	Anglo-Chinese Junior C JC2 Preliminary Examination Higher 2	College	A Methodist Institution (Founded 1886)
CANDIDATE NAME	Answers	FORM CLASS	
TUTORIAL CLASS		INDEX NUMBER	
CUEMICTOV			0700/00

CHEMISTRY

Paper 2 Structured Questions

9729/02 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			

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 5 th 6 th 7 th 8 th										
Y 6530 9353 11							33606	-			
			Ζ	7004	8496	27107	31719				
	(a)	(1)	State and explain the group number of	Υ.				[1]			
		Y be	longs to <u>Group 17</u> . There is a large jump	between	the 7 th ar	nd 8 th ionis Lauantum	sation ene	ergies, 11			
					(principa	quantum) <u>onon</u> . [.1			
		• <u>Com</u>	Generally well done. However, many	y students	s misspel [:]	t 'principa	l' as 'prin	ciple'.			
			Also, the terms 'principal quantum	shell' an	d 'subsh	ell' should	d not be	used			
			interchangeably.								
		(ii)	Complete the electronic configurations	of Y ⁺ and	Z ⁺.						
			Y ⁺ : 1s ² <u>2s²2p⁶3s²3p⁴</u> Z ⁺ : 1s ² <u>2s²2p⁶3s²3p³</u>								
		Comments Students should write out the electronic configuration of elements Y and Z first before removing an electron.									
		(iii)	From your answer in (a)(ii) , explain expected to be lower than Z .	why the	second i	onisation	energy o	f Y is [1]			
		The second ionisation energy for <u>element Y</u> involves removing a <u>paired electron</u> from the 3p subshell that has interelectronic <u>repulsion</u> while the second ionisation energy for element Z involves removing an unpaired electron from the 3p subshell.									
	 A significant number of students were able to identify that there was greate interelectronic repulsion in Y but did not mention this was due to the paired electrons. For the 2nd IE of Z, only the electrons in the 3p subshell are unpaired, the inner electrons are still paired so it is incorrect to say that there are no paired electrons in Z. 							reater <u>paired</u> d, the paired			
		(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]									

		The effect of the <u>higher</u> (effective) <u>nuclear charge of Y</u> is more dominant than the interelectronic repulsion between the paired electrons, so the 3p <u>electron to be removed is held more tightly by the nucleus</u> [1]						
		 Comments Many students struggled to adequately account for the higher second IE of Y. Students should recognise that there are two factors to consider: 1. effective nuclear charge and 2. interelectronic repulsion. The predominant factor is determined based on data given. Some managed to identify the predominant factor of higher effective nuclear charge but did not link it to the valence electron being more tightly held by the nucleus. 						
(b)	(i)	The atomic radii of some Period 4 elements are shown in Fig. 1.1.						
		V to Zn Ga to Br [4]						
		 From V to Zn, the atomic radii remains relatively invariant. While nuclear charge increases from V to Zn, electrons are added to the inner shell / 3d subshell, increasing shielding effect on valence electrons. Increase in effective nuclear charge is minimal/effective nuclear charge remains relatively constant. From Ga to Br, the atomic radii of the elements decreases across the Period. Across the Period, increasing nuclear charge and approximately constant shielding effect causes effective nuclear charge to increase. The valence electrons experience stronger nuclear attraction and are pulled closer to the nucleus. Hence, atomic radius decreases across the Period. 						
		 Comments This question tested two main learning outcomes: 1. Describing and explaining the general trend in atomic radius across the Period (Ga to Br) in terms of shielding effect and nuclear charge 						



Comments							
	•	Most students were able to get at least 1m. When labelling orbitals, students should follow the convention (e.g. d_{yz} and not d_{zy}).					
		[Total: 12]					

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.									
	$ \begin{array}{c} & & H \\ & & H \\ 1 - methylcyclohexene \end{array} \qquad borane \qquad \qquad$									
			Fig. 2.1							
	(a)	(i)	Explain the role of borane in Fig. 2.1. [1]							
			BH_3 is a <u>lewis acid</u> as it <u>accepts an electron pair</u> from the alkene.							
			BH ₃ is an <u>electrophile</u> as <u>borane is electron-deficient</u> OR <u>alkene is electron-rich</u> .							
			Comments							
			 Some students merely stated the role of borane without any explanation. 							
		(ii)	Suggest why the <i>trans</i> configuration is favoured in the product formed in Fig. 2.1. [1]							
			Steric hindrance is minimised/ There is less interelectronic repulsion when the bulky							
			OR							
			Cis configuration is not favoured because the bulky methyl and BH ₃ ⁻ groups are on the <u>same side</u> , hence there is <u>more steric hinderance</u> .							
			Comments							
			• Students should always explain what they understand by 'steric hindrance'.							
	(b)	Sug	gest a chemical test that would allow you to distinguish between 2-methylcyclohexanol							
		and	ethanol. Include a relevant equation in your answer. [2]							
		To s	eparate test tubes containing each sample, add $I_2(aq)$, NaOH(aq) and heat/warm.							
		Yello	ow ppt observed for ethanol but not for 2-methylcyclohexanol.							
			$CH_2OH + 4I_2 + 6NaOH \rightarrow CHI_3 + HCOONa + 5NaI + 5H_2O$							
		DNA	: lodoform test. Must state R&C used.							
		DNA	: if 2 tests were applied. Qn asked for 1 chemical test only.							
			Some students did not mention 'heat' for iodoform test							
		•	Some students did not read the guestion properly and missed out on giving an							
			equation.							

	 A significant number of students were unable to give the correct balanced equation for iodoform test. A common mistake was to give CH₃COO⁻ as one of the products. 						
	•	 A minority of students thought that cyclohexanol was the same as phenol which is 					
		a big misconception.					
(c)	Borane dimerises to form the more stable diborane, B_2H_6 , shown in Fig 2.2.						
		$H \rightarrow H \rightarrow H$					
		H B H					
	(i)	Fig 2.2 Suggest two unusual features about the bonding shown in Fig 2.2. [2]					
		Bridging hydrogen forms two bonds when it has only one valence electron					
		OR Hudragen should not be able to accent a long pair of electrone as it does not have					
		an empty orbital.					
		Boron forms four bonds when it has only three valence electrons.					
		Boron/hydrogen should not be able to form dative bonds since it does not have a					
		lone pair of electrons.					
	Comments Most students could score at least 1m.						
	(ii) Fig 2.3 depicts another equivalent representation of the bonding in diborane. The bridging B-H-B bonds are curved, giving it the name 'banana bonds'.						
		H H H O.119 nm					
		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]					
		12					
		Comments					
		 6, 8, 14 electrons were given in students' responses. 					
	(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]					

	Since <u>3 atoms share a pair of electrons</u> instead of 2 atoms, the bond length is expected to be <u>longer</u> .				
	 Comments Poorly done. Those who identified that the bond length is expected to be longer did not give an adequate explanation. 				
(d)	1-methylcyclohexene can react with iodine monochloride, ICl.				
	Name and describe the mechanism of this reaction, showing curly arrows, charges, dipoles and any relevant lone pairs. [3]				
	$\begin{array}{c} & & & \delta + & \delta - & slow \\ & & & & & & & & & & & & & & & & & & $				
	 Comments A minority of students did not use 1-methylcyclohexene as the starting structure even though it was already given in the question. A significant number of students did not draw the curly arrows correctly, or drew the wrong intermediate. Slow step was also not labelled and some did not give the name of the mechanism. 				
	[Total: 11]				

3	Cyanogen chloride, C/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.								
			sp						
			Comments						
			 A minority of students were penalised for notation (sp¹). 						
		(ii)	Name the <i>type of reaction</i> occurring in equation 1. [1]						
			Nucleophilic substitution / hydrolysis						
			Comments						
			Generally well done.						

	(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 for the reaction is $k = 4.2 \text{ mol}^{-1} \text{ dm}^{\circ} \text{ s}^{-1}$.			
			$rate = k[C[CN][OH^{-}]]$			
			Comments			
			Students should use the units of the rate constant to identify the overall order of the reaction			
		(ii)	Calculate the concentration of cyanogen chloride in the solution. [1]			
			$[ClCN] = \frac{0.06}{61.5} \div \frac{100}{1000} = 9.76 \times 10^{-3} \text{ mol dm}^{-3}$			
			Comments			
			Mostly well done.			
		(iii)	Using your answer in (b)(ii) and the information in (b)(i) , deduce the half-life of the			
			reaction. [1]			
			Since [C/CN] << [OH ⁻], this is a pseudo first-order reaction.			
			rate = $k'[ClCN]$, where $k = k[OH^-]$			
			$k = 4.2 \times 2 = 8.4 \text{ s}^{-1}$			
			$t_{\frac{1}{2}} = \frac{m_2}{8.4} = 0.0825 \text{ s}$			
			Comments			
			 Poorly done. Many students did not identify that [OH⁻] is in large excess compared to the calculated value of [C/CN] in (b)(ii), making this a pseudo first-order reaction. 			
(c) (i) li			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]			
			$M = \frac{mRT}{m}$			
			pV = pV			
			$=\frac{0.15 \times 8.31 \times (127 + 273)}{102700 \times 72.3 \times 10^{-6}}$			
			$= 67.1 \text{ g mol}^{-1}$			
			The relative M is 67.1			
			 Comments Relative molecular mass has no units. Only molar mass has units of g mol⁻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]			

	Cyanogen chloride does not behave ideally, due to <u>strong permanent dipole-</u> permanent dipole (pd-pd) interactions OR instantaneous dipole-induced dipole (id-id) interactions between cyanogen chloride molecules.					
	This leads to a <u>smaller p (or V or pV)</u> due to particles colliding with the walls of the container with reduced force, hence <u>larger value of calculated relative molecular</u> <u>mass</u> .					
	 Comments The assumption of volume of gas particles being significant as compared to the volume of gas was not a valid consideration because this would result in the pV value being larger than that of an idea gas (calculated <i>M</i>_r value would be smaller than expected) 					
(d)	Cyanogen chloride can react with sulfinic acids to form sulfonyl cyanides. An example of a sulfinic acid is shown in Fig.3.1.					
	С С С С С С С С С С С С С С С С С С С					
	Fig. 3.1					
	Chiral centres have four different substituent groups bonded to it. The lone pair of electrons on atoms can also be considered as a distinct group. Identify the chiral carbons of sulfinic acid shown on Fig. 3.1 by marking them with an asterisk (*).					
	Generally well done. Students should note that sulfur is also chiral.					
(e)	Cyanogen chloride can trimerise to form a 6-membered cyclic molecule with molecular formula, (C/CN) ₃ . This molecule has no overall dipole moment.					
	Suggest a possible structure of the trimer. [1]					
	C_{I} N C_{I} C_{I} C_{I} C_{I}					
	 Comments Students should pay attention to the number of bonds that carbon and nitrogen can form. Where possible, avoid having 4 bonds for N atom as this would create a positive charge. 					
	[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.							
				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)	Ехр	lain the high melting po	pints of gold a	nd pyrite.		[2]
			Golo	d has giant metallic s	structure. Fes	S ₂ has giant ig	onic lattice s	tructure. Large
			amo	ounts of energy are req	uired to overco	ome the strong	metallic bond	ls / electrostatic
			forc stro	<u>es of attraction</u> betwe	en gold ions	and its sea of	delocalised	electrons, and S_2^{2-} ions
			500	ng ionic bonds / electro		<u>or attraction</u> be	iweenie a	10.02 10115.
			Con	nments				
				 This was generally and Table and Table as h 	well done. A	small number	of responses	identified both
				g_{010} and FeS_2 as n Some students mis	iaving giant m	etailic structure	es and metalli baving to cor	c bonding. mare between
				the melting points of	of gold and Fe	S_2 .		
		(11)			,			
		(11)	Mor	is Hardness Scale is a stance's hardness is n	i measure of a	a substance's r inst another su	esistance to a	scratching. The
			on t	he Mohs Hardness Sca	ale. A substan	ce can only scr	atch a substa	ance of equal or
			lowe	er Mohs hardness valu	e. Istinguish hat	waan gold and	n vrita	[4]
			Suggest a simple way to distinguish between gold and pyrite. [1]					
			Scra the	atch the two samples a mineral that is not scra	gainst each o	ther. The mine	ral that is scra	atched is gold,
			OR a ma	Cut/Obtain the same v ass balance. The heav	volume of both vier sample is	⊨substances, w gold.	eigh the sub	stances using
			OR	take a sample of gold :	and pyrite and	l calculate their	densities	
			Un					
			<u>Con</u>	nments Somo rosponsos wor	o voquo in th	oir description	of how the	regults of their
			•	method would allow b	oth materials	to be distinguis	hed.	
			•	Some responses pro	posed using	another materia	al of Mohs H	lardness value
				between 2.5 and 6.3 should be used as far	. Students sh	ould keep in n	nind that spe	ecific examples
		(iii)	Pyri	te and steel have simil	ar values on t	he Mohs Hardr	ess Scale th	at are relatively
			high	er than that of metals	s. Explain this	s phenomenon	, making ref	erence to their
			The	lattice structure of ovri	ite is made up	of alternating F	e^{2+} and S_{2}^{2-}	[∠] ions of different
			<u>size</u>	s. OR Pyrite has stron	g ionic bonds	/ high lattice er	nergy.	
	Steel is an alloy composed of different metals, hence its lattice structure is made up of <u>different sized</u> metal atoms.							
	The distortion in both lattice structures require larger force for the layers to slide/shift over one another, hence both pyrite and steel are relatively hard.							

(b)	Due How expo	 Comments Most responses stopped after identifying the structure of pyrite and steel. Some responses identified steel as being ionic. This awards no marks. Students should take note to ensure the identified structure and bonding are correctly matched. There were responses which mentioned the giant ionic lattice structures had weaker id-id between its molecules. A handful of responses were able to identify that having high Mohs Hardness value meant difficulty for layers to slide over one another. to its shiny and gold-like appearance, pyrite is widely used in decorative items. ever, over time, items with pyrite were found to be cracked and discoloured. When sed to air and moisture, the iron-containing mineral can form rust, Fe₂O₃, along with 					
	a tox	Construct a balanced equation of the formation of rust from pyrite. [1]					
	(1)						
		$2\Gamma e S_2 + 0 O_2 + \Pi_2 O \rightarrow \Gamma e_2 O_3 + 3 O O_2 + \Pi_2 O O_4$					
		$2FeS_2 + 7O_2 + 3H_2O \rightarrow Fe_2O_3 + SO_2 + 3H_2SO_4$					
		$2FeS_2 + \frac{13}{2}O_2 + 2H_2O \rightarrow Fe_2O_3 + 2SO_2 + 2H_2SO_4$					
		$2\text{FeS}_2 + \frac{11}{2}\text{O}_2 + \text{H}_2\text{O} \rightarrow \text{Fe}_2\text{O}_3 + 3\text{SO}_2 + \text{H}_2\text{SO}_3$					
		Any equation for 1m					
		 Comments Despite having multiple possible answers, this question was poorly done. Incorrect responses left out either O₂ or H₂O as one of the required reactants for rusting to occur. 					
	(ii)	Draw the 'dot-and-cross' diagram of the disulfide ion, S_2^{2-} . [1]					
		$\begin{bmatrix} \mathbf{x} & \mathbf{x} & \mathbf{y} \\ \mathbf{x} & \mathbf{y} \\ \mathbf{x} & \mathbf{x} \\ \mathbf{x} $					
	 Comments In general the cohort performed below expectations for this question. Incorrect responses included forming double bonds or dative bond between the 2 S atoms, as well as when one S atom gains both electrons. Students should take note to show the distinction between the electrons of two adjacent atoms clearly. 						



	By Hess' Law,
	$-178 = 347 + 762 + 1560 + 2(279) + (-512) + LE(FeS_2)$ LE(FeS_2) = -2890 kJ mol ⁻¹ (3 s f)
	 Comments Some responses included the S-S bond energy in their calculation, showing a lack of understanding of the term enthalpy change of atomisation of S(s). Some students formed S₂²⁻ first, before removing electrons from Fe atom to form Fe²⁺. This is conceptually wrong. There were careless mistakes in the application of Hess' Law, or correct application but incorrect calculation carried out.
	[Total: 10]



9729/Mid-Year Learning Checkpoint/2024





6	The salinity of seawate	r is due to the ma	any dissolved molecules and i	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 s	eawater.				
			Table 6.1	1		
		species	concentration in parts per			
		opeoloo	million (ppm)			
		Cl⁻	19300			
		Na ⁺	10800			
		Ca ²⁺	420			
		HCO3 [−]	116			
		CO32-	9.54			
		Si(OH) ₄	9.32			
		CO ₂	0.660			
		SiO(OH)₃ [−]	0.285			
	The concentration of d	issolved species	s is measured in parts per mi	llion. This refers to the		

mass 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		<i>K</i> _a at 25 ℃	
		1	$CO_2(g) \rightleftharpoons CO_2(aq)$		-	
	2		$CO_2(aq) + H_2O(I) \rightleftharpoons H_2CO_3(aq)$		-	
	3		$H_2CO_3(aq) + H_2O(I) \rightleftharpoons HCO_3^-(aq)$	+ H₃O⁺(aq)	4.5×10^{-7}	
		4	$HCO_3^-(aq) + H_2O(I) \rightleftharpoons CO_3^{2-}(aq) + H_2O(I) \models CO_3^{2-}(aq) + H_2O(I) \models CO_3^{2-}(aq) \vdash CO_3^{2-}(aq) + CO_3^{2-}(aq) \vdash CO_3^$	- H₃O⁺(aq)	4.7×10^{-11}	
Proc	ess 3 ectivel	and 4 rep ly.	resent the first and second acid disso	ociation consta	ant of carbonic a	acid
(a)	(a) Some species in Table 6.1 form Brønsted-Lowry conjugate acid-base pairs w responsible for buffering the pH of seawater.			ase pairs which	are	
	(i)	Identify t	wo Brønsted-Lowry conjugate acid-ba	ase pairs in Ta	able 6.1.	
		conjugat	e acid-base pair 1:HCO₃⁻ ar	nd CO3 ²⁻		
		conjugat	e acid-base pair 2: Si(OH) ₄	and SiO(OH) ₃	Ē	[1]
 Students generally recognized the characteristics of a Brønsted-Lo conjugate acid-base pair. A significant portion of answers include H₂CO₃ / HCO₃⁻ as a response, e though H₂CO₃ was not found in Table 6.1. 				even		
	how the buffer system helps to maintain the pH of seawater. [1] $\begin{array}{c} HCO_{3}^{-} + OH^{-} \rightarrow CO_{3}^{2^{-}} + H_{2}O\\ CO_{3}^{2^{-}} + H^{+} \rightarrow HCO_{3}^{-}\\ OR\\ Si(OH)_{4} + OH^{-} \rightarrow SiO(OH)_{3}^{-} + H_{2}O\\ SiO(OH)_{3}^{-} + H^{+} \rightarrow Si(OH)_{4} \end{array}$					[1]
	 Comments Students should use a full arrow to illustrate the action of a buffer in overcoming small amounts of H⁺ or OH⁻ added. Balanced equations should be written. 					
(b)) The carbon–oxygen bond length in some compounds is given in Table 6.3.					
	Table 6.3					
S		species	s containing carbon–oxygen bond			
				0.7	143	
1			HUHU	0.2	123	
			11.00	~	10.4	
	(i)	Draw the	H ₂ CO ₃	0.2	134	[1]

		 Comments Some students thought that the species was ionic in nature. All bonds in the species must be shown in a displayed formula. The bond between oxygen and hydrogen atom was not shown in some answers.
	(11)	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]
		The <u>p orbital</u> of O atom can <u>overlap</u> with the π system of <u>C=O bond</u> . This allows for <u>delocalisation / resonance of electrons</u> across the C-O bond. OR There is partial <u>double bond character</u> in the C-O bond.
		 Comments Some answers which described the number of single and double bonds in each species or referred to the number of sigma and pi bonds, were not given credit. Other weak responses described the overlap of atomic orbitals to give sigma and pi bonds but did not link this to the bond length. Strong responses demonstrated clearly the structure (atomic orbitals) to property (bond length) relationship.
	Proce step step carbo	ess 2 is thought to proceed via the two steps described below. 1: Water behaves as nucleophile and attacks a carbon dioxide molecule. 2: An intramolecular proton transfer occurs within the intermediate to form pnic acid.
	(iii)	Draw a mechanism for process 2. Show relevant curly arrows, dipoles, charges and lone pairs of electrons in your answer. [2]
		$O = C = O^{\delta_{-}} \longrightarrow O^{\bullet} C^{\bullet} O^{\bullet} $ $H^{\bullet} O^{\bullet_{-}} H^{\bullet_{-}} H^{\bullet_{-$
		 Comments Students should make use of the displayed formula of H₂CO₃ to help them identify the bonds broken and formed in each step. Most students could identify that the carbon atom in CO₂ behaves as the electrophile (through the polarity of the C=O bond) but did not break the C=O bond when H₂O attacked. The curly arrows for step 2 as well as the structure of the intermediate proved to be challenging for many students

	(iv)	Hence, suggest and explain which step is likely to be the rate determining step in the mechanism of (b)(iii) . [1]	
		Step 1 because this step is endothermic.	
		OR Step 1 involves bond breaking of the stronger C=O π bond. / breaking a stronger bond	
		OR The second step involves a charged species, hence it reacts faster.	
		 Comments Weak responses merely restated the question, e.g. step 1 is the slow step, without any attempts to explain. Strong responses linked the rate of reaction to the energy required to break bonds (activation energy) or the frequency of collision between charged species (rate constant). 	
(c)	(i)	Write the K_a expression for process 3. [1]	
		$K_{a} = \frac{[HCO_{3}^{-}][H^{+}]}{[H_{2}CO_{3}]}$ Accept [H_{3}O^{+}] for [H^{+}]	
		 Comments This question is generally well done. 	
	(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]	
		There is 0.66 g of CO ₂ in 10 ⁶ g of water. $[CO_2] = [H_2CO_3] = \frac{0.66}{44} \times 10^{-3} = 1.50 \times 10^{-5} \text{ mol dm}^{-3}$ $[HCO_3^-] = \frac{116}{61} \times 10^{-3} = 1.90 \times 10^{-3} \text{ mol dm}^{-3}$ $\mathcal{K}_a = \frac{[1.90 \times 10^{-3}][1 \times 10^{-8}]}{[1.50 \times 10^{-5}]} = 1.267 \times 10^{-6}$ $= 1.27 \times 10^{-6} \text{ mol dm}^{-3}$	
		 <u>Comments</u> Many students struggled to convert concentration from ppm to mol dm⁻³. Some responses assumed [HCO₃⁻] to be equal to [H⁺]. Strong responses recognised that [H₂CO₃], [HCO₃⁻] and [H⁺] are different. 	
	(iii)	Suggest a reason why the K_a value calculated in (c)(ii) differs from that in Table 6.2.	
		The <u>temperature at which the pH of seawater</u> was measured was <u>not at 25 °C</u> (non-standard conditions). OR Density of seawater is not 1 g cm ⁻³	
		 <u>Comments</u> Weak responses discussed shifts in POE which do not affect the value of <i>K</i>_a. 	

		• Strong responses referenced ideas discussed in 6(a)(i) and 6(a)(ii).					
Cora from This and carb calci With	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.						
find	it incre	eawater are decreasing.	Id their calcium carbona	te skeletons.			
(d)	State atmo	e one human activity that sphere.	at is increasing the emi	ssion of carbon dioxide	into the [1]		
	Burn	ing of petroleum / fossil	fuels / natural gas (CH ₄)				
(e)	Com • / The	ments Answers should draw re fuels. K _{sp} values and relative s	eference to the activitie solubilities of CaCO ₃ , Ca	s which involve carbon $a(OH)_2$ and $Ca(HCO_3)_2$ a	– based are given		
	belov	N.	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 preci (i)	n carbon dioxide is bubb pitate is observed. Write the <i>K</i> _{sp} expressio	led into a saturated solu	tion of calcium hydroxide and state its units.	e, a white [1]		
		$K_{sp} = [Ca^{2+}][OH^{-}]^{2}$, unit	s: mol ³ dm ⁻⁹				
	Comments This question was generally well done. There were occasional slips in determining the units of <i>K</i> _{sp} .						
	(ii) Calculate the concentration, in mol dm ⁻³ , of Ca ²⁺ (aq) in a saturated solution of calcium hydroxide. [1]						
		Let x be the solubility of Ca(OH) ₂ . x $(2x)^2 = 5.02 \times 10^{-6}$ [Ca ²⁺] = 1.0787 × 10 ⁻² = <u>1.08 × 10⁻²</u> mol dm ⁻³					
		Comments There were some	errors in determining the	e solubility of Ca(OH) ₂ .			
	(iii)	Calculate the concent carbonate begins to pro	ration of CO ₃ ²⁻ (aq) pro	esent in solution when	calcium [1]		

		$[CO_{2}^{2}] = \frac{6 \times 10^{-9}}{10^{-9}}$
		1.08×10^{-2}
		$= 5.556 \times 10^{-7}$
		$= 5.56 \times 10^{-7} \text{ mol dm}^{-3}$
		Comments
		 Many responses assumed [CO₃²⁻] = [Ca²⁺] but they did not realise this was
		in a saturated calcium hydroxide solution.
	(iv)	The following reaction occurs when carbon dioxide is continuously bubbled
		through a saturated solution of calcium hydroxide.
		$H_2CO_3 + CO_3^{2-} \rightleftharpoons 2HCO_3^{-}$ K_c
		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]
		$K_{\rm c} = \frac{4.5 \times 10^{-7}}{4.7 \times 10^{-11}} = 9.57 \times 10^3$
		4.7 × 10 ^a Position of equilibrium lies to the right
		Comments
		• Strong responses quickly recognised how to manipulate the identified
		equations in Table 6.2 correctly while weak responses struggled with the
		manipulation.
	(v)	Using the equation provided in (e)(iv) and information from Table 6.4, predict
	(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
	(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]
	(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] $CaCO_{3}(s) \rightleftharpoons Ca^{2+}(aq) + CO_{3}^{2-}(aq) (1)$
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	(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]				
		With increasing CO_2 emissions, [HCO ₃ ⁻] is increased / [CO ₃ ²⁻] is decreased. Corals will have to pump out more H ⁺ for [CO ₃ ²⁻] to be increased to the saturation point for precipitation of CaCO ₃ to occur.				
	 Comments Students are required to draw concepts related to ionic product and precipitation. Strong answers were contextualised, referenced points mentioned in 6(e)(v) or discussed the idea of 'pumping protons out of the calcifying space to increase [CO₃²⁻]' from the text. 					
(f)	Arag preci	onite and calcite are two differ ipitated by corals.	ent solid forms of c	alcium carbonate that	can be	
	Som	ne information about these two for	orms of calcium carl Table 6.5	oonate is provided belo	ow.	
		form of calcium carbonate	$\Delta H_{\rm f}^{\rm e}$ / kJ mol ⁻¹	$\Delta S_{\rm f}^{ m e}$ / J mol ⁻¹ K ⁻¹		
		aragonite	-1207.8	+88.0		
		calcite	-1207.6	+91.7		
	(i)	The entropy change, ΔS_{rxn}^{e} , of formula:	a reaction, can be o	determined using the fo	ollowing	
		$\Delta S_{rxn}^{e} = \sum m\Delta$	S _f ⁰(products) − ∑n∆	S _f e(reactants)		
		where m and n are the coeffici equation.	ents of the products	and reactants in the b	alanced	
		Use information from Table 6.5 to show that the conversion of aragonite to calcite is a spontaneous process under standard conditions.				
		CaCO ₃ (a	aragonite) \rightarrow CaCO	3 (calcite)	[2]	
		$\Delta H_{rxn}^{\bullet} = -1207.6 + 1207.8$ = +0.2 kJ mol ⁻¹ $\Delta S_{rxn}^{\bullet} = 91.7 - 88.0$ = +3.70 J mol ⁻¹ K ⁻¹ $\Delta G_{rxn}^{\bullet} = \Delta H_{rxn}^{\bullet} - T\Delta S_{rxn}^{\bullet}$ = 200 - 298(+3.7) = -903 J mol ⁻¹ OR -0.903 kJ mol ⁻¹				
		 Comments Various errors were made in the calculation of Δ<i>H</i>, ΔS and Δ<i>G</i>. A common one was the lack of conversion from J to kJ in the calculation of Δ<i>G</i>. Some students could not remember the temperature for standard conditions 				
		[Total: 22]				