chemical formula of its conjugate base.

……..[1]

(v) Use Fig. 6.3 to explain why both borate and phosphate buffers are equally suitable for storing contact lenses.

……..…....

……..…....

……..…....

……..[1]

[Total: 12]

7 Titanium dioxide, TiO_2, is used as a catalyst in water purification. TiO_2 absorbs light energy to generate reactive oxygen species, which then break down the organic pollutants in water.

Using TiO_2 in the form of nanoparticles increases its effectiveness for water purification.

(a) State the meaning of the term *nanoparticle*.

……..……..[1]

(b) Explain why TiO_2 nanoparticles are more effective in the removal of organic pollutants in water compared to bulk TiO_2.

……..……..

……..……..

……..……..[2]

(c) Explain why the use of TiO_2 nanoparticles for water purification can be hazardous to human health.

……..……..

……..……..[1]

[Total: 4]

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Section B

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

8 (a) Define the term *standard enthalpy change of neutralisation*.

……

…….... [1]

(b) An experiment was conducted to determine the maximum temperature change when sodium hydroxide is added to an excess of nitric acid.

50 cm^3 of nitric acid was transferred into a polystyrene cup and the temperature of the solution was measured and recorded at regular time intervals. At t = 2.5 min, 50 cm^3 of 1.00 mol dm^{-3} sodium hydroxide was added into the polystyrene cup. The temperature of the reaction mixture was measured until t = 8.0 min.

The results are shown in Fig. 8.1.

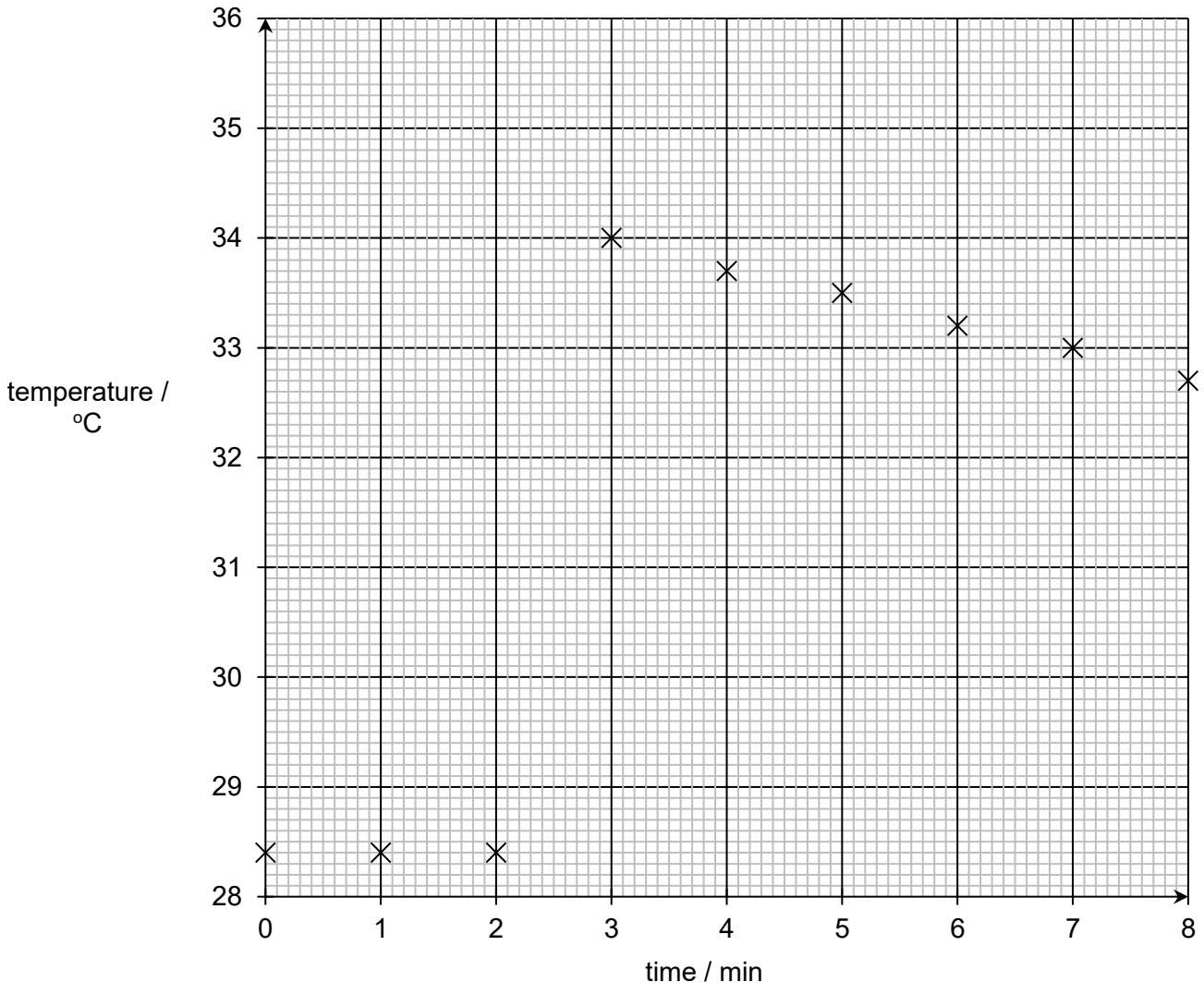


Fig. 8.1

(i) Draw two separate lines of best fit.

The first line should take into account the temperatures before the addition of sodium hydroxide.

The second line should take into account the temperatures after the addition of sodium hydroxide.

Extend both lines to t = 2.5 min.

Use your graph to determine the maximum temperature rise, ΔT_{max}, of the experiment at t = 2.5 min.

Show your working.

ΔT_{max} = ... °C

[2]

(ii) Using your answer to **(b)(i),** calculate the energy, in kJ, evolved during the reaction.

You should assume that the specific heat capacity of the reaction mixture is 4.18 J g^{-1} K^{-1} and the density of the solution is 1.00 g cm^{-3}.

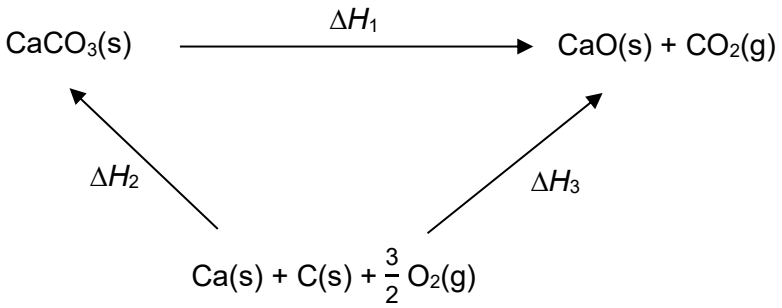
[1]

(iii) Hence, calculate a value for the enthalpy change of neutralisation, in kJ mol^{-1}, for the reaction between sodium hydroxide and nitric acid.

[2]

(c) Calcium carbonate, $CaCO_3$, decomposes to form calcium oxide and carbon dioxide when heated.

An energy cycle involving the decomposition of $CaCO_3$ is shown in the diagram.



(i) Use the data to determine a value, in kJ mol^{-1}, for ΔH_2 and ΔH_3.

$\Delta H_f^{\ominus}$ $CaCO_3(s)$ = −1210 kJ mol^{-1}
$\Delta H_f^{\ominus}$ $CaO(s)$ = −636 kJ mol^{-1}
$\Delta H_c^{\ominus}$ $C(s)$ = −394 kJ mol^{-1}

ΔH_2 = …….. kJ mol^{-1}

ΔH_3 = …….. kJ mol^{-1}

[2]

(ii) Use your answers to **(c)(i)** to calculate a value, in kJ mol^{-1}, for ΔH_1.

Show your working.

ΔH_1 = …….. kJ mol^{-1}

[2]

(d) Calcium carbonate is a sparingly soluble compound.

When an excess of solid calcium carbonate is added to water, some calcium carbonate dissolves, and the following equilibrium is established.

$$CaCO_3(s) \rightleftharpoons Ca^{2+}(aq) + CO_3^{2-}(aq) \qquad \Delta H = -13 \text{ kJ mol}^{-1}$$

(i) Write the expression for K_c for the dissolution of calcium carbonate.
Include the units.

K_c =

units = ……..……..

[2]

(ii) At equilibrium, only 6.50×10^{-6} mol of calcium carbonate dissolved in 100 cm^3 of water.

Using your answer to **(d)(i)**, calculate the value of K_c.

[2]

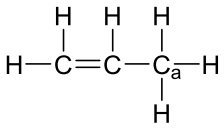
(iii) State and explain the effect on K_c when temperature of the mixture is increased.

……..

……..

…… [2]

(e) Propene contains both σ and π bonds.



(i) Draw a labelled diagram to show how two p orbitals form a σ bond.

[1]

(ii) Draw a labelled diagram to show how two p orbitals form a π bond.

[1]

(iii) State the bond angle and shape about C_a in propene.

Explain your answers using the Valence Shell Electron Pair Repulsion Theory.

……..

……..

……..

……..[2]

[Total: 20]

9 (a) (i) State what is meant by the term *electronegativity*.

……..……..

……..….[1]

(ii) State how the bonding in the chlorides of the elements sodium to sulfur changes across Period 3.

Explain this change in terms of the electronegativities of these elements.

……..……..

……..……..

……..……..

……..……..

……..….[2]

(b) Sodium has a larger atomic radius than chlorine.
Explain the difference in the atomic radii of sodium atom and a chlorine atom.

……..……..…...

……..……....

……..……..…...

……..……....

……..……..…..[2]

(c) Sodium oxide, aluminium oxide and sulfur(VI) oxide are each added to separate samples of

- water,
- dilute sulfuric acid,
- aqueous sodium hydroxide.

Write equations to show any reactions which occur.

sodium oxide

……

……

aluminium oxide

……

……

sulfur(VI) oxide

……

……
[6]

(d) Name the shape and state the bond angle in a molecule of sulfur dioxide.
Explain your answers using the Valence Shell Electron Pair Repulsion theory.

Draw a diagram to illustrate your answer.

……

……

……[3]

(e) When sodium thiosulfate reacts with an acid, a yellow precipitate of sulfur and sulfur dioxide gas is produced.

$$Na_2S_2O_3(aq) + 2HCl(aq) \longrightarrow S(s) + SO_2(g) + H_2O(l) + 2NaCl(aq)$$

Four sets of experiments were performed separately to determine the rate of reaction and the results are shown in Table 9.1.

Table 9.1

expt	volume of 1.00 mol dm^{-3} $HCl(aq)$ used / cm^3	volume of 0.20 mol dm^{-3} $Na_2S_2O_3(aq)$ used / cm^3	volume of water used / cm^3	initial rate / mol dm^{-3} s^{-1}
1	30.0	40.0	0.0	0.0625
2	30.0	20.0	20.0	0.0313
3	40.0	30.0	0.0	0.0500
4	20.0	30.0	20.0	0.0500

(i) Explain why water was added in experiments 2 and 4.

……..……...

……..……...

……..…..[1]

(ii) Determine the order of reaction with respect to each reactant and hence deduce the rate equation for this reaction. Use data from Table 9.1 to explain your answers.

……..……...

……..……...

……..……...

……..……...

……..……...

……..……...

……..…..[3]

(iii) Sketch a graph of volume of SO_2 against time for this reaction, showing two half-lives clearly.

[1]

(iv) With reference to the graph drawn in **(e)(iii)**, comment on the half-lives obtained.

……..……...

……..…..[1]

[Total: 20]

– END OF PAPER –