Catholic Junior College
JC2 Preliminary Examination
Higher 2

CANDIDATE NAME	
CLASS	**2T**

CHEMISTRY
Paper 2 Structured Questions

9729/02
28 August 2023
2 hours

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

READ THESE INSTRUCTIONS FIRST

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

Answer **all** questions in the spaces provided on the Question Paper.
The use of an approved scientific calculator is expected, where appropriate.

A Data Booklet is provided.

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

For Examiner's Use		
Paper 1		**30**
Paper 2	**Q1**	**/13**
	Q2	**/12**
	Q3	**/14**
	Q4	**/14**
	Q5	**/10**
	Q6	**/12**
		75
Paper 3		**80**
Paper 4		**55**
OVERALL (100%)		
GRADE		

This document consists of **19** printed pages and **1** blank page.

[Turn over

1 (a) Nitrogen and phosphorus are elements of Group 15 in the Periodic Table.

(i) Explain why phosphorus has a larger atomic radius than nitrogen.

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……[2]

(ii) Nitrogen exists naturally as gaseous diatomic N≡N molecules whereas phosphorus is a solid and exists as P_4 molecules comprising P–P single bonds.

Suggest why phosphorus does **not** occur naturally as P≡P molecules.

……

……

……[1]

(b) Nitrate, NO_3^-, and phosphate, PO_4^{3-}, are oxoanions of nitrogen and phosphorous respectively.

(i) Draw dot–and–cross diagrams to show the bonding in NO_3^- and PO_4^{3-} ions. Hence, suggest the shape of each of these ions. [4]

ion	NO_3^-	PO_4^{3-}
dot-and-cross diagram		
shape		

(ii) The 2s and 2p orbitals of nitrogen atoms can hybridise in the same way as the 2s and 2p orbitals of carbon atoms.

With reference to your answer in **(b)(i)**, state the hybridisation state of nitrogen in NO_3^-.

……[1]

(iii) Table 1.1 shows the bond lengths of two nitrogen–oxygen bonds.

Table 1.1

bond	N–O	N=O
bond length (pm)	136	115

The experimental bond length of each nitrogen–oxygen bond in the nitrate ion, NO_3^-, is 128 pm.

With reference to your answers in **(b)(i)** and **(b)(ii)**, explain this observed bond length in NO_3^-.

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…… [1]

(c) A *nuclear reaction* is a reaction in which there is a change to an atomic nucleus.

A scientist attempts to produce $^{32}_{15}P$ synthetically using a nuclear reaction where a neutron collides with an isotope **E** of another element as shown in the equation below (n represents a neutron).

$$\text{isotope } \mathbf{E} + n \rightarrow {}^{32}_{15}P + {}^{3}_{1}H$$

Identify isotope **E**, showing clearly its mass number.

……[1]

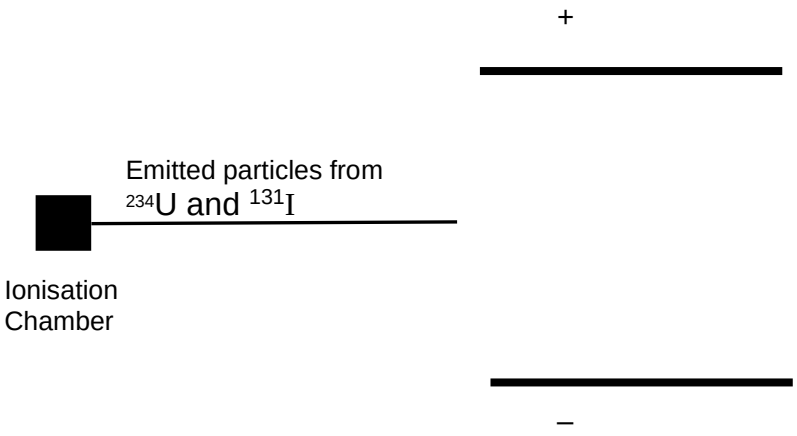
(d) Another type of nuclear reaction is radioactive decay, which occurs spontaneously in elements with an unstable atomic nucleus.

Uranium–234 is used in nuclear power generation, and emits a constant stream of α particles, which are equivalent to Helium–4 nuclei.

Iodine–131 is used in treatment for thyroid cancer. On decaying, it emits β particles, which can be considered as electrons.

A small amount of Uranium–234 and Iodine–131 are separately placed in an ionisation chamber to emit a constant stream of radiation, and the emitted particles are passed through an electric field.

(i) On the diagram below, sketch the deflection path for the emitted particles in an electric field.
You may label the emitted particles as α particles and β particles respectively.



[1]

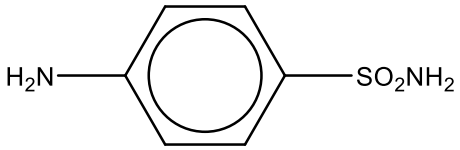
(ii) A deflection of +16° was observed when a beam of α particles was passed through an electric field.
In another experiment, a beam of doubly charged **X** particles was passed through the electric field under the same experimental conditions. The angle of deflection was found to be –4°.

Suggest the identity of ion **X**. Show your working.

[2]

[Total: 13]

2 **(a)** Sulfanilamide is an antibiotic used to treat streptococcal infections.



sulfanilamide

(i) Explain why sulfanilamide is soluble in dilute HC*l*.

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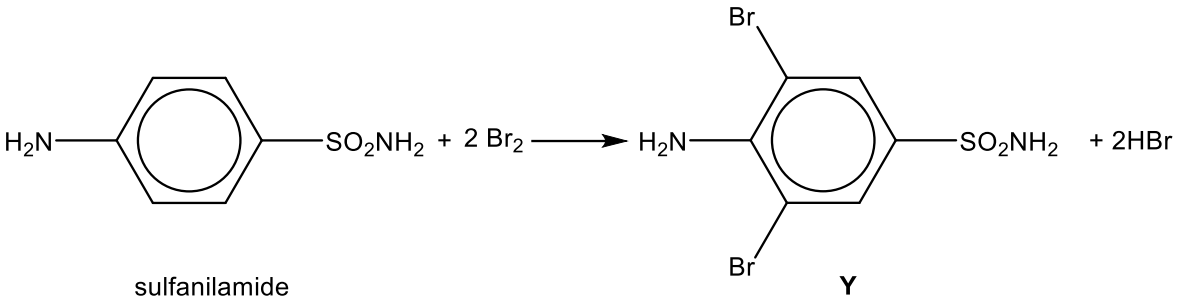
……[2]

(ii) In sulfanilamide, the carbon atoms are sp^2 hybridised. Draw a labelled diagram to show the orbitals overlapping between any two carbon atoms in sulfanilamide.

[2]

(iii) A 0.3 g sample containing sulfanilamide (M_r of 172.1) was dissolved and diluted to 100 cm^3. A 20 cm^3 aliquot was used to react with 1.33 x 10^{-3} mol Br_2 (which was in excess) to form **Y**.



sulfanilamide **Y**

KI was then added to react with any remaining unreacted Br_2. The liberated iodine was subsequently titrated with 15.70 cm^3 of 0.1 mol dm^{-3} sodium thiosulfate as shown in the equations below.

$$Br_2 + 2I^- \rightarrow 2Br^- + I_2$$

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

Calculate the percentage by mass of sulfanilamide in the sample.

[4]

(b) **(i)** Describe the reaction of SO_3 with water. Include the approximate pH value of any resulting solution, and write an equation for any reaction that occurs.

……

……..

……[2]

(ii) Write the electronic configuration of sulfur.

……[1]

(iii) Explain why sulfur has a lower first ionisation energy than phosphorus.

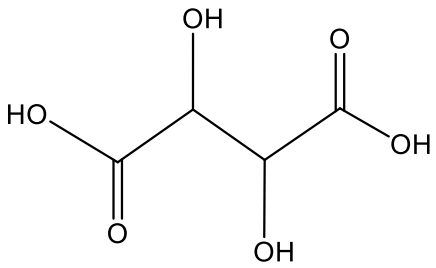
……

……..

……[1]

[Total: 12]

3 Wine contains varying concentrations of different acids, and the amount of acids is influenced by factors such as climate and the fermentation process of grapes that make the wine. The principal acid present in grapes is tartaric acid, which gives wine the tart taste.



Tartaric acid

(a) In an experiment to determine the tartaric acid content of a 750 cm^3 bottle of white wine, a titration was carried out and 17.60 cm^3 of 0.01 mol dm^{-3} NaOH was found to react with 25.0 cm^3 of diluted white wine. The original white wine was ten times more concentrated.

(i) Write an equation for the reaction that has taken place.

[1]

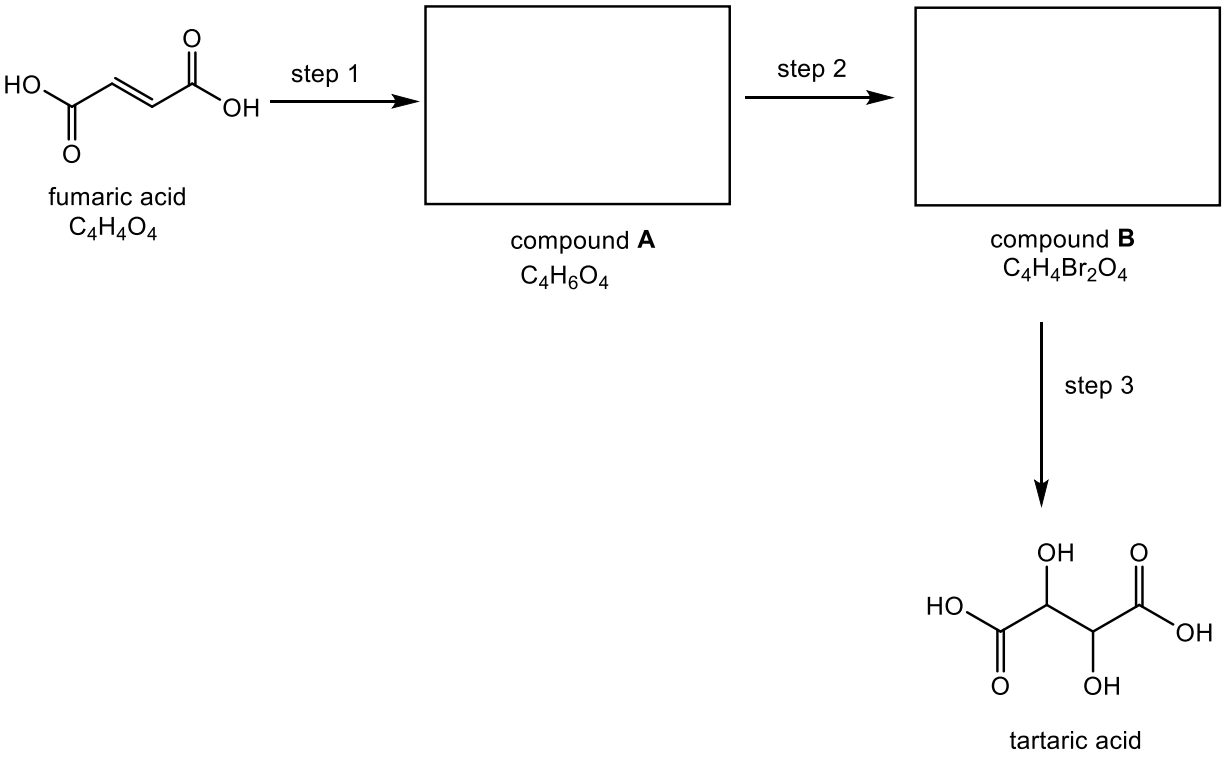
(ii) Calculate the total mass of tartaric acid present in the original 750 cm^3 bottle of white wine.

[2]

(iii) Tartaric acid is a muscle toxin and in high doses causes paralysis and death. The median lethal dose is about 7.5 grams tartaric acid per kg mass for a human. Based on your answer in **(a)(ii)**, deduce whether a 70 kg human might die from an overdose of tartaric acid after drinking 5 bottles of white wine.

[1]

(b) Tartaric acid can be synthesised from fumaric acid, which occurs widely in nature, in a 3-step synthetic route as shown.



fumaric acid
$C_4H_4O_4$

compound **A**
$C_4H_6O_4$

compound **B**
$C_4H_4Br_2O_4$

tartaric acid

(i) Give the reagents and conditions for step 1.

……[1]

(ii) Name the types of reaction occurring in step 2 and step 3.

Step 2:…… [1]

Step 3:……[1]

(iii) Draw the structures for intermediate compounds **A** and **B** in the boxes above. [2]

(iv) Suggest a simple chemical test to distinguish between fumaric acid and tartaric acid.

……

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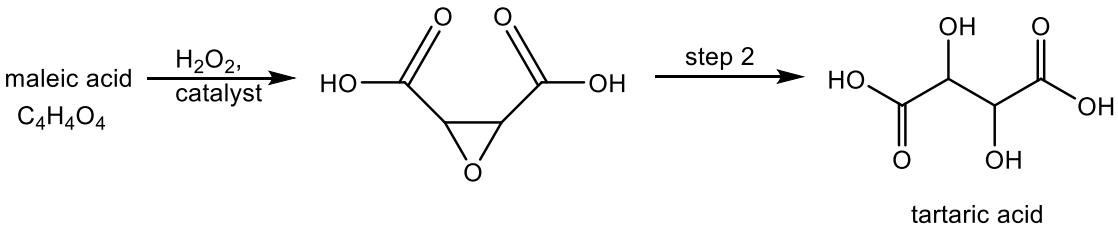
……[2]

(c) Tartaric acid can also be prepared from maleic acid, $C_4H_4O_4$, by reacting with hydrogen peroxide in the presence of a catalyst as shown below.



tartaric acid

Name the type of reaction occurring in step 2.

……[1]

(d) Maleic acid and fumaric acid are stereoisomers with different physical properties. Maleic acid is less soluble in water compared to fumaric acid.

(i) Draw the skeletal formula of maleic acid, clearly displaying the stereoisomerism it exhibits.

[1]

(ii) Suggest a reason why maleic acid is less soluble in water in comparison with fumaric acid.

……

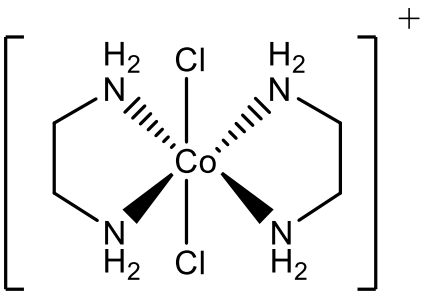
……

……[1]

[Total: 14]

4 **(a)** When air is passed through an aqueous solution containing $CoCl_2$, $H_2NCH_2CH_2NH_2$ and HCl, a green complex cation **X** with formula $[Co(H_2NCH_2CH_2NH_2)_2Cl_2]^+$ is produced. Evaporation of **X** at 90°C produces a red complex cation **Y** with the same formula as **X**. **X** has no dipole moment, whereas **Y** does. Complex cations **Y** and **Z** rotate plane-polarised light in opposite directions but with equal magnitude.

The structure of complex cation **X** is given below:



(i) In the boxes below, suggest the structural formulae of complex cations **Y** and **Z**. [2]

cation **Y**	cation **Z**

(ii) Suggest the isomeric relationship between complex cations **Y** and **Z**.

……[1]

(b) **(i)** When $NH_3(aq)$ is added to a sample of $[Cu(H_2O)_6]^{2+}(aq)$, a pale blue precipitate is produced, which dissolved in excess ammonia to produce a dark blue solution.

Complete the equation for the formation of the pale blue precipitate. Include state symbols.

$[Cu(H_2O)_6]^{2+}(aq)$ + ……$NH_3(aq)$ → ……..…[1]

(ii) The dark blue solution can also be prepared by adding copper metal to an alkaline solution of oxygen dissolved in aqueous ammonia. With reference to the *Data Booklet*, write a balanced equation for this reaction and calculate the $E^{\ominus}_{cell}$ of this reaction.

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..……..

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……..

……...……[2]

(iii) Explain why so many transition metal complexes are coloured.

..…….

..…….

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……

……..……..

……...……[3]

(c) Transition metal compounds are frequently coloured. Some data about chromium compounds are given in the table below.

salt	colour	K_{sp} value at 25 ^{o}C
$BaCrO_4$	yellow	1.2×10^{-10}
Ag_2CrO_4	red	1.1×10^{-12}

(i) Write an expression for K_{sp} of Ag_2CrO_4, stating its units.

[1]

(ii) Calculate the solubility of Ag_2CrO_4 in g dm^{-3}.

[2]

(iii) State the expected observations when 50 cm^3 of 2.0×10^{-4} mol dm^{-3} K_2CrO_4 solution is added to 50 cm^3 of a mixture of 8.0×10^{-5} mol dm^{-3} $AgNO_3$ solution and 8.0×10^{-5} mol dm^{-3} $Ba(NO_3)_2$. Justify your answer with relevant calculations.

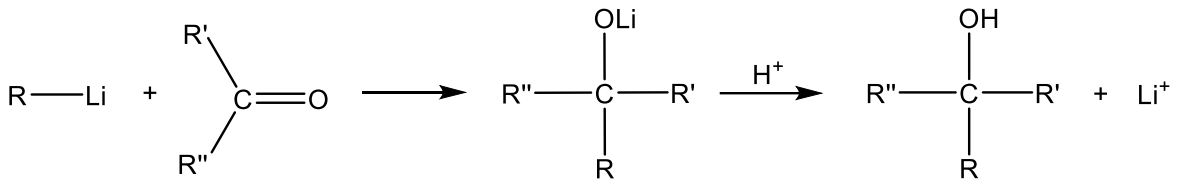
[2]

[Total: 14]

5 Alkali metals, such as lithium, are good reducing agents and can reduce the carbon-halogen bonds of alkyl halides to give organolithium compounds.

The carbon-lithium covalent bond in organolithium compounds is polarised $\overset{\delta-}{C}-\overset{\delta+}{Li}$. Organolithium compounds act as sources of negatively charged carbon, i.e. carbanions, and are useful reagents in organic synthesis involving carbon-carbon bond formation. They react with carbonyl compounds to give lithium alkoxides, which form alcohols on treatment with dilute acid. This sequence is known as the organolithium reaction.

$$R{-}X + 2Li \rightarrow R{-}Li + LiX$$



(R is an alkyl group; R' and R'' are either alkyl groups or H)

For example, propan−1−ol can be synthesised from 1−bromoethane and methanal.

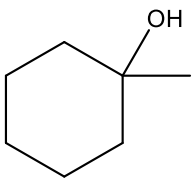
$$CH_3CH_2Br \rightarrow CH_3CH_2Li$$
$$CH_3CH_2Li + CH_2O \rightarrow CH_3CH_2CH_2OLi$$
$$CH_3CH_2CH_2OLi + H^+ \rightarrow CH_3CH_2CH_2OH + Li^+$$

(a) Deduce the structures of a suitable bromoalkane, RBr, and a suitable carbonyl compound, R'R''CO, to synthesise each of the following alcohols.

(i) $CH_3CH(OH)CH_2CH_3$

[2]

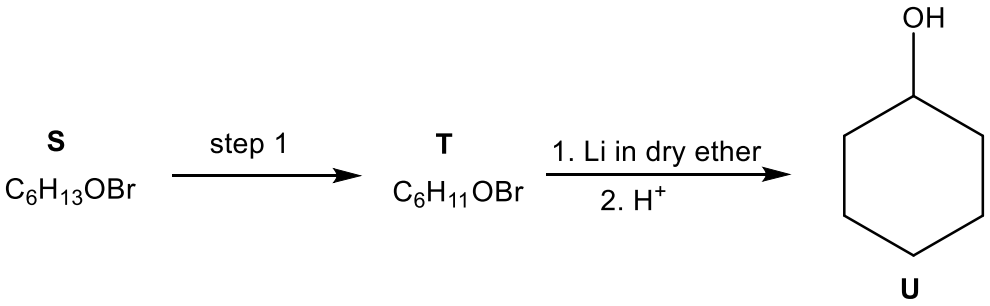
(ii)



[2]

(b) Compound **U** can be synthesised by the following route involving an intramolecular organolithium reaction.

T gives a silver mirror when boiled with Tollens' reagent. **T** also gives a cream precipitate when heated with ethanolic silver nitrate.



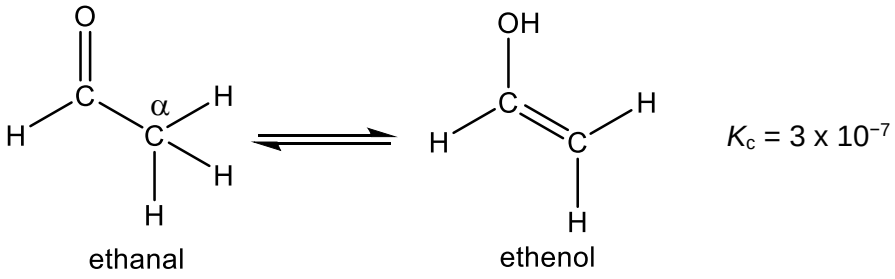
(i) State the reagents and conditions for step 1.

……[1]

(ii) Draw the structures of **S** and **T**.

[2]

(c) *Tautomers* are isomers of organic compounds which are readily interconverted. Ethanal and ethenol are tautomers, and they rapidly equilibrate as shown.

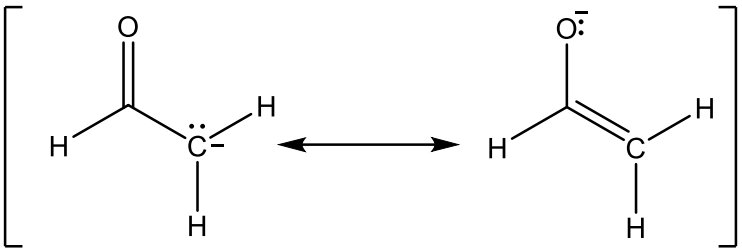


(i) State what the K_c value indicates about the position of equilibrium **and** identify the major species in the mixture.

……..

……[1]

(ii) Ethanal has an acidic hydrogen on its α-carbon. In the presence of strong bases, the hydrogen on its α–carbon is abstracted to form a resonance-stabilised enolate anion as shown below:

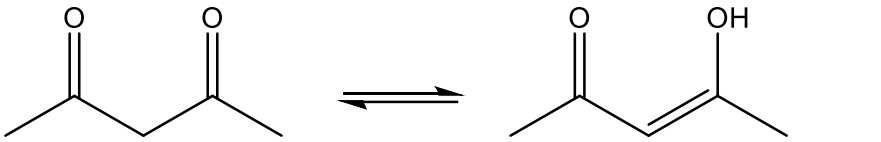


two resonance structures of the enolate anion

Resonance structures differ only in the position of their electrons.

Complete the diagram above by drawing in curly arrows to show movement of electrons to form the second resonance structure. [1]

(iii) Another pair of tautomers is shown below. Draw a fully labelled diagram to show why 4-hydroxy-3-penten-2-one is the dominant form at equilibrium.



2,4-pentanedione (15%) 4-hydroxy-3-penten-2-one (85%)

[1]

[Total: 10]

6 Tin metal, Sn, and its salts have many uses in daily life. The commonly used tin salts include tin(II) chloride, $SnCl_2$, and tin(IV) oxide, SnO_2.

Tin(IV) oxide, SnO_2, has long been used as a white colorant in ceramic glazes for earthenware and wall tiles. Synthetic tin(IV) oxide, SnO_2, is produced by burning tin metal, Sn, in air.

(a) Define the term *standard enthalpy change of formation* of SnO_2.

……..

……. [1]

Tin(IV) oxide is also formed when anhydrous tin(IV) chloride, $SnCl_4$, fumes in humid air as shown in the equation below:

$$SnCl_4(s) + 2H_2O(l) \rightarrow SnO_2(s) + 4HCl(g) \qquad \Delta H^{\ominus} = -463 \text{ kJ mol}^{-1}$$

(b) Use the enthalpy change of reaction given above and the relevant standard enthalpy change of formation data from Table 6.1 to calculate the standard enthalpy change of the following conversion:

$$HCl(g) \rightarrow HCl(aq) \qquad \Delta H^{\ominus} = x \text{ kJ mol}^{-1}$$

Table 6.1

compound	$\Delta H_f^{\ominus}$ / kJ mol^{-1}
$SnO_2(s)$	−578
$H_2O(l)$	−286
$SnCl_4(s)$	−510
$HCl(aq)$	−167

[3]

(c) Tin(II) chloride solution, $SnCl_2(aq)$, acidified with small amount of hydrochloric acid, is used for tinplating of steel, during the production of tin cans. An electric potential is applied, and tin metal is formed at the cathode via electrolysis.

(i) Write the half-equation for the reaction that occurs at the cathode during electrolysis of tin(II) chloride.

…….. [1]

(ii) In an experiment, a current of 2.50 A was passed through a tin(II) chloride solution for 2 hours.

Tin produced at the cathode is isolated and cleansed. It has a mass of 9.11g.

Calculate the mass of tin that would be deposited at the cathode, assuming that the process is 100% efficient. Hence, calculate the percentage efficiency of this electrolysis process.

[4]

(d) Tin can form various compounds with organic molecules. Such tin-based organometallic compounds consist of Sn−C covalent bonds and often exhibit *cis-trans* isomerism, where the ligands around the Sn atom can be arranged in different spatial orientations.

Consider a series of tin(IV) organometallic compounds with the general formula $Sn\mathbf{X}_2\mathbf{Y}_2$, where **X** and **Y** are monodentate ligands. You may assume a square planar geometry around the tin atom.

In the *cis*-isomer, two similar ligands are positioned next to each other whereas in the *trans*-isomer, two similar ligands are positioned directly opposite each other.

(i) Draw the structural formula and label clearly the *cis* and *trans* isomers of a tin(IV) compound when **X** = CH_3 and **Y** = OCH_2CH_3.

[2]

(ii) Suggest, with a reason, whether the *cis* or *trans* isomers are more stable.

……

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…….. [1]

[Total: 12]

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