NATIONAL JUNIOR COLLEGE
SH2 PRELIMINARY EXAMINATION
Higher 2

CANDIDATE NAME			
SUBJECT CLASS		REGISTRATION NUMBER	

CHEMISTRY

9729/02
Paper 2 Structured Questions
29 August 2022
2 hours

Candidates answer on Question Paper.
Additional Materials: Data Booklet

READ THE INSTRUCTIONS FIRST

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

Answers **all** questions.

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

For Examiner's Use	
1	/15
2	/21
3	/15
4	/10
5	/14
Paper 2 Total	/75

	Marks	Weightings
Paper 1	/30	**15%**
Paper 2	/75	**30%**
Paper 3	/80	**35%**
Paper 4	/55	**20%**

Overall Percentage	
Grade	

This document consists of **23** printed pages and **1** blank page.

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

1 **(a)** Chemists have recently established that four molecules of water are required for the dissociation of a single molecule of HC*l* (reported in *Science*, 2009).

Given that 1.00 dm^3 of water contains 55.6 mol of H_2O, calculate the number of molecules of hydrogen chloride, HC*l*, that should therefore dissociate in 1.00 dm^3 of water.

[1]

No. of molecules of HCl = ¼ × 55.6 × 6.02 × 10^{23} = 8.3678 × 10^{24}
= 8.37 × 10^{24} **[1]**

(b) Commercial concentrated hydrochloric acid, HC*l*, fumes strongly on exposure to moist air and thus is known as 'fuming hydrochloric acid'.

1.00 cm^3 of fuming hydrochloric acid was transferred with a graduated pipette to a 100 cm^3 volumetric flask. The volume was made up to 100 cm^3 with deionised water and the solution was labelled **F**. 10.0 cm^3 of solution **F** was neutralised by 24.75 cm^3 of 0.0500 mol dm^{-3} of aqueous sodium hydroxide.

Calculate the concentration of HC*l* in the fuming hydrochloric acid in mol dm^{-3}.

[2]

Amount of NaOH = 0.02475 × 0.0500 = 0.0012375 mol **[1]**
Amount of HCl in volumetric flask = 10 × 0.0012375 = 0.012375 mol
[HCl] = 0.012375 / 0.00100 = 12.4 mol dm^{-3} **[1]**

Must scale up, no ECF

(c) **(i)** The halide ions, X^- (where X = C*l*, Br, I), show clear trends in their physical and chemical properties.

State and explain the relative thermal stabilities of the hydrogen halides, HX.

……..…...

……..……...

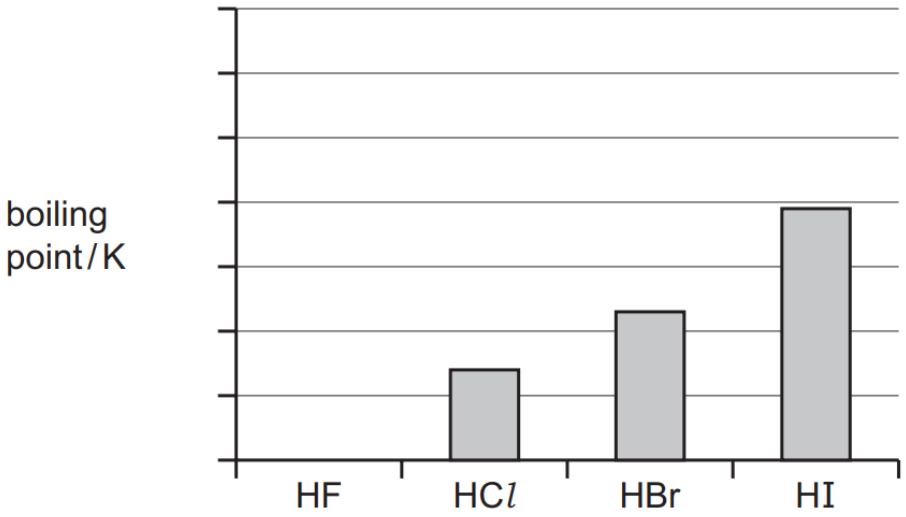
[2]

Thermal stability decreases from HCl to HI. **[1]**

H-X Bond energy decrease **[½]** OR Less effective overlapping between the orbitals of H atom and Halogen atom as size of halogen atom increases **[½]**

hence less energy to break the H-X decreases. **[½]**

The bar chart below shows the boiling points of HC*l*, HBr and HI. The boiling point of HF is not shown.



(ii) Explain why HI has a higher boiling point than HC*l* and HBr.

……...……...

……..

[1]

HI, HCl and HBr has **instantaneous dipole-induced dipole attraction between molecules. HI** has the **largest electron cloud size/most number of electrons [½]**, hence largest energy is required to overcome the **greater instantaneous dipole-induced dipole attraction** than in that HCl and HBr. **[½]**

(iii) Complete the bar chart above to show the boiling point of HF.
Explain your answer.

……...……...

……..

[2]

HF has the highest boiling point shown on graph [1]

More energy is required to overcome the **stronger hydrogen bonding between HF molecules[1]** than the instantaneous dipole-induced dipole attraction (and permanent dipoles) in HCl, HBr, HI

(d) Indium and aluminium are elements in Group 13 of the Periodic Table. Indium has very similar chemical properties to aluminium.

- Indium reacts vigorously with hydrochloric acid to form a colourless gas and a soluble salt.
- Indium oxide, In_2O_3, is amphoteric. In_2O_3 is a white solid which dissolves in excess aqueous NaOH.
- Gaseous indium bromide, In_2Br_6, contains coordinate bonds.

(i) Identify the formula of the salt formed when indium reacts with hydrochloric acid.

..... [1]

$InCl_3$ **[1]**

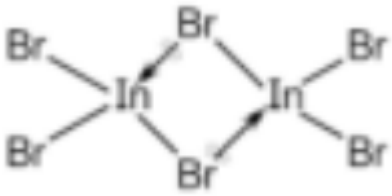
(ii) Construct an equation for the reaction of In_2O_3 with excess aqueous NaOH.

..... [1]

$In_2O_3 + 2NaOH + 3H_2O \rightarrow 2NaIn(OH)_4$

$In_2O_3 + 2\ OH^- + 3H_2O \rightarrow 2\ In(OH)_4^-$ **[1]**

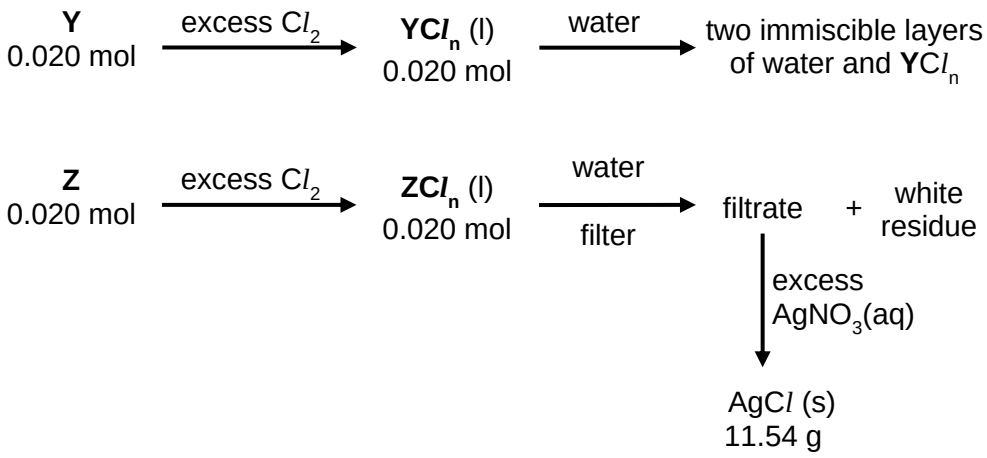
(iii) Draw a diagram that clearly shows the types of bonds in a molecule of In_2Br_6 (g). [1]



[1]

Must show dative bond from Br to In or label as dative

(e) In the periodic table, element **Y** is above element **Z** in the same group. Elements **Y** and **Z** are subjected to a series of reactions shown in the flowchart below.



(i) Calculate the value of n in **Z**Cl_n.

[1]

Amount of AgCl = 11.54 ÷ 143.4 = 0.0805 mol
ratio Z:Cl is 1:4
n = 4 **[1]**

(ii) Suggest the identities of elements **Y** and **Z** and explain why **Y**Cl_n and **Z**Cl_n react differently with water.

……

……

……

[2]

Y: Carbon [½] and **Z: Silicon [½]**
Si in $SiCl_4$ has **empty energetically accessible d orbitals / vacant orbitals in the valence shell [½]** to accept the lone pair from water and hence can undergo hydrolysis while C in CCl_4 **does not have**. **[½]**

(iii) Write a balanced equation for the reaction of **Z**Cl_n with water.

……

[1]

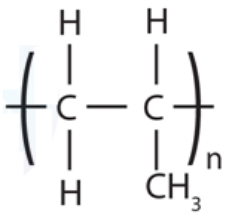
ZCl_4 + 4 H_2O → $Z(OH)_4$ + 4 HCl or
SiCl_4 + 4 H_2O → $Si(OH)_4$ + 4 HCl or
SiCl_4 + 4 H_2O → $SiO_2 \cdot 2H_2O$ + 4 HCl
SiCl_4 + 2 H_2O → SiO_2 + 4HCl **[1]**

[Total:15]

2 **(a)** Oil spills are hazardous as they affect the marine ecosystem, and the marine life-forms existence gets threatened. It becomes increasingly important to employ various clean up methods for tackling the menace that oil spills pose to the marine ecosystem.

(i) Oil consists mainly of hydrocarbons. Sheets of sorbents, usually made of materials like polypropene, can be used to absorb oil.

The structure of polypropene is given below.



Structure of polypropone

Sorbent sheets

Suggest how sorbents are able to absorb and effectively remove oil from water.

……...

……...

……...

……...

[2]

The sorbents have **large M_r with large electron cloud size/ non-polar [½]** and **can form strong [½] instantaneous dipole – induced dipole interactions [½]** between the oil and material of the sorbent and hence allowing oil to be removed. The sorbents **do not form favourable interactions/ weaker idid [½]** with water and hence do not absorb water.

Must state "strong" or to the effect

(ii) Another method for removing the oil spill that is floating on the sea surface is to ignite and burn it off. One of the major components of oil is decane, $C_{10}H_{22}$. Such burning of oil will cause an increase in temperature of the sea.

A simulation was done with the following scenario: 500 g of decane floating over 200 dm^3 of water was burnt off.

Given that the enthalpy change of combustion of decane is −300.9 kJ mol^{-1}, determine the rise in temperature of the body of water.

M_r of decane ($C_{10}H_{22}$) = 10 × 12 + 22 = 142

Amount of decane burnt = (500) ÷ 142 = 3.521 mol **[1]**

Amount of heat released = 3.521 × 300.9 × 1000 = 1.059 × 10^6 J **[1]**

$q = mc\Delta T$
$\Delta T = 1.059 \times 10^6 \div (200 \times 1000 \times 4.18) = 1.27$ K (3.sf) **[1]**

[3]

(iii) The actual temperature rise differs from the calculated value in **(a) (ii)**.
Suggest a reason for the discrepancy.

……...

Decane does not undergo complete combustion.

Incomplete transfer of heat energy.

Fuel is burning on the surface of the water/ heat transfer to air and not water. heat loss to air.

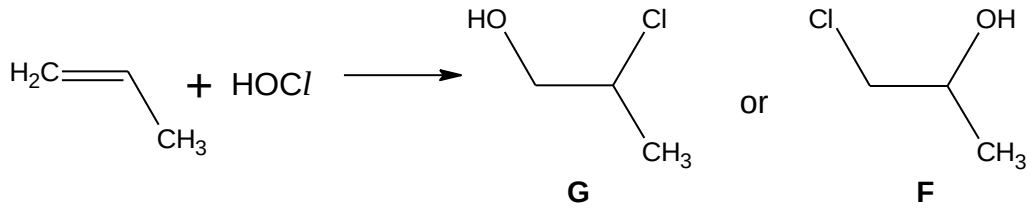
OR Sea water heat capacity differs from that water.

OR Some of the heat energy is used to evaporate the water.

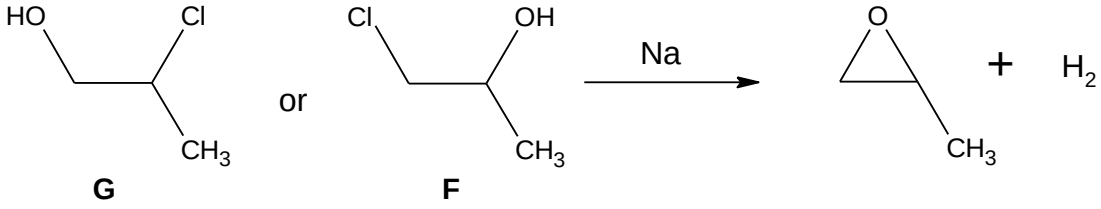
[1]

(b) Propene is the second most important starting material in the petrochemical industry. It is involved in a two-step synthesis to make a class of compounds known as epoxides.

Step **1**: Propene is reacted with HOC*l* to give two possible products, **G** or **F**.



Step **2**: The mixture of **G** and **F** is treated with Na to give the epoxide.



(i) State the type of isomerism between **G** and **F**.

…… Structural/ constitutional/ positional isomerism**[1]**……

(ii) Determine the type of reaction that occurs in **each step.**

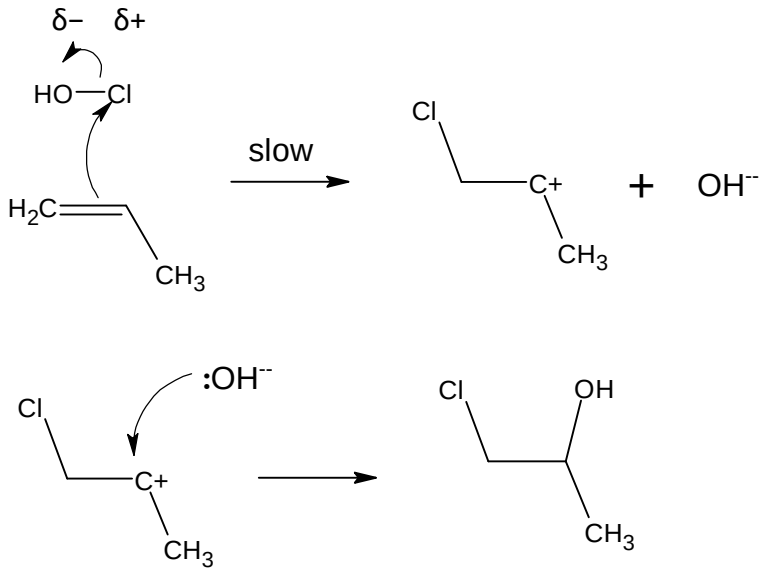
Step 1: …… (electrophilic addition) **[1]**

Step 2: …….. (nucleophilic substitution) **[1]**

[2]

(iii) Outline the mechanism for formation of **F** in step 1.
In your answer, show any relevant charges, lone pairs of electrons and movement of electrons.

[2]



General marking

(iv) Hence explain why **F** is the major product in the first step.

……...

……...

[2]

F is formed via a secondary carbocation that has **more electron-donating alkyl groups [½]** to **disperse the positive charge/electron deficiency[½]** in the carbocation, making the **carbocation more stable[½]** than that of G, hence forming in **greater quantity [½]**, leading to F as the major product.

(v) Suggest the importance of Na in the formation of epoxide.

……...

To **deprotonate the OH [½]**, and **generate a stronger nucleophile [½]**, for the intramolecular nucleophilic substitution.

[1]

(c) Allyl chloride, $ClCH_2CH{=}CH_2$, is produced by the chlorination of propene at high temperatures

equation 1 $\quad CH_3CH{=}CH_2 + Cl_2 \rightarrow ClCH_2CH{=}CH_2 + HCl$

(i) At lower temperatures, the main product is 1,2-dichloropropane.

Explain why the formation of allyl chloride, $ClCH_2CH=CH_2$, occurs at high temperatures.

……...

……...

At high temperature, there is sufficient energy for the Cl_2 molecule to undergo homolytic fission / break Cl-Cl bond to form **free radicals.**

[1]

Must recognise to form radicals/ free radical substitution

(ii) $ClCH_2CH=CH_2$ contains a C=C bond. Draw labelled diagrams to show how orbitals overlap to form

- a σ (sigma) bond

sp^2-sp^2 orbital labelled

- a π (pi) bond.

p-p orbital labelled

Must show hybridised orbital vs p orbital
No need to label head-on vs sideways overlap➔ show in diagram

[2]

(iii) Describe the mechanism for the formation of $ClCH_2CH=CH_2$ in equation 1.

[3]

Free radical substitution [1]

Initiation:

$Cl-Cl \xrightarrow[\text{(or Heat)}]{\text{UV Light}} 2\,Cl\bullet$

Propagation:
$Cl\bullet + CH_3CH=CH_2 \longrightarrow HCl + \bullet CH_2CH=CH_2$
$\bullet CH_2CH=CH_2 + Cl_2 \longrightarrow ClCH_2CH=CH_2 + Cl\bullet$

Termination:
$2Cl\bullet \longrightarrow Cl_2$
$\bullet CH_2CH=CH_2 + Cl\bullet \longrightarrow ClCH_2CH=CH_2$

Minus ½
Header
Half headed arrow
…

	(iv)	Other than $ClCH_2CH=CH_2$, two other mono-substituted chloropropenes can also

be formed by the same mechanism in **(c)** (**iii**).

Complete Table 2.1 with

- the structures of the two other chloropropenes
- the expected ratio in which the three chloropropenes will be formed

chloropropene	$ClCH_2CH=CH_2$	$CH_3CCl=CH_2$ **[1/2]**	$CH_3CH=CHCl$ **[1/2]**
Ratio **[1]**	**3**	**1**	**2**

Table 2.1

[2]

[Total:22]

3 Vanadium is a transition metal that form stable coloured ions of various oxidation states in aqueous solutions. Some of the ions of vanadium and their corresponding colours are shown in the table below.

formula of vanadium ion	VO_2^+	VO^{2+}	V^{3+}	V^{2+}
colour of aqueous solution	yellow	blue	green	violet

(a) Explain why vanadium can form ions of variable oxidation states.

Due to the ***close similarity in energies*** of the **3d and 4s orbitals** **[1]**, both 3d and 4s electrons can be removed from vanadium to form **stable ions** of different oxidation states.

[1]

(b) Data about calcium and vanadium are given below.

	calcium	**vanadium**
relative atomic mass	40.1	50.9
electronic configuration	$[Ar]4s^2$	$[Ar]3d^34s^2$
atomic radius (metallic) /nm	0.197	0.122
density / g cm^{-3}	1.54	6.07

Using the data provided, explain why the density of vanadium is significantly greater than that of calcium. (No calculations are required.)

- **V has stronger metallic bonds as both 3d and 4s electrons could contribute to the sea of delocalised electrons [½],**

- **Smaller atomic radii [½]**

- With **more atoms of *higher relative atomic mass*** **[½]** in a more *closely packed* metallic lattice or **packed per unit volume [½],**

vanadium has significant higher density than calcium

[2]

(c) Predict, by calculating $E^{\ominus}_{cell}$ values, the reaction(s) that occur in each experiment. State the observation(s) that would be made in each experiment.

(i) Experiment **A**:
Excess acidified hydrogen peroxide is added to an aqueous solution containing VO^{2+} ion.

$H_2O_2 + 2H^+ + 2e \rightleftharpoons 2H_2O$ $E^{\ominus} = +1.77$ V

$VO^{2+} + 2H^+ + e \rightleftharpoons V^{3+} + H_2O$ $E^{\ominus} = +0.34$ V

$VO_2^+ + 2H^+ + e \rightleftharpoons VO^{2+} + H_2O$ $E^{\ominus} = +1.00$ V

$2VO^{2+} + H_2O_2 \rightarrow 2VO_2^+ + 2H^+$ $E^{\ominus}_{cell} = 1.77 - 1.00 = +0.77$ V (>0) **[1]**

Blue yellow

Observation: blue to yellow **[1]** **OR blue to green to yellow.**

[2]

(ii) Experiment **B**:
Excess tin is added to an acidic aqueous solution containing VO^{2+} ion.

$Sn^{2+} + 2e \rightleftharpoons Sn$ $E^{\ominus} = -0.14$ V

$V^{3+} + e \rightleftharpoons V^{2+}$ $E^{\ominus} = -0.26$ V

$VO^{2+} + 2H^+ + e \rightleftharpoons V^{3+} + H2O$ $E^{\ominus} = +0.34$ V

$VO_2^+ + 2H^+ + e \rightleftharpoons VO^{2+} + H2O$ $E^{\ominus} = +1.00$ V

$2VO^{2+} + 4H^+ + Sn \rightarrow 2V^{3+} + Sn^{2+} + 2H_2O$

blue green

$E^{\ominus}_{cell} = 0.34 - (-0.14) = +0.48$ V (>0) **[1]**

$2V^{3+} + Sn \rightarrow 2V^{2+} + Sn^{2+}$

green violet

$E^{\ominus}_{cell} = -0.26 - (-0.14) = -0.12$ V (<0) **[1]**

……

……

……

……

……

……

[3]

(d) The vanadium-containing ion in 50 cm^3 of a 0.800 mol dm^{-3} solution of ammonium metavanadate, NH_4VO_3, reacts with 506 cm^3 of sulfur dioxide gas measured at 20.0 °C and 98.0 kPa. In the reaction, sulfur dioxide is oxidised according to the equation given below.

$$SO_2 + 2H_2O \rightarrow SO_4^{2-} + 4H^+ + 2e^-$$

(i) Calculate the final oxidation state of the vanadium ion in the solution.

(ii) Hence write a balanced equation for the reaction between VO_3^- and SO_2.

$pV = nRT$

$n_{SO_2} = \frac{pV}{RT} = \frac{(98\times10^3\times506\times10^{-6})}{8.31\times(20+273)} = 0.02$ mol **[1]**

$n_{VO3-} = 50 \times \frac{0.800}{1000} = 0.04$ mol

no. of electron transferred in the reaction = $0.02 \times 2 = 0.04$ mol

no. of electron gained per mole of $VO^{3-} = \frac{0.04}{0.04} = 1$

The oxidation state of V in VO_3^- = +5

Final oxidation state of the vanadium ion in the solution = 5 – 1 = +4 **[1]**

$2VO_3^- + 4H^+ + SO_2 \rightarrow 2VO^{2+} + SO_4^{2-} + 2H_2O$ **[1]** [3]

(e) Vanadium(V) oxide, V_2O_5, is obtained by the action of heat on ammonium metavanadate, NH_4VO_3. V_2O_5 is an orange-coloured solid that catalyses the Contact process:

$$2SO_2\,(g) + O_2\,(g) \rightleftharpoons 2SO_3\,(g)$$

(i) State the type of catalysis involved.

Heterogeneous catalyst **[1]**

……

[1]

(ii) Explain briefly how V_2O_5 catalyses the Contact process.

Adsorption [½]

~~The gaseous reactant molecules are adsorbed onto V2O5 surface with the~~ **formation of weak interaction/bonds [½]**

……

Reaction

Surface concentration of the reactants on the catalyst **increases**/ the **reactant molecules are brought closer together [½]** and

Existing bonds in the reactant molecules weakens [½].

The **activation energy is lowered [½]**

.....

.....

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.....

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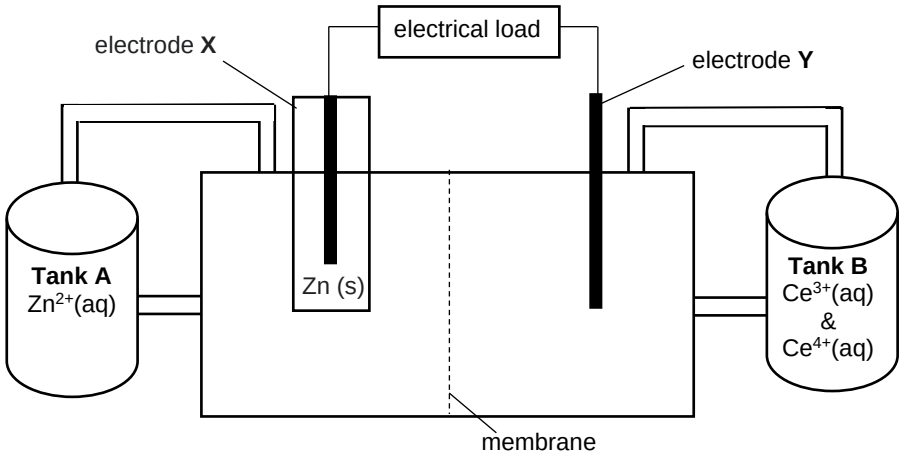
.....

.....

[3]
[Total: 15]

4 **(a)** Flow batteries are one of the most viable technologies for larger scale energy storage. Zinc–cerium battery is a flow battery with graphite electrodes where the electrolytes can be pumped from separate storage tanks into the cell. A thin membrane, separating the two electrolytes, allows selected ions to flow through it.



(i) During discharging, electrons flow from electrode **X** to electrode **Y**.
Write the equation for the reaction that occurs at the cathode and the anode respectively.

Cathode: $Ce^{4+} + e \rightarrow Ce^{3+}$ **[1]**

Anode: $Zn \rightarrow Zn^{2+} + 2e$ **[1]**

[2]

Must be Full arrow

(ii) Given the standard cell potential, $E^{\ominus}_{cell}$, of the Zn-Ce battery is 2.2 V, calculate the standard free energy change, $\Delta G^{\ominus}$ and state its units.

$\Delta G^{\ominus} = -nFE^{\ominus}_{cell}$

$= -(2)(96500)(2.2)$

$= -424600$

$= -425000$ J mol^{-1} or -425 kJ mol^{-1} **[1]**

[1]

(iii) Explain why it is necessary to have a membrane that allows selected ions to flow through it in the Zn-Ce battery.

This helps **to maintain electrical neutrality** (prevent build up of charges in the two half cell), so that electrical energy can continue to flow. **[1]**

[1]

(iv) The Zn-Ce battery can be recharged by applying current across the two electrodes. How long would it take, in hours, to recharge a Zn-Ce battery at a current of 2 A to deposit 6.1 g of Zn?

$Zn^{2+} + 2e \rightarrow Zn$

Amt of Zn = 6.1/65.4 = 0.09327 mol

Amt of e = 2 × 0.09327 = 0.1865 mol **[1]**

$Q = I \times t = nF$

$t = nF/I$
$= 0.1865 \times 96500 / 2$
$= 9000$ s **[½]**
$= 2.50$ hrs **[½]**

[2]

(v) During charging process, a side reaction occurs at electrode **Y** that requires the electrode to be replaced periodically.

Identify the side reaction and give a reason why electrode **Y** needs replacement.

At electrode Y: $H_2O \rightarrow O_2 + 4H^+ + 4e$ or H_2O is oxidised to form O_2 **[½]** during the charging process.

Oxygen is produced in the side reaction **($C + O_2 \rightarrow CO_2$) [1] or where C atoms in graphite are oxidized by oxygen**.

hence **corrode the graphite electrode [½]** and need to be replaced.

[2]

(b) Supercapacitors are gaining attention in wearable and lightweight electronic devices due to its fast charging–discharging capacity, and long lifespans compared to a typical battery. The cathode electrode material for supercapacitors must have high temperature stability.

Using relevant data from the *Data Booklet*, describe and explain which compounds, manganese(II) carbonate, $MnCO_3$, or magnesium carbonate, $MgCO_3$, is more suited for use as the cathode electrode in supercapacitors.

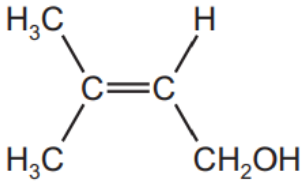
Ionic radius: Mn^{2+} = 0.083nm and Mg^{2+} = 0.065nm **[1]**

Both Mn^{2+} and Mg^{2+} has the same charge of +2, but Mn^{2+} has smaller ionic radius than that of Mg^{2+}. Hence **Mn^{2+} has lower charge/ionic size ratio with lower polarising power [½]. More energy is needed to break less polarized C–O bond [½]** of carbonate anion in $MnCO_3$, therefore **$MnCO_3$ is more suited with higher thermal stability [1].**

[3]
[Total: 11]

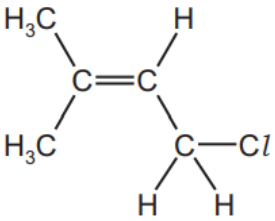
5 Prenol is a naturally occurring organic molecule found in many fruits. It contains both an alkene and an alcohol functional group.

Prenol



(a) State the reagents and conditions to convert **G** to prenol.

G



…….... [1]

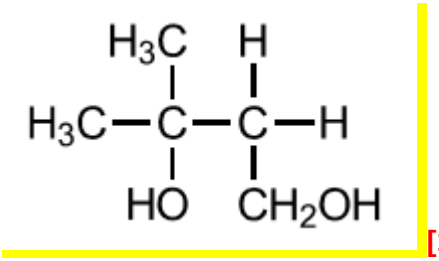
NaOH/KOH(aq), heat **[1]**

(b) Prenol reacts with steam to form a mixture of three isomers, **J**, **K** and **L**, with molecular formula $C_5H_{12}O_2$.

(i) When **J** is heated with excess acidified potassium manganate(VII), it forms an organic product which does not react with 2,4-dinitrophenylhydrazine.

Suggest a structure of **J**.

[1]



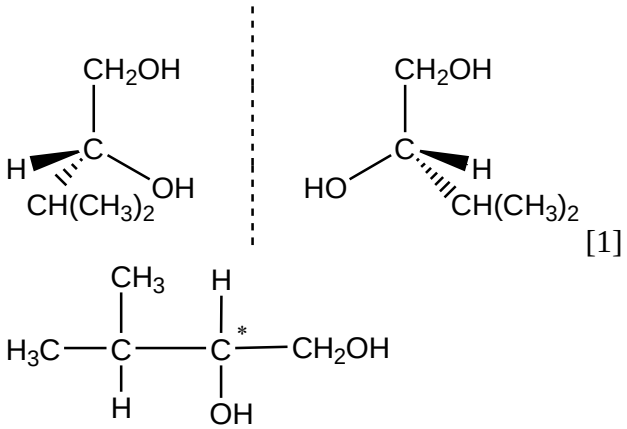
[1]

K and **L** are stereoisomers. **K** and **L** both react when heated with excess acidified potassium manganate(VII) to form **M**, $C_5H_8O_3$. **M** forms an orange precipitate on reaction with 2,4-dinitrophenylhydrazine.

(ii) Name the type of stereoisomerism shown by **K** and **L**, and draw structures to illustrate the stereoisomerism.

……[2]

Optical /enantiomerism [1]



[1]

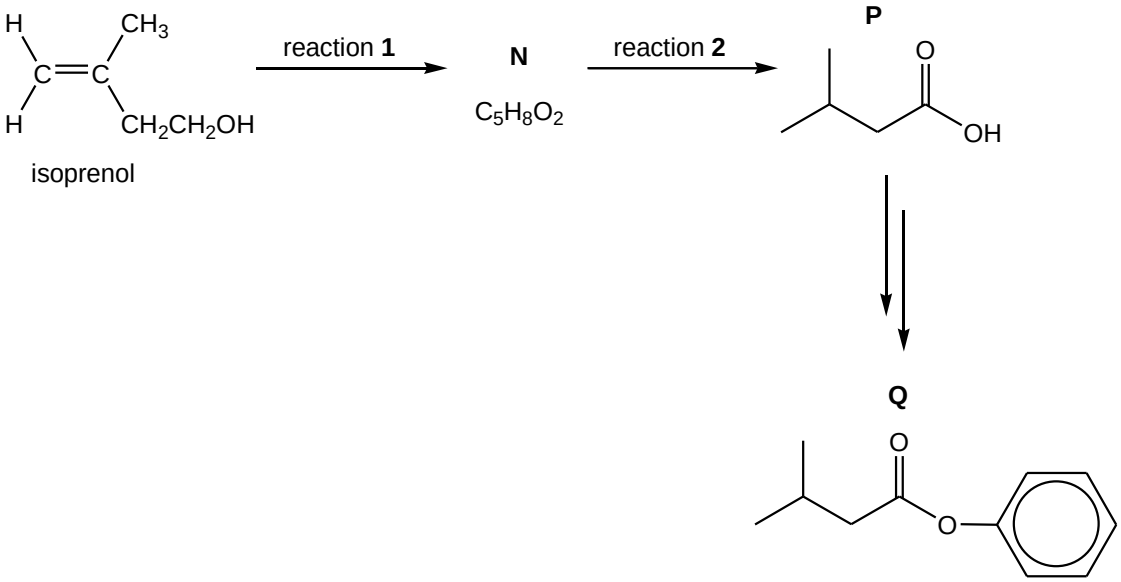
(iii) Give the balanced equation to represent the reaction of **K**, $C_5H_{12}O_2$, with acidified potassium manganate(VII) to form **M**, $C_5H_8O_3$.

Use [O] to represent an atom of oxygen provided by the oxidising agent.

……[1]

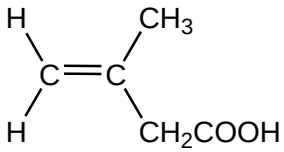
$C_5H_{12}O_2 + 3[O] \rightarrow C_5H_8O_3 + 2H_2O$ **[1]**

(c) Isoprenol is a structural isomer of prenol. The series of reactions shows how isoprenol can be used to form **Q**, a sweet-smelling liquid.



(i) Suggest the structure of **N**.

[1]



[1]

(ii) Suggest the reagents and conditions for reactions 1 and 2.

reaction 1: ……

reaction 2: ……

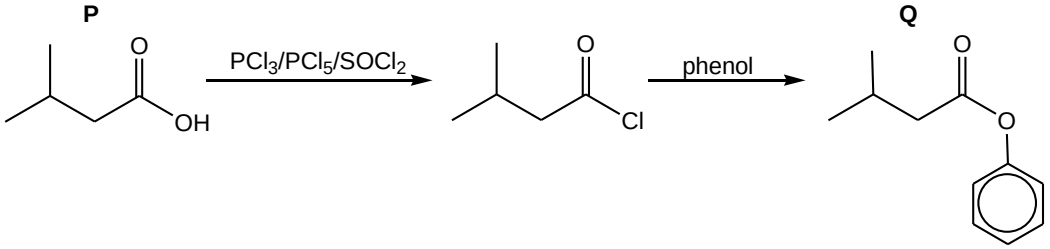
[2]

Step 1: $K_2Cr_2O_7$, H_2SO_4(aq), heat with reflux **[1]**
(Cannot be $KMnO_4$, otherwise will cleave C=C bond)

Step 2: H_2, Ni, high temperature/ H_2, Pt **[1]**
(Cannot be $LiAlH_4$, $NaBH_4$, cos non-polar C=C bond)

(iii) Suggest the step(s) to convert **P** to **Q**, showing the structure(s) of any intermediate(s) formed.

[3]



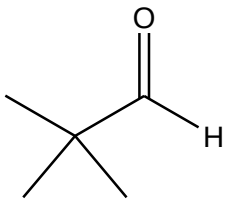
Intermediate **[1]**
Step 1: PCl_3/ PCl_5/$SOCl_2$, anhydrous **[1] or zero**
Step 2: Phenol **[½]**, NaOH(aq) **[½]**

(iv) Compound **S**, a structural isomer of isoprenol, gives a brick-red precipitate when treated with alkaline solution of copper(II) tartrate. **S** gives only one

mono-chlorinated product when reacted with chlorine gas under ultraviolet light.

Suggest the structure of **S**.

[1]



[1]

[Total: 14]