



HWA CHONG INSTITUTION
C2 Preliminary Examination
Higher 2

CANDIDATE
NAME

CT
GROUP

2	3	S		
---	---	---	--	--

CENTRE
NUMBER

S				
---	--	--	--	--

INDEX
NUMBER

--	--	--	--	--

CHEMISTRY

9729/02

Paper 2 Structured Questions

28 August 2024

2 hours

Candidates answer on the Question Paper.

Additional Materials: Data Booklet

READ THESE INSTRUCTIONS FIRST

Write your **name**, **CT group**, **centre number** and **index number** on all the work 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.

DO NOT WRITE ON ANY BARCODES.

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

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

A Data Booklet is provided.

No. of sheets of writing paper submitted (if any)	
For Examiner's Use	
1	/ 6
2	/ 13
3	/ 18
4	/ 15
5	/ 23
Deductions (s.f.)	
Deductions (units)	
Deductions (structures)	
Total	/ 75

Answer all questions in the space provided.

- 1 (a) Complete the energy level diagram in Fig. 1.1, showing the relative energy levels of orbitals in the 3rd principal quantum shell.

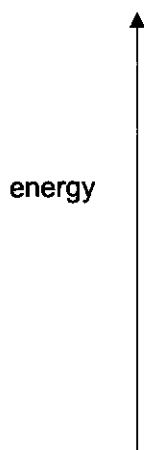


Fig. 1.1

[2]

- (b) (i) Explain what is meant by the term *first ionisation energy*.

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

- (ii) Use your knowledge of the variation in first ionisation energy of the Period 3 elements (Na to Ar) to predict and explain how the first ionisation energy varies in each pair of elements.

- arsenic and selenium

.....
.....
.....
.....

- bromine and krypton

.....
.....
.....
.....

[3]

[Total: 6]

- 2 Polyfluoroalkyl substances (PFAS) is a group of compounds that have multiple fluorine atoms attached to an alkyl chain, giving these compounds waterproof properties, leading to widespread use in textiles, cosmetics, and food packaging.

Poly(tetrafluoroethene), PTFE, is an early and popular example of PFAS made by polymerising tetrafluoroethene, $F_2C=CF_2$.

- (a) (i) State the shape and bond angle around the carbon atom in $F_2C=CF_2$.

.....
 [2]

- (ii) Carbon atoms in $F_2C=CF_2$ are sp^2 hybridised.

Explain what is meant by sp^2 hybridisation with reference to the carbon atom in $F_2C=CF_2$.

.....

 [1]

- (iii) The shape of the carbon atom in $F_2C=CF_2$ depends on the arrangement of the hybridised orbitals.

Apply the principles of the VSEPR theory to explain how the hybridised orbitals are arranged in the second shell of the sp^2 carbon atom.

.....
 [1]

- (b) Explain why $F_2C=CF_2$ is a gas at room temperature whereas PTFE is a solid.

.....

 [2]

- (c) In recent years, scientific evidence indicates that PFAS pose health and environmental concerns. Due to its persistence in the environment, it has been dubbed "forever chemicals".

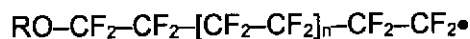
Suggest why PFAS would last in the environment "forever".

.....

 [1]

(d) The mechanism of polymerisation of PTFE consists of four separate stages **A** to **D**.

- A** homolytic fission of an organic peroxide, RO–OR, produces two RO• radicals
B RO• reacts with one F₂C=CF₂ molecule to produce a new radical
C repeated steps involving production of a series of new radicals to produce



- D** two radicals combine to form RO–CF₂–CF₂–[CF₂–CF₂]_(2n+2)–CF₂–CF₂–OR

- (i) This polymerisation can also be carried out using a non-symmetrical molecule such as CH₂=CHCl to give poly(chloroethene).

Write equations to show the formation of RO–CHCl–CH₂• and RO–CHCl–CH₂–CHCl–CH₂• in stages **B** and **C** of the polymerisation of CH₂=CHCl.

.....
 [2]

- (ii) Fig. 2.1 shows a section of poly(chloroethene), where R₁ and R₂ represent chlorinated alkyl chains.

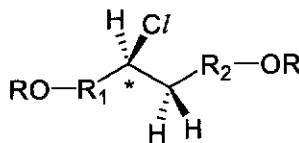


Fig. 2.1

Explain why the carbon atom labelled with * is chiral.

.....

 [1]

(iii) Fig. 2.2 shows four repeating units within poly(chloroethene).

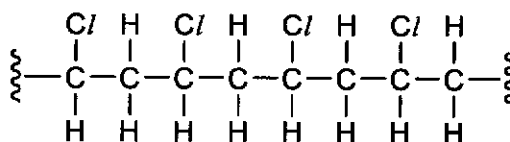


Fig. 2.2

The free radical polymerisation of poly(chloroethene) results in different stereochemical arrangements along the carbon chain.

The different arrangements can be classified into **three** types.

Types 1 and 2 result in polymers that have regular, crystal lattice structures with higher melting points.

Type 3 results in polymers that have poor packing and are unable to crystallise.

By considering Fig. 2.2 and your answers to (d)(i) and (d)(ii), complete Fig. 2.3 by showing the positions of hydrogen and chlorine atoms for the three types of arrangements.

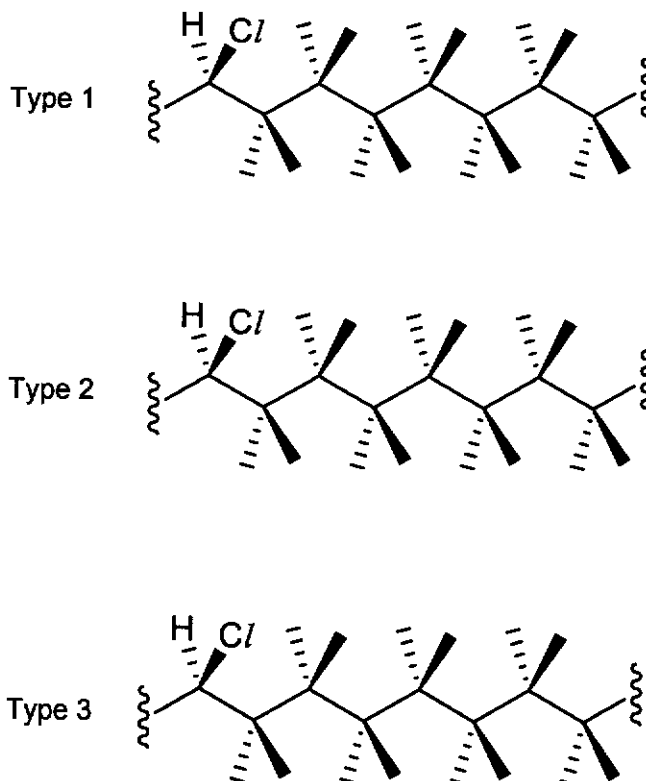


Fig. 2.3

[3]

[Total: 13]

- 3 (a) Explain, with the aid of a labelled Boltzmann distribution diagram, the effect on the rate of reaction by increasing temperature.

.....
.....
.....
.....
.....
.....
.....
.....[3]

- (b) Two different mechanisms for the nucleophilic substitution of halogenoalkanes are called S_N1 and S_N2 . 2-bromopropane, a secondary bromoalkane, can undergo both S_N1 and S_N2 .
- (i) Draw a mechanism for the reaction between 2-bromopropane and OH^- via S_N2 . Show relevant lone pairs and dipoles, and use curly arrows to indicate the movement of electron pairs.

[2]

- (ii) Using collision theory, explain how the rate of reaction varies as the concentration of 2-bromopropane increases.

.....
.....
.....
.....
.....
.....
..... [2]

- (iii) An investigation of the kinetics of the nucleophilic substitution of 2-bromopropane with OH⁻ in a certain solvent is carried out. The overall rate equation of this nucleophilic substitution is found to be:

$$\text{rate} = y [\text{2-bromopropane}] + z [\text{2-bromopropane}][\text{OH}^-]$$

where y and z are rate constants.

Circle the part(s) of the rate equation which corresponds to S_N2. Explain your answer with reference to the mechanism you have drawn in (b)(i).

.....
.....
.....
.....
.....
..... [2]

(iv) The results of two such experiments in (b)(iii) are recorded in Table 3.1.

Table 3.1

expt	[2-bromopropane] / mol dm ⁻³	[OH ⁻] / mol dm ⁻³	initial rate / mol dm ⁻³ s ⁻¹
1	0.10	0.10	7.1×10^{-7}
2	0.10	0.20	1.2×10^{-6}

Use the results to calculate the values of y and z for the rate equation shown in (b)(iii), stating their units.

$y = \dots\dots\dots$

units of $y = \dots\dots\dots$

$z = \dots\dots\dots$

units of $z = \dots\dots\dots$

[4]

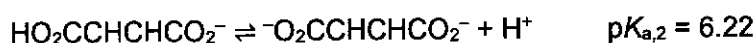
4 Dicarboxylic acids are organic compounds that contain two carboxylic acid ($-\text{CO}_2\text{H}$) functional groups. Industrially, they are important precursors in chemical synthesis of useful compounds.

(a) Maleic acid, $\text{HO}_2\text{CCHCHCO}_2\text{H}$, exhibits stereoisomerism. State the type of stereoisomerism present and explain how it arises.

.....

[2]

(b) Maleic acid ionises in two stages.



Maleic acid can be used to make a buffer that is used to determine the amount of trace metals in seawater. The pH of the buffer solution was adjusted to 6.50 with sodium hydroxide.

(i) Explain why the predominant forms of maleic acid present in the above buffer are $\text{HO}_2\text{CCHCHCO}_2^-$ and $^-\text{O}_2\text{CCHCHCO}_2^-$.

.....
[1]

(ii) Calculate the ratio of the concentrations of $^-\text{O}_2\text{CCHCHCO}_2^-$ and $\text{HO}_2\text{CCHCHCO}_2^-$ present in the above buffer solution.

[1]

(iii) Write equations to show how the above buffer helps to maintain pH when a small amount of acid or base is added.

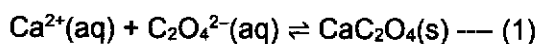
.....
[2]

- (iv) Deduce whether the above buffer is more effective in buffering against added acids or bases. Give your reasoning.

.....

[1]

- (c) Calcium ethanedioate, CaC_2O_4 , is found in kidney stones. At sufficiently high concentrations, ethanedioate ions react with the calcium ions in the kidney to form solids via equilibrium 1 below.



- (i) The solubility of calcium ethanedioate is $6.70 \times 10^{-3} \text{ g dm}^{-3}$ at 25°C . Calculate the value of its solubility product.

[2]

- (ii) The concentration of $\text{Ca}^{2+}(\text{aq})$ in a sample of body fluids is $2.20 \times 10^{-3} \text{ mol dm}^{-3}$. Calculate the concentration of $\text{C}_2\text{O}_4^{2-}(\text{aq})$ just before calcium ethanedioate begins to precipitate.

[1]

- (iii) By referring to equilibrium 1, suggest one way a person may try to reduce the formation of kidney stones. Explain your reasoning.

.....

 [1]

(d) Malonic acid, $\text{HO}_2\text{CCH}_2\text{CO}_2\text{H}$, is used as a precursor for the reaction scheme in Fig. 4.1.

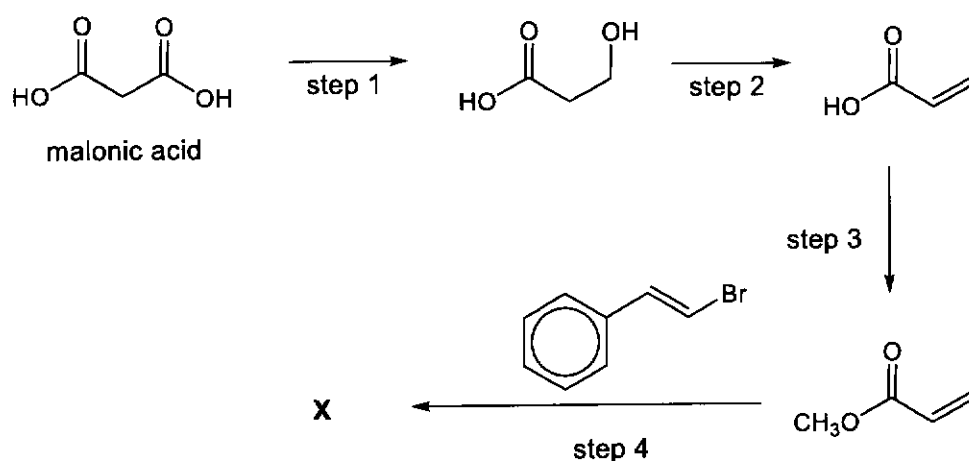


Fig. 4.1

(i) Give the reagents and conditions for steps 1 to 3.

step 1:

step 2:

step 3:

[3]

(ii) The Heck reaction is the palladium-catalysed C–C bond formation between halogen compounds and alkenes. This reaction produces a *trans* alkene as the major product.

An example of the Heck reaction is shown in Fig. 4.2.

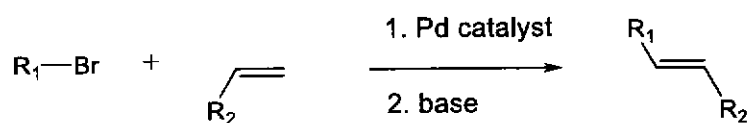


Fig. 4.2

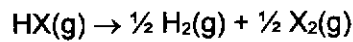
In step 4 of Fig. 4.1, palladium catalyst and base were also added. Suggest the structure of **X**.

X:

[1]

[Total: 15]

- 5 (a) (i) The equation for the thermal decomposition of hydrogen halides is shown below.



Describe the thermal decomposition of HCl, HBr and HI, giving observations where relevant, and explain any variation in their thermal stabilities.

.....

[3]

- (ii) Using data from the *Data Booklet*, calculate the standard enthalpy change for the decomposition of 1 mole of HCl(g).

[2]

- (b) Dilute hydrochloric acid is frequently used in the chemistry laboratory. It is prepared via dilution of known volumes of concentrated HCl with suitable volumes of water, which allows for dilute solutions of different concentrations to be produced.

- (i) "37% w/w HCl" is a concentrated HCl reagent from manufacturers. This label indicates that 100 g of the reagent contains 37 g of HCl.

Calculate the concentration, in mol dm⁻³, of HCl in this reagent, given that its density is 1.2 g cm⁻³.

[2]

- (ii) Hence, calculate the volume, $v \text{ cm}^3$, of 37% w/w HCl which must be diluted with sufficient water to make 250 cm^3 of $0.100 \text{ mol dm}^{-3}$ hydrochloric acid.
If you were unable to obtain an answer in (b)(i), use the value of 11.9 mol dm^{-3} .

[1]

- (iii) Define the term *standard enthalpy change of formation* of a substance.

.....
[1]

- (iv) Using your answer in (a)(ii) and the information given in Table 5.1, calculate the standard enthalpy change for the following dilution, with the aid of an energy cycle.

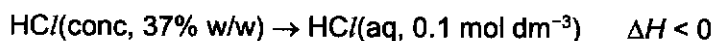


Table 5.1

standard enthalpy change of formation of $\text{HCl}(\text{aq, } 0.1 \text{ mol dm}^{-3})$	$-167.2 \text{ kJ mol}^{-1}$
standard enthalpy change for the reaction $\text{HCl}(\text{g}) \rightarrow \text{HCl}(\text{conc, 37\% w/w})$	$-62.6 \text{ kJ mol}^{-1}$

[3]

- (v) Two outlines for preparing 250 cm³ of 0.100 mol dm⁻³ hydrochloric acid are presented below.

Outline A

1. Transfer v cm³ of 37% w/w HCl into a 250 cm³ volumetric flask. (volume v was calculated in (b)(ii))
2. Slowly add deionised water into the volumetric flask and top up to the mark.

Outline B

1. Transfer 150 cm³ of deionised water into a 250 cm³ volumetric flask.
2. Slowly add v cm³ of 37% w/w HCl into the volumetric flask.
3. Top up to the mark with deionised water.

Using the information provided about the dilution in (b)(iv), explain whether outline A or B is preferred.

.....
[1]

- (c) The following experiment, based on an approach known as coulometric titration, aims to determine a value for Faraday's constant and Avogadro's constant. Fig. 5.1 shows the electrolytic setup for the experiment. The electrolyte contains a known amount of dilute hydrochloric acid, which will be neutralised as the electrolysis proceeds.

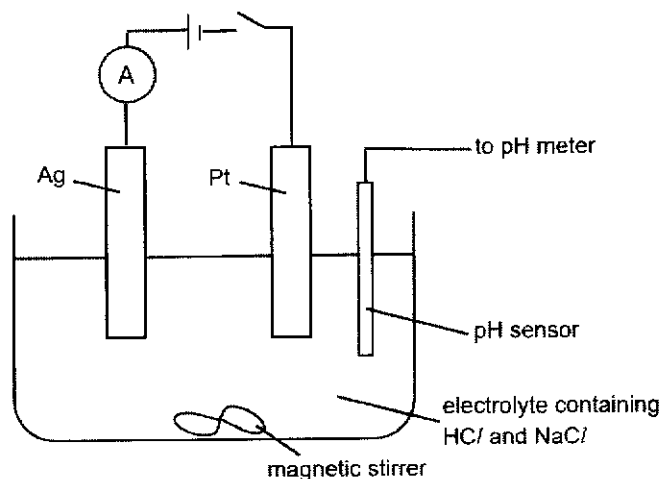
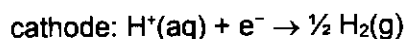
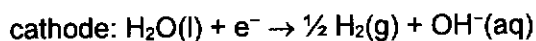


Fig. 5.1

When the switch is closed, the following reaction occurs at the inert Pt cathode before the known amount of dilute hydrochloric acid is completely used up, i.e. before the equivalence point is reached.

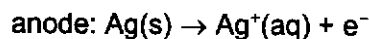


Once the equivalence point is reached, the following reaction occurs at the cathode.



Overall, for every electron passed during the electrolysis, one H⁺(aq) ion is consumed from the electrolyte (before the equivalence point) or one OH⁻(aq) ion is produced (after the equivalence point). The electrolyte pH thus increases in a similar way to a conventional titration.

At the Ag anode, the following reaction occurs.



The procedure for the experiment is as follows:

1. Transfer 2.50 cm^3 of $0.100 \text{ mol dm}^{-3} \text{ HCl(aq)}$ into a 250 cm^3 beaker.
2. Add 97.5 cm^3 of $0.2 \text{ mol dm}^{-3} \text{ NaCl(aq)}$ into the beaker. (NaCl(aq) is added, instead of deionised water, to maintain sufficient electrical conductivity of the electrolyte.)
3. Construct the electrolytic setup in Fig. 5.1.
4. Close the switch and start a stopwatch at the same time. Record the pH of the electrolyte indicated by the pH meter and the current indicated by the ammeter at regular time intervals.
5. Open the switch at time $t = 240 \text{ s}$, which is beyond the equivalence point of the titration.

Student X carried out the experiment at a constant current of 0.24 A . Fig. 5.2 shows the variation of electrolyte pH with time obtained by student X.

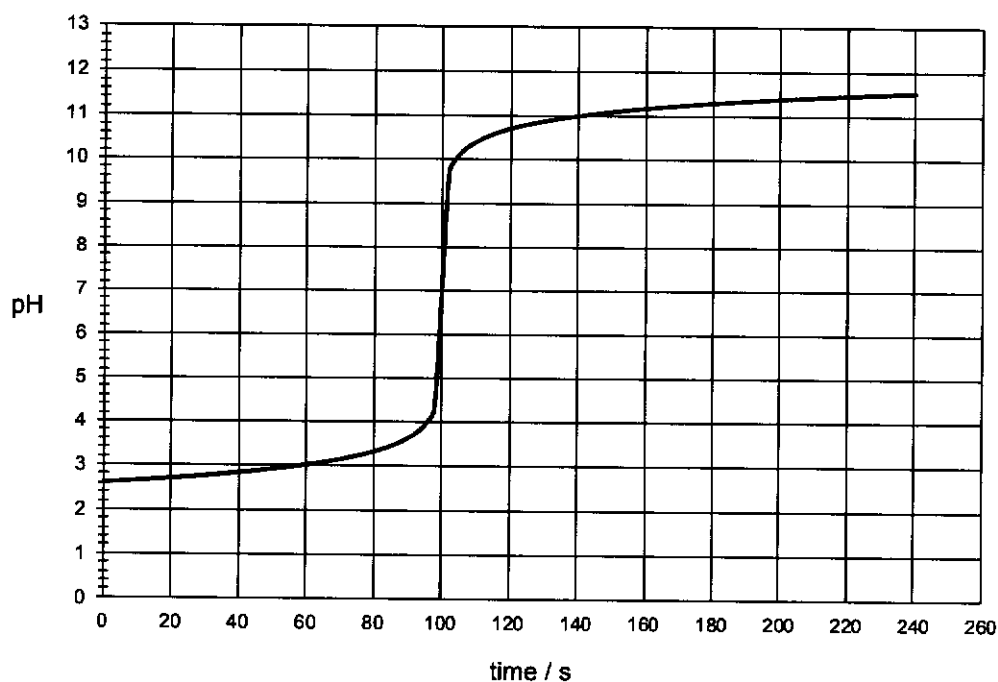


Fig. 5.2

- (i) From Fig. 5.2, state the time taken to reach equivalence point, t_{eq} .

.....[1]

- (ii) Calculate the total quantity of charge that passed through the circuit up to time t_{eq} .

[1]

- (iii) Calculate the initial amount, in moles, of HCl in the electrolyte. Hence, calculate a value for Faraday's constant.

[2]

- (iv) Use your answer in (c)(iii) to find a value for Avogadro's constant, given that the electronic charge is $1.60 \times 10^{-19} \text{ C}$.

[1]

- (v) NaCl(aq) was added in step 2 to maintain electrical conductivity. Another reason was to prevent silver ions produced at the anode from reaching the cathode, by precipitating them as silver chloride.

With reference to relevant E^\ominus values, explain why it is important that silver ions are prevented from reaching the cathode.

.....

[2]

- (vi) Student Y also carried out the experiment, but he did not use a pH meter. Instead, he added a few drops of an acid-base indicator (working range = 10.2 to 12.0) into the electrolyte, and recorded the time t_{eq} when the indicator changed colour.

By referring to Fig. 5.2, suggest whether the value of t_{eq} obtained by student Y will be smaller or larger than expected (if different from expected). Give your reasoning.

.....
[1]

- (vii) Student Z also carried out student X's experiment over 240 s, but controlled the applied current such that it decreased linearly during this time period. Fig. 5.3 shows the variation of current with time in the experiments conducted by both students on the same axes.

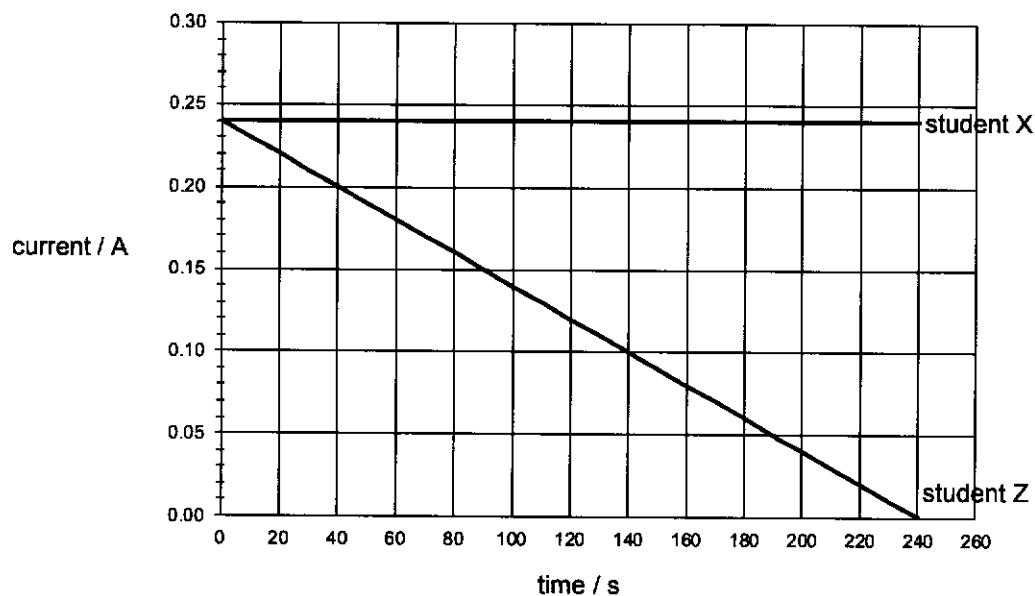


Fig. 5.3

Use Fig. 5.3 to suggest the value of the ratio of total charge passed in student Z's experiment to the total charge passed in student X's experiment. Hence, use Fig. 5.2 to suggest the final pH obtained in **student Z's** experiment.

ratio:

final pH:

[2]

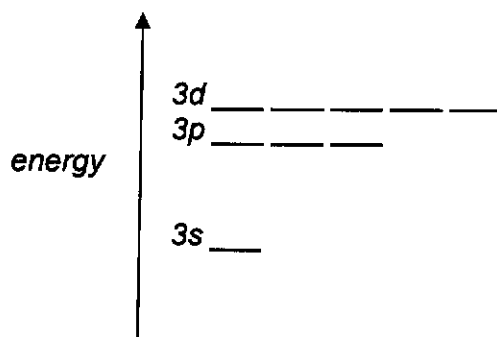
[Total: 23]



HWA CHONG INSTITUTION
2024 C2 H2 CHEMISTRY PRELIMINARY EXAMINATION
SUGGESTED SOLUTIONS

Paper 2

1 (a)



[1] Correct number of orbitals for each subshell with labels

[1] Correct relative energy gap (bigger gap between 3s and 3p than 3p and 3d)

(b) (i) First ionisation energy is the **energy required to remove one mole of electrons from one mole of free gaseous atoms to form 1 mole of unipositively charged gaseous ions.**

(b) (ii) 1st IE of Se is lower than As [1/2]
Selenium has a lower 1st IE than arsenic because **selenium contains a paired electron in one of its p orbitals**, thus it **experiences inter-electron repulsion**. So, less energy is required to remove the outermost electron in selenium compared to arsenic.

[1] Explains that inter-electron repulsion in p-orbital leads to lower 1st IE in Se compared to As.

1st IE of Kr is higher than Br [1/2]

Krypton has a higher 1st IE than bromine because krypton has a greater effective nuclear charge than bromine. This is inferred from the fact the krypton **has a larger proton number / greater nuclear charge**, and **electrons are added to the same quantum shell / leading to a relatively constant shielding effect**. Therefore, the attraction between the nucleus and the outermost electron is stronger, and more energy is required to remove the outermost electron in krypton than bromine.

[1] Uses effective nuclear charge to explain the stronger attraction between the outermost electron in Kr and the nucleus compared to that in Br, leading to higher 1st IE.

2 (a) (i) Trigonal planar [1], 120° [1]

2 (a) (ii) **One 2s orbital is mixed with two 2p orbitals to give 3 hybridised sp^2 orbitals.**

[1/2] correct type of atomic orbitals (2s and 2p)

[1/2] correct number of atomic orbitals (1 and 2 respectively)

(a) (iii) **The three sp^2 hybridised orbitals are degenerate and will be equally spaced apart in a trigonal planar arrangement to minimise repulsion.**

[1/2] Indication of number of hybrid orbitals (state 'three' or 'trigonal planar')

[1/2] Applying VSEPR Theory in the context of hybrid orbitals (i.e. hybrid orbitals will be equally spaced apart / minimise repulsion).

(b) PTFE has a **greater number of electrons / larger electron cloud** than $F_2C=CF_2$ [1], thus it is more polarisable and has stronger dispersion forces than $F_2C=CF_2$. **More energy is required to overcome the stronger dispersion forces in PTFE [1]**, and so it has a higher boiling point, and is a solid at room temperature while $F_2C=CF_2$ is a gas.

(c) The C–C and C–F bonds in PFAS are **very strong [1]** and do not break/hydrolyse in typical environmental conditions.

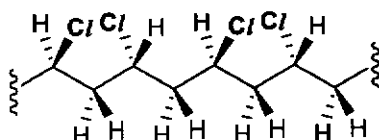
(d) (i) $RO\cdot + CHCl=CH_2 \rightarrow RO-CHCl-CH_2\cdot$ [1]

$RO-CHCl-CH_2\cdot + CHCl=CH_2 \rightarrow RO-CHCl-CH_2-CHCl-CH_2\cdot$ [1]

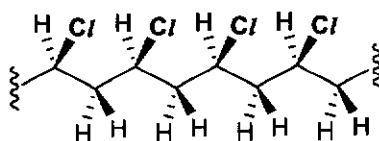
(d) (ii) The carbon atom is chiral because it has a **tetrahedral geometry [1/2]** and **is bonded to four different groups [1/2]**.

(d) (iii)

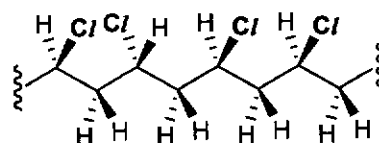
Type 1



Type 2



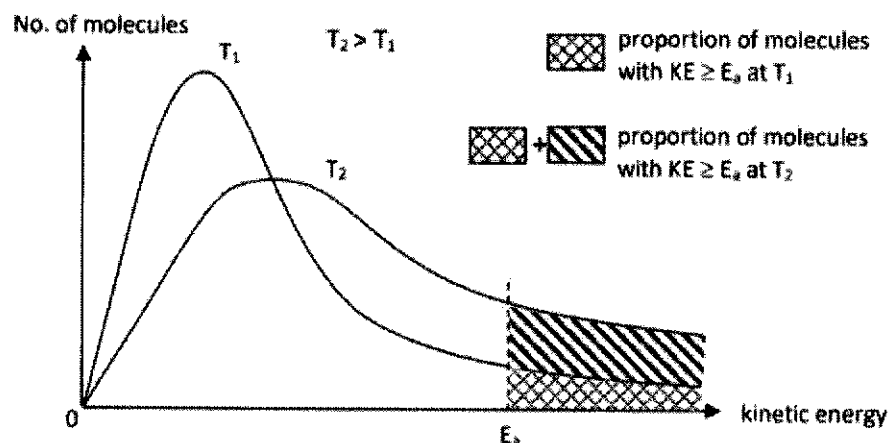
Type 3



[1] Type 1 ; [1] Type 2

[1] Type 3 (any variation showing more random arrangement in the stereochemical arrangements)

3 (a)



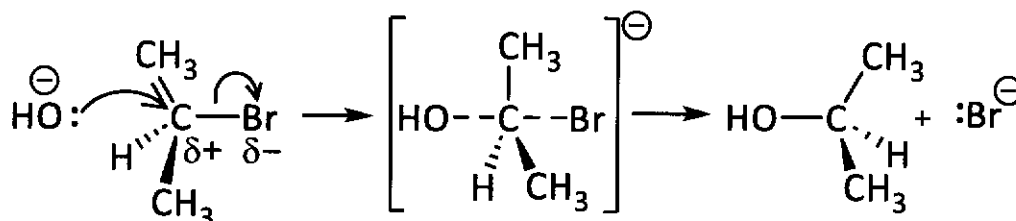
[1] diagram, taking note of:

- axes
- labels
- shape of graph (starts from intersection of axes),
- shaded areas (legend can be embedded in response)

[-0.5] for each error

At higher temperatures, there is a **higher proportion of molecules that have kinetic energies greater than or equal to E_a** [1] Hence, **frequency of effective collisions is higher** [0.5], **increasing rate of reaction** [0.5].

(b) (i)



[2] Drawing of mechanism, inclusive of the following:

- Partial charges on C-Br atoms
- NO indication of slow or fast steps
- Balanced equations for the step of the mechanism (including balance of charge)
- Correct structure of transition state
- Lone pair on O atom of OH^-
- Correct drawing and placement of curly arrows

(b) (ii) When the concentration of 2-bromopropane increases, the number of **2-bromopropane molecules per unit volume increases** / **the 2-bromopropane molecules are closer** [1]. This **increases the frequency of effective collisions** which in turn **increases the rate of reaction** [1].
[-0.5 for not mentioning effective collisions]

- 3 (b) (iii) Circle z [2-bromopropane][OH⁻]. [1]
In the mechanism, **both** reagents / the 2-bromopropane and OH⁻ are involved in the **rate-determining/only/slow step**. [1]

- (b) (iv) rate = y [2-bromopropane] + z [2-bromopropane][OH⁻]

From experiment 1,

$$7.1 \times 10^{-7} = y(0.1) + z(0.1)(0.1)$$

From experiment 2,

$$1.2 \times 10^{-6} = y(0.1) + z(0.2)(0.1)$$

Both equations – [1]

$$y = 2.20 \times 10^{-6}$$

units of y = s⁻¹

$$z = 4.90 \times 10^{-5}$$

units of z = mol⁻¹ dm³ s⁻¹

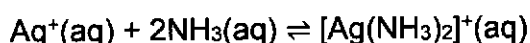
Each unit – [1]

Each value – [0.5]

- (c) (i)

compound	observations	solubility of residue (if any)	
		in dilute aqueous ammonia	in concentrated aqueous ammonia
2-bromopropane	cream ppt	insoluble	soluble/partially soluble [0.5]
2-chloropropane	white ppt [0.5]	soluble	soluble [0.5]
iodobenzene	no ppt [0.5]	-	-

- (c) (ii) When NH₃ is added, the Ag⁺ forms the **[Ag(NH₃)₂]⁺** complex. [1]



The formation of the [Ag(NH₃)₂]⁺ complex **decreases [Ag⁺]** [1],

The ionic product of [Ag⁺][Cl⁻] decreases to below K_{sp}. Hence, AgCl dissolves. [0.5]

OR Hence position of equilibrium of AgCl(s) ⇌ Ag⁺(aq) + Cl⁻(aq) shifts rightwards to increase [Ag⁺], allowing AgCl(s) to dissolve.

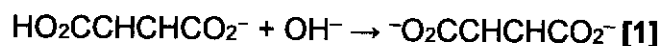
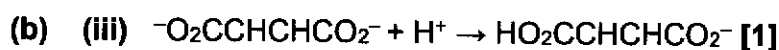
However, as K_{sp} of AgBr is relatively lower, the addition of dilute NH₃(aq) is insufficient to lower [Ag⁺] till the [Ag⁺][Br⁻] decreases to below that of the K_{sp} of AgBr. Hence, AgBr does not dissolve. [0.5]

- 4 (a) **Cis-trans isomerism** [1]

It occurs due to restricted bond rotation caused by the presence of the C=C bond [0.5] **and different groups present on each carbon of the C=C.** [0.5]

4 (b) (i) The pH of the buffer is at 6.5 which is higher than $pK_{a,1}$. Hence the first proton would have completely dissociated at this point. [1]

(b) (ii)
$$K_{a,2} = \frac{[-O_2CCHCHCO_2^-][H^+]}{[HO_2CCHCHCO_2^-]}$$
$$10^{-6.22} = (10^{-6.5}) \frac{[-O_2CCHCHCO_2^-]}{[HO_2CCHCHCO_2^-]}$$
$$\frac{[-O_2CCHCHCO_2^-]}{[HO_2CCHCHCO_2^-]} = 1.90546 \approx 1.91 \text{ (3 s.f.)}$$



(b) (iv) The ratio calculated in (b)(iii) suggests higher concentration of the conjugate base ($-O_2CCHCHCO_2^-$), hence the buffer removes acids more effectively. [1]

(c) (i) $s = \frac{6.70 \times 10^{-3}}{128.1} = 5.230 \times 10^{-5}$ [1]

$K_{sp} = [Ca^{2+}][C_2O_4^{2-}] = s^2 = 2.735 \times 10^{-9} \approx 2.74 \times 10^{-9} \text{ mol}^2 \text{ dm}^{-6}$ [1]

(c) (ii) $K_{sp} = [Ca^{2+}][C_2O_4^{2-}] = [C_2O_4^{2-}](2.20 \times 10^{-3}) = 2.735 \times 10^{-9}$

$[C_2O_4^{2-}] = 2.735 \times 10^{-9} \div (2.20 \times 10^{-3}) = 1.24 \times 10^{-6} \text{ mol dm}^{-3}$ [1]

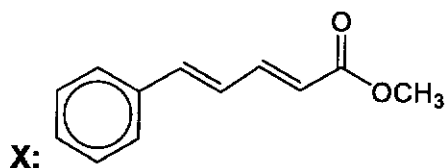
- (c) (iii)
- Drink more water to reduce the concentration of Ca^{2+} and ethanedioate ions in your body. Position of equilibrium 1 will shift to the left and less solid is formed.
 - Reduce intake of foods high in ethanedioate ions (chocolate, spinach etc.) or Ca^{2+} ions (e.g. milk, dairy product). Position of equilibrium 1 will shift to the left and less solid is formed.
 - Increase the intake of acidic foods will lower the concentration of ethanedioate ions due to the formation of $H_2C_2O_4$. Position of equilibrium 1 will shift left and less solid is formed.

(d) (i) step 1: **one mole equivalent or limited** LiAlH₄ (in dry ether) [1]

step 2: **excess** concentrated H₂SO₄, heat [1]

step 3: CH₃OH, (a few drops of) conc H₂SO₄, heat [1]

(d) (ii)



5 (a) (i) HCl does not decompose even on strong heating. [0.5]

Strong heating of HBr yields brown fumes of Br₂. [0.5]

Violet fumes of I₂ are obtained when a red-hot rod is plunged into a jar of HI. [0.5]

The thermal stability decreases from HCl to HBr to HI. [0.5]
 As down Group 17, the H–X bond length increases and bond strength decreases [0.5] so less energy is needed to break the H–X bond. [0.5]

- 5 (a) (ii) Bond broken: $1 \times \text{H–Cl}$: 431 kJ mol^{-1}
 Bond formed: $\frac{1}{2} \times \text{H–H}$: $\frac{1}{2} \times 436 = 218 \text{ kJ mol}^{-1}$
 Bond formed: $\frac{1}{2} \times \text{Cl–Cl}$: $\frac{1}{2} \times 244 = 122 \text{ kJ mol}^{-1}$

$$\begin{aligned} \text{Standard enthalpy change of decomposition of HCl} \\ &= 431 - 218 - 122 \\ &= +91.0 \text{ kJ mol}^{-1} \end{aligned}$$

[1] for correct bond energy values

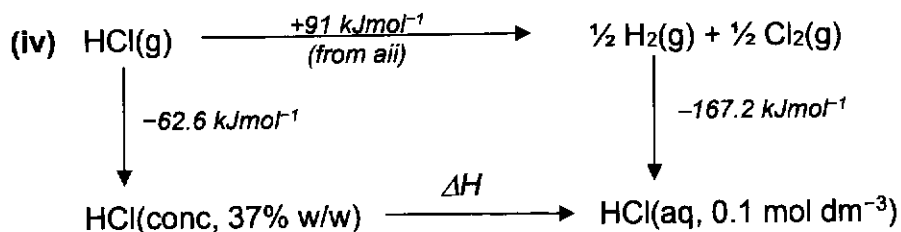
[1] for correct coefficients and application of bond breaking/forming and final answer

- (b) (i) Volume of 100 g of conc HCl = $100 \div 1.2 \div 1000 = 0.0833 \text{ dm}^3$ [1]
 Concentration of conc HCl = $(37 \div 36.5) \div 0.0833 = 12.2 \text{ mol dm}^{-3}$ [1]

- (b) (ii) Number of moles of HCl required = $250 \div 1000 \times 0.1 = 0.025 \text{ mol}$

$$\text{Volume } v = 0.025 \div 12.2 = 0.00205 \text{ dm}^3 = 2.05 \text{ cm}^3 \text{ [1]}$$

- (b) (iii) It is the enthalpy change when 1 mole of a substance is formed from its constituent elements in their standard states at 298K and 1 bar. [1]



$$\Delta H = -(-62.2) + 91 - 167.2 = -13.6 \text{ kJ mol}^{-1}$$

[2] for energy cycle

[1] for correct application of Hess Law and final answer

- (b) (v) As the dilution in (b)(iv) is exothermic, outline B is preferred as the heat liberated while diluting the concentrated acid is transferred to / absorbed by a larger volume of water/solution already in the flask, to avoid the temperature from rising too high. [1]

(c) (i) $t_{\text{eq}} = 100 \text{ s}$ [1]

(c) (ii) $Q = It = 0.24 \times 100 = 24.0 \text{ C}$ [1]

- 5 (c) (iii) Number of moles of HCl = $2.50 \div 1000 \times 0.100 = 0.000250 \text{ mol}$ [1]

Number of moles of electrons passed
= number of moles of H^+ = 0.000250 mol

$$F = Q / n_e = 24.0 \div 0.00025 = 96\,000 \text{ C mol}^{-1} \text{ [1]}$$

- (iv) $L = F / e = 96000 \div (1.60 \times 10^{-19}) = 6.00 \times 10^{23} \text{ mol}^{-1}$ [1]
(c) (v) $Ag^+ + e^- \rightleftharpoons Ag$ $E^\ominus = +0.80 \text{ V}$ --(1)
 $2H^+ + 2e^- \rightleftharpoons H_2$ $E^\ominus = 0.00 \text{ V}$ --(2)
 $2H_2O + 2e^- \rightleftharpoons H_2 + 2OH^-$ $E^\ominus = -0.83 \text{ V}$ --(3)

[0.5] for quoting the reduction potential for (1) and at least one of (2) and (3)

The reduction potential for Ag^+/Ag is more positive than for H^+/H_2 and H_2O/H_2 ,
[0.5] so silver ions will be preferentially reduced at the cathode [0.5]

so (1) will occur in addition to/instead of (2) and (3), so t_{eq} obtained may be too large/ t_{eq} may not be obtainable/pH may not change.

[0.5] correct argument about the effect on the experiment

- (c) (vi) t_{eq} obtained by student Y will be larger than expected because the working pH range of the given indicator (10.2 to 12.0) is higher than the equivalence point pH of 7 (and also higher than the range of pH at the rapid change at the equivalence point). [1]

- (c) (vii) ratio = 0.500 or 1:2 or $\frac{1}{2}$ [1]

Final pH = 10.7 [1] (accept 10.6 to 10.8)

