Name:_____ **Class:**_____

JURONG PIONEER JUNIOR COLLEGE
JC2 PRELIMINARY EXAMINATION 2025

CHEMISTRY **8873/02**
Higher 1
29 August 2025

Paper 2 **2 hours**

Additional materials: Data Booklet

READ THESE INSTRUCTIONS FIRST

Write your name, class and exam index number on all the work you hand in.
Write in dark blue or black pen on both sides of the paper.
You may use a HB pencil for any diagrams, graphs.
Do not use staples, paper clips, glue or correction fluid.

Section A (60 marks)
Answer **all** the questions.

Section B (20 marks)
Answer **one** question.

The use of an 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 Examiner's Use		
Section A	1	/15
	2	/16
	3	/11
	4	/12
	5	/6
Section B	6	/20
	7	/20
Penalty (delete accordingly)		
Missing/wrong **units** in final answer		**–1 / NA**
Total		/80

This document consists of **24** printed pages and **4** blank pages.

Section A

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

For Examiner's Use

1 A unknown metal sulfate has the formula **M**SO_4. The hydrated form of the metal sulfate has the formula **M**$SO_4.xH_2O$.

(a) Name the types of bonds that are present in the metal sulfate.

Electrostatic forces of attraction between oppositely charged ions (ionic bond) and covalent bonds. [2]

(b) When 6.24 g of the hydrated metal sulfate is strongly heated, thermal decomposition occurs. In addition to water, a solid oxide, **M**O, and a gaseous oxide are also produced. The solid oxide had a mass of 1.99 g.

The volume of the gaseous oxide produced was 600 cm^3 at r.t.p. A strongly acidic solution is produced when the gaseous oxide is dissolved in water.

(i) Write a balanced equation for the thermal decomposition of the hydrated metal sulfate.

$MSO_4.xH_2O \rightarrow MO + SO_3 + xH_2O$ [1]

(ii) Calculate the relative atomic mass of metal **M**.

Hence, suggest the identity of metal **M**.

Amount of gaseous oxide = $(600 \times 10^{-3}) / 24 = 0.0250$ mol

1 gaseous oxide ≡ 1 MO

Amount of MO = 0.0250 mol

A_r of M = (1.99 / 0.025) – 16 = 63.6
M is Cu [3]

(iii) Using your answer in **(b)(ii)**, calculate the integer x in **M**$SO_4.xH_2O$.

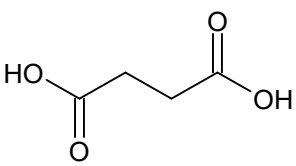
M_r of hydrated metal sulfate = 63.6 + 32.1 + 64.0 + 18x = 159.7 + 18x

Amount of MO = Amount of $MSO_4.xH_2O$

$$0.0250 = \frac{6.24}{159.7+18x}$$

3.993 + 0.45x = 6.24
0.45x = 2.25
x = 4.99
x ≈ 5 [2]

(c) The metal ion, $\mathbf{M}^{2+}$, can catalyse the hydrolysis of ester **N** into butanedioic acid and methanol as shown below.

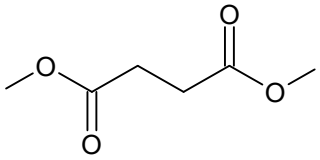
ester **N** + $2H_2O \rightarrow$  + $2CH_3OH$

butanedioic acid methanol

(i) State the number of σ bonds and π bonds in a molecule of butaedioic acid.

13 σ bonds, 2 π bonds [1]

(ii) Draw the skeletal formula of ester **N**.



[1]

Butanedioic acid polymerises with 1,4–butanediamine to give nylon–4,4.

(iii) State the type of reaction and the catalyst required for the polymerisation process to occur.

condensation, dicyclohexylcarbodiimide DCC [2]

(iv) Explain why clothing made from nylon–4,4 fibers are prone to creasing.

The polymers in nylon–4,4 are linked by hydrogen bonds. Water molecules can penetrate the areas between the polymer chains and break the original hydrogen bonds. The amide groups will now form hydrogen bonds with water molecules.

When the material is dried, the water molecules leave and new hydrogen bonds will be formed between the polymer chains (in different positions). As a result, this locks in place any creases that had formed. Hence polyamides are prone to creasing. [2]

(v) Suggest why nylon–4,4 is less of an environmental concern than HDPE when disposed in a landfill.

Landfills may contain acid (or base) waste or acids from natural processes and would degrade more rapidly than HDPE as the amide linkages undergo hydrolysis.

Or other logical answers [1]

[Total: 15]

For Examiner's Use

2 The artificially produced isotope of cobalt, $^{60}_{27}Co$, is used as a source of x-rays in medical radiotherapy.

(a) Write the full electronic configuration of cobalt ion, $^{60}_{27}Co^{2+}$.

$1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 3d^7$ [1]

(b) In an experiment, a sample of cobalt was vaporised, ionised and passed through an electric field. It was observed that a beam of $^{60}_{27}Co^{2+}$ gives an angle of deflection of 8º.

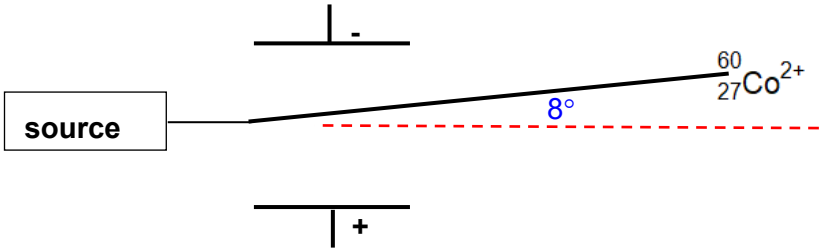
(i) Calculate the angle of deflection of $^{32}_{16}S^{2-}$ beam.

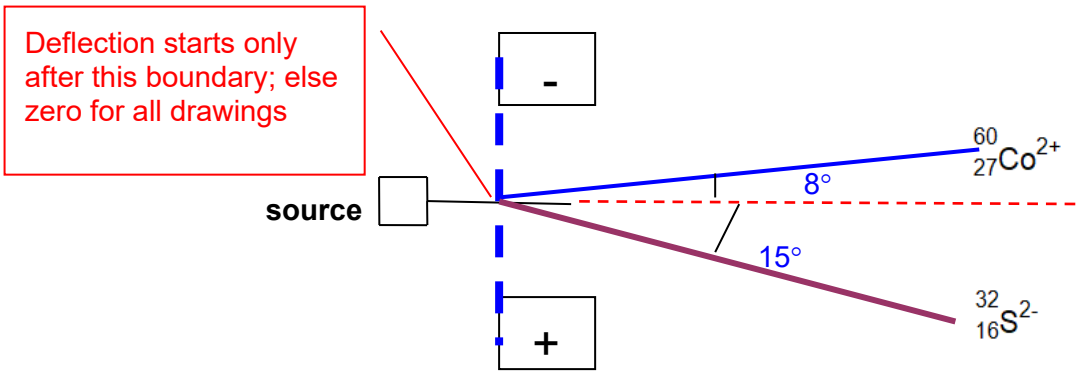
$$\frac{\text{Angle}_{S^{2-}}}{8} = \frac{\left(\frac{2}{32}\right)_{S^{2-}}}{\left(\frac{2}{60}\right)_{Co^{2+}}}$$

Angle of deflection for $^{32}_{16}S^{2-}$ = $\frac{2}{32} \times \frac{60}{2} \times 8$ = 15.0 °

[1]

(ii) Sketch and label on the diagram below, how the beams of $^{32}_{16}S^{2-}$ would be deflected.





[1]

(c) Aqueous hydrogen peroxide, H_2O_2, oxidises tartrate ion, $C_4H_4O_6^{2-}$ in the presence of cobalt(II) chloride homogeneous catalyst in the equation given below.

$$5H_2O_2(aq) + C_4H_4O_6^{2-}(aq) \rightarrow 4CO_2(g) + 2OH^-(aq) + 6H_2O(l)$$

(i) State what is meant by the term *homogeneous* when it is applied to cobalt(II) chloride in the oxidation of tartrate ion by hydrogen peroxide.

The Co^{2+} catalyst and H_2O_2 and $C_4H_4O_6^{2-}$ reactants are in the same/ aqueous phase. [1]

(ii) By considering the structure of H_2O_2, suggest why the reaction between hydrogen peroxide and tartrate ion has a high activation energy.

The lone pairs of electrons on the oxygen atoms of H_2O_2 repel the negatively charged tartrate ion. [1]

(iii) The reaction between hydrogen peroxide and tartrate ion is very colourful as pink Co^{2+} is oxidised to green Co^{3+} by hydrogen peroxide in the first step. This is followed by the reduction of Co^{3+} back to Co^{2+} when it reacts with the tartrate ion. The colour changes continues until all the reactants are used up.

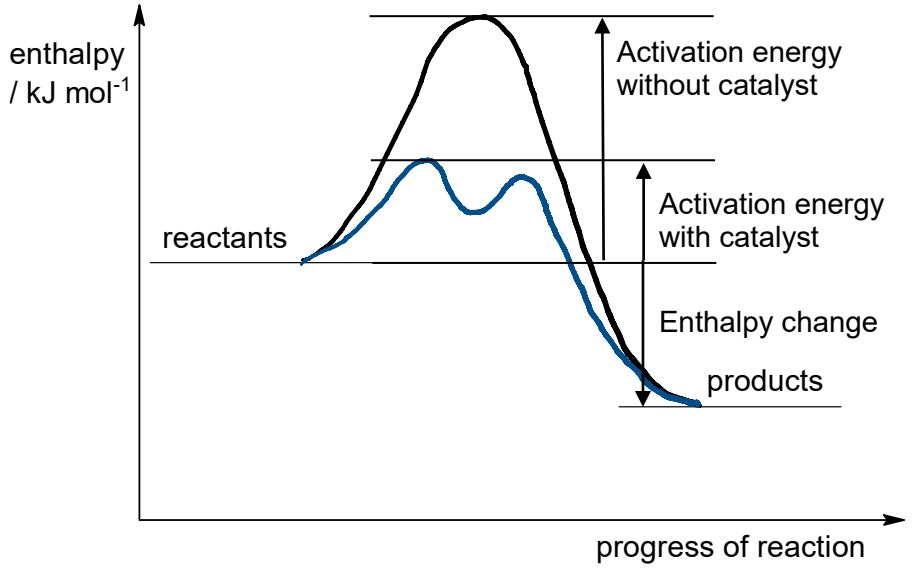
Outline the mode of action of how cobalt(II) chloride catalyses the oxidation of tartrate ion by hydrogen peroxide.

State the species involved in each step of the reaction.

Step 1: Co^{2+} would first be oxidised by H_2O_2 into Co^{3+}. H_2O_2 is reduced to H_2O/OH^-.

Step 2: Co^{3+} then oxides $C_4H_4O_6^{2-}$ into CO_2 and Co^{2+} is regenerated. [2]

(iv) Hence, construct an energy profile diagram to show changes, if any, to the enthalpy change or activation energy **before and after** the addition of cobalt(II) chloride.



[2]

(d) Hydrogen peroxide and iodide ions react in acidic solution as shown.

$$H_2O_2(aq) + 2I^-(aq) + 2H^+(aq) \rightarrow 2H_2O(l) + I_2(aq)$$

A series of experiments were conducted to determine the rate equation of the reaction.

(i) Use the following data to deduce the orders with respect to $[H_2O_2]$, $[I^-]$ and $[H^+]$, explaining your reasoning.

Experiment	$[H_2O_2]$ / mol dm^{-3}	$[I^-]$ / mol dm^{-3}	$[H^+]$ / mol dm^{-3}	Initial rate / mol dm^{-3} s^{-1}
1	0.05	0.05	0.05	1.25×10^{-3}
2	0.10	0.05	0.05	2.50×10^{-3}
3	0.10	0.20	0.05	1.00×10^{-2}
4	0.15	0.10	0.10	7.50×10^{-3}

Comparing experiments 1 and 2, when $[H_2O_2]$ was doubled from 0.05 to 0.10 mol dm^{-3} while keeping $[I^-]$ and $[H^+]$ constant, the rate doubled from 1.25 x 10^{-3} to 2.50 x 10^{-3} mol dm^{-3} s^{-1}. Hence, rate is proportional to $[H_2O_2]$ and thus order of reaction w.r.t. $[H_2O_2]$ is 1.

Comparing experiments 2 and 3, when $[I^-]$ was quadrupled from 0.05 to 0.20 mol dm^{-3} while keeping $[H_2O_2]$ and $[H^+]$ constant, the rate quadrupled from 2.50 x 10^{-3} to 1.00 x 10^{-2} mol dm^{-3} s^{-1}. Hence, rate is proportional to $[I^-]$ and thus order of reaction w.r.t. $[I^-]$ is 1.

Comparing experiments 1 and 4,

$$\frac{7.50\text{x}10^{-3}}{1.25\text{x}10^{-3}} = \frac{0.15 \text{ x } 0.10 \text{ x } 0.10^{a}}{0.05 \text{ x } 0.05 \text{ x } 0.05^{a}}$$

$6 = 6 \text{ x } 2^a$

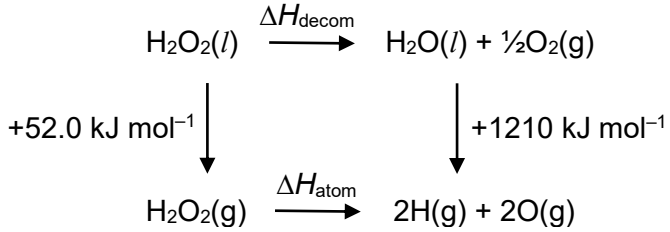
$a = 0$

order of reaction w.r.t. $[H^+]$ is 0. [3]

(ii) Using data from experiment 2, calculate the rate constant, k, for the reaction and state its units.

$$k = \frac{2.50\text{x}10^{-3}}{0.10 \text{ x } 0.05} = 0.500 \text{ mol}^{-1} \text{ dm}^3 \text{ s}^{-1}$$ [1]

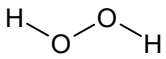
(e) The following shows an energy cycle to determine the enthalpy change of decomposition of hydrogen peroxide.



(i) Define the term *bond energy*.

Bond energy is the heat absorbed when 1 mole of a covalent bond between 2 atoms in the gaseous state is broken. [1]

(ii) The structure of H_2O_2 is shown below.



Using data from the Data Booklet, calculate the enthalpy change of atomisation of $H_2O_2(g)$, ΔH_{atom}.

Hence, calculate the enthalpy change of decomposition of $H_2O_2(l)$, ΔH_{decom}.

For "$H_2O_2(g) \rightarrow 2H(g) + 2O(g)$", 2 O–H bonds and 1 O–O bond is broken.

ΔH_{atom} = Total bond energy = (2 x 460) + 150 = +1070 kJ mol^{-1}

$\Delta H_{decom} + (+1210) = (+52.0) + (+1070)$

$\Delta H_{decom} = (+52.0) + (+1070) - (+1210)$

$= -88$ kJ mol^{-1} [2]

[Total: 16]

3 Magnesium, aluminium and silicon are elements in Period 3 of the Periodic Table.

All three elements react with oxygen to form stable oxides.

(a) Three unlabelled containers, each containing only one of the oxides, were reacted separately with aqueous NaOH and aqueous HC*l*.

Write balanced equations for any reaction that occured.

Only Al_2O_3 will dissolve NaOH(aq). MgO and SiO_2 does not dissolve in NaOH(aq).

$Al_2O_3 + 2NaOH + 3H_2O \rightarrow 2Na[Al(OH)_4]$

Only Al_2O_3 and MgO will dissolve in HCl(aq). SiO_2 does not dissolve in HCl(aq).

$MgO + 2HCl \rightarrow MgCl_2 + H_2O$

$Al_2O_3 + 6HCl \rightarrow 2AlCl_3 + 3H_2O$ [3]

(b) Aluminium rods can often be found on top of buildings as part of the lightning protection system. The lightning protection system provides a safe path for the energy to travel and hence minimising damage on buildings.

State and explain why aluminium is suitable for this role.

Aluminium is a good conductor of electricity due to the presence of mobile valence electrons, in the sea of delocalised electrons, as charge carriers. [2]

(c) State and explain, in terms of bonding and structure, how the melting point of silicon dioxide differs from that of carbon dioxide.

CO_2 has simple covalent/molecular structure whereas SiO_2 has a giant covalent structure.

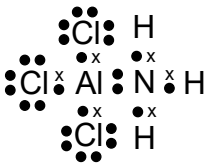
A larger amount of energy is needed to overcome the stronger covalent bonds between Si and O atoms compared to the weaker instantaneous dipole–induced dipoles forces of attractions between CO_2 molecules.

Hence, SiO_2 have a higher melting point than CO_2. [3]

(d) Aluminium chloride reacts with ammonia to form an addition product.

$$NH_3 + AlCl_3 \rightarrow NH_3AlCl_3$$

(i) Draw the dot–and–cross diagram of the addition product.



[1]

(ii) Explain why ammonia is soluble in water.

[2]

The formation of hydrogen bonding between ammonia and water releases sufficient energy to overcome the hydrogen bonding in ammonia and in water.

[Total: 11]

4 **(a)** Compound **P** contains 51.9 % carbon, 9.73 % hydrogen and 38.4 % chlorine by mass.

When 0.100 mol of compound **P** is added to aqueous silver nitrate, 14.3 g of silver chloride is formed.

Compound **P** reacts with hot aqueous sodium hydroxide to give a compound that decolourise hot acidified potassium manganate(VII).

The reaction of compound **P** with hot ethanolic sodium hydroxide gives only one compound.

(i) Calculate the molecular formula of compound **P**.

	C	H	Cl
% by mass	51.9	9.73	38.4
Mass / g in 100 g	51.9	9.73	38.4
Amount / mol	4.325	9.73	1.082
ratio	4.00	8.99	1.00
Simplest ratio	4	9	1

Molecular formula of compound P is $(C_4H_9Cl)_n$.

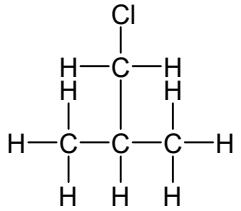
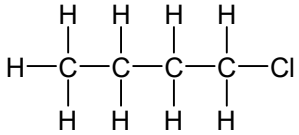
Amount of AgCl = 14.3 / 143.4 = 0.100 mol

0.100 mol of compound P forms 0.100 mol of AgCl. Thus 1 P ≡ 1 Cl.

Molecular formula of compound P is C_4H_9Cl. [2]

(ii) Draw the displayed formula for compound **P**.

Explain your answer with reference to the reactions and the functional groups present in the compounds.

Compound P  or 

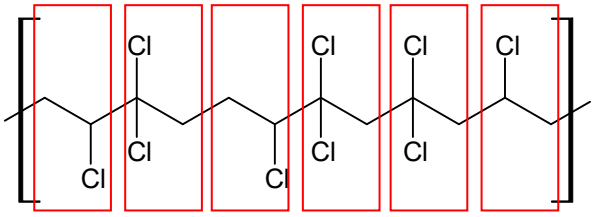
Compound P reacts with hot aqueous sodium hydroxide: Compound P, a halogenoalkane, undergoes substitution to form an alcohol.

Subsitution product of compound P decolourise hot acidified potassium manganate(VII): Product undergoes oxidation, product is a primary or secondary alcohol.

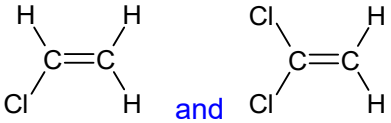
Compound P undergo elimination to form a terminal alkene, the alcohol is on the terminal carbon. [4]

(b) Cling wrap is a thin transparent plastic film usually used for sealing food items. It is a co-polymer formed from more than one monomer.

(i) The following following shows a segment of a polymer chain of cling wrap.



Draw the displayed formulae for the two monomers used to make cling wrap.


and

[2]

(ii) Suggest if cling wrap is a thermoplastic or thermoset polymer.

Using the structure of the polymer in **(b)(i)**, explain your answer.

Thermoplastic.
The inert side chains /Cl groups do not allow for the formation of cross–links. [2]

(iii) The minimum molar mass of a molecule of cling wrap is 1000 g mol^{-1}.

What is the minimum number of repeat units in a molecule of cling wrap.

M_r of C_2H_3Cl = 62.5
M_r of $C_2H_2Cl_2$ = 97
M_r of 1 repeat unit = 62.5 + 97 = 159.5
Minimum number of repeat unit = 1000 / 159.5 = 6.27 ≈ 7 [2]

[Total: 12]

For Examiner's Use

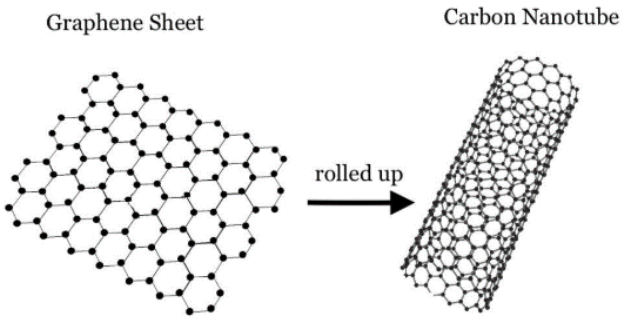
5 Carbon can exist in several different forms, including graphene and carbon nanotubes.

Graphene is colourless as the layer is just one atom thick. Graphene can be rolled into carbon nanotubes. Carbon nanotubes are black since they have a dimension larger than the nanoscale.

Carbon nanotubes are black because their structure is thicker and no longer on the nanoscale in all dimensions. A single carbon nanotube is extremely strong and has a very high tensile strength. However, materials made from many smaller carbon nanotubes arranged randomly are not as strong, as the alignment of the tubes is important for maximising strength.

In addition to their strength, carbon nanotubes are also excellent conductors of heat and electricity. Their unique combination of properties, small size, strength and conductivity, makes them useful in a wide range of applications such as energy storage, electronics, structural reinforcement, biomedical applications, and water treatment.

(a) Sketch a diagram to show the arrangement of carbon atoms in a carbon nanotube and use it to explain why carbon nanotubes are good electrical conductor.



Carbon nanotube has high electrical conductivity as the electron in the unhybridised 2p orbital is delocalised over the hexagonal layer to act as mobile charge carrier.

[2]

(b) Suggest why a single carbon nanotube would have high tensile strength.

Each carbon atom forms strong covalent bonds with 3 adjacent C atoms via sigma bonds / head-on overlap. This forms a network of very strong covalent bonds between the carbon atoms, giving rise to very high tensile strength.

[1]

(c) Suggest why a material made of many smaller carbon nanotubes with their random arrangement would not be as strong.

The interactions/ attractions between the nanotubes would be weak instantaneous dipole-induced dipole forces. These id-id forces are very weak compared to the strong covalent bonds between the atoms. It is easier to break the id-id forces than the covalent bonds hence the material would be weaker.

[1]

(d) Carbon nanotubes have a dimension which is larger than the nanoscale. Suggest why carbon nanotubes are still classed as nanomaterials.

Carbon nanotubes only need to have at least one dimension from 1-100 nm on the nanoscale to be classify as nanomaterials.

[1]

(e) Electronic devices could be made with a layer of graphene on the surface of the screen but **not** a layer of carbon nanotubes. Suggest why graphene could be used rather than carbon nanotubes.

Graphene is a single layer of graphite and it is transparent. Carbon nanotubes has a dimension greater than nanoscale. As it is much thicker than graphene, it does not allow light to pass through and is black in colour.

[1]

[Total: 6]

Section B

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

For Examiner's Use

6

(a) The table gives successive ionisation energies of element **X**.

	1st	2nd	3rd	4th	5th	6th	7th
I.E. / kJmol^{-1}	870	1800	3000	3600	5800	7000	13200

(i) State and explain the group that element **X** belongs to.

Group 16.

There is a big difference between the 6th and 7th I.E. This indicates that the 7th electron is from the inner quantum shell which is more strongly attracted to the nucleus. [2]

(ii) **W** is the element before element **X** in the Periodic Table from period 3.

State and explain the difference in the first ionisation energy between element **X** and element **W**.

Electronic configuration of W: ns^2np^3
Electronic configuration of X: ns^2np^4

Interelectronic repulsion between paired electrons in p orbital of X makes it easier to remove the valence electron compared to unpaired electron in p orbital of W. Hence, the 1st I.E of X is lower than that of W. [1]

(iii) State and explain the general trend of the first ionisation energy across the Period 3.

Across a Period, there is an increase in no. of protons / nuclear charge increases.

The number of quantum shells remains the same hence the shielding effect remains relatively constant.
The nuclear attraction on the outermost electrons increases and hence more energy is required to remove the valence electron.

∴ 1st IE generally **increases** across the Period. [2]

(b) A bottle of tonic water contains carbon dioxide dissolved in water. A number of equilibria exist within a bottle of tonic water.

equilibrium **I** $CO_2(g) \rightleftharpoons CO_2(aq)$

equilibrium **II** $CO_2(aq) + H_2O(l) \rightleftharpoons H_2CO_3(aq)$

equilibrium **III** $H_2CO_3(aq) \rightleftharpoons HCO_3^-(aq) + H^+(aq)$

equilibrium **IV** $HCO_3^-(aq) \rightleftharpoons CO_3^{2-}(aq) + H^+(aq)$

(i) Write a K_c expression for equilibrium **III**.

$$K_c = \frac{[HCO_3^-][H^+]}{[H_2CO_3]}$$

[1]

(ii) K_c for equilibrium **III** has a numerical value of 2.0×10^{-6}.

Calculate the concentration of $H^+(aq)$ ions in this equilibrium when the concentration of $H_2CO_3(aq)$ is 0.50 mol dm^{-3}.

$$K_c = \frac{[HCO_3^-][H^+]}{[H_2CO_3]}$$

$$K_c = \frac{[X][X]}{[0.50]} = 2.0 \times 10^{-6}$$

$$[X] = [H^+] = 1.00 \times 10^{-3}\ mol dm^{-3}$$ [1]

(iii) Use the value calculated in **(ii)** to calculate the pH of the tonic water.

pH = **–lg[H^+],** –lg [1.00×10^{-3}] = 3 [1]

(iv) When the bottle cap is released and removed from a bottle of tonic water, bubbles of gas are seen escaping out of the liquid.

Suggest why this occurs. Explain your answer.

Once cap is opened, **pressure is lowered**. Position of equilibrium **I** shift to **left** to **increase** the number of moles of **CO_2(g)**. More CO_2 bubbles observed. [2]

(v) Methyl red is an indicator that is red in solutions below pH 4.2 and yellow in solutions above pH 6.3. This indicator is added to a bottle of tonic water immediately after it is opened.

The bottle is left open until no further changes is observed.

Suggest what would be observed during this time. Use the equilibria **I** to **IV** to explain your answer.

Initial pH = 3, so colour of indicator will show **red**. When cap is removed, **[CO_2](g)** will **decrease**, position of equilibrium **I** will shift to **left** to increase the number of moles of CO_2(g).

This causes the **[CO_2](aq)** to **decrease**. Position of equilibrium **II** will shift to **left** to compensate for the decrease of **[CO_2](aq),** which results in the **decrease of [H_2CO_3](aq).**

To compensate for the decrease of [H_2CO_3](aq), both Position of equilibrium **III** and in turn equilibrium **IV** to shift to **left** which results in the **decrease of [H^+](aq).** Since pH = –lg[H^+], the **pH of tonic water will increase**, which colour of indicator will reflect **yellow**. [3]

(c) Atmospheric carbon dioxide levels have been increasing due to the burning of fossil fuels. A side effect is the acidification of water bodies as carbon dioxide dissolves in water to form carbonic acid, H_2CO_3.

(i) Write an equation, including state symbols, to represent the standard enthalpy of neutralisation of carbonic acid with sodium hydroxide, NaOH.

$NaOH(aq) + \frac{1}{2}H_2CO_3(aq) \rightarrow \frac{1}{2}Na_2CO_3(aq) + H_2O(l)$ [1]

A student collected a 25.0 cm^3 sample of lake water. The initial temperature of the water was 24.8 °C. 25.0 cm^3 of 1.00 mol dm^{-3} NaOH, in excess, was added to the sample and the temperature was monitored over several minutes.

The highest temperature, corrected for heat loss, was 28.8 °C.

(ii) Given that the specific heat capacity of the mixture is 4.2 J g^{-1} K^{-1}, calculate the heat change for the neutralisation of carbonic acid.

Take the density of the mixture to be 1.0 g cm^{-3}.

$\Delta T = 28.8 - 24.8 = 4.0$ °C m = 25.0 + 25.0 = 50.0 g

Heat change, q = m c ΔT = 50.0 x 4.2 x 4.0 = 840 J [1]

(iii) Given that the standard enthalpy of neutralisation of carbonic acid is –42.7 kJ mol^{-1}, calculate the concentration of carbonic acid in the lake water.

$nH_2O = q / \Delta H = 840 / (42.7 \times 103) = 0.0197$ mol

$nH_2CO_3 = 0.0197 / 2 = 0.00984$ mol

$[H_2CO_3] = 0.00984 / (25.0 \times 10^{-3}) = 0.393$ mol dm^{-3} [2]

(iv) Suggest why this method of determining the concentration of carbonic acid in the lake water is inaccurate.

There may be other acids in the lake water. (accept other sensible answers) [1]

(d) Sodium bicarbonate, $NaHCO_3$, also known as baking soda, can be formed by reacting sodium carbonate, Na_2CO_3, with carbon dioxide.

$$Na_2CO_3(s) + CO_2(g) + H_2O(l) \rightarrow 2NaHCO_3(s)$$

Use the information below to calculate the standard enthalpy of reaction for the production of $NaHCO_3$ from Na_2CO_3.

compound	ΔH_f / kJ mol^{-1}
Na_2CO_3	–1131
$NaHCO_3$	–947
CO_2	–394
H_2O	–286

$\Delta H_r = 2(-947) - [(-1131) + (-394) + (-286)]$
$= -83$ kJ mol^{-1} [2]

[Total: 20]

7 Elements in Group 17 of the Periodic Table form many compounds with different properties.

(a) Describe what happens when A*l*C*l*$_3$ is added to water.

State the pH of the resultant solution.

Include an equation to aid your explanation.

$AlCl_3$ dissolves in water to form $Al(H_2O)_6^{3+}(aq)$ ions. Due to the high charge density of Al^{3+} ions, $Al(H_2O)_6^{3+}$ hydrolyses in water to give an acidic solution of pH 3.

Hydration: $AlCl_3(s) + 6H_2O(l) \rightarrow [Al(H_2O)_6]^{3+}(aq) + 3Cl^-(aq)$
Hydrolysis: $Al(H_2O)_6^{3+}(aq) \rightleftharpoons [Al(H_2O)_5(OH)]^{2+}(aq) + H^+(aq)$
or
$AlCl_3(s) + 6H_2O(l) \rightleftharpoons [Al(H_2O)_5(OH)]^{2+}(aq) + H^+(aq) + 3Cl^-(aq)$ [3]

(b) Upon heating, the hydrogen halides decompose to give hydrogen and the corresponding halogen.

Describe and explain how the thermal stability of the hydrogen halides differ from HC*l* to HI

From HCl to HI, the atomic radius increases from Cl to I, the bond length of H–X bond increases. Hence, the strength of H–X bond decreases and the ease of breaking H–X bond increases.
1 – 2
Hence, the thermal stability of HX decreases down the group.

[2]

(c) Fluorine and bromine are in Group 17 of the Periodic Table.

The K_a value for hydrofluoric acid, HF is 5.6×10^{-4} mol dm^{-3}.

The K_a value for hydrobromic acid, HBr, is much greater than 5.6×10^{-4} mol dm^{-3}.

Solutions of equal concentration of the two acids HF(aq) and HBr(aq) are prepared.

(i) Explain the meaning of the terms *acid*, *strong acid* and *weak acid*, in terms of BrØnsted-Lowry theory of acids.

A Bronsted acid is a **proton (H^+) donor**.
Strong acids **ionise completely in aqueous solution**.
Weak acids **ionise partially in aqueous solution**.

[3]

(ii) Suggest how the pH of these two solutions differ. Explain your answer in terms of the K_a values and the equilibrium positions in each solutions.

$HA(aq) \rightleftharpoons A^-(aq) + H^+(aq)$

Since the K_a of HBr is larger than that of HF, for the same concentration of acid, a greater proportion of HBr will be dissociated (or extent of dissociation is greater) as its equilibrium will lie more to the right compared to HF. Hence, the HBr solution will have a higher $[H^+]$ and a lower pH.

[2]

(iii) 40.00 cm^3 of 0.100 mol dm^{-3} sodium hydroxide was added to the hydrofluoric acid in **(c)**.

Calculate the pH of the mixture at 25 °C.

Since both acid and base has the same concentration, there is 20.00 cm^3 of sodium hydroxide in excess.

Amount of sodium hydroxide in excess = $20.00 \times 10^{-3} \times 0.100$
= 0.00200 mol

$[NaOH] = (0.00200 \times 10^3) / (20 + 40)$
= 0.0333 mol dm^{-3}

pOH = –log 0.0333
= 1.48

pH = 14 – 1.48
= 12.5 [2]

(d) Sodium hypochlorite, NaOC*l*, is the active ingredient in bleach.

(i) When aqueous NaOC*l* is heated, it forms sodium chloride and sodium chlorate, $NaClO_3$.

State the type of reaction that happens when aqueous NaOC*l* is heated.

Explain your answer by stating the changes in oxidation state of the species involved.

Redox/ Disproportionation.

Cl is +1 in NaOCl. It undergoes reduction to –1 in NaCl and oxidation to +5 in $NaClO_3$. [3]

The mass of NaOC*l* in bleach can be determined by first reacting the hypochlorite ion, OCl^- with iodide to produce iodine.

$$OCl^- + I^- + 2H^+ \rightarrow I_2 + Cl^- + H_2O$$

The liberated iodine is then titrated with sodium thiosulfate, $Na_2S_2O_3$. $Na_2S_2O_3$ is added until the solution turns pale yellow.

$$I_2 + 2S_2O_3^{2-} \rightarrow 2I^- + S_4O_6^{2-}$$

Starch is then added as an indicator and the end–point of the reaction is reached when the blue–black colour of the starch–iodine complex is discharged.

A 25.0 cm^3 sample of an industrial bleach was first diluted to 1 dm^3. 25.0 cm^3 of the diluted bleach was pipetted into a conical flask and 10.0 cm^3 of 1.00 mol dm^{-3} aqueous iodide (in excess) was added.

The liberated iodine required 20.10 cm^3 of 0.200 mol dm^{-3} $Na_2S_2O_3$ for complete reaction.

(ii) Calculate the amount of iodine liberated by 25.0 cm^3 of the diluted bleach.

Amount of $S_2O_3^{2-}$ = (20.10 / 1000) x 0.200 = 4.02 x 10^{-3} mol

2 $S_2O_3^{2-}$ ≡ 1 I_2
Amount of I_2 liberated = (4.02 x 10^{-3}) / 2 = 2.01 x 10^{-3} mol [1]

(iii) Hence, calculate the mass of NaOC*l* in the industrial bleach.

1 OCl^- ≡ 1 I_2
Amount of OCl^- in 25.0 cm^3 of diluted bleach = 2.01 x 10^{-3} mol

Amount of OCl^- in 25.0 cm^3 of industrial bleach
= 2.01 x 10^{-3} x (1000 / 25) = 0.0804 mol

Mass of NaOCl in 25.0 cm^3 of industrial bleach
= 0.0804 x 74.5 = 5.99 g [3]

(iv) Explain why is starch required to be used as an indicator for the titration.

The original colour change without starch is yellow to colourless. It is difficult to determine the end–point colour change.

Or distinct colour change with starch from blue/blue-black to colourless. [1]

[Total:20]

Additional answer space

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

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