Anglo-Chinese Junior College

JC2 Preliminary Examination
Higher 2

A Methodist Institution
(Founded 1886)

CANDIDATE NAME		FORM CLASS	
TUTORIAL CLASS		INDEX NUMBER	

CHEMISTRY **9729/02**

Paper 2 Structured Questions

21 August 2024
2 hours

Candidates answer on the Question Paper.

Additional materials: Data Booklet

READ THESE INSTRUCTIONS FIRST

Write your form class, index number and name 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.

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	
Question no.	**Marks**
1	**/ 12**
2	**/ 11**
3	**/ 10**
4	**/ 10**
5	**/ 10**
6	**/ 22**
Presentation of answers	
TOTAL	**/ 75**

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

Section B: Structured Questions (75 marks)

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

1 **Y** and **Z** are two elements found in Period 3. Their fifth to eighth ionisation energies are given in Table 1.1.

Table 1.1

successive ionisation energies / kJ mol^{-1}	5th	6th	7th	8th
Y	6530	9353	11019	33606
Z	7004	8496	27107	31719

(a) **(i)** State and explain the group number of **Y**.

…………………………………………………………………………………………………

…………………………………………………………………………………………………

…………………………………………………………………………………………………

……………………………………………………………………………………………[1]

(ii) Complete the electronic configurations of **Y**$^+$ and **Z**$^+$.

Y$^+$ $1s^2$………………………………………………………………………………

Z$^+$ $1s^2$……………………………………………………………………………[1]

(iii) From your answer in **(a)(ii)**, explain why the second ionisation energy of **Y** is expected to be lower than **Z**.

…………………………………………………………………………………………………

…………………………………………………………………………………………………

……………………………………………………………………………………………[1]

(iv) However, it turns out that the second ionisation energies of **Y** and **Z** are 2300 kJ mol^{-1} and 2260 kJ mol^{-1} respectively.
Suggest why **Y** has a higher second ionisation energy than **Z**.

…………………………………………………………………………………………………

……………………………………………………………………………………………[1]

(b) **(i)** The atomic radii of some Period 4 elements are shown in Fig. 1.1.

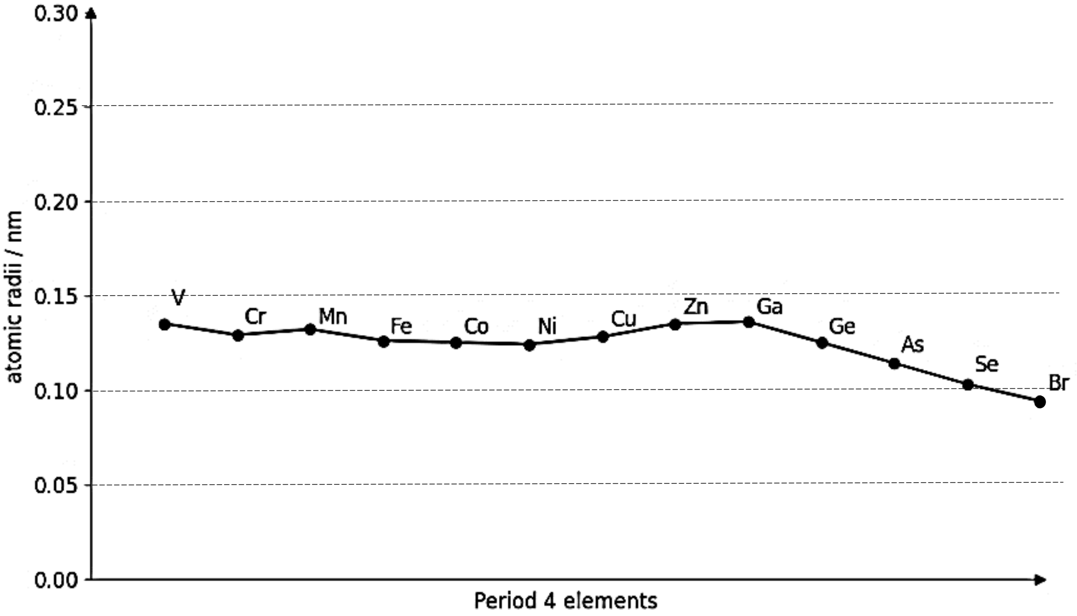


Fig. 1.1

With reference to Fig. 1.1, describe and explain the shape of the graph from

- V to Zn
- Ga to Br

……………………………………………………………………………………………

……………………………………………………………………………………………

……………………………………………………………………………………………

……………………………………………………………………………………………

……………………………………………………………………………………………

……………………………………………………………………………………………

……………………………………………………………………………………………

……………………………………………………………………………………………

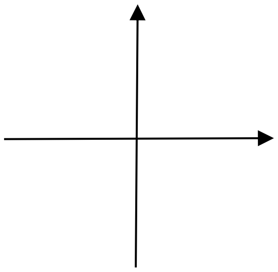
……………………………………………………………………………………………

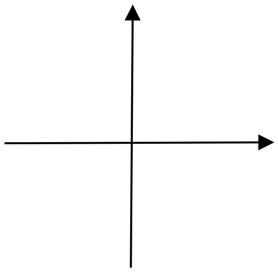
……………………………………………………………………………………………[4]

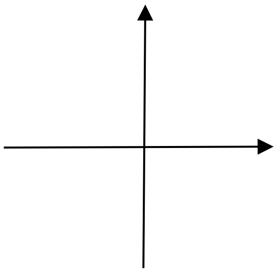
(ii) With reference to the *Data Booklet* or otherwise, on Fig. 1.1, sketch the ionic radii of the Period 4 elements.

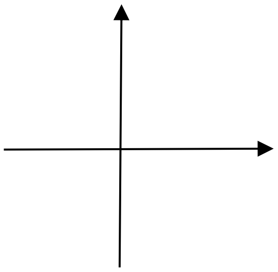
You may assume that V to Zn form doubly charged cations. [2]

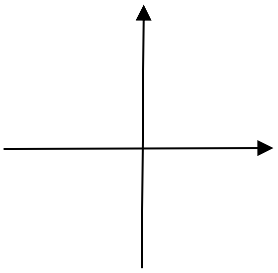
(c) Draw and label the d orbitals in cobalt ion.











[2]

[Total: 12]

BLANK PAGE

2 The hydroboration-oxidation reaction of an alkene bond using borane, BH_3, provides a useful method for hydration. Using this reaction, 1-methylcyclohexene can be converted to trans-2-methylcyclohexanol as shown in Fig. 2.1.

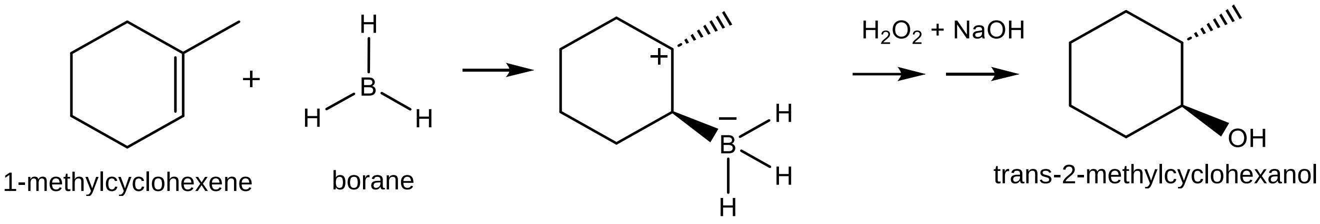


Fig. 2.1

(a) **(i)** Explain the role of borane in Fig. 2.1.

…………………………………………………………………………………………

…………………………………………………………………………………………

…………………………………………………………………………………………[1]

(ii) Suggest why the *trans* configuration is favoured in the product formed in Fig. 2.1.

…………………………………………………………………………………………

…………………………………………………………………………………………

…………………………………………………………………………………………[1]

(b) Suggest a chemical test that would allow you to distinguish between 2-methylcyclohexanol and ethanol. Include a relevant equation in your answer.

…………………………………………………………………………………………

…………………………………………………………………………………………

…………………………………………………………………………………………

…………………………………………………………………………………………[2]

(c) Borane dimerises to form the more stable diborane, B_2H_6, shown in Fig. 2.2.

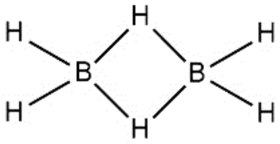


Fig. 2.2

(i) Suggest **two** unusual features about the bonding shown in Fig. 2.2.

……………………………………………………………………………………………

……………………………………………………………………………………………

……………………………………………………………………………………………

………………………………………………………………………………………[2]

(ii) Fig. 2.3 depicts another equivalent representation of the bonding in diborane. The bridging B-H-B bonds are curved, giving them the name ‘banana bonds’.

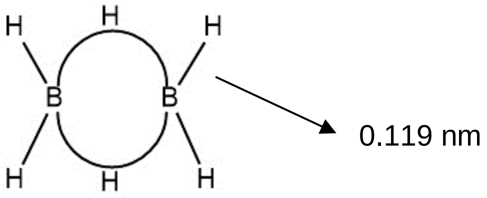


Fig. 2.3

The ‘banana bonds’ consist of three-centre-two-electron bonds, which are electron-deficient chemical bonds where three atoms share two electrons.

State the total number of bonding electrons in diborane.

………………………………………………………………………………………[1]

(iii) The B–H bonds in diborane have different bond lengths. The terminal B–H bonds are 0.119 nm in length.

Explain how the bond length of the bridging B–H bonds compares with the terminal B–H bonds.

Note: Fig. 2.3 is not drawn to scale.

……………………………………………………………………………………………

……………………………………………………………………………………………

………………………………………………………………………………………[1]

(d) 1-methylcyclohexene can react with iodine monochloride, I*Cl*.

Name and describe the mechanism of this reaction, showing curly arrows, charges, dipoles and any relevant lone pairs.

[3]

[Total: 11]

3 Cyanogen chloride, C*l*CN, exists as a highly toxic gas and reacts rapidly with hydroxide ions.

equation 1 $ClCN + OH^- \rightarrow HOCN + Cl^-$

(a) **(i)** State the hybridisation of the carbon atom in cyanogen chloride.

……………………………………………………………………………………[1]

(ii) Name the *type of reaction* occurring in equation 1.

……………………………………………………………………………………[1]

(b) **(i)** 0.06 g of cyanogen chloride was fully dissolved in 100 cm^3 of 2 mol dm^{-3} aqueous sodium hydroxide.

The rate constant, *k*, for the reaction is 4.2 $mol^{-1}\,dm^3\,s^{-1}$.

Construct the rate equation for equation 1.

……………………………………………………………………………………[1]

(ii) Calculate the concentration of cyanogen chloride in the solution.

[1]

(iii) Using your answer in **(b)(ii)** and the information in **(b)(i)**, deduce the half-life of the reaction.

[1]

(c) **(i)** In a separate experiment, 0.15 g of gaseous cyanogen chloride was found to occupy a volume of 72.3 cm^3 at 127 °C and a pressure of 102.7 kPa.

Calculate the relative molecular mass of cyanogen chloride using the experimental data.

[1]

(ii) Pure cyanogen chloride was used in the experiment.

Suggest why there is a difference between the theoretical value of its relative molecular mass and the value obtained in **(c)(i)**.

………………………………………………………………………………………………

………………………………………………………………………………………………

………………………………………………………………………………………………

………………………………………………………………………………………………[2]

(d) Cyanogen chloride can react with sulfinic acids to form sulfonyl cyanides.

An example of a sulfinic acid is shown in Fig. 3.1.

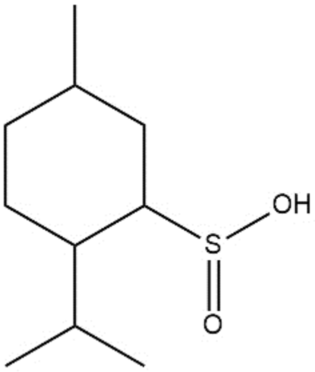


Fig. 3.1

Chiral centres have four different substituent groups bonded to it. The lone pair of electrons on atoms can also be considered a distinct group.

Identify the chiral carbons of sulfinic acid shown on Fig. 3.1 by marking them with an asterisk (*). [1]

(e) Cyanogen chloride can trimerise to form a 6-membered cyclic molecule with molecular formula, $(ClCN)_3$. This molecule has no overall dipole moment.

Suggest a possible structure of the trimer.

[1]

[Total: 10]

4 Pyrite, FeS_2, is often referred to as "Fool's Gold" because it resembles gold to the untrained eye. It is one of the most abundant sulfide mineral available.

Table 4.1 shows some physical properties of pyrite and gold against other substances.

Table 4.1

compound	gold	FeS_2 (pyrite)	steel
melting point / °C	1064	1177	1425
Mohs hardness	2.5	6.3	6.5
density / g cm^{-3}	19.0	5.0	7.9

(a) **(i)** Explain the high melting points of gold and pyrite.

…………………………………………………………………………………………………

…………………………………………………………………………………………………

…………………………………………………………………………………………………

…………………………………………………………………………………………………

………………………………………………………………………………………………[2]

(ii) Mohs Hardness Scale is a measure of a substance's resistance to scratching. The substance's hardness is measured against another substance of known hardness on the Mohs Hardness Scale. A substance can only scratch a substance of equal or lower Mohs hardness value.

Suggest a simple way to distinguish between gold and pyrite.

…………………………………………………………………………………………………

…………………………………………………………………………………………………

………………………………………………………………………………………………[1]

(iii) Pyrite and steel have similar values on the Mohs Hardness Scale that are relatively higher than that of metals. Explain this phenomenon, making reference to their lattice structure.

……………………………………………………………………………………………

……………………………………………………………………………………………

……………………………………………………………………………………………

……………………………………………………………………………………………

…………………………………………………………………………………………[2]

(b) Due to its shiny and gold-like appearance, pyrite is widely used in decorative items. However, over time, items with pyrite were found to be cracked and discoloured. When exposed to air and moisture, the iron-containing mineral can form rust, Fe_2O_3, along with a toxic gas, SO_2, and corrosive acid.

(i) Construct a balanced equation of the formation of rust from pyrite.

…………………………………………………………………………………………[1]

(ii) Draw the 'dot-and-cross' diagram of the disulfide ion, S_2^{2-}.

[1]

(c) Iron(II) compounds are generally only stable in neutral, non-oxidising conditions. It is difficult to determine the lattice energy of FeS_2 experimentally.

Table 4.2

	value / kJ mol^{-1}
standard enthalpy change of formation of FeS_2(s)	–178
standard enthalpy change of atomisation of Fe(s)	+347
standard enthalpy change of atomisation of S(s)	+279
$2S(g) + 2e^- \rightarrow S_2^{2-}(g)$	–512

Use the data given in Table 4.2, together with data from the *Data Booklet* to calculate the lattice energy of FeS_2.

Show your working.

[3]

[Total: 10]

BLANK PAGE

5 2–(2–chloroethyl)phenol can be used in a synthesis pathway shown in Fig. 5.1.

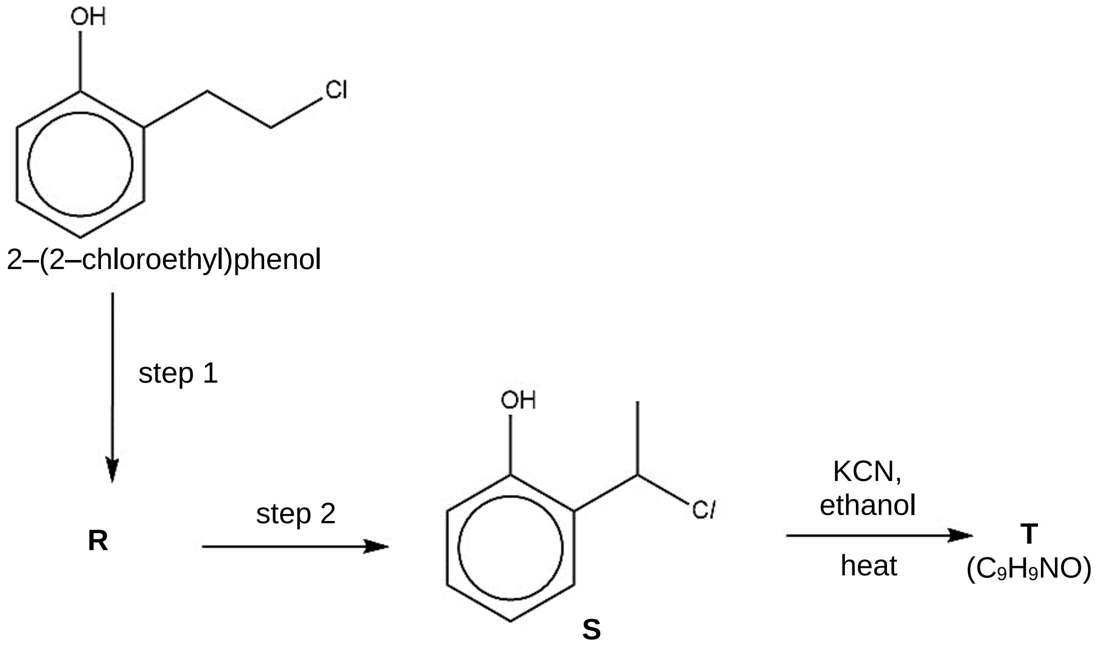


Fig. 5.1

1 mol of compound **R** reacts with 3 mol of aqueous Br_2 to give a white precipitate.

(a) **(i)** Suggest what this observation indicate about the functional groups in **R**.

…………………………………………………………………………………..……………

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

(ii) Describe the reagents and conditions needed for steps 1 and 2.

Step 1: ………………………………………………………………………………………

Step 2: ……………………………………………………………………………………[2]

(iii) Suggest the structures of **R** and **T**.

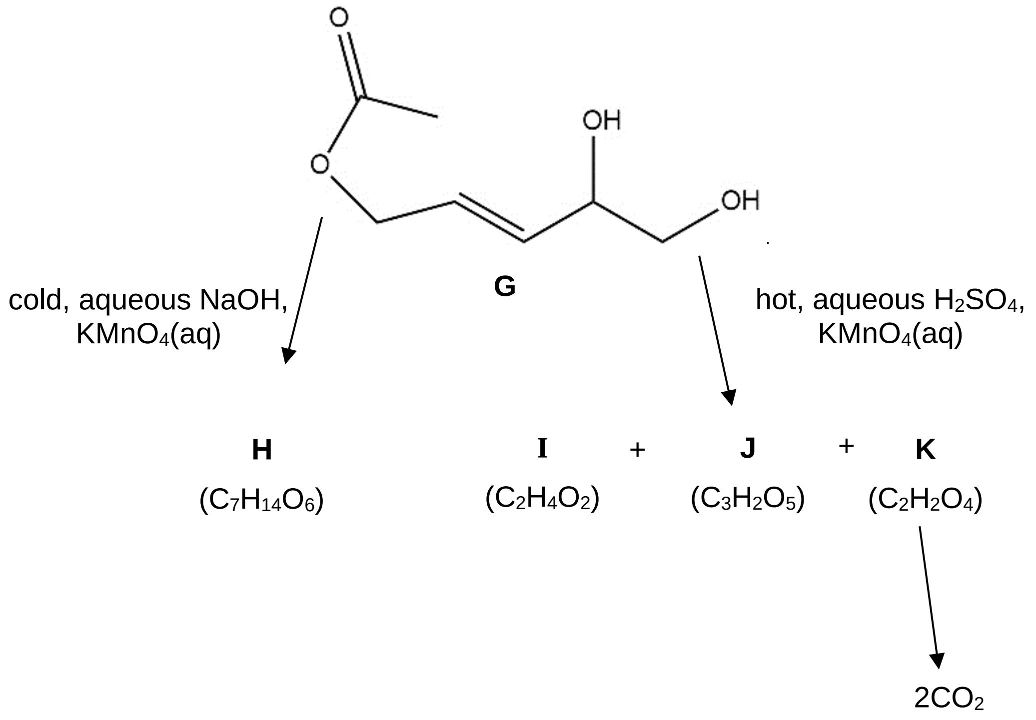
[2]

(iv) Describe the relationship between 2-(2-chloroethyl)phenol and compound **S**.

……………………………………………………………………………………………[1]

(b) Hot, concentrated potassium manganate(VII) oxidises several classes of organic compounds to ketones, carboxylic acids or carbon dioxide. By this means, the structures of compounds can be determined. Some compounds are easily oxidised, while others require longer heating.

Compound **G** can be oxidised by $KMnO_4$ under different conditions to give various products.



Suggest the structures of the compounds **H**, **I**, **J** and **K**.

[4]

[Total: 10]

6 The salinity of seawater is due to the many dissolved molecules and ions present in it. Table 6.1 shows some significant species present in seawater, some of which play a role in maintaining the pH of seawater.

Table 6.1

species	concentration in parts per million (ppm)
Cl^-	19300
Na^+	10800
Ca^{2+}	420
HCO_3^-	116
CO_3^{2-}	9.54
$Si(OH)_4$	9.32
CO_2	0.660
$SiO(OH)_3^-$	0.285

The concentration of dissolved species is measured in parts per million. This refers to the mass in grams of the species dissolved in a million grams of water.

Oceans serve as a natural sink for carbon, by absorbing about 30% of carbon dioxide emissions from the atmosphere. The processes, and their associated equations, involved in the absorption of carbon dioxide by seawater are numbered 1 to 4 in Table 6.2.

Table 6.2

process	equation	K_a at 25 °C
1	$CO_2(g) \rightleftharpoons CO_2(aq)$	-
2	$CO_2(aq) + H_2O(l) \rightleftharpoons H_2CO_3(aq)$	-
3	$H_2CO_3(aq) + H_2O(l) \rightleftharpoons HCO_3^-(aq) + H_3O^+(aq)$	4.5×10^{-7}
4	$HCO_3^-(aq) + H_2O(l) \rightleftharpoons CO_3^{2-}(aq) + H_3O^+(aq)$	4.7×10^{-11}

Process 3 and 4 represent the first and second acid dissociation constant of carbonic acid respectively.

(a) Some species in Table 6.1 form Brønsted-Lowry conjugate acid-base pairs which are responsible for buffering the pH of seawater.

(i) Identify two Brønsted-Lowry conjugate acid-base pairs in Table 6.1.

conjugate acid-base pair 1: ……………………………………………………………..……..

conjugate acid-base pair 2: ………………………………………………………….. [1]

(ii) Using one of the conjugate acid-base pairs in **(a)(i)**, write equation(s) to show how the buffer system helps to maintain the pH of seawater.

……………………………………………………………………………………………

…………………………………………………………………………………………… [1]

(b) The carbon–oxygen bond length in some compounds is given in Table 6.3.

Table 6.3

species containing carbon–oxygen bond	bond length / nm
CH_3OH	0.143
HCHO	0.123
H_2CO_3	0.134

(i) Draw the displayed formula for H_2CO_3.

[1]

(ii) Considering the overlap of atomic orbitals, suggest why all the carbon–oxygen bonds in H_2CO_3 have a bond length that is in between that of CH_3OH and HCHO.

……………………………………………………………………………………………

……………………………………………………………………………………………

……………………………………………………………………………………………

…………………………………………………………………………………………… [2]

Process 2 is thought to proceed via the two steps described below.

step 1: Water behaves as nucleophile and attacks a carbon dioxide molecule.

step 2: An intramolecular proton transfer occurs within the intermediate to form carbonic acid.

(iii) Draw a mechanism for process 2. Show relevant curly arrows, dipoles, charges and lone pairs of electrons in your answer.

[2]

(iv) Hence, suggest and explain which step is likely to be the rate determining step in the mechanism of **(b)(iii)**.

………………………………………………………………………………………….…..

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

(c) **(i)** Write the K_a expression for process 3.

[1]

(ii) The concentration of CO_2 is assumed as the concentration of H_2CO_3 while the density of water is 1 g cm^{-3}. The pH of seawater is 8.0.

Use this information and that from Table 6.1 to calculate another value for the first acid dissociation of H_2CO_3.

[2]

(iii) Suggest a reason why the K_a value calculated in **(c)(ii)** differs from that in Table 6.2.

…………………………………………………………………………………………

………………………………………………………………………………………… [1]

Corals are soft bodied organisms that build their skeletons by precipitating calcium carbonate from seawater, allowing for the storage of large amounts of carbon in the corals' skeleton. This is done by bringing seawater into a calcifying space between the existing coral skeleton and the coral body, where protons are pumped out to increase the concentration of carbonate ions. The carbonate ions are then precipitated together with calcium ions as calcium carbonate on the surface of the existing coral skeleton.

With rising carbon dioxide emissions into the atmosphere due to human activities, the pH levels of seawater are decreasing. This has led to an acidification of the oceans and corals find it increasing challenging to build their calcium carbonate skeletons.

(d) State one human activity that is increasing the emission of carbon dioxide into the atmosphere.

………………………………………………………………………………………… [1]

(e) The K_{sp} values and relative solubilities of $CaCO_3$, $Ca(OH)_2$ and $Ca(HCO_3)_2$ at 25 °C are given in Table 6.4.

Table 6.4

species	K_{sp} value	solubility
$CaCO_3$	6.0×10^{-9}	sparingly soluble
$Ca(OH)_2$	5.02×10^{-6}	sparingly soluble
$Ca(HCO_3)_2$	–	soluble

When carbon dioxide is bubbled into a saturated solution of calcium hydroxide, a white precipitate is observed.

(i) Write the K_{sp} expression for calcium hydroxide and state its units.

....

.... [1]

(ii) Calculate the concentration, in mol dm^{-3}, of $Ca^{2+}(aq)$ in a saturated solution of calcium hydroxide.

[1]

(iii) Calculate the concentration of $CO_3^{2-}(aq)$ present in solution when calcium carbonate begins to precipitate.

[1]

(iv) The following reaction occurs when carbon dioxide is continuously bubbled through a saturated solution of calcium hydroxide.

$$H_2CO_3 + CO_3^{2-} \rightleftharpoons 2HCO_3^-$$

Use information from Table 6.2 to calculate a value for K_c and state what the K_c value indicates about the position of equilibrium.

.... [1]

(v) Using the equation provided in **(e)(iv)** and information from Table 6.4, predict and explain the likely observations made when carbon dioxide is continuously bubbled through a saturated solution of calcium hydroxide.

....

....

....

....

.... [2]

(vi) Using the equation provided in **(e)(iv)** and your answer in **(e)(v)**, describe how the increasing carbon dioxide emissions in the atmosphere makes it challenging for corals to build their calcium carbonate skeleton.

....

....

.... [1]

(f) Aragonite and calcite are two different solid forms of calcium carbonate that can be precipitated by corals.

Some information about these two forms of calcium carbonate is provided below.

Table 6.5

form of calcium carbonate	$\Delta H_f^\ominus$ / kJ mol^{-1}	$\Delta S_f^\ominus$ / J mol^{-1} K^{-1}
aragonite	−1207.8	+88.0
calcite	−1207.6	+91.7

The entropy change, $\Delta S_{rxn}^\ominus$, of a reaction, can be determined using the following formula:

$$\Delta S_{rxn}^\ominus = \sum m\Delta S_f^\ominus(\text{products}) - \sum n\Delta S_f^\ominus(\text{reactants})$$

where m and n are the coefficients of the products and reactants in the balanced equation.

Use information from Table 6.5 to show that the conversion of aragonite to calcite is a spontaneous process under standard conditions.

$$CaCO_3\text{ (aragonite)} \rightarrow CaCO_3\text{ (calcite)}$$

[2]

[Total: 22]

End of Paper