Anglo-Chinese Junior College

JC2 Preliminary Examination
Higher 1

A Methodist Institution (Founded 1886)

CANDIDATE NAME		FORM CLASS	
TUTORIAL CLASS	2CHX _ _	INDEX NUMBER	

CHEMISTRY

8873/02

Paper 2 Structured Questions

27 Aug 2025
2 hours

Candidates answer on the Question Paper.
Additional Materials: Data Booklet

READ THESE INSTRUCTIONS FIRST

Write your name and index number in the spaces on all the work you hand in.
Write in dark blue or black pen.
You may use a soft pencil for any diagrams, graphs or rough working.
Do not use staples, paper clips, highlighters, glue or correction fluid.

Section **A**
Answer **all** questions.

Section **B**
Answer **one** question.

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

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

For Examiners' use only	
Section A	
1	/ 13
2	/ 7
3	/ 10
4	/ 7
5	/ 13
6	/ 10
Section B	
7 or 8	/ 20
Total	/ 80

Section A

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

1 In the presence of an acid catalyst, ethanal reacts with methanol to form 1,1-dimethoxyethane.

$$CH_3CHO(l) + 2CH_3OH(l) \overset{H^+}{\rightleftharpoons} CH_3CH(OCH_3)_2(l) + H_2O(l)$$

ethanal methanol 1,1-dimethoxyethane

(a) 0.20 mol dm^{-3} of ethanal and 0.1 mol dm^{-3} of methanol were placed in a reaction vessel. Strong acid was then added as a catalyst. It was found that the equilibrium mixture contained 0.025 mol dm^{-3} of 1,1-dimethoxyethane.

Calculate the equilibrium concentrations of the other reactants and products.

	CH_3CHO	CH_3OH	1,1-dimethoxyethane	H_2O
Initial/ mol dm^{-3}	0.20	0.10	0.00	0.00
Change/ mol dm^{-3}	– 0.025	– 0.05	+ 0.025	+ 0.025
At equilibrium/ mol dm^{-3}	0.175	0.05	0.025	0.025

[3]

(b) Write the expression for the equilibrium constant for this reaction, K_c, stating its units.

$Kc = [CH_3CH(OCH_3)_2]\,[H_2O] / [CH_3CHO]\,[CH_3OH]^2$

$mol^{-1}dm^3$

[2]

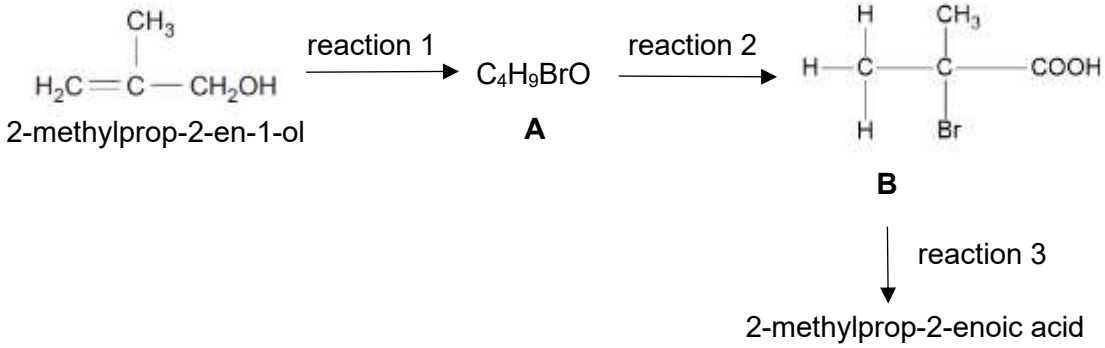
(c) Use your answers in **(a)** to calculate the value of K_c.

$Kc = [0.025]\,[0.025] / [0.175]\,[0.05]^2$

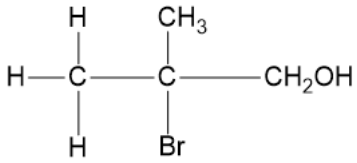
$= 1.43\ mol^{-1}dm^3$

[1]

(d) 2-methylpropenoic acid can be obtained from 2-methylprop-2-en-1-ol.



(i) To prevent the C=C bond from reacting in other reactions, reaction 1 is first carried out. Draw the structure of **A**.



[1]

(ii) Suggest the reagents used in reaction 1.

HBr(g)

……..….[1]

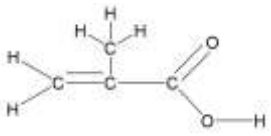
(iii) Name the type of reaction in reaction 2 and 3.

reaction 2: Oxidation

reaction 3: Elimination

[2]

(iv) Draw the displayed formula of 2-methylprop-2-enoic acid.



[1]

(v) Suggest a chemical test to distinguish between 2-methylprop-2-en-1-ol and **B**. State the observations.

……

……..….[2]

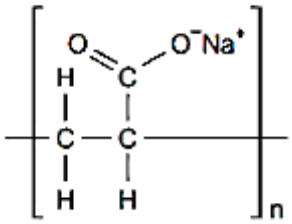
Either $KMnO_4$ with dilute sulfuric acid, Heat

B: Purple $KMnO_4$ remains, 2-methylprop-2-en-1-ol: (purple) $KMnO_4$ decolourises

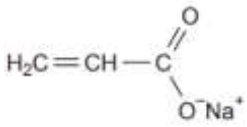
Or aqueous bromine
B: orange Br_2 remains, 2-methylprop-2-en-1-ol: (orange) Br_2 decolourises

[Total: 13]

2 (a) Sodium polyacrylate is a superabsorbent polymer that can absorb and retain large amounts of water relative to its own mass. It is widely used in diapers.



(i) Draw the monomer used to make sodium polyacrylate.



[1]

(ii) Explain why this polymer is an addition polymer.

The monomer has a C=C bond/pi bond which is broken during polymerisation. There is no elimination of small molecule.

……

……[2]

(iii) Using the information provided above, explain, in terms of structure and bonding, the property of this hydrogel.
The presence of $-COO^-Na^+$ in the polymer allows the formation of ion-dipole interactions water molecules hence making it hydrophilic.

……

……[1]

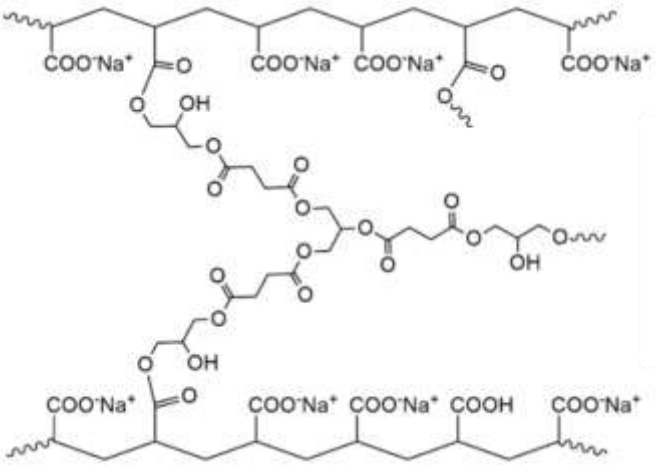
(iv) In an experiment, 4.0×10^{-6} mol of polymer absorbed 150 g of water. This mass of water is 300 times the mass of polymer used.

Calculate the relative molecular mass of the polymer.

Mass of polymer used = 150/300 = 0.5 g
Mr = 0.50/4.0 x 10^{-6} = 125000

[1]

(v) After polymerisation, sodium polyacrylate is further processed to form crosslinked sodium polyacrylate found in commercial products. The following diagram shows the structure of crosslinked sodium polyacrylate.



Explain how crosslinking of sodium polyacrylate allows it to remain as a solid mass in wet diapers.

……

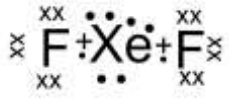
……[2]

Crosslinking of polymer chains forms covalent bonds between chains. Thus giving rise to the high tensile strength in this polymer/strengthening the structure of the polymer.

[Total: 7]

3 (a) The noble gas xenon was once thought to be inert. It has since been discovered that xenon will react with strong oxidants. For example, xenon reacts with fluorine gas, forming a series of fluorides, XeF_2, XeF_4 and XeF_6.

(i) Draw dot-and-cross diagram of xenon difluoride and state its bond angle.



180°

[2]

(ii) Name the shape of xenon difluoride.

.....[1]

Linear

(iii) Explain the three-dimensional arrangement using the principles of the VSEPR theory.

……..……..

……..….[2]

To minimize repulsion, the electron pairs will spread themselves as far apart as possible.

Since lone pair-lone pair repulsion is greater than lone pair-bond pair repulsion and lone pair-bond pair repulsion is greater than bond pair-bond pair repulsion, hence the linear arrangement is adopted.

OR

The linear arrangement is adopted to maximise the separation between the two bond pairs by placing them on opposite sides of plane with the maximum angular separation of 180º so as to minimize the repulsion due to them resulting in a more stable arrangement.

(b) The boiling points of some fluoride compounds are shown in Table 3.1.

Table 3.1

compound	M_r	boiling point/ °C
CF_4	88	−127.8
ClF_3	92.5	11.8
PF_3	88	−101.8

Explain the difference in boiling points using structure and bonding.

……

……

……[3]

CF_4, ClF_3 and PF_3 exist as simple molecular structures.

Though ClF_3 and PF_3 are polar, ClF_3 has the highest bp due to largest and most polarisable electron cloud which implies that it has strongest id-id interactions. Largest amt of energy. is needed to overcome the interactions.

Less energy is required to overcome the weaker instantaneous dipole-induced dipole between CF_4 molecules than permanent dipole-permanent dipole between PF_3 molecules.

(c) Explain why the ionic bond in lithium iodide, LiI, has greater covalent character than that of lithium fluoride, LiF.

……

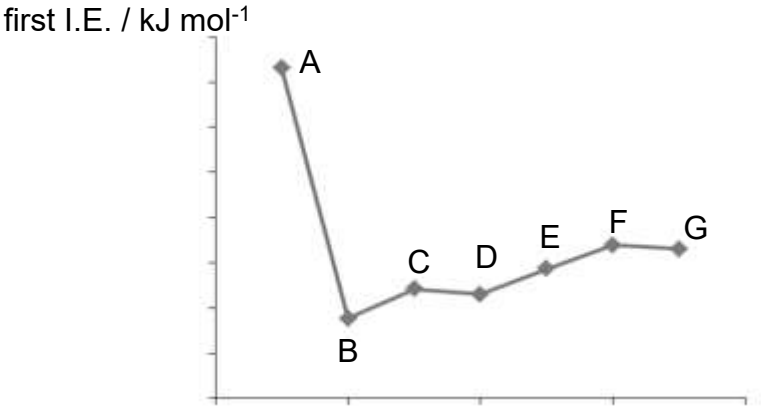
……

……[2]

I^- has a larger ionic radius/size than F^-, resulting in a greater extent in the distortion of the electron cloud of I^- /polarisability of the anion by Li^+, leading to greater sharing of electrons between the two nuclei. The ionic bond in LiI will thus have greater covalent character than that of while LiF.

[Total: 10]

4 The first ionisation energy of some consecutive elements in periods 2 and 3 are plotted.



(a) Explain why the first ionisation energy of element **A** is much higher than that of element **B**.

……

……

……[1]

A has one fewer principal quantum shell than B. Thus the electron in A is more strongly attracted to the nucleus as compared to the electron in B. Hence the removal of first electron from A requires much more energy.

(b) Write an equation to represent the second ionisation energy of element A.

……[1]

$A^+(g) \rightarrow A^{2+}(g) + e^-$

(c) Explain the increasing trend of the first ionisation energies from element B to G.

……

……

……[2]

Across B to G, there is an increasing nuclear charge and approximately constant shielding effect. Hence, effective nuclear charge increases. Consequently, valence electrons experience stronger nuclear attraction across the period. Therefore, more energy required to remove a valence electron. Hence, first I.E. generally increases across the period.

(d) State which element is sulfur and explain your answer.

G.

Element A is Ne in Period 2 as it has much higher 1st IE than the rest of the elements in Period 3. Since Na is B and thus G is sulfur.

OR

From B to G, they are all elements in Period 3. There are two anomalies from B to G. The second dip is due to inter-electronic repulsion between the paired 3p electron in G. Hence G is sulfur.

……

……..….[2]

(e) State the number of occupied principal quantum shells in one atom of sulfur in its ground state.

……..….[1]

3

[Total: 7]

5 **(a)** A student determined the concentration of ethanoic acid, CH_3COOH in a bottle of kitchen vinegar. He added 10 cm^3 of vinegar to a volumetric flask and followed by deionised water to make up the solution to 250 cm^3. The diluted vinegar was then poured into the burette.

On titration, 25 cm^3 of 0.0450 mol dm^{-3} $Ba(OH)_2$ was exactly neutralised by 25.45 cm^3 of the diluted vinegar.

(i) Write the balanced equation between CH_3COOH and $Ba(OH)_2$.

……[1]

$Ba(OH)_2 + 2CH_3COOH \rightarrow (CH_3COO)_2Ba + 2H_2O$

(ii) Calculate the amount of CH_3COOH neutralised.

Amount of $Ba(OH)_2$ = 0.0450 x 25/1000 = 0.001125 mol

Amount of CH_3COOH = 0.001125 x 2 = 0.00225 mol

[2]

(iii) Calculate the amount of CH_3COOH in 250 cm^3 solution.

Amount of CH_3COOH = 250/25.45 x 0.00225 = 0.0221 mol

[1]

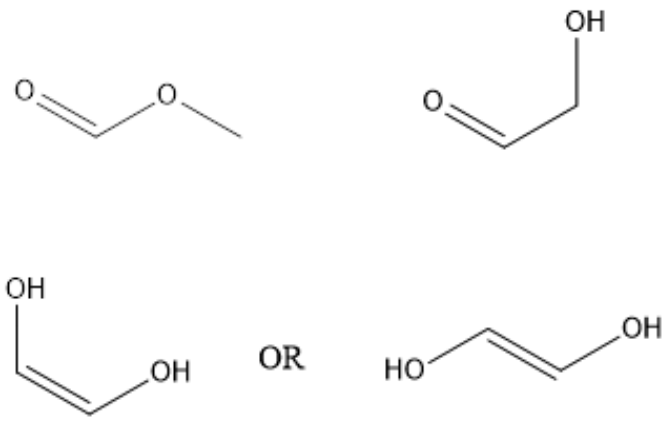
(iv) Determine the amount of CH_3COOH in 10 cm^3 of vinegar.

Amount of CH_3COOH = 0.0221 mol

[1]

(b) Other than ethanoic acid, there are other non-cyclic compounds that have the same molecular formula, $C_2H_4O_2$.

Draw the skeletal formulae of three other non-cyclic isomers, with different functional groups from each other, which have this molecular formula.



[3]

(c) Ethanoic acid can be used to synthesis compound **W** which has the molecular formula $C_4H_8O_2$.

W decolourises the aqueous chlorine.

When 0.10 mol of **W** reacts with excess carboxylic acid under suitable conditions, 0.20 mol of water is formed, together with a neutral compound.

For each reaction mentioned above, identify and explain the type and number of each functional group present.

(i) reaction with aqueous chlorine

An alkene is present since W undergoes addition with Cl_2 (aq).

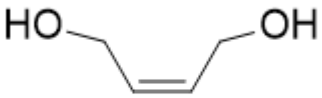
[1]

(ii) reaction with carboxylic acid

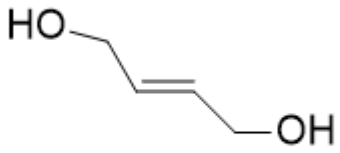
Alcohol functional group is present since W forms esters with excess carboxylic acid. As 1 mole of –OH group produces 1 mole of H_2O and the mole ratio of W:H_2O is 1:2, there are 2 alcohol groups

[2]

(d) Draw **two** possible skeletal formulae of **W** and name the type of isomerism they show.

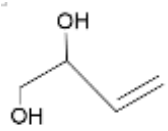


cis



trans

correct skeletal structures
cis-trans isomerism



constitutional isomerism

The answers given above are non-exhaustive.

[2]

[Total: 13]

6 Sunscreens are essential for protecting the skin from harmful ultraviolet (UV) radiation, which can cause sunburn, premature aging, and increase the risk of skin cancer. There are two main types of sunscreens based on how they work:

1. Physical Sunscreens, containing TiO_2 or ZnO, are effective against UV A and UV B. They work as physical blockers sitting on the surface of the skin to reflect or scatter UV rays.
2. Chemical Sunscreens are effective in blocking mostly UV B and some UV A. They work by using the organic compounds that absorb UV radiation.

(a) Nanoparticles of TiO_2 are preferred over bulk TiO_2 in sunscreen formulations while bulk TiO_2 is often used as a pigment in paints. Bulk TiO_2 particles scatter visible light, leading to a white, opaque appearance.

(i) Define what is meant by the term *nanoparticles*.

……

……

……[1]

Nanoparticles are particles with all 3 dimensions between 1 and 100 nanometers (nm), exhibiting unique properties not found in their larger bulk material counterparts.

(ii) Describe the structure, bonding and properties, such as melting, solubility in water and conductivity, of bulk TiO_2.

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……[4]

Bulk titanium dioxide (TiO_2) has a giant ionic lattice structure.

The bonding in TiO_2 is primarily ionic, formed due to the strong electrostatic attraction between positively charged Ti^{4+} ions and negatively charged O^{2-} ions.

Due to the strong ionic bonds in the giant lattice, a large amount of energy is needed to break the bonds, resulting in a high melting point.The strong ionic lattice is not broken down easily by water, making TiO_2 insoluble in water.

Bulk TiO_2 is an electrical insulator in the solid state because the ions are fixed in the lattice and cannot move freely.

Alternative:

Titanium dioxide (TiO_2) has a complex crystal structure that varies depending on the specific phase. The three main phases are rutile, anatase, and brookite. Accept giant covalent structure as alternative answers.

(iii) Suggest two reasons why nanoparticles of TiO_2 are preferred over bulk TiO_2 in sunscreen formulations.

……

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……[2]

Nanoparticles have a high surface area to volume ratio, increasing interaction with UV radiation.

The small size results in change in physical appearance. Smaller particles make the sunscreen transparent, avoiding the white cast/colour of bulk TiO_2.

(b) Since 2021, Hawaii prohibits the sale, distribution, and offering of over-the-counter sunscreens containing oxybenzone and octinoxate — two chemical UV filters linked to coral bleaching and genetic damage in coral larvae.

On July 1, 2025, Hawaii introduced authorised state-funded dispensers of mineral-based sunscreen containing nanoparticles of ZnO or TiO_2 at all state beaches for distribution and reef protection.

By relating to the properties of nanoparticles, explain why the above measure may cause harm to marine life and the environment.

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……[3]

Accept any 3 of the following:

- Many nanoparticles are not biodegradable, meaning they persist in the marine environment.
- Nanoparticles are small enough to penetrate biological membranes and accumulate in tissues of small organisms.
- Ingest unknowingly resulting in bioaccumulation.
- These organisms are eaten by fish and other aquatic life moving up the food chain, affecting larger fish, seabirds, and even humans who eat seafood.

[Total: 10]

Section B

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

7 Hydrogen stands out as a clean energy with strong potential to meet future energy needs sustainably. Producing hydrogen through electrolysis of water relies on the use of highly effective and durable catalysts. Advancing fuel cell technology is crucial in addressing key challenges related to the generation, conversion, and storage of clean energy.

(a) In the electrolysis of water, hydrogen gas is produced at the cathode and oxygen at the anode.

In acidic media:

Anode: $H_2O \rightarrow 2H^+ + ½\ O_2 + 2e^-$

Cathode: $2H^+ + 2e^- \rightarrow H_2$

Identify the types of reactions at the anode and cathode.

Anode ……

Cathode ……

[2]

Anode oxidation

Cathode reduction

(b) Ammonia is now being explored as a hydrogen carrier for clean fuel. A hydrogen carrier is a substance that can store and release hydrogen when needed. It helps to safely transport and deliver hydrogen energy in a more practical form.

(i) In terms of the structure and bonding of hydrogen, suggest why hydrogen carrier is needed to safely transport and deliver hydrogen.

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……...[2]

Hydrogen has small molecules with high risk of leaks and has weak instantaneous dipole−induced dipole (ID−ID) so it requires low temperature or very high pressure to liquefy for transportation.

(ii) Suggest why ammonia is emerging as one of the most promising hydrogen carriers.

……

……

……...[2]

Any two of the following may be accepted:

- Easily manufactured using Haber Process
- high hydrogen content: 17.6% by weight
- easier to liquefy than hydrogen (liquefies at −33 °C)
- can be used directly as a fuel in some fuel cells or engines

(iii) Traditional synthesis of ammonia uses the Haber Process:

$$N_2\,(g) + 3H_2\,(g) \rightleftharpoons 2NH_3\,(g) \quad \Delta H < 0$$

With reference to bond strength and activation energy, describe the type of bonding present in N_2 and explain why a catalyst is necessary in the Haber Process.

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……...[2]

N_2 has a triple covalent bond which has high bond dissociation energy or a large amount of energy is required to break this bond.

A catalyst lowers the activation energy needed to break this bond, thus more molecules will have energies greater than the activation energy allowing the reaction to proceed faster in the Haber Process.

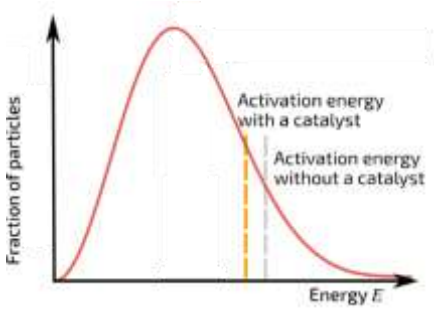
(iv) Using bond energies in the *Data Booklet*, calculate the enthalpy change for the Haber Process reaction in **7(b)(iii)**.

[2]

$\Delta H = (944) + 3\,(436) - 6\,(390) = 2252 - 2340 = -88.0\ kJ\ mol^{-1}$

(v) Using the Boltzmann distribution, illustrate and explain how a catalyst affects the rate of the reaction.

[2]



- correct axes (*Fraction of particles* vs *Energy)*
- smaller area for uncatalysed reaction with lower proportion of particles
- bigger area for catalysed reaction with higher proportion of particles

With catalyst, more molecules have energy greater than activation energy, hence rate increases.

(vi) Outline the mode of action of heterogeneous catalysis in the Haber Process.

Name the catalyst and include bond forming and bond breaking in your answer.

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……[4]

- finely divided iron
- N_2 and H_2 diffuse to the surface of iron.
- N_2 and H_2 adsorb on iron's surface weakening N≡N triple bond and H−H singe bond.
- N_2 and H_2 react and N−H bonds form.
- NH_3 diffuse away from the surface of iron.

(c) The yield of ammonia is affected by pressure, temperature, and the removal of products.

$$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g) \quad \Delta H < 0$$

(i) Using Le Chatelier's Principle, explain how increasing pressure and decreasing temperature affect the position of equilibrium.

……

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……[2]

Increasing pressure favours the forward reaction (fewer gas molecules: 4 → 2).

Decreasing temperature favours the forward reaction as it is exothermic (ΔH is negative).

(ii) Comment on the temperature and pressure at which Haber Process operate industrially.

……

……

……

……

……..[2]

Although a low temperature favours the forward reaction which may result in a higher yield, the rate of reaction would be too slow if temperature used is too low. A compromise temperature (~450°C) to achieve reasonable yield at a faster rate.

Although using a high pressure favours the forward reaction which may result in a higher yield, the cost to maintain the equipment would be too costly. A moderate pressure is used to be cost effective.

[Total: 20]

8 Green industrial bleaching refers to environmentally friendly methods used to remove colour from materials like paper pulp or textiles, with minimal harm to the environment and human health.

(a) Historically, chlorine, Cl_2, was used in pulp and paper bleaching. While effective, it caused serious environmental issues.

(i) Suggest how the physical state of Cl_2 might influence its environmental impact.

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……

……..[2]

Gaseous Cl_2 can be transported by air and pose wider environmental contamination or affects regions far from source or greater exposure risks when released into the environment poisoning due to inhale

(ii) State and explain the trend in oxidising power of the halogens down Group 17.

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……..[2]

Down Group 17, oxidising power of the halogens decreases.

This is because atomic radius increases and the abilitiy of the halogens to attract an electron decreases. The halogens become less able to accept electrons.

(b) In the pursuit of greener industrial bleaching processes, researchers are exploring the use of chlorine dioxide, ClO_2, due to lower environmental impact compared to chlorine gas.

(i) The standard enthalpy change of formation of $ClO_2(g)$ is +102 kJ mol^{-1}.

Define the standard enthalpy change of formation of $ClO_2(g)$.

……

……

……...[1]

The standard enthalpy change of formation of $ClO_2(g)$ is the energy change when 1 mole of $ClO_2(g)$ is formed from its elements in their standard states.

(ii) With reference to the standard enthalpy change of formation of $ClO_2(g)$, suggest why ClO_2 must be handled with care and how its thermodynamic properties influence its use in industrial processes.

……

……

……

……..[3]

Since ΔH_f° of $ClO_2(g)$ is positive, the reverse reaction (ClO_2 (g) $\rightarrow Cl_2$ (g) + O_2 (g)) has a negative ΔH. Hence, ClO_2 is unstable and decomposes readily and its decomposition can be explosive. This instability means it cannot be stored as a compressed gas or is generated on-site or handled with care.

Alternative:

The reverse reaction (decomposition) releases a large amount of energy, it can decompose violently and explosively, especially at high concentrations or when exposed to heat, shock, or light. It can be set off by minor sparks or even sunlight.

(iii) The reaction of chlorine dioxide in water is shown below:

$$2ClO_2(aq) + H_2O(l) \rightarrow HClO_2(aq) + HClO_3(aq) \quad \text{...equation 8.1}$$

Find the oxidation numbers to chlorine in each compound in the above equation.

ClO_2 .....

$HClO_2$ .....

$HClO_3$ ..... [2]

ClO_2 +4

$HClO_2$ +3

$HClO_3$ +5

(iv) State and explain the type of reaction which occurs in equation 8.1.

……

……

……...[2]

Disproportionation. Cl in ClO_2 is both oxidised and reduced in the same reaction.

(c) During aqueous bleaching, chlorous acid, $HClO_2$, and chloric acid, $HClO_3$, are produced. $HClO_2$ exists transiently in solution and contributes to the oxidising environment during the bleaching process.

(i) Chlorous acid, $HClO_2$, is a weak Brønsted-Lowry acid.

Define the term Brønsted-Lowry acid.

……

……

……...[1]

Brønsted-Lowry acid is a substance that donates a proton in solution and itself forms a conjugate base.

(ii) Write an equation to represent how $HClO_2$ reacts with water.

……...[1]

$HClO_2$ (aq) + H_2O (l) ⇌ H_3O^+ (aq) + ClO_2^- (aq)

(iii) Given that the value of K_a for the reaction of $HClO_2$ with water is 1.1×10^{-2}, write the K_a expression based on your answer to **8(c)(ii)** and calculate the pH of a 0.100 mol dm^{-3} solution of $HClO_2$.

[3]

$K_a = [ClO_2^-][H_3O^+]/[HClO_2]$

$x^2 = 1.1 \times 10^{-2} \times 0.100$

$= 1.1 \times 10^{-3}$

$x = 3.32 \times 10^{-2}$

$[H^+] = 3.32 \times 10^{-2}$ mol dm^{-3}

$pH = -\log (3.32 \times 10^{-2}) = 1.48$

(iv) $HClO_2$ and $HClO_3$ are both oxoacids of chlorine present in the bleaching process. Their K_a are 1.1×10^{-2} and 5.0×10^2 respectively.

With reference to molecular structure of the oxoacids and oxidation state of chlorine, compare and explain the relative strengths of the two acids using their K_a values.

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……..[3]

K_a of $HClO_3$ is much greater than K_a of $HClO_2$, so $HClO_3$ is the stronger acid.

Cl in $HClO_3$ has +5 oxidation state; Cl in $HClO_2$ has +3.

The Cl in $HClO_3$ with higher oxidation number withdraws electron density from O–H bond more strongly, in turn weakens O–H bond to a greater extend and facilitates proton donation making it the stronger acid.

Alternative:

$HClO_3$ has more electronegative oxygen atoms, and hence greater electron withdrawing effect increases turn weakens O–H bond to a greater extend.

[Total: 20]

Additional answer space

If you use the following pages to complete the answer to any question, the question number must be clearly shown.

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